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Appetite at “high altitude” [Operation Everest III (Comex-’97)]: a simulated ascent of Mount Everest

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Westerterp-Plantenga, Margriet S., Klaas R. Westerterp, Mira Rubbens, Christianne R. T. Verwegen, Jean-Paul Richelet, and Bernard Gardette. Appetite at “high altitude” [Operation Everest III (Comex-’97)]: a simulated ascent of Mount Everest. *J. Appl. Physiol.* 87(1): 391–399, 1999.—We hypothesized that progressive loss of body mass during high-altitude sojourns is largely caused by decreased food intake, possibly due to hypobaric hypoxia. Therefore we assessed the effect of long-term hypobaric hypoxia per se on appetite in eight men who were exposed to a 31-day simulated stay at several altitudes up to the peak of Mt. Everest (8,848 m). Palatable food was provided ad libitum, and stresses such as cold exposure and exercise were avoided. At each altitude, body mass, energy, and macronutrient intake were measured; attitude toward eating and appetite profiles during and between meals were assessed by using questionnaires. Body mass reduction of an average of 5 ± 2 kg was mainly due to a reduction in energy intake of 4.2 ± 2 MJ/day ($P < 0.01$). At 5,000- and 6,000-m altitudes, subjects had hardly any acute mountain sickness symptoms and meal size reductions ($P < 0.01$) were related to a more rapid increase in satiety ($P < 0.01$). Meal frequency was increased from 4 ± 1 to 7 ± 1 eating occasions per day ($P < 0.01$). At 7,000 m, when acute mountain sickness symptoms were present, uncoupling between hunger and desire to eat occurred and prevented a food intake necessary to meet energy balance requirements. On recovery, body mass was restored up to 63% after 4 days; this suggests physiological fluid retention with the return to sea level. We conclude that exposure to hypobaric hypoxia per se appears to be associated with a change in the attitude toward eating and with a decreased appetite and food intake.

hypoxia; energy balance; food intake; satiety; macronutrients

ONE OF THE MOST COMMON observations made on a sojourn by humans at high altitude is an initial loss of body weight, which seems to be an inevitable consequence of chronic hypobaric hypoxia (5, 9, 12). The initial weight loss has been attributed to a combination of effects. It has been reported (1, 5, 12) that energy and protein intake at high altitudes were continuously decreased by 30 and 40%, respectively; this may partly explain the body weight loss. Only when consumption is stimulated by offering attractive food items to the subjects and by prescribed food intake has a diminished weight loss been shown, e.g., at 4,300 m (3). In addition to a reduced energy intake (1, 5, 12), increased energy

expenditure (19, 20), dehydration and diuresis (9, 23), and intestinal malabsorption (2) have been reported. Moreover, acute mountain sickness (AMS) occurs after rapid ascent to a moderate-to-high altitude. Symptoms of AMS are headache, fatigue, nausea, and dizziness (15). As such, AMS contributes to reduced energy intake by appetite suppression, i.e., the inability to eat or drink due to nausea. AMS is dependent on rate of ascent, elevation, and acclimatization and usually decreases after a few days (15). However, appetite suppression or short-term anorexia may persist after other AMS symptoms have disappeared or at an altitude where acclimatization is incomplete (19). In addition to appetite suppression reported at moderate-to-high altitudes (4,000 m and higher) partly due to AMS, short-term anorexia might occur due to increased physical activity (28). Moreover, at high altitudes (1, 2, 6, 8, 9), as well as after increased physical activity (28), dietary preferences for carbohydrate have been shown when subjects were given a variety of palatable foods ad libitum. The studies on energy balance at high altitudes reported body weight loss due to reduced energy intake and discussed the possibility of reduced appetite (1, 5, 12), but they did not assess the appetite profile as such. Moreover, possible loss of appetite due to hypobaric hypoxia was, except in one study (12), not separated from possible changes in appetite due to overexertion, cold, stress, or a qualitatively or quantitatively limited food supply.

The aim of this study was to assess the contribution of long-term hypobaric hypoxia per se to the possible changes in different features of appetite that may explain the possible changes in size and composition of the diet at high altitudes (5,000–7,000 m).

