

The Relationship between On-water Performance and Physical Characteristics in Elite and Sub-elite Outrigger Canoe Paddlers

King, T.¹, McQuillan, J.¹, Gill, N.^{1,2} & Driller, M.^{1*}

¹ Health, Sport and Human Performance, University of Waikato, Hamilton, New Zealand

² New Zealand Rugby Union

*Correspondance: mdriller@waikato.ac.nz

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Abstract

Objectives: The aim of the present study was to compare and investigate the relationship between 500 m on-water performance and physical characteristics in elite and sub-elite outrigger canoe paddlers. **Methods:** A total of 16 males participated in the study including eight elite paddlers (age: 24.8 ± 10.5 yrs., total paddling experience: 12.5 ± 5.2 yrs.) and eight sub-elite paddlers (age: 34.4 ± 15.4 yrs., total paddling experience: 6.8 ± 5.2 yrs.). Body mass, height, sitting height, arm span, arm length, body fat percentage, 50 kg muscular endurance (bench press and bench pull), peak oxygen uptake (VO_{2peak}) and Wingate performance (30 sec maximal effort) were assessed and subsequently correlated with 500 m outrigger canoeing performance at a national championship's regatta. **Results:** When group data were combined, *moderate* to *strong* correlations were found between 500 m outrigger canoeing performance and absolute VO_{2peak} ($r = -0.61$), upper limb length ($r = -0.60$) 50 kg bench press ($r = -0.56$), total paddling experience ($r = -0.53$), body mass ($r = -0.51$), sitting height ($r = -0.51$), singles paddling experience ($r = -0.49$), height ($r = -0.48$) and Wingate distance ($r = -0.42$). When groups were compared, elite paddlers showed significantly greater Wingate mean power and distance, paddling experience and 500 m on-water performance times than sub-elite paddlers ($p < 0.05$). However, there were no significant differences in anthropometrical measures, muscular endurance and VO_{2peak} between the two groups ($p < 0.05$). **Conclusion:** VO_{2peak} and upper limb length were the best predictors of performance over the 500 m sprint distance across the entire group. Thirty-second Wingate mean power and distance, years of paddling experience and subsequent 500 m on-water performance differentiated elite from sub-elite paddlers.

Key words: Waka Ama, canoeing, VO_{2max} , water sports

Introduction

Outrigger canoe racing has become a popular sport around the globe and in 2016, outrigger canoeing appeared as an official sport at the Rio Paralympic Games. Outrigger canoes consist of a hull with an attachment (ama) that extends out from the port side via two booms (kiato) to keep it afloat. The most common sprint distance in the singles division is 500 m, which takes between two-three minutes to complete (West, 2006). According to Gastin (2001), maximal efforts of up to 75 seconds derives approximately equal energy contribution from the anaerobic and aerobic energy systems, with increasing reliance placed on the aerobic energy system beyond this point in time. Based on the duration, the energy contribution during maximal intensity ranges between 27-37% anaerobic and 63-73% aerobic (Gastin, 2001) for the 500 m sprint distance.

Optimal outrigger canoe performance requires a complex combination of anthropometric, physiological and biomechanical factors (Humphries et al., 2000; LaBreche, 2001; Yamada et al., 2001; Dascombe et al., 2002; Stanton et. al., 2002; Sealey, 2010). Finding the relationship between these characteristics and performance may be valuable for crew selection and fitness assessment (Sealey, 2010). In relation to 250 m outrigger canoeing performance, Humphries et al. (2000) found *moderate* correlations for height, sitting height, arm span, $VO_2\text{max}$, humerus and femur widths and *strong* correlations for one repetition max bench press, acromial width and both right and left peak paddle force in 21 amateur outrigger canoe paddlers. A more recent study by Sealey (2010) found *moderate to strong* correlations between 1000 m ergometer performance and mean and peak power, $VO_2\text{peak}$, mean heart rate, and peak lactate in 17 trained female outrigger canoeists. Sealey (2010) reported $VO_2\text{peak}$ values of $\sim 3.17 \text{ L}\cdot\text{min}^{-1}$ in the female paddlers, and 1000 m ergometer times ranged between 5-7 minutes. In elite flat-water kayakers, Fry and Morton (1991) found *moderate* correlations between $VO_2\text{max}$ and 500 m performance. In their study, they reported absolute and relative $VO_2\text{peak}$ scores of $\sim 4.78 \text{ L}\cdot\text{min}^{-1}$ and $\sim 59.22 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, respectively. The time to complete 500 m in the flat-water kayak in this cohort was ~ 2 minutes and just over 4 minutes for the 1000 m distance. Furthermore, a study on competitive canoe and kayak paddlers demonstrated high correlations between two-minute time trial performance and absolute $VO_2\text{max}$, Wingate mean power, Wingate peak power and bench press strength (Hamano et al., 2015).

