Physiological Responses and Adaptations to Exposure from Moderate to Extreme Altitude: A Case Study of the Youngest Malaysian Climber to Scale Mt. Everest

Adam Feizrel Linoby
Mohd Azmi Nias
Badli Esham Ahmad
Sufyan Zaki
Roger Canda
Hanifa Sariman
Zulkhairi Azam
Aripin Amat

ABSTRACT

The intense environmental conditions at the summit of Mt. Everest put human physiology near the limit of tolerance. The immediate (acute) effects of severe oxygen deprivation of extreme altitudes related to the human response and the adaptations to prolonged exposure (chronic) are complex. Mohd Nasuha Shamsudin, the youngest Malaysian climber to scale Mt. Everest was selected for the case study. Analysis of both acute and chronic physiological responses and his self-reported health related symptoms during his expedition to summit of Mt. Everest was studied. The purpose of this study was to describe the respondent's responses and adaptation to his cardiovascular, respiratory, bioenergetics, physical performance as well as the health problems in different level of altitude. The finding, found several primary symptoms of hypoxia including headache, nausea, dizziness, insomnia, shortness of breath upon exertion, persistent rapid pulse, excessive flatulence and general fatigue upon reaching to high altitude. The respondent also reported common problem at high altitude including loss of appetite, dehydration and severe 'khumbu cough'. Useful information was gained based on the climber's self-reported measurement and experience in relations to the extreme altitude acclimatization and sickness and the physiological implication at an altitude.

Keywords: *physiological responses, acclimatization, Everest, hypoxia, Malaysian*

Introduction

The composition and temperature of the atmosphere at high altitude is substantially different than at the sea level. These differences can affect living organisms, including humans. At high altitude, atmospheric pressure is lower compared to sea level. This is due to the two competing physical effects of gravity, which cause the air to be as close as possible to the ground; and the temperature of the air, which causes the molecules to bounce off each other and expand. (Askew, E., 2002) The lower atmospheric pressure affects animals and humans, due to the decrease in the partial pressure of oxygen. Because of the lower pressure, the air expands as it rises, which causes it to cool. Thus, high altitude air is cold, which is a characteristic of alpine climate. This climate dramatically affects the ecology at high altitude (Beall et al., 2002). Since few people have experienced such altitudes, it is hard to know who may be affected. There are no specific factors such as age, sex, or physical condition that correlate with susceptibility to altitude sickness. Some people get it and some people don't, and some people are more susceptible than others. Most people can go up to 8,000 feet (2,438 meters) with minimal effect (Hackett et al., 1981).

Extreme temperatures is not the only obstacle that humans face. According to Huey et al. (2001), high altitudes also pose serious physiological challenges on the body. Some of these effects are reduced arterial P02, the rebalancing of the acid-base content in body fluids, increased hemoglobin, increased RBC synthesis and enhanced circulation. Oxygen (O2) diffuses down a pressure gradient across the alveoli in the lungs into the circulatory systems and binds to hemoglobin (Hb) (Berne & Levy, 1993).While at high altitude when oxygen pressure falls, the body puts in place a number of counter measures. Breathing and pulse rates increase, as does the heart's pumping efficiency, and the size and number of red blood cells, which are responsible for the blood's oxygen carrying capacity. Rusko et al. (2004) stated in his study that, the shortage of oxygen also has a number of unwanted consequences; increased pressure in the pulmonary (lung) circulation; changes in blood pH (acidity) values; disturbances in the fluid/electrolyte (salt) balance; as well as the leakage and spread of blood or fluid into surrounding vessels and tissues (fluid extravasations or edema).

