Physiological and Neuropsychological Characteristics of World-Class Extreme-Altitude Climbers

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ON MAY 8, 1978, Reinhold Messner and Peter Habeler demonstrated that altitudes higher than 8500 meters could be climbed without bottled oxygen. Until then it had been widely assumed that such a feat was physically impossible due to the low oxygen tensions on the summit slopes of Mount Everest, K2, Kangchenjunga and Lhotse. This opinion was in part based on the experiences on the British pre-war Everest Expeditions when the altitude of 8560 meters could never be passed without supplementary oxygen. It is noteworthy, however, that members of these expeditions ascended to that altitude without oxygen and suffered no permanent ill effects. After Hillary's and Tensing's successful ascent of Mount Everest with massive use of oxygen, it seemed clear that future expeditions would use the same tactics. Some scientists also claimed that the eventual summiters of an ascent without oxygen would suffer from severe brain damage.

After Messner's and Habeler's summit success, "oxygenless" ascents of the four mountains were repeated by a number of climbers. However, it became obvious that the true limits of human tolerance to hypoxia are touched during those adventures and that there is no margin for errors. This point had already been stressed by Hillary, who expressed the opinion that the summit of Everest could eventually be reached without oxygen, but that the risks involved were enormous. In the last eight years this prediction has been sadly confirmed by the death of several world-class climbers above 8000 meters due to avoidable accidents and/or exhaustion.

The recent interest in the physiological problems connected with the climbing to altitudes higher than 8500 meters is illustrated by the exciting work performed during Dr. West's American Medical Research Expedition to Mount Everest in 1981 (1), and Dr. Houston's Operation Everest II in 1985 (2). This prompted us to study some characteristics of world-class climbers who all had reached the summit of one of the four highest peaks in the world without supplementary oxygen (3). Among them were the two climbers who have summited all fourteen 8000-meter peaks and climbers who have climbed 8000-meter peaks including Everest in 24 to 48 hours from Base Camp to the top and back. (See Table 1.) The studies were done two to 12 months after the last extreme altitude exposure, that is at a time when most physiological changes induced by hypoxia have presumably disappeared. We focused our investigations on the mechanisms responsible for oxygen uptake and delivery to tissues and on the permanent effects of hypoxia on the brain. In a number of tests the static and dynamic long-volumes were measured and found to be within normal limits for an age-matched control population. Interestingly enough the most successful climber has lung volumes at the lowest limits of normal. The dimensions of the right and left heart were measured by echocardiography, using ultrasound for imaging and were found to be normal. This was somewhat a surprise since we had expected that the right heart would be enlarged as a consequence of increased pressure in the pulmonary circulation induced by hypoxia. However, apparently these changes are rapidly reversible upon return to sea level. The morphology and metabolic activity of the muscle was studied in biopsies taken from the thigh. There was an increased content of certain slow-twitch, fatigue-resistant fibers in the muscles of these climbers. There were also changes in fiber size leading to a favorable condition for tissue oxygenation. This was further illustrated by the fact that the number of blood capillaries per area was significantly greater in these climbers than in controls. There were signs for an increased capacity of the muscle to oxidize fat, which may be of advantage during prolonged exercise.

Table 1
Subjects' Climbing History

Subject	*Country of Origin*	*Age*	*Peaks over 8500 meters*		*Peaks Between 8000 & 8500 meters*
			Without O_2	*With* O_2	*Without* O_2
RM	Italy	42	5		13
JK	Poland	39	4		10
EL	Switzerland	28	2		7
MD	Germany	50	2	1	3
KW	Poland	37	1	1	3
WR	Poland	44	1	1	1
DS	UK	42	1	1	2
HK	Italy	31	1		6
NJ	Switzerland	27	1		4
FM	Italy	38	1		2
PH	Austria	38	1		1
HE	Germany	38	1		1

It has been suggested that climbers like Messner and Habeler might be extraordinary in their capacity to take up and/or to utilize oxygen. It was postulated that climbing without bottled oxygen to the top of Mount Everest might only be possible for individuals, characterized by an extremely high maximal aerobic power. We, therefore, performed studies on the maximal oxygen uptake in these climbers in two different laboratories under different experimental conditions. The maximal oxygen uptake represents the functional capacity of the cardiovascular system to transport oxygen to the tissues of the body and is defined as the maximal amount of oxygen a person can take in and use during physical work. Much to our surprise the maximum oxygen uptake of elite climbers, even though it was higher than observed in untrained subjects fell within the range of amateur marathoners but was well below the values of elite long-distance runners. The mean value for the whole group was 60 ml oxygen per kg per min, whereas world-class marathon runners reach values higher than 80 ml.