Despite being the most competitive event in outrigger canoeing World Championship level, to our knowledge, there is no published research that has specifically focused on the 500 m sprint distance. Furthermore, participants employed in earlier outrigger canoe studies have been classified as amateur (Humphries et al., 2000), trained (Sealey, 2010), experienced (LaBreche, 2001), competitive (Stanton et. al., 2002) or state level (Dascombe et. al., 2002), therefore, researchers are yet to report on the characteristics of elite level paddlers. The aim of the present study was to compare and investigate the

relationship between physical characteristics and 500 m on-water performance in elite and sub-elite outrigger canoe paddlers.

Methods

Participants

A total of 16 male participants volunteered to take part in the current study. For analysis, participants were split into two groups; elite paddlers ($n = 8$, age: 24.8 ± 10.5 yrs, total paddling experience: 12.5 ± 5.2 yrs) and sub-elite paddlers ($n = 8$, age: 34.4 ± 15.4 yrs, total paddling experience: 6.8 ± 5.2 yrs). Inclusion criteria for ‘elite’ paddlers included participation in the elite division at a World Championship campaign within the past two years. The criteria for ‘sub-elite’ was nationally competitive outrigger canoeists who have not competed in the elite division at a World Championship campaign. All participants qualified to compete at the 2018 New Zealand Waka Ama Sprint Championships in the 500 m sprint distance event in either the master’s, premier or junior men singles division. Each participant signed written informed consent prior to any testing being completed. Ethical approval was provided by the institutions Human Research Ethics Committee.

Procedures

Physiological/physical testing took place in a temperature-controlled sport science laboratory ($21 \pm 1^\circ\text{C}$), where two testing sessions were separated by a 24-hour period to allow for adequate recovery. The 500 m on-water performance times were taken from publicly available results at the New Zealand National Championships regatta. Physical testing took place within two weeks prior to the National Championships regatta in order to align with the paddlers peak physical performance. The timeline of the study design is shown in Figure 1.

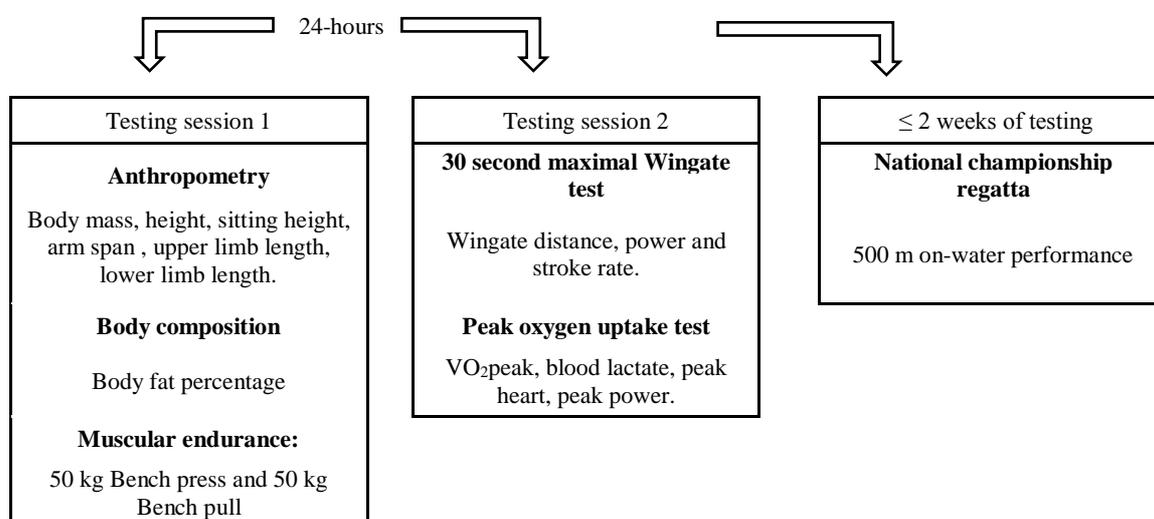


Figure 1. Timeline of the study design.

