OBJECTIVE RESEARCH

Energy Expenditure During an Ultraendurance Alpine Climbing Race

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Objective.—Accurate reports of energy expenditure (EE) during prolonged mountaineering activity are sparse. The purpose of this study was to estimate EE during a winter ultraendurance climbing race and individual mountaineering activities in Mont Blanc, France.

Methods.—Seven days before the race, resting metabolic rate (RMR) and maximal oxygen consumption (VO2max) were measured in 10 experienced male climbers (30.0 ± 0.9 years). Three days before (reference period) and during the race, heart rate (HR) was recorded for estimation of total daily EE (TDEE), and the type and duration of all activities were collected through questionnaires. Total DEE was calculated by adding DEE during sleep (DEE sleep), sedentary (DEE sedentary), and during exercise (DEE exercise). Daily energy expenditure during exercise was determined through assumption of the rectilinear relationship between heart rate (HR) and VO2. Anthropometric measurements were performed 7 days before, just before, and immediately after the race.

Results.—Total time of the race averaged approximately 29 hours and 29 minutes, including 11 hours and 24 minutes in the hut, plus 18 hours and 5 minutes dedicated to climbing. During the race, TDEE was 43.6 ± 1.2 MJ · d−1. Energy expenditures for cross-country skiing and alpine climbing were similar (57.3 ± 2.1 kJ · min−1 and 54.0 ± 2.9 kJ · min−1, respectively). An energy deficit of 33.5 ± 2.3 MJ resulted after the race, with a mean weight loss of 1.52 ± 0.31 kg (P < .001).

Conclusions.—Experienced climbers expended a high level of energy during a winter ultraendurance alpine climbing race at moderate altitude under high degrees of difficulty and risk exposure. These results provide comparative data on the energy cost of the main mountaineering activities during a race: cross-country skiing and alpine climbing.

Key words: winter mountaineering, energy expenditure, heart rate

Introduction

Alpine climbing represents the traditional climbing model in Mont Blanc, France. Winter mountain climbing takes place in a hostile environment (wind, cold temperature, short daylight hours, and hypoxia) and entails significant risk exposure (avalanche, falling rocks). Such conditions require autonomy for food and materials. Moreover, mountain climbing involves cross-country skiing, hiking, and climbing on different surfaces (snow, ice, rocks). During an alpine climbing race, participants classically sleep in a hut or in a bivouac, and the duration of the race averages 24 to 72 hours. Alpine climbing includes prolonged exercise with short periods of rest under moderate hypoxic exposure along with food and beverage restriction. Exercise typically involves short periods of high intensity and long periods of submaximal intensity that require anaerobic and aerobic energy pathways.

Most research concerning the energy cost of mountaineering has focused on high-altitude expeditions, and scarce data are available concerning acute climbing at moderate altitudes below 4000 m. For example, participants were found to have a negative energy balance after 8 days between 4260 m and 7000 m altitude spent in preparation for the Mount Everest expedition and also at the end of the expedition to the...
summit at 8872 m. In contrast, there is only 1 study that investigated energy requirements of a technical mountaineering expedition (7 days of ice climbing) at moderate altitude. In this study, only 2 among the 6 participants were monitored for heart rate (HR) to estimate energy expenditure (EE) of a 6-hour summit ascent in the North Cascade Range of the United States (Mount Baker). Additionally, these authors used HR monitoring to estimate energy costs of selected mountaineering activities, such as trail hiking (during ascent and descent) and technical ice climbing. Results of this study showed that 1) EE for the 6-hour ascent reached 10.40 MJ and 12.96 MJ (14.7 kJ min$^{-1}$ and 18.3 kJ min$^{-1}$), respectively, for the 2 participants, and 2) technical ice climbing produced the highest EE of all mountaineering activities studied.

