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Perception disorders and behavior changes in high-altitude mountaineers

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High-altitude mountaineering involves exposure to reduced partial oxygen pressure, which leads to a number of psychical and physical disturbances in the climber's body and has an impact on the function of the central nervous system. These disorders can be intensified by external environmental factors such as energy deficit, fatigue, high true altitude, stress and cold. The climber's central nervous system can experience functional and morphological changes, mostly of a non-permanent character. All these factors can lead to perception disorders and changes of behavior in climbers as compared with their perception abilities and behaviors at lower altitudes. Problems with concentration, rational assessment of situations and one's own capabilities – and in extreme cases – delusions or autistic symptoms may also occur. Emphatic behaviors of climbers at high altitudes seem to be seriously hindered, since their brain function focuses on survival. An assessment of ethical behaviors in such conditions is very difficult as humans normally behave ethically at "sea-level" where the brain functions properly in under appropriate partial oxygen pressure.

KEY WORDS: high altitude sickness, behavior changes, hypoxia, alpine conditions, climbing, perception disorders.

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What is already known on this topic?
Climbing the altitude of 3000 m, especially by unadapted individuals or individuals with health problems hindering their adaptation, may lead to a number of physical and mental disorders. The climbers may experience neurological disorders as well as perception disorders and behavior changes.

Introduction

The concept of high altitude is fairly conventional. Most authors define the altitude of 1500-3500 m as high altitude; 3500-5500 m as very high altitude; and above 5500 m as extreme altitude [1].

The main variable affecting the body's physiology and ability to function at high altitudes is oxygen concentration, which, for example, at 2000 m, is about 79% of sea-level oxygen concentration, while at 8000 m, only about 34% [1]. Such low oxygen concentration can be tolerated by a well-adapted human body for a relatively short time, i.e. for 1-2 days or even shorter. If it is longer, the compensatory capabilities of the body decrease radically leading to death.

There are two mechanisms that enable humans to function or even continue physically exhausting climbing at altitudes over 7000 m. In terms of physiology the simplest solution is the use of oxygen tanks to make up the oxygen deficiency. However, ascents with the use of bottled oxygen are commonly regarded as "unsportsmanlike". One must also account for the so-called "oxygen trap". If the use of bottled oxygen becomes suddenly impossible due to, for example, a sudden weather break, avalanche or loss of equipment, a great oxygen deficiency occurs which can be compared to sudden decompression of the cabin of an airplane flying at a high altitude. The other compensatory mechanism is acclimatization, i.e. a step-by-step adaptation to high-altitude alpine conditions. The rate of adaptation is crucial here. The more time to adapt the body has, the less intensive symptoms of height intolerance are. However, even the most appropriate acclimatization procedures do not guarantee the avoidance of health problems. Researchers claim that about 50% of alpine climbers experience symptoms of high altitude sickness after reaching the altitude of 4700-4900 m [2, 3]. It should be kept in mind that such research studies have been usually conducted on carefully selected groups of young, physically fit persons with no serious health problems, who know the rules of high-altitude climbing and are aware of the importance of acclimatization. A high level of physical fitness, or even the best performance fitness of the body at sea-level or slightly above it, do not ensure a lower risk of incidence of acute mountain sickness [4]. A prospective study on participants who were training before a mountaineering expedition revealed that the incidence of high altitude sickness was no lower in intensively training individuals [5]. There are, however, large differences between individual climbers. Many professional climbers can function well and continue climbing at 8000 m, while in many other individuals a high-altitude cerebral edema can occur already at an altitude of 3500 m. These differences can be genetically explained [6].

Factors intensifying disorders of the function of the central nervous system at high altitudes

The incidence of perception disorders and behavior changes during high altitude mountaineering is complex. The increasing oxygen deficiency is only a part of this problem. Other factors include exposure to high true altitude, low temperature, harsh weather conditions and reduced supplies of calories.