Anthropometry and Body Composition

Body composition and anthropometric measurements including body mass, body fat %, height, sitting height, arm span, upper limb length and lower limb length were obtained prior to the muscular endurance test protocols and were measured to the nearest 0.1 kg, 0.1 % and 0.1 cm, respectively, using a Tanita TBF-215 body composition analyser and anthropometric steel tape measure (Lufkin, Apex, AC). The body composition scales used in the current study have been previously validated for body fat % against the gold standard measure of DXA-derived body composition (Boneva-Asiova and Boyanov, 2008).

Muscular Endurance Test

Upper-body muscular endurance was determined using a bench press and bench pull test using a standardized load of 50 kg for each test. Given the relatively homogenous group of athletes, we opted for an absolute load rather than a weight relative to body mass. In an attempt to synchronize the speed of each repetition we used a metronome set at 30 repetitions per minute. Participants began with a 10 min active warm-up including dynamic stretching followed by some low to moderate intensity lifts on the bench press and bench pull prior to the test. Each participant performed practice lifts on both exercises with the 20 kg bar unloaded.

50 kg Bench Press

Participants began the bench press test by lying in a supine position on the bench with their feet flat on the floor and the head rested on the bench. The starting position of the bar for the bench press was with arms at full extension and the beep of the metronome would signal the commencement of each repetition. One repetition was counted as the bar touching the chest at the bottom of the repetition and the arms were fully extended at the top of the repetition. Failure to touch the chest at the bottom of a rep during the bench press was not counted as a rep. The recorded score was the number of successful repetitions completed. The test was terminated by the researcher when the participant failed to keep in time with the metronome or the participant voluntarily stopped.

50 kg Bench Pull

Participants began the bench pull by lying in a prone position with their chin touching the edge of the bench. The legs were kept in a relaxed position on top of the bench in a flexed or extended knee position. The starting position of the bar for the bench pull was with arms in full extension and the beep of the metronome would signal the start of each repetition. The bar was required to touch the bottom of the bench during flexion of the bench pull and arms were to achieve full extension at the

bottom of the repetition. If a participant failed to touch the bench with the bar the repetition was not counted. The recorded score was the number of successful repetitions completed. The test was terminated by the researcher when the participant failed to keep in time with the metronome, or the participant stopped voluntarily.

Wingate Test

Anaerobic power was assessed using a 30 second Wingate test on an outrigger canoe ergometer (MultiStroke O1-M, Kayak Pro, Florida, USA). The Wingate test was performed as described by Baror (1987). The Wingate test consisted of a five-minute warm-up on the ergometer at a self-selected intensity, followed by minimum five-minute rest period before the 30 second all-out effort. During the five-minute warm-up, participants were instructed to perform a 10-15 second maximal sprint, to familiarise them with the effort required during the Wingate test. Participants were verbally instructed to paddle as hard as possible for the 30 second effort. All participants were required to change stroke sides after 15 seconds but could self-select the side that they started on. During the test participants were able to view (time, distance and power). Mean power (W), distance (m) and mean stroke rate (strokes.min⁻¹) were recorded at the end of the 30 second effort for analysis. A five-minute active recovery at self-selected intensity was then performed after the Wingate test with an additional five-minute passive rest period prior to starting the next maximal oxygen uptake test.

Peak Oxygen Uptake Test

A peak oxygen uptake test was performed on the same outrigger canoe ergometer (MultiStroke O1-M, Kayak Pro, Florida, USA) to determine VO_{2peak} , VO_2 peak power, peak heart rate (HR), and peak blood lactate concentration. Cardiorespiratory-metabolic variables were measured throughout the peak oxygen uptake test using the Parvo Medics TrueOne 2400 metabolic analyser (Parvo Medics, Inc., Salt Lake City, UT). The analyzer was calibrated before each test using alpha gases of known concentration according to the manufacturer's instructions. VO_{2peak} was taken as the highest VO_2 value recorded during a 1-min period of the final stage in the test. Heart rate was measured continuously using a heart rate monitor with chest strap (Polar Electro Oy., Finland). The maximal oxygen uptake test began approximately ten minutes after the completion of the Wingate test. Participants performed the test against a resistance set at level one on the resistance lever (maximum=10). The peak oxygen uptake test started at 25 W for one-minute increasing by 15 W.min⁻¹ incrementally thereafter until volitional exhaustion. Participants were encouraged to complete as many stages as possible before they could no longer maintain the target power output. A blood lactate sample was taken via the earlobe three minutes after the completion of the test using the Lactate Pro analyser (Lactate Pro, Akray, Japan). The test–

retest reliability of the Lactate Pro has been previously reported, with technical error of measurement results ranging from 0.1 to 0.4 mmol. L⁻¹ at blood lactate concentrations of 1 to 18 mmol. L⁻¹ (Tanner et al., 2010). Previous research has shown that peak blood lactate concentrations occur between 3-9 minutes following maximal exercise (Weinstein et al, 1998), and blood lactate taken 3-minutes following a maximal exercise bout has shown good test-retest reliability, with a typical error of measurement of ~0.48mmol.L⁻¹ (Driller et al., 2013).

