International Journal of Performance Analysis in Sport

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rpan20

Determinants of Boat Velocity during a 200 m Race in Elite Paralympic Sprint Kayakers

A. J. Redwood-Brown, H. L. Brown, B. Oakley & P. J. Felton

To cite this article: A. J. Redwood-Brown, H. L. Brown, B. Oakley & P. J. Felton (2021): Determinants of Boat Velocity during a 200 m Race in Elite Paralympic Sprint Kayakers, International Journal of Performance Analysis in Sport, DOI: 10.1080/24748668.2021.1986351

To link to this article: https://doi.org/10.1080/24748668.2021.1986351

Published online: 20 Nov 2021.

INTERNATIONAL JOURNAL OF PERFORMANCE ANALYSIS IN SPORT
https://doi.org/10.1080/24748668.2021.1986351

RESEARCH ARTICLE

Determinants of Boat Velocity during a 200 m Race in Elite Paralympic Sprint Kayakers

A. J. Redwood-Brown [a*], H. L. Brown [a,b,c], B. Oakley [b,c] and P. J. Felton [a]

[a]SHAPE Research Centre, School of Science and Technology, Nottingham Trent University, Nottingham, U.K; [b]British Canoeing Performance Department, Nottingham, U.K; [c]English Institute of Sport, London, UK

ABSTRACT

This study investigates the relationships between boat velocity, stroke rate and displacement per stroke in Paracanoe 200m Sprint Kayak races. Data were analysed from 646, 200m efforts performed by 13 international Paracanoe athletes between 2017 and 2020 (Male: N= 6, female: N= 7) using boat-based GPS unit (Catapult S5). Significant differences between the Paralympic classifications were observed for boat velocity, stroke rate and displacement per stroke across both genders ($p < 0.001$) and Paracanoe classification ($p < 0.001$). Stroke rate was found to be the best predictor of boat velocity across classifications explaining between 13% and 34% of the variation. However, displacement per stroke was found to be more important for males than females potentially due to strength and anthropometric differences. Boat velocity, stroke rate and displacement per stroke values for the final 150m (measured in 50 m splits) indicated evidence for a mix of all-out and positive pacing strategies. The results of this study suggest intricate differences exist in Paracanoe Sprint Kayak based on gender and classification between athletes. This information is useful in the coaching of Paracanoe Sprint Kayak with evidence that physical preparation, training, and race strategy can be individualised to each athlete.

ARTICLE HISTORY
Received 21 July 2021
Accepted 24 September 2021

KEYWORDS
Kinematics; stroke rate; distance per stroke; paralympic athletes; canoe

1. Introduction

Flat-water Paracanoe sprint kayak is a competitive discipline where athletes race head-to-head over three distances: 200 m, 500 m and 1000 m using a two-blade paddle (International Canoe Federation, 2021). The race is won by the boat with the highest mean velocity across the race distance (Goreham et al., 2018). The average velocity of the kayak across the race is a product of two variables: the average stroke rate (the number of strokes per minute) and the average displacement per stroke (displacement of both the water and aerial phases of one stroke (Kendal & Sanders, 1992). As displacement per stroke is proportional to the average net force (the difference between the propulsive force created by each stroke and the aerodynamic and hydrodynamic drag forces (Mann & Kearney, 1980; Michael et al., 2008; Sperlich & Baker, 2002) across the stroke), it is

CONTACT A. J. Redwood-Brown athalie.redwoodbrown@ntu.ac.uk School of Science and Technology, Nottingham Trent University, Clifton Lane, Nottingham, NG11 8NS.

often used to analyse the efficiency of the technique of the stroke (McDonnell et al., 2013a). In contrast, average stroke rate is often used to analyse race strategy or pacing (Brown et al., 2011; McDonnell et al., 2013b).

Previous research on the sensitivity of boat velocity in relation to variations in stroke rate and displacement per stroke in the Paracanoe Sprint Kayak is extremely limited. However, the effect on boat velocity of stroke rate and displacement per stroke has been investigated in Canoe Sprint Kayak (McDonnell et al., 2013a). McDonnell et al. (2013a) established a large association ($r = 0.86$, $p < 0.01$) between stroke rate and boat velocity, but no association between displacement per stroke and boat velocity, using the reported mean values from five previous studies (Baker et al., 1999; Bourgois et al., 1997; Hay & Yanai, 1996; Kendal & Sanders, 1992; Timofeev et al., 1996). Although (Pickett et al. (2021) reported stroke rates to be higher when comparing elite to sub-elite, no differences were found between athletes in the elite group. There was a difference, however, in displacement per stroke within the elite group with faster race times associated with longer stroke lengths, highlighting the importance of the technique. To ensure the importance of stroke rate and displacement per stroke, partial correlations (in which either measure was controlled for), were conducted, and found to have near perfect correlation with performance outcomes ($r < -0.97$). Pickett et al. (2021) concluded that the ability to exhibit greater stroke lengths at relatively high stroke rates, despite fatigue, were key determinants of 200 m kayak race performance. This agreed with earlier studies which suggested similar boat velocities can be achieved with differing variations between stroke rate and displacement per stroke, within appropriate pacing strategies (Brown et al., 2011; Goreham et al., 2021; McDonnell et al., 2013b).

