Calorie Requirements During Ultra Distance Paddling

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Measurement of calorie expenditure during exercise

The direct way to measure the rate of calorie expenditure is to measure oxygen uptake during exercise. Measurements are typically confined to the laboratory and require expensive metabolic equipment as well as stationary ergometers. More recently, small, lightweight wearable metabolic systems have been developed; however their use is limited and they are expensive. Thus, data that include direct measurements of oxygen uptake during exercise have traditionally been limited to activities that can be performed on a stationary ergometer or treadmill. While kayak ergometers are available, research specific to kayaking is very limited and almost entirely directed toward Olympic style flatwater and slalom kayaking.

The rate of oxygen uptake is expressed as liters per minute (l/min) or milliliters per kilogram body mass per minute (ml/kg/min). One liter of oxygen is approximately 5 calories; thus 1 liter oxygen uptake per minute is 5 calories expended per minute. Thus, from oxygen uptake measurements, rate of calories expended can be determined. Likewise, total calorie expenditure can be calculated based on total exercise time. For the discussion below, studies that included direct measurements of calorie expenditure did so from oxygen uptake measurements taken during exercise. Whereas studies that provided estimated calorie expenditure typically derived it from heart rate measures. This is possible when the relationship between exercise oxygen uptake and heart rate for an individual athlete has been pre-determined from laboratory measurements. Another indirect method is the use of well defined metabolic equations for cycling, running and walking and applying them when knowing the velocity at which the athlete is performing. Currently, there is no established equation for kayaking or canoeing.

Compendium of Physical Activities – estimation of calorie expenditure during kayaking

Estimations of calorie expenditure for all types of activities, including kayaking and canoeing can be found in the 2011 *Compendium for Physical Activities.* The estimations for kayaking or canoeing come from a handful of studies, primarily involving male Olympic-style athletes. Measurements of energy expenditure were taken under controlled conditions during either kayak ergometer exercise or on the water in flat conditions (with use of a portable metabolic system) and thus, do not account for several varying factors that can affect calorie expenditure, including water and wind conditions, boat and paddle, and length of time the athlete has been paddling.

The table below was copied from the 2011 *Compendium of Physical Activities* and includes several types of water sports. The energy expenditure for each category is given in METs or metabolic equivalents. One MET is equal to an oxygen uptake value of 3.5 ml/kg/min. To convert this into calories per minute, body mass must be taken into account. Thus, while a specific MET value may be assigned to an activity, calories expended each minute will be a function of body mass. For example, canoeing on a camping trip is assigned a MET value of 4. To calculate calories per minute, use the following equation:

(MET x 3.5 ml/kg/min x body mass, kg)/1000 x 5 = calories per minute

For example, this translates into the following for a 70-kg person

(4 x 3.5 x 70)/1000 x 5 = 4.9 cal/min or 294 calories per hour

CODE	METS	MAJOR HEADING	SPECIFIC ACTIVITIES
18020	4.0	water activities	canoeing, on camping trip (Taylor Code 270)
18025	3.3	water activities	canoeing, harvesting wild rice, knocking rice off the stalks
18030	*7.0*	water activities	canoeing, portaging
18040	2.8	water activities	canoeing, rowing, 2.0-3.9 mph, light effort
18050	5.8	water activities	canoeing, rowing, 4.0-5.9 mph, moderate effort
18060	12.5	water activities	canoeing, rowing, kayaking, competition, >6 mph, vigorous effort
18070	3.5	water activities	canoeing, rowing, for pleasure, general (Taylor Code 250)
18080	12.0	water activities	canoeing, rowing, in competition, or crew or sculling (Taylor Code 260)
18090	*3.0*	water activities	diving, springboard or platform
18100	5.0	water activities	kayaking, moderate effort
18110	4.0	water activities	paddle boat
18120	3.0	water activities	sailing, boat and board sailing, windsurfing, ice sailing, general (Taylor Code 235)
18130	4.5	water activities	sailing, in competition
18140	3.3	water activities	sailing, Sunfish/Laser/Hobby Cat, Keel boats, ocean sailing, yachting, leisure
18150	6.0	water activities	skiing, water or wakeboarding (Taylor Code 220)
18160	7.0	water activities	jet skiing, driving, in water
18180	15.8	water activities	skindiving, fast
18190	11.8	water activities	skindiving, moderate
18200	7.0	water activities	skindiving, scuba diving, general (Taylor Code 310)
18210	5.0	water activities	snorkeling (Taylor Code 310)
18220	*3.0*	water activities	surfing, body or board, general
18222	*5.0*	water activities	surfing, body or board, competitive
18225	*6.0*	water activities	paddle boarding, standing