500 m On-water Performance

On-water performance times for the 500 m distance were obtained from the 2018 New Zealand Waka Ama Sprint Championship regattas official timing (www.wakaama.co.nz). The times were taken from each participant's first race in their heat since not all participants progressed to the finals. All participants were instructed to give a maximal effort during their first heat, regardless of where their competitors were in the race. While participants were spread across heats, all heats were held at 10 am (\pm 1 hr). Temperature was ~20°C and humidity ~80% with light headwinds (<11 km /h).

Statistical Analyses

Descriptive statistics and data are expressed as a means \pm standard deviations (SD) and with ranges where appropriate. Pearson correlation coefficients (*r*) were used to determine the relationship between selected variables. Positive values denote positive linear correlation. Negative values denote negative linear correlation. The size of each correlation is described using an *r* value of 0.0-0.19; “very weak”, 0.20-0.39; “weak”, 0.40-0.59; “moderate”, 0.60-0.79; “strong”, 0.80-1.0; “very strong. An unpaired Students T-test was used to determine the difference between elite and sub-elite participants, with statistical significance set at $p < 0.05$. All statistical analyses were performed using Statistical Package for Social Science (V. 25.0, SPSS Inc., Chicago, IL).

Results

Physical characteristics and 500 m on-water performance in elite and sub-elite outrigger canoeists are displayed in Table 1. No significant differences were found between groups for anthropometry and body composition measures ($p > 0.05$). Significant differences were found between groups for total paddling experience and singles paddling experience ($p < 0.05$). Elite paddlers showed significantly higher Wingate mean power (323.8 ± 55.7 W vs. 240.1 ± 32.6 W, $p < 0.05$) and Wingate distance (148.7 ± 7.8 m vs. 134.7 ± 6.5 m, $p < 0.05$) when compared to sub-elite paddlers. Elite paddlers also

showed significantly faster 500 m on-water performance times (144.9 ± 4.9 vs. 154.2 ± 6.8 s, $p = .007$) compared to sub-elite paddlers.

When data was pooled (Table 2), a *strong* correlation was found between 500 m on-water performance and absolute VO_2peak ($3.9 \pm 0.5 \text{ L}\cdot\text{min}^{-1}$, $r = -0.61$). 50 kg bench press (31.4 ± 9.8 reps, $r = -0.56$) had a *moderate* correlation to 500 m outrigger canoeing performance.

Table 1: Comparison of physical characteristics and 500 m performance in elite and sub-elite outrigger canoeists. * significant difference between groups ($p < 0.05$)

	Mean (\pm SD)		p-value
	elite ($n = 8$)	sub-elite ($n = 8$)	
Age (yrs.)	24.8 ± 10.5	34.4 ± 15.4	0.166
Total paddling experience (yrs)	12.5 ± 5.2	6.8 ± 5.2	0.020*
Singles paddling experience (yrs)	8.9 ± 4.9	3.4 ± 3.2	0.047*
Anthropometry and body composition			
Body mass (kg)	94.4 ± 8.5	85 ± 13.7	0.120
Height (cm)	181.6 ± 5.0	179.9 ± 7.3	0.583
Sitting Height (cm)	94.4 ± 3.3	93.2 ± 3.8	0.509
Arm span (cm)	189.4 ± 6.9	188.5 ± 9.1	0.827
Upper limb length (cm)	78.7 ± 2.1	76.9 ± 3.1	0.196
Lower limb length (cm)	112.8 ± 3.3	112.8 ± 5.1	0.977
Body fat (%)	21.0 ± 4.9	19.6 ± 2.8	0.528
Muscular endurance test			
50 kg Bench press (reps)	34.8 ± 12.4	28.0 ± 11.0	0.268
50 kg Bench pull (reps)	29.1 ± 8.4	22.5 ± 3.9	0.061
Wingate test			
Wingate mean power (W)	323.8 ± 55.7	240.1 ± 32.6	0.003*
Wingate distance (m)	148.7 ± 7.8	134.7 ± 6.5	0.002*
Stroke rate (spm)	86.8 ± 12.6	78.8 ± 8.5	0.159
Peak oxygen uptake test			
VO_2peak ($\text{L}\cdot\text{min}^{-1}$)	4.1 ± 0.7	3.7 ± 0.6	0.166
VO_2peak ($\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)	45.6 ± 8.1	44.5 ± 2.0	0.719
Blood lactate ($\text{mmol}\cdot\text{L}^{-1}$)	7.8 ± 3.4	7.8 ± 2.6	0.968
VO_2 peak heart rate (bpm)	187.8 ± 17.4	177.8 ± 9.1	0.183
VO_2 peak power (W)	207.2 ± 38.7	175.4 ± 29.5	0.086
National championship regatta			
500 m on-water performance (s)	144.9 ± 4.9	154.2 ± 6.8	0.007*

