*International Journal of Sports Physiology and Performance,* 2008, 3, 207-218


# Prediction of Flatwater Kayaking Performance

**Ken A. van Someren and Glyn Howatson**

***Purpose:*** To determine the relative importance of anthropometric and physiological attributes for performance in the 1000-m, 500-m, and 200-m flatwater kayaking events. ***Methods:*** Eighteen competitive male kayakers completed performance trials over the 3 distances and a battery of anthropometric and physiological tests. ***Results:*** Performance times (mean ± SD) for 1000 m, 500 m, and 200 m were 262.56 ± 36.44 s, 122.10 ± 5.74 s, and 41.59 ± 2.12 s, respectively. Performance in all 3 events was correlated with a number of physiological parameters; in addition, 500-m and 200-m performance was correlated with upper body dimensions. 1000-m time was predicted by power output at lactate turnpoint expressed as a percentage of maximal aerobic power, work done in a 30-s ergometry test and work done in a 2-min ergometry test (adjusted $R^2$ = 0.71, SEE = 5.72 s); 500-m time was predicted by work done and the fatigue index in a 30-s ergometry test, work done in a 2-min ergometry test, peak isometric and isokinetic function (adjusted $R^2$ = 0.79, SEE = 2.49 s); 200-m time was predicted by chest circumference, humeral breadth, peak power, work done, and the fatigue index in a 30-s ergometry test (adjusted $R^2$ = 0.71, SEE = 0.71 s). ***Conclusions:*** A number of physiological variables are correlated with performance in all events. 1000-m, 500-m, and 200-m times were predicted with a standard error of only 2.2%, 2.0%, and 1.7%, respectively.

***Keywords:*** anthropometry, physiological assessment, Olympic

Flatwater kayak racing has been an Olympic sport since 1936, in which distances of 1000 m and 500 m are contested. In addition, the 200-m distance was introduced to the international racing program in 1994, though it is not currently an Olympic event. At the 2007 world championships the gold medal times (min:s) for men's single kayaks over the 1000-m, 500-m, and 200-m distances were 3:40.11, 1:36.28, and 35.28, respectively. The energetic demands of these events have been calculated in U.S. national team male kayakers during laboratory ergometry, showing aerobic contributions of 82%, 62%, and 37% in the 1000 m, 500 m and 200 m, respectively.[1]

Van Someren is with the English Institute of Sport, St. Mary's High Performance Centre, Twickenham, U.K., and Howatson is with the School of Human Sciences, St. Mary's University College, Twickenham, U.K.

There is considerable literature describing the physiological and anthropometric attributes of international kayakers competing in the 1000-m and 500-m distances,[2-10] but only one study has addressed the 200-m event.[11] Significant differences in anthropometric measures (height, sitting height, body mass, upper arm and forearm circumferences) and physiological parameters (forced vital capacity, upper body isokinetic torque, work done in a 1-minute supramaximal kayak ergometry test, maximal oxygen consumption, and time to exhaustion in an incremental kayak ergometry test) have been reported between Australian state-selected and nonselected 1000-m and 500-m kayakers.[7] In addition, international level 200-m kayakers have been reported to exhibit superior anthropometric (chest, upper arm and forearm circumferences, humeral breadth, mesomorphy) and physiological (anaerobic power and capacity, isometric torque, and isokinetic power) characteristics as compared to their national level counterparts.[11] Performance in the 1000-m and 500-m events may been predicted by both aerobic and anaerobic capacities in men and women,[7,10] whereas anaerobic capacity alone has been shown to predict performance in the 200-m event.[11] Such investigations provide an evidence base for appropriate assessment and training practices of flatwater kayakers and may offer the basis for talent identification; however, no study to date has investigated the relationship of anthropometric and physiological parameters with performance in all three events. Therefore the aim of this investigation was to determine the relative importance of anthropometric and physiological attributes and their ability to predict performance in the 1000-m, 500-m, and 200-m flatwater kayaking events. Given that it is common for kayakers to compete over more than one distance, such an investigation within the same population sample provides direct comparison of the determinants of performance for the 1000-m, 500-m, and 200-m distances.

# Methods

## Subjects

Eighteen male kayakers (age 25 ± 4 years) ranging from international to club level volunteered to participate in this study. Ten of the subjects had competed internationally in one or more of the events; 8 of the subjects were club level. Prior to participation, all subjects completed a pretest health-screening questionnaire and provided written informed consent. All experimental procedures were approved by the University Ethics Committee for Teaching and Research and the study was conducted in accordance with the Declaration of Helsinki.

