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Energy Balance during Backpacking

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Key words

- oxygen consumption
- energy expenditure
- energy intake
- heart rate

Abstract

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Energy expenditure and energy intake was determined in three subjects during a 160-kilometer backpacking trip. Prior to the trip, heart rate and oxygen consumption during treadmill walking while carrying a backpack was measured. Subjects recorded heart rate during hiking. Heart rate was used to estimate energy expenditure based on the heart rate: oxygen consumption relationship (Heart Rate Method). Expenditure was also estimated from distance walked and elevation gained (Terrain Method). Subjects recorded food consumption, and were weighed upon finishing the hike. Mean heart rate during hiking was

105 ± 12 beats per minute. According to the Heart Rate Method, net expenditure averaged 3410 ± 955 kilocalories on days 1–4, and 2586 ± 974 kilocalories on day 5. Net expenditure from the Terrain Method was approximately 28% lower. Gross expenditure, using the Heart Rate Method, averaged 4928 ± 1050 kilocalories on days 1–4, and 3550 ± 1052 kilocalories on day 5. Energy intake averaged 2134 ± 625 kilocalories on days 1–4, and 1117 ± 320 kilocalories on day 5. Expected weight loss due to the caloric deficit was 1.8 ± 0.4 kilograms, and actual weight loss was 1.7 ± 0.6 kilograms. Subjects expended nearly 5000 kilocalories per day and did not consume sufficient food to maintain body mass. ±?

Introduction

▼
Backpacking is a popular recreational activity that potentially involves significant caloric expenditure over many hours of hiking per day, sometimes for several days. Carrying sufficient calories to sustain such activity while also trying to keep the weight of food and cooking equipment low can be challenging.

The energy cost of backpacking has not been adequately described in the scientific literature. Several studies have evaluated the energy cost of treadmill walking while carrying a load [8–10], but the only description of the energy cost of outdoor backpacking are two case reports of a single subject [4, 5]. One of the reports analyzed one trip by the subject [4], while the other report included that trip and added one other [5]. The gross energy expenditure of the 76-kg male in those studies ranged from 6.8 to 11.7 kcal·min⁻¹. The total daily energy expenditure during backpacking was not reported. Furthermore, no study has reported the dietary patterns and energy intake of backpackers.

This study sought to evaluate energy balance during backpacking by measuring both energy expenditure (EE) and energy intake (EI). The major dietary sources of calories were examined. Two methods of determining EE were utilized, an estimation derived from distance traveled and elevation gained, and a calculation based on measured heart rate during backpacking as compared to the relationship of heart rate and oxygen consumption established in a laboratory.

Methods

▼ Subjects

Three experienced backpackers volunteered for the study. Written, informed consent was obtained following approval of the study procedures by the university's Institutional Review Board. The subjects were a 32-year-old female (subject A), a 34-year-old male (B) and a 52-year-old male (C). All three were aerobically fit ($\dot{V}O_{2max}$ ranged from 57 to 73 ml·min⁻¹·kg⁻¹), and regularly participated in running, swimming or bicycling in addition to backpacking. Subjects

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Table 1 Subject characteristics

Subject	Age	Sex	Height (cm)	Mass (kg)	% fat	$\dot{V}O_{2\max}$ (ml·min ⁻¹ ·kg ⁻¹)
A	32	F	164	58.9	25	57
B	34	M	177	69.1	12	73
C	52	M	175	63.8	13	62

F, female; M, male

Table 2 Trip description

Day: Route	Distance (km)	Gross elevation gain (m)	Net elevation gain (m)	Daytime temp. (C)
1: Black Horse Gap to Cornelius Creek shelter (CC)	37.3	2130	226	13
2: CC to Matts Creek shelter (MC)	28.5	1110	-704	8-14
3: MC to Brown Mountain Creek shelter (BMC)	34.6	1540	171	13
4: BMC to The Priest shelter (TP)	36.5	2100	745	11-22
5: TP to Reed's Gap	24.6	1250	-363	14
Total	161.5	8130	75	8-22

A and B were apparently healthy, while subject C had asymptomatic, single-vessel coronary artery disease that was medically managed.