In free living conditions, there are 2 gold standard methods to estimate daily total EE (DTEE): doubly labeled water and indirect calorimetry by expired gas measurements. Doubly labeled water requires a measurement period of 4 to 20 days and cannot discriminate different physical activities in the same exercise. Indirect calorimetry using expired gas measurement with a portable recorder system ($\text{K4}$, COSMED, Italy) is limited to 4 to 5 hours of data gathering. An alternative method that is feasible for estimation of TDEE during ultraendurance activities in field conditions is HR recording. This method allows determination of sequential EE levels during different mountaineering activities. Heart rate recording presents disadvantages to estimating EE for a single subject, but it remains a reliable method for a group in field conditions. Heart rate recording error rates are lower than those for accelerometer or questionnaire methods.

The purpose of this study was to estimate, using the HR monitoring method, the TEE in professional climbers engaged in a winter season alpine climbing race lasting approximately 30 hours in Mont Blanc and to estimate EE corresponding to different activities of the race.

**Methods**

**PARTICIPANTS**

Ten male professional climbers (mean age 30.0 ± 0.9 years) from the French Military Group of High Mountain in Chamonix, France, participated in the experiment. Climbers of this military operational group are physically trained and adapted to moderate altitude because of their keeping residence in Chamonix (altitude 1042 m). The study was approved by the Medical Ethics Committee of the School of Medicine, Hospital Cochin, France.

**GENERAL PROTOCOL**

This study involved 3 measurement periods. **Preliminary period:** 7 days before the race, preliminary testing was done on rested participants at the medical clinic of the military school at Chamonix. **Reference period:** 3 days before the race (reference period), diet, exercise (duration and intensity), and sleep were standardized for the group. **Race period:** duration of climbing race. During the race, HR and motor activity of the participants were recorded, and the participants were instructed to note on standardized questionnaires all their activities and food intake. Anthropometric measurements were performed during the first period and just before and immediately after the race.

**ANTHROPOMETRIC MEASUREMENTS**

Height was measured with a height gauge (accuracy of 1 cm). Body weight was measured with an electronic balance (Sega, France) with an accuracy of ± 100 g. The percentage of body fat content was calculated from skinfold thickness measured at 4 sites (subscapular, biceps, triceps brachialis, and suprailiac) with a Holtain calliper (Crymich, UK). Lean body mass was calculated by subtracting body fat weight from body weight. Body mass index was defined as the individual’s body weight divided by the square of height (kg/m$^2$).

**PRELIMINARY PERIOD: SEVEN DAYS BEFORE THE RACE**

**Total daily energy expenditure determination**

Total DEE was calculated by adding DEE during sleep (DEE sleep), sedentary (DEE sedentary), and exercise (DEE exercise). The DEE exercise was determined through the assumption of the rectilinear relationship between HR and oxygen consumption (VO$_2$) and thus between HR and EE exercise. The DEE sedentary was determined using a steady state of VO$_2$ for each sedentary activity. The DEE sleep was determined using the measured resting metabolic rate (RMR). This definition of TDEE has previously been published in the literature.
humidity 40.1 ± 2.68%). Exercise started with a 15-minute warm-up period of 90 W at 80 rpm, after which workload was increased by 30 W every 2 minutes until exhaustion. During exercise, VO$_2$, carbon dioxide production (VCO$_2$), and HR were measured continuously using indirect calorimetry (Quark B2, COSMED, Italy). VO$_{2\text{max}}$ level was reached when a levelling off in oxygen uptake was observed. When the levelling off was not seen, VO$_{2\text{max}}$ was considered reached when 1) blood lactate levels reached 8 mmol·l$^{-1}$, 2) and/or the age-predicted maximum HR was reached, 3) and/or a respiratory exchange ratio in excess of 1.1 was reached.\textsuperscript{12}

**Daily energy expenditure sedentary determination**

Five days before the race, DEE sedentary was determined. For each activity (eg, reading, cooking, watching TV), once steady state was reached, participants’ expired air was collected for 10 minutes using the same indirect calorimetry. The EE during each sedentary activity (calculated from an Elia and Livesey equation\textsuperscript{13}) was added to determine the DEE sedentary.