## Procedures

Subjects completed performance trials over 1000 m, 500 m, and 200 m on a measured flatwater course, under race conditions, at the same national ranking event. Race time was measured electronically to the nearest one hundredth of a second. In addition, subjects reported to the laboratory on 3 separate occasions, 3–7 days apart, within 3 weeks of the performance trials. The first visit was to allow subjects to be familiarized with the equipment and procedures employed. During the second and third visits, subjects undertook a battery of anthropometric and physiological tests. The second visit comprised anthropometric measurements followed by a

30-second anaerobic test and cardiorespiratory assessment, separated by 45-minute rest. The third visit comprised measurement of pulmonary function followed by dynamometric assessment of strength and power and an accumulated oxygen deficit test, again separated by 45-minute rest. To ensure subjects reported to the laboratory in an appropriate physical state for assessment, subjects were instructed to continue their normal diet and to restrict their physical training for a 24-hour period prior to these visits.

## Anthropometric Measurements

Stature, sitting height, and body mass were measured using a stadiometer and balance scales (Avery, Birmingham, U.K.), calibrated before and after completion of the study. Arm span was measured using a metal tape, between the distal ends of the third fingers, with the subject standing with outstretched arms in a horizontal plane.

Body composition was assessed using skinfold calipers (Harpenden, British Indicators Ltd., St. Albans, U.K.) to measure the skinfolds at four sites (biceps, triceps, subscapular, and suprailiac) on the right side of the body. These skinfold sites and the equation for the estimation of body density were adopted from the procedures of Durnin and Womersley,[12] thus allowing for the calculation of lean body mass and body fat. [13]

Biepicondylar breadths of the humerus and femur and circumferences of the relaxed upper arm, the flexed and tensed upper arm, the relaxed forearm, the tensed forearm, and the calf were measured on the right side of the body, using standard anthropometric procedures.[14] Chest circumference was measured at the perimeter of the mesosternale at the end of normal expiration.[14] Heath-Carter somatotype ratings for endomorphy, mesomorphy, and ectomorphy were also calculated.[15]

## Physiological Measurements

***Pulmonary Function.*** Pulmonary function was measured using an ergospirometer (Oxycon Alpha, Mijnhardt b.v., The Netherlands). Wearing a nose clip, and following a maximal inspiration, subjects performed a maximal expiration for the determination of forced vital capacity (FVC), forced expiratory volume in 1 second ($FEV_1$), the forced expiratory ratio (FER), and peak expiratory flow (PEF).

***Cardiorespiratory Assessment.*** Subjects performed an incremental step test on an air-braked kayak ergometer (K1 ERGO, Garran, Australia). The ergometer was fitted with a fan restrictor supplied by the manufacturer, to decrease the braking effect upon the flywheel and replicate open water kayaking, which has been previously described and shown to accurately simulate the physiological demands of open water kayaking.[16] The ergometer was interfaced with a computer for the measurement of performance data.

Following a 5-minute warm-up of ≤80 W, subjects performed discontinuous exercise bouts of 4 minutes starting at a work rate of 80 W. Each stage was separated by a 30-second period for the collection of capillarized, earlobe blood samples to determine whole blood lactate concentrations (P-GM7, Analox Instruments, Hammersmith, U.K.) and increased by 20 W until a blood lactate concentration of 4 $mmol \cdot L^{-1}$ or more was observed. Thereafter, subjects completed a continu-

ous 1-minute incremental step test, of 20 W increments, until exhaustion which was defined as the inability to maintain the desired work rate. Standardized verbal encouragement was given by the same test investigator.

Throughout the test, heart rate was measured and recorded every 5 seconds via short wave telemetry (Polar Accurex Plus, Polar OY, Finland). Expired air was analyzed throughout the test, via an on-line gas analyzer (Oxycon Alpha, Mijnhardt b.v., The Netherlands). The analyzer was calibrated prior to and after each trial, according to manufacturer's instructions. Maximal oxygen consumption ($VO_{2max}$), maximal aerobic power (MAP), and peak heart rate (HRpeak) were determined as the highest values averaged over a 1-minute period. Following the test, blood lactate concentrations were plotted against power output and the lactate turn-point (LTP), defined as the work rate preceding an increase in blood lactate concentration of ≥1 $mmol \cdot L^{-1}$,[17] was identified. The power output at LTP was also expressed relative to MAP (LTP-%MAP), and the rate of oxygen consumption at LTP was expressed relative to$VO_{2max}$ (LTP-%$VO_{2max}$).