Initial testing

Subjects participated in initial testing to determine physical characteristics (Table 1), and to establish a relationship between heart rate (HR) and oxygen consumption ($\dot{V}O_2$) during simulated backpacking. Subjects' mass and height were measured on a balance scale with stadiometer (Detecto, ■city, country?), and body composition was assessed by aerometric densitometry (BodPod, ■city, country?). The latter was performed during initial testing only, to characterize the subjects.

For maximal exercise testing, subjects were fitted with a chest strap HR monitor (Polar■city, country?) and a mouthpiece attached to a mass flow sensor and metabolic cart (V_{\max} 29C, ■manufacturer, city, country■). The flow sensor was calibrated against a 3-L syringe and the O_2 and CO_2 analyzers were calibrated against known gases prior to each test. Subjects wore their personal hiking footwear and backpacks during the exercise test, loaded with weights similar to those each proposed to use during the backpacking trip. The combined mass of footwear and packs was 11.1 kg, 15.6 kg and 11.5 kg for subjects A, B and C, respectively. The footwear included trail running shoes for subjects A and B and lightweight hiking boots for subject C, with masses of 0.6 kg, 0.7 kg and 1.2 kg, respectively. The treadmill protocol incorporated fast walking up steep grades and consisted of the following stages, each 3 minutes in length: 4.8 km·hr⁻¹, 0% grade; 5.6 km·hr⁻¹, 0% grade; 6.4 km·hr⁻¹, 0% grade; 6.4 km·hr⁻¹, 5% grade; 6.4 km·hr⁻¹, 10% grade; 6.4 km·hr⁻¹, 15% grade; 6.4 km·hr⁻¹, 20% grade. $\dot{V}O_{2\max}$ was defined as the highest $\dot{V}O_2$ obtained over any continuous minute during the test. The HR and $\dot{V}O_2$ of the last minute of each stage were used to construct regressions for each subject for later determination of $\dot{V}O_2$ from HR values measured in the field.

Field testing

Prior to the backpacking trip, the subjects were weighed wearing minimal clothing, all equipment and other clothing were weighed, all food was weighed, and the volume of water to be

initially carried was measured. Due to logistical needs, including depositing the weight scale at the end of the proposed hiking route, these measurements occurred three days prior to the start of the trip. The measurements were repeated immediately upon finishing the hike. Subjects used hiking poles during the trip (which were weighed with equipment), but not during treadmill testing due to the width of the treadmill. Hiking poles may improve one's balance over uneven terrain, but have no effect on the energy cost of uphill treadmill walking while carrying a backpack [6,7], and therefore the lack of poles during the treadmill test should not influence the results.

The backpacking consisted of a five-day trip on a rugged section of the Appalachian Trail in Virginia, covering a total distance of 161.5 km (Table 2). The elevation ranged from 201 to 1349 m. The trip occurred during late spring. Daytime temperatures ranged from 8 to 22°C, and were no higher than 14°C on four of the five days.

Subjects wore a chest strap HR monitor during all hiking. Each time a subject stopped hiking for more than one minute, the duration and the average HR of the just completed section was recorded. The time-weighted mean HR during hiking for each subject was calculated for each day. This value was converted to a net $\dot{V}O_2$ based on the laboratory regression of HR and $\dot{V}O_2$, assuming 3.5 ml·min⁻¹·kg⁻¹ for resting $\dot{V}O_2$ (1 metabolic equivalent, or MET).

Resting energy expenditure was assumed to be 1 kcal·hr⁻¹ per kg of body mass, i.e., equivalent to 1 MET [2]. Subjects camped at the trail-head the night prior to the hike, and thus 24 hours were used to calculate the total EE due to resting metabolism (EE_{rest}) for the first day and the next three days. For the fifth day, the subjects exited the trail at 3:30 p.m. and were immediately weighed. Thus, 15.5 hours were used to calculate EE_{rest} for that day. The energy expenditure caused by hiking that was in excess of resting metabolism was termed EE_{net}. Gross EE for each day (EE_{gross}) was the sum of EE_{rest} and EE_{net}.