Heights reached by climbers, especially true altitudes, definitely affect their perception ability. Regardless of the altitude above sea level, one can perceive distances or sizes of objects by looking at them from above or below [7]. When looked at from above all distances, including the perception of the height and the distance to the nearest safe base camp, become subjectively larger, which definitely increases the fear of not accomplishing the task. This interesting phenomenon can be explained by the positioning o the viewer against the horizon. When looked at from below, there are a number of indirect reference points between the viewer and the horizon, which reduce the viewer's perception of "infinite distance". In a distance assessment from above (especially while in the mountains) the reference point is the horizon, i.e. a line "infinitely distant" from the viewer. For a viewer from above, a given point will always be near the horizon. This phenomenon serves as an explanation of experiences of individuals suffering from acrophobia [7].

Another factor negatively affecting the logical, critical and decision-making functions of the brain is quantitative and qualitative sleep deficiency. It increases with altitude: the lower partial pressure of oxygen, the less regenerating the sleep [8]. It is a vicious circle: sleep disorders have a negative impact on the ability to function at high altitude and regeneration mechanisms, which in turn may lead to the intensified symptoms of high altitude sickness and sleep disorders.

The proper function of the body not only requires the appropriate amount of oxygen for the brain, but also energy. High-altitude climbing expeditions and physical efforts in extreme conditions demand high supplies of assimilable energy [9]. Authors of an exercise physiology study assessed the energy expenditure of participants in a desert expedition, who covered a daily distance of 25 km at sea level [10]. Their daily energy expenditure was estimated at 4.817 ± 794 kcal, accounting for difficulties in energy supplies and prior recommendations to participants to gain about 5 kg in weight to increase energy supplies of the body [10]. During high-altitude climbing expeditions, especially at above 8000 m and in winter conditions, the energy expenditure increases significantly. With the higher altitude; i.e. higher energy demands, energy stores are more and more difficult to replenish. Climbers experience loss of appetite, nausea or vomiting, difficulties in meal preparation, quantitative limits of food (reduced backpack weight) and all sorts of satiation problems caused by the impaired function of the digestive tract [11]. It should also be noted that with an increased altitude the olfactory and gustatory functions become significantly impaired, and eating related olfactory sensations are seriously disturbed. A statistically significant decrease of the olfactory function at high altitudes was noted at the altitude of 2200 m [12]. This definitely contributes to the loss of appetite and increased energy deficit. Decision making, logical thinking and self-control ability depend on energy supplies, i.e. appropriate glucose blood levels [13]. A low glucose blood concentration weakens volitional processes: A lowered activation of the prefrontal cortex can be noticed followed by an increased stress level and the focus on survival. While making decisions one subconsciously avoids actions other than strictly life-saving ones [14]. Changes in the glucose blood level, mainly in the form of short periods of hyperglycemia and longer periods of hypoglycemia, can precede symptoms of high altitude disease [15].

Another (hardly measurable) factor affecting the decision-making ability and cognitive processes is fatigue connected with long-lasting stress and awareness of the importance of undertaken decisions. A study of 1000 parole rulings made by experienced judges revealed that 75% of favorable judicial rulings were made at the start of the day, when the judges were not tired yet, and than the percentage of favorable rulings dropped gradually to nearly zero at the end of the day [16].

Disorders of the function of the central nervous system at high altitude

The brain reacts quickly to sudden drops in partial pressure of oxygen, which is due to its large oxygen consumption needs. In conditions of physiological partial pressure of oxygen, i.e. below 2000 m, the human brain consumes about 20% of assimilated oxygen. The mentioned changes of the partial oxygen pressure lead to the so called “air hunger”, when the oxygen demands cannot be successfully met. It should be remembered that reaching high altitudes requires intensive brain activity, overcoming multiple problems related with climbing, long-lasting concentration and constant preparedness for sudden and unexpected situations. At high altitudes a number of neurological symptoms of disorders of short-term memory, concentration, awareness and – most importantly – rational behavior may occur [1].