**Daily energy expenditure sleep determination**

Four days before the race, DEE sleep was determined using RMR measurement. At 0800 hours, overnight-fasted participants were seated at rest in a quiet room (environmental conditions: ambient temperature 17.8 ± 0.49°C, barometric pressure 671.9 ± 1.04 mm Hg, relative humidity 43.26 ± 2.05%, clothing insulation 0.77 clo). Resting metabolic rate was measured by indirect calorimetry using measurement of VO$_2$ and VCO$_2$. Before each test, the oxygen and carbon dioxide analyzers were calibrated using gases of known concentrations. Resting metabolic rate is formalized in an abbreviated Elia and Livesey equation\textsuperscript{13}: RMR (kJ/d) = 15.82*VO$_2$+5.18*VCO$_2$.

**REFERENCE PERIOD: THREE DAYS BEFORE THE RACE**

The reference period took place at Chamonix. All participants were given a controlled diet providing 12.13 MJ·d$^{-1}$ that replicated their normal energy intake (EI), and they also maintained their normal physical training. They were asked to eat the whole diet, of which 55% was carbohydrate (5.69 g ·kg$^{-1}$·d$^{-1}$), 35% was fat, and 15% was protein. They were also instructed to note on a standardized questionnaire all their activities, including when they exercised.\textsuperscript{14}

Participant HRs were recorded using POLAR S810 (Polar electro Oy, Kempele, Finland) over 15-second intervals to determine DEE exercise. Heart rates were averaged per minute. For each changing activity, participants were instructed to log an event on their POLAR S810. In addition, the participants’ motor activity was recorded during the daytime and at night by an Actiwatch actometer (CNT, UK) that subjects wore on their nondominant wrist. It includes an internal acceleration sensor recording movements and accumulating them over a 15-second interval. The sums were saved to a microchip inside the actometer for later computer extraction to visualize them as an activity rest plot. According to standard criteria, sleep was analyzed from questionnaires and actigraphy measures to determine sleep period time (time from falling asleep to last awakening), total sleep time, difference between sleep period time and wakefulness after sleep onset, and sleep efficiency index (total sleep time/time in bed).\textsuperscript{15}

**CLIMBING RACE**

**Race description**

The climbing race took place in the winter of 2005 (temperature ranged from −5°C to +19°C, wind varied from 0 to 10 km·h$^{-1}$, source: the French National Weather Service) (Figure 1). At 1100 hours on the morning of the race, participants ascended by cableway from Chamonix to the departure point of the climbing race, namely the “Aiguille du Midi” at 3800 m (in the Chamonix valley). The race began at 1330 ± 0008 hours. Carrying rucksacks (20.0 ± 2.8 kg, ie, 20.6% of body mass), participants downhill skied until they reached 2400 m altitude (average speed: 1105 m·h$^{-1}$). They then cross-country skied to an elevation of 2750 m toward the “Requin” hut. (total up hill: 350 m, average speed: 270 m·h$^{-1}$). From this point, they downhill skied to the “Requin” hut (altitude 2516 m), reaching it at 1651 ± 0020 hours. Both dinner and breakfast were taken at the hut. Participants went to bed at 2107 ± 0030 hours and got up at 0302 ± 0035 hours. They started the next leg of the race at 0415 ± 0030 hours.

Participants began cross-country skiing to reach an altitude of 2850 m (height variation: 384 m, average speed: 193 m·h$^{-1}$). After reaching the bergschrund, they followed standard climbing techniques to reach the “Dent du Requin” summit at 3422 m via the north face. The ascent started at 0700 hours. In keeping with the International Mountaineering and Climbing Federation (UIAA) scale, the ascent ranked V/VII for risk exposure and 5/7 in terms of difficulty. Participants reached the top at 1302 ± 0041 hours. The final part of the race included 2 hours of roping down and then 3 hours of downhill skiing in order to finish at Chamonix.
(1820 ± 0100 hours). The total distance traversed for the race was approximately 20 km.