EE_{net} was determined in two ways: (1) from distance traveled and elevation gained (Terrain Method), and (2) from the net $\dot{V}O_2$ derived from measured HR (HR Method). In the Terrain Method, topographic data available from the Appalachian Trail Conservancy was used to determine both the distance traveled

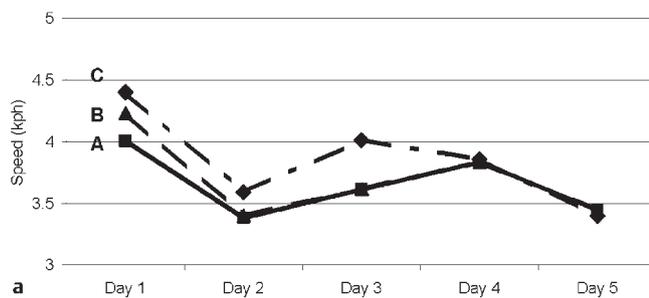


Fig. 1a Average speed during hiking for each day.

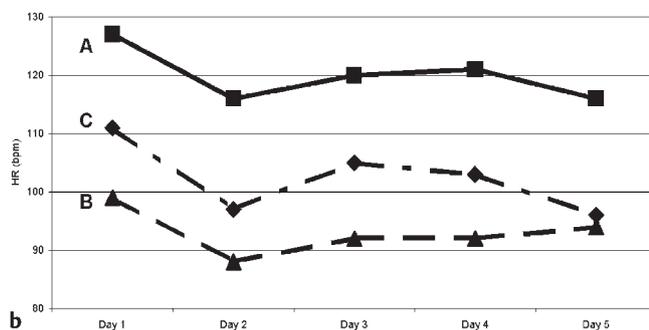


Fig. 1b Average heart rate (HR) during hiking for each day.

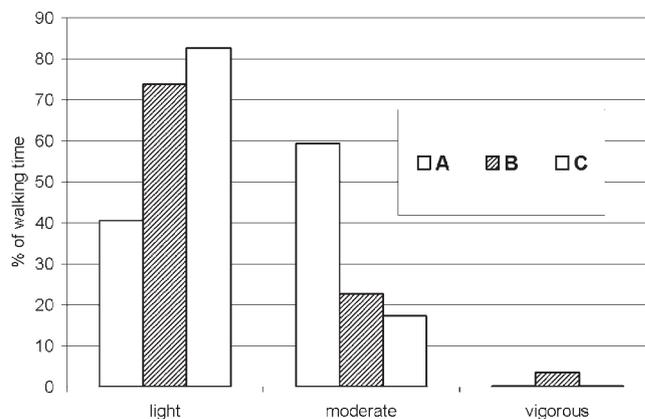


Fig. 2 Percentage of hiking time spent at light (<40% HRR), moderate (40–59% HRR), and vigorous (>60% HRR) intensities.

each day and the sum of all elevation gains made each day (Table 2). Distance traveled was converted to kcal of EEnet by the following equation:

$$EE \text{ due to distance} = \frac{(m \text{ traveled})(\text{combined mass})}{(2000 \text{ kg} \cdot \text{m} \cdot \text{kcal}^{-1})}$$

Combined mass was the mass of the subject plus all food, clothing and equipment. This was measured prior to and at the conclusion of the hike, and interpolated for the intervening days. The coefficient of 2000 kg·m per kcal was derived from the American College of Sports Medicine equation for the oxygen cost of walking, in which 1 kg·m of horizontal movement requires 0.1 mL of O₂ consumption, and by assuming that the consumption of 1 L of O₂ results in 5 kcal of energy expenditure [2]. Vertical ascent was converted to kcal of EEnet by the following equation:

$$EE \text{ due to elevation gain} = \frac{(m \text{ gained})(\text{combined mass})}{(111.1 \text{ kg} \cdot \text{m} \cdot \text{kcal}^{-1})}$$

The coefficient of 111.1 kg·m per kcal was derived from the American College of Sports Medicine equation for the oxygen cost of walking, in which 1 kg·m of vertical ascent requires 1.8 mL of O₂ consumption [2].

