



**HAL**  
open science

## **Operation Everest III (COMEX '97): effects of prolonged and progressive hypoxia on humans during a simulated ascent to 8,848 m in a hypobaric chamber.**

Jean-Paul Richalet, Paul Robach, Jarrot Sébastien, Jean-Christophe Schneider, Nick Mason, Nick Massan, Emmanuel Cauchy, Jean-Pierre Herry, Bernard Gardette, Claude Gortan

### ► To cite this version:

Jean-Paul Richalet, Paul Robach, Jarrot Sébastien, Jean-Christophe Schneider, Nick Mason, et al.. Operation Everest III (COMEX '97): effects of prolonged and progressive hypoxia on humans during a simulated ascent to 8,848 m in a hypobaric chamber.. COMEX. 1998. hal-04678314

**HAL Id: hal-04678314**

**<https://hal.science/hal-04678314v1>**

Submitted on 27 Aug 2024

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial - NoDerivatives 4.0 International License



The present document is the property of COMEX SAS. It has been entrusted to the ORPHY laboratory, which scanned and uploaded it.

COMEX (Compagnie Maritime d'Expertises), established in 1962, has positioned itself in the offshore activities sector, where it held a leading international position, becoming the world's foremost company in engineering, technology, and human or robotic underwater interventions. Comex designed a Hyperbaric Testing Center in 1969 and developed its own research programs on various breathing mixtures used in deep-sea diving (helium and later hydrogen). These research efforts led to spectacular advancements in this field, including several world records, both in real conditions and simulations. Comex still holds the world record at -701 meters, achieved in its chambers during Operation HYDRA 10.

The ORPHY laboratory focuses on major physiological functions, their regulation, interactions, and their contribution to the development and prevention of certain pathologies. The primary mechanisms studied involve metabolic aspects (oxygen transport and utilization, energetics, etc.) and electrophysiological aspects (contractility and excitability), mainly related to respiratory, vascular, and/or muscular functions. These mechanisms are studied under various physiological and physiopathological conditions, ranging from the cellular and subcellular levels to the entire organism. In Europe, the ORPHY laboratory is one of the leaders in hyperbaric physiology and diving research.

Being a major player in innovation and expertise in the field of pressure, COMEX maintains a scientific archive from its experimental diving campaigns. The value of this archive is both scientific and historical, as it documents a remarkable chapter in the history of marine exploration and contains results obtained during dives that are very unlikely to be replicated in the future.

**Operation Everest III (COMEX '97): effects of prolonged and progressive hypoxia on humans during a simulated ascent to 8,848 m in a hypobaric chamber.**

Jean-Paul Richalet, Paul Robach, Sébastien Jarrot, Jean-Christophe Schneider, Nick P. Mason, Emmanuel Cauchy, Jean-Pierre Herry, Bernard Gardette and Claude Gortan.

Association pour la Recherche en Physiologie de l'Environnement, Laboratoire Réponses cellulaires et fonctionnelles à l'hypoxie (EA 2363), U.F.R. Médecine, Université Paris Nord, Bobigny; Ecole Nationale de Ski et d'Alpinisme, Chamonix; COMEX S.A., Marseille, France

Tel: 33 1 48 38 77 57

Fax: 33 1 48 38 77 77

e-mail: richalet@smbh.univ-paris13.fr

24/07/98

## Abstract

Exposure to high altitude induces physiological or pathological modifications that are not always clearly attributable to a specific environmental factor: hypoxia, cold, stress, inadequate food. The principal goal of hypobaric chamber studies is to determine the specific effect of hypoxia. Eight male volunteers (« altinauts »), aged 23 to 37 were selected. They were first pre-acclimatized in the Vallot Observatory (4,350m) before entering the chamber. The chamber was progressively (30 days) decompressed down to 253 mmHg barometric pressure, with a recovery period of 3 days at 5,000m in the middle of the decompression period. Eighteen protocols were organized by 14 european teams, exploring the limiting factors of physical and psychological performance, and pathophysiology of acute mountain sickness (AMS). All subjects reached 8,000m and 7 of them reached the simulated altitude of 8,848m. Three altinauts complained with transient neurological symptoms which resigned rapidly with reoxygenation. Body weight decreased by 5.4 kg through a negative caloric balance. Four days only after the return to sea-level, subjects had recovered 3.4 kg, i.e. 63% of the total loss. At 8,848m, mean SaO<sub>2</sub> was 68±3 %, PaO<sub>2</sub> 34 ± 4 mmHg, PCO<sub>2</sub> 12 ± 2 mmHg, pH 7,57 ± 0.02. Hemoglobin concentration increased from 14.8 ± 1.4 to 18.4 ± 1.5 g/dl at 8000m and recovered within 4 days at sea-level. AMS score increased rapidly at 6000m and was maximal at 7000m, especially for sleep. AMS was related to alteration in color vision and elevation of body temperature. VO<sub>2</sub>max decreased by 59% at 7000m. The purpose of this paper is to give a general description of the study and the time course of main clinical and physiological parameters. The altinauts reached the "summit" (for some of them three consecutive times) in better physiological conditions than it would have been possible in the mountains, probably because acclimatization and other environmental factors such as cold and nutrition were controlled.

The exposure of humans to the environment of high altitude regions induces various physiological adjustments or pathological manifestations which are not always clearly attributed to one or another stressor associated with this particular milieu. Altitude hypoxia, cold, inadequate food or liquid intake, exhaustion, psychological stress are the main environmental impact factors that could modify human physiology and behavior at high altitude. The first objective of hypobaric chamber studies is to isolate hypobaric hypoxia from the other stressors. The possibility to use advanced technology and sophisticated equipment as well as ethical and safety considerations give a net advantage to chamber studies as compared to field studies when the effect of hypoxia is the main question. Paul Bert was the first scientist at the end of the last century to use a hypobaric chamber to study the effect of altitude hypoxia on himself (1) and was able to demonstrate that the well known effects of acute altitude exposure (dyspnea, tachycardia, dizziness) were due to the lack of oxygen and not to hypobaria itself. In 1946, the US Navy promoted a study called "Operation Everest" where four subjects were able to reach the standard altitude equivalent to Mount Everest (235 mmHg) after a 30-day period of confinement in a small chamber (3.3m x 3.3m x 2.3m) (3). In 1985, Operation Everest II was directed by Charles Houston, John Sutton and Allen Cymerman. It was a large scale investigation which produced a lot of new interesting data and allowed the formulation of new concepts in the field of high altitude physiology and medicine (4). Eight male subjects entered the chamber, six of them reached the "summit" (ambient pressure of 240 mmHg) after a 40 day stay in the chamber. In 1989, Operation Everest Turbo demonstrated the positive effects of pre-acclimatization in a hypobaric chamber before an expedition to Mount Everest (6). Six subjects (five male and one female) were intermittently exposed to equivalent altitudes up to 8848m for 5 days and showed physiological and clinical signs of acclimatization. The objectives of the present study were to use the advantages of chambers studies (pure hypoxia, advanced technology, safety) to address some specific questions remained unanswered by previous chamber or field studies.