Both stroke rate and displacement per stroke are considered dependent on the athlete's physical attributes and technical ability in Canoe Sprint Kayak (Michael et al., 2009). The force produced during each stroke is likely to result from the ability of the paddler to produce muscular force or, alternatively, through the ability to transfer force through the paddle (Pickett et al., 2021). Previous research has identified that an individual's execution of the kayak stroke is directly linked to their physical capability to move key joints within their body (Mann & Kearney, 1980). Specifically, the coordination and synchronisation required of the trunk and legs, due to their role in force production during the paddle stroke (Brown et al., 2011). In Paracanoe sprint kayak the ability of athletes to use these joints is often impaired. Previous research has identified that Sprint Canoe athletes have a significantly greater joint range of motion and power output within these joints compared to their Paracanoe counterparts (Bjerkefors et al., 2019). The level of impairment also affects the athlete's technical ability with three levels recognised for the 2020 Tokyo Paralympic games: KL1 – athletes with no or very limited trunk function and no leg function; KL2 – athletes with partial trunk and leg function; KL3 – athletes with trunk function and partial leg function (International Canoe Federation, 2018). The reduced functionality within these joints has resulted in the requirement for equipment adjustments in Paracanoe sprint kayak to aid performance and reduce injury (Cutler et al., 2017). These include increasing the width of the hull and relocating the cockpit to increase stability, as well as, the addition of trunk support where required. These physical and equipment differences are likely to alter the stroke rates and displacements per stroke compared to those observed in Canoe Sprint Kayak athletes. It is likely, therefore, that these previous findings are not reliable to predict Paracanoe sprint kayak performance and thus coaching strategies.

Despite the Paracanoe sprint kayak being introduced to the International Canoe Federation's competition programme in 2009, and the Paralympic games in 2016, there remains limited understanding on how the physical and equipment differences within Paracanoe sprint kayak affects the stroke rate – displacement per stroke ratio with boat velocity (Collins et al., 2019). The aim of this study is to investigate the relationship between stroke rate and displacement per stroke with boat velocity for gender and impairment classification in Paracanoe Sprint Kayak.

2. Materials and methods

2.1. Study design

Kinematic data were obtained for all completed 200 m Paracanoe sprint kayak race rehearsals and races between January 2017 and March 2020 within the British Canoeing Paracanoe performance programme. The data were pooled for the analysis (McDonnell et al., 2013a) and efforts were selected to determine if they were maximal and from a stationary start. Any effort that was conducted in an extreme weather condition (wind speed >5 m/s) was disregarded. Participants consented to the use of these data as part of standard practices within the British Canoeing Paracanoe performance programme, and ethical approval was granted in accordance with Nottingham Trent University guidelines.

2.2. Data collection and parameter determination

Kinematic data were collected by accelerometer global positioning units, recording GPS at 10 Hz and tri-axial accelerations at 100 Hz (Optimeye S5, Catapult Sports). Previous studies have used this method to determine accurate measurements of the boat velocity and kayak stroke determinants (Goreham et al., 2021; Janssen & Sachlikidis, 2010; Pickett et al., 2021; Vadai & Gingl, 2016; Vadai et al., 2013; Worsey et al., 2019). The GPS and accelerometer data were downloaded and filtered using a low-pass Butterworth filter via Catapult's custom software. Pre-determined software-specific cut-off frequencies of 0.65 Hz for the GPS data and 2 Hz for the acceleration data were used. The filtered data for each 200 m race effort was then exported into the visualisation tool Neptune (Version 1.1.0) for further analysis.

The GPS data across each 200 m effort were used to determine the average boat velocity for the 200 m effort. The average boat velocity was also determined for three 50 m splits within the "speed maintenance phase" defined between 50 and 200 m (Split 1:50–100 m; Split 2:100–150 m; Split 3:150–200 m).

Individual stroke cycles and stroke times were identified automatically in Neptune, using the accelerometer time history. The time history forms a sinusoidal waveform due to the boat accelerating when the paddle is in the water and decelerating during the aerial phase of the stroke (Vadai & Gingl, 2016; Vadai et al., 2013). A visual inspection was also performed for reliability of stroke identification by two experienced coaches. These calculations were recorded and compared against both one and another and against the software. The average stroke rate was calculated by transforming the average stroke time into strokes per minute for the whole 200 m effort, and the three 50 m splits in the speed maintenance phase. Similarly, the average displacement per stroke was calculated by dividing the average velocity by the average stroke time for a total of 200 m effort and three 50 m splits.

2.3. Data cleaning

Efforts were grouped based on gender and Paracanoe Sprint Kayak classification and the mean absolute deviation (MAD) for 200 m effort time was calculated within each group (Leys et al., 2013). All outliers, potentially included in the error (e.g., unidentified non-maximal effort), were identified using a moderate rejection criterion of 2.5 and excluded from the analysis (Miller, 1991).

2.4. Statistical analysis

Statistical analysis was performed using SPSS v.26 (IBM, USA) with an alpha value of 0.05 used to determine the significance of the pooled data.

A between-group analysis was conducted using a Student's t-test for independent variables to compare the kinematic parameters between genders across the whole 200 m effort, the speed maintenance phase, and the three 50 m splits. If the assumption of normality was violated for any of the parameters, the non-parametric Mann–Whitney U-test was performed instead. Similarly, to compare the kinematic parameters across the three Paracanoe sprint kayak classifications across the whole 200 m effort, the speed maintenance phase, and the three 50 m splits, a One-Way ANOVA with Bonferroni adjusted post-hoc student t-tests was used. If the assumption of normality was violated for any of the parameters, the non-parametric Kruskal-Wallis One-Way ANOVA with Bonferroni adjusted post-hoc Mann–Whitney U-tests was performed instead. For all significant differences, Hedges' *g* was calculated to determine the size of the difference (small effect: $g \geq 0.20$; medium effect: $g \geq 0.50$; large effect: $g \geq 0.80$: Cohen, 1988).

