Energy turnover in a sailing crew during offshore racing around the world

STEFAN BRANTH, LEIF HAMBRÆUS, KLAAS WESTERTERP, AGNETA ANDERSSON, RONNIE EDSGREN, MARKUS MUSTELIN, and ROGER NILSSON

Department of Nutrition, University of Uppsala, Uppsala, SWEDEN; Department of Human Biology, University of Limburg, Maastricht, THE NETHERLANDS

ABSTRACT

BRANTH, S., L. HAMBRÆUS, K. WESTERTERP, A. ANDERSSON, R. EDSGREN, M. MUSTELIN, and R. NILSSON. Energy turnover in a sailing crew during offshore racing around the world. *Med. Sci. Sports Exerc.*, Vol. 28, No. 10, pp. 1272–1276, 1996. Energy turnover during offshore sailing was studied in 11 male crew members of one team during the first three legs of the 1993–1994 Whitbread Round The World Race. The effect of racing on the energy balance of the crew members was studied by anthropometric measurements and dietary intake as calculated from food inventories before and after each leg. Energy turnover, calculated from dietary intake and release of endogenous energy as a result of changes in body composition, was higher than expected (about 18–20 MJ·d^{-1}). These findings were confirmed using the doubly labeled water technique in six crew members during the third leg, in which mean energy turnover was found to be 19.3 MJ·d^{-1}. Changes in body weight and composition indicated a negative energy balance during all legs.

OFFSHORE SAILING RACE, ENERGY TURNOVER, FOOD INTAKE, DOUBLY LABELED WATER, FOOD INVENTORY, ANTHROPOMETRY

Few studies of energy balance and nutritional status during an offshore sailing race have been performed (3,6). This is remarkable as impaired energy and nutrient intakes may lead to short-term effects on physical performance and alertness, which may be harmful to the outcome of the race.

The physiological stress during offshore sailing depends on many factors, including weather conditions (heavy sea, hard wind) and the type of craft. Work on deck can sometimes be quite difficult (e.g., changing headsails in a heavy sea). Furthermore, there is a continuous need to counterbalance the movements of the boat, and trimming the sails requires very vigorous sustained contractions of arm muscles. The watch system (usually 4-h watches and 3 h of sleep) makes it impossible to get a full night's sleep and also causes circadian variations in physical and mental performance, as well as meal frequency and order. In addition to physical challenges, the need to make rapid decisions to find the best course results in mental stress. The modern offshore racing yacht is also quite extreme and more similar to a large dinghy than a conventional displacement yacht, thus necessitating a well-trained crew to counterbalance the boat and compensate for the waves, further adding to stress. Finally, since offshore racing continues for several days to several weeks, social problems may occur as a result of interactions between crew members sharing cramped quarters in stressful situations.

A specific complicating factor from the nutritional point of view is that little fresh food is available. As a result of weight restrictions, the stores are limited, and most food items are freeze dried. Consequently, there is a risk of low intake of certain nutrients such as vitamins, which may have an impact on energy turnover and stress. The possibilities for studying the nutritional situation in a crew on an offshore racing sailing yacht are unique, however, because control of the food items available and consumed on board is complete. Complete information on the crew's food consumption can be obtained through food inventories taken before the start and after the finish of the race. For practical reasons, however, it is impossible to obtain any individual food records during racing conditions.

The aim of this study was to determine the effect of an offshore sailing race on the energy turnover and body composition of the members of one crew during the 1993–1994 Whitbread Round The World Race and to estimate their group average energy and nutrient intakes, using food inventories obtained during the various legs of the race. To confirm the findings obtained from food inventories, a study of energy turnover using the doubly labeled water technique was performed in six crew members during one of the legs.

METHODS

Subjects. Eleven male members of one crew team (from Intrum Justitia) were studied during the first three legs of the 1993–1994 Whitbread Round The World Race

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TABLE 1. Anthropometric data regarding crew members (values refer to the situation before the race).