Table 2: Correlations between physical characteristics and 500 m on-water performance ($n=16$)

Variable	Correlation	Strength
VO ₂ peak (L.min ⁻¹)	-0.61	Strong
Upper limb length (cm)	-0.60	Strong
50 kg bench press (reps)	-0.56	Moderate
Total paddling experience (yrs)	-0.53	Moderate
Body mass (kg)	-0.51	Moderate
Sitting height (cm)	-0.51	Moderate
Singles paddling experience (yrs)	-0.49	Moderate
Height (cm)	-0.48	Moderate
Wingate distance (m)	-0.42	Moderate
Wingate mean power (W)	-0.38	Weak
VO ₂ peak power (W)	-0.38	Weak
Arm span (cm)	-0.37	Weak
VO ₂ peak heart rate (bpm)	-0.35	Weak
Blood lactate (mmol. L ⁻¹)	0.25	Weak
Lower limb length (cm)	-0.22	Weak
50 kg bench pull (reps)	-0.21	Weak
Wingate stroke rate (spm)	-0.21	Weak
VO ₂ peak (mL. kg. ⁻¹ min ⁻¹)	-0.18	Very weak
Body fat (%)	-0.09	Very weak

Discussion

The current study is the first to assess the physical characteristics of elite outrigger canoe paddlers in comparison to sub-elite paddlers. Furthermore, to our knowledge, this is the first study to look at the relationship between different lab-based test measures and on-water performance at a National Championship regatta. The key findings from the current study showed that elite paddlers demonstrated significantly greater Wingate mean power and distance, paddling experience and 500 m on-water performance times than sub-elite paddlers. Additionally, absolute VO₂peak expressed as L.min⁻¹ was the single best predictor of 500 m on-water performance ($r = -0.61$).

Our results are consistent with other canoe studies that have shown correlations between paddling performance and VO₂peak (Humphries et al., 2000; Sealey 2010; Fry and Morton, 1991; Hamano et al., 2015). Humphries et al. (2000) found a lower (*moderate*) correlation, between 250 m outrigger canoeing performance and VO₂max ($r = -0.59$), than our current study. While Sealey et al. (2010) found a higher (*moderate*) correlation between 1000m ergometer performance and VO₂peak ($r = -0.69$). Furthermore, in a study by Fry and Morton, (1991) multiple performance distances were correlated with VO₂max whereby a *moderate* correlation was found for 500 m performance ($r = -0.56$) and an even *stronger* correlation for 1000 m performance ($r = -0.71$) in elite flat-water kayakers. These results suggest that the VO₂peak becomes progressively more important as the distance of the event

increases. Indeed, previous research on track runners has shown that the aerobic energy system contribution to events over 200 m, 400 m, 800 m and 1500 m was 29%, 43%, 66% and 84%, respectively (Spencer and Gastin, 2001). This would highlight the need for athletes to possess a greater VO_2peak , as event duration increases. In the current study, the 500 m performance test was completed in ~2.5 minutes, slightly longer than the duration of an 800 m run reported by Spencer and Gastin (2001), which was just under 2 minutes. Given the aerobic contribution was 66% in their study for this distance, it is reasonable to assume that the aerobic contribution in our study would be similar, taking into account less muscle mass required in paddling vs. running. Given the likely larger contributions of the aerobic energy system, it is somewhat unsurprising that VO_2peak was one of the best predictors of on-water 500 m paddling performance in the current study.