A within-group analysis was conducted on each Paracanoe boat classification using a repeated measures ANOVA with Bonferroni-adjusted post-hoc paired t-tests to identify potential changes in the kinematic variables within the speed maintenance phase (50–200 m) using the 50 m splits. If the assumption of normality was violated for any of the parameters, the non-parametric Friedman Test with Bonferroni adjusted post-hoc Wilcoxon signed-rank tests was performed instead. For all significant differences, Cohen's *d* was calculated to determine the size of the difference (small effect: $g \geq 0.20$; medium effect: $g \geq 0.50$; large effect: $g \geq 0.80$: Cohen, 1988).

The average differences between two consecutive splits were determined as a percentage of the earlier split and compared across the three Paracanoe sprint kayak classifications. A One-Way ANOVA with Bonferroni adjusted post-hoc student t-tests was used (or a non-parametric Kruskal-Wallis One-Way ANOVA with Bonferroni adjusted post-hoc Mann–Whitney U-tests), as well as, Hedges' *g*, to investigate the differences.

To investigate the importance of displacement per stroke and stroke rate on boat velocity, single and multivariable linear regression models were developed for each Paracanoe classification. The percentage of variance of the dependent variable (boat velocity) explained by the independent variables (displacement per stroke and stroke rate) in each regression equation was determined by Wherry's R^2-value (1931). This represents an attempt to estimate the proportion of variance that would be explained by the model had it been derived from the population (athletes from each Paracanoe classification) from which the sample was taken. The size of the association was interpreted using Hopkins et al. (2009) as: trivial (r^2 = 0% to 10%), moderate (r = 10% to 25%), large (r = 25% to 50%), very large (r = 50% to 81%), or nearly perfect (r = 81% to 100%).

3. Results

Kinematic data were collected from 735 individual 200 m efforts. A total of 89 efforts were removed due to being classified as outliers, resulting in 646 efforts being included for further analysis. These efforts were made by seven female and six male international Paracanoe Sprint Kayak athletes and split by gender and Paracanoe classification (Female: KL1 – 8; KL2 – 126; KL3 – 180; Male: KL1 – 78; KL2 – 103; KL3 – 151).

3.1. Gender effects

The male Paracanoe athletes produced significantly faster average boat velocities across the 200 m effort compared to their female counterparts (Table 1). On average the male kayakers also had higher average stroke rates, and for the KL2 and KL3 classifications larger average displacements per stroke (Table 1). For the KL1 classification, no difference was observed in displacement per stroke between males and females.

3.2. Paracanoe classification effects

Significant differences were observed across all three Paracanoe classifications for boat velocity, stroke rate and displacement per stroke for both males ($p < 0.001$) and females ($p < 0.001$).

Average boat velocity was the slowest in the KL1 classification for both males and females (Table 1). This was significantly different to the boat velocity in the KL2 and KL3 classifications (females: KL1 vs KL2, $p < 0.001$, $g > 0.8$; KL1 vs KL3, $p = 0.01$, $g > 0.8$; males: KL1 vs KL2, $p < 0.001$, $g = 0.68$; KL1 vs KL3, $p < 0.001$, $g > 0.8$). The fastest classification differed between KL2 for females and KL3 for males (Table 1). The difference in boat velocity between the KL2 and KL3 classifications was significant for both males ($p < 0.001$; $g > 0.8$) and females ($p < 0.001$; $g > 0.8$).

Table 1. Average boat velocity, stroke rate and displacement per stroke for all efforts grouped by gender and Paracanoe classification.

	KL1		KL2		KL3	
parameters	*female*	*male*	*Female*	*male*	*female*	*male*
boat velocity (m/s)	*3.51 ± 0.1*	*3.88 ± 0.1* [c]	*3.92 ± 0.2*	*4.40 ± 0.2* [c]	*3.71 ± 0.2*	*4.64 ± 0.2* [c]
stroke rate (SPM)	*113 ± 2*	*127 ± 7* [c]	*115 ± 7*	*126 ± 7* [c]	*110 ± 8*	*131 ± 7* [c]
displacement per stroke (m)	1.89 ± 0.03	1.88 ± 0.1	*2.09 ± 0.1*	*2.15 ± 0.1* [b]	*2.07 ± 0.1*	*2.18 ± 0.1* [c]

Bold italic text denotes significant difference (p < 0.05) between groups
[a] small effect size (g ≥ 0.20), [b] medium effect size (g ≥ 0.50), [c] large effect size (g ≥ 0.80)

Similarly, the average displacement per stroke was lowest in the KL1 classification for both males and females (Table 1). This was significantly different to the displacement per stroke in the KL2 and KL3 classifications (females: KL1 vs KL2, $p < 0.001$, $g > 0.8$; KL1 vs KL3, $p = 0.01$, $g > 0.8$; males: KL1 vs KL2, $p < 0.001$, $g = 0.68$; KL1 vs KL3, $p < 0.001$, $g > 0.8$). The classification with greatest displacement per stroke again differed between the KL2 classification for females and the KL3 classification for males (Table 1). The difference in displacement per stroke, however, was only significant between the KL2 and KL3 classifications for males ($p < 0.001$; $g = 0.3$) and not females.

