

A Comparison of Energy Output and Input among Elite Rowers

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Competitive rowing, with the exception of single sculling, is one of the most unique of all endurance sports as it involves two or more athletes working together in a rhythmic, synchronous manner. Therefore, it appears from a purely physical basis that a multiple oared boat is only as strong as its weakest link. Furthermore, unlike other predominantly aerobic sports, rowing is characterized by exceedingly high muscular power production and energy expenditure in a very limited time frame.

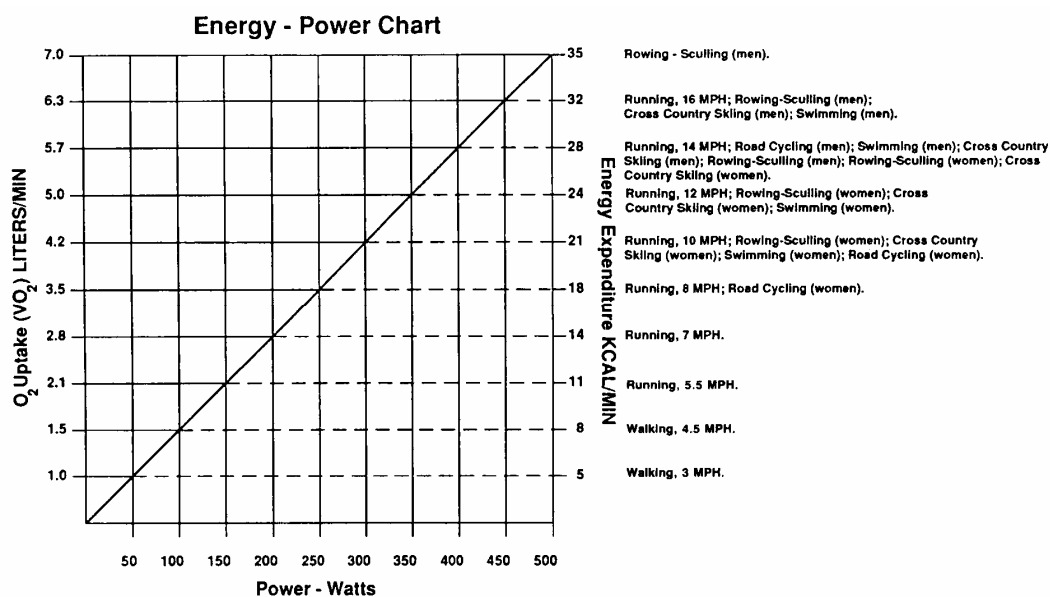
Maximum power and metabolic responses are necessary to compete successfully over 2000 meters (m). Typical training sessions use exercise intensities that range from very low submaximal work to short term supramaximal efforts. Based on our research and that of others, rowing ranks at the top of the list as the most physiologically demanding of any aerobic sport. Some time ago, we determined that rowers performing 2000m competitive efforts generated average power outputs of between 250 and 550 watts depending on whether they were heavyweights or lightweights, male or female (4). The higher power outputs for men often surpass 0.7 horsepower and the best women approach half of a horsepower for average outputs for six minutes of work.

As might be expected, these excessive power outputs require extraordinary amounts of energy to sustain them (Figure 1). It has been estimated that a 2000m race is fueled by about 25-35 large calories produced every minute (4). These estimates have been obtained by measuring the amount of oxygen consumed during ergometer work and actual on-the-water testing. The body's ability to take in, deliver, and use oxygen is probably one of the best measures of aerobic fitness. Although it takes five to eight minutes to row 2000m, the relative proportion of aerobic to anaerobic metabolic contribution is roughly 75% to 25% respectively (6). If a rower expects to achieve success at the international level, it will be necessary to produce maximal oxygen consumptions that approach 4.5 liters/minute for women and 6.0 liters/minute for men (slightly less for lightweight rowers).

Maximal oxygen consumption (VO_2 max) is often used as the "yard stick" to determine aerobic capacity. However, a rower's ability to row at a high percentage of his/her maximum aerobic capacity without tiring and increasing mechanical efficiency (ME) are more important factors. We have found that being able to row 2000m at an oxygen consumption that is 98% or higher of VO_2 max and increasing mechanical efficiency are far more important than VO_2 max itself. We have recently reported that one of the most common reasons for individual successes by U.S. rowers in international competition over the last 10 years has been the significant improvement of mechanical efficiency (5), and it is doubtful that a rower can be successful at the international level without achieving a ME of greater than 20%. There is a wide variance in the energy and time it takes to row a highly

competitive 2000m race compared to the amount of time and energy used for training. During the season most competitive rowers spend between one and two hours on the water every day. During a competitive effort a rower will expend a total of about 200 kcal. This is small compared to the range of 1000 to 2000 kcal that is often the cost of a single training session depending on the intensity and duration of exercise. Our higher value was measured for heavyweight men while lightweight women expend as much as 0.290 kcal/min/kg.