The above information is a generalization of calorie expenditure during canoeing and kayaking and can be useful when estimating total daily calorie expenditure from several activities performed in a day. However, when kayaking makes up a significant portion of the day, the error associated with the estimation is great when attempting to determine an athlete's daily calorie requirements. For this report, calorie expenditure specifically for long distance recreational and competitive kayaking is examined more closely in an attempt to derive a more accurate estimate of energy expenditure during ultra distance paddling.

To begin, the following sub-list of specific kayak and canoe activities was created from the above list:

CODE	METS	MAJOR HEADING	SPECIFIC ACTIVITIES
18040	2.8	water activities	canoeing, rowing, 2.0-3.9 mph, light effort
18050	5.8	water activities	canoeing, rowing, 4.0-5.9 mph, moderate effort
18060	12.5	water activities	canoeing, rowing, kayaking, competition, >6 mph, vigorous effort
18070	3.5	water activities	canoeing, rowing, for pleasure, general (Taylor Code 250)
18080	12.0	water activities	canoeing, rowing, in competition, or crew or sculling (Taylor Code 260)
18100	5.0	water activities	kayaking, moderate effort

MET level for canoeing at light effort, 2.0-3.9 mph (18040) was derived from two sources; one which estimated calorie expenditure in New Guinea adults that canoed as part of their daily lifestyle (published in 1974) and the other from an exercise physiology textbook (published in 1981) which may have derived its information from estimation studies, including the 1974 study. The Compendium authors reported the average of these two sources. The second category (18050) is canoeing at 4.0 to 5.9 mph or moderate effort and has a MET level almost twice that of light effort canoeing. The single source for this category is the same exercise physiology textbook mentioned previously. The ‘canoeing for pleasure’ category (18070) information came from a study (1978) that used a questionnaire to estimate daily calorie expenditure among adults living in Minnesota. Calories expended during canoeing was not measured, rather it was estimated.

Two categories are specific to canoeing or kayaking competition (18060 and 18080). The 18080 category was derived from the Minnesota questionnaire study and appears to be concentrated on sculling or crew racing. The 18060 category is worth discussing in more detail as it is a compilation of five studies. The MET level is considerably higher than the leisure level of canoeing, as to be expected. It is equivalent to an oxygen uptake of about 44 ml/kg/min (12.5 x 3.5 ml/kg/min). Only well trained athletes have maximal oxygen uptake values high enough to sustain this level of intensity for the few minutes required to complete a competition. The value provided is the average determined from the studies, which ranged from 9.3 to 15.4 METs. One of these studies simulated crew in a water tank and will not be included in the following discussion. Three studies included direct measurements of oxygen uptake during flatwater kayaking under race conditions (distances of 1000 to 2000 meters). These studies included only well-trained or elite male athletes. The total number of athletes among the three studies was 27. Two of these three studies also tested differences in calorie expenditure when wash riding, a drafting strategy similar to that used in cycling. Without drafting, calorie expenditure amounted to approximately 13.6 METs, 10-15% more than wash riding conditions. Typical velocities ranged from 8.4 to 9.2 mph. The last study from this category tested both male and female slalom kayakers in a 30-meter straight course. The athletes ranged from beginners to elite. Velocities tested were 4.5 and 5 mph at MET levels of 10.2 and 12.2, respectively.

The last category is 18100, kayaking at a moderate pace. Interestingly, the MET value was derived from the same study that tested the slalom kayakers, but this time using two slower velocities of 3.1 and 3.6 mph (MET value 4.1 and 6.1, respectively). The average of the two MET values is reported in the Compendium list.