Hypoxia, without exposure to the rigors of climbing high mountains in relatively extreme climate circumstances, was created in a hypobaric chamber in Comex, Marseille. The temperature and humidity of the hypobaric chamber were comfortable, and physiological and psychological effects that are caused by real altitude factors, such as cold and stress, were excluded. Overexertion, such as would occur on an actual mountain expedition, was avoided, and palatable foods and fluids were offered in sufficient quantity, and a choice of macronutrient composition was allowed. A possible change in food intake may occur as a change in meal size and/or meal frequency. This can be related to a change in the appetite profile during a meal or during the day, respectively. Subjective appetite ratings might lend support to clarification of possible changes in food intake. Moreover, possible dissociations between the different appetite ratings (e.g., being hungry but hav-

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Fig. 1. Operation Everest-Comex. Staying at 4,350 m represents the acclimatization period in field station Vallot. After staying at "7,000 m", a recuperation period at "5,000 m" was included before pressure was decreased to simulate "8,000 m" and higher. Subjects stayed for only a few hours each time at "8,848 m." Pressures by which the different altitudes were simulated are included. SL, sea level; HA, high-altitude condition; RSL, return to sea level.

ing no desire to eat) would explain possible deviations in appetite regulation. A possible overall change in attitude toward eating is assessed by using the Three Factor Eating Questionnaire (TFEQ) (14).

It is hypothesized that under conditions of hypobaric hypoxia per se and a sedentary lifestyle, a negative energy balance occurs that is largely due to reduced food intake. This reduced food intake might be caused by a change in the appetite profile and in the attitude toward eating. Eight men were exposed to extreme magnitudes of hypoxia by this simulated stay at several altitudes up to that of Mt. Everest (8,848 m), i.e., Operation Everest III (Comex-'97) (10).

METHODS

Subjects

Subjects were eight men plus one replacer, who indeed replaced one of the other subjects after the run-in period. Subjects gave their informed consent to participate in the study. The relevant characteristics of the eight subjects who completed the study were as follows: age, 26 ± 4 (SD) yr (range: 23–37 yr); height, 1.80 ± 0.07 m (range, 1.72–1.90 m); and weight, 74.3 ± 6.6 kg (range, 65.4–82.7 kg). One of the subjects was a medical doctor. Subjects were selected on the

basis of being healthy, and one of the inclusion criteria was that they had been at an altitude of 5,000 m or higher before the experiment (10). Subjects were also psychologically tested for their ability to be confined for over a month (10). The protocols were approved, after revision, by the Ethical Committee of the Hospital of the University of Marseille, France.

Procedures

The experiments were carried out in a hypobaric chamber, which consisted of a bedroom, a small bathroom, and an exercise room. Temperature and humidity were controlled. Average temperature was 21°C (range, 18 – 24°C), and average relative humidity was 41% (range, 30–60%). The observations started with baseline measurements over 7 days (Comex, Marseille, France), referred to as the normoxia period (NM). During this week, subjects stayed in the hypobaric chamber to get used to the confinement. Subsequently, the subjects were transported by car and helicopter to a field station on Mt. Blanc (Observatoire Vallot, altitude 4,350 m) in the French Alps, where they stayed for 1 wk to acclimatize. Thus the first acclimatization did not take place in the hypobaric chamber; this reduced the period of confinement. Thereafter, they were transported back to Marseille. One subject suffered from pulmonary and cerebral edema and had to be excluded from the subsequent experiment. His place was taken by the replacer, who had also joined this run-in

Table 1. Body mass, energy intake, percentage energy from protein, fat and carbohydrate, at each altitude