Subject	Age (yr)	Height (m)	Weight (kg)[a]	Body Mass Index	Body Fat[b] (%)	Basal Metabolic Rate[c] (MJ)
1[d]	26	1.73	77.3	26.1	23	7.6
2[d]	26	1.89	89.5	25.8	13	8.2
3	27	1.87	89.6	25.5	23	8.1
4	28	1.98	88.9	22.7	18	8.1
5[d]	32	1.86	79.4	22.5	19	7.6
6	34	1.75	78.8	24.2		7.4
7	36	1.76	99.2	31.0		8.4
8[d]	38	1.83	84.8	25.1	24	7.9
9[d]	38	1.83	70.7	20.9		7.2
10[d]	44	1.82	82.0	24.2	20	7.7
11	44	1.87	80.0	22.9	26	7.7
Mean	33.9	1.84	83.7	24.6		7.8

[a] After overnight fasting and voiding morning urine.
[b] According to skinfold measurements.
[c] Calculated according to FAO/WHO/UNU (2).
[d] Participated in the doubly labeled water study during third leg.

TABLE 2. Dietary intake and composition during the first three legs.

	First Leg: Southampton—Punta del Este	Second Leg: Punta del Este—Freemantle	Third Leg: Freemantle—Auckland
Nutrient ($g \cdot d^{-1}$)			
Carbohydrate	526	393	476
Fat	149	142	156
Protein	140	136	129
Energy ($MJ \cdot d^{-1}$)	14.7	15.8	17.1
Energy percent (E%)			
Carbohydrate	45	51	52
Fat	39	34	35
Protein	16	15	13

(Southampton to Punta del Este, 25 days; Punta del Este to Freemantle, 26 days; Freemantle to Auckland, 13 days). The stopovers lasted 23 days in Punta del Este and 32 days in Freemantle. The anthropometric data of the crew members are shown in Table 1.

Procedures. Racing conditions prevented recording individual dietary intake during the race itself. However, the mean food intake of the crew members was calculated from food inventory records obtained immediately before starting and after finishing each of the first three legs. The inventories were performed by the crew member responsible for the dietary planning (M.M.); any losses from leftovers or products thrown overboard were recorded. The total amount of food items consumed was used to calculate energy and nutrient intake using food tables and, when available, declaration of content according to the manufacturers. The mean daily dietary intake of energy, proteins, fats, and carbohydrates during the first three legs was then calculated based on the results from the food inventories by dividing the total amount of energy and nutrients consumed by the number of crew members and number of days (Table 2). The energy intake and energy distribution among the macronutrients was altered throughout the race based on results of food inventories and nutritional assessments during the previous leg.

Anthropometric measurements. Body weight after overnight fasting and voiding morning urine was recorded before the start of the first and third leg as well as at the finish of each leg. The same electronic scale (from EKS International AB, Sweden, accuracy ± 0.1 kg) was used for all body weight measurements. The body weight changes could thus be calculated during the first and third legs. Skin caliper measurements were performed using a Harpenden caliper (John Bull, British Indicators, St. Albans, England) on four locations on the right side of the body (biceps, triceps, subscapula, and suprailiac folds, respectively) before the start in Southampton and after arrival from each of the three first legs. The mean of three measurements at each site was used in the calculations. Body fat content was then calculated using the age specific equation suggested by Durnin and Womersley (1). In addition, measurements of bioimpedance were performed using XITRON 4000B (Xitron Technologies Inc., San Diego, CA) to estimate total body water.

Basal metabolic rate (BMR) was estimated using the age-gender-anthropometry (weight and height) related equations given by WHO/FAO/UNU 1985 (2). The contribution of endogenous energy was estimated by assuming a release of 38 $kJ \cdot g^{-1}$ lost body weight (based on body weight measurements) or lost fat (from skinfold and labeled water techniques, respectively).

