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Citation for published version (APA):

Sjodin, A. M., Andersson, A. B., Hogberg, J., & Westerterp, K. R. (1994). Energy balance in cross-country skiers: a study using doubly labeled water. *Medicine and Science in Sports and Exercise*, 26(6), 720-724. <https://doi.org/10.1249/00005768-199406000-00011>

Document status and date:

Published: 01/01/1994

DOI:

[10.1249/00005768-199406000-00011](https://doi.org/10.1249/00005768-199406000-00011)

Document Version:

Publisher's PDF, also known as Version of record

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Energy balance in cross-country skiers: a study using doubly labeled water

ANDERS M. SJÖDIN, AGNETA B. ANDERSSON,
JEANETTE M. HÖGBERG, and KLAAS R. WESTERTERP

*PhysTest Scandinavia AB, and
Department of Nutrition,
University of Uppsala,
Uppsala, SWEDEN; and
Department of Human Biology,
University of Limburg,
Maastricht, THE NETHERLANDS*

ABSTRACT

SJÖDIN, A. M., A. B. ANDERSSON, J. M. HÖGBERG, and K. R. WESTERTERP. Energy balance in cross-country skiers: a study using doubly labeled water. *Med. Sci. Sports Exerc.* Vol. 26, No. 6, pp. 720–724, 1994. Energy intake covering energy expenditure is essential for performance as well as for health aspects in endurance athletes. This study was performed to determine the energy needs for elite cross country skiers during a week of training and to demonstrate whether energy balance could be maintained. Energy intake was calculated from weighed dietary records and doubly labeled water was used to simultaneously measure energy turnover. Average daily energy intake ranged from 15.7 to 20.4 MJ·d⁻¹ in the females and from 25.7 to 36.0 MJ·d⁻¹ in the males. This correlated well with the data for average daily energy turnover ($r = 0.96$; $P = 0.0001$) that ranged from 15.1 to 20.2 MJ·d⁻¹ and from 25.4 to 34.9 MJ·d⁻¹ in females and males, respectively. The mean difference being 0.1 (± 1.9) MJ·d⁻¹. The close match between energy intake and energy expenditure has not previously been shown in athletes at these high levels of energy turnover. However, if energy intake over separate 24-h periods was compared with corresponding data for training, no significant relationship was found. This indicates that the athletes were not in energy balance during shorter periods. Furthermore, the validity of theoretical calculations of energy turnover, in highly trained subjects, derived from multiples of estimated BMR, is questioned.

ENERGY INTAKE, ENERGY TURNOVER, ENERGY REQUIREMENT, FOOD INTAKE, DOUBLY LABELED WATER, WEIGHED FOOD RECORDS, DIETARY RECORDS, ENDURANCE ATHLETES

A sufficient energy intake (EI) to balance the high energy turnover (ET) in endurance athletes during competition as well as training has been shown to be of great importance for performance (6). Furthermore, there is increasing evidence that a negative energy balance may have several adverse effects on

health, e.g., on the immune system (9) as well as on sex hormones and bone mineralization (7,11,21).

So far, few methods are available to quantify the energy requirement for subjects engaged in various athletic activities, without interfering with these activities. Laboratory experiments, using advanced technology such as a respiration chamber or a calorimeter suit, can have excellent accuracy but questionable relevance for the athlete under normal training situations. The alternative has often been field studies using indirect methods based on reported food intake, weight stability, and activity records. These methods are not optimal according to present standards (33) stating that recommendations for EI should, when possible, not be based on recorded EI but actual measurements of ET.

The aim of this field study was to determine the energy needs for skiers during normal training and to demonstrate whether energy balance could be maintained by measuring simultaneously ET and EI in a group of elite cross-country skiers, using the doubly labeled water technique and weighed food records, during a period with a typical training program. Previous field studies in physically active subjects have indicated energy balance by weight stability despite significant discrepancies between measured ET and reported EI (17,28,30).

The study was performed after acceptance from the Ethical Committee of the Faculty of Medicine, University of Uppsala. Written informed consent was obtained from the subjects.

SUBJECTS AND METHODS

Four females and four males, from the Swedish national teams (Table 1), volunteered for the study. The study was performed during a preseason training camp, in the later part of October, with normal training volume

TABLE 1. Anthropometric data, BMR (calculated according to WHO/FAO/UNU 1985) and average daily training time for females (F1-F4) and males (M1-M4) as well as mean values and standard deviations for the two groups.