Going to altitude or hypoxic environment is not easy and sometimes can be life-threatening situations. Acclimatization to high altitude in a mountainous environment is very important in order to reduce the risks of getting severe mountain sickness and requires many days as human physiological is very complex and is characterized by considerable individual variability (Huey & Eguskitza, 2001).There has been a great deal of interest in the factors thought to be related with human physiology and its effects to the human performance. However, uncertainty remains about the causes and inconsistence factors of physiological responses and adaptations while at altitudes (Rusko et al. 2004; Villafuerte et al. 2004; Wilber R. L. (2004). In addition, there are limited amount of data about the overall physiological parameters describing the responses and adaptations at different levels of altitude in most high altitude studies (Rusko, et al., 2004). Many of the high altitude studies tend to report the prevalence of either the health problem or focusing on the physiological effect at altitude (Valencia-Flores et al.,2004). Information on the effect of exposure to difference height of altitude as well as the signs and symptoms of altitude related sickness might aid in the interpretation of the human physiological implication from mild to high altitude.

Mohd Nasuha Shamsudin was used as the subject in a single case study design. He was one of the seven climbers who managed to conquer Mount Everest under the Everest-Felda 2013 project and was recorded as the first to reach the summit at an altitude of 8,848m at 8.31am local time on 21 May 2013. Mohd Nasuha was also recorded for being the youngest Malaysian male climber to summit the Mount Everest. The purpose of this study is to determine the effect of the respondent's exposure to different altitudes on physiological responses and adaptations (i.e cardiovascular, respiratory, metabolic-bioenergetics and physical performance) during the expedition. In detail, this study analyzed the respondent's physiological parameters which include oxygen saturation, heart rate, blood pressure and Peak Expiratory Flow Rate (PEFR). While there is currently no universally accepted classification of altitude, this case studyused the classification system as proposed by International Society for Mountain Medicine where three altitude regions that reflect the amount of oxygen in the atmosphere. High altitude will be used for altitudes in the range of 1500 to 3500 meters, very high altitude for altitude in between 3500 to 5500m and extreme altitude for altitudes above 5500 m (Pollard et al., 2001).

Response and Acclimatization to Altitude

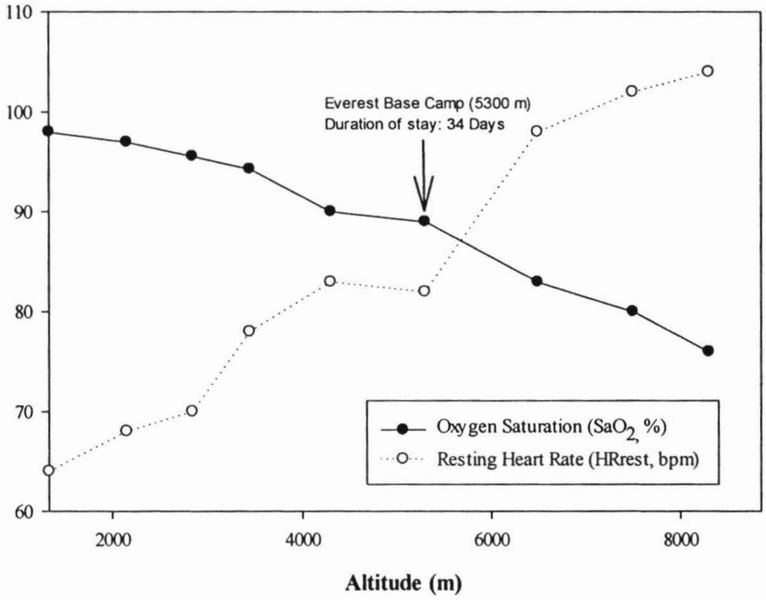
Reduction of atmospheric pressure of oxygen or partial pressure of oxygen (PO_2) at high altitude will diminish the supply of oxygen to the body and cause hypoxia (reduced arterial blood oxygen content). Immediate body response to high altitude will depend on individual fitness level, intensity of work and the altitude at which he or she is exposed. Upon acute exposure to high altitude, several physiological parameters will increase including heart rate, respiratory ventilation, blood pressure, catecholamine production and marked decreased in maximal oxygen uptake (Berne & Levy, 1993).