## Subjects

*Selection of subjects.* Eighteen male subjects answered to the call for participation. We will call them « altinauts », as a combination of altitude and astronauts. Nine were selected from various criterion: experience of mountaineering, maximal oxygen uptake, hypoxic ventilatory and cardiac response to hypoxia at rest and exercise, psychological profile and motivation, interest for science in general and high altitude physiology in particular. Eight subjects and one alternate entered the study for basal normoxic studies. Finally, eight altinauts underwent the altitude chamber program. Their characteristics were the following:

- #1. K.B. 23 yr old, male nurse, high level climber in the Alps, no altitude experience above Mont Blanc (4807m), lives in Chamonix (1035m), smokes 2 cig./day; height 180cm; weight 66kg.
- #2. E.C. 37 yr old, medical doctor specialized in emergency medicine and mountain rescue, mountain guide, participated in various high altitude expeditions including ARPE scientific expedition to Mount Sajama (6542m) in 1991, reached the altitude of 8760m without supplementary oxygen on Mount Everest in 1990, lives in Chamonix (1035m), occasional smoker; height 183cm; weight 77 kg.
- #3. G.D. 25 yr old, medical student (last year), has a good mountaineering experience, climbed various summits in the Andes and reached the altitude of 6435m, lives in Toulouse (146m), non smoker; height 190cm; weight 80 kg.
- #4. J.F.F. 25 yr old, medical student (last year), has a good mountaineering experience, climbed various summits in the Andes and reached the altitude of 6435m, lives in Toulouse (146m), non smoker; height 188cm; weight 83 kg.
- #5. M.G. 26 yr old, medical student (last year), has a good mountaineering experience, climbed various summits in the Andes and reached the altitude of 6435m, lives in Toulouse (146m), non smoker; height 176cm; weight 72 kg.
- #7. G.S. 25 yr old, electrician, high level climber in the Alps, no altitude experience above 4100m, lives in Challes les Eaux (310m), smokes 4 to 5 cig./day; height 177cm; weight 70 kg.
- #8. P.S. 25 yr old, skiman, good climber in the Alps, has an experience of trekking in Nepal up to 5200m, lives in Servoz (815m), non smoker; height 172cm; weight 65 kg.
- #9. A. H. 27 yr old, master in law, regular climber, moderately trained as compared with the others, no experience of high altitude above 4300m, lives near Paris (60 m), non smoker; height 176cm; weight 80 kg.

## Methods

### *Location and schedule of experiments.*

Subjects were studied at the COMEX S.A. facilities in Marseille, France. The hypobaric chamber consisted in three rooms, one spherical study room (diameter 5m, available volume 65 m<sup>3</sup>) connected to a cylindrical living room with eight sleeping bunks and a table for meals (length 8 m, available volume 32 m<sup>3</sup>) via an airlock room usable for toilets and shower (available volume 8 m<sup>3</sup>) (Figure 1). Pressures in the living room and airlock on one side and in the study room on the other side were controlled independently by a computerized system. Food and drinks, urine and blood samples, and any necessary small object could be transferred between outside and inside the chamber via two pass through devices. Altinauts were constantly monitored through five video cameras and audio systems by two technicians who were continuously present to manage the chamber, day and night. During day time, a medical doctor was present in the control room. During night time, a doctor could be called at any time and be present on the site within 15 minutes. Oxygen at mask was available at each bed location, in the dining room and in the study room. A portable oxygen bottle with a mask was also available within the chamber, as well as an emergency pack usable by one of the subject who was a medical doctor trained for high-altitude emergencies. In case of severe problems necessitating emergency evacuation, a subject could be taken out of the chamber within 30 minutes from 8848m equivalent altitude, and quicker from lower altitudes.

Eighteen protocols were planned and executed by fourteen scientific teams from France, England and Netherlands to study the effect of prolonged hypobaric hypoxia on various systems:

1. Role of hemoconcentration on aerobic performance, with related hydroelectrolytic hormones.
2. Alpha motoneuron excitability and recruitment of motor units.
3. Sensori-motor control and maximal performance of skeletal muscles.
4. Production of oxygen free radicals at rest and exercise.
5. Coordination during a simulated traverse climb of short duration.
6. Transport of oxygen and oxyhemoglobin dissociation curve.
7. Acclimatization and cardiac and ventilatory response to hypoxia, ventilatory response to CO<sub>2</sub>.
8. Role of peripheral chemoreceptors on ventilatory acclimatization.

9. Defense responses of respiratory tract. Variation of cough frequency with altitude.
10. Role of NO, endothelin and eicosanoids in the pathophysiology of pulmonary hypertension. Effects of a supplementation with L-arginine.
11. Cardiac function evaluated by echocardiography. Formation of circulating bubbles.
12. Autoregulation of cerebral blood flow evaluated by transcranial Doppler.
13. Calcium and phosphate metabolism, with related hormones.
14. Modification of basal metabolic rate and distribution of total body water by doubly labeled water.
15. Sensitivity of adipose tissue to various lipolytic or antilipolytic agents. Variation in body composition.
16. Psychological adaptation to prolonged hypoxia: cognitive and affective sensorimotor aspects.
17. Psychological adaptation to prolonged hypoxia: individual psychological profile, decision taking and solving group problems.
18. Determinants of food consumption: taste sensitivity, appetite and satiety.

The protocols and the risks were clearly explained to all the subjects who signed a consent of participation. The protocols were approved, after revision, by the ethical committee of University Hospital of Marseille. Special recommendations from the committee were to restrict blood gases to arterialized capillary blood sampling, maximal exercise no higher than 7000 m, dopamine infusion at a maximal dose of 3  $\mu\text{g}/\text{kg}/\text{min}$  for protocol #8, avoid the use of CO breathing to measure plasma volume in protocol #1.

The schedule of experiments was the following:

1. *Basal normoxic measurements* were performed on the nine subjects within the chamber with open doors from March 10<sup>th</sup> to 16<sup>th</sup>.
2. *Pre-acclimatization period*. In order to shorten the time spent within the chamber, subjects were allowed to pre-acclimatize in the Alps, at Refuge des Cosmiques (3650m) for one day and Observatoire Vallot (4350m) for 7 days. During this period, free climbing activity was allowed and no scientific observation was performed. This period was planned, not only to allow a rapid entrance to the chamber at 5000 m but also to test the ability of the subjects to withstand high altitude and community life in a hostile environment. During this period, subject #6 suffered from high altitude pulmonary edema (documented by X-ray after evacuation at Chamonix hospital) together with urine bladder retention probably due to prior atropine administration for systematic eye fundus



examination before ascent to high altitude. He was excluded from the study and the alternate subject (#9) was then fully included in the study.

*3. Hypobaric chamber period.* Subjects descended from Observatoire Vallot on April 1<sup>st</sup> at mid-day and entered the chamber on April 2<sup>nd</sup> at mid-day. They spend their first night in the chamber at 4500m then went up to 5000m where they started the experimental procedures. The ascent profile is shown on figure 2. The pressures were chosen as the real pressures for the latitude of Mount Everest (11), up to 253 mmHg for the altitude of 8,848m. Except in the last period of ascent to the "summit", the pressure changes were performed early in the morning, before wake up and breakfast, within 15 minutes for an altitude difference of 500 m, 30 minutes for an altitude difference of 1000 m, and 90 minutes for an altitude difference of 1500 or 2348 m. Experiments were performed at sea-level (SL), at 5000m (HA1), 6000m (HA2), 7000m (HA3), return to 5000m (RHA1), 8000m (HA4), 8848m (HA5) and after the return to sea-level (RSL). Subjects spent their last night in the chamber at 5000m, after the last "summit" climb. During the days when no experiments were performed, altinauts were strongly encouraged to do some exercise on the treadmill or on the cycloergometer. Most of them did so (30 to 90 minutes per day), although their motivation was quite decreasing with increasing altitude.

*4. Recovery period.* Altinauts left the chamber on May 2<sup>nd</sup> and underwent the RSL experiments until May 5<sup>th</sup>. This type of observation is quite unique: very rare studies have explored the time course of physiological and psychological parameters after return to normoxic conditions.