Subject	Age (yr)	Height (cm)	Weight (kg)	FFM (kg)	BMR (MJ·d ⁻¹)	Training (min·d ⁻¹)
F1	28	164	52.5	42.6	5.4	147
F2	23	164	48.2	42.0	5.1	167
F3	25	168	59.2	48.2	5.8	182
F4	24	166	57.8	46.8	5.7	182
Mean	25	166	54.4	44.9	5.5	170
SD	2	2	5.1	3.1	0.3	17
M1	28	174	70.0	62.3	7.3	208
M2	27	178	72.8	64.9	7.5	196
M3	24	188	81.5	72.3	8.0	210
M4	25	181	76.0	66.4	7.7	233
Mean	26	180	75.1	66.5	7.6	212
SD	2	6	4.9	4.2	0.3	16

for this group at the time of the year. Females were observed for 7 d and males, arriving 1 d later in the camp, for 6 d.

ET was measured using the doubly labeled water technique (18,23). The subjects were given a weighed dose of a mixture of 99.8 atoms % $2\text{H}_2\text{O}$ in 10.0 atoms % H_2^{18}O so that baseline levels (ppm) were increased with 150 (SD 10) for 2H and 300 (SD 20) for ^{18}O . Urine samples were collected, for isotope measurement, before dosing at night and from the second voiding every morning thereafter. Isotope abundance in the urine samples was measured with an isotope-ratio mass spectrometer (Aqua Sira®; VG Isogas) and CO_2 production was calculated as previously described (29). All samples were measured in duplicate. CO_2 production was converted to ET using an energy equivalent based on the individual food quotient (FQ) calculated (4) from the macronutrient composition of the diet according to the dietary records, and assuming $\text{FQ} = \text{RQ}$.

To assess the level of ET, ET was also expressed as a multiple of the Basal Metabolic Rate (BMR). BMR was calculated with the equations (WHO/FAO/UNU 1985):

$$\text{BMR}(\text{kJ} \cdot \text{d}^{-1}) = 55.6 \cdot \text{weight (kg)}$$

$$+ 1397.4 \cdot \text{height (m)} + 146 \text{ (females)}$$

$$\text{BMR}(\text{kJ} \cdot \text{d}^{-1}) = 64.4 \cdot \text{weight (kg)}$$

$$- 113 \cdot \text{height (m)} + 3000 \text{ (males)}.$$

EI was calculated from weighed dietary records. Females recorded food intake during the first 5 d of the 7-d observation period and the males for 4 d of the 6 d of ET measurement. The subjects were carefully instructed and assisted by two dietitians at all meals, separately weighing all food items consumed. At the same time in between meal consumption of snacks and sport drinks was recorded. From these dietary records EI as well as the energy contribution from the different macronutrients were calculated by means of a computerized nutrient calculation system using the Swedish nutrient data base (National Food Administration, PC-Diet 1988).

Nude body mass was measured every morning, after overnight fasting and voiding, with a digital balance (EKS Electronic $0-120 \pm 0.1$ kg). Body water was measured, once at the start of the observation period, by means of isotope dilution. Total body water was calculated according to the formula (25):

$$[(2\text{H dilution space}/1.04) + (18\text{O dilution space}/1.01)]/2.$$

Fat free mass (FFM) was calculated from body mass and total body water assuming a hydration coefficient of the FFM of 0.73 (19). Training records were used to assess the physical activity of the subjects.

Statistical calculations were performed using a PC program (STATGRAPHICS, Statistical Graphics System Ver. 5.0). Results are shown as means $\pm$ 1 SD if not otherwise stated.

RESULTS

ET of the subjects during the observation period ranged from $15.1 \text{ MJ} \cdot \text{d}^{-1}$ to $34.9 \text{ MJ} \cdot \text{d}^{-1}$ reflecting differences in subject characteristics as well as different training schedules (Table 2).

TABLE 2. Energy balance.

Subject	Δ Weight (kg)	EI (MJ·d ⁻¹)	ET (MJ·d ⁻¹)	ET (METs)	E-balance (%)
F1	+0.4	18.2	19.4	3.6	-6.2
F2	-0.1	18.7	15.1	3.0	+19.2
F3	-0.2	20.4	20.2	3.5	+1.0
F4	-0.4	15.7	18.6	3.3	-18.4
Mean	-0.2	18.2	18.3	3.4	-1.1
SD	0.3	1.9	2.2	0.3	15.7
M1	-0.4	27.4	28.6	3.9	-4.4
M2	+0.4	25.7	25.4	3.4	+1.1
M3	+0.7	31.6	32.2	4.0	-1.9
M4	+0.9	36.0	34.9	4.5	+3.0
Mean	+0.4	30.2	30.2	4.0	-0.6
SD	0.6	4.6	4.2	0.5	3.3

Body weight change over the observed period. Average daily energy intake (EI) and average daily energy turnover (ET) in $\text{MJ} \cdot \text{d}^{-1}$ as well as multiples of BMR (METs) and the resulting energy balance (E-balance = $\text{EI} - \text{ET}$ in percent of ET).

