1988

Prediction factors for determining acute mountain sickness

Guy W. Leadbetter

The University of Montana

Let us know how access to this document benefits you.
Follow this and additional works at: https://scholarworks.umt.edu/etd

Recommended Citation
https://scholarworks.umt.edu/etd/3279

This Thesis is brought to you for free and open access by the Graduate School at ScholarWorks at University of Montana. It has been accepted for inclusion in Graduate Student Theses, Dissertations, & Professional Papers by an authorized administrator of ScholarWorks at University of Montana. For more information, please contact scholarworks@mso.umt.edu.
COPYRIGHT ACT OF 1976

THIS IS AN UNPUBLISHED MANUSCRIPT IN WHICH COPYRIGHT
SUBSISTS. ANY FURTHER REPRINTING OF ITS CONTENTS MUST BE
APPROVED BY THE AUTHOR.

MANSFIELD LIBRARY
UNIVERSITY OF MONTANA
DATE: 1988
PREDICTION FACTORS FOR DETERMINING
ACUTE MOUNTAIN SICKNESS

by
Guy W. Leadbetter III
B. A., Bowdoin College, 1977

Presented in partial fulfillment of the requirements
for the degree of
Master of Science
University of Montana
1988

Approved by

Thomas R. Whidden
Chairman, Board of Examiners

Date
March 22, 1988
ABSTRACT

Leadbetter, Guy W. III, M.S., March 1988  Exercise Physiology

Prediction factors for determining acute mountain sickness (86 pp.)

Director: Thomas R. Whiddon

Acute mountain sickness (AMS) is associated with many physiological changes incurred while climbing to altitude. The study investigated simple measurements: fitness level, estimated percent body fat, age, and blood pressure (BP) - to determine whether significant correlations (p < .05) existed with AMS-cerebral (AMS-C) and AMS-respiratory (AMS-R), as determined by the Environmental Symptoms Questionnaire (ESQ III). The primary problem of this study was to investigate whether a combination of simple measurements could be used before ascent to predict AMS.

Thirty six males and four females with varying degrees of climbing experience ranging from 0 to 18 years and who ranged in age from 20 to 70 years took part in a Genet Expedition climb of the West Buttress Route of Mount McKinley during the summer of 1987. Prior to the ascent the climbers were assessed for fitness level, percent body fat, age, and BP. The climbers ranged in percent body fat from 5% to 29% and fitness level from 39ml.kg.\(^{-1}\).min\(^{-1}\) to 67ml.kg.\(^{-1}\).min\(^{-1}\). The subjects responded to the ESQ III at altitudes of 2590 m, 3475 m, 4328 m, and 5242 m.

An increase in the incidence of AMS occurred with an increase in altitude. The data at the 4328 m elevation provided the researcher with the optimal data to assess the prediction variables and their relationship with AMS.

A Pearson product moment correlation on fitness level, percent body fat, age, and BP to both AMS-C and AMS-R at 4328m were determined and the only significant (p < .05) correlations were found to exist between fitness and AMS-C (r=-.42, p<.01) and fitness and AMS-R (r=-.31, p<.05).

A discriminant analysis found fitness, percent body fat, and age combined to relate to AMS-C at (r=.58, p<.01) and fitness, and percent body fat were combined to relate to AMS-R at (r=.43, p<.05). Two prediction equations were developed.

The conclusion is that fitness level is inversely related to AMS-C and AMS-R. Therefore, aerobic training should precede high altitude climbs.
ACKNOWLEDGEMENTS

Sincere appreciation goes to Dr. Tom R. Whiddon whose experience, time, and encouragement were inspiring on the road to this accomplishment. Many thanks goes to Dr. James Ulrich and Dr. Michael F. Zupan for their time, advice, and knowledge in computer science. Particular gratitude to Dr. Dona Boggs for sharing her expertise in altitude physiology and whose patience and inspiration made this endeavor possible. I also extend many thanks to the participants of the study and a special thanks to the Genet Expedition staff who are always willing to promote research in an effort to make mountain travel a safe and enjoyable experience. Finally, all my love to my wife Ann and my daughter Kate who made many sacrifices make this an enjoyable experience.
# TABLE OF CONTENTS