Figure 1: Energy - Power Chart



Because of the extremely high energy expenditures associated with rowing training and racing, one should be concerned about adequate energy intake to fuel the muscles of rowers. This is a problem because of the difficulty that rowers sometimes experience in maintaining body weight, especially lean body mass.

We recently conducted a study of 28 elite female and 16 elite male rowers, all candidates for the National Team. Their physical characteristics are listed in Table 1.

Table 1: Physical Characteristics of Subjects (X/ \pm SE)

	Number of Athletes (n)	Age (yrs)	Height (cm)	Weight (kg)	Body Fat (%)
Women	28	24 (0.78)	178.6 (0.3)	73.6 (2.41)	14.8 (0.36)
Men	16	23 (0.87)	194.1 (0.49)	89.0 (2.36)	8.7 (0.29)

Daily energy expenditure, in kilocalories, was estimated for each athlete by measuring maximal oxygen consumption and heart rate during both rest and maximal ergometric rowing. Using biotelemetry procedures, average daily caloric expenditure was extrapolated by relative heart rate data. Noting the intensity of

various training regimens permitted an estimation of average daily caloric cost. Average daily energy output for our subjects is displayed in Table 2.

Table 2: Summary of Results ($\bar{X}/\pm SE$)

Power Output	VO₂ max	HR max	Energy Output	Energy Input	%kcal Cho	%kcal Fat	%kcal Pro	%kcal Alcoh
Watts	ml²/min	b/min	kcal/day	kcal/day				
Heavyweight Women								
285	4277	191	3177	3169	52.0	34.6	13.0	0.40
2.3	0.06	1.76	103.9	167.7	1.30	1.13	0.45	0.17
Heavyweight Men								
428	6200	188	4710	4688	49.6	49.6	15.1	1.00
2.6	0.08	2.85	98.7	321.7	3.57	3.57	0.93	0.54

Sports nutrition is a topic that is often misunderstood and woefully abused. The often-used "shot-gun" approach to meeting caloric needs by simply increasing caloric intake without regard to nutrient source is scientifically contrary to the need for a more careful study of the nutritional requirements of rowers.

A comprehensive protocol of nutritional assessment, followed by individual dietary counseling for the 28 heavyweight women and 16 heavyweight men trying out for the 1987 National Team provided a rare, in-depth look at the extent to which the nutritional needs of elite rowers were being met by their diets.

Two individual sessions, separated by approximately eight weeks, were conducted with each athlete by a registered dietitian. At the first session, the purpose, procedure, and projected benefits of nutritional counseling to the rower were outlined. A diet history, the rower's usual dietary patterns, health habits, and a detailed-as-possible recall by the athlete of food intake and workout intensity/schedule over a typical 24-hour period as well as anthropometric measurements were taken.

This 24-hour record was then assessed and any recommendations for immediate changes in food consumption habits were made. Each rower was urged to take advantage of a more comprehensive computerized nutritional assessment and evaluation of their food intake. Those who elected to participate in the in-depth counseling were provided detailed verbal and written instructions on how to keep a record of all foods and beverages consumed over a three-day period. Each three-day food record was analyzed for the nutrient level and the caloric distribution of the three energy-providing nutrients.

At a second individual counseling session held with each rower who returned a three-day food record, results of the analysis were shared in detail. An evaluation form was developed by the consultant to include a summary of desirable changes in dietary practices and specific food recommendations. Counseling also included reinforcement of present dietary practices considered to be appropriate and the provision of an opportunity for questions. Each rower left the second conference knowing how well his/her normal food intake met his/her nutrition needs during training, and if recommendations for change were made, exactly how to implement those changes in terms of food choices. Summary information for each rower was shared with the appropriate coach.

The significant commonality in the rowers' diets was that many were too low in carbohydrate and too high in fat. Percent of total calories from carbohydrate, protein, and fat surprised many rowers who, by virtue of the fact that they ate bran muffins for breakfast and spaghetti at dinner, considered their diet to provide ample carbohydrate. In order to replenish glycogen to the working muscles during strenuous daily training, research (3) has established that an athlete's diet should provide either 60% of the calories as carbohydrate or 650 grams of carbohydrates per day. Table 2 shows, however, that the average three-day intake of calories from carbohydrate for women was 52% and for men only 49.6%. One male was getting only 34% of his calories as carbohydrate, while a woman recorded only 36% (neither was selected for the National Team). Conversely, fat levels (mean of 34.6% of calories for women and 34.3 % for men) were higher than the recommended desirable range of 28-30%.

Adequacy of protein intake is more appropriately reflected by individual need as dictated by kilograms of body weight than by percent of total calories as protein. Only the latter measurement is reflected in Table 2. The extent to which each athlete's diet met the need for protein varied with the individual's size, so a group mean is not appropriate. Protein need was, however, individually calculated for each rower at 1.4 grams protein/kg of body weight, as recommended by recent research findings. Nearly 40% of the women had diets below this level while all of the men had adequate protein intake using this standard.