Lengthy stay at high altitude would allow the body to improve its tolerance to changes in altitude. The acclimatization will depend on the adaptability of the body to chronically adjust to low oxygen environment. Reports from studies show that the complete acclimatization can be achieved as early as 12 days for 'responder' at an altitude above 2000 m and may take several months for the 'non-responder' subject (Wilber, 2004). Increase ability to adapt to altitude will result in improving body cardiovascular, pulmonary, bioenergetics and will likely enhance an individual's physical performance.

Cardiovascular

Majority of studies has reported significant increases in resting and sub maximal heart rate upon exposure to moderate (Wagner, et al. 1986), and high altitudes (Saltin B. 1988; Klausen 1966; Wagner, et al. 1986). Figure 1 shows that during exposure from *high altitude*, there was a gradual increase in the respondent's resting heart rate and from very high altitude to extreme altitude region, the increase was steeper. At 6000 m, the resting heart rate increased dramatically, almost to 100 bpm (beat per minute). This acute response was primarily due to an increase in cardiac output from the rise of heart rate to compensate for the lack of oxygen in the body. The increased in cardiac output also led to arterial desaturation, which resulted in increased of blood pressure. Several studies have shown that significant increase in catecholamine production in the body would also trigger the adjustment of heart rate (Huey & Eguskitza, 2001; Rusko et al., 2004). Several studies have reported that through acclimatization process, a reduction in resting and sub maximal heart rate would occur, indicating a return to normal homeostasis within this system (Saltin, B. 1988; Klausen, 1966; Wagner et al. 1986). This seems to explain the sudden reduction of respondent's resting heart rate after a lengthy stay (34 days) at Everest Base Camp (5300 m). The reduction shows that the respondent is a 'responder' to acclimatization at high altitude.

Figure 1: Nasuha's Mean Oxygen Saturation and Resting Heart Rate at Altitude



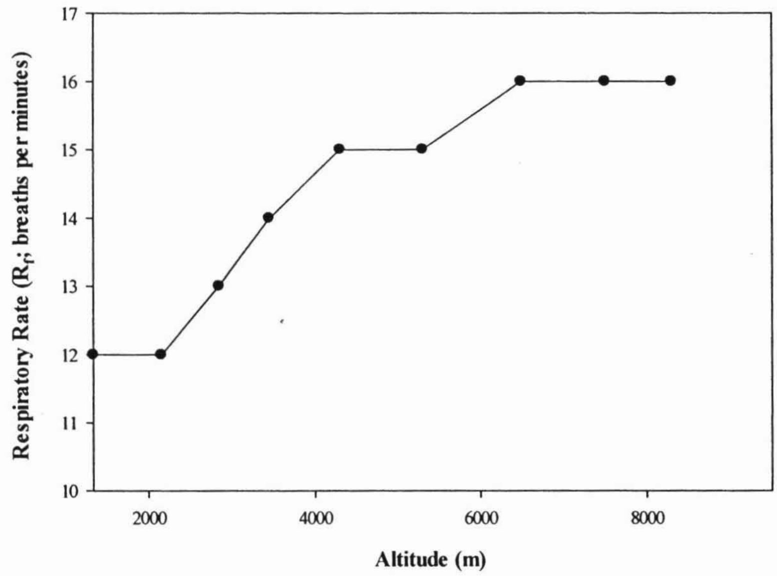
At rest oxygen saturation is significantly lower at high altitude. It is a common observation that oxygen saturation falls during exercise at altitude (Wilber, 2004). Figure 1 shows that at an altitude of 2,000 m, the respondent's level of oxygen saturation in the blood is gradually decreased. After exposure to higher altitudes from 4,000 m to 6,000 m, the oxygen saturation level drops exponentially from the normal value up to extreme altitude. The decrease in oxygen saturation occurred at increasing altitude and this is due to an increased in oxygen demands. Hence, arterial hemoglobin oxygen saturation (SaO_2%) will decrease at increasing altitude and affect even the elite endurance athletes (Rusko et al., 2004).