Measurements by means of doubly labeled water technique. During the third leg, energy turnover was measured using the doubly labeled water technique (7) in six crew members. Percent body fat before and after was also calculated. In the evening before the start of the race, subjects were given a weighed dose of a mixture of 99.84 atoms% ^2H_2O in 10.0 atoms% $H_2{}^{18}O$ so that the baseline levels (ppm) were increased from 150 to 300 ppm for ^2H and from 2000 to 2300 for ^{18}O. A second weighed dose of 4 g 99.84 atoms% ^2H_2O in water (for total body water measurement only) was given in the evening of the day of arrival. Urine samples were collected for isotope measurements immediately before the first evening dose, and two independent urine samples were obtained from the second voiding the next morning and from the morning of arrival. Isotope presence in the urine samples was measured with an

TABLE 3. Body weights and weight changes throughout the first three legs (for those who participated in all three legs, N = 10).

	Mean	(*N*)	Range
Weight before first leg	84.0	10	70.7–99.2
After first leg	80.9	10	68.5–93.6
After second leg	79.4	10	67.2–91
Before third leg	81.6	8	73.2–93.3
After third leg	80.5	8	72.4–91
Weight changes			
During first leg (25 d)	−3.2	10	−0.3 to −6.7
During third leg (13 d)	−1.1	8	0 to −2.1
Between second and third leg (32 d)	+4.2	8	2.1–6.4

TABLE 4. Calculation of mean total energy turnover based on food inventories, body weight changes, and doubly labeled water technique (DLW) during the third leg.

	First Leg	Third Leg	
No. of subjects	11	11	6[a]
Mean energy intake			
From food inventories (EI)	14.7	17.1	17.1
From doubly labeled water calculation		—	16.0[b]
Endogenous energy release			
From body weight changes (EE_{bw})	3.7	4.3	2.8
From skinfold measurements ($EE_{skinfold}$)	2.7	—[a]	—[a]
From doubly labeled water (EE_{dlw})	—	—	2.9#
Total energy turnover (ET)			
ET_{dlw}			19.3
EI + EE_{bw}	18.4	21.2	19.9
EI + $EE_{skinfold}$	17.4	—[c]	—[c]
EI + EE_{dlw}	—		20.0[b]

[a] Refers to those on whom DLW estimates were performed.
[b] Based on studies on four persons only.
[c] No skinfold measurement data given as measurements were not performed by the same investigator and not before the start.

isotope-ratio mass spectrometer (Aqua Sira, VG Isogas, Middlewich, Cheshire, UK), and CO_2 production and total body water were calculated using isotope dilution as previously described (9). All samples were measured in duplicate. The values of CO_2-production were converted into energy turnover using an energy equivalent that was based on the food quotient (FQ) calculated from the food inventories and from individual changes in body composition calculated from deuterium dilution at the start and at the end of the observation interval. Fat free mass (FFM) was calculated from body mass and total body water assuming a hydration coefficient of the FFM of 73% (4).

RESULTS

Table 3 shows body weights of the crew at the end of the first three legs; weight losses during the first and third legs, for which body weight immediately before the start and after arrival were registered; and the weight gain during the 32 d in Freemantle between arrival from the second and start of the third leg. The mean weight loss was more than 3 kg during the first leg and less (1.1 kg) during the third leg. The rate of weight gain during the 32-d stopover between the second and third leg (131 $g \cdot d^{-1}$) was similar to the rate of weight loss during leg one (128 $g \cdot d^{-1}$).