There are several problems with the above estimations of MET level for kayaking and canoeing. First, the MET calculated for moderate kayaking is based on one study where athletes paddled slalom or wild water racing kayaks. Differences between slalom and flatwater kayaks are significant and can greatly affect calorie requirements. Thus, it is likely that applying 5 METs to a moderate pace in a flatwater kayak will significantly overestimate calorie requirements. Second, some of the values are based on estimations and not measurements. Third, where values were derived from studies that directly measured calorie expenditure, measures were performed under specific conditions and with small groups of athletes, almost entirely males. Fourth, much of the data were acquired under racing conditions where athletes performed at maximal intensities. Fifth, if velocity is the determinant of intensity as it appears to be in the Compendium list, none of the information applies to conditions where significant water current or wind is present, which can greatly affect paddle velocity at a given amount of effort.

Overall, while the *Compendium for Physical Activities* provides a variety of choices concerning kayaking and canoeing, it appears the information is generalized from a small group of studies, and not entirely from direct measurement of calorie expenditure. Thus, it has limited use to long distance paddlers that range from recreational to elite levels of competition. However, in conjunction with other data, the Compendium may be useful in developing estimates of calorie expenditure for ultra distance paddlers.

Direct measurements of calories expended during kayaking

The specific goal is to estimate calories expended during submaximal intensities of paddling, intensities that can be performed continuously for several hours. To get to the answer, attention is drawn to studies that measured calorie expenditure (oxygen uptake) directly while athletes paddled in the water or on a kayak ergometer. Thus far, these tests have primarily included European or Australian Olympic or world class flatwater and slalom kayak/canoe athletes. These athletes train for 200m, 500m and 1000m distances which can be performed singly, doubly or with 4 paddlers in a boat. The Olympic competitions include 500m for men and women and 1000m for men. During these events, the single kayaker or canoeist completes the course within 2 to 4 min. Flatwater kayak racing also includes a marathon race (42 km), but this is not an Olympic event. Only one study included athletes that compete in this longer distance. Thus, these studies involve a different type of athlete from the kayaker that trains for extreme distances and multi-day races that cover several hundred miles of paddling.

With the exception of one study that included ergometer measurements, all measurements were performed while athletes paddled in flat water conditions where no wind or current was present. Distances covered were small, reflecting the type of competition these athletes engage in. Athletes were generally tested while performing at a typical race pace (8.4 to 9.2 mph). Thus, given the type of conditions in which these athletes were tested, the rates of calorie expenditures were maximal or near maximal. Data from many of these studies were used to come up with a MET level for competition kayaking or canoeing in the *Compendium for Physical Activity.*

There is one useful piece of information from these studies. On average, peak or maximal oxygen uptake (VO_2max) is about 45-50 ml/kg/min (12.9 – 14.3 METs) for well trained female paddlers and 50-60 ml/kg/min (14.3 – 17.1 METs) for well trained male paddlers. For the most part, these are athletes that are training for competition regularly. These data might best represent the aerobic capacity of the top tier athletes competing in adventure paddle races (e.g., Carter Johnson, Robin Benincasa). However, it is likely that most competitors in a given race (such as the MR 340) do not train as heartedly as the athletes represented here. Additionally, many long distance paddle athletes are considerably older than the athletes studied. Thus, these VO_2max values may apply only to a small group of competitive long distance paddlers.

Examining energy expenditure during ultra distance cycling and running

By combining our knowledge of the energy expended during other ultra distance sports such as cycling or running with the above information concerning VO_2max values in kayakers, we can make some inferences that apply to long distance paddling. Elite male endurance cyclists and runners typically have VO_2maxes ranging from 65 to 75 ml/kg/min (18 to 21 METs). From the previous information, we know that elite (Olympic) male kayakers have VO_2maxes ranging from 50 to 60 (14 to 17 METs). From this we can determine that the kayaker's aerobic capacity is about 75% of the cyclist or runner. The next step is to determine a reasonable percent of aerobic capacity that would be required to perform a long distance activity lasting several hours in a day, either as a single event or repeated over multiple days.