Responses to a high altitude are complex processes involving more symptoms than simply memory, coordination or mood disorders. An important problem related to high altitude climbing are morphological and biochemical changes in the brain. Due to the oxygen deficiency at 7000-8000 m permanent damage to the brain may occur [17]. Long exposure to anoxemic hypoxia can result in grey matter atrophy as well as changes in the white matter [18]. The properly functioning neurons enable acquisition of skills and information, learning, logical analysis of data, and precision of association relative to the actual external circumstances. The cerebral cortex fulfills three main functions: motor, sensory, and association. The last one is responsible for one’s meaningful perception experience of the world, i.e. for connecting facts or for spatiotemporal orientation. At the tissue level, hypoxia leads to a relatively quick occurrence of physiological changes in the brain. In a famous experiment called EVEREST II a group of volunteers spent 40 days in conditions simulating a 40-day ascent of Mount Everest. They were in an altitude chamber with a gradually decreasing partial pressure of oxygen and temperature relative to the real altitude. Neurological changes such as disorders of memory, association and logical thinking appeared in participants after a few days and remained for a number of days after the “expedition” reached the peak, i.e. until the partial oxygen pressure was restored to the sea-level value [19].

The specific impact of high altitudes on the instinct of self-preservation still remains debatable. There are some reports showing that people at high altitudes experience increased suicidal tendencies [20]; however, there have not been any objective studies on this issue among climbing communities. Without a doubt, exposure to high altitude has been shown to induce changes in the hippocampus, cortex and striatum, including neurodegeneration, DNA fragmentation and increased apoptosis. These changes intensified after 7 days following the exposure to conditions corresponding to the altitude of 6100 m, but they receded after 21 following the exposure [21]. The results of these studies show that climbers can “return to normalcy” some time after a high-altitude expedition. However, during alpine climbing morphological changes in the brain may affect cerebral functions.

The aforementioned changes observed in the brain at high altitudes (both true and absolute) must affect in some way the behavior and the psyche of climbers. Along the increasing altitude climbers may experience disturbances of their assessment of situations, apathy, or even “intellectual void” [22]. The ability of critical thinking can be seriously impaired, and delusions, in particular persecution delusions, may occur. Other symptoms may include increased alienation and withdrawal [22]. These phenomena definitely affect group and social behavior patterns, including the willingness to help others.

Universal ethics or "sea-level ethics"

The properly functioning cognitive and coordination processes in humans, such as the ability of an objective assessment of situations, anticipation (of weather or snow conditions) or assessment of one's own skills are crucial in high altitude mountaineering. They also affect the behavior of climbers towards themselves and other expedition participants. The question remains to what extent decisions made in extreme conditions are climbers' conscious decisions, or are merely instinctive realizations of "autonomous' actions of the human brain. This question is one of the crucial ethical issues related to climbers' behavior at high altitude. Ethics, as a branch of philosophy developed in ancient Greece, was a "sea-level ethics" created by and for individuals functioning in conditions of normal partial oxygen pressure determining the proper function of the brain. Many decisions made by humans in an objective manner, are in fact, determined by a number of often unnoticed external stimuli. In high altitude conditions climbers are influenced by a variety of extreme environmental factors such as increased hypoxia associated with oxygen deficiency, exposure to true altitude, fatigue, cold and stress. All of them lead to situations in which climbers' decisions may differ from decisions otherwise undertaken at low altitudes in normal conditions. Under such circumstances the function of the brain may slip out of volitional control. The famous Minnesota Starvation Experiment conducted by Ancel Keys in the 1940s brought many interesting, although ethically controversial, results regarding the function of the human brain in extreme conditions. The volunteers for the experiment, who had been selected from the ranks of conscientious objectors, received gradually reduced food rations until the level of a few hundred kcal a day was reached. At some point the hunger became such a strong stimulant that the experimenters disallowed outdoor walks because the participants began to rummage through garbage bins in search for food leftovers. However, further reductions of food rations and thus lowering energy supplies, did not evoke participants' resistance. Inactivity, increased apathy and decline of interpersonal relations were noted among the participants. After the rations were increased and nourishment was improved, intense protests ensued accompanied by demands of larger food rations [23]. The participants did not put up a struggle at the most critical moment, when their central nervous system regarded their resistance as a completely redundant energy expenditure. Even when facing death from starvation – an experience reported by many participants – they were unable to engage in any form of activity [24].