***Accumulated Oxygen Deficit (AOD).*** A 2-minute supramaximal self-paced kayak ergometry test was performed for the determination of total work (2 min work) and AOD, which was calculated using the regression of oxygen consumption and power output data from the incremental ergometry test, thus allowing for the prediction of oxygen cost during supramaximal exercise.[18] A high degree of reliability for the measurement of AOD during kayak ergometry has been reported, with test-retest correlation coefficients of 0.98.[19] Expired air was analyzed throughout the test and peak post-exercise blood lactate was measured as previously described, from samples taken at 1-minute intervals following the test (2 min peak La).

***30-second Anaerobic Test.*** A 30-second supramaximal test was performed on the kayak ergometer to determine peak power (30 s PP), total work (30 s work), and the fatigue index (30 s FI), which was calculated as the percentage decrement from peak power to the lowest power output recorded during the test. Following 10 minutes of self-paced warm-up, subjects were instructed to increase the work rate to 100 W over a period of 5 to 10 seconds prior to the start of the test. The test was then started on the command of the test investigator, and subjects performed an all-out 30-second effort, without pacing. This protocol has previously been shown to provide a high level of repeatability for the supramaximal testing of kayakers.[20] Peak post-exercise blood lactate (30 s peak La) was measured as previously described.

***Dynamometric Assessment of Strength and Power.*** An isokinetic dynamometer (Cybex II, Lumex Inc., New York, U.S.A.) interfaced with a software programme (HUMAC, Computer Sports Medicine Inc., Massachusetts, U.S.A.) was used for the assessment of the isometric and isokinetic strength and power characteristics of subjects, as previously described.[11] The dynamometer was positioned to allow the subjects to simulate a kayak stroke on the dominant side, thus performing trunk rotation, shoulder extension, and elbow flexion in one motion, to exert a pulling force in the horizontal plane.

Following a self-selected warm-up of submaximal isokinetic and contractions and stretching, subjects completed a series of maximal isometric contractions on their dominant side, for which maximal torque was measured. Two contractions

were performed at positions of 70, 55, 40, 25, 10, and 0° through the simulated kayak stroke. The angle of 70° corresponded to the subject being in a fully extended position, as at the start of the kayak stroke, and 0° corresponded to the back of the stroke. Subjects then performed three repetitions of maximal isokinetic contractions through the complete movement, on their dominant side, at velocities of 90, 150, 210, 270, and 300 $deg \cdot s^{-1}$, during which torque and power were measured. The highest measure of isometric torque at any position (ISOM) and the greatest measure of isokinetic power (ISOK) were used in the statistical analyses.

### Methodological Limitations

The 1000-m, 500-m, and 200-m performance trials were conducted under racing conditions at a 2-day competition. Some kayakers qualified for finals through heats and semi-finals, whilst some were eliminated in the qualifying rounds; as a result, the number of races performed over the 2-day event varied between subjects. It should, however, be noted that for those kayakers progressing to finals, the initial round of heats were performed submaximally. It is therefore unlikely that an additional submaximal round would have any significant detrimental effect on subsequent performance. In addition, this limitation was considered preferential to that of performance times being measured in time trial rather than racing conditions.

The incremental ergometer test, performed to determine the lactate response to exercise and cardiorespiratory fitness, started at a power output of 80 W for all subjects. Due to differences in ability between subjects, there was a disparity in the number of 4-minute steps performed prior to commencing the continuous 1-minute step test. Whilst this has implications for the total duration of the incremental test, the additional steps performed by the higher-level subjects were of a low intensity, which would be expected to have limited impact upon the final power output achieved in the test.

### Data Analysis

All results are presented as mean ± *SD* values. Pearson product-moment correlation coefficients were used to determine the relationship of anthropometric and physiological parameters with 1000-m, 500-m, and 200-m race times. In addition, physiological variables were scaled to body mass using exponents of 1.0 and 0.67; the relationship of these relative values with performance was also determined. Variables that were significantly correlated with performance were entered into backward multiple regression analysis to predict performance with the lowest standard error of estimate in the three events. A significance level of $P < 0.05$ was selected prior to all analyses.