The main mechanism by which the body compensates for low environmental oxygen tensions is hyperventilation that is an increase in ventilation both in frequency and volume. Ventilation at rest was higher in the world-class climbers than in control subjects, both at sea level and at 5300 meters in a decompression chamber. This observation is in agreement with previous reports by Schoene and co-workers (4) who observed that among the climbers of the American Medical Research Expedition to Mount Everest the summiters were characterized by resting hyperventilation and by a greater ventilatory response to hypoxia. This is probably either the consequence of a persisting ventilatory acclimatization or an inborn advantage of these climbers enabling them to climb so high without too much punishment. The ventilatory response to exercise at sea level was virtually the same in climbers as in control subjects. During exercise at 5300 meters, however, the ventilatory response of the climbers was higher than in controls.

On the whole it appears that the main feature of a successful extreme altitude climber are a high capacity to oxydize fat in the muscles, a favorable geometry for blood-tissue gas exchange and respiratory control centers with immediate and sensitive reaction to hypoxia. The maximal capacity to take up and to use oxygen is not extraordinary in the group of climbers studied and far below that of world-class marathoners. However, it is reasonable to suggest that a skilled climber with a very high oxygen uptake capacity would perform better than the best of the present day's climbers. The most important feature, however, for climbing the highest peaks of the world without supplementary oxygen is a strong motivation and an exceptional drive. Reinhold Messner and Jerzy Kukuczka, the first mountaineers who climbed all the 8000-meter summits typify these climbers. They are characterized by rather normal physiological features, but by the obsessive need to be the first and best and to climb "by fair means," that is without the aid of oxygen in any phase of the ascent.

Hypoxia acutely impairs the function of the brain. Climbers to extreme altitude repeatedly have reported hallucination of the visual, auditive and somatosensory type. Impaired sensory, perceptual and motor performance has been observed in the laboratory under simulated high-altitude conditions and in climbers in the Himalaya. These impairments of vital cerebral functions may lead to faulty behavior and deadly mistakes. Most of these changes seem to be rapidly reversible upon return to low altitude although climbers have reported defective short-term memory for months after an expedition. The question whether there is any permanent residual brain damage particularly after repetitive extreme altitude exposure has been hotly debated, and it has been suggested that climbing to extreme altitude without bottled oxygen should be discouraged similarly to professional boxing since it might cause permanent brain injury.

We have therefore studied eight of our most successful extreme altitude climbers with a comprehensive battery of neuropsychological tests (5). These individuals had collectively climbed more than sixty 8000-meter peaks without supplementary oxygen. The clinical and neurological examination of all of them was entirely normal and most of them had a higher IQ than a control population. In a test of concentration, however, the majority performed irregularly and with a high error score. Memory assessment revealed a defective short-term memory in half of the subjects with normal long-term memory. The cognitive flexibility which was assessed with measurements for spontaneous word and figure idea production and adaptive flexibility was also impaired in half of the subjects. There was no significant impairment of motor performance. Altogether the dysfunctions found in concentration, short-term memory and cognitive flexibility as well as a lack of perceptual or other higher cortical defects suggested a dysfunction of the fronto-temporal basal brain areas. There was also some correlation of these changes with pathological findings in the electroencephalogram.

These climbers function entirely normally in daily life and in the challenging environment of extreme altitude. The subtle changes which are most likely a consequence of repetitive hypoxic stress to the brain can only be detected in certain tests. It should also be remembered that the British climbers who first ascended to extreme altitude without bottled oxygen in the years of 1921 to 1938 had subsequently very successful professional careers and remained astute and sharp into their old days.

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