

Review article

## The metabolic demands of kayaking: A review

Jacob S. Michael ✉, Kieron B. Rooney and Richard Smith

School of Exercise and Sport Science, Faculty of Health Sciences, Sydney University, Australia.

### Abstract

Flat-water kayaking is one of the best-known competitive canoeing disciplines in Australia and across the European countries. From a stationary start, paddlers are required to paddle their kayaks with maximal effort along the length of the competing distance. The ultimate criterion of kayak performance is the time taken to paddle a designated competition distance. In flat-water racing, events are contested over 500 and 1000 metres. To approximate the ultimate criterion over these distances, the velocity of the kayak should be measured. Furthermore, other factors that affect performance, such as force, power, technique and aerobic fitness, would all provide a valuable insight to the success of the kayak paddler. Specific research performed examining the physiological demands on kayak paddlers demonstrate high levels of both aerobic power and anaerobic capacity. It is the purpose of this review to present the published physiological data relating to men's and women's kayaking. With a number of recent publications, a need for an updated review is necessary. The present review summarises recent data on anthropometrics, physiological characteristics of successful and unsuccessful kayak athletes and methods of physiological testing. Due to the fact that more data have been reported for male competitors than for their female counterparts, the demands of kayaking on male athletes will be the main focus for this review. The review also suggests areas for future research into flatwater kayaking performance. Understanding the physiological requirements of kayaking can assist coaches and athletes in a number of ways. During competition or training, such information is helpful in the selection of appropriate protocols and metabolic indices to monitor an athlete's performance improvements and assess an athlete's suitability for a particular race distance. Furthermore, it may aid the coach in the development of more specific training programs for their athletes.

**Key words:** Kayak, ergometer, anthropometry, oxygen demand, aerobic power, lactate.

### Introduction

#### Energy demand during competitive kayaking

Flatwater kayaking is a sport that places exceptional demands on the upper body and trunk musculature (Tesch, 1983). Previous research papers (Bishop, 2000; Fry and Morton, 1991; Gray et al., 1995; Tesch, 1983) suggest that flatwater kayak paddlers possess high values for maximal aerobic and anaerobic capacities and upper-body muscle strength.

Kayak paddlers spend the majority of their race at or around peak  $\dot{V}O_2$  (Bishop, 2000) and obtain the majority of the required energy from the aerobic system (Bishop, 2000; Fernandez et al., 1995). Zamparo et al. (1999) concluded that the fraction of average power provided by oxidative processes increased with the distance

covered, whereas that provided by anaerobic sources decreased. In brief, the aerobic contribution, expressed as a fraction of  $\dot{V}O_2$  max, was shown to be 73% for the 500m and 85% for the 1000m (lasting approximately 1min 45 and 3min 45 respectively). These data support that of an earlier study performed in six elite kayak paddlers (Tesch et al., 1976). The importance of the anaerobic contribution, however, cannot be discounted. Studies such as Bishop (2000) and Fernandez et al. (1995) suggest that Olympic kayak paddlers not only need a high aerobic power, but the anaerobic contribution is also very important for successful performance.

#### Anthropometric characteristics of kayakers

Anthropometric data available for male and female, elite sprint canoe/kayak paddlers suggest a homogenous shape and size (Ackland et al., 2003). Ackland et al. (2003), assessed 50 male and 20 female sprint canoe/kayakers who competed at the Sydney Olympic Games (2000) representing 9 countries (Table 1). Sydney Olympic paddlers compared to paddlers represented at the Montreal Olympics in 1976, were approximately five kilograms heavier on average. However, with comparable skin fold values for the two groups, it was suggested by Ackland et al. (2003) that the subjects in the present sample have a higher proportion of lean body mass. It was therefore speculated by Ackland et al. (2003) that the morphology of elite paddlers have altered during the past 25 years and shifted toward a heavier but more lean physique. The winning times for the k1 500m and k1 1000m events from the two Olympic games (1976 vs. 2000) show a vast improvement and give some indication of the developmental trends and support the suggestion of improved physical capacity over the two distances. Over the 500m distance, the times went from winning in 1:46.41 in 1976 to the present winning time of 1:37.919, and over the 1000m event, from 3:48.20 to 3:25.898. Arguably, the technological advancements in boat and paddle design should also be considered as it was suggested by Robinson et al. (2002) that the time differences presented have been closely related to these technological advancements, as well as changes in the paddlers themselves.