Day	Simulated Altitude, m	Body Mass, kg	Energy Intake, MJ	Energy Source, %		
				Protein	Fat	Carbohydrate
–12 to –7	0	74.3 ± 6.6	13.5 ± 1.8	18.4 ± 1.4	36.2 ± 2.8	45.4 ± 2.8
2–6	5000	72.3 ± 6.1^a	12.0 ± 1.8^b	16.3 ± 0.9^c	33.7 ± 2.9^d	50.0 ± 3.8^e
9–12	6000	71.5 ± 5.9^a	10.5 ± 2.5^b	16.4 ± 0.7^c	34.4 ± 3.4^d	49.2 ± 3.2^e
15–19	7000	70.7 ± 5.5^a	7.5 ± 1.8^b	17.1 ± 1.9	36.3 ± 3.8	46.6 ± 5.1
26–28	8000	69.6 ± 5.7^a	6.2 ± 2.1^b	17.2 ± 2.4	36.4 ± 4.8	46.4 ± 5.4
35	0	72.2 ± 6.4				

Values are means $\pm$ SD; values for day 35 are from Ref. 10. ^aDifferent from altitude 0 (day –12 to day –7); $F(1,7) = 62.3$; $P = 0.0001$; $F(1,7) = 48.4$; $P = 0.0002$; $F(1,7) = 36.5$; $P = 0.0005$; $F(1,7) = 42.6$; $P = 0.0003$, respectively. ^bDifferent from altitude 0 (day –12 to day –7); $F(1,7) = 8.6$; $P = 0.02$; $F(1,7) = 13.0$; $P = 0.009$; $F(1,7) = 80.9$; $P = 0.0001$; $F(1,7) = 91.8$; $P = 0.0001$, respectively. ^{cde}Different from altitude 0 (day –12 to day –7); $F(1,7) = 12.9$; $P < 0.01$, $F(1,7) = 12.3$; $P < 0.01$.

Fig. 2. Energy intake and energy expenditure at each simulated altitude. Energy intake is compared with normoxia. * $P < 0.01$ for total daily energy intake, compared with normoxic. # $P < 0.05$ for energy intake during a meal or from snacks, compared with normoxia.

part of the experiment. After they arrived in Marseille in the afternoon (*day 1*), subjects went straight into the hypobaric chamber where they stayed for a subsequent period of 31 days. During this period, the ascent to the peak of Mt. Everest (8,848 m) was simulated. The ambient pressures were the equivalent pressures at 0, 5,000, 6,000, 7,000, 8,000 and 8,848 m on Mt. Everest (Fig. 1). Pauses before the final ascent (e.g., at 5,000 m) were taken to enhance further acclimatization or recuperation. During these pauses, no protocols were run, and the activity level of the subjects was low. The 18 protocols were scheduled so that samples could be taken on most of the days. Protocols with activities took place on different days to exclude possible effects on each other (for the other experiments, see Ref. 10). This resulted in scheduling appetite protocols during meals at simulations of 5,000 and 6,000 m, the questionnaires during the day at simulations of 5,000, 6,000, and 7,000 m, and the TFEQ at simulations of

5,000, 6,000, 7,000, and 8,000 m. Although one subject left the chamber shortly before the end of the 31 days (10), all subjects completed the appetite protocols.

To provide an optimal food choice, the subjects were free to choose their meals, but the menus from day to day consisted of similar foods with a relative variety. The following meal types were given ad libitum; only the type of meat and cooked vegetable varied between days. Breakfast consisted of white bread, butter, jam, orange juice, sugar, coffee, and milk. Lunch consisted of white bread, iceberg lettuce, tomatoes, mayonnaise, cheese, meat, yogurt, macaroni or rice, and a cooked vegetable. Dinner consisted of potatoes, a cooked vegetable, meat, sauce, cheese, white bread, pudding, and fruit. Between meals, dark chocolate, Snickers candy bars, biscuits, nuts, cake, and sticky buns were available. Coffee, tea, and mineral water were also available ad libitum.

Measurements

Body weight. To examine whether loss of body mass occurred, subjects recorded body weight each day in the morning, after voiding, by using a Mettler Toledo Spider 1 scale.

AMS. AMS symptoms (i.e., headache, fatigue, dizziness, and nausea) were scored daily on a four-point (0–3) scale (10, 15).

Energy and macronutrient intake. To be able to examine whether the subjects were in energy balance, food intake was measured daily during the whole experimental period (includ-

Table 2. Rates of changes in scores of hunger, satiety, and pleasantness of taste during meals at different simulated altitudes, and meal durations

Simulated Altitude	Meal Duration, min	Rate of Changes in Scores (VAS/min)		
		Hunger	Satiety	Pleasantness of taste
Breakfast				
0 m	30 ± 3	2.0 ± 0.1	1.8 ± 0.2	0.7 ± 0.05
5,000 m	27 ± 3	1.9 ± 0.1	3.0 ± 0.3‡	0.7 ± 0.04
6,000 m	21 ± 2*	2.2 ± 0.2	1.7 ± 0.2	0.7 ± 0.04
Lunch				
0 m	31 ± 3	2.2 ± 0.2	2.0 ± 0.2	0.5 ± 0.04
5,000 m	22 ± 2*	2.2 ± 0.3	3.4 ± 0.3‡	0.5 ± 0.03
6,000 m	32 ± 3	2.2 ± 0.2	2.3 ± 0.2	0.5 ± 0.04
Dinner				
0 m	49 ± 4	1.2 ± 0.1	1.1 ± 0.1	0.5 ± 0.05
5,000 m	29 ± 3*	1.4 ± 0.1	2.6 ± 0.3‡	0.4 ± 0.03
6,000 m	15 ± 2*	1.9 ± 0.1†	3.0 ± 0.3‡	0.4 ± 0.02

Values are means ± SD. VAS, visual analog scale. Comparisons to normoxia: * $F(1,7) = 13.6$; $P < 0.01$, $F(1,7) = 12.9$; $P < 0.01$, $F(1,7) = 24.7$; $P < 0.01$, $F(1,7) = 63.8$; $P < 0.001$, respectively. † $F(1,7) = 8.7$; $P < 0.05$. ‡ $F(1,7) = 15.7$; $P < 0.01$; $F(1,7) = 18.6$; $P < 0.01$; $F(1,7) = 20.1$; $P < 0.01$; $F(1,7) = 28.9$; $P < 0.01$, respectively.

Table 3. Attitude toward eating (TFEQ scores) at different simulated altitudes

Day	Simulated Altitude, m	F1, cognitive restraint	F2, disinhibition	F3, hunger
–11	0	7 ± 3	5 ± 1	5 ± 3
3	5,000	7 ± 3	5 ± 1	5 ± 3
10	6,000	6 ± 2	4 ± 1	5 ± 3
16	7,000	5 ± 2*	4 ± 2	4 ± 2
27	8,000	4 ± 2*	3 ± 2*	3 ± 2*

Values are means ± SD. F1, F2, and F3 are the factors 1, 2, and 3 of the Three Factor Early Questionnaire, namely, cognitive restraint, disinhibition, and hunger, respectively. *Different from normoxia; lowest F -value $F(1,7) = 7.9$; $P < 0.05$.

ing the normoxia period). Breakfasts and snacks were provided in baskets, with food items to choose from, so a dietary record was executed by using household measures or writing down the exact weight of the food after weighing it on a table scale. Lunch and dinner were provided individually, the choice having been determined beforehand. Here food intake was recorded for each subject by the experimenter, who weighed the food before it was served as well as the leftovers at the end of the meal. From these observations, meal sizes

and meal frequencies were calculated. Metabolizable energy content of the food intake was derived from food tables (18). The food table gives the physiological value of combustion in the body. The percentages of energy from the macronutrients were calculated by using the Becel programme (18).

Attitude toward eating and appetite profile. To assess the attitude toward food intake, we used a French translation of the Three Factor Eating Questionnaire (14) that was completed by the subjects on the second day (*day - 11*) during the

normoxia period, and on the second day at simulated altitudes of 5,000 m (*day 3*), 6,000 m (*day 10*), 7,000 m (*day 16*), and 8,000 m (*day 27*).

Appetite profile. The appetite profile over a day was studied on "quiet days," when no other activity protocol was executed, to avoid possible interference. The appetite profile supports food-intake data (26, 27) and consists of relevant questionnaires completed by the subjects. On the third day at simulated altitudes of 0 m (*day -10*), 5,000 m (*day 4*), 6,000 m (*day 11*), and 7,000 m (*day 17*), a questionnaire (in French) with the following seven questions was completed by the subjects 10 times per day (before and after breakfast, midmorning, before and after lunch, in the afternoon, before and after dinner, in the evening, and before going to sleep). Subjects used 100-mm Visual Analog Scales to indicate: How hungry are you? How full are you? How satiated are you? How thirsty are you? These questions were anchored with responses (not at all—very). Other questions and responses, respectively were: How much could you eat? (not much—very much); How is your desire to eat? (very weak—very strong); and How is your appetite? (very weak—very strong). Subjective ratings on these questions lend support to the interpretation of the food-intake pattern, because hunger and satiety during the day are observed to be related to meal frequency and meal interval (26, 27). Fullness may be synchronized with satiety, whereas how much one could eat, desire to eat, and appetite may be synchronized with hunger. A synchronization or dissociation may lend support to interpretation of deviations in food-intake patterns.

On the fourth day at simulated altitudes of 0 (*day -9*), 5,000 m (*day 5*), and 6,000 m (*day 12*), the appetite profile during a meal was assessed. For this a questionnaire (in French) with the following four questions was completed by the subjects every 3 min during each meal (while the subject was chewing) by using Visual Analog Scales: How hungry are you? How satiated are you? How pleasant is the taste of the food now in your mouth? (all anchored: not at all—very) and How strong is the taste of the food now in your mouth? (anchored: very weak—very strong). These questions were asked to assess how meal size would be determined. Along with the development of satiety and reduction of hunger, sensory-specific satiety could play a role. This is why pleasantness of taste and taste intensity had to be completed (11).

Moreover, every 6 min, the subjects were asked to rate how pleasant it is to have a meal (anchored: not at all—very).

In a different protocol, other parameters that are relevant for this study (digestive efficiency, energy expenditure, body composition, and water balance at the different simulated altitudes) were assessed in the same subjects (24).

Statistics

Body weights, accumulated AMS symptoms, 24-h energy- and macronutrient-intake data, meal frequency, and percent of energy from meals and from snacks were averaged over the eight subjects for the whole period of each simulated altitude. These data were compared between each simulated altitude and normoxia.

The same parameters were collected separately on the days when the appetite profile questionnaires were completed. To check on how representative the data on these days were, these data were compared with the data collected from the complete periods at each altitude.

Attitude toward eating was assessed by comparing the TFEQ scores at each simulated altitude with those at normoxia.

The scores on each of the questions that represented the appetite profile during the day were compared between each simulated altitude at which the questionnaire was completed and normoxia.

Using the appetite profiles obtained during the meals, we compared the scores at the latest time point of the meal with those at the first time point of the meal. When significant changes in scores occurred, the rate at which those changes occurred was calculated. These figures were compared between the simulated altitudes of 5,000 m, 6,000 m, and normoxia. Comparisons were made by using repeated measures ANOVA and Scheffé's post hoc *F*-test (Statview SE-Graphics).

A regression analysis was performed for the possible relationship between altitude and energy intake (Statview SE-Graphics).

RESULTS

Body weight was significantly reduced at each simulated altitude, compared with normoxia (Table 1), and resulted in a weight loss of 5.0 ± 2.0 kg at a simulation of 8,848 m. Recovery of loss of body mass started immediately during the 4-day recovery period and resulted in a final average reduction of body mass of 2 kg (10).

Cumulative AMS symptoms were 0 at normoxia, 0.6 ± 0.4 at simulated 5,000 m, 3.1 ± 2 at simulated 6,000 m, 7.0 ± 3 at simulated 7,000 m, and 10.0 ± 2 at simulated 8,000 m. AMS symptom scores were significantly different from normoxia at simulations of 6,000 m [$F(1,7) = 8.1$; $P < 0.05$], 7,000 m [$F(1,7) = 12.9$;

Fig. 3. *A*: hunger before, after, and between meals, during days at normoxia (*day -10*) and at simulations of 5,000 m (*day 4*), 6,000 m (*day 11*), and 7,000 m (*day 17*). VAS, visual analog scale. Hunger increased in the morning, afternoon, and evening [$F(1,7) = 8.2$, $P < 0.05$] and decreased before lunch and before dinner [$F(1,7) = 8.6$, $P < 0.05$] compared with normoxia. * $P < 0.05$ for differences between each simulated altitude and normoxia. *B*: desire to eat before, after, and between meals during days at normoxia (*day -10*) and at simulations of 5,000 (*day 4*), 6,000 (*day 11*), and 7,000 (*day 17*) m. Desire to eat increased (5,000 m simulation) in the morning and in the afternoon [$F(1,7) = 13.3$; $P < 0.01$] but decreased during 6,000 and 7,000 m simulations, in the morning, before lunch, in the afternoon, and before dinner [$F(1,7) = 8.1$; $P < 0.05$]. Desire to eat also decreased in the evening during simulations of 5,000, 6,000, and 7,000 m [$F(1,7) = 13.1$; $P < 0.01$], all compared with normoxia. * $P < 0.01$ for simulated 5,000-m altitude compared with normoxia. # $P < 0.05$ for simulated 6,000- and 7,000-m altitudes compared with normoxia. $SP < 0.01$ for all simulated altitudes compared with normoxia. *C*: satiety scores before, after, and between meals during days at normoxia (*day -10*) and at simulations of 5,000 (*day 4*), 6,000 (*day 11*), and 7,000 (*day 17*) m. Satiety scores were lower before breakfast, in the morning, in the afternoon, before dinner, and at a simulated 5,000 m [$F(1,7) = 8.6$; $P < 0.05$] compared with normoxia. * $P < 0.05$ at simulated 5,000-m altitude compared with normoxia. # $P < 0.05$ for simulated 6,000- and 7,000-m altitudes compared with normoxia. At simulations of 6,000 and 7,000 m, satiety scores were higher before lunch, after lunch, and before dinner compared with scores at normoxia [$F(1,7) = 8.5$; $P < 0.05$]. *D*: thirst scores before, after, and between meals, during days at normoxia (*day -10*) and at simulations of 5,000 (*day 4*), 6,000 (*day 11*) and 7,000 (*day 17*) m. Thirst did not differ significantly between normoxia and the simulated altitudes [$F(1,7) = 2.7$; $P < 0.1$].

$P < 0.01$], and 8,000 m [$F(1,7) = 29.6$; $P < 0.001$] (10). The AMS symptom of nausea mainly occurred at simulations of 7,000 and 8,000 m.

Energy intake was significantly and progressively reduced at each simulated altitude, compared with normoxia (Table 1, Fig. 2). The regression analysis of energy intake and altitude showed a relationship of energy intake = $14.4 \text{ MJ} - 0.00086$ (altitude in m); $r = 0.88$; $P < 0.05$.

Energy balance [calculated by food-intake records and doubly labeled water data (24)] was negative during days 2–16 at 5,000–7,000 m [$-3.0 \pm 1.2 \text{ MJ/day}$; $F(1,7) = 8.0$; $P < 0.05$] and during days 17–30 at 7,000–8,848 m [$-4.0 \pm 1.5 \text{ MJ/day}$; $F(1,7) = 30.4$; $P < 0.001$] (24).

The macronutrient composition of the food the subjects chose did not change between simulations of 7,000 or 8,000 m and normoxia; however, at simulations of 5,000 and 6,000 m, carbohydrate intake was relatively increased, at the expense of fat and protein intake (Table 1).

Energy intake and macronutrient composition, on the days when the appetite profiles were determined during the day or during meals, were representative for the average daily energy intake and macronutrient composition (Table 1 and Fig. 2) at that particular altitude [$F(1,7) = 2.4$; $P > 0.1$].

Meal frequencies had increased significantly [from 4 ± 1 to 7 ± 1 eating moments per day; $F(1,7) = 13.2$; $P < 0.01$] at simulations of 5,000, 6,000, and 7,000 m compared with normoxia, as well as percentages of energy intake from snacks [from 8.2 to 23% energy from snacks; $F(1,7) = 9.2$; $P < 0.05$; see also Fig. 2].

Most meal sizes were decreased during simulations of high altitudes [Fig. 2, lowest F -value [$F(1,7) = 13.2$; $P < 0.01$], including a decrease in meal duration (Table 2), lowest F -value [$F(1,7) = 14.3$; $P < 0.01$].

Attitude toward eating (TFEQ scores) did not change significantly from normoxia to simulations of 5,000 and 6,000 m; however, at a simulated 7,000 m, the cognitive restraint score, showing unrestrained eating at baseline [<9 ; (25)], had decreased compared with the previous levels (Table 3). At the simulation of 8,000 m, all three scores (cognitive restraint, disinhibition, and hunger) had decreased significantly compared with normoxia (Table 3).

The appetite profile during the day differed between simulations of 5,000, 6,000, and 7,000 m and normoxia, and these differences consisted of deviations in hunger, desire to eat, estimation of how much one could eat, satiety and, fullness. For examples, see Fig. 3, A–C. Thirst did not differ significantly between normoxia and the simulated altitudes [$F(1,7) = 2.7$; $P < 0.1$] (Fig. 3D).

During the meals, perceptions of taste intensity and of pleasantness to have a meal showed fluctuations, but the perceptions did not change from the start to the end of the meal. Hunger decreased and satiety increased significantly, from a few minutes after the start to a few minutes before the end of a meal [lowest F -value: $F(1,7) = 92.4$; $P < 0.0001$] (Fig. 4, A–C). The pleasant-

ness of the taste of the food in the mouth fluctuated during the meal but showed an overall statistically significant decrease from 3 min after the start to the end of a meal [lowest F -value: $F(1,7) = 8.4$; $P < 0.01$].

The rate of decrease in pleasantness of taste did not differ within a meal type (breakfast, lunch, or dinner) between different simulated altitudes (Table 2). Moreover, it was independent of perception of taste intensity and of pleasantness to have a meal.

The rate at which hunger decreased was significantly faster only during dinner at a simulated 6,000 m when compared with the rate during dinner at normoxia. At breakfast, lunch, and dinner at simulated 5,000 m and at dinner at simulated 6,000 m, the rates at which satiety increased were significantly faster compared with the same type of meal at normoxia (Table 2).

DISCUSSION

During a 31-day simulation of an ascent to the peak of Mt. Everest (i.e., staying at “altitudes” of 5,000, 6,000, 7,000, and 8,000 m), body mass of the subjects (lean young men) was reduced significantly. We conclude that the main reason was being exposed to hypobaric hypoxia, which was isolated from other factors that usually are part of the rigors of climbing high mountains, such as cold, stress, or overexertion. During the 4-day recovery period, body mass increased immediately again, to an average final weight that was 2 kg less than that at the start of the experiment.

Body mass was reduced by an average of $5.0 \pm 2.0 \text{ kg}$; this was caused by a negative energy balance, which was mainly due to a reduced energy intake. The daily average of the negative energy balance was -3.0 MJ/day during simulations of 5,000 and 6,000 m, and -4.0 MJ/day during simulations of 7,000 and 8,000 m (24). These data show that it is hardly possible to maintain energy balance at high altitude, even when the activity level is low and even though subjects were partly acclimatized. The negative energy balance is mainly attributed to the decreased energy intake, because energy expenditure was also decreased (24). Other factors that might have contributed to the loss of body mass are a change in water balance and a change in digestion efficiency or malabsorption. With respect to water balance, during the subjects’ stay in the Vallot field station at 4,350 m, when no protocols were executed, increased diuresis might have taken place. This would be in line with the rapid restoration of body mass on recovery (an average of 3 kg in 4 days) and suggests physiological fluid retention with the return to sea level. During the stay in the hypobaric chamber, however, water balance had not influenced progressive loss of body mass (24).

The reduced energy intake is in good agreement with other decreases found in the literature (2, 7, 8, 12, 21) for mountain sojourns up to 26 days duration. Only when subjects were stimulated to eat, was energy-intake reduction partly prevented, and body mass loss was relatively less (3).