Three subjects did not follow the complete schedule. One subject (#1) experienced neurological symptoms at 8000m (day 25): while performing a cognitive test, he suddenly could not speak and hardly write. These symptoms rapidly disappeared with pure oxygen breathing but a severe headache of migraine type could not be relieved by oxygen breathing and was not tolerated by the subject. The evacuation was rapidly decided and executed while oxygen breathing. The subject was brought to an emergency care unit where neurological examination, eye fundus, cerebral magnetic resonance imaging were performed and revealed strictly normal. Subject #8 suffered from neurological symptoms at 8848m (day 29): he felt dizzy and could not recognize his friends within the chamber, had the sensation of floating in the air. All signs disappeared with oxygen inhalation but the subject and his colleagues were still anxious and for safety reasons, subject #8 was evacuated from the chamber. Neurological examination and magnetic resonance imaging performed after evacuation were strictly normal. Subject #3 suffered from neurological

symptoms at his second ascent to 8848m (day 30): sudden pain in the back, paralysis of the left lower limb, with aphasia and facial paralysis. Symptoms disappeared rapidly with oxygen inhalation. Subject was brought down to 6500 m where he felt perfectly well. He was kept under oxygen inhalation while his friends underwent their third ascent to 8848m and stayed with them at 5000m during the last night in the chamber. Neurological examination and magnetic resonance imaging performed after leaving the chamber were strictly normal. As a whole, 8 out of 8 altinauts reached 8000m, 7 reached 8848m among whom 5 reached the "summit" three times, one twice and another one only once. All altinauts, included those who left the chamber before time, underwent the protocols planned during the RSL period, the delay from leaving the chamber being respected. Subjects were not allowed to take medications except paracetamol for severe headache. One subject entered the chamber two days after a dental abscess evacuation and took antibiotics for 5 days within the chamber. Dexamethazone (8 mg IV) was given to subject #1 before evacuation on day 25. Despite strong encouragement not to take any medication against insomnia, sleeping pills (10 to 20 mg zolpidem) were occasionally given to some of the subjects upon their strong request and mainly to avoid a severe conflict between altinauts and the staff. As far as no sleep study was performed and that the plasma half life of zolpidem is 2.4 hours, this drug use was considered has having potentially minimal influence on protocols performed the day after. However, any effect (mainly beneficial) cannot be excluded either on psychological or physical tests.

Environmental conditions. Pressure variations were continuously monitored in the chamber. Mean values for the altitudes where experiments were performed are shown in Figure 2. Variations in the chamber temperature are shown in Figure 3A. During experiments, temperature was, most of the time, kept between 18°C and 24°C. Hygrometry is shown in Figure 3B. It varied with outside ambient hygrometry and was mostly between 30 and 60 %. Nyctoemeral rhythm was maintained: altinauts woke up at 07:00 - 07:30 and went to bed between 22:00 and midnight.

## Methods

Each protocol will be described in detail in other articles. The main purpose of the present paper is to give a general description of the study and the time course of main clinical and physiological parameters. Daily questionnaire, body weighing and basal physiological parameters were recorded in the morning just

after wake up, before breakfast, except at HA4 and HA5 where they were recorded after two to three hours of exposure to the corresponding altitude. Body weight was measured by a whole body scale (Mettler-Toledo, type Sider 1-150, Switzerland). Body mass index was calculated as body weight / height<sup>2</sup> as an overall indication of fat proportion in body composition. Liquid and food intake were carefully measured daily by weighing personal food plateau entering and leaving the chamber, for each subject. Day time food intake, outside principal meals (breakfast, lunch, dinner) were noted by the subject himself via a careful weighing using a table food scale within the chamber (Kern, model 440-53, Prolabo, France). Twenty four hour urine was collected and weighed daily, outside the chamber. Acute mountain sickness (AMS) score (Lake Louise Consensus, ref 10) was self recorded (headache: 0 to 3; gastrointestinal symptoms: 0 to 3; fatigue/weakness: 0 to 3; dizziness/lightheadedness: 0 to 3), as well as an evaluation of insomnia, ataxia and dyspnea (each coded from 0 to 3). Rectal temperature was taken every morning before standing up. Heart rate, systemic arterial pressure and transcutaneous arterial saturation were measured daily in the morning before breakfast (Hewlett Packard, model Viridia M3 ). Color vision was evaluated in the same time by an anomaloscope, as an objective measurement of AMS (7). The color vision index presented here is, for each individual, the variation from the sea-level basal value. Blood hemoglobin concentration was obtained through peripheral venous blood sampling and measured by a CO-oximeter (Chiron Diagnostics, model 270). CO-oximeter was kept inside the chamber and was calibrated for each chamber pressure. Blood gases were measured from arterialized capillary blood obtained from ear lobe previously heated with capsaicin cream. Blood gases analyzer (Chiron Diagnostics, model 348) was outside the chamber and capillary blood samples were passed through an air lock and analyzed within 2 minutes after sampling. Maximal oxygen uptake was measured using a step by step progressive exercise on a cycloergometer (Monark) until exhaustion. Ventilation, oxygen and CO<sub>2</sub> concentrations were analyzed using a Medical graphics system modified for low values of CO<sub>2</sub> pressures and with a more powerful gas pumping system for high altitudes. The apparatus was kept within the chamber and functioned perfectly up to 7000 m.

Statistics. Values presented are mean  $\pm$  standard deviation. Analysis of variance with repeated measures is used to assess the significance of variations with time and altitude.

## Results

Variations of each symptom being part of AMS score as well as total AMS score, insomnia, ataxia and dyspnea scores are shown in figure 4.

Total AMS score was almost zero at 5000m thanks to the pre-acclimatization period on Mont Blanc. Symptoms appeared at 5500m and 6000m, raised at 6500m and were maximum at 7000m. During the recovery at 5000m, AMS score went back to zero after 3 days, stayed very low upon reascent until 7000m was reached again, peaked on the third ascent at 8000m, but was lower during ascent to 8848. One subject still felt some symptoms one day after leaving the chamber (day 32). Among the four items included in the AMS score, the trend was different. The headache score was zero at 5000m, peaked at 7000m and was relatively low at 8000m and 8848m. At 6000m and 7000m, there was a progressive decline with time due to clinical acclimatization.

Gastrointestinal symptoms were zero up to 5500m, increased on the first days at 6000m, 7000m then declined rapidly with time at a given altitude. However, it increased with the successive intermittent exposures to 8000m. Fatigue increased with time and altitude up to 7000m, progressively returned to zero after 3 days of recovery at 5000m, then raised again with altitude and reached its maximum on the third exposure to 8000m, whereas the exposure to 8848m was better tolerated, probably because it was shorter. Dizziness score was very low during the whole period, peaked at 7000m and showed a small rise at 8000m and 8848. Dyspnea score always showed a peak on the first day at a new altitude, progressively raised with altitude with a peak at 6500m, did not completely returned to zero on recovery at 5000m, raised again with reascent and reached its maximum at 8848m. Ataxia score was very low during the whole period except at 7000m, on the first exposure to 8000m and at both exposures to 8848m. Some altinauts still complained with one of these symptoms one to three days after return to sea-level. Quality of sleep was already not perfect at 5000m, progressively altered with altitude up to 7000m, took three days to restore on recovery at 5000m, raised again and peaked during the nights spent at 7000m between days at 8000m. Recovery after descent to sea-level was immediate.

Mean variations in body weight are shown in figure 5. Mean body weight loss was 5.4 kg (7.3% of initial body weight). During the preacclimatization period on Mont-Blanc, 1.4 kg were already lost. Then, the loss was progressive, up to 7000m. As soon as the first day on recovery at 5000m, 0.7 kg were recovered and 0.15 kg more within two more days. Reascent to 8848m led to a further loss of 1.7 kg in 7 days. The individual maximal weight loss varied from 2.9 to 10.0 kg and was related to initial body mass index ( $p < 0.005$ ). The rate of

weight gain after return to sea-level was dramatically high: after 4 days of recovery, mean body weight increased by 3.4 kg, i.e. 63% of the total weight loss.

Mean caloric input decreased by 11% at 5000m, by 22% at 6000m, by 44% at 7000m, and by 55% at 8000m (Westerterp et al., in preparation).

Resting heart rate and transcutaneous arterial saturation are shown in figure 6. SaO<sub>2</sub> decreased with altitude and increased with re-exposure to the same altitude, due to ventilatory acclimatization. The lowest mean SaO<sub>2</sub> was reached at 8000m : 67.9 %. Heart rate increased with altitude, up to 7000m and mirrored variations in SaO<sub>2</sub>. No further increase was observed at 8000m and 8848m. During return to sea-level, some individuals showed values of heart rate lower than before entering the chamber.