The mean ET and EI for females were 18.3 ± 2.2 MJ·d⁻¹ and 18.2 ± 1.9 MJ·d⁻¹, respectively. The corresponding values for males were 30.3 ± 4.2 MJ·d⁻¹ and 30.2 ± 4.6 MJ·d⁻¹. The mean difference between ET and EI, for the entire group, being 0.1 ± 1.9 MJ·d⁻¹. Furthermore, there was a very high correlation ($r = 0.96$; $P = 0.0001$) between ET and EI as illustrated in Figure 1.

The daily variation in training time was greater than the variation in EI (Fig. 2). No significant correlation between training time and EI over the corresponding 24-h periods was found. Even if EI was expressed as multiples of BMR, in an attempt to reduce the effect of differences in subject characteristics (Fig. 2), no significant correlation ($P = 0.07$) was found.

Body mass did not change significantly ($+0.2 \pm 0.5$ kg) during the observation period. The dietary record showed a mean energy contribution, to the total energy intake, of 13% from protein, 28% from fat, and 58% from carbohydrates, which is in accordance with dietary guidelines for optimal food intake in the population at large as well as for endurance athletes (16). The food quotient (FQ) calculated was 0.88 ± 0.008 ; 16% of EI and 25% of the carbohydrates consumed came from various types of sport drinks.

DISCUSSION

The doubly labeled water technique used in this study has been shown to be both practical and valid to determine ET in humans under normal living conditions (10,23,26) as well as during periods of intense physical activity (27). The estimation of EI using dietary records is, however, associated with a number of methodological problems. Registration periods of 7 d are often recommended to minimize the effect of day-to-day variations as well as tendencies to adapt the food intake in order to

Figure 1—The relationship between energy turnover (ET) and energy intake (EI) (dotted circles, females; stars, males). The equation for the fitted line was $y = 1.2 + 0.95x$ ($r = 0.96$, $p = 0.0001$).

Figure 2—Reported energy intake over 24-h periods plotted against training time for the corresponding 24 h for each subject ($r = 0.36$, $p = 0.07$).

make the registration easier or to be a “good subject” (3,8,15). Own unpublished data from food records of skiers in a similar situation, however, indicate that food intake is not influenced by the day of the week, etc., to any great extent during an intensive training period. Therefore, we chose only to register food intake during 4–5 d in order to favor good compliance to accurately weigh and record the amounts of food and drinks consumed and to reduce the extra work for the subjects. We also believe that a high motivation in this group to constantly select food in order to optimize performance minimizes the risk that the registration itself may influence food intake.

Several authors have shown that energy balance is essential even during short periods in order to maintain optimal performance (22). Surprisingly, there was no significant correlation between EI and training time, on a daily basis, seen in our study. This may indicate practical problems to consume more energy with the present food regime used by this group. Over a longer period of time (6–7 d), however, energy balance was achieved by, deliberately or not, reducing the time of training to compensate for previous days in negative energy balance and not by a delayed increase in EI as described in the literature (12).

The relevance of correlating training time and EI on a 24-h basis, as a crude reflection of energy balance, can of course be questioned since intensity and thereby the energy cost of training may vary from day to day. Calculation of ET on a daily basis, by means of doubly labeled water, is unfortunately not possible, with the present technique, due to the biological half-life of the isotopes involved. Previous recordings of heart rate in this group of athletes (not published) show small day-to-day variations within subjects during this type of endurance training. Despite expected interindividual differences we believe that this comparison can be useful as an indication

of the daily energy balance. Especially if we compare differences, within each subject, in training time·d⁻¹ with the corresponding data for EI (Fig. 2), we see a clear discrepancy indicating energy imbalance.