## Results

The performance times (mean ± SD) for 1000 m, 500 m, and 200 m were 262.56 ± 36.44 s, 122.10 ± 5.74 s, and 41.59 ± 2.12 s, respectively. Table 1 presents the anthropometric variables and their relationship with performance times. No anthropometric variables were correlated with 1000-m performance; however, chest circumference and humeral breadth were correlated with performance in

both the 500 m ($r$ = –0.50 and –0.65, respectively) and the 200 m ($r$ = –0.53 and –0.83, respectively).

Physiological variables and their relationship with performance times are presented in Table 2. Performance at 1000 m was correlated with LTP-%MAP ($r$ = –0.51), 30 s PP ($r$ = –0.65), 30 s work ($r$ = –0.74), and 2 min work ($r$ = –0.83). The physiological variables correlated with performance in both the 500 m and 200 m were: MAP ($r$ = –0.66 and –0.59, respectively), power at LTP ($r$ = –0.52 and –0.54, respectively), 30 s PP ($r$ = –0.84 and –0.68, respectively), 30 s work ($r$ = –0.87 and –0.74, respectively), 30 s FI ($r$ = –0.52 and –0.54, respectively), 2 min work ($r$ = –0.74 and –0.64, respectively), ISOM (r = –0.60 and –0.47, respectively) and ISOK ($r$ = –0.66 and –0.57, respectively). Physiological variables expressed in absolute terms demonstrated stronger relationships with performance in all 3 events than when scaled to body mass using exponents of either 1 or 0.67; consequently, only absolute measures and their relationship with performance are presented.

Regression analysis provided the following performance prediction equations:

1000 m time =

$$398.99 - (1.05 \times \text{LTP-\%MAP}) - (1.827 \times 30\text{ s work}) - (1.342 \times 2\text{ min work})$$

$$\text{Adjusted } R^2 = 0.71,\ \text{SEE} = 5.72\text{ s}$$

500 m time =

$$182.98 - (1.676 \times 30\text{ s work}) - (0.713 \times 30\text{ s FI}) - (0.859 \times 2\text{ min work}) - (0.026 \times \text{ISOM}) + (0.04 \times \text{ISOK})$$

$$\text{Adjusted } R^2 = 0.79,\ \text{SEE} = 2.49\text{ s}$$

200 m time =

$$55.71 + (0.114 \times \text{chest circumference}) - (2.541 \times \text{humeral breadth}) + (0.019 \times 30\text{ s PP}) - (1.015 \times 30\text{ s work}) - (0.132 \times 30\text{ s FI})$$

$$\text{Adjusted } R^2 = 0.71,\ \text{SEE} = 0.71\text{ s}$$

## Discussion

This is the first study to report the anthropometric and physiological characteristics of a heterogeneous group of flatwater kayakers and to identify the relationship of these characteristics with performance in the 1000-m, 500-m, and 200-m events. This study therefore provides direct comparison between the three events within the one group of subjects; this is particularly relevant given that many kayakers compete over more than one distance. Further, we have demonstrated that such characteristics account for between 70 and 80% of the variance in race time and that performance can be predicted in all 3 events with a low error of estimate (≤2.2%).

Although the kayakers investigated in this study were disparate in performance standard, the anthropometric and physiological characteristics of the international athletes, as shown by the upper limits of the ranges presented in Tables 1 and 2, are