Conversely, there were no differences in stroke rate for females for Paracanoe classification apart from between KL2 and KL3 ($p < 0.001$; $g = 0.65$), where the KL2 classification was observed to have a higher stroke rate. For males, the stroke rate was significantly different between the KL3 classification, which had the highest (Table 1), and both with KL1 ($p < 0.001$; $g = 0.57$) and KL2 ($p < 0.001$; $g = 0.67$) classifications. No difference was observed between the KL1 and KL2 classifications for males.

3.3. Pacing

The average boat velocity for the final three 50 m splits (50–100 m, 100–150 m, and 150–200 m) indicated that Paracanoe sprint kayakers use an all-out or positive pacing strategy (Figure 1). All athletes reached a peak average velocity prior to or in the first split (50–100 m) and then demonstrated a gradual decline in boat velocity, of similar magnitudes, as the effort progressed towards 200 m. Visual inspection appears to indicate that males had a faster drop off in boat velocity than females for both the KL2 and KL3 classifications, but similar levels were observed in the KL1 classification.

A similar pattern was observed for stroke rate, with the average stroke rate decreasing with distance travelled through the effort (Figure 1). Again, males had a faster drop off in stroke rate than females in both the KL2 and KL3 classifications, with a similar rate observed in the KL1 classification. The average displacement per stroke remained similar with distance for all three classifications for females, and within the KL1 classification for males (Figure 1). Increases in displacement per stroke were observed in both the KL2 and KL3 classifications as the effort progressed.

3.4. Regression analysis

The best predictor of average boat velocity across the 200 m effort was the stroke rate for all Paracanoe sprint kayak classifications explaining between 12.9% and 34.1% of the variation in boat velocity (Table 2). The mechanical relationship between boat velocity with stroke rate and displacement per stroke was identified within the regression models with near perfect r^2 values (96.3–99.1%). No regression model was found for females in the KL1 classification due to the lower number of efforts ($n = 8$).

The unstandardised coefficients were extremely consistent across all classifications for stroke rate (range: 0.031–0.034) suggesting an increase in boat velocity of 0.1 m/s would require an increase of approximately 3 strokes per minute with no change in the displacement per stroke (Table 2). The coefficient of displacement per stroke, however, was more heavily weighted for males (range: 1.99–2.00) compared to females (range: 1.81–1.72),