Elevation lost during descents was ignored, i.e., it was assumed that downhill walking required the same energy expenditure as level walking. This was done because laboratory research has clearly demonstrated a U-shaped relationship between the energy cost of walking on progressively steeper grades of descent [11]. Specifically, the energy cost of downhill walking gradually lessens from 0 to 10% grade, but gradually increases from 10% to 45% grades, surpassing the cost of level walking for descents steeper than 20%. Due to the ruggedness of the terrain in this study, with some descents steeper than 20%, a first approximation for the energy cost of downhill walking was to assume that, on average, it was similar to that of level walking.

For the HR Method, the regression of HR and $\dot{V}O_2$ obtained during treadmill testing was used to estimate the gross $\dot{V}O_2$ for the average HR measured during hiking each day for each subject. The correlation coefficients (*r*) for these regressions were 0.99 for each subject. Net $\dot{V}O_2$ was calculated as gross $\dot{V}O_2$ minus 3.5 ml·min⁻¹·kg⁻¹, and was then multiplied by the day-to-day body mass of each subject (interpolated from pre- and post-measurements) to express the $\dot{V}O_2$ in L·min⁻¹. The conversion factor of 5 kcal per L of oxygen consumption was not used to translate $\dot{V}O_2$ into EE. Rather, this value was adjusted based on the non-protein respiratory quotient associated with the respective HR values in the laboratory treadmill test. Finally, the net kcal·min⁻¹ was multiplied by the number of minutes of walking per day to determine the total EEnet.

Subjects recorded every item of food consumed. As all of these items were commercially prepared, the number of calories and the grams of protein, carbohydrate and fat were determined from the manufacturer's label. Caloric equivalencies for protein, carbohydrate and fat were assigned as 4 kcal·g⁻¹, 4 kcal·g⁻¹ and 9 kcal·g⁻¹, respectively. While the volume of water carried by the subjects was recorded at the start and end of the trip (for calculations of total mass carried by the subjects), water consumption was *ad libitum* and not recorded. Water was replenished frequently from natural sources, using filtration (subjects A and B) or iodine treatment (subject C) for purification.

Results

During laboratory testing, resting and maximum heart rates were 68–196 bpm for subject A, 45–171 bpm for subject B, and 64–181 bpm for subject C. Mean daily HR during hiking was 105 ± 12 bpm (mean + SD), which was 37 ± 5% of heart rate reserve and 57 ± 4% of maximum heart rate (HR_{max}). As seen in Fig. 1, HR varied from day to day based on the speed of hiking. The daily values in Fig. 1 range from 38–46% HRR or 59–65% HR_{max} for subject A, 34–43% HRR or 51–58% HR_{max} for subject B, and 27–40% HRR or 53–61% HR_{max} for subject C. For individual segments of hiking lasting at least one hour, HR ranged from 80 to 133 bpm, or from 14 to 67% of heart rate reserve. As seen in Fig. 2, the two subjects with the higher $\dot{V}O_{2\text{max}}$ values spent the great majority (74–83%) of their hiking time at a low relative intensity (<40% HRR), while one subject spent a majority of time

Table 3 Energy expenditure and intake (kcal). HR Method used to determine EEnet

	Day 1	Day 2	Day 3	Day 4	Day 5
Subject A					
▶ EEnet	2833	2176	2629	2674	1845
▶ EEgross	4246	3575	4014	4044	2723
▶ EI	1510	1415	1375	1447	790
Subject B					
▶ EEnet	5096	3657	4684	4659	3689
▶ EEgross	6755	5306	6321	6286	4734
▶ EI	1860	2900	2890	3131	1430
Subject C					
▶ EEnet	3550	2489	3150	3317	2224
▶ EEgross	5082	4013	4667	4827	3195
▶ EI	2200	2195	2243	2445	1130

EEnet, net energy expenditure; EEgross, gross energy expenditure; EI, energy intake

(59%) at a moderate relative intensity (40–59% HRR). Only one subject spent any time (3.5%) at a vigorous intensity ($\geq 60\%$ HRR). Net time spent hiking averaged 9.0 ± 0.6 hours on days 1–4, and 7.2 ± 0.1 hours on day 5, while time spent on rest breaks during the hiking averaged 1.9 ± 0.4 hours on days 1–4, and 1.2 ± 0.1 hours on day 5.