**ABSTRACT** ......................................................... ii

**ACKNOWLEDGEMENTS** ........................................ iii

**LIST OF TABLES** ................................................ vi

**LIST OF FIGURES** ............................................... vii

<table>
<thead>
<tr>
<th>CHAPTER</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td><strong>INTRODUCTION</strong> .......................... 1</td>
</tr>
<tr>
<td></td>
<td>Statement of the Problem ................. 7</td>
</tr>
<tr>
<td></td>
<td>Significance of the Problem ............. 7</td>
</tr>
<tr>
<td></td>
<td>Hypotheses ................................... 8</td>
</tr>
<tr>
<td></td>
<td>Assumptions .................................. 8</td>
</tr>
<tr>
<td></td>
<td>Scope ........................................ 9</td>
</tr>
<tr>
<td></td>
<td>Limitations .................................. 9</td>
</tr>
<tr>
<td></td>
<td>Definitions .................................. 10</td>
</tr>
<tr>
<td>II</td>
<td><strong>REVIEW OF THE LITERATURE</strong> .......... 11</td>
</tr>
<tr>
<td></td>
<td>Introduction ................................ 11</td>
</tr>
<tr>
<td></td>
<td>Preventative Protocol ...................... 12</td>
</tr>
<tr>
<td></td>
<td>Mechanisms of AMS ........................... 14</td>
</tr>
<tr>
<td></td>
<td>Environmental Symptoms Questionnaire ... 18</td>
</tr>
<tr>
<td></td>
<td>AMS and Pre-climb Predictors ............. 24</td>
</tr>
<tr>
<td>III</td>
<td><strong>METHODOLOGY</strong> ......................... 28</td>
</tr>
<tr>
<td></td>
<td>Subjects Selection ......................... 28</td>
</tr>
<tr>
<td></td>
<td>Introduction of Subjects to the Study ... 28</td>
</tr>
<tr>
<td></td>
<td>Variable Test Measurements ............... 29</td>
</tr>
<tr>
<td></td>
<td>Step Test .................................... 29</td>
</tr>
<tr>
<td></td>
<td>Skin Fold Measurements (% Body Fat) ... 30</td>
</tr>
<tr>
<td></td>
<td>Blood Pressure ............................. 31</td>
</tr>
<tr>
<td></td>
<td>Environmental Symptoms Questionnaire III 32</td>
</tr>
<tr>
<td></td>
<td>Procedures .................................. 32</td>
</tr>
<tr>
<td></td>
<td>Questionnaires' method of statistical analysis 32</td>
</tr>
<tr>
<td></td>
<td>Statistical Design ......................... 33</td>
</tr>
<tr>
<td></td>
<td>Pearson Product-Moment Correlation ...... 33</td>
</tr>
<tr>
<td></td>
<td>Analysis of Variance ....................... 34</td>
</tr>
<tr>
<td></td>
<td>Discriminant Analysis ..................... 34</td>
</tr>
</tbody>
</table>
Table of Contents cont.

