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The Science behind Flatwater Kayak Racing

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Kayaking is the use of a human powered boat to move through the water. Kayaks and canoes date back to the ancient times when they were used as a major mode of transportation and for fishing and hunting. Since the sport of canoe/kayak was established in the mid 19th century in London, it has gone through major technological changes to allow for optimal comfort, speed and performance. The main factors that affect this performance and hence how fast the kayak moves include the force and power provided by the paddler, technique and aerobic fitness (Michael et al., 2008; Aitken and Neal, 1992; Mann and Kearney, 1980). There have been a number of publications looking at these major factors affecting kayak paddling performance. It is the purpose of this article to briefly explain the significance of the papers and also demonstrate how coaches and athletes can work towards successful padding performances.

From a stationary start, paddlers are required to place exceptional demands on the muscles of the upper body to move their kayaks as fast as possible along the length of the competing distance. However, the faster your kayak moves, the greater the energy cost of paddling a given distance will be. Peak kayak paddling performance is therefore dependant upon maximal metabolic power (aerobic and anaerobic) complimented with superior paddling technique.

Kayaking is a sport that relies heavily on aerobic power. Aerobic power refers to energy produced by the aerobic energy system which generally supplies energy for low-intensity exercise for a long duration. Although kayaking is a speed dominated event, research has found kayakers obtain the majority of the required energy from the aerobic energy system during racing (Tesch, 1983). Values have been shown to be 73% for the 500m and 85% for the 1000m (Zamparo *et al.,* 1999). These high values suggest the importance of aerobic work at kayak training to develop a strong aerobic base. This is important as it allows a kayaker to work for longer and at a higher intensity by delaying fatigue and allowing for an improved recovery time.

The level of aerobic power is determined by measuring the rate at which the body can breathe in oxygen to the lungs, transfer oxygen from the lungs to the heart, deliver the oxygen through the blood to the working muscles, extract the oxygen from the blood to the muscles, and then use the oxygen in the muscles for energy production. Aerobic power is expressed as $\dot{V}O_2$ max, the maximum volume of oxygen that can be taken up and used by the body. This reflects the physical fitness of the athlete. $\dot{V}O_2$ max is expressed either as an absolute rate, in litres of oxygen per minute (l/min), or as a relative rate, in millilitres of oxygen per kilogram of bodyweight per minute (ml/kg/min). $\dot{V}O_2$ max is the athlete's aerobic limit. It has been consistently demonstrated however, that upper body exercise elicits lower rates of oxygen consumption than those observed during lower body and whole body exercise, due to the limitation of peripheral factors. For this reason, an individual rarely achieves their $\dot{V}O_2$ max during upper body exercise, and therefore the aerobic power for upper body work is commonly referred to as $\dot{V}O_2$ peak.

Once the intensity increases beyond the aerobic threshold the body uses anaerobic methods to produce energy. This causes lactic acid to be produced. The relatively high peak blood lactate concentration values observed following maximal kayak racing (13 mM; Tesch, 1983) indicate a significant anaerobic contribution to kayak paddling. When comparing these values to sedentary subjects, it was suggested by Pendergast *et al.* (1979) that the kayak paddlers were capable of developing at least twice the anaerobic power of sedentary subjects for arm cranking exercises. This notable difference between sedentary subjects and their kayaking counterparts demonstrates the kayak paddlers' ability to withstand high levels of arm exercise before fatigue sets in.

When measuring the $\dot{V}O_2$ peak of Olympic kayakers, values have been reported to reach as high as 4.67 L/min (58.8ml/kg/min) during an on water 1000m race (Tesch, 1983). Although these values seem quite high considering an average sedentary person has a $\dot{V}O_2$ peak of approximately 35 ml/kg/min, when compared to other sports where endurance is an important component, such as rowing, running and cycling, these values do not quite compare. Especially when you want to compare your recent kayak $\dot{V}O_2$ max test results to 7 time Tour de France winner Lance Armstrong (road cycling) who recorded a whopping 84 ml/kg/min (5.5-6 L/min) (Wilmore and Costill, 2005). In sports like rowing however, although the peak absolute $\dot{V}O_2$ of rowers compare favourably with the results obtained for road cycling and distance runners (~5-6 L/min; Billat *et al*., 1996), when the $\dot{V}O_2$ max was expressed in relative units (~64 ml/kg/min; Di Prampero *et al*., 1971) 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 are small, thin and lightweight compared rowers and also kayakers, who have a larger body mass.