Ackland et al. (2003) noted that sprint kayak paddlers possess unique characteristics not commonly observed in the general population. These include a lean body composition with proportionately large upper body girths and narrow hips (for males). The mean somatotype recorded by Ackland et al. (2003) (1.6 – 5.7 – 2.2 for males, 2.4 – 4.7 – 2.0 for females) demonstrated that kayak paddlers are best described as mesomorphs.

Despite the suggestion put forward by Ackland et al. (2003) that elite sprint kayak paddlers physical

**Table 1. Morphological characteristics of Olympic sprint paddlers at Sydney 2000.**

	Female Paddlers (n = 20)		Male Paddlers (n = 50)	
	Mean ( $\pm$ SD)	Range	Mean ( $\pm$ SD)	Range
Age (years)	26.4 (5.1)	19.0 – 36.0	24.8 (3.0)	20.0 – 31.0
Body Mass (kg)	67.7 (5.7)	59.1 – 80.7	85.2 (6.2)	73.6 – 99.8
Height (m)	1.70 (.06)	1.59 – 1.84	1.84 (.06)	1.70 – 1.96
Seated Height (cm)	90.4 (2.6)	84.8 – 98.0	96.9 (3.0)	91.6 – 103.1
Sum of 8 Skinfolde (mm)	80.0 (16.9)	52.9 – 103.7	55.4 (15.2)	30.9 – 116.1

Data obtained from Ackland et al. (2003) (pp288).

characteristics are homogeneous, Fry and Morton (1991) and van Someren et al. (1999) argue that although success is not correlated with greater body mass, the kayaker can be of considerable size without compromising performance. Casual inspection of the data in Table 1 suggests a range of morphological characteristics of this population. It is interesting to note that a comparable on water sport, rowing, relies heavily on the morphological characteristics of their athletes for talent identification as there are different weight classes. However, when analysing the morphological characteristics of elite rowers, especially where size restrictions apply, there is a relatively small variation. Previous studies (Secher, 1990; 1992; 1993; Shephard, 1998) suggest that successful rowing competitors are very tall, with a large lean body mass and aerobic power. However, a slight variance may be accepted and incorporated in a variety of positions in sports where the athletes size and shape are a product of the nature of the sport (Ackland et al., 2003). Kayaking is one such sport, where although paddlers possess unique characteristics not commonly observed in the general population, there is no single trait that distinguishes an elite kayak paddler.

Considering the potential role of physical characteristics, when examining paddlers using the ergometry system, all subjects overcome the same resistance in order to perform work, irrespective of body mass (Bishop, 2000; van Someren et al., 1999). Thus, an increased body mass may not only not compromise ergometry performance, but might enhance it. Kayak racing is performed on water and as mentioned above in the study by Ackland et al. (2003), kayakers are now heavier and have a greater percent lean body mass compared to 25 years ago. While a larger individual may have a larger absolute peak  $\text{VO}_2$ , potentially, a too large body mass of the kayaker may negatively affect the relative peak  $\text{VO}_2$  attainable and cause the kayak to sit deeper in the water, increasing

wetted area of the kayak (Jackson, 1995). This increased wetted area will increase the frictional and wave drag (Jackson, 1995) thereby increasing the resistance that must be overcome by the kayaker to propel the kayak forward (Pendergast et al., 2005). Thus, the question then arises: how are power output and kayak drag affected with an increased lean body mass; do they cancel each other out, or is there an advantage in being light? Further research is essential to examine the full potential of the advantages and disadvantages between the range of body types mentioned above and examine the energy cost associated.

The energy cost of kayaking is determined by the drag of the kayak and the efficiency of the kayaker to overcome that drag. As such, the importance of both drag and efficiency in determining the metabolic requirement of kayaking, which is highly variable, is critical. The energy cost of paddling a given distance increases with increasing velocities according to a power function (Pendergast et al., 1989; 2003; 2005; Zamparo et al., 1999). Peak kayak paddling performance is therefore dependant upon maximal metabolic power (aerobic and anaerobic) complimented with superior locomotion economy.