Respiratory

There is an increase in resting and sub maximal ventilation upon arrival to altitude. This is accomplished through both an increase in rate and volume of breaths (McArdle et al., 2001).Figure 2 shows that breathing rate of the respondent start to risen up above 2000 m altitude. Gradual increase from 12 to 15 breaths per minute is recorded up until an altitude of 4000 m. Known as the hypoxic ventilatory response, there is considerable evidence of individual variations (i.e., responders/non-responders). Ascending to altitude stimulates ventilation as a result of carotid and aortic body sensitivity to reduced partial pressure of oxygen in blood. At the same time this reduces the partial pressure of carbon dioxide, resulting in a lowered H+ concentration in the blood (Klausen, 1966; Wagner et al. 1986).

Chronic exposure to altitude will increase pulmonary blood pressure and vascularity, allowing for improved pulmonary perfusion. Ventilation continues to be elevated with acclimatization and may be an indication of increased chemoreceptor sensitivity to blood gas changes occurring at altitude (Brooks, G.A. et al, 2000). This is evidenced in the respondent as can be seen in Figure 2.

Figure 2: Nasuha's Mean Respiratory Rate at Altitude



Metabolic and Bioenergetic Responses

As mentioned earlier, there is an increase in catecholamine release upon acute exposure to reduced partial pressure of oxygen. The increased catecholamine secretion would allow for a greater reliance on glycolysis for energy production and carbohydrate utilization rate (Huey& Eguskitza, 2001; Rusko et al., 2004). As shown in Table 1, the respondent might go from predominant fat to carbohydrate metabolism as he moves towards the extreme altitude. Starting from base camp (5300 m), the respondent reported a striking reduction of body weight that included both body fat and muscle mass. It has been reported that with prolonged exposure to altitude there is a weight loss and associated changes in body composition. Factors responsible for the loss of weight include loss of appetite and significant reductions in fat absorption. It is possible that alterations in protein metabolism might have occurred. Both losses in lean tissue and body fat have been reported to be in direct association to increased elevation (Rusko et al., 2004).

Table 1 shows that for a higher workload, the level of exertion is increased as the partial pressure of oxygen is reduced. This is reflected in the decline in maximal oxygen consumption (VO_2max) seen with increasing altitudes. Seemingly this decline may begin as low as 1340 m above sea level with a steady decline at a rate of 9% - 10% for each increase in elevation of 1000 m. Because of this apparent decline in VO_2max, performance based on oxygen utilization is reduced (Huey & Eguskitza, 2001). The respondent reported as a very hard climbing at extreme altitude of above 7000 m. This may explained by decreased lactate efflux to the blood and subsequent decrease in muscle tissue pH. This of course would lead to an earlier onset of fatigue (Rusko et al., 2004). Lastly, as mentioned earlier, the hyperventilatory response at altitude adversely affects performance in that the increased work of breathing could lead to an earlier onset of fatigue (McArdle et al., 2001).

Table 1: Nasuha's Rating of Perceived Exertion (RPE) at Five Different Altitudes

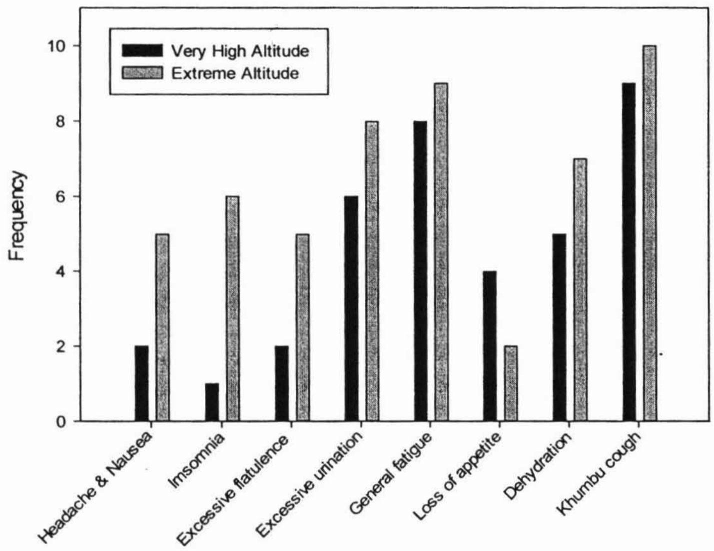
Altitude	RPE	Effort (%)	Remarks
Mild; 1340-2000m	8	40	Very light walking
Moderate; 2000-2999m	9	50	Light walking and climbing
High; 3000-5499m	13	70	Somewhat hard – steady pace climbing
Very High; 5500-6999m	17	90	Hard climbing
Extreme: >7000m	19	100	Very hard climbing