**Nutrition during the climbing race**

During the climbing race, participants were fed a high-energy diet providing a mean of 16.74 MJ·d⁻¹. The composition was 68% carbohydrates (9.6 g/kg·d⁻¹), 25% fat, and 7% protein (1.0 g/kg·d⁻¹). This caloric level has been shown to maintain physical performance during an endurance activity expending approximately 34 MJ·d⁻¹.¹⁶ In addition, a high-carbohydrate diet (~70% of dietary energy) that elevates muscle glycogen stores has been recommended to enhance endurance capacity compared with a normal (~50%) carbohydrate diet.¹⁶,¹⁷ All foods were preweighed, packaged, given to the participants during the race, and checked at the return to Chamonix. Mandatory fluid intake consisted of 2 L during the climbing race (1 L each day) and 2 L in the hut. Energy intake during the climbing race was indirectly measured by collecting the remains of uneaten food, weighing them, and summing the published kcalorie content for each food item under the assumption that the rest of the food was consumed.

**Total direct energy expenditure during the climbing race**

Participants were instructed to note on a standardized questionnaire all their activities.¹³ Mountain exercise activities were defined as cross-country skiing, downhill skiing, alpine climbing, downhill hiking, and transition activities. Transition activities represent breaks in activity, equipment changes, and nutrition pauses. Hut activities were divided into sedentary activity and sleep period. Using the same method as for the reference period, the TDEE during the climbing race was estimated. During the race, HR was monitored by POLAR S810. For each change in activity, participants were instructed to make an entry on their POLAR S810. Daytime and nighttime profiles were recorded by an Actiwatch actometer.

**STATISTICS**

Statistical analysis was performed with SIGMASTAT software (SYSTAT software, USA). Results are expressed as the mean ± SEM of absolute values. Variability of means was checked using a normality test and an equal variance test. A 1-way ANOVA for repeated measures was used to study the differences in the mean values among the mountaineering activities. If the main effect was statistically different (P < .05), the change from different activities values was calculated using a posthoc test (Tukey test). The parametric paired Student’s t test was used to compare variables for sleep data between the Reference night and the Hut night.

**Results**

**PRELIMINARY PERIOD**

The mean height of participants was 1.81 ± 0.01 m. The mean body weights, body mass index, and percent of
Energy Expenditure During Mountaineering

Table 1. Anthropometric characteristics*

<table>
<thead>
<tr>
<th></th>
<th>Preliminary period</th>
<th>Before climbing race</th>
<th>After climbing race</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (kg)</td>
<td>72.37 ± 1.64</td>
<td>72.35 ± 1.45</td>
<td>70.40 ± 1.42†</td>
</tr>
<tr>
<td>Body mass index</td>
<td>22.17 ± 0.37</td>
<td>22.17 ± 0.32</td>
<td>21.57 ± 0.31</td>
</tr>
<tr>
<td>Body fat mass (%)</td>
<td>10.42 ± 0.81</td>
<td>10.66 ± 0.74</td>
<td>10.59 ± 0.73</td>
</tr>
<tr>
<td>Lean body mass (kg)</td>
<td>64.64 ± 1.49</td>
<td>64.61 ± 1.26</td>
<td>62.91 ± 1.21</td>
</tr>
</tbody>
</table>

*Values are mean ± SEM, n = 10.
†Significant difference between before and after alpine climbing race, P < .001.

Body mass and lean body mass are summarized in Table 1. Mean RMR was 8.73 ± 0.38 MJ·d⁻¹. The mean VO₂max was 55.06 mL·min⁻¹·kg⁻¹.

REFERENCE PERIOD

Estimation of TDEE over the reference period was 12.61 ± 0.22 MJ·d⁻¹. It included 7.24 ± 0.35 MJ·d⁻¹ for DEE exercise, 2.20 ± 0.12 MJ·d⁻¹ for DEE sedentary, and 3.17 ± 0.15 MJ·d⁻¹ for DEE sleep.