### Oxygen demands during kayaking

#### *VO<sub>2</sub> measures of kayakers*

Exercise physiologists have utilised a variety of testing methods to estimate  $\text{VO}_2$  peak in kayakers (Table 2). The proportion of whole body musculature required during exercise in studies testing kayak paddlers varies. Physiological tests of kayak paddlers have been carried out during on water analysis (Gray et al., 1995; Pendergast et al., 1989; Tesch, 1983; van Someren et al., 1999), kayak ergometry (Billat et al., 1996; Bishop et al.,

**Table 2.  $\text{VO}_2$  measures ( $\text{L}\cdot\text{min}^{-1}$ ) of kayakers.**

Author	Subjects (male)	Ergometer $\text{VO}_2$ ( $\text{L}\cdot\text{min}^{-1}$ ) *			Kayak paddling $\text{VO}_2$ ( $\text{L}\cdot\text{min}^{-1}$ ) †		
		Leg	Arm	(Legs+arms)	Kayak	500m	1000m
Tesh et al. (1976)	6 elite kayakers	5.41			4.61	4.2	4.71
Pendergast et al. (1979)	8 unskilled kayakers	3.1	2.9	3.9	3.5		
Tesch (1983)	6 elite kayakers	5.36	4.3				4.67
Hahn et al. (1988)	5 elite kayakers			5.17	4.62		
Pendergast et al. (1989)	17 kayakers (range of skill level)	4.61	2.82	3.81			
Fry and Morton (1991)	38 well trained kayakers				4.78		
Billat et al. (1996)	9 elite kayakers				4.01		
van Someren et al. (1999)	9 well trained kayakers						4.27
Bishop et al. (2002)	8 experienced kayak paddlers				4.0		

\* denotes that the ergometer exercise tests were carried out to exhaustion, representing the max  $\text{VO}_2$ .

† denotes that the kayak paddling tests were maximal efforts for that distance, not maximal exercise tests.

2002; Fry and Morton, 1991; Hahn et al., 1988; Pendergast et al., 1979; Tesh et al., 1976), arm cranking (Bergh et al., 1976; Pendergast et al., 1979; Tesch, 1976; 1983; Tesch and Lindeberg, 1984), bicycle ergometry (Bergh et al., 1976; Pendergast et al., 1979; Pyke et al., 1973; Tesch et al., 1976), treadmill running (Sidney and Shephard 1973; Tesch, 1983; Tesch et al., 1976) and combined activity of the legs and arms (Bergh et al., 1976; Hahn et al., 1988; Pendergast et al., 1979). The effects of proportion of muscle used must be taken into account when discussing kayak paddler performance.

Although a number of testing methods have been preformed, the ideal method of testing is to measure oxygen consumption on the water. Six male Swedish sprint kayakers of Olympic standard were reported to reach a peak oxygen uptake of  $4.67 \text{ L}\cdot\text{min}^{-1}$  during an on water 1000m race (Tesch, 1983). In another study by van Someren et al. (1999) 9 well trained kayak paddlers produced an average peak value of  $4.27 \text{ L}\cdot\text{min}^{-1}$  for  $\text{VO}_2$  for the same race distance at maximal effort, lower than the  $4.71 \text{ L}\cdot\text{min}^{-1}$  and  $4.67 \text{ L}\cdot\text{min}^{-1}$  reported when measuring elite Swedish kayak paddlers (Tesch et al., 1976 and Tesch, 1983 respectively). Considering that all studies examined paddlers during maximal efforts, it was speculated that the differences observed were a result of the subject characteristics in the study by van Someren et al. (1999). The subject population were not of elite standard and one could argue they were at a lower skill and conditioning level.

Findings by Fry and Morton (1991) further support van Someren et al. (1999). It can therefore be assumed from these results presented that the more skilled paddlers are more likely to obtain a greater peak rate of oxygen consumption. Studying 38 kayak paddlers from the Western Australian championships, Fry and Morton (1991) classified the paddlers as either state team paddlers and non-state team members based on an objective selection policy, including performance time and position. Using a Monarch mechanically braked bicycle ergometer mounted on a kayak frame, the  $\text{VO}_2$  peak values for the subjects were determined using a progressive test to exhaustion. The mean  $\text{VO}_2$  peak values for the state team kayakers reached  $4.78 \text{ L}\cdot\text{min}^{-1}$ , a value significantly higher than the mean  $\text{VO}_2$  peak for the non-state team paddlers ( $3.87 \text{ L}\cdot\text{min}^{-1}$ ). However, when maximal oxygen consumption was expressed in  $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ , although remaining higher, there was no significant difference between the state and non-state team paddlers. Bishop (2000) explains that while a large aerobic power is very important, anthropometric characteristics can also influence performance. Paddlers of the state team were found to be slightly heavier and taller than the less successful paddlers. Significant strength differences and reduced, but not significant skinfold measurements, were also found to be associated with the state team members. To account for the difference in oxygen consumption, Fry and Morton (1991) suggested that the aerobic power to weight ratio is not as important for kayak success as absolute aerobic power. This implies that the kayaker can afford to be large without detriment to success provided they can produce high levels of aerobic power.