Systolic and diastolic arterial pressures are given on figure 7. No significant variations were observed, neither in systolic nor in diastolic arterial pressures. There was a progressive slight increase of rectal temperature with altitude, but the most striking observation was peaks of temperature at 7000m in some subjects, with concomitant rise in clinical score of AMS (Figure 8). The high values of rectal temperature were only seen when the AMS score was high (Figure 9).

Variation of color vision index in the red/green axis with altitude is shown on figure 8. Color index decreased with altitude at and above 6000 m, showing a slight relation with AMS: color vision index was lower when AMS was different from zero (significant when score equals 2 or 3).

As expected, maximal oxygen consumption decreased with altitude (Table 1): -50% at 5000m, -58% at 6000m and -59% at 7000m. Resting values of PO<sub>2</sub>, PCO<sub>2</sub> and pH in arterialized capillary blood at different altitudes are shown in table 1. Individual values at 8,848 m (day 30) ranged from 29.3 to 38.8 mmHg for PO<sub>2</sub>, 10.5 to 15.3 for PCO<sub>2</sub> and 7.541 to 7.606 for pH. Hemoglobin concentration increased with altitude exposure. Four days after leaving the chamber, it was not different from basal SL values (table 1).

## Comments

Detailed results of each protocol will be presented and discussed elsewhere. However, general observations and comments can be made. This operation was a great success, both from a scientific and from a human point of view. Approximately 80% of the expected studies have been completed. Seven out of eight altinauts reached the maximal equivalent altitude. No major accident occurred. The only comparable study previously organized on the same topics

was Operation Everest II (OEII) in 1985 (4). No major difference in the main clinical and physiological measured parameters was found between the two studies. However, some interesting variations resulted from the different profile of ascent. Pre-acclimatization At Vallot Observatory allowed a much better clinical status at 5,000 m during OEIII than during OEII: symptoms of AMS appeared at 6,000 m only. However, with exposure above 7,000 m, headache, dyspnea and lethargy were similarly present in both Operations. Body weight loss - mainly due to dramatic decrease in food intake - was similar, although slightly less in OEIII: 7.3% vs 8.9% of initial body weight (8). A great care was given to the choice of palatable food that was every day adapted to the mood and cravings of the altinauts. This may explain part of the difference. The decrement in  $\dot{V}O_2$ max was greater in OEIII than in OEII, at 5000m and 6000m. However, basal SL  $\dot{V}O_2$ max was higher in the present study (57.4 ml/min/kg) than in OEII (51.2) and it has been suggested that subjects with higher  $\dot{V}O_2$ max at SL may show a larger decrease at high altitude (2). The further decrease in  $\dot{V}O_2$ max between 6000 and 7000m was insignificant, probably because the 7-day period of acclimatization between the two altitudes was efficient to minimize the effect of increasing altitude. Blood gases were similar in both operations, although values at extreme altitude were slightly higher in OEIII. Similarly, mean SaO<sub>2</sub> at the " summit " is higher in OEIII (68% ) than in OEII (58%) (9). This important difference probably comes from the fact that we have chosen a different value of barometric pressure for a given altitude, taken into account the effect of latitude (11). At the maximal equivalent altitude, barometric pressure was chosen as 240 mmHg in OEII and 253 mmHg in OEIII. However, it is not clear what was the exact FIO<sub>2</sub> and PIO<sub>2</sub> at extreme altitudes in OEII (9,2). Anyway, in that portion of the oxygen dissociation curve, a slight difference in PaO<sub>2</sub> may induce a great variation in SaO<sub>2</sub>.

The speed of recovery from hypoxia when leaving the chamber was quite surprising for us, especially the gain of body weight (63% of total loss in 4 days). This particular aspect was not addressed in OEII. Hemoglobin concentration also went back to sea-level values within four days. This rapid hemodilution effect of reoxygenation (or recompression) is concomitant with a great increase in plasma volume (Robach et al, in preparation).

The relation between severe AMS and body temperature was recently suspected (5) and confirmed in the present study. It may indicate that an inflammatory process is concomitant with the development of AMS. Color vision is slightly altered at high altitude, especially in subjects suffering from AMS. This observation confirm previous findings (7) and may help in providing an objective measurement in the evaluation of AMS; however no clear correlation was found

between the variation in color vision index and the intensity of AMS evaluated by the subjective Lake Louise scoring system.

What is similar to what is observed in the field and what is not ?

The easy availability of palatable food, the absence of cold stress, the relatively low energy expenditure and absence of prolonged physical exercise, the absence of common dangers of climbing mountains, the confinement within a closed space, are factors which differ from field studies. The relative good clinical status of our altinauts throughout the study, their ability to withstand for few hours extreme hypoxic conditions let us think, in comparison with OEII experiment, that the pre-acclimatization period in the " real mountain " and the recovery period at 5000m before the final ascent may have had a beneficial physiological and psychological impact. However, the three cases of neurological transient incidents may warn us about the potential damage that may induce such experiments on the brain of young healthy volunteers.

## References

1. Bert P. *La pression barométrique*. Masson éd. Paris, 1878.
2. Cymerman A., Reeves J.T., Sutton J.R., Rock P.B., Groves B.M., Malconian M.K., Young P.M., Wagner P.D., Houston C.S. Operation Everest II: maximal oxygen uptake at extreme altitude. *J. Appl. Physiol.* 66: 2446-2453, 1989.
3. Houston C.S. Operation Everest. *U.S. Naval Medical Bulletin.* 46: 1783-1792, 1946.
4. Houston C.S., Sutton J.R., Cymerman A. and J.T. Reeves. Operation Everest II: man at extreme altitude. *J. Appl. Physiol.* 63: 877-882, 1987.
5. Maggiorini M., Bärtsch P., Oelz O. Elevated body temperature in severe acute mountain sickness (AMS). In « *Hypoxia and Mountain Medicine* », J.R. Sutton, G. Coates and C. Houston eds. Queen City Printers Inc. Burlington, VT, 1992, p 311 (abstract n°62).
6. Richalet J.-P., Bittel J., Herry J.-P., Savourey G., Le Trong J.L., Auvert J.F., Janin C. Use of a hypobaric chamber for pre-acclimatization before climbing Mount Everest. *Int J Sports Med.* 13, S216-S220, 1992
7. Richalet J.-P., Rutgers V., Bouchet P., Rymer J.-C., Kéromès A., Duval-Arnould G., Rathat C. Diurnal variations of acute mountain sickness, color vision and plasma cortisol and ACTH at high altitude. *Aviat. Space Environ. Med.* 60 :105-111, 1989.
8. Rose M.S., Houston C.S., Fulco C.S., Coates G., Sutton J.R., Cymerman A. Operation Everest II: nutrition and body composition. *J. Appl. Physiol.* 65: 2545-2551, 1988.
9. Sutton J.R., Reeves J.T., Wagner P.D., Cymerman A., Malconian M.K., Rock P.B., Young P.M., Walter S.D., Houston C.S. Operation Everest II: oxygen transport during exercise at extreme simulated altitude. *J. Appl. Physiol.* 64: 1309-1321, 1988.



10. The Lake Louise Consensus on the definition and quantification of altitude illness. In: *Hypoxia and Mountain Medicine*, J.R. Sutton, G. Coates, C.S. Houston eds. Queen City Printers Inc. Burlington, VT, 1992, p 327-330.
11. West J.B. Prediction of barometric pressure at high altitudes with use of model atmospheres. *J. Appl. Physiol.* 81: 1850-1854, 1996.

### Acknowledgments.

We express our gratitude to all the administrative and technical crew of COMEX S.A. for its assistance to the investigators and to the alpinists during the whole experiment. This experiment was made possible by the attribution of grants from Région PACA and Ministère Jeunesse et Sports, France.