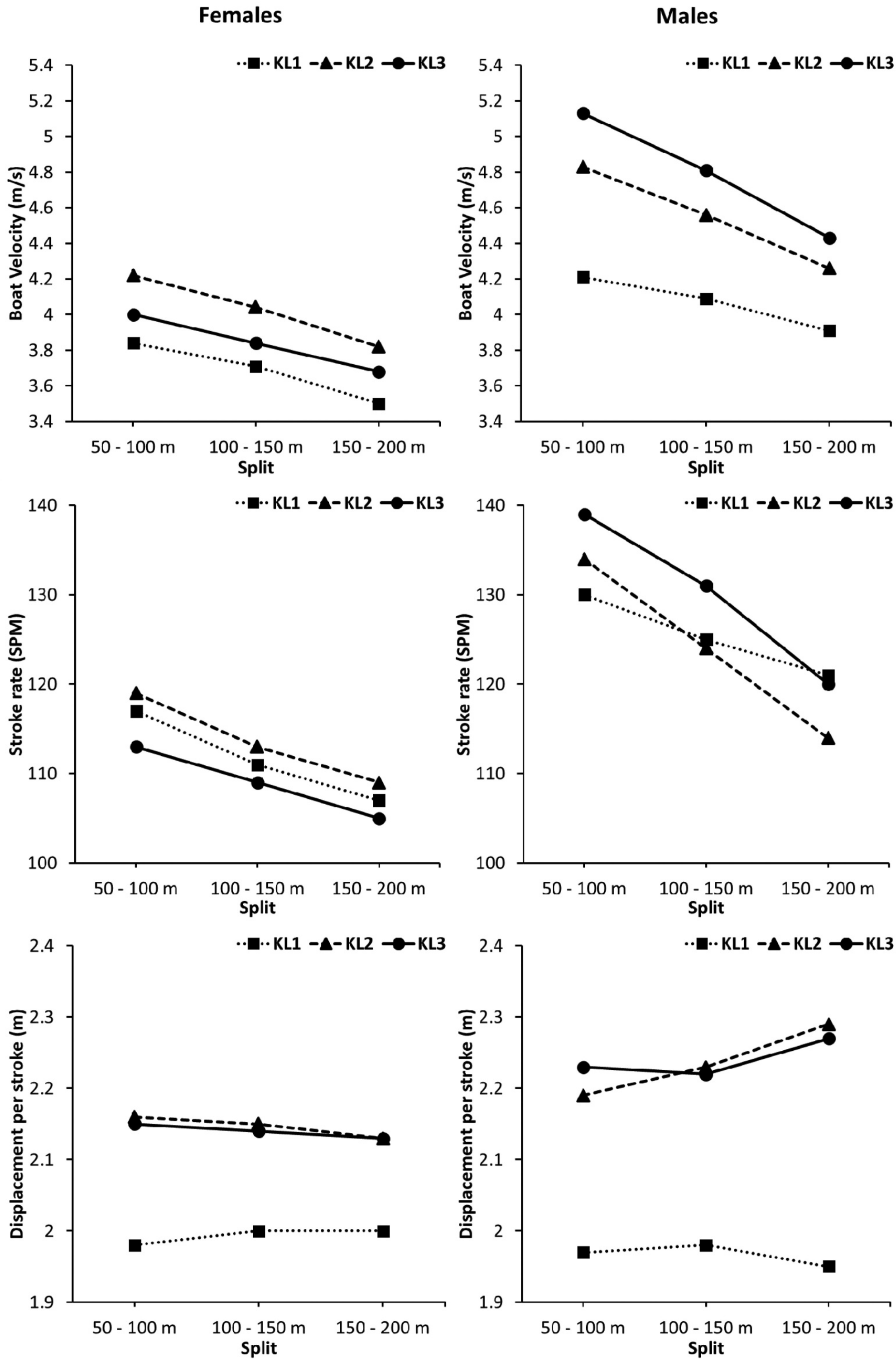

Figure 1. Average female and male boat velocity, stroke rate and displacement per stroke for the final three 50 m splits of the 200 m effort for each of the Paracanoe Kayak classifications.

Table 2. Regression equations predicting female and male boat velocity for the three Paracanoe classifications.

	model	parameters	B	95% CI	p	r^2
female						
KL1	1	*no variables entered*				
KL2	1	stroke rate	0.011	0.007–0.014	< 0.001	26.1
	2	stroke rate	0.033	0.032–0.034	<0.001	97.9
		displacement per stroke	1.81	1.76–1.87		
KL3	1	stroke rate	0.015	0.012–0.018	< 0.001	34.0
	2	stroke rate	0.032	0.032–0.033	<0.001	99.1
		displacement per stroke	1.72	1.69–1.75		
males						
KL1	1	stroke rate	0.012	0.008–0.016	< 0.001	34.1
	2	stroke rate	0.031	0.029–0.032	<0.001	96.3
		displacement per stroke	2.00	1.89–2.11		
KL2	1	stroke rate	0.008	0.004–0.012	< 0.001	12.9
	2	stroke rate	0.033	0.032–0.035	<0.001	97.1
		displacement per stroke	1.99	1.91–2.06		
KL3	1	stroke rate	0.012	0.009–0.016	< 0.001	21.8
	2	stroke rate	0.034	0.033–0.035	<0.001	96.6
		displacement per stroke	1.99	1.92–2.06		

suggesting an increase in boat velocity of 0.1 m/s with no change in stroke rate would require approximately a 6 cm increase in displacement for females compared to 5 cm for males (Table 2).

4. Discussion

This study is the first to investigate the relationship between stroke rate and displacement per stroke on boat velocity using on-water performance data from the Paracanoe Sprint Kayak. The results of this study found significant differences in boat velocity and kinematic parameters between Paracanoe kayak athletes which may indicate that they potentially generate boat velocity differently based on their physical and technical limitations.

Boat velocity is a product of stroke rate and displacement per stroke (Pickett et al., 2021). Multiple regression returned almost near perfect models with 96.3–99.1% of the variance in boat velocity explained (Table 2). Previous research examining stroke kinematics has found that a strong relationship exists between stroke rate and performance compared to displacement per stroke and performance (Brown et al., 2011; Hirano et al., 2016; Kendal & Sanders, 1992; McDonnell et al., 2013b; Pickett et al., 2021). Within this study, stroke rate was found to be the largest predictor of boat velocity for all Paracanoe Sprint Kayak classifications (Table 2). For each model, the coefficient for stroke rate was consistent indicating the importance of this variable across both gender and Paracanoe classification for boat velocity. While the coefficient of displacement per stroke was consistent for males and female, it differed suggesting this was the limiting factor in boat velocity between the genders (Table 2). The consistency of these coefficients indicates that at an elite level, athletes separated via gender and impairment into each classification demonstrate similar levels of technical ability and displacement per stroke. This suggests that the variation in performance observed can be explained by the athlete's peak stroke rate and their ability to maintain this under fatigue during the latter parts of the race (Pickett et al., 2021). It has been observed, however, that the fastest boat velocities do not necessarily have the highest stroke rates, and that displacement per stroke should also be considered, therefore enhancing this relationship is vital to underpin individual performances (McDonnell et al., 2013b) .

Boat velocity was seen to be significantly slower for the most impaired Paracanoe Sprint Kayak classification (KL1) for both males and females. Athletes in this classification have impaired trunk function, and this appears to limit their ability to generate larger displacements per stroke compared to their KL2 and KL3 counterparts (Figure 1; Table 1). It has previously been established that a strong posture and large range of motion of the trunk are important contributors to maximise displacement per stroke via kayak technique (Brown et al., 2011). This finding agrees with research in other Paralympic sports, where performance has been reported to be correlated with the ability to produce force through trunk muscle recruitment (Altmann et al., 2018). Despite this, the stroke rate was similar for the KL1 classification compared to the KL2 and KL3 classifications (Figure 1).

The average male boat velocity for both the KL2 and KL3 classification was lower than previously reported for 200 m male Sprint Kayak athletes (KL2: 4.40 m/s; KL3: 4.64 m/s: Sprint Kayak (Pickett et al., 2021): 5.19 m/s). Differences in both stroke rate (KL2: 126 SPM; KL3: 131 SPM; Sprint Kayak (Pickett et al., 2021): 142 SPM) and displacement per stroke (KL2: 2.15 m; KL3: 2.18 m; Sprint Kayak (Pickett et al., 2021): 2.24 m) exist and are likely effects caused by the impairment experienced by KL2 and KL3 athletes. The increased boat velocity for KL3 male athletes compared to their KL2 counterparts was achieved by attaining larger displacements per stroke and higher stroke rates (Table 1).