Two studies have tested cyclists while they competed in long distance multi-day events, such as the RAAM (Bircher et al,, Knectle et al.). Typically, these athletes pedal 20-21 hr each day for several days. Another study tested a cyclist while riding a stationary cycle ergometer for 24 hr continuously in the lab (White et al.). An estimation of calorie expenditure during the multi-day races leads to the conclusion that the athletes were performing on average 55-60% of VO_2max. During the 24-hr cycling, measurements were performed and intensity of exercise averaged 55% of VO_2max. Among these studies, VO_2max averaged 60-65 ml/kg/min.

In runners, estimated intensity as a function of distance has been determined to be about 66% of VO_2max for continuous running events lasting approximately 8 hours and 46% for 24 hours (Davies et al.). In another study, a male runner competed in a 1005 km race that he completed in 199 hours (Eden et al.). Running time was 21 hours per day and this required approximately 34% of VO_2max.

To extrapolate the long distance cycling and running data to kayakers, assume that VO_2max of a well trained kayak athlete is about 75% of the average VO_2max among the cyclists and runners from the previous studies, or 45-50 ml/kg/min. If it can also be assumed that kayaking continuously for 20-21 hr per day requires 45-55% of VO_2max, we can estimate oxygen uptake to be 20 to 28 ml/kg/min (5.8 to 7.9 METs). However, given that the maximal power output of a kayaker is about 60% of the cyclist's power output, it is likely that muscle fatigue during continuous kayaking will occur more quickly and at a lower relative intensity than during cycling due to the much smaller muscle mass being recruited. Therefore, the kayak athlete is likely utilizing closer to 35-45% of his or her VO_2max, bringing the estimated MET level to 4.5 to 7 METs. These numbers are not far off from those provided in the *Compendium for Physical Activity*.

Examining energy expenditure during ultra-endurance events that include paddling

Some studies tested athletes during eco or adventure races that involved more than one activity. Among these studies, only one included an activity comparable to kayaking (Zimberg et al.). The athletes in this study were seven male athletes that had participated in the Brazilian Ecomotion Pro adventure race that covers 477 km and is comprised of horse riding, trekking, mountain biking, duck canoeing and vertical techniques. The investigators attempted to simulate the race in the laboratory. From their data, attention is drawn to the duck canoeing portion of the race.

First, they estimated that athletes performed the race at approximately 35% of VO_2max. Second, because this was a simulation, the athletes performed arm ergometer exercise in place of the duck canoeing. Third, arm ergometer VO_2max was measured to be 39 ml/kg/min. With this information, calorie expenditure was estimated. The athletes performed the duck canoeing during two separate intervals, lasting 7.5 hr and 2.5 hr. The estimated calorie expenditure was 290 cal/hr and 260 cal/hr for each interval, respectively. Because the athletes were arm cranking and not kayaking, a 10% increase in the estimation for paddling can be applied. This is based on a previous study that compared arm cranking to kayaking (Forbes & Chilibeck). It is not certain how the authors of the previous study estimated the intensity to be 35% of VO_2max, but note that it is similar to the estimation made earlier for long distance paddling.

At this point, it might be of interest to apply this information to estimate the calories expended by Carter Johnson while he broke the 24-hr flatwater paddle record. The distance covered was officially recorded as 150.34 miles and according to the athlete, he stopped approximately 45 minutes during the paddle. Based on his log book and total distance and time, his average velocity was near 6.5 mph. The athlete encountered 15-20 knot headwinds during several hours of the paddle and as this was a competition against time, he most likely attempted to paddle at intensities greater than moderate. Further, calorie expenditure is known to increase by as much as 10-15% over a 15-hr period. Using our estimated range of 4.5 to 7 METs, we can assume that this athlete has the capacity to perform closer to 7 METs. Using a range of 6 to 7 METs and assuming a body mass of 70 kg, the athlete expended 7.4 to 8.6 calories per minute; about 440 – 515 calories per hour or a total of 10200 – 12000 calories for the entire race.