The net energy expenditure was greater using the HR Method than the Terrain Method. On days 1–4, EEnet by the HR Method averaged 3410 ± 955 kcal, while EEnet by the Terrain Method averaged 2460 ± 471 kcal. On day 5, respective values for EEnet were 2586 ± 974 and 1769 ± 177 kcal. Using the HR Method, EEnet averaged 6.3 ± 1.7 kcal·min⁻¹ (5.6 metabolic equivalents, METs, above rest), and during short segments ranged from 2.1 to 15.6 kcal·min⁻¹ (2.0–12.9 METs above rest). EErest averaged 1518 ± 108 kcal on days 1–4, and averaged 964 ± 84 kcal on day 5. EEgross, using the HR Method value for EEnet, averaged 4928 ± 1050 kcal on days 1–4, and averaged 3550 ± 1052 kcal on day 5. **Table 3** provides individual data for EE and EI.

Energy intake averaged 2134 ± 625 kcal on days 1–4. On day 5, EI averaged 1117 ± 320 kcal. The largest food sources were snack bars (32% of all calories), trail mix (29%) and freeze-dried dinners (27%). Remaining sources of energy were cheese (5%), beef jerky (3%) and other (4%). Of all calories, 57% were consumed during short breaks during hiking. (The total for snack bars and trail mix exceeds this figure because some snack bars were used as breakfast items.) Calories from macronutrient substrates were 52% carbohydrates, 17% protein and 31% fat.

Using the HR Method to determine EEnet, the caloric deficit between EEgross and EI averaged 2722 ± 770 kcal per day. Based on this deficit, the expected weight loss for the 5-day trip was 1.8 ± 0.4 kg per person. The actual weight loss determined from pre- and post-measurements was 1.7 ± 0.6 kg. Actual and expected weight loss per person is illustrated in **Fig. 3**. The expected weight loss when using the Terrain Method to determine EEnet was only 1.2 ± 0.2 kg.

Discussion

Subjects in this study expended approximately 5000 kcal (~ 21 kJ) per 24-hr day on an extended backpacking trip. Their caloric intake was insufficient to maintain body mass. Only two other case reports of a single subject have described the energy expenditure of backpacking, in which the subject was reported

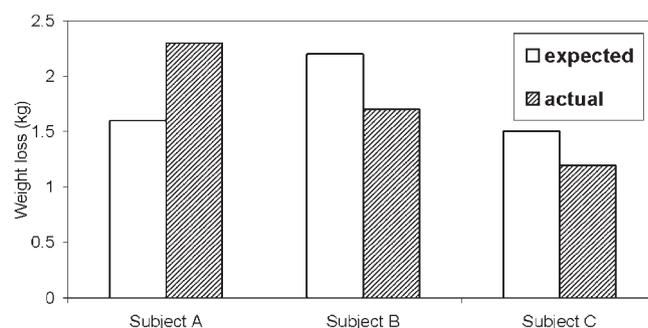


Fig. 3 Actual and expected weight loss for each subject. The heart rate method was used to determine net energy expenditure, which was combined with estimated resting EE to determine gross EE. Expected weight loss was based on gross EE minus calories consumed.

to have a gross EE that ranged from 6.8 to 11.7 kcal·min⁻¹ [4,5]. In the current study, gross EE during hiking ranged from 3.1 to 16.8 kcal·min⁻¹. Thus, the current subjects varied their intensity of effort to a greater degree than did the subject in the previous report.

A gross EE of 5000 kcal per day is high but not unprecedented. A study of the Tour de France found that four athletes averaged 6000 kcal for gross EE over the course of three weeks, including a 5-day period in the mountains when they averaged 6800 kcal per day [13]. Of course, the subjects in that study were more highly fit than the current subjects, and were engaged in competition, not recreation.