We are very grateful to the nine volunteers for their patience and courage throughout this exceptional experience: Kim Bodin, Emmanuel Cauchy, Guillaume Despiau, Jean-François Finance, Mathieu Gayet, Vincent Marchand, Guillaume Sabin, Philippe Serpollet et Alexandre Héritier.

## Legend of figures

Figure 1. Plan of the hypobaric chambers at COMEX facilities.

Figure 2. Simulated progression profile. SL, HA1 to HA5, RSL: periods of experimental studies.

Figure 3. Variations of ambient temperature (3A) and hygrometry (3B) in the main experimental chamber.

Figure 4. AMS score. Total score, headache score, gastrointestinal score, dizziness score, fatigue score, insomnia score, ataxia score and dyspnea score. Mean values for the group. Standard deviations are not shown.

Figure 5. Mean variations in body weight. Standard deviations are not shown.

Figure 6. Mean resting heart rate and transcutaneous arterial saturation. Standard deviations are not shown.

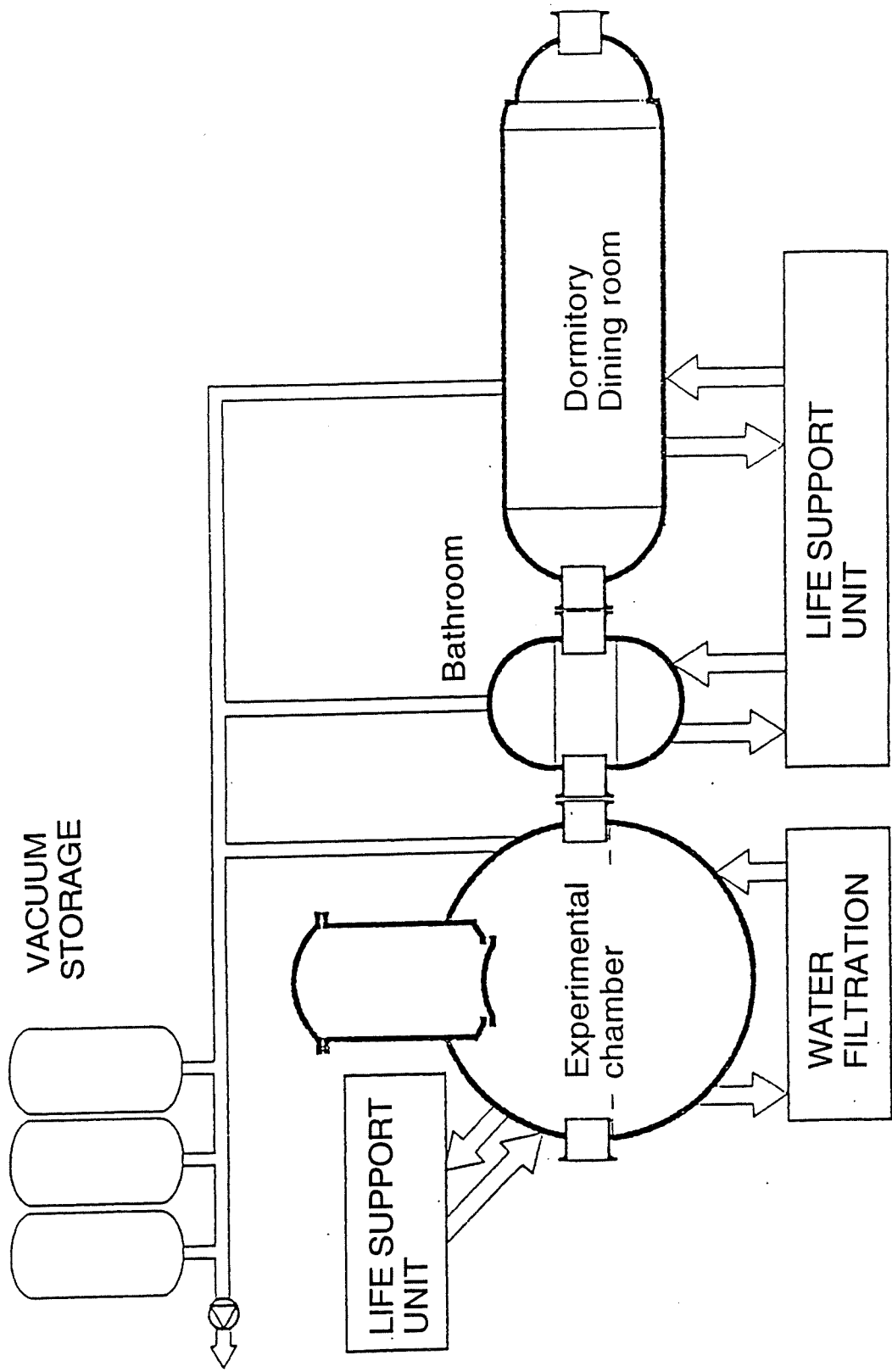
Figure 7. Variations of mean systolic and diastolic arterial pressures. Standard deviations are not shown.

Figure 8. Variations of rectal temperature (T<sub>rec</sub>), Color vision index and AMS score with increasing altitude. Mean  $\pm$  SD. Altitude vs sea-level: \*\*,  $p < 0.01$ ; \*\*\*,  $p < 0.001$ .

Figure 9. Variations of rectal temperature (T<sub>rec</sub>) and Color vision index as a function of each level of AMS score. Mean  $\pm$  SD. AMS score different from 0 vs AMS score = 0 : \*,  $p < 0.05$ ; \*\*\*,  $p < 0.001$ .

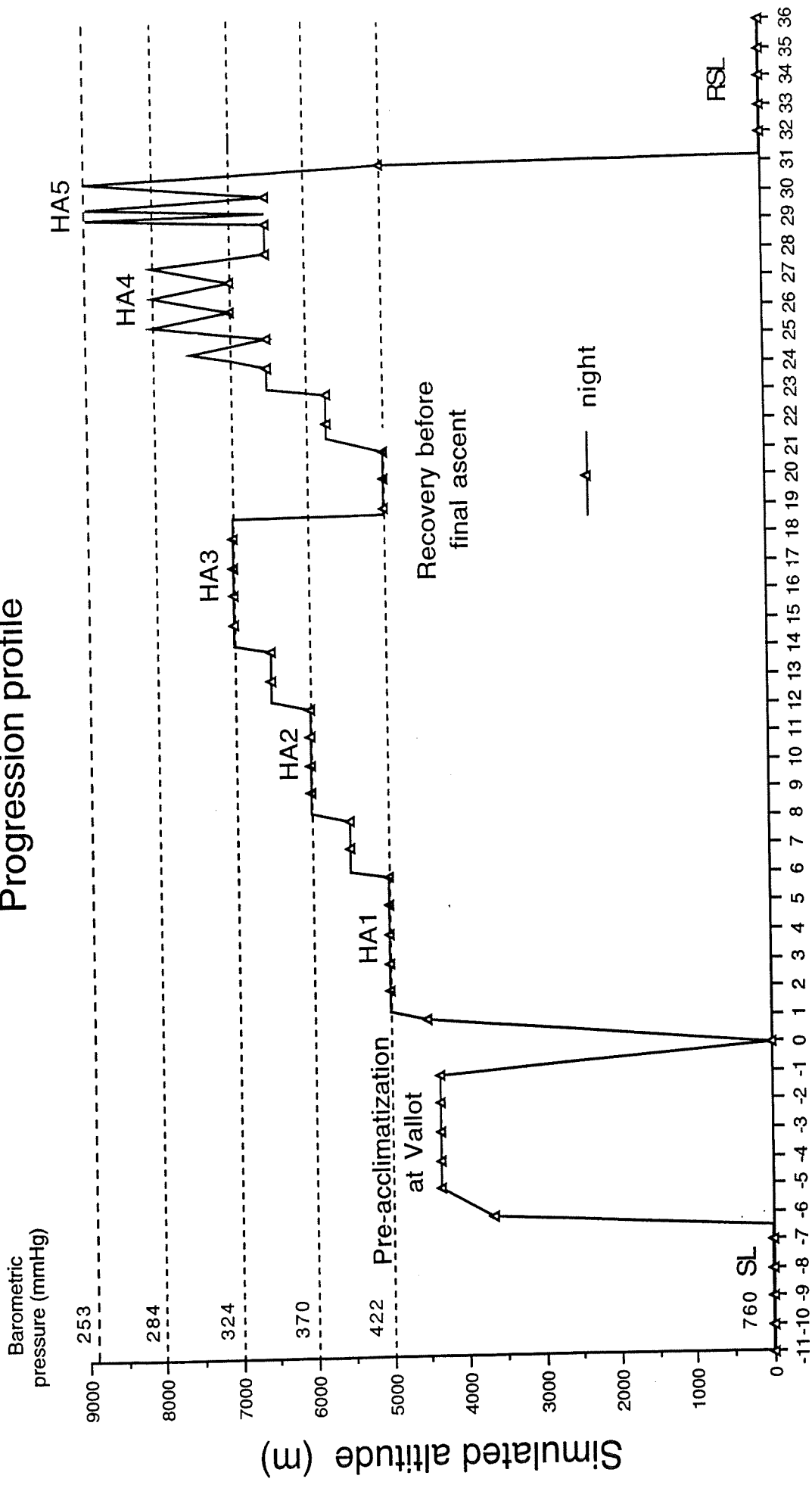
Table 1. General characteristics of the subjects. Maximal oxygen uptake, resting blood gases and hemoglobin concentrations. Mean  $\pm$  SD. BMI: body mass index. n=8 except at 8848m where n=7.