A potential confounder to the suggestion from Fry and Morton (1991) above is that no measures of technique or skill, other than time to complete the task, were recorded. One could argue that on the basis of rowing studies by Smith and Loschner (2000) skilled kayak paddlers are better able to minimise any excess body movements within the kayak to provide a more powerful and efficient stroke compared to their sub-elite counterparts. Rowing studies, such as Loschner et al. (2000) and Smith and Loschner (2000) have analysed the movement of a rowing scull and found the amount of yaw (sideways deviation), pitch (bobbing movement) and roll (roll of the boat from side to side) induced in the boat by a rower affected the efficiency of boat propulsion and hence influenced the velocity of the rowing scull. Considering the complex nature of kayaking, this could potentially manifest as a change in oxygen consumption of the athlete if differences in technique are assumed between performance level and would be a fertile area of future investigation.

#### *$\text{VO}_2$ peak of kayakers vs others sports*

Maximal measures of oxygen uptake are typically determined in a laboratory during treadmill running or pedalling a cycle ergometer. However, athletes who are predominantly involved in upper-body work may not be accustomed to this form of exercise. Consequently, testing the lower body is potentially inappropriate as it is not specific to the trained task of the athlete and as a result the performance may not elicit optimal results of  $\text{VO}_2$  peak. Stromme et al. (1977) determined the  $\text{VO}_2$  peak of cross-country skiers, rowers and cyclists during uphill running on a treadmill and during maximal performance on their specific sport activity. All athletes attained higher levels of  $\text{VO}_2$  peak during their specific sport activity than during treadmill running (male and female skiers: 2.9% and 3.1%, respectively,  $p < 0.001$ , rowers: 4.2%, cyclists: 5.6%, respectively,  $p < 0.01$ ).

Although the absolute values of peak  $\text{VO}_2$  for kayaking have been described to be quite high (Tesch, 1983), they are not quite as high as other sporting events such as road cycling, rowing or running (Table 3). An apparent difference is also evident when examining  $\text{VO}_2$  peak in relative units among the different sporting disciplines. A number of researchers (Fry and Morton, 1991; Hahn et al., 1988; Tesch, 1983; van Someren and Oliver, 2001) have suggested values of the relative  $\text{VO}_2$  peak for kayaking ( $58 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ) compare favourably with water sports such as swimming ( $58.4 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ; Roels et al., 2005). However in sporting activities where the lower body is the main source of energy output, such as road cycling and distance running, values tend to be around  $73 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$  (Billat et al., 1996, Lee et al., 2002) and  $74 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$  (Lucia et al., 1999), much higher than those reported for kayaking. Similarly in rowing, although the peak absolute  $\text{VO}_2$  of rowers compared favourably with the results obtained for road cycling and middle distance runners ( $\sim 5\text{-}6 \text{ L}\cdot\text{min}^{-1}$ ), when the  $\text{VO}_2$  was expressed in relative units ( $\sim 64 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ) these were not quite as high as the mean values obtained for the other endurance type athletes mentioned above. The differences may be explained by the fact that generally, long distance runners

**Table 3.** VO<sub>2</sub> values for kayaking compared to other sports.

Sport	Authors	VO <sub>2</sub> max (absolute) (L·min <sup>-1</sup> )	VO <sub>2</sub> max (relative) (ml·kg <sup>-1</sup> ·min <sup>-1</sup> )	Power and Velocity at VO <sub>2</sub> max *
<b>Kayaking</b>	Tesch, 1983	4.7	58.8	
	Hahn et al., 1988	4.62	58.5	
	Fry and Morton, 1991	4.78	58.9	
	Billat et al., 1996	4.01	53.8	239 W
<b>Canoeing</b>	Hahn et al., 1988	3.49	44.2	
	Bunc and Heller, 1991	4.17	51.9	
<b>Rowing</b> (heavy weight; ~ 85kg)	Di Prampero et al. 1971	5.0	58.8	
	Secher, 1990	6.0	68.2	
	Lakomy and Lakomy, 1993	4.8	60	
<b>Swimming</b> (400m)	Billat et al. 1996	4.41	59.6	1.46 m·s <sup>-1</sup>
	Lavoie et al. 1981	4.31	58.4 (5.6)	
	Roels et al. 2005	5.6	58.4	
<b>Road Cycling</b>	Billat et al. 1996	5.61	72.4	419 W
	Lee et al. 2002	5.45	73.0	
	Lucia et al. 1999	5.10	74.0	
	Billat et al. 1996	5.11	74.9	6.22 m·s <sup>-1</sup>
<b>Running</b> (up to 3000m)	Draper and Wood, 2005	5.0	68.9	
	Caputo and Denadai, 2004	6.3	68.8	