One of the most frequently asked questions by the athletes was, "Should I be taking a vitamin/mineral tablet(s) each day?" Table 3 shows the percentage of men and women who were able to meet their need for selected vitamins and minerals through their diet alone. The standard for Vitamin C was set at three mg/kg of body weight, considerably higher than the Recommended Dietary Allowance (RDA) of 60 mg for Vitamin C.

Table 3: Percentage of Heavyweight Rowers Who Met Vitamin and Mineral Needs Through Food Intake

Gender	Vitamin C 3mg/kg wt	Vitamin B ₁ 0.5mg/1000kcal	Vitamin B ₂ 0.6mg/1000kcal	Niacin 6.6mg/1000kcal
Women n=28	43	96	89	86
Men n=16	40	90	90	90

Gender	Calcium 800mg	Iron 18mg, 10mg	Potassium 4000mg	Magnesium 5mg/kg wt
Women n=28	86	64	57	54
Men n=16	100	100	70	70

All of the women and all but one of the men received more than 60 mg of Vitamin C per day, however, only 43 and 40 percent of the women and men respectively were taking in enough Vitamin C to meet the higher level of three mg for each kg of body weight. This standard is based on Van Huss's review of the literature (7) that concluded that it would be prudent for athletes in training to consume three to five mg Vitamin C/kg body weight per day. Many of the rowers were advised to increase their intake of fruits and vegetables high in Vitamin C, such as citrus fruit and juices, cantaloupe, watermelon, strawberries, broccoli, spinach, brussel

sprouts, cabbage and tomatoes. Increasing fruits and vegetables would also help to increase potassium and magnesium, which were low in many of the rowers' diets.

Intake of the B vitamins, important as co-enzymes in the metabolism of energy by the body, was adequate for most of the rowers. Since need for these vitamins is directly related to the intake of calories, each athlete's sufficiency was related to caloric intake over the three-day period. Calcium was figured at the RDA level of 800 mg per day, however women were urged to try to consume 1000 mg/day in view of the role of calcium in decreasing risk of osteoporosis. This is particularly important for any female athlete who is amenorrheic.

The RDA of 10 mg iron for men and 18 mg for women was used as the standard. Many of the women had a diet that was too low in iron, a finding consistent with data from the non-athletic population as well. The men had no difficulty meeting their lower need for iron.

Suggestions were made to each athlete regarding specific dietary changes to bring vitamin and mineral intake to an optimal level. Use of vitamin/mineral supplements was fairly common, and in many cases unwarranted, since the athlete either was obtaining, or with small changes could obtain, the recommended levels of nutrients from food. Natural supplementation is the preferred route.

These elite U.S. rowers were both interested in and concerned about their diet. It is an important factor which they totally control. Keeping track of their food intake and then seeing their nutritional profile was both a revelation and, for the conscientious, a road map to improved eating for competing.

Summary

Several important discoveries resulted from this comparative study. Although there is only a small difference between excessive energy output over intake, if this portion is allowed to accumulate then rowers would have difficulty in maintaining body weight (especially muscle mass). This phenomenon is sometimes evident during peak summer training.

Like all heavily trained athletes, rowers must be concerned with keeping caloric intake at high levels. However, athletes must be more aware of identifying specific food sources to insure that muscle glycogen levels and vitamin and mineral intakes remain optimal. A careful analysis of rowing training and competition demonstrates that maintaining high muscle glycogen levels during training is essential for achieving maximal performances (2). It appears that these optimal glycogen levels can be assured by the daily ingestion of at least 60% carbohydrates.

When considering the immediate pre-competition meal, it is important that the athlete's diet does not vary from the recommendations already made in this article. As competition nears, carbohydrates should be kept at 60-70% of the intake. A meal should be eaten three to four hours prior to the event and should consist of 800-1200 kcals consisting primarily of carbohydrates. At the same time, adequate fluid consumption should be ensured. Both training and competition benefit from good nutrition and therefore dietary planning for the athlete should be as important as planning training programs and race strategies.

References

1. Astrand, P.O. and K. Rodahl. *Textbook of Work Physiology*, 2nd ed., New York: McGraw-Hill 1977, p. 454.
2. Costill, D.L., et al. Muscle Glycogen Utilization During Prolonged Exercise on Successive Days. *J.Appl.Physiol.*, 31:834, 1971.
3. Evans, W. and V. Hughes. Dietary Carbohydrates and Endurance Exercise. *Am. Clin. Nutr.*, 41:1146-54, 1985.
4. Hagerman, F.C., et al. Energy Expenditure During Simulated Rowing. *J. Appl. Physiol.*, 45:87-93, 1978.
5. Hagerman, F.C. Applied Physiology of Rowing. *Sports med.*, 1(4): 303-326,1984.
6. Hagerman, F.C. and E. Falkel. Defining the Energy Systems. *American Rowing*, 18(5): 36-39, 1986.
7. Van Huss, W. Vitamin C and Physical Performance. In Stull, G. (Ed.): *Encyclopedia of Physical Education, Fitness and Sports*. Training, Environment, Nutrition and Fitness. Salt Lake City: Brighton, 1980.