**Table 1 Anthropometric Characteristics and Their Relationship With Performance in Flatwater Kayakers**

| | | | Correlation with Performance | | |
|---|---|---|---|---|---|
| | Mean ± SD | Range | 1000 m | 500 m | 200 m |
| Body mass (kg) | 83.2 ± 5.2 | 74.0 – 94.5 | 0.07, $P = 0.786$ | –0.43, $P = 0.076$ | –0.32, $P = 0.199$ |
| Stature (cm) | 184.3 ± 4.4 | 174.0 – 190.5 | 0.27, $P = 0.283$ | –0.11, $P = 0.656$ | 0.49, $P = 0.846$ |
| Sitting height (cm) | 95.8 ± 2.9 | 89.2 – 100.5 | 0.17, $P = 0.165$ | –0.25, $P = 0.326$ | –020, $P = 0.432$ |
| Arm span (cm) | 192.0 ± 7.2 | 177.0 – 203.5 | 0.14, $P = 0.571$ | –0.10, $P = 0.702$ | –0.06, $P = 0.805$ |
| Body fat (%) | 12.8 ± 2.6 | 9.0 – 20.2 | 0.10, $P = 0.707$ | –0.28, $P = 0.264$ | –0.31, $P = 0.209$ |
| Lean body mass (kg) | 72.4 ± 3.1 | 65.8 – 76.9 | 0.04, $P = 0.865$ | –0.41, $P = 0.083$ | –0.23, $P = 0.367$ |
| Arm circumference (cm) | | | | | |
| Upper arm, relaxed | 31.8 ± 1.9 | 28.9 – 37.0 | –0.05, $P = 0.833$ | –0.26, $P = 0.293$ | –0.16, $P = 0.530$ |
| Upper arm, tensed | 36.3 ± 1.7 | 33.2 – 39.3 | –0.02, $P = 0.931$ | –0.43, $P = 0.077$ | –0.44, $P = 0.067$ |
| Forearm, relaxed | 29.9 ± 1.3 | 27.2 – 33.0 | –0.11, $P = 0.660$ | –0.38, $P = 0.125$ | –0.37, $P = 0.135$ |
| Forearm, tensed | 30.9 ± 1.4 | 28.4 – 33.9 | –0.02, $P = 0.954$ | –0.34, $P = 0.163$ | –0.28, $P = 0.266$ |
| Chest circumference (cm) | 105.4 ± 3.5 | 96.8 – 112.0 | 0.18, $P = 0.467$ | **–0.50, $P = 0.034$** | **–0.53, $P = 0.023$** |
| Humerus breadth (cm) | 7.4 ± 0.3 | 6.9 – 7.9 | –0.13, $P = 0.647$ | **–0.65, $P = 0.008$** | **–0.83, $P = 0.001$** |
| Femur breadth (cm) | 9.9 ± 0.4 | 9.3 – 10.8 | 0.25, $P = 0.370$ | –0.35, $P = 0.205$ | –0.46, $P = 0.083$ |
| Endomorphy | 2.5 ± 0.8 | 1.7 – 4.9 | –0.16, $P = 0.554$ | –0.34, $P = 0.202$ | –0.45, $P = 0.080$ |
| Mesomorphy | 4.5 ± 1.2 | 2.3 – 6.2 | –0.13, $P = 0.632$ | –0.28, $P = 0.300$ | –0.44, $P = 0.092$ |
| Ectomorphy | 2.4 ± 0.9 | 0.3 – 3.9 | 0.16, $P = 0.556$ | 0.16, $P = 0.547$ | 0.26, $P = 0.334$ |

Significant correlations are highlighted in bold text.