CLIMBING RACE

Body mass and energy intake during the race

Body mass, lean body mass, and percent of body fat mass changes during the race are presented in Table 1. At the end of the climbing race, participants lost an average of 1.52 ± 0.31 kg body weight (P < .001). No significant difference was observed for lean body mass and percent of body fat mass. The EI during the race was measured at 14.78 ± 0.69 MJ. The macronutrient distribution was 70.3% ± 1.1% for carbohydrates (8.2 ± 0.3 g/kg·d⁻¹), 7.5% ± 0.2% for protein (0.8 ± 0.1 g/kg·d⁻¹), and 22.1% ± 1% for fat.

Estimation of energy expenditure and energy deficiency during the race

Total time of the race was 29 hours and 29 minutes, including 11 hours and 24 minutes in the hut, plus 18 hours and 5 minutes dedicated to mountaineering activities. The total EE was estimated at 48.73 ± 2.12 MJ, representing an EE at 43.57 ± 1.23 MJ·d⁻¹. Energy deficiency was estimated at 33.53 ± 2.31 MJ·d⁻¹. Analysis of each activity showed that the longest activity was represented by sleep followed by sedentary activity in the hut (7 hours 36 minutes and 5 hours 20 minutes, respectively). Daily energy expenditure during sleep was 6.1 ± 0.4 kJ·min⁻¹ for a total of 2.6 ± 0.2 MJ, and DEE sedentary was 13.8 ± 0.4 kJ·min⁻¹ for a total of 4.4 ± 0.2 MJ. These activities were the least expensive in terms of energy cost. Energy expenditure for mountaineering activities showed that cross-country skiing was the most expensive compared with other mountaineering activities, representing an average of 57.32 ± 2.09 kJ·min⁻¹. Comparison between mountaineering activities showed no statistically significant difference between cross-country skiing and alpine climbing, nor between downhill skiing and downhill climbing. Our results showed significant differences between the uphill and downhill activities (Table 2).

Sleep time during the race

Participants slept less during the night in the hut than during the night of the reference period (P < .001). During the climbing race, the total sleep time was less (P < .001) (Table 3).

Discussion

The primary purpose of our study was to investigate the EE of a winter alpine climbing race lasting approximately 30 hours. Using HR recording, participants were estimated to expend 43.6 MJ·d⁻¹ (TEE of the race: 48.7 MJ), which is higher than that expended by cyclists during the Tour de France (between 29.4 MJ·d⁻¹ and 33.7 MJ·d⁻¹) and below that described for a single participant in the Race Across America (between 63.2 MJ·d⁻¹ and 97.4 MJ·d⁻¹). A study by Watts et al. determined an estimation of EE during a 6.5-hour alpine ascent on snow and ice from 1636 m to 3266 m in the North Cascade Range of the United States. This study took place in the summer (July), with the authors monitoring and recording the HR of 2 climbers to estimate EE. Total energy expenditure for the 2 climbers was 14.7 kJ·min⁻¹ and 18.3 kJ·min⁻¹ (total 10.4 MJ and 12.96 MJ).

In our study, participants were estimated to expend a mean of 54.0 kJ·min⁻¹ to 57.3 kJ·min⁻¹ for the ascent, including cross-country skiing and alpine climbing. Several factors explained the large difference for the estimation of EE between our results and those of Watts et al. They studied physically active amateur partici-
pants who accomplished the shorter ascent to the summit walking on snow and ice, using crampons, carrying a load of 8 kg to 9 kg, under very good conditions on a clear day with a summit temperature of $-3^\circ C$. This ascent did not have a classification for difficulty and risk exposure, and the authors noted that it is a typical glacier route taken by recreational climbers. The 2 participants had an average HR of 120 beats per minute (bpm), or 67% of maximal HR. In comparison, we followed 10 professional climbers engaged in summit ascent (cross-country skiing and alpine climbing) in winter, with backpacks weighing approximately 20 kg. The summit ascent ranked V/VII for risk exposure and 5/7 in terms of difficulty. The mean climber HR during the race was 140 bpm, or 75% maximal HR. Thus, the differences in subject numbers, fitness levels, and type of mountaineering activities during the ascents make our study difficult to compare with that of Watts et al and probably account for the large differences observed in estimated EE.