<table>
<thead>
<tr>
<th>CHAPTER</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>IV RESULTS AND DISCUSSION</td>
<td>38</td>
</tr>
<tr>
<td>Results</td>
<td>38</td>
</tr>
<tr>
<td>Discussion</td>
<td>57</td>
</tr>
<tr>
<td>Fitness Level and Percent Body Fat</td>
<td>57</td>
</tr>
<tr>
<td>Age</td>
<td>61</td>
</tr>
<tr>
<td>Percent Body Fat</td>
<td>62</td>
</tr>
<tr>
<td>Blood Pressure</td>
<td>63</td>
</tr>
<tr>
<td>Summary of Findings</td>
<td>63</td>
</tr>
<tr>
<td>V SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS</td>
<td>65</td>
</tr>
<tr>
<td>Summary</td>
<td>65</td>
</tr>
<tr>
<td>Conclusion</td>
<td>66</td>
</tr>
<tr>
<td>Recommendations</td>
<td>67</td>
</tr>
<tr>
<td>APPENDIX A - ENVIRONMENTAL SYMPTOMS QUESTIONNAIRE III</td>
<td>69</td>
</tr>
<tr>
<td>APPENDIX B - GENERAL INFORMATION QUESTIONNAIRE</td>
<td>71</td>
</tr>
<tr>
<td>APPENDIX C - STEP TEST PROTOCOL</td>
<td>73</td>
</tr>
<tr>
<td>APPENDIX D - FITNESS CALCULATOR</td>
<td>75</td>
</tr>
<tr>
<td>APPENDIX E - FACTOR WEIGHTS FOR AMS-C &amp; AMS-R QUESTIONS FROM ESQ III</td>
<td>77</td>
</tr>
<tr>
<td>APPENDIX F - COMPUTATION OF INDIVIDUAL FACTOR SCORES FOR AMS-C &amp; AMS-R</td>
<td>79</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>81</td>
</tr>
</tbody>
</table>
LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Measures of Central Tendency and Variability for Prediction Factors for AMS</td>
<td>39</td>
</tr>
<tr>
<td>2</td>
<td>AMS-C &amp; AMS-R Factor Score Means at Selective Altitudes</td>
<td>43</td>
</tr>
<tr>
<td>3</td>
<td>Group Factor Score Means</td>
<td>44</td>
</tr>
<tr>
<td>4</td>
<td>The Number of Subjects in the AMS Groups at the Four Altitudes</td>
<td>44</td>
</tr>
<tr>
<td>5</td>
<td>The Group Means and the Significance Difference Between the Group Means (Analysis of Variance) for the Test Variables at 4328m</td>
<td>53</td>
</tr>
<tr>
<td>6</td>
<td>A Pearson Product-Moment Correlation of the Prediction Factors Versus AMS-C and AMS-R at 4328m</td>
<td>54</td>
</tr>
<tr>
<td>7</td>
<td>A Discriminant Analysis on the Prediction Variables for AMS-C and AMS-R at 4328m</td>
<td>55</td>
</tr>
<tr>
<td>8</td>
<td>Discriminant Function Coefficients</td>
<td>56</td>
</tr>
<tr>
<td>9</td>
<td>The Classification System for Known and Predicted AMS Subjects</td>
<td>57</td>
</tr>
</tbody>
</table>
### LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>AMS-C group division</td>
<td>41</td>
</tr>
<tr>
<td>2</td>
<td>AMS-R group division</td>
<td>42</td>
</tr>
<tr>
<td>3</td>
<td>Group mean factor scores at selected altitudes.</td>
<td>45</td>
</tr>
<tr>
<td>4</td>
<td>Sea level fitness group means at selected altitudes illustrating the difference between the not sick and the sick</td>
<td>47</td>
</tr>
<tr>
<td>5</td>
<td>Percent body fat group means at selected altitudes depicting differences between the not sick and the sick</td>
<td>48</td>
</tr>
<tr>
<td>6</td>
<td>Age group means at selected altitudes illustrating the differences between the not sick and sick</td>
<td>49</td>
</tr>
<tr>
<td>7</td>
<td>Systolic blood pressure means at selected altitudes showing the difference between the not sick and the sick</td>
<td>50</td>
</tr>
<tr>
<td>8</td>
<td>Diastolic blood pressure means at selected altitudes illustrating the difference between the not sick and sick</td>
<td>51</td>
</tr>
</tbody>
</table>
CHAPTER 1

INTRODUCTION

Acute mountain sickness (AMS) was first documented in China by Too Kin, a Chinese official, in 37-32 BC. As Too Kin traveled over the western range of the Himalayan Karakorum Range, he recorded the following:

Next one comes to Big Headache and Little Headache Mountains as well as Red Earth and Swelter Hills. They make a man so hot that his face turns pale, his head aches and he begins to vomit. Even the donkeys and swine react this way (Gilbert, 1983).