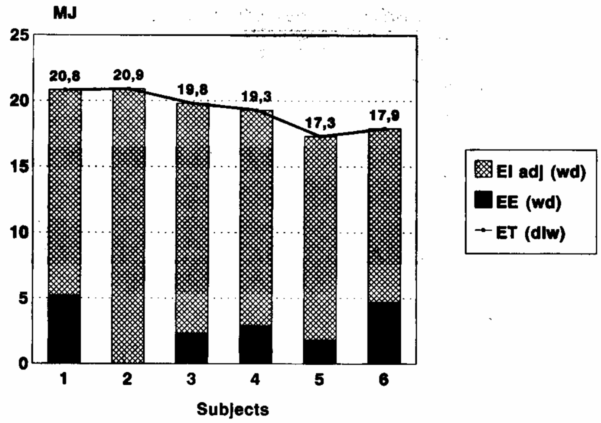

Figure 1—Energy turnover (ET) vs energy intake (EI) and endogenous energy (EE) based on weight differences (wd) and doubly labeled water (dlw) technique (Whitbread Round the World Race 1993–1994, third leg).

Table 4 shows the energy turnover based on mean values of energy intake (EI) in the crew members (based on food inventories) plus release of endogenous energy (EE) (based on body weight changes (EE_{bw}) during the first three legs). Food intake was inadequate during all three legs as weight loss occurred in almost all crew members.

Calculation of total energy turnover (ET) as the sum of mean EI and EE based on body weight changes in each crew member indicated a mean energy turnover of 18.4 MJ during the first leg. Based on the sum of mean EI and EE estimated from skinfold measurements, ET was slightly lower (17.4 MJ) (Table 4). During the third leg, ET was 21.4 when calculated as the sum of EI and EE based on body weight changes in 11 crew members. It was slightly lower (19.3 MJ, with a range from 17.3 to 20.9) in the six crew members for whom ET was analyzed using the doubly labeled water technique. For these six men, however, the mean value for total energy turnover based on mean ET (17.1 MJ) and EE from changes in body weight (2.8 MJ) was similar to the doubly labeled water estimate (19.9 MJ vs 19.3 MJ). For technical reasons, body fat content was estimated by deuterium dilution in only four of these six men. For these four men the endogenous energy release was 3.7 MJ (2.9–4.0), giving a total ET of 20.0 MJ.

Figure 1 shows the energy turnover, based on the doubly labeled water technique, as well as the endogenous energy released as a result of the reduction of body weight and the calculated individual dietary energy intake needed to balance the energy turnover in the six crew members. The total energy intake (calculated as the sum of total energy turnover minus endogenous energy released in each individual) of the six studied crew members (99.1 MJ) was very similar to that calculated by multiplying the mean dietary energy intake, calculated from the food inventories, by six (101.4 MJ).

DISCUSSION

Offshore racing in sailing yachts for weeks at a time presents a unique nutritional challenge. Especially during racing, limited storage space and accepted weight load means that the supplies are limited and most food items must be stored dry, often as freeze-dried products. Possibilities to keep fresh food aboard are few so that vitamin intake may be limited, potentially causing energy deficiency and leading to a negative impact on health.

Few studies have been performed on the nutrient intakes and energy turnover during offshore racing. The lack of interest of the nutritional demands of sailing may be because sailing has been considered by some to result in a low energy cost. However, sailors engaged in difficult competitions in match racing, as well as in offshore racing, insist that sailing can be hard physical work, particularly in windy conditions. Fogelholm et al. (3) assessed the dietary intake and serum indicators of nutritional status in 14 crew members during a transatlantic race. They calculated the crew's intake from inventory food records performed by the cook and obtained a mean intake by dividing the total consumption by the number of crew members. They found a mean energy intake of 13.3 $MJ \cdot d^{-1}$, which was much lower than what we found (18–20 MJ). This may be due to differences in the racing conditions: The Whitbread race is more difficult and the yacht is more extreme, as it has low displacement and is more apt to plane and surf on the ocean waves. Fogelholm and Lahtinen (3) also found the intake of most nutrients was sufficient but that intake of vitamin B_6, magnesium, and zinc was low. In this paper we report only on the energy balance studies. Our findings regarding micronutrient intakes and plasma levels will be reported elsewhere.