Our results also, for the first time, document different EE related to the different mountaineering activities involved in the race. All uphill activities were more expensive for energy cost than downhill activities. In addition, the highest EE level occurred during cross-country skiing (57.3 kJ \text{ min}^{-1}), which could be classified as severe work. While not statistically significant, it appears that participants expend more energy during cross-country skiing (57.3 kJ \text{ min}^{-1}) than during alpine climbing (54 kJ \text{ min}^{-1}). The latter activity was also higher in absolute values than those found by Watts et al for ice climbing (39.7 kJ \text{ min}^{-1}) and snow hiking (30.1 kJ \text{ min}^{-1}). It would be interesting in future studies to evaluate the influence of climber position on a rope on energy costs. Climbing in the lead position likely results in higher EE compared with the second position.

Two major interacting factors may account for the high level of EE estimated, namely, the method used for EE evaluation and/or the type and conditions of exercise. Different methods exist to estimate EE during exercise depending on the duration of the exercise. For periods of exercise over several days, the gold standard is the doubly labelled water technique. For exercise over periods of 1 hour to 5 hours, the standard is indirect calorimetry, which allows measurement of fractional oxygen inspired air, fractional carbon dioxide expired air, and volume of air expired. For exercise lasting 1 day to 4

| Table 2. Energy expenditure for each mountaineering activity during climbing race* |
|---------------------------------|---------------------------------|---------------------------------|-----------------|-----------------|
|                                 | **Duration** | **Mean (beats per min)** | **% Maximal** | **kJ/min** | **MJ** |
| Cross-country skiing†          | 3 h 9 min ± 24 min | 140 ± 3 | 74.8 ± 1.5 | 57.3 ± 2.1 | 10.4 ± 2.0 |
| Downhill skiing‡               | 4 h 14 min ± 21 min | 122 ± 6 | 65.4 ± 1.7 | 44.8 ± 1.7 | 8.0 ± 1.0 |
| Alpine climbing§               | 3 h 55 min ± 22 min | 136 ± 4 | 72.4 ± 2.3 | 5.4 ± 2.9 | 9.9 ± 1.7 |
| Downhill climbing (walking, roping down)¶ | 1 h 53 min ± 15 min | 120 ± 4 | 64 ± 2.7 | 42.7 ± 2.9 | 5.4 ± 1.1 |

*Values are mean ± SEM, n = 10.
†Significant difference between cross-country skiing and downhill skiing, $P < .001$ (HR mean, EE kJ/min), $P < .05$ (HR % maximal).
‡Significant difference between downhill skiing and alpine skiing, $P < .05$ (HR mean, EE kJ/min).
§Significant difference between climbing and downhill climbing, $P < .05$ (EE MJ), $P < .01$ (HR mean, EE kJ/min).
¶Significant difference between cross-country skiing and downhill climbing, $P < .05$ (HR % maximal), $P < .001$ (HR mean, EE kJ/min).

| Table 3. Change of night actigraphy parameters* |
|---------------------------------|---------------------------------|-----------------|
| **Reference period**           | **Climbing race**               |
| Time in bed                    | 8 h 41 min ± 10 min             | 5 h 59 min ± 14 min† |
| Total sleep time               | 7 h 36 min ± 13 min             | 5 h 13 min ± 7 min† |
| Wakefulness after sleep onset  | 51 ± 5 min                     | 32 ± 5 min†      |
| Sleep latency                  | 10 ± 6 min                     | 11 ± 6 min       |
| Sleep efficiency               | 87.67% ± 1.60%                 | 88.26% ± 2.45%   |