Note: all athletes studies were male and of professional and elite calibre.

\* Power output and velocity at VO<sub>2</sub> max obtained from Billat et al. (1999).

are small, thin and lightweight compared to kayakers or rowers, who have a larger body mass. One body type and training style will favour better performance in each sporting discipline. Another important concept is what is the active muscle mass involved in generating the VO<sub>2</sub>max. For example, if the VO<sub>2</sub>max of a kayaker is divided by the mass of only the upper body (discounting the legs that are not used extensively in kayaking) their relative VO<sub>2</sub>max may be even high than that of distance runners.

To describe the differences present Billat et al. (1996) examined the power output at VO<sub>2</sub>peak of different sporting athletes. Billat et al. (1996) studied 41 elite national class sportsmen; road cyclists (n = 9), flatwater kayak paddlers (1000m) (n = 9), middle distance swimmers (400m) (n = 9) and long distance runners (3000-10 000m) (n = 14). The athletes were required to perform two tests; a maximal VO<sub>2</sub> test and an all out exercise bout performed at the power or velocity that elicited VO<sub>2</sub>peak (see Table 3). Each subject performed the exercise tests on their specific ergometer, using a Cosmed device (a telemetric oxygen measuring system) to measure VO<sub>2</sub>peak. Notably, on the kayak ergometer, the power output of kayak paddlers at VO<sub>2</sub>peak was only 57% of the power output produced by cyclists on their respective ergometer (Table 3). Billat et al. (1996) suggested it was the result of the smaller muscle mass involved with paddling a kayak. It can be speculated that if the kayakers VO<sub>2</sub> were to be normalised for arm mass and the cyclists for leg mass for example, the differences observed in VO<sub>2</sub> may not be quite as large as those presented and thus compare favourably with other endurance sporting events. Interestingly, in the study by Billat et al. (1996) when examining the time to exhaustion for kayak paddlers, a significantly higher time was reported when comparing the results of cyclists (p < 0.05). Furthermore, it was also reported by Billat et al. (1996) that the heart rates and blood lactate levels for the kayak paddlers were similar among all sports except for swimmers, who generated

lower HR and blood lactate levels at the end of the incremental tests.

### Anaerobic component of kayaking

#### *Anaerobic threshold of kayakers*

van Someren and Oliver (2001) reported the mean lactate threshold of kayak paddlers at a blood lactate concentration of 2.7 mmol·L<sup>-1</sup>, at a HR of 170 beats/min and a VO<sub>2</sub> of 44.2 ml·kg<sup>-1</sup>·min<sup>-1</sup>. The lactate threshold presented, corresponded to a percentage of 89.6% of the maximum heart rate and 82.4% of the VO<sub>2</sub> peak. These values presented indicate the extreme nature of kayaking and the undue demands it places upon the anaerobic system. Considering that, it was noted by Bishop (2000) earlier, that kayak paddlers spend the majority of their race at or around VO<sub>2</sub>peak. In another study by DalMonte and Leonard (1976), it was reported that the onset of blood lactate accumulation of international kayakers occurred in a time frame between 79 and 87% of VO<sub>2</sub>peak. Furthermore Bunc and Heller (1991), who defined the ventilatory threshold as the level of maximal exercise at which the subject is still capable of working close to steady state, reported that the values of the ventilatory threshold in international male canoe/kayaker paddlers corresponded to an exercise intensity of between 83 and 85% of VO<sub>2</sub>peak. At intensities greater than the anaerobic threshold, the rates of anaerobic glycolysis and subsequent lactate production are very high (Bishop et al., 2001).