Table 1 shows the reading of Rating of Perceived Exertion (RPE) at 5 Different Altitudes. The purpose of using 5 different altitude classifications was to make it easier for the respondent to report the RPE scale and shows a greater RPE range from mild to extreme altitude. RPE reading shows an increase from 8 (mild) with 40% effort to 19 (extreme) with full effort reported by the respondent towards the summit of Mount Everest.

Health Problems Related to High Altitude

Incidence of health problems faced by the respondent at high altitude and extreme altitude are mostly similar with what have been reported at extreme altitude. Based on the findings, as shown in figure 3, acute mountain sickness (AMS), commonly characterized by headache, nausea, dizziness, insomnia, shortness of breath upon exertion, persistent rapid pulse with increasing altitude occurred more frequent during extreme altitude above 5500 m. Besides the common AMS experienced by the respondent, he also experienced the signs and symptoms of excessive gas and urine production. These symptoms have been reported by several studies as the acclimatization signs of a climber going towards high altitude region (Hackett et al., 1981; Klausen, 1966; Wagner et al. 1986). As mentioned earlier, the respondent reported a striking reduction of body weight that included both body fat and muscle mass. This is common with prolonged exposure to altitude. Both losses in lean tissue and body fat have been reported to be in direct association to increased elevation. Factors responsible for the loss of weight included loss of appetite and significant reductions in fat absorption (Hackett et al., 1981).

Figure 3: Nasuha's Incidences of Health Problems at Very High and Extreme Altitudes



Coughing is the highest incidence affecting the climber with the frequency of 9 times and 10 times at high altitude and extreme altitude respectively. The respondent reported to have suffer from severe Khumbu cough. Majority who spend time at extreme altitude (over 5500m) will develop some degree of the Khumbu cough. It is caused by the low humidity and sub-zero temperatures experienced at altitude, and is thought to be triggered by over exertion (Freer L., 2004). The subject reported that he had suffered from acute coughing that led him to have a minor tear on his muscle chest. The pain in the chest along with the increase hyperventilation as reported in Figure 2 made it harder for the respondent's body to makes adjustment to the decreasing level of oxygen as he ascend to higher altitude. Medical management that was taken by the respondent in order to reduce the intensity of the cough which included drinking plenty hot water, taking throat lozenges, wearing a mask at night, inhaling oxygen and avoiding over exertion so as to keep the breathing rate down hence, decrease the volume of cold air passing through lungs.

Conclusion

Most of the data reported by the respondent confirmed other literature findings. Upon acute exposure to high altitude, several physiological parameters will increase including heart rate, respiratory ventilation, blood pressure, catecholamine production and marked decreased in maximal oxygen uptake. The data used by current case study also agrees with other prior studies which indicate that lengthy stay at altitude will promote gradual chronic adaptation or acclimatization in that the body will improve its tolerance to changes in altitude. Increase ability to adapt to altitude will result in improve body cardiovascular, pulmonary, bioenergetics and will likely to enhance an individual physical performance. The respondent also suffered common health problems at high altitude including AMS and severe Khumbu cough. Useful information was gained based on the climber's self-reported data in relations to the extreme altitude acclimatization and sickness and the physiological implication at an altitude.

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ADAM FEIZREL LINOBY, MOHD AZMI NIAS, BADLI ESHAM AHMAD, MOHD SUFYAN ZAKI, ROGER CANDA, HANIFA SARIMAN,MOHD ZULKHAIRI MOHD AZAM, ARIPIN AMAT.
Universiti Teknologi MARA (Pahang).
linoby@pahang.uitm.edu.my.