Another famous early documentation of AMS was noted in the 16th century by father Jose Acosta in the Pariacaca Mountain Range of Peru. Acosta's observation captured the essence of AMS, and perhaps the more deadly High Altitude Pulmonary Edema (HAPE), and High Altitude Cerebral Edema (HACE). The following is an excerpt from his journal during a trip over an assumed 4800 m. pass:

I felt such a deadly pain that I was ready to hurl myself from the horse onto the ground; and although there were many of us, each one hastened his pace without waiting for his companion in order to leave quickly from that evil spot; I found myself alone with an Indian, whom I begged to help me stay on the beast. And immediately there followed so much retching and vomiting that I thought I would lose my soul, because
after what I ate and the phlegm, there followed bile and more bile, both yellow and green, so that I brought up blood from the violence that I felt in my stomach. It did not last for more than three or four hours, until we went a long ways downward and arrived at a more agreeable atmosphere; where I found all of my companions, about 14 or 15, all extremely tired, some going about pleading for confession thinking that they were going to die. Others dismounted, vomiting, experiencing diarrhea, going completely astray; and I was told that some had lost their lives from that accident. Yet, ordinarily it does no injury of importance, besides that temporary fatigue and distressing grief (Gilbert, 1983).

In the chronical, Acosta also mentions that those going into the mountains from sea level are affected far greater than those going into the mountains after coming from the high plains. These observations have been the basis of many altitude studies concerning the phenomena of altitude adaptations and treatments. (Acosta mentioned one treatment perhaps without knowing it, "symptoms subsided upon going downward") (Houston, 1980).

During the seventeenth and throughout the early eighteenth century very few documentations were made of altitude illness. During this period a greater understanding of AMS resulted from discoveries concerning the properties of air, atmospheric pressure and their role in sustaining life. In the late 1700's a French scientist named Antoine-Laurent Lavoisier performed experiments that once and for all proved the gas oxygen existed. With the discovery of oxygen as the essential gas for life, research began again at high altitude to investigate the effects of reduced oxygen on man. One of the first scientific
expeditions to study altitude effects on man was conducted on Mont Blanc located in the French Alps. Horace-Benedict de Saussure documented pulse and respiration at various altitudes as well as observing the physiological reactions of himself and his companions. An example from his chronical is as follows:

I myself who am so accustomed to the air of the mountains, who feel better in this air than in that of the plain, was completely exhausted..." And when he tried to conduct his various experiments: "...I was constantly forced to interrupt my work and devote myself entirely to breathing... the kind of fatigue which results from the rarity of the air is absolutely unconquerable; when it is at its height, the most terrible danger would not make you take a single step further (Houston. 1980).

Observations and data collected by men like De Saussure contributed to the basic understanding of the physiological changes that occur with AMS.

Conrad Meyer-Ahrens of Leipzig Germany in 1854 summarized, from a collection of travellers' tales and scientific studies on altitude, a formulated symptomology of altitude sickness hard to surpass even today. An excerpt from his summary and conclusion follows:

The principal symptoms (of altitude illness) or at least those which occur oftenest in man are: discomfort, distaste for wine (however, the contrary has sometimes been noted), intense thirst (especially for water, which quenches the thirst best), nausea, vomiting; accelerated and panting respiration; dyspnea, acceleration of the pulse, throbbing of the large arteries and the temples; violent palpitations, oppression, anxiety, asphyxia; vertigo, headache, tendency to syncope, unconquerable desire for sleep, though the sleep does not refresh but is disturbed by anguish; finally, astonishing and very strange
muscular fatigue. These symptoms do not always appear all together... Others are observed, although less frequently, such as pulmonary, renal, and intestinal hemorrhage (in animals also); vomiting of blood; oozing of blood from the mucous membrane of the lips and the skin (due merely to the desiccation of these membranes), blunting of sensory perceptions and the intelligence, impatience, irritability,... finally, buzzing in the ears... All that we have just said about the etiology of mountain sickness shows (1) that it appears at varying altitudes; (2) that meteorological conditions, temporary or general personal characteristics, and the speed of walking vary the altitude at which one is attacked and the severity and number of symptoms... In my opinion, the principal role belongs to the decrease of the absolute quantity of oxygen in the rarefied air, the rapidity of evaporation and the intense action of light, directed or reflected from the snow, whereas the direct action of the decreased pressure should be placed in the second rank. I find the immediate causes of mountain sickness in the changes made in the composition and formation of the blood by the decrease in oxygen and the exaggerated evaporation, changes to which are added others due to the action of light on the cerebral function, an action which affects the preparation of the blood liquid (Houston, 1980).