The trend in boat velocity between the KL2 and KL3 classifications was inversed for females (Table 1), whereas boat velocity was higher for KL2 female athletes compared to the KL3 classification. This difference was explained by the KL2 athletes producing higher stroke rates, with both classifications achieving similar displacements per stroke. As KL2 athletes have higher levels of lower limb physical impairment than their KL3 counterparts (KL3 – trunk function with partial leg function e.g. a unilateral lower limb amputation; KL2 – partial trunk and leg function e.g. a bilateral impairment), it is highly likely that the result for males (where the KL3 classification had the highest boat velocity) is more probable. An explanation, however, may lie in the adaptation to the athlete's individual impairment. The kayak stroke is cyclical in nature, and to maximise forward propulsion of the boat ideally requires equal power transfer from each side of the stroke (Harrison et al., 2019). The ability to do this has previously been identified as a differing factor between Olympic and novice or intermediate paddlers (Helmer et al., 2011; Limonta et al., 2010; Vadai et al., 2013). It is possible that the challenge of maintaining the symmetry of the kayak stroke could be as heavily impacted in the KL3 classification as the KL2, due to the asymmetry of lower limb function associated with the impairment. Caution nevertheless must be applied to this interpretation due to the study design (data being pooled, and convenience sampling leading to a few individuals contributing to each pool). It is probable that the trend for boat velocity across Paracanoe classifications in the global population is closer to that observed for the males in this study. Future research should aim to investigate this using a wider range of participants, as well as, investigating the effect of impairment on the Paracanoe kayak stroke technique, fatigue, muscle development and performance.

Across all three Paracanoe classifications evidence of positive or all-out pacing strategies were observed (Figure 1). In these strategies, athletes maximally accelerate to peak velocity, after which, a gradual linear fatigue-induced decline in velocity occurs as the athletes proceeded to the end of the race (Pickett et al., 2021). It has been argued that Sprint Kayakers use an all-out pacing strategy (Goreham et al., 2021; Hirano et al., 2016; McDonnell et al., 2013a) as the velocity-time history matches other sprint events of a similar time duration (Abbiss & Laursen, 2008). More recently, however, it has been argued that a positive, rather than all-out, pacing pattern is adopted by elite Sprint Kayakers since the time to peak velocity is greater than in other sports (Pickett et al., 2021). Pickett et al. (2021) declares, however, that it is unclear which strategy is adopted as it is unknown whether the additional time is due to the task of accelerating a kayak through water. This study is further clouded by the different levels of impairment Paracanoe athlete's exhibit, which can affect their anaerobic power output (Hutzler et al., 1998). One potential avenue to explore is the pattern of the kinematic parameters. As an all-out pacing strategy will result in considerable muscular fatigue (Abbiss & Laursen, 2008), it would be expected that stroke rate and displacement per stroke follows a declining pattern under exhaustion. For all three Paracanoe classifications, while stroke rate followed this pattern, the effect on displacement per stroke was mixed (Figure 1). Male athletes in the KL2 and KL3 classification could increase their displacement per stroke, while female athletes and those in the KL1 classification either maintained or decreased theirs in the latter stages of the effort. This may be due to differences in the technical ability to execute the paddle stroke under fatigue, or due to the greater strength of males and lower impairment classes allowing them to maintain power despite muscle fatigue. This may provide evidence that athlete impairment, and gender influence the pacing strategy adopted. Those where the kinematic parameters decline during the effort indicate an all-out approach, whilst those able to maintain their kayak stroke technique during each effort may adopt a positive strategy. In the future, research is required to investigate pacing strategies adopted in the different Paracanoe Kayak classifications and their causes.

Gender differences with large effect sizes in boat velocity were observed in all three Paracanoe classifications. Males were seen to have faster boat velocities, which were achieved using a combination of higher stroke rates and increased displacement per stroke for the KL2 and KL3 classifications (Table 1). It has previously been reported that both stroke rate and displacement per stroke are dependent on the athlete's physical attributes and technical ability in Canoe Sprint Kayak (Michael et al., 2009). Since males possess greater muscle mass and absolute strength, as well as, larger anthropometrics, than females, it is expected that males will attain higher boat velocities via increased stroke rates and displacements per stroke as demonstrated in this study. The lack of difference in displacement per stroke between genders in the KL1 classification, however, may indicate that trunk function is key in the kayak stroke, and when impaired this significantly reduces the athlete's ability to use their physical characteristics to generate force (Table 1). When analysing the drop-off in performance across the effort, females were more resistant to fatigue with smaller drop-offs in performance (Figure 1). This agrees with previous findings which suggests that although weaker, females are more resistant to muscle fatigue (Billaut & Bishop, 2009). Again, the results for KL1 are similar indicating the limitation on performance in this classification may be due to the physical impairment in this classification.

One of the limitations of this study is the approach of pooling multiple efforts from individuals to complete this analysis like previous studies (McDonnell et al., 2013a). This invalidates the statistical assumption that the data is completely independent, however, to overcome this a large sample size of differing Paracanoe athletes is required. In this study, all the Paracanoe kayak elite athletes within the British Canoeing Paracanoe performance programme participated. To go beyond this approach, future research could adopt a correlational approach using on-water GPS technology from competitions where multiple athletes could be recruited. This, however, would require multi-national co-operation and agreement which may not be attainable. Despite this, this study is the first study to analyze and report boat velocity and the kinematic parameters associated with this.