The absolute aerobic values attained by elite paddlers were higher than several previous outrigger canoe studies (for review, see Canyon and Sealey, 2016) including Malaysian ($2.86 \pm 0.5 \text{ L}\cdot\text{min}^{-1}$; Singh et al., 1995), Great Britain ($3.56 \pm 0.6 \text{ L}\cdot\text{min}^{-1}$; Marrin and Pout, 2005) and Japanese dragon boaters ($3.8 \text{ L}\cdot\text{min}^{-1}$; Ho et al., 2013) and competitive sprint canoe and kayak paddlers (Canoe: $3.83 \pm 0.3 \text{ L}\cdot\text{min}^{-1}$, Kayak: $3.81 \pm 0.3 \text{ L}\cdot\text{min}^{-1}$; Hamano et al., 2015). In contrast, our participants presented VO_2peak values slightly lower than elite flat-water kayakers ($4.4 \pm 0.5 \text{ L}\cdot\text{min}^{-1}$; Pickett et al., 2017) which could be due to greater rotation and activation of the legs, causing greater muscle mass activation and higher stroke rate during kayak paddling.

The correlation between upper limb length and 500 m on-water performance was consistent with a similar study on canoe and kayak paddlers (Hamano et al., 2015). The upper limb length of elite paddlers ($78.7 \pm 2.1 \text{ cm}$) in this study were similar to both canoe ($78.3 \pm 2.8 \text{ cm}$) and kayak paddlers ($78.0 \pm 3.2 \text{ cm}$) (Hamano et al., 2015) while sub-elite paddler's measures displayed lower upper limb lengths than both canoe and kayak paddlers (Hamano et al., 2015). Larger upper limb length may help the paddler to reach further forward during a stroke increasing stroke length. Stroke length is inversely proportional to stroke rate (Stanton et al., 2002) which means paddlers with longer could employ a slower stroke rate for the same given velocity. The use of a slower stroke rate ($\leq 55 \text{ strokes}\cdot\text{min}^{-1}$) during a 1000 m ergometer time trial has shown to be less physiologically demanding than a faster stroke rate ($\geq 65 \text{ strokes}\cdot\text{min}^{-1}$) despite no significant difference in performance time (Sealey, 2010). Specific on-water stroke length or stroke rate was not measured in this study therefore, future research should quantify the relationship between arm length, stroke length and stroke rate during specific on-water outrigger canoeing in elite paddlers to assess any difference in efficiency.

Anaerobic capacity is also important over the 500 m distance as it accounts for approximately 32% of the energetic demand for an event of this duration (Gastin, 2001). Elite paddlers mean power (W) and distance (m) during the 30 second Wingate test were 26% and 9% greater, respectively, than sub-elite paddlers in the current study. Furthermore, their mean 500 m on-water performance times were 9.3

seconds faster than sub-elite performances. The ability to produce high power output during the first 30 seconds of a 500 m distance event may contribute to the superior 500 m performance times displayed by elite paddlers. The on-water performance measures were limited therefore future research may consider including video analysis, boat speed GPS and stroke rate technology such as a cadence sensor in order to further assess outrigger canoe performance. limitation of the current study was that the athletes did not partake in the same heat at National Championships. Although the conditions did not vary between races, it is possible that conditions and race tactics employed by others in the heat may have affected the performance times. Future research should aim to mitigate these factors by considering an on-water individual time-trial outside of a competition setting. However, as mentioned, participants were instructed to perform a maximal effort in their first heat, regardless of what their opponents were doing. To minimise the possible change in environmental conditions, we only took times from the heats which occurred within ± 1 hour of 10am.

Conclusion

Our findings suggest that elite paddlers possess greater Wingate mean power and distance during an anaerobic Wingate test, overall paddling experience and 500 m on-water performance times than sub-elite paddlers. Furthermore, we found VO_{2peak} to be the best predictor of 500 m performance when groups were combined. Therefore, a peak oxygen uptake and anaerobic Wingate test on an outrigger canoeing ergometer may serve as effective methods for assessing and monitoring a paddlers aerobic and anaerobic capacity which may aid in talent identification, crew selection or physical fitness assessment.

Practical Applications

Results from the current study may be used to guide coaches and practitioners working in the sport of outrigger canoeing when it comes to talent identification of young athletes entering the sport. We would suggest that VO_{2peak} , upper limb length and upper-body strength (50kg bench-press) tests may serve as appropriate measures for identifying athletes, as they were the most closely related to on-water 500m performance.

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