Influenced by Meyer-Ahrens, a distinguished physiologist named Paul Bert in the late 1800’s began the first scientific studies in decompression chambers simulating the effects of altitude. His findings helped to define AMS symptoms which are recognized today.

In the nineteenth century climbers became aware of AMS symptoms and began to record them. During a documented climb Edward Whymper, one of the most renowned climbers of the late 1800’s, acknowledged the presence of AMS on a climb at the 4877 m level in the Peruvian Andes.

I found myself lying flat on my back...incapable of making the least exertion. We knew the enemy was upon us and that we were experiencing our first attack of mountain sickness. We were feverish, had intense headaches and were unable to satisfy our desire for
air except by breathing with open mouths. Headaches for all three of us were intense and rendered us almost frantic or crazy (Houston, 1980).

As climbers attempted to conquer higher peaks, many expeditions were forced to abort summit attempts. Edward Fitzgerald and his party were thwarted by AMS in their summit attempt of Argentina's Mt. Aconcagua (6960 m) in 1897. He reported symptoms of AMS as nausea, ataxia, weakness, black specks in eyes, headaches and upon descent the symptoms subsided (Houston, 1980).

The first organized investigations of AMS were conducted by The International High Altitude Expedition in 1921. This group of scientists led by Joseph Barcroft set up a research station at 4600 m in Cerro de Pasco, Peru and worked for 2 months studying altitude acclimatization. They studied respiration, chest size, mental capacity, and physical capacity of the Andean natives (Houston, 1980). The findings broadened the base of knowledge in the symptomology of altitude illness.

The U.S. Navy became very interested in high altitude research during WWII and conducted an important study on AMS. Houston (1980) designed this study called "Operation Everest" to examine the biochemical, ventilatory, and circulatory changes that occur in a slow ascent. The treatment was a simulated climb of 30 days to the altitude equivalent of Mt. Everest (9550 m) in a decompression chamber. They reported integrated ventilatory and circulatory changes which restored the oxygen pressure of
the tissues to normal sea level values despite the lowered partial pressure of atmospheric oxygen. Their findings also refuted the hypothesis that the respiratory drive would be so weakened due to lack of oxygen that upon returning to sea level they might stop breathing (Houston, 1980).

Contemporary researchers (Grover, 1982; Hackett, 1981, 1982; Lahiri, 1977; Milledge, 1983a, 1983c, 1984; and Schoene, 1985, 1987, have made great progress with the advancement of pulmonary physiology and more sophisticated techniques and equipment, in attempting to determine the internal mechanisms responsible for AMS symptoms.

Research studies conducted at high altitude have shown high incidence of AMS among trekkers and serious climbers alike. For instance Hackett, Rennie, and Levine (1976) reported that of 278 climbers passing through Pheriche, Nepal 52.5% acquired AMS. Houston found 44% of the 7500 climbers checked on Mt. Ranier came down with AMS. In another study conducted by Frayser on Mt. Logan (5330 m), he documented a 38% incidence of AMS in a group of 25 climbers (Hackett et al., 1976).