**Table 2 Physiological Characteristics and Their Relationship With Performance in Flatwater Kayakers**

| | | | Correlation with Performance | | |
|---|---|---|---|---|---|
| | Mean ± SD | Range | 1000 m | 500 m | 200 m |
| FVC (L) | 6.33 ± 0.55 | 5.29 – 7.31 | –0.37, $P$ = 0.162 | –0.43, $P$ = 0.094 | –0.47, $P$ = 0.068 |
| $FEV_1$ (L) | 5.23 ± 0.57 | 4.31 – 6.06 | –0.26, $P$ = 0.340 | –0.45, $P$ = 0.081 | –0.16, $P$ = 0.554 |
| FER (%) | 81.8 ± 7.0 | 72.0 – 93.0 | –0.05, $P$ = 0.854 | –0.16, $P$ = 0.566 | 0.17, $P$ = 0.539 |
| PEF ($L \cdot min^{-1}$) | 731.5 ± 95.8 | 596.0 – 874.0 | –0.30, $P$ = 0.252 | –0.29, $P$ = 0.279 | 0.04, $P$ = 0.893 |
| $VO_{2max}$ ($L \cdot min^{-1}$) | 4.55 ± 0.46 | 3.60 – 5.30 | –0.01, $P$ = 0.967 | –0.21, $P$ = 0.403 | –0.02, $P$ = 0.953 |
| HR peak ($beats \cdot min^{-1}$) | 188 ± 10 | 166 – 209 | –0.07, $P$ = 0.797 | –0.19, $P$ = 0.485 | 0.09, $P$ = 0.740 |
| MAP (W) | 242.7 ± 33.8 | 180.7 – 295.6 | 0.18, $P$ = 0.497 | **–0.66, $P$ = 0.004** | **–0.59, $P$ = 0.013** |
| LTP (W) | 164.4 ± 19.0 | 125.0 – 200.0 | –0.01, $P$ = 0.964 | **–0.52, $P$ = 0.032** | **–0.54, $P$ = 0.025** |
| LTP-%$VO_{2max}$ (%) | 80.9 ± 4.5 | 76.2 – 93.1 | 0.03, $P$ = 0.925 | 0.05, $P$ = 0.840 | –0.13, $P$ = 0.611 |
| LTP-%MAP (%) | 68.9 ± 3.9 | 61.2 – 77.7 | **–0.51, $P$ = 0.043** | 0.32, $P$ = 0.209 | 0.14, $P$ = 0.594 |
| 30 s PP (W) | 555.5 ± 102.6 | 400.0 – 758.0 | **–0.65, $P$ = 0.005** | **–0.84, $P$ < 0.001** | **–0.68, $P$ = 0.003** |
| 30 s work (kJ) | 13.93 ± 2.30 | 11.03 – 18.16 | **–0.74, $P$ = 0.001** | **–0.87, $P$ < 0.001** | **–0.74, $P$ = 0.001** |
| 30 s FI (%) | 32.2 ± 8.2 | 19.9 – 45.9 | –0.27, $P$ = 0.299 | **–0.52, $P$ = 0.033** | **–0.54, $P$ = 0.024** |
| 30 s peak La ($mmol \cdot L^{-1}$) | 8.1 ± 1.6 | 4.9 – 10.6 | –0.09, $P$ = 0.713 | –0.37, $P$ = 0.146 | –0.14, $P$ = 0.594 |
| 2 min work (kJ) | 35.25 ± 5.37 | 26.22 – 44.13 | **–0.83, $P$ = 0.001** | **–0.74, $P$ = 0.001** | **–0.64, $P$ = 0.008** |
| 2 min peak La ($mmol \cdot L^{-1}$) | 9.4 ± 1.0 | 8.1 – 10.8 | 0.37, $P$ = 0.215 | 0.02, $P$ = 0.950 | 0.20, $P$ = 0.513 |
| AOD (ml $O_2 Eq \cdot kg^{-1}$) | 49.5 ± 11.5 | 21.8 – 71.7 | –0.18, $P$ = 0.517 | –0.27, $P$ = 0.309 | –0.05, $P$ = 0.856 |
| ISOM ($N \cdot m$) | 424.6 ± 70.5 | 326.0 – 569.0 | 0.36, $P$ = 0.137 | **–0.60, $P$ = 0.008** | **–0.47, $P$ = 0.047** |
| ISOK (W) | 678.7 ± 124.6 | 440.0 – 845.0 | –0.02, $P$ = 0.951 | **–0.66, $P$ = 0.003** | **–0.57, $P$ = 0.013** |

Significant correlations are highlighted in bold text.

similar to those previously reported for international male flatwater kayakers.[2-9,11] This study also highlights that performance is more closely related to absolute rather than relative measures of physiological capacity. Given that an increase of 1% in hull friction drag (which is largely determined by the mass of the kayaker) has been calculated to result in a reduction in boat speed of 0.27%, and that an increase in power output of 1% will increase boat speed by 0.33%,[21] it appears that kayakers can afford to increase body dimensions and absolute measures of physiological capacity in the pursuit of improving performance. In contrast, however, relative measures of physiological capacity have been reported to be more closely associated than absolute measures with 500-m performance in women.[10] It is possible that this disparity may be explained by differences in body composition between men and women and therefore the ability to generate power relative to body mass.