Day in chamber	-10	2	10	17	26	30	35
Condition	SL	5000	6000	7000	8000	8848	RSL
Age	26.6 $\pm$ 4.3						
Height, cm	180 $\pm$ 6						
BMI, kg.m <sup>2</sup>	22.9 $\pm$ 1.5						
Body weight	74.3 $\pm$ 6.6	72.9 $\pm$ 6.2	71.6 $\pm$ 6.0	70.4 $\pm$ 5.8	69.8 $\pm$ 5.8	70.2 $\pm$ 5.4	72.2 $\pm$ 6.4
kg		*	***	***	***	***	***
VO <sub>2</sub> max	57.4 $\pm$ 3.9	28.7 $\pm$ 4.2	23.9 $\pm$ 2.9	23.5 $\pm$ 2.6	/	/	51.1 $\pm$ 6.3
ml/min/kg		***	***	***			*
PO <sub>2</sub>	101.8 $\pm$ 3.9	51.1 $\pm$ 3.4	49.3 $\pm$ 3.3	40.2 $\pm$ 5.0	37.0 $\pm$ 4.6	33.6 $\pm$ 3.7	102.3 $\pm$ 6.0
mmHg		***	***	***	***	***	
PCO <sub>2</sub>	40.3 $\pm$ 3.1	27.5 $\pm$ 1.4	19.8 $\pm$ 2.0	18.0 $\pm$ 2.6	14.3 $\pm$ 2.1	12.4 $\pm$ 1.7	31.6 $\pm$ 2.1
mmHg		***	***	***	***	***	***
pH	7.41 $\pm$ 0.03	7.47 $\pm$ 0.02	7.51 $\pm$ 0.02	7.49 $\pm$ 0.02	7.57 $\pm$ 0.02	7.57 $\pm$ 0.02	7.43 $\pm$ 0.01
		***	***	***	***	***	
Hb	14.8 $\pm$ 1.4	16.4 $\pm$ 1.2	17.3 $\pm$ 1.3	16.9 $\pm$ 1.3	18.4 $\pm$ 1.5	/	14.9 $\pm$ 1.2
g/dl		*	***	**	***		***