Energy intake during ultra distance racing events

Because the caloric demand of the activity significantly determines the energy intake requirements, it is also useful to study the calorie intakes of ultra distance athletes. Nutritional recommendations for exercise are based on studies that have tested the effects of carbohydrate ingestion during exercise typically lasting 1 to 4 hr. Many of these studies tested trained cyclists having VO_2maxes of about 60 ml/kg/min and riding at intensities of 60 to 75% of VO_2max. Using a typical body weight of 75 kg, estimated calorie expenditure per hour is 800 to 1000 calories for the cyclist. From the above discussion we can surmise that an elite kayak paddler expends about 400 to 500 calories per hour. The current nutrition recommendation for endurance events (ACSM, 2009) is to consume 0.7 gram carbohydrate per kilogram body mass per hour or 30 to 60 grams per hour (120 to 240 calories) Because carbohydrate will most likely be the only source of energy during a 2 to 4 hour cycling race, it is reasonable to assume that these athletes are therefore, replacing only 20-25% of calories expended. Could this be the case with the paddling athlete that paddles for > 12 hr at a time?

Summary of calorie expenditure and calorie intake during ultra distance race events.

Study	Time, hr	Calories expended per hr	Energy intake per hr*
Zimberg (simulated eco race)	67	366	220 (60%)
Colombani (swim, run, cycle, mt bike, rollerblade)	18.6	664	275 (44%)
Rejc (hiking, cycling, mt bike)	19.5	625	250 (40%)
Stewart (cycling)	46.7	310	230 (77%)
White (cycling)	24	823	441 (54%)
Kimber (Ironman triathlon)	12 (men) 12.6 (women)	836 680	328 (39%) 247 (36%)

* *In parentheses is the percentage of calorie expenditure replaced by intake.*

Several studies have gathered information on nutrition intake during ultra distance races. The table above provides a summary of these studies and includes both estimated calorie expenditure and known quantity of calorie intake. With the exception of one study (Kimber et al.), the athletes were males. Among the studies, the athletes replaced an average of 52% of calories expended. This is considerably higher than the carbohydrate calories consumed during events lasting up to four hours. It also appears from these studies that length of the race is associated with a greater percent of calories replaced. The reason for this could be related to the intensity (rate of calorie expenditure) of the exercise which is inversely related to the length of the race. Quite simply, it becomes more difficult to replace all expended calories as the rate of expenditure increases. It can also be assumed that athletes competing in ultra distances stop occasionally for short periods of time, which provides them additional opportunities to consume foods or beverages. The ultra endurance athletes in these studies also did not limit themselves to just carbohydrate, but rather consumed foods and beverages that provided both fat and protein calories. Because fat provides twice as many calories as carbohydrate and protein, consuming fat can add a considerable amount of calories during ultra distance events.

Applying the information to the 2011 Florida Ultra Marathon paddle race

Thus far, data presented are almost entirely from athletes under the age of 35 years. Most studies also include athletes that are highly trained or elite-level. Many ultra endurance races include female athletes and athletes ranging in ages that span several decades. Many competitors are over 65 years of age and many more are not elite or highly trained athletes. An example of such a race among ultra distance paddlers is the Ultra Marathon held in Florida each year. The Ultra Marathon race covers approximately 67 miles along the gulf coast. Athletes that compete in this race typically finish under 24 hours. The best recorded time for a single male paddler is 11 hours. For this report, the 2011 race was studied and five (4 males, 1 female) participants provided their nutrition intake. All males competed in the single kayak division while the female athlete competed in the double mixed division. The youngest athlete was 38 years of age and three athletes were over 60 yrs of age.

To apply the information above to the athletes performing in the Ultra Marathon race, some factors were considered. First, there is an age-related decline in VO_2max of about 5 to 10% each decade after 30 yrs of age. Among the five competitors tested, all of them were experienced paddlers, but only one had experience in kayak competition. Based on this information, the average VO_2max associated with kayaking is estimated to be approximately 34 ml/kg/min for this group. Under conditions where headwinds and currents are not significant, we can assumed the athletes were paddling at 35-45% of VO_2max or 3.4 to 4.4. On average this is 3.9 METs. The table below provides a summary of calorie expenditure and the known quantity of calorie intake for each athlete and average of the group.