When the rate rise of blood lactate is plotted as a function of work load for sedentary subjects and white water kayakers (Pendergast et al. 1979), it is clear that the anaerobic threshold for sedentary subjects occurred at a lower work load (75W) requiring approximately 70% of their arm VO<sub>2</sub>peak compared to the kayakers. The anaerobic threshold for kayakers increased to approximately 125W, which corresponded to approximately 80% of their arm VO<sub>2</sub>peak. This notable difference observed between the sedentary subjects and their kayaking counterparts

demonstrates the kayak paddlers' ability to withstand high levels of arm exercise before fatigue sets in.

#### *Anaerobic power of paddlers*

Tesch (1983) suggested that the elite paddlers examined in his study exhibited a well developed anaerobic capacity for upper-body exercise. The relatively high peak blood lactate concentration values observed following maximal kayak racing (13 mM; Tesch, 1983) indicate a significant anaerobic contribution to kayak performance (Bishop, 2000) (Table 4). It was suggested by Pendergast et al. (1979) that the kayaker paddlers were capable of developing at least twice the anaerobic power of sedentary subjects for arm cranking exercises. In light of this however, Pyke et al. (1973) suggested that to assess the physiological responses to work by kayakers, the circular movement of hand/arm cranking on an ergometer does not closely simulate the movements required on the water. It is essential to utilise specific ergometers to allow for an accurate comparative analysis.

Associated with the results presented above, were the findings presented by Davis et al. (1976) and Tesch and Lindeberg (1984) who reported kayakers to have lower blood lactate levels during similar absolute exercise intensities or work loads relative to maximal oxygen uptake when compared to sedentary subjects performing arm exercise. Therefore, as previously mentioned by Tesch (1983), in kayaking and numerous other sporting events that require high aerobic energy supply, the anaerobic energy system seems to be an important factor for successful performance.

To compare the lactate levels among a number of different sporting athletes Tesch and Lindeberg (1984) studied 7 elite male kayak paddlers, 6 national calibre weight/power lifters, 8 local and national calibre body builders and 6 physically active non athletes. All subjects performed upper body exercise seated on an arm crank ergometer. Results suggested that the kayakers exhibited a significantly lower blood lactate concentration ( $p < 0.05$ ) at all power outputs tested. The authors suggested that factors other than muscle volume determined the rate of blood lactate accumulation during progressive arm exercise. This was most evident when comparing the lactate response in the kayak paddlers (endurance trained athletes) with that of the strength trained athletes, who exhibited significantly greater upper body mass. Similarly, lower blood lactate levels were reported by kayak paddlers than their sedentary subject counterparts during comparable absolute or relative work loads. It was suggested by Pendergast et al. (1979) that low values recorded when measuring the lactate of kayakers was a result of a relatively high early lactate threshold and thus

a decreased release of lactate (relative to sedentary subjects) from trained muscle performing the submaximal work. As the work intensity increased, the kayakers were more able to perform aerobically for a longer period of time, therefore delaying the onset of blood lactate accumulation.

When five moderately active subjects underwent a month of kayak training, Ridge et al. (1976) reported a significant reduction (up to a 6%) in the level of blood lactate accumulated at the same relative work loads on the kayak ergometer compared to the pre-test. Furthermore, training has also shown to decrease the arterial lactate for a given exercise load in the study by Klassen et al. (1970). The data presented by Klassen et al. (1970) reflects a training-induced decrease in overall release of lactate from tissues to blood as well as an increase in clearance of lactate from plasma during exercise. The muscular lactate clearance reflects a reduction in glycogenolysis and enhanced muscle enzyme capacity (Bergman et al., 1999; Stallknecht et al., 1998). An enhanced lactate transport capacity in the muscle has also been suggested to contribute to the high clearance following training (Brooks et al., 1999).

#### **Conclusion**

Elite male kayakers appear homogeneous in shape and physical size, being differentiated from the general population by their greater upper body girth and narrow, hips (Ackland et al., 2003) and demonstrate superior aerobic and anaerobic qualities (Hahn et al., 1988; Tesch et al., 1976; Tesch, 1983; Pendergast et al., 1989; Zamparo et al., 1999). Kayakers have reported  $\text{VO}_2$  peak values of around  $58 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$  ( $4.7 \text{ L}\cdot\text{min}^{-1}$ ) and lactate values of around 12 mM during laboratory and on water testing. For kayaking, a sport that relies on high maximal aerobic power, the anaerobic energy system also seems to be important for successful performance. van Someren and Oliver (2001) reported that the mean lactate threshold occurred at a blood lactate concentration of  $2.7 \text{ mmol}\cdot\text{L}^{-1}$ , at a HR of  $170 \text{ beats}\cdot\text{min}^{-1}$  and a  $\text{VO}_2$  of  $44.2 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ . The lactate threshold presented corresponded to a percentage of 89.6% of the maximum heart rate and 82.4% of the  $\text{VO}_2$  peak.