This study was designed to explore whether certain factors can be used in predicting a person's susceptibility to AMS prior to the high altitude ascent. Several studies (Hackett, 1978; Schoene, 1982; Wright & Fletcher, 1987) have examined single factors, but have failed to isolate any one factor that plays a major role in predicting AMS.
Therefore this research will combine fitness level, percent body fat, age and blood pressure to determine whether any two or more combined may be used as AMS predictors prior to altitude ascent.

**Statement of the Problem**

The purpose of this study is to investigate whether relationships exist between selective combinations of the variables; fitness level, percent body fat, age and blood pressure with the propensity to acquire AMS-respiratory (AMS-R) and AMS-cerebral (AMS-C).

**Significance of the Problem**

Acute Mountain Sickness has been defined and classified by earlier works on altitude illness (Hackett, 1978 and Auerbach, 1983). The malady has become common knowledge among climbers and sojourners in recognizing dangerous signs and symptoms of altitude maladaptations. Many studies have attempted to find a relationship between AMS and various physiological measurements: fitness level, percent body fat, age, and vital capacity (Consulazio, Matoush, Johnson, & Daws, 1968; Dill, Hillyard, & Miller, 1980; Guillard & Klepping, 1983; Harvey, Chettle, & James, 1979; Picon-Reategui, Lozano, & Vildivieso, 1961a, 1961b; Surks, Chinn, & Matoush, 1966; Young et al., 1982). The findings have been contradictory. This study is approaching the problem in a different way. Selected variables that have been found to be associated with AMS...
will be combined statistically and examined for their joint predictability of AMS.

If AMS were predictable, steps toward prevention could be implemented with high risk individuals to avoid expensive and potentially dangerous high altitude adventures. There are many factors and variables involved in the study of physiology at altitude and researchers consider AMS a result of multiple causes, but to identify accurate predictors of AMS through simple testing could save money and lives.

Hypotheses

The primary hypothesis states that by using a combination of two or more of the variables - fitness, percent body fat, age and blood pressure - a significant ($p < .05$) regression equation can be developed to predict the occurrence of AMS-C and AMS-R.

The subproblem examined was whether there would be a significant ($p < .05$) difference between the variables - fitness, percent body fat, age and blood pressure - between the climbers who developed AMS-C and AMS-R and climbers who did not develop AMS-C and AMS-R.

Assumptions

The first assumption is that the Environmental Symptoms Questionnaire III (ESQ III) is a valid instrument to measure AMS and that all subjects were able to identify and record the signs and symptoms of AMS accurately on the
ESQ III. The questionnaire has been successfully tested by Sampson, Cymerman, Burse, Mater, and Rock (1983) atop Pike's Peak (4300 m). Fifty-eight men completed 650 ESQ III's during a 1-3 week stay at the 4300 m level. The results indicated a highly accurate diagnosis compared with the diagnosis of experienced high altitude researchers.

Another assumption is that all the subjects were healthy before the climb thus restricting the subjects' ailments to AMS and not other confounding illnesses.

**Scope**

The study includes 40 climbers signed up to climb the West Buttress of Mt. McKinley with ages ranging between 20 and 70 years. The treatment in this study was the natural altitude environment at designated camps along the route: 2590 m, 3475 m, 4328 m, and 5242 m. The questionnaire was filled out at each camp on the day following their arrival.

**Limitations**

This study had no control over environmental conditions nor upon physiological changes that may occur because of diet and/or ascent speed. Extremely cold weather has been reported to increase the effects of AMS (Hackett, 1978). The inability to control total nutrient content of the subjects' diet may have influenced their severity of certain AMS symptoms. For example, decreased caloric and fluid intake may result in dehydration which promotes similar AMS symptoms such as: (a) headache, (b)
weakness, (c) fatigue and/or (d) nausea. Exercise intensity (ascent rate) has been associated with AMS (Milledge, Catly, Williams, Withey, & Minty, 1983b; Williams, 1979; Young et al., 1982) but group dynamics and weather makes control of this factor unfeasible. The methods and preventative measures taken by Genet Expedition, the guiding concession, also may contribute to the enhancement or reduction of AMS due to their acclimatization methods.