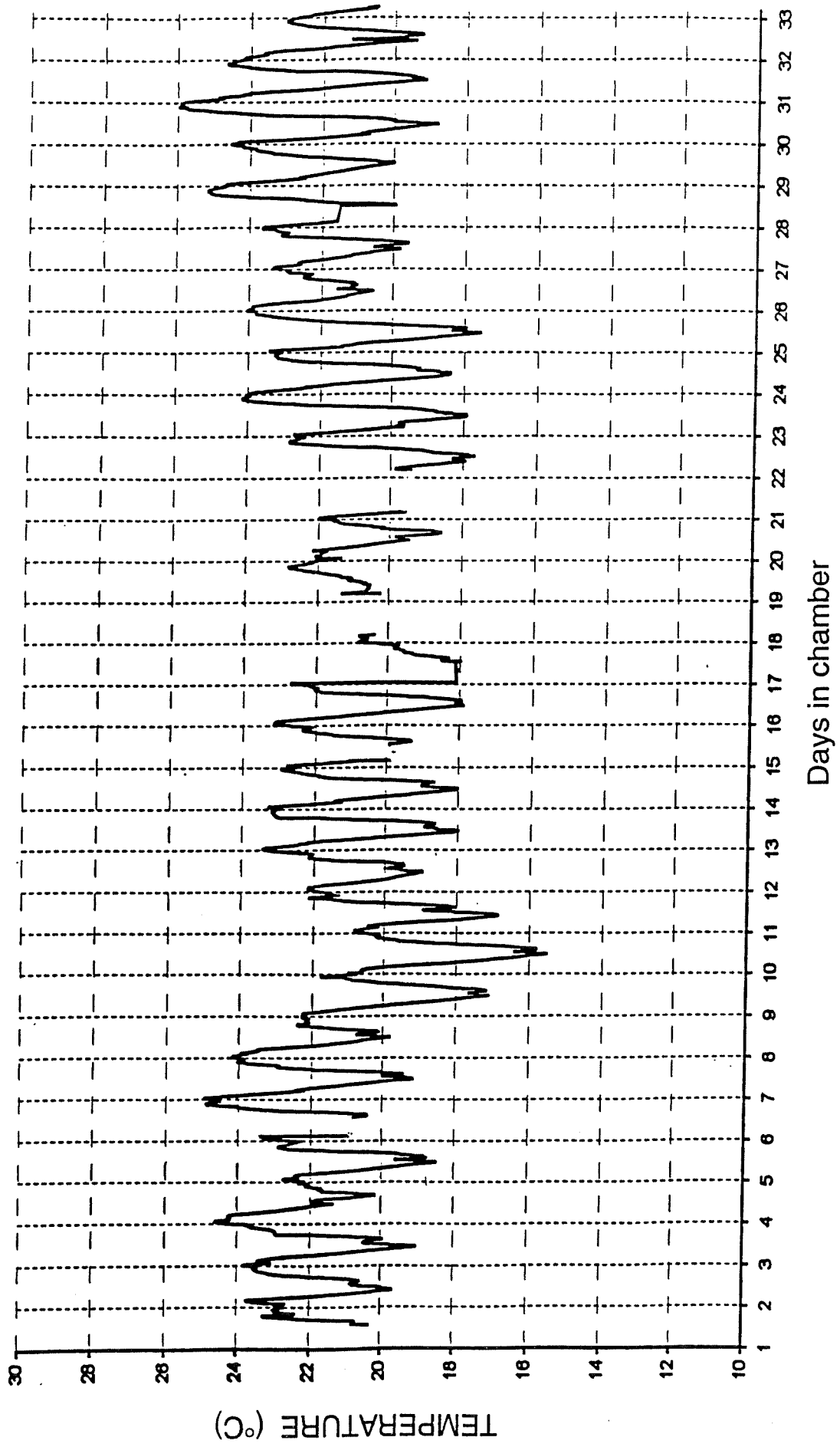
# Operation EVEREST III COMEX '97

## Progression profile

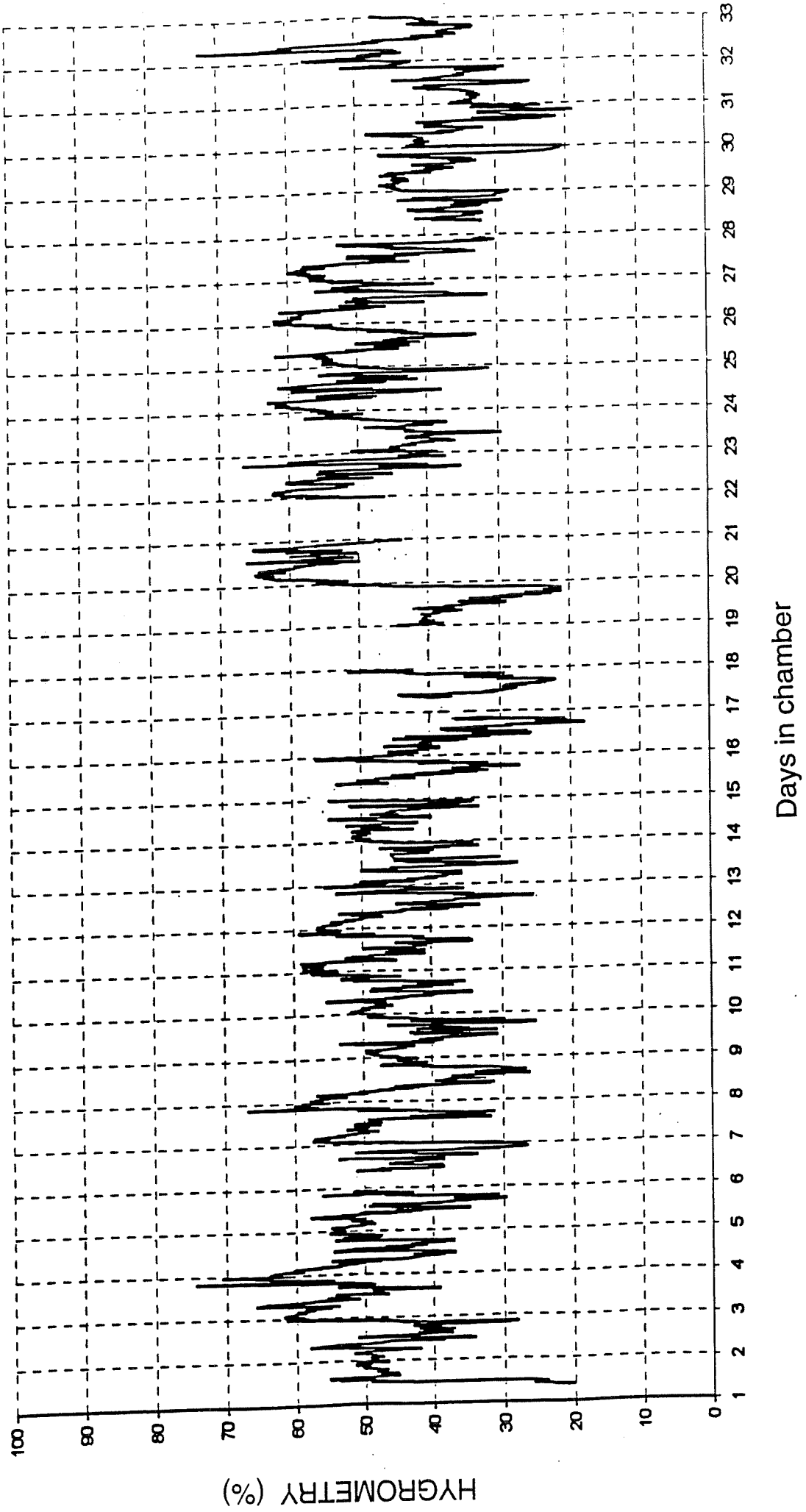


Day in chamber

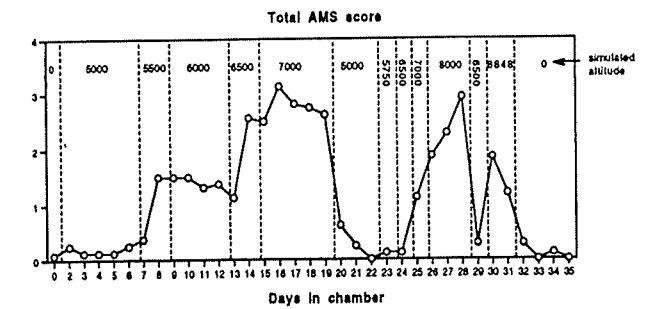
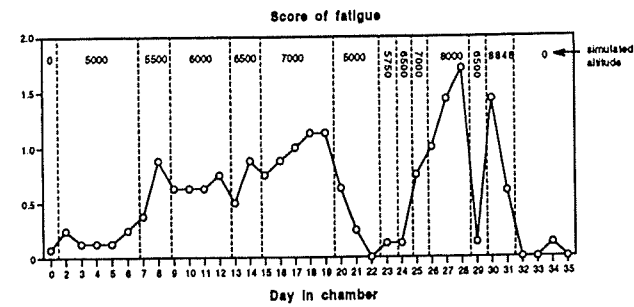
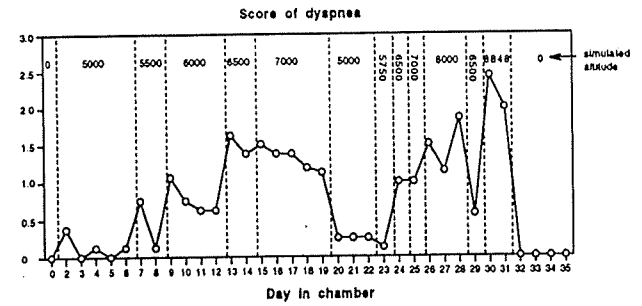
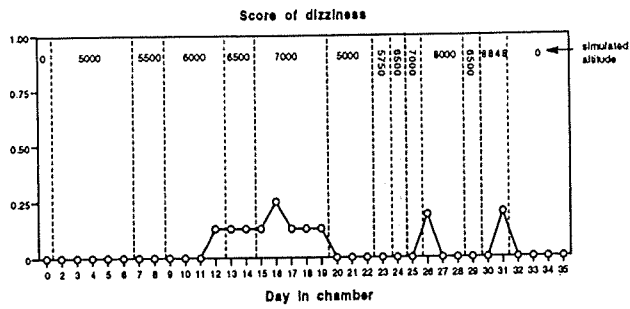
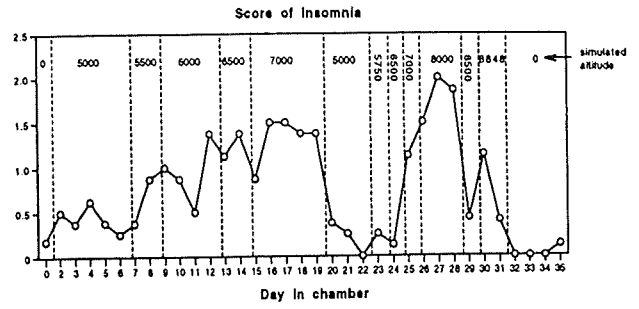
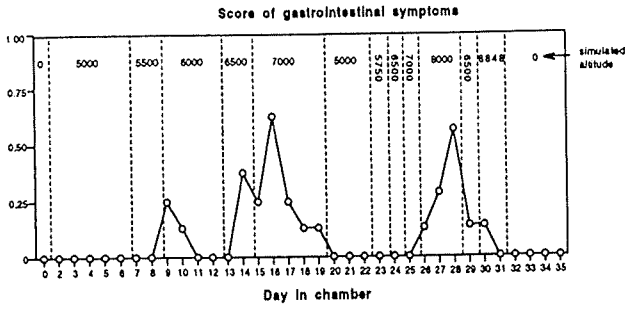
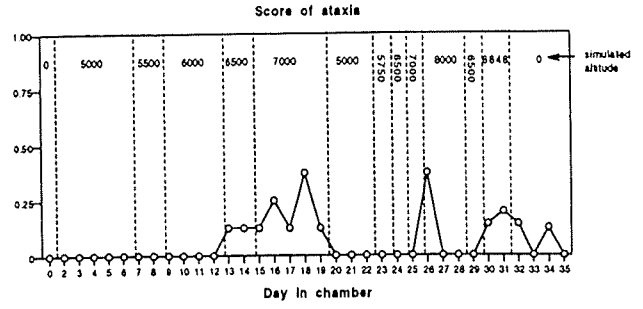
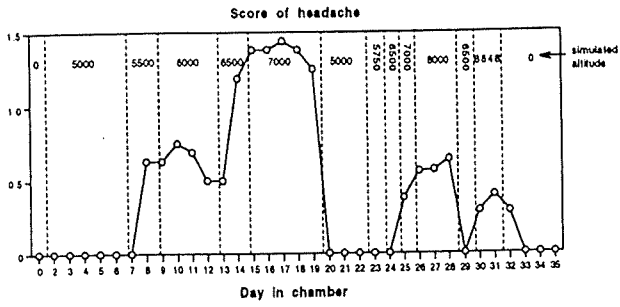
OPERATION EVEREST III (COMEX '97)