Estimating energy intake from dietary records or interviews is frequently unreliable due to methodological problems and often yields results that are low when compared with results from doubly labeled water measurement of energy expenditure (5). However, in our study the results for total food consumption based on the food inventories is reliable because control over the food items available was complete. With this method, however, only mean intake based on total consumption divided by the number of crew members can be obtained. It was not possible to interfere with the race to record individual consumption.

Our findings indicate that energy turnover during offshore racing is remarkably high. This has not been previously reported. The high energy turnover is further illustrated by calculation of the BMR factor, i.e., the ratio between total energy expenditure and calculated BMR (2), which was found to be high (mean 2.51, range 2.32–2.75). Economic restrictions prevented studies on body composition before the start of the second leg, which was most unfortunate as this leg is the most difficult and may have been associated with even higher values for energy turnover. However, the high values for energy turnover appear to be valid as data obtained using the doubly labeled water technique during the third leg confirmed our estimates of energy turnover during the first and third legs. These estimates were based on studies of changes in body composition by means of anthropometric measurements and on dietary intake based on food inventories. Studies by means of bioimpedance measurements did not reveal any significant changes in body water content that could explain the weight changes during the first, second, or third legs, or during the stopover between the second and third legs.

It was only possible to perform studies on energy turnover using the doubly labeled water technique during the third leg because for methodological reasons the experimental period cannot last for more than about 2 wk at this level of energy turnover (8). Financial constraints meant that only six crew members could be studied during this stage. This was unfortunate as this leg probably represented the least difficult part of the race. On the other hand, difficult weather conditions and seas occurred during this leg, which makes it reasonable to suggest that the total energy expenditure values were representative. This idea is further supported by the fact that weight loss per day was similar in the first and third legs. For practical reasons it was also not possible to collect any urine specimens between the start and the finish of the leg. Nevertheless, the results obtained from our experimental protocol (i.e., using a 4-point method) compensated for this to some extent, and the data obtained appear to be reliable.

A final possible limitation of our procedure relates to our assumption that body weight loss occurred solely through fat loss (i.e., we assumed a value of 38 $kJ \cdot g^{-1}$ lost body tissue). Because some loss of lean tissue may also have occurred, we may have overestimated the endogenous energy released. However, the close correspondence between energy turnover estimated by two different methods suggest that this was not a serious limitation. Furthermore, the close relation between energy turnover estimated by the doubly labeled water technique and that based on calculations from mean energy intake and endogenous energy release based on anthropometric methods has a practical implication: it appears that the latter methods are relatively valid and give sufficient precision for analysis of group mean energy turnover.

The observed energy turnover of 18–20 MJ is very high and almost equivalent to that registered in top athletes during training camps. The reason for such a high energy turnover is not evident at this point. The physical workload associated with shifting and trimming sails is intensive, but this occurs only during relatively short periods. However, the crew members almost never experience any periods with basal or sleeping metabolic rate throughout the day. This is due to many factors, including the irregular biological rhythm resulting from the watch schedule, a lack of sleep, the continuous movements of the boat that call for compensatory muscle activity to keep balance, and the continuous stress. Further studies are needed to confirm the fluctuations in energy turnover throughout the day under these conditions as well as to verify to what extent body weight changes could be due to differences in body water content.

In conclusion, our results reveal that energy turnover during offshore racing is surprisingly high and similar to that observed in athletes during training camps. This must be taken in consideration when planning the diet for offshore racers. As an energy deficit leading to loss in body weight negatively affects physical and mental performance, we recommend that more interest be devoted to planning the diet during future offshore races.

The findings seem to indicate that food inventories, combined with anthropometry to estimate changes in body composition, may give valid information about group mean total energy expenditure and energy balance under these conditions.

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Address for correspondence: Leif Hambraeus, Department of Nutrition, Dag Hammarskjölds väg 21, S-752 37 Uppsala, Sweden.

R.E., M.M., and R.N. are members of the Intrum Justitia team.

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