Definitions

1. **Fitness Level** - Relative maximal oxygen consumption, (Max. VO₂), is the maximum amount of oxygen consumed in ml·kg⁻¹·min⁻¹ (Sharkey, 1979).

2. **Acute Hypoxia** - Physiological responses occurring between 0 and 1 hour at high altitude (Dempsey & Forster, 1982).

3. **Short-Term Hypoxia** - Physiological changes occurring between 1 hour and several months at high altitude (Dempsey & Forster, 1982).

4. **Long-Term Hypoxia** - Physiological adaptations that have taken place over years and generations of living at high altitude (Dempsey & Forster, 1982).

5. **Prediction variables, prediction factors, discriminant variables, or test measurements** = Fitness levels, percent body fat, age and blood pressure.
CHAPTER 2

REVIEW OF THE LITERATURE

Introduction

Present efforts in the altitude field have focused on studying the cause of various signs and symptoms. Many of the biochemical changes resulting from a lack of oxygen at high altitude have been determined. However, science has yet to find the definitive reason to explain AMS. Understanding AMS is further complicated by individual differences including: genetic factors, environmental factors and even mental attitudes. Research studies have shown AMS may affect the same person differently the second time around (Hackett et al., 1976). AMS is a mystifying and intriguing topic that poses a threat to high altitude sojourners thus justifying the pursuit of scientists to make the high altitude environment a safer place to visit.

This chapter contains a review of the literature pertaining to this study. It has been divided into four parts: a) The development of a now established AMS prevention protocol made possible by the development of a classification system defining AMS terms and symptoms; b)
An overview of the physiological mechanisms associated with AMS; c) Literature justifying the validity of the major questions on the ESQ III used in this study and; d) Literature relating AMS with the pre-climb measurements (independent variables), as they relate to the hypotheses of this study.

Preventative Protocol

The terms acute mountain sickness (AMS) high altitude pulmonary edema (HAPE) and high altitude cerebral edema (HACE) have amassed a variety of definitions, because of complex changes that individuals may encounter at various altitudes. Hackett, a pioneer in the search for answers to altitude physiology, has studied AMS on Mt. McKinley and Mt. Everest and has devised a widely accepted classification system of the general AMS symptoms that may occur when over 3048 m (Hackett, 1978). These symptoms and classifications of AMS are as follows:

A. Most common symptoms of AMS:
   1) Headache— in the morning and while walking, neither of which are relieved by medication.
   2) Insomnia
   3) Loss of appetite
   4) Periodic breathing (Cheyne-Stokes)
   5) Lassitude (lethargy)
   6) Ataxia
   7) Reduced urine output (possible peripheral edema)

B. Classification:
   1) Mild: a few symptoms, but nothing serious and usually disappears within 24 hours, i.e.; headache, insomnia, loss of appetite, and shortness of breath.
   2.) Moderate: progression of symptoms to an uncomfortable level; headache only partially
relieved by medication, added ataxia, weakness, and decreased urine output.
3) Severe: showing signs of HACE and HAPE, (which will be described together because most symptoms overlap), such as: increased heart rate, coughing, rales, cyanosis of fingernails, and both amnesia and hallucination (particular to HACE).

Since the conditions for AMS have been recognized and defined, simple preventative measures have been suggested to reduce the incidence of death and severe cases of AMS. In 1975 69% of those people that flew to 2950 m to begin their trek toward Mt. Everest incurred AMS. In 1977 after the Himalayan Rescue Association implemented a prevention program, the incidence of AMS declined to 43%.

The preventative measures now established from that program are as follows:

A. Graded ascent
   - Do not fly or drive to high altitude. Start below 3000 m and walk up.
   - If taken to altitude, do not exert yourself or move higher for the first 24 hours.
   - Once above 3000 m limit your net gain in altitude to 300 m per day.
   - Carry high and sleep low. i.e.; sleep below the highest altitude reached that day.
   - Take a 24 hour acclimatization break for every 1000 m gain in elevation.