Although the absolute values of peak  $\text{VO}_2$  for kayaking have been described to be quite high (Tesch, 1983), they are not quite as high as other sporting events such as road cycling, rowing or running. Billat et al. (1996) showed on the kayak ergometer, the power output of kayak paddlers at  $\text{VO}_2$  peak was only 57% of the power output produced by cyclists on their respective ergometer. In other sports, such as road cycling and distance running

**Table 4.** Lactate values recorded for kayak paddlers (mM).

Author	Subjects	Ergometer (mM)			Kayak paddling (mM)	
		Leg	Arm	Kayak	500m	1000m
Sidney and Shephard, 1973	10 elite kayakers	14.1				
Tesh et al. 1976	6 elite kayakers				13.2	12.9
Tesch, 1983	6 elite kayakers	14.2	13.5	14.0		13.0
Pendergast et al. 1989	17 kayakers (range of skill level)					12.0
Bishop et al. 2002	8 experienced kayak paddlers				13.0	

where the lower body is the main source of energy output, values tend to be around  $73 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$  (Billat et al., 1996, Lee et al., 2002) and  $74 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$  (Lucia et al., 1999) respectively, much higher than those reported for kayaking. When comparing the results from bicycle ergometry in Tesch et al. (1976) to the results presented for kayak paddling in the same study, it was reported that the oxygen uptake for the 500m races corresponded to 77% of the individual  $\text{VO}_2$  peak during the leg exercise. In the 1000m, the oxygen uptake corresponded to 87% of  $\text{VO}_2$  peak of the leg exercise. It was also reported by Hahn et al. (1988) that the peak oxygen uptake recorded on the kayak ergometer was 89.1% of the maximal oxygen uptake achieved on the arm/leg ergometer. These studies suggest that physiological differences exist between upper and lower body aerobic exercise. It was therefore speculated that if the kayakers  $\text{VO}_2$  were to be normalised for arm mass and the cyclists for leg mass for example, the differences observed in  $\text{VO}_2$  may not be quite as large as those presented and thus compare favourably with other endurance sporting events.

It was the purpose of this review to summarise published physiological data relating to men's and women's kayaking. It can be concluded that flatwater kayaking is characterised by exceptional demands on upper body performance. A successful kayaker not only requires high aerobic power, but a high anaerobic energy yield and great upper body muscle strength is also of great importance. Consequently the peak relative  $\text{VO}_2$  value attainable is negatively affected.

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## AUTHORS BIOGRAPHY



### Jacob S. MICHAEL

#### Employment

PhD student, Faculty of Health Sciences, Sydney University, Australia.

#### Degree

BappSc

#### Research interest

Physiology and biomechanics of kayaking.

**E-mail:** jmic3063@mail.usyd.edu.au



### Kieron B. ROONEY

#### Employment

Lecturer, Exercise Health and Performance Research Group, University of Sydney, Australia.

#### Degree

PhD

#### Research interest

Biochemistry, exercise physiology, creatine supplementation, insulin secretion and carbohydrate metabolism.

**E-mail:** K.Rooney@fhs.usyd.edu.au



### Richard SMITH

#### Employment

Lecturer, Exercise Health and Performance Research Group, University of Sydney, Australia.

#### Degree

PhD

#### Research interest

Water sport biomechanics, footwear.

**E-mail:** R.Smith@usyd.edu.au

## Key points

- Flat water kayaking is characterised by exceptional demands on upper body performance.
- When examining the oxygen consumption, it is notable that although a high value is attainable, they are not quite as high as other sporting events such as road cycling, rowing or running where lower body is dominant.
- Elite kayakers demonstrate superior aerobic and anaerobic quantities and have reported maximal oxygen consumptions of around  $58 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$  ( $4.7 \text{ L}\cdot\text{min}^{-1}$ ) and lactate values of around  $12 \text{ mM}$  during laboratory and on water testing.

### ✉ Jacob S. Michael

Faculty of Health Sciences, C42 – Cumberland Campus. East Street PO Box 170, Lidcome NSW 1825, Australia.