These results however, do not suggest that kayakers are not as fit as other endurance athletes. An important concept to remember is that kayaking is predominantly an upper body sport and if the $\dot{V}O_2$ peak of a kayaker was divided by the mass of only the upper body (discounting the legs that are not used extensively in kayaking) their relative $\dot{V}O_2$ max may even match those of distance runners or cyclists. It can be speculated that if the kayakers $\dot{V}O_2$ were to be normalised for arm mass and the cyclists for leg mass for example, the differences observed in $\dot{V}O_2$ may not be quite as large as those presented and thus compare favourably with other endurance sporting events.

Knowing your $\dot{V}O_2$ max is extremely useful but only if you do something with the information you have. Developing a training plan with the specific requirements of increasing your aerobic and anaerobic threshold is a positive step in your training time. But only if you know where your thresholds are to begin with; otherwise how will you know how hard to go and how will you know if you've improved it or not? A $\dot{V}O_2$ max test will clearly demonstrate the levels and threshold values to target at training. Through training you can make significant improvements in the efficiency of your aerobic engine thus allowing you to perform at your best.

Peak physical fitness alone however, does not guarantee success; poor technique can decrease a paddler's efficiency by increasing the amount of work performed by the body. At elite levels, this decrease in efficiency due to biomechanical factors can be the difference between winning and loosing. Although there are no papers examining the forces developed within a kayak, previous studies analysing the technique or movement patterns of the paddler throughout the stroke are helpful in building a scientific description of technique. As a result of numerous research papers analysing technique, the following description of the patterns of movements are used by coaches and athletes to monitor paddling technique through video analysis. Movements of the blade tip and joint centre paths are divided into four phases: 1) the catch; 2) the pull; 3) the exit; and 4) the recovery. The stroke begins with the paddler entering their blade well forward and close to the longitudinal axis of the kayak. With the body rotated on the paddling side strong pressure is applied to the footbar through the foot of the stroke side leg. The blade is then moved backwards and laterally until the instant of blade exit. Simultaneously, the stroke side knee and hip are extended to help drive the hip backwards and produce body rotation. Body rotation includes movement throughout the thoracic vertebrae, shoulder girdle and pelvis. The completion of the exiting action establishes the recovery position. During recovery the stroke side hand is raised slightly above the shoulder and pushed forward to full arm extension. The blade is then lowered into the water for the next stroke on the same side. The opposite side paddle stroke begins when the exiting actions are complete from the first stroke and continues throughout the recovery phase of the opposite side.

Although helpful, the analysis of joint centre paths described above only attempts to describe the movement patterns of the limbs. Further examination of the forces that contribute to making the kayak faster also play an important role in monitoring and improving technique. As a paddler races towards the finish line, each stroke moves the kayak forward. However, within each stroke the kayak speeds up and then slows down due to the dynamic movement of the paddler and the varying magnitude of force application via the paddle. During the pull phase of the stroke the velocity of the kayak increases, while during the recovery phase the velocity of the kayak slows down. This is because, the movement of a kayak, semi-submerged in water, is opposed predominately by hydrodynamic drag. Therefore, during the pull phase, the paddle force applied by the paddler exceeds the drag force acting to slow the kayak down. Thus in order to achieve optimum performance of the kayak, drag forces on kayak and paddler must be minimised and factors which contribute to improved propulsive forces must be maximised.

There are few quantities that can be changed to reduce the negative effects of drag and maintain a constant kayak velocity. Friction drag can be minimised by a reduction in either the friction coefficient, the ratio of the force of friction between the kayak and water or a reduction in the wetted surface area, the area of the kayak in contact with the surrounding water. The coefficient of friction depends on the materials used; for example, with a low coefficient of friction two materials slide past each other easily, steel on ice, while rubber on pavement has a high coefficient of friction as the materials do not slide past each other easily at all. The main contributor to the wetted surface area is the total weight of the paddler. Hence, the question then arises; how may body size and shape influence kayak paddling performance?

While a larger individual may have a larger absolute peak $\dot{V}O_2$, potentially, a too large body mass of the kayaker may negatively affect the relative peak $\dot{V}O_2$ attainable and cause the kayak to sit deeper in the water, increasing wetted area of the kayak. This increased wetted area will increase the drag thereby increasing the resistance that must be overcome by the kayaker to move the kayak forward. With the hull design and shape already set at an optimal level and material coatings on the hull, such as textured surfaces, being prohibited, it appears that blade or paddle force is the main variable that needs to be maximised to attain higher average kayak velocities. The mass of the paddler determines the wetted and frontal area of the kayak and therefore the power to weight ratio of the paddler should be optimised. Again, another question: 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.

With a greater understanding of the physiological requirements and biomechanical properties of kayaking coaches and athletes can work towards successful padding performances. Examination of what is occurring to an athlete's technique under the stress of competition is an important step in improving race times. This information may aid the coach in the development of more specific training programs for their athlete and can also be used to examine causative factors with regard to injury and may suggest strategies for rehabilitation..

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