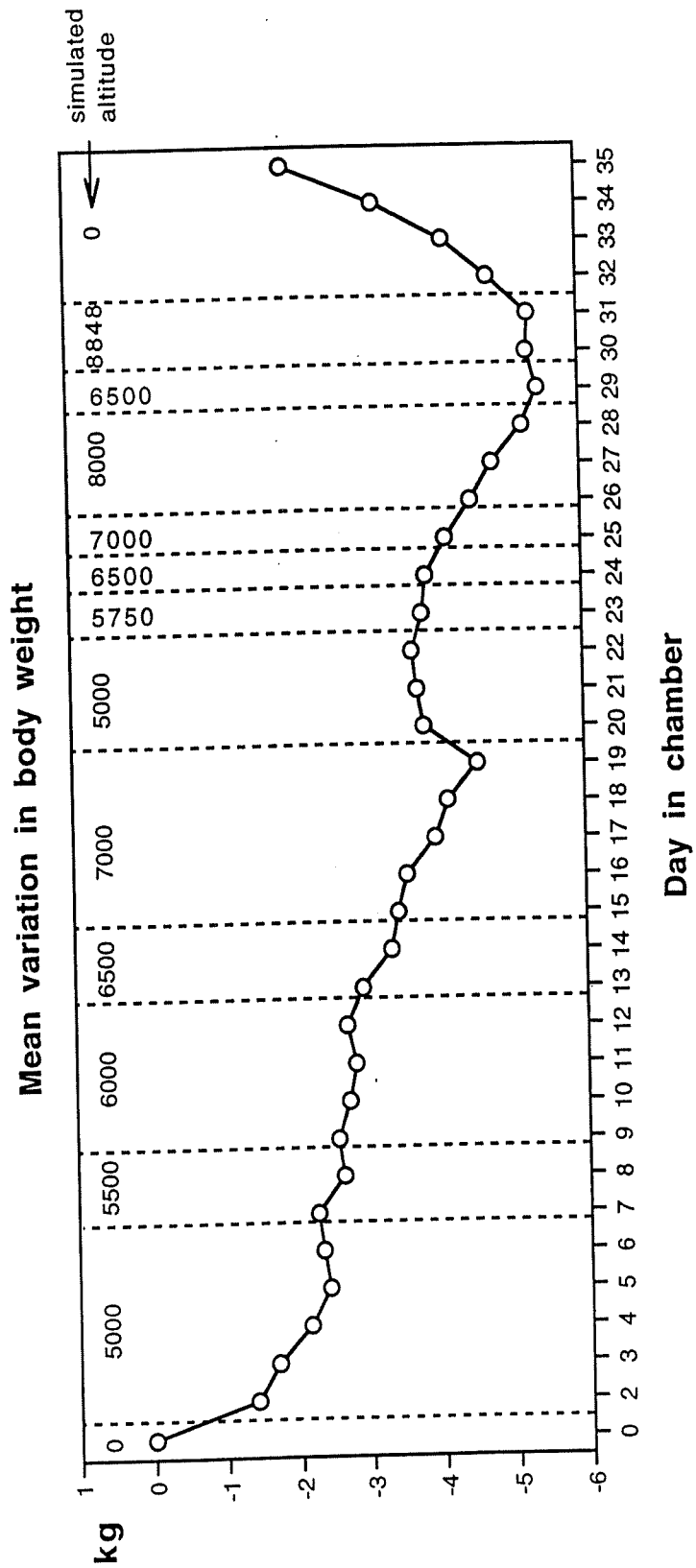


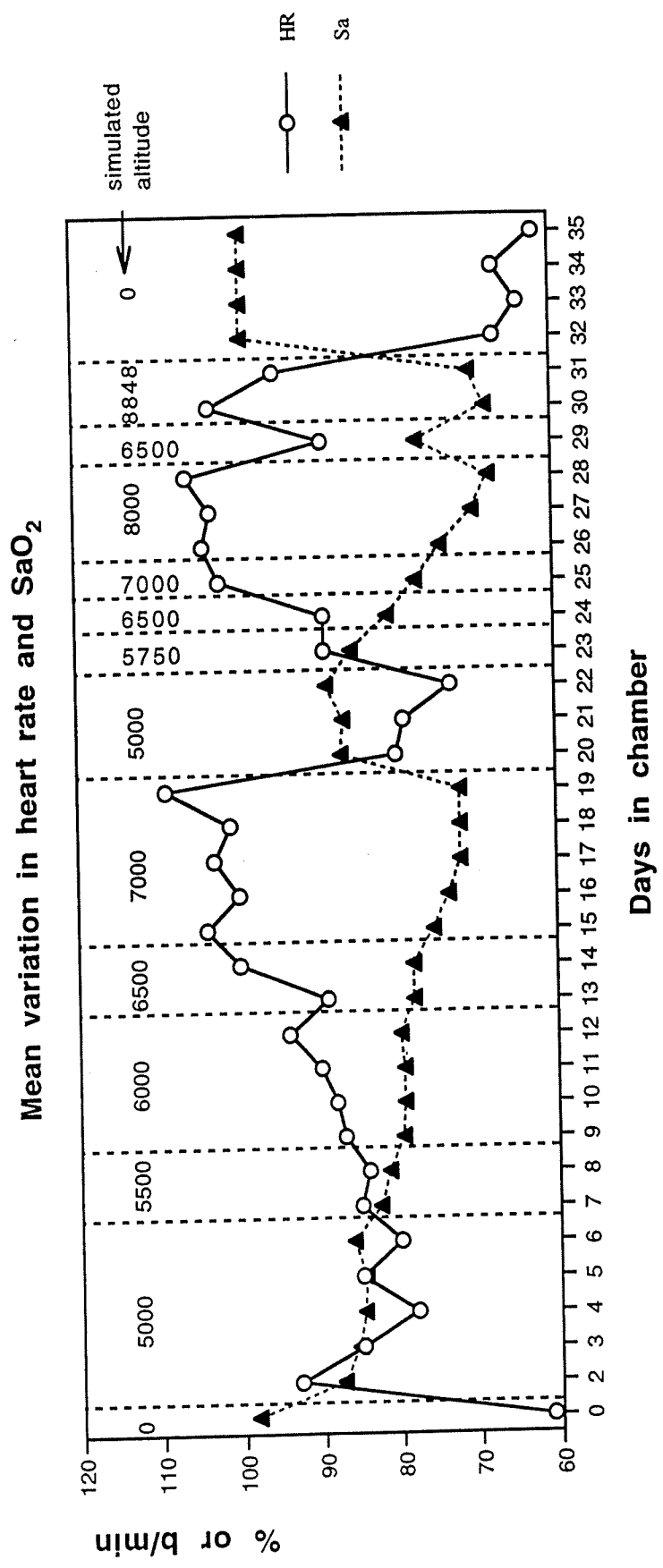
OPERATION EVEREST III (COMEX '97)











% or b/min