Summary of calorie expenditure and calorie intake during the 2011 Florida Ultra Marathon race.

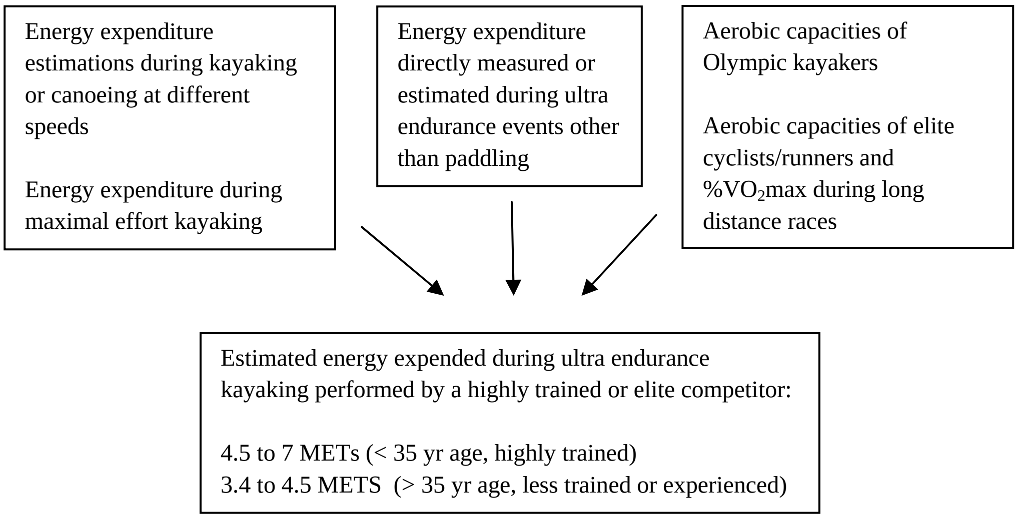
Athlete	Body mass, kg	Time, hr*	Calories expended per hr	Total calories expended	Total calories consumed	Percent replaced
M1	93.6	17.2	383	6593	3060	46
M2	79.5	19.85	326	6462	2620	41
M3	84	25.5	344	8771	2733	31
M4	84	24.5	344	8428	2962	35
M avg	85.3	21.8	349	7599	2844	37
F	63.6	22.4	229	5834	4100	70
Avg	80.9	21.9	325	7255	3095	43

** These are estimated paddle times, not official race times.*

From the data shown in the table, the male athletes replaced on average less than 40% of calorie expenditure, with the greatest amount replaced by the first-place finisher. Relative to calorie expenditure, the female athlete's intake was considerably higher than the males. This is most likely due to several hours spent off the water during which she consumed additional calories. Overall, the low intake among these athletes can be partially attributed to the difficult marine conditions that were encountered during the entire race. However, it is noteworthy that despite the marine conditions and the unique challenge of consuming calories while engaging in continuous upper body exercise, these athletes managed to consume a good amount of calories.

<u>Summary</u>

The estimation of calorie expenditure during ultra distance paddling is based on several assumptions and has yet to be tested using direct measurements of oxygen uptake. Thus far, there are limited data and even fewer that are directly related to the ultra distance paddler. Despite this, the *Compendium of Physical Activity* offers calorie expenditure estimates for several paddling levels and types, thereby providing a meaningful base from which to extrapolate to conditions that are specific to the ultra distance competitor. Information gathered from ultra endurance sports such as cycling and running is useful in that endurance capacity and performance have many physiological characteristics that are not necessarily sport specific; thus, calorie expenditure estimated during ultra distance running or cycling can carry over to paddling races. For instance, typical aerobic capacity of ultra endurance cyclists and runners are well known and long distance events require a percentage of capacity such that the longer the distance, the lower the percent of maximum capacity required. Understanding the difference in aerobic capacity between cyclists or runners and paddlers allows some determination of calorie expenditure during ultra distance paddling events.



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