There is a limited amount of data in the literature regarding energy requirements, based on actual measurements of ET in subjects engaged in endurance training. Data on energy requirements based on reported food intake are more frequently published. Fogelholm (13) presented a review of reported dietary intakes of athletes, using various types of questionnaires, during normal endurance training. From these data (52 studies, published between 1982 and 1992) calculated weighed mean EI was 9.8 (range 6.7–19.2) MJ·d⁻¹ for female endurance athletes and 16.8 (range 10.3–24.8) for males. However, the term “normal endurance training,” included various training routines as well as individual and possible seasonal differences which may influence ET.

In addition it seems natural to question the validity of using recorded food intake to determine energy needs. Underestimations of EI up to 35% have been reported (17,24,31) when EI, based on recorded food intake, is compared with measured ET using the doubly labeled water technique. This is, however, in contrast to the high correlation between ET and EI found in this study. A possible explanation may be found in differences in methodology to obtain data to determine EI as well as the group and the situation studied.

In an attempt to determine the energy demands of elite cross-country skiing and how this was covered in their diet, Fogelholm et al. (14) studied energy needs as well as EI in a group of Finnish elite cross-country skiers during different periods of the year. To estimate ET, they used a method based on calculated BMR times 1.5 for ET during the nonexercising periods and activity factors, as described by Wilson et al. (32), to predict the energy cost during exercise. Using this method Fogelholm found that the energy needs of cross-country skiers in November was around 13 MJ·d⁻¹ for the females and 18 MJ·d⁻¹ for males. The corresponding values of EI found in this study were 14 MJ·d⁻¹ and 19 MJ·d⁻¹, respectively. If we apply this method to the subjects in our study we find measured ET to be 39% higher than the calculated value for ET. This indicates that the factors used to calculate ET, from BMR, during sedentary conditions and/or activity may not be valid for these subjects. If the factor for sedentary life, 1.5, is thought to be valid the activity factor should be 15 instead of the proposed 10. The factor we found is more in line with recently published factors for classification of energy cost during racing or maximal uphill skiing (1) and not moderate endurance training as in the present study. On the other hand, if we believe in the factors used for calculating ET during training the factor

by which BMR should be multiplied to get an estimate of the energy cost of sedentary life would be 2.7 in average instead of the proposed 1.5. It can further be questioned whether BMR, calculated according to WHO/FAO/UNU (1985), is valid for these highly active subjects since RMR has been reported to be elevated after intense physical activity (2,5,20). It makes the previously used activity factors questionable, at least in special groups like elite endurance athletes with extremely high metabolic capacities and a training that will highly influence the metabolic rate at a given experienced intensity and calls for further validation before they are used to assess energy needs in these subjects.

Only a few comparable studies of ET in elite endurance athletes based on actual measurements of energy turnover are found in the literature. Using the doubly labeled water technique, Haggarty et al. (17) reported a mean ET of 14.6 (SEM 0.63) MJ·d⁻¹ and a corresponding EI of 9.7 (SEM 1.24) MJ·d⁻¹ for a group of female endurance athletes registered during a 3-wk training period. This comparison between ET and EI implies a negative energy balance in the magnitude of 30%. Westerterp et al. (30) showed levels of ET in four males during three different stages of a cycling race over 22 d (Tour de France) at 29.4 MJ·d⁻¹, 36.0 MJ·d⁻¹, and 35.7 MJ·d⁻¹ with corresponding values for EI of 24.5 MJ·d⁻¹, 26.3 MJ·d⁻¹, and 23.2 MJ·d⁻¹. This means a calculated negative energy balance of 13, 21, and 35% for the different stages of the race, despite weight stability over the periods studied. The same pattern was found in a group of 13 lean subjects 40 wk after the start of an activity intervention study (28) where EI was found to be 19% lower than ET measured with doubly labeled water. Such discrepancies are of course not consistent with maintained energy stores in the body.

According to the data on ET and EI presented in this paper, our group of elite endurance athletes was in energy balance during a period of very high energy turnover. To our knowledge there is presently no other study in the literature, showing energy balance, based on simultaneously measured ET and EI, at these high levels of energy turnover. We believe that energy balance at these levels of physical activity can only be shown in a highly motivated group with an awareness of the importance of good nutrition, using suitable methods, such as doubly labeled water and supervised weighed dietary records over a limited observation period.

The authors wish to express their gratitude to the subjects for their dedicated participation and to Professor Leif Hambræus for his guidance and constructive criticism throughout the study.

This work was supported by Procordia AB and PhysTest Scandinavia AB.

Address for correspondence: Anders Sjödén, Dag Hammar-skjöldsväg 21, S-752 37, Uppsala, Sweden.

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