Performance time in the 1000-m event was correlated with a range of physiological characteristics, including measures of fractional utilization (the percentage of maximal aerobic power attained at LTP) and anaerobic power and capacity (peak power and work done in a 30-second ergometry test, and work done in a 2-minute ergometry test). This supports previous research identifying relationships in performance with supramaximal exercise capacity; in contrast, however, we did not find relationships with anthropometric characteristics, isokinetic strength, or maximal oxygen consumption that have been previously reported.[7] Race time in the 1000 m was predicted by measures of fractional utilization and anaerobic capacity (work done in the 30 s and 2 min ergometry tests), accounting for 71% of the variance in performance time and with an error of estimate of 7.72 s (2.2%). This finding reflects the estimated 82% aerobic and 18% anaerobic energetic demands of the 1000-m event,[1] and indicates that kayakers training for the 1000-m event must address both aerobic and anaerobic aspects of energy metabolism and physiological capacity. This prediction of performance does, however, differ from that previously reported for the 1000-m event by Fry and Morton, in which maximal oxygen consumption, time to exhaustion during an incremental ergometer test, isokinetic torque, chest girth, and sitting height accounted for 92% of the variance in performance time, but yielded an error of estimate of 10.39 seconds.[7] Although the current prediction model provides a lower error of estimate, we have identified novel parameters that are related to performance. This can only be explained by differences in the physical attributes of the individual kayakers investigated in these studies, which may also account for the contrasting findings for the relationships of anthropometric and physiological characteristics with performance in these studies.

Performance in the 500-m and 200-m events was correlated with the same anthropometric and physiological characteristics, which comprised upper body dimensions (chest circumference and humerus breadth), maximal aerobic power, fractional utilization (power output at LTP), anaerobic power and capacity (peak power, work done and fatigue index in the 30 s ergometry test; work done in the 2 min ergometry test) and muscular strength and power (peak isometric torque and isokinetic power). Many of these relationships support those reported for 500-m performance in men[7] and women[10]; in contrast, however, previous work has found significant relationships with sitting height, arm girth, forced vital capacity, and maximal oxygen consumption[7] that were not identified in this study. With respect to the 200-m event, this study supports our previous report of significant relationships with chest circumference and estimates of anaerobic power (peak

power in a 30 s ergometry test and peak isokinetic power) and anaerobic capacity (work done in 30 s and 2 min ergometry tests); it does not support the previous finding of relationships with upper arm and forearm girth, and peak lactate following supramaximal exercise.[11]

Perhaps the only discernible difference in the relationships of anthropometric and physiological characteristics with performance in the 500-m and 200-m events is that measures of anaerobic capacity (ie work done in the 30 s and 2 min ergometry tests) were more closely related with performance in the 500-m than the 200-m distance. Given the relative durations and consequent energetic demands of these events, this finding is perhaps not surprising. Although there was some commonality in the characteristics found to predict performance in both the 500-m and 200-m events, there were also characteristics unique to each prediction. Performance in the 500 m was predicted by measures of muscular strength and power (peak isometric torque and isokinetic power) and anaerobic capacity (work done in the 30 s and 2 min ergometry tests and the fatigue index in the 30 s test), which accounted for 79% of the variance in performance with an error of estimate of 2.49 seconds (2.0%). Fry and Morton [7] have previously reported maximum ventilation, maximal oxygen consumption, body mass, sum of 8 skinfolds, isokinetic torque, and work done in a 60-second supramaximal ergometer trial to account for 83% of the variance in 500-m time and predict performance with an error of 8.02 seconds. Again, the different physical characteristics of the individual kayakers in our study and that of Fry and Morton probably account for the contrasting findings of parameters correlating with, and predicting, performance.

Measures of anaerobic power (peak power in 30 s ergometry test) and capacity (work done and the fatigue index in the 30 s ergometry test), together with upper body dimensions (chest circumference and humeral breadth), accounted for 71% of the variance in 200-m performance time with an error of estimate of 0.71 seconds (1.7%). This largely concurs with our previous publication that 200-m performance is predicted by work done in a 30-second supramaximal ergometer test ($R^2 = 0.53$, SEE = 1.11 seconds) in a heterogeneous group of international and national level kayakers (N = 26), and that humeral breadth predicted 200-m performance ($R^2 = 0.54$, SEE = 0.52 second) in the international-level kayakers (N = 13).

The current findings indicate that aspects of power and anaerobic capacity must be addressed to improve performance over both the 500-m and 200-m distances; in addition, the development of cardiorespiratory fitness is also likely to be important given the relationship of fractional utilization and maximal aerobic power with performance. Indeed, the relationship of such a wide range of physiological characteristics with performance in these events is consistent with the documented energetic demands of these events: 38% anaerobic and 62% aerobic for the 500 m, 63% anaerobic, and 37% aerobic for the 200 m.[1]