As a percentage of maximum heart rate, the subjects averaged 57% overall, while DeVoe reported that a single subject averaged 64–77% HR_{max} during three backpacking trips on the same route in three successive years [3–5]. The lower average HR in the current study could be due to the higher aerobic capacity of our subjects (57 – 73 versus 54 ml·min⁻¹·kg⁻¹), or differences in self-selected intensity relative to the terrain. However, lack of knowledge of DeVoe's resting HR limits the ability to accurately define the cardiac response in that subject. Heart rate reserve accounts for resting HR and therefore provides a better index of the cardiac response. The subjects in this study averaged only 37% of heart rate reserve during hiking, and this ranged from 14 to 67%. According to the American College of Sports Medicine, intensities lower than 40% of HRR are considered "light", 40–59%

HRR is “moderate”, and 60–85% HRR is “vigorous” [2]. Thus, subjects in this study performed backpacking primarily at a “light” intensity, despite the fact that they carried a weighted backpack over rough terrain. The low relative intensity can be explained by the need for the subjects to pace themselves for several hours of effort each day, and because these particular subjects possessed high levels of aerobic fitness. Given the low relative intensity, backpacking would not be expected to stimulate an increase in aerobic capacity in already well-trained subjects, but clearly results in the expenditure of a large number of calories, which could contribute to other health related benefits. While the relative intensity for these subjects was low, the absolute intensity during hiking averaged 6.6 METs (range: 3 to 13 METs), and intensities of 6 METs or more are often considered “vigorous” in epidemiological studies [1,12].

When individuals with heart disease engage in exercise at an intensity of 6 METs or more, their risk of a heart attack or of sudden death increases substantially over their risk at rest [1,12]. However, this risk is greatly reduced if the individual regularly engages in such “vigorous” exercise; for example, the risk of heart attack is 105-fold higher for a sedentary person with heart disease who suddenly engages in exercise at or above 6 METs, but is only 2.4-fold higher for a cardiac patient who normally performs such exercise at least 5 times a week [12]. Therefore, cardiac patients who are currently sedentary should not participate in backpacking unless they first complete a program of training in which they gradually improve to the point where they regularly exercise above 6 METs.

One limitation of this study was the methodology used to estimate energy expenditure. Two methods were used, a Terrain Method and a HR Method. The Terrain Method was an attempt to use first principles of the energy demands associated with hiking to calculate EE. Unfortunately, the accuracy of this method was likely influenced by several problems. As described in the Methods, the EE of downhill walking is complex, in that it becomes progressively less as the grade changes from 0 to –10%, then progressively increases, surpassing that of level walking at –20% [11]. As a first approximation, it was assumed that all downhill walking was of equal energy expenditure to level walking. Without highly detailed topographic data (i.e., meter by meter changes in elevation along the trail), it is impossible to know the precise grades that were encountered and, therefore, this assumption was likely incorrect. A second problem associated with topography is that variations in terrain were more numerous than can be represented on topographic maps. Therefore, the gross elevation gain was almost certainly more than indicated in **Table 2**. A third consideration is that the energy cost of walking, even when carrying backpacks, has been measured on the smooth surface of treadmills. The need to step over frequent obstacles, such as rocks and fallen tree limbs, would likely increase the EE of hiking, especially when walking downhill. The Terrain Method yielded a net EE that was 28% less than the HR Method. Given that the HR method was better at predicting weight loss in the final energy balance, it is likely that the HR Method was the more accurate of the two. Field trials of backpacking in which portable oxygen consumption equipment is worn would be useful to address this issue.

Subjects in this study derived slightly more than 50% of their calories from carbohydrates and slightly more than 30% from fat. A higher percentage of calories from carbohydrates is often recommended for endurance activity, and the subjects in the Tour de France study averaged 62% [13]. It is interesting that the majority of calories (57%) were consumed during the hours of hiking, as opposed to while in camp. This high percentage is likely due to the large number of hours spent on the trail (approximately 11 hours each on days 1–4). In the Tour de France, 49% of calories were consumed during racing, which took a shorter length of time and did not include rest breaks. In the Tour de France, subjects maintained energy balance, while subjects in the current study were in negative energy balance. This difference might be attributable to two factors. First, the athletes needed to remain competitive over three weeks, providing a strong incentive to maintain energy balance. Second, the athletes were provided food by support cars during racing and by support personnel at other times, while the backpackers had to carry all of their food for the 5-day trip. Of course, the number of subjects in both of these studies was low (3 and 4), and broad conclusions about dietary patterns can not be made with confidence.

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