The behavior patterns of individuals with symptoms of high altitude sickness can be compared to symptoms experienced during panic attacks. Both states involve similar metabolic and vegetative changes [25]. It seems that such human behaviors are predominantly determined by the self-preservation instinct [26]. The observed symptoms include the increasing feeing of isolation and withdrawal, reminiscent of autistic symptoms. Also such individuals can experience hallucinations and delusions, in particular, persecution delusions. In such conditions humans confine their behaviors to a very few, simple physiological functions: breathing, fluid taking and motor control. Often the simplest activities such as entering a tent, taking off boots or strapping on crampons may be challenging tasks, and their successful accomplishment may require long hours [26]. More complex decisions, for example, related to emphatic behaviors towards the other expedition participants may exceed the capabilities of the climber's brain.

Conclusion

The human body is prepared to function in the most optimal way at relatively low altitudes. The process of evolution made marine animals adapt to living conditions on land, and further stages of evolution could take place away from the sea. The human body can function without major problems at the altitude of 2000-2500 m. Alpine climbing expeditions, in particular above the level of 8000 m in winter conditions, are examples of the most extreme physical and psychical loads of the human body. Humans are in no way physiologically adapted to such conditions, and remaining in such conditions defies the human instinct of self-preservation. High-altitude climbers are stimulated by the need of adventure, seeking new sensations and the need to prove oneself. These motivations come from relatively newly evolved brain structures, being the locations of centers associated with empathy, ability to sacrifice for others, even at the expense of one's health or life. At the start of a climbing expedition these centers function equally efficiently. Further on, climbers begin to experience hypoxia, sleep depravation, fatigue, reduced energy supplies and frequent episodes of hypoglycemia. With the increasing elevation the distance to a safe base camp becomes longer, and covering this distance becomes more and more difficult. At the metabolic and psychical levels panic reactions are activated. An anoxic and undernourished brain is not able to function efficiently and optimally. It gradually deactivates those areas which are not essential for life preservation. The brainstem and neuronal structures, which control all regulatory and reproductive systems of the body that are more primitive than emotions, work properly. The activity of the limbic system decreases, although the area of the hippocampus responsible for the analysis of contextual situations and for signaling life-threatening situations to the amygdalae (in consequence, activating the fight-escape mechanism) remains active. The activity of the neocortex – which is best developed in primates and is responsible for the so-called higher functions such as social behaviors, culture or empathy not directly necessary for survival - declines gradually. It is this area of the brain which contains centers responsible for ethical assessment of behaviors and for stimulation to act emphatically. The ability to act in accordance with one's own system of values is only possible as long as in the fragile balance between conscious will and autonomy of the brain fighting for survival the former prevails.

Objective disorders of cognitive functions and changes of behavior in high-altitude climbers have been well documented. These disorders can be now studied further, and metabolic or morphological changes in the climber's body can be qualitatively or quantitatively assessed. A much more difficult question is whether at a certain altitude human "sea-level" ethical mechanisms can cease to function, independently of our own will. Can we consciously act unethically in order to increase our chances of survival?

This question will most likely remain unanswered. Any objective answer to this question would require examinations of the human brain in conditions in which it does not function properly, but this, by default, disqualifies any proper research conduct. It should be accepted that we are unable to predict human behaviors at high altitudes. This uncertainty and the need to prove oneself are definitely the motivations for mountaineers to reach such altitudes.

What this study adds?

The study discusses cognitive and behavioral disorders experienced by high-altitude climbers. The authors examine the effects of such factors as fatigue, low temperature and life-threatening situations that often occur in synergy. They also indicate problems connected with the function of the central nervous system and problems related to the assessment of climbers' behaviors from the perspective of the so-called "sea-level ethics".

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