5. Conclusion

The results of this study suggest that stroke rate is the biggest predictor of boat velocity in the elite Paracanoe Sprint Kayak. Displacement per stroke was found to be more influential on boat velocity for male athletes compared to females, potentially due to their greater physical ability and susceptibility to fatigue. This suggests that key determinants of Paracanoe 200 m Sprint Kayak performance are the ability to exhibit greater displacement per stroke at high stroke rates, whilst resisting the effects of fatigue accumulation. The findings also suggest that differences due to impairment experienced by athletes in each Paracanoe classification impact performance and their pacing strategies. The results of this investigation are likely to be useful in the coaching of Paracanoe Sprint Kayak with the suggestion that race and training strategies be individualised for the athlete based on their classification, with greater adaptations made for KL1 athletes to highlight the impact due to their impairment.

Acknowledgments

This project was supported by British Canoeing in particular, the Paralympic Performance Department.

Disclosure statement

The authors acknowledge the support of British Canoeing and Nottingham Trent University. The authors report no conflicts of interest. The authors declare that the results of this study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

ORCID

A. J. Redwood-Brown http://orcid.org/0000-0002-9198-0088
P. J. Felton http://orcid.org/0000-0001-9211-0319

References

Abbiss, C. R., & Laursen, P. B. (2008). Describing and understanding pacing strategies during athletic competition. *Sports Medicine*, *38*(3), 239–252. https://doi.org/10.2165/00007256-200838030-00004

Altmann, V. C., Groen, B. E., Hart, A. L., Vanlandewijck, Y. C., & Keijsers, N. (2018). Classifying trunk strength impairment according to the activity limitation caused in wheelchair rugby performance. *Scandinavian Journal of Medicine & Science in Sports*, *28*(2), 649–657. https://doi.org/10.1111/sms.12921

Baker, J., Rath, D., Sanders, R., & Kelly, B. (1999). A three-dimensional analysis of male and female elite sprint kayak paddlers. *Paper presented at the ISBS-conference proceedings archive,* Perth, Western Australia, Australia, June 30 - July 06.

Billaut, F., & Bishop, D. (2009). Muscle fatigue in males and females during multiple-sprint exercise. *Sports Medicine*, *39*(4), 257–278. https://doi.org/10.2165/00007256-200939040-00001

Bjerkefors, A., Rosén, J. S., Tarassova, O., & Arndt, A. (2019). Three-dimensional kinematics and power output in elite para-kayakers and elite able-bodied flat-water kayakers. *Journal of Applied Biomechanics*, *35*(2), 93–100. https://doi.org/10.1123/jab.2017-0102

Bourgois, J., Van Renterghem, B., Janssens, M., Vrijens, J., & De Blieck, C. (1997). Comparative study of specific ergometry and field tests in kayaking. *Paper presented at the 2nd annual congress of European college of sport science*, Copenhagen, Denmark 810–811.

Brown, B. M., Lauder, M., & Dyson, R. (2011). Notational analysis of sprint kayaking: Differentiating between ability levels. *International Journal of Performance Analysis in Sport*, *11*(1), 171–183. https://doi.org/10.1080/24748668.2011.11868538

Cohen, J. (1988). Statistical power analysis for the social sciences. Hillsdale, NJ: Erlbaum https://doi.org/10.1016/b978-0-12-179060-8.50006-2

Collins, L., Simon, S., & Carson, H. J. (2019). Para-adventure: A hyper-dynamic problem for the inclusive coach. *Sport in Society*, *22*(7), 1165–1182. https://doi.org/10.1080/17430437.2018.1504776

Cutler, B., Eger, T., Merritt, T., & Godwin, A. (2017). Comparing para-rowing set-ups on an ergometer using kinematic movement patterns of able-bodied rowers. *Journal of Sports Sciences*, *35*(8), 777–783. https://doi.org/10.1080/02640414.2016.1189587

Goreham, J. A., Landry, S. C., Kozey, J. W., Smith, B., & Ladouceur, M. (2018). FUNCTIONAL DATA ANALYSIS: A NEW METHOD TO INVESTIGATE PACING STRATEGIES IN ELITE CANOE KAYAK SPRINT. *ISBS Proceedings Archive*, *36*(1), 426. https://commons.nmu.edu/isbs/vol36/iss1/86

Goreham, J. A., Miller, K. B., Frayne, R. J., & Ladouceur, M. (2021). Pacing strategies and relationships between speed and stroke parameters for elite sprint kayakers in single boats. *Journal of Sports Sciences*, 39(18), 1–8. https://doi.org/10.1080/02640414.2021.1927314

Harrison, S. M., Cleary, P. W., & Cohen, R. C. (2019). Dynamic simulation of flat water kayaking using a coupled biomechanical-smoothed particle hydrodynamics model. *Human Movement Science*, *64*, 252–273. https://doi.org/10.1016/j.humov.2019.02.003

Hay, J. G., & Yanai, T. (1996). *Evaluating the techniques of elite US kayakers. A Report to US Olympic Committee and US Canoe and Kayak Team.Iowa City, IA: University of Iowa*,

Helmer, R., Farouil, A., Baker, J., & Blanchonette, I. (2011). Instrumentation of a kayak paddle to investigate blade/water interactions. *Procedia Engineering*, *13*, 501–506. https://doi.org/10.1016/j.proeng.2011.05.121