## Conclusions

The relationship of anthropometric and absolute physiological attributes with performance varies between events, particularly between the 1000 m and the shorter events of 500 m and 200 m. Performance times for 1000 m, 500 m, and 200 m may be predicted with a standard error of only 2.2%, 2.0%, and 1.7%, respectively. In

part, these findings contrast with previously reported prediction models; however, this study has identified determinants of performance for all 3 events within the same group of subjects. Given how greatly the physical characteristics of the subjects may influence study findings, we believe that by investigating the 3 flatwater kayak events within a single subject group, this study allows direct comparison of the 3 events. As such, it provides an evidence base for the prescription of training and robust criteria for the selection of appropriate anthropometric and physiological variables for the longitudinal monitoring of relevant fitness parameters in flatwater kayakers. Further research is required to confirm whether such performance determinants can be used to predict performance to the same degree in a more homogeneous group of kayakers.

## References


1. Byrnes WC, Kearney JT. Aerobic and anaerobic contributions during simulated canoe/kayak events. (Abstract) *Med Sci Sports Exerc.* 1997;29:S220.
2. Ackland TR, Ong KB, Kerr DA, Ridge B. Morphological characteristics of Olympic sprint canoe and kayak paddlers. *J Sci Med Sport.* 2003;6:285-294.
3. Cermak J, Kuta I, Parizkova J. Some predispositions for top performance in speed canoeing and their changes during the whole year training program. *J Sports Med.* 1976; 15:243-251.
4. Tesch PA, Piehl K, Wilson G, Karlsson J. Physiological investigations of Swedish elite canoe competitors. *Med Sci Sports.* 1976;8:214-218.
5. Tesch PA. Physiological characteristics of elite kayak paddlers. *Can J Appl Sport Sci.* 1983;8:87-91.
6. Shephard RJ. Science and medicine of canoeing and kayaking. *Sports Med.* 1987;4:19-33.
7. Fry RW, Morton AR. Physiological and kinanthropometric attributes of elite flatwater kayakists. *Med Sci Sports Exerc.* 1991;23:1297-1301.
8. Misigoj-Durakovic M, Heimer S. Characteristics of the morphological and functional status of kayakers and canoeists. *J Sports Med Phys Fitness.* 1992;32:45-50.
9. Sklad M, Krawczyk B, Majle B. Body build profiles of male and female rowers and kayakers. *Biol Sport.* 1994;11:249-256.
10. Bishop D. Physiological predictors of flatwater kayak performance in women. *Eur J Appl Physiol.* 2000;82:91-97.
11. van Someren KA, Palmer GS. Prediction of 200-m sprint kayaking performance. *Can J Appl Physiol.* 2003;28:505-517.
12. Durnin JVGA, Womersley J. Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged from 16 to 72 years. *Brit J Nutr.* 1974; 32:77-97.
13. Siri WE. Body volume measurement by gas dilution. In: Brozek J, Henschel A, ed. *Techniques for Measuring Body Composition.* Washington, DC: National Academy of Sciences, National Research Council; 1961:108-117.
14. Norton K, Whittingham N, Carter L, Kerr D, Gore C, Marfell-Jones M. Measurement techniques in anthropometry. In: Norton K, Olds T, ed. *Anthropometrica.* Sydney: University of New South Wales Press; 1996:25-76.
15. Heath BH, Carter JEL. A modified somatotype method. *Am J Phys Anthrop.* 1967;27:57-74.
16. van Someren KA, Phillips GRW, Palmer GS. Comparison of physiological responses to open water kayaking and kayak ergometry. *Int J Sports Med.* 2000;21:200-204.

17. Thoden J. Testing aerobic power. In: MacDougall JD, Wenger HA, Green HJ, ed. *Physiological Ttesting of the High Performance Athlete*. 2nd ed. Champaign, IL: Human Kinetics; 1991:107-174.
18. Medbø JI, Mohn AC, Tabata I, Bahr R, Vaage O, Sejersted OH. Anaerobic capacity determined by maximal accumulated $O_2$ deficit. *J Appl Physiol.* 1988; 64:50-60.
19. Terrados N, Fernandez B, Perez-Landaluce J. Anaerobic capacity in elite kayakers. (Abstract). *Med Sci Sports Exerc.* 1991;23:S106.
20. van Someren KA, Dunbar GMJ. Supramaximal testing on a kayak ergometer: reliability and physiological responses. (Abstract). *J Sports Sci.* 1997;15:33-34.
21. Jackson PS. Performance prediction for Olympic kayaks. *J Sports Sci.* 1995;13:239-245.