As we hypothesized, the observed reduced energy intake appeared to be due to reduced appetite, which

Fig. 4. Appetite profile (hunger and satiety) during meals [breakfast (A), lunch (B), dinner (C)] at normoxia (0), and at simulations of 5,000 and 6,000 m. VAS ratings at every 3 min are shown. A: at breakfast, hunger and satiety changed significantly, at each altitude, from 3 min to 30, 27, and 21 min, respectively; * $P < 0.0001$. B: at lunch, hunger and satiety changed significantly from level at 3 min to levels at 30, 30, and 21 min, respectively; * $P < 0.0001$. C: at dinner, hunger and satiety changed significantly from level at 3 min to levels at 48, 27, and 15 min, respectively; * $P < 0.0001$.

has been suggested previously (1, 5, 12), but had not been quantified.

When AMS symptoms were not present or barely present, we observed a change in the meal pattern from a gorging to a nibbling style, i.e., an increase in meal frequency. This change in meal pattern was related to a change in appetite profile during the day. It is not clear

whether the switch to a nibbling pattern may be learned, and therefore caused the change in the appetite profile, or whether this switch is an effect of the change in appetite profile. The switch to a nibbling pattern might be functional in an attempt to meet the energy intake requirements for a sustained energy balance. This is in line with previously reported energy-

intake compensation in nibblers but not in gorgers (29), while energy expenditure is not different between these two eating patterns (17).

Within this changed meal pattern, meal sizes were reduced, due to a more rapid increase of satiety and decrease of hunger, with a constant decrease of pleasantness of taste with a certain meal type. Hunger and satiety feelings did not change immediately after the start of the meal, probably due to positive feedback from pleasantness of taste (11), and they had reached their final level a few minutes before the meal was finished. Moreover, hunger and satiety scores were not always complementary to each other. These phenomena are well known, and we have observed those previously with normoxia (26, 27). Taste perception and pleasantness of having a meal did not change significantly from the start to the end of the meal, so these factors did not determine the end of the meal.

In regard to macronutrient balance, the relative increase in carbohydrate intake shown at simulated altitudes of 5,000 and 6,000 m does not cause a difference in the fuel mixture that is oxidized, because loss of body mass consisted mainly of loss of fat mass (24), allowing fat oxidation from stores.

When AMS symptoms were present, the meal pattern (at least at a simulation of 7,000 m) remained a nibbling pattern. However, interest in food intake was lost, as was shown from the reduced scores on the cognitive restraint factor of the TFEQ (at 7,000 and 8,000 m); although hunger was present, appetite was depressed. At a simulation of 7,000 m, the features of the appetite profile were uncoupled, in the sense that depressed appetite prevented the volunteers from reacting to increased hunger. It might be suggested that boredom or isolation in a chamber rather than hypoxia per se contributes to the observation of reduced food intake. However, in studies with similar boredom or isolation effects, such as those we conducted in respiration chambers, we observed an increase rather than a decrease in food intake (20). Thus boredom is an unlikely cause of decreased food intake under conditions that include palatable and varied diets.

One of the indications of depressed appetite might have been an increase in the serum leptin level, because leptin is a key mediator in the neuroendocrine regulation of food intake and energy expenditure (4). Because elevated leptin levels at high altitude were found to be associated with loss of appetite and AMS (16), we speculate that leptin might have played a role in the observed dysregulation of energy balance at high altitude.

From the point of view of adaptation to hypobaric hypoxia, we suggest that a change in body mass as well as a change in the appetite profile and in meal pattern might contribute to prevention of an even more negative energy balance. This mechanism was effective under circumstances without AMS; however, when AMS was present, the mechanism was overruled.

We conclude that, under conditions of hypobaric hypoxia per se and a sedentary lifestyle, a negative energy balance occurs due to reduced food intake. This

reduced food intake appears to be caused by a change in the appetite profile and in the attitude toward eating.

These findings are not only relevant for elite mountain climbers but also relate to research findings with respect to energy balance problems in chronic obstructive pulmonary disease patients. These patients suffer from a reduced appetite, possibly partly because of their relative hypoxic circumstances (13). This study therefore provides insight into the reduced appetite effect due to hypoxia in healthy men but separate from the clinical condition of chronic obstructive pulmonary disease patients.

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