Hirano, T., Kashiwagi, Y., Yamagishi, M., Senba, S., Kato, T., & Funato, K. (2016). SEX DIFFERENCES IN RACE PROFILE AND STROKE VARIABLES DURING 200-M SPRINT IN JUNIOR KAYAKERS. *Paper presented at the ISBS-conference proceedings archive*. Tsukuba, Japan, July 18-22

Hopkins, W., Marshall, S., Batterham, A., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine Science in Sports Exercise*, *41*(1), 3. https://doi.org/10.1249/mss.0b013e31818cb278

Hutzler, Y., Ochana, S., Bolotin, R., & Kalina, E. (1998). Aerobic and anaerobic arm-cranking power outputs of males with lower limb impairments: Relationship with sport participation intensity, age, impairment and functional classification. *Spinal Cord*, *36*(3), 205–212. https://doi.org/10.1038/sj.sc.3100627

International Canoe Federation. (2018). *ICF paracanoe KAYAK classification manual*. https://www.canoeicf.com/sites/default/files/icf_paracanoe-kayak_classification_manual_19-08-2018.pdf

International Canoe Federation. (2021). *Paracanoe*. https://www.canoeicf.com/disciplines/paracanoe

Janssen, I., & Sachlikidis, A. (2010). Validity and reliability of intra-stroke kayak velocity and acceleration using a GPS-based accelerometer. *Sports Biomechanics*, *9*(1), 47–56. https://doi.org/10.1080/14763141003690229

Kendal, S. J., & Sanders, R. H. (1992). The technique of elite flatwater kayak paddlers using the wing paddle. *Journal of Applied Biomechanics*, *8*(3), 233–250. https://doi.org/10.1123/ijsb.8.3.233

Leys, C., Ley, C., Klein, O., Bernard, P., & Licata, L. (2013). Detecting outliers: Do not use standard deviation around the mean, use absolute deviation around the median. *Journal of Experimental Social Psychology*, *49*(4), 764–766. https://doi.org/10.1016/j.jesp.2013.03.013

Limonta, E., Squadrone, R., Rodano, R., Marzegan, A., Veicsteinas, A., Merati, G., & Sacchi, M. (2010). Tridimensional kinematic analysis on a kayaking simulator: Key factors to successful performance. *Sport Sciences for Health*, *6*(1), 27–34. https://doi.org/10.1007/s11332-010-0093-7

Mann, R. V., & Kearney, J. T. (1980). A biomechanical analysis of the Olympic-style flatwater kayak stroke. *Medicine and Science in Sports and Exercise*, *12*(3), 183–188. https://doi.org/10.1249/00005768-198023000-00010

McDonnell, L. K., Hume, P. A., & Nolte, V. (2013a). A deterministic model based on evidence for the associations between kinematic variables and sprint kayak performance. *Sports Biomechanics*, *12*(3), 205–220. https://doi.org/10.1080/14763141.2012.760106

McDonnell, L. K., Hume, P. A., & Nolte, V. (2013b). Place time consistency and stroke rates required for success in K1 200-m sprint kayaking elite competition. *International Journal of Performance Analysis in Sport*, *13*(1), 38–50. https://doi.org/10.1080/24748668.2013.11868630

Michael, J. S., Rooney, K. B., & Smith, R. (2008). The metabolic demands of kayaking: A review. *Journal of Sports Science & Medicine*, *7*(1), 1.

Michael, J. S., Smith, R., & Rooney, K. B. (2009). Determinants of kayak paddling performance. *Sports Biomechanics*, *8*(2), 167–179. https://doi.org/10.1080/14763140902745019

Miller, J. (1991). Reaction time analysis with outlier exclusion: Bias varies with sample size. *The Quarterly Journal of Experimental Psychology*, *43*(4), 907–912. https://doi.org/10.1080/14640749108400962

Pickett, C. W., Abbiss, C., Zois, J., & Blazevich, A. J. (2021). Pacing and stroke kinematics in 200-m kayak racing. *Journal of Sports Sciences*, *39*(10), 1096–1104. https://doi.org/10.1080/02640414.2020.1859242

Sperlich, J., & Baker, J. (2002). Biomechanical testing in elite canoeing. *Paper presented at the ISBS-conference proceedings archive*, Caceres, Spain

Timofeev, V., Gorodetsky, K., Sokolov, A., & Shklyaruk, S. (1996). Energetic, biomechanical, and electromyographic characteristics of elite kayakers and canoeists. *Current Research in Sports Sciences (Pp*, *191-197*(Springer). https://doi.org/10.1007/978-1-4757-2510-0_29

Vadai, G., & Gingl, Z. (2016). Can the fluctuations of motion be used to estimate the performance of kayak paddlers? *Journal of Statistical Mechanics: Theory and Experiment*, *(2016*(5), 054040. https://doi.org/10.1088/1742-5468/2016/05/054040

Vadai, G., Gingl, Z., Mingesz, R., & Makan, G. (2013). Performance estimation of kayak paddlers based on fluctuation analysis of movement signals. Paper presented at the *2013 22nd International Conference on Noise and Fluctuations (ICNF)*, Montpellier, France 1–4. https://doi.org/10.1109/icnf.2013.6579010

Worsey, M. T., Espinosa, H. G., Shepherd, J. B., & Thiel, D. V. (2019). A systematic review of performance analysis in rowing using inertial sensors. *Electronics*, *8*(11), 1304. https://doi.org/10.3390/electronics8111304