*Values are mean ± SEM, n = 10.
†Significant difference in change from reference period, $P < .001$. 
days, EE is evaluated by indirect methods, such as HR, questionnaires, and activity recall, or motion sensors. In our study, participant HR was recorded to evaluate DEE exercise, given that it is a reasonably accurate and practical method under field conditions. It has been established that the margin of error for use of HR recording to estimate DEE decreases from 30% when evaluating one subject to 10% for a group. Heart rate measurements were also used to estimate EE during the climbing race, despite the bias introduced by the change of the linear relationship between VO2 and HR at altitude. The bias that could have been introduced involved 1) the linear regression established at sea level and 2) the shift of linear regression related to altitude effects inducing overestimation of EE. Studies have found that sea level linear regression between VO2 and HR is not altered at altitudes of 4600 m and 5800 m. These same authors demonstrated that during moderate exercise at altitude, the HR for a same VO2 was higher than at sea level. Several studies could help determine the overestimation of EE introduced by the change in linear regression between VO2 and HR at altitude. Compared with sea level, during acute moderate altitude hypoxia (from 1000 m to 4500 m), VO2max and maximal HR values decreased in sedentary and trained subjects, the maximal HR value decrease being greater in trained subjects. Percent reduction of VO2max was estimated to be 4% at 1000 m, 10% at 2500 m, 15% at 3500 m, and 25% at 4500 m. Maximal HR decrease was approximately 3 bpm at 1000 m and at 2500 m, and 6 bpm at 3500 m. Our subjects lived at and were thus adapted to the altitude at Chamonix (1042 m), where their VO2max test was performed, and the mean altitude of the race was 2700 m. In addition, they had an intermediate VO2max (55.06 ± 1.52 mL/min·kg⁻¹), showing that they were trained subjects but not elite athletes. We would thus predict overestimation of EE during exercise activities of ~5% due to altitude influence.

In the same way, altitude hypoxia may influence calculation of the RMR used to estimate DEE sleep and DEE sedentary in the hut (altitude 2516 m). Resting metabolic rate was calculated from the oxygen and carbon dioxide values using the sea level Elia and Livesey equation. Butterfield et al. and Mawson et al. showed an increase of RMR of approximately 10% to 20% at 4300 m (compared with sea level) using a similar equation. Any influence of altitude-related hypoxia on the estimation of DEE sleep and DEE sedentary was likely negligible, because our climbers were adapted to the maximal altitude at which DEE sleep and DEE sedentary were determined (2500 m [hut altitude]). The overestimation of TDEE during the climbing race did not likely exceed 5% (2.18 MJ·d⁻¹) due to altitude influence.

The second major factor that may account for the high level of EE estimated during the climbing race is related to the type and conditions of exercise. Type of exercise (skiing, mountaineering, ice climbing, snow walking, alpine climbing), duration and intensity of exercise, and load carriage are well known to increase EE. Our subjects participated in all of these types of exercise. Two important points are represented by the duration of the exercise and load carriage. The time of physical exercise during the climbing race represented approximately 60% per day, whereas during the Tour de France it was approximately 25% per day. The difference of exercise duration may explain the difference of TDEE.

In the present study, the energy intake was 31% of EE, and calculated energy deficiency was approximately 33.5 MJ. A significant loss of 1.5 kg body weight was measured after the race. Dehydration was likely the cause of body weight loss, because no significant change occurred in percent body fat mass or lean body mass after the race. The results of this study confirm the high level of EE reached with the race.

**Conclusions**

Climbers expended high levels of energy during a winter ultraendurance climbing race at moderate altitude under a high degree of difficulty and risk exposure. These results provide comparative data on the energy cost of cross-country skiing and alpine climbing, the main mountaineering activities during a winter climbing race. Investig-
igation of metabolic and hormonal responses during such extreme EE would provide supporting information to back up the energy cost data. Our results affirm the importance of adequate nutrition for athletes involved in such extreme exercise.

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