B. Prevention of dehydration
   - Drink enough to produce clear and copious amounts of urine.

C. Avoidance of overexertion
   - Keep pulse below 145 beats per minute.

D. High carbohydrate diet
   - 70 - 80% carbohydrate diet has been shown to increase oxygen blood levels and to reduce symptoms of AMS at high altitude.

E. Alcohol and sedatives
   - Do not consume any alcohol or sedatives.
This preventative campaign has been successful in reducing the high incidence of AMS. The present study may work in conjunction with these preventative measures to further reduce AMS incidence.

Mechanisms of AMS

AMS is an illness that encompasses several physiological malfunctions associated with high altitude. Many research findings have implicated hypoxia as the major contributing factor in high altitude illness (Capen, Latham, & Wagner, 1979; Cruz et al., 1980; King & Robinson, 1972; & Pappenheimer, 1984). Based upon Dempsey and Forster's (1982) classification of AMS, three hypoxic stages occur in the following chronological order: acute hypoxia, short-term hypoxia, and long-term hypoxia.

During acute hypoxia the low partial pressure of atmospheric oxygen creates an oxygen deficiency (ie. low arterial PO\(_2\)) and immediately the body attempts to adjust to it; ventilation increases because of the low PaO\(_2\) sensed at the carotid bodies. Carbon dioxide (CO\(_2\)) is lost in excess of production due to the increased volume of expired air per minute (V\(_{\text{e}}\)) (Lahiri, 1977; Zink, and Brendel 1982).

Short-term hypoxic acclimatization begins when V\(_{\text{e}}\) increases beyond the acute hypoxic stage where administration of oxygen will not return the V\(_{\text{e}}\) back to normal levels as it would with acute hypoxia. It can therefore be assumed that other little understood time
dependent mechanisms are controlling \( V' \), and now causing the changes in \( P_{\text{a}O_2} \) and pH (Dempsey & Forster, 1982). The carbonic acid–bicarbonate buffer system also plays a role of maintaining a steady pH (Cruz et al., 1980; Lahiri, 1977). Other physiological parameters to be investigated during this short term hypoxic stage are: ventilation, blood composition, fluid balance (kidneys), and circulation (coronary, pulmonary and cerebral blood flow).

Ventilation and it's response to hypoxia via blood and cerebral spinal fluid (CSF) pH, \( P_{\text{a}O_2} \), and \( CO_2 \) concentration play a major role in whether a person can adapt to altitude. The human body has other backup systems that compensate for the failure of one system, making it difficult to pinpoint exactly which system or systems provide the major contributions to ventilatory control during AMS (Lahiri, 1977). One possible explanation is that the control mechanism may vary from one individual to another or from one situation to another. Some of the general thoughts pertaining to these control mechanisms will be discussed under the ESQ III subheading of this section (Dempsey & Forster, 1982).

Effects on blood composition occur immediately on arrival at altitude and continue in the weeks that follow. A glycoprotein hormone, erythropoietin, is activated to increase red blood cell and hemoglobin production, thus facilitating the oxygen delivery system. The catalyst 2,3-Diphosphoglycerate (2,3 DPG) is also activated and
released into the blood, shifting the oxygen-hemoglobin curve to the right (Auerbach, 1983). A similar effect occurs when ventilation decreases during altitude sleep causing a high PCO₂ which decreases the pH of the blood because of the carbonic acid buffer system. This pH change, called the Bohr Effect, also allows greater O₂ release to the tissues (Lahiri, Maret, Sherpa, & Peters, 1984; & Zink & Brendel, 1982).

Fluid balance has been closely studied with respect to pulmonary and cerebral edema. The main mechanism is the control of aldosterone which acts on the kidneys to retain sodium through the renin-angiotensin pathway (Milledge et al., 1983a). Vessel permeability, cell swelling, and sodium reabsorption are all associated with this pathway, and may play a role in the development of AMS (Green & Stockley, 1979; King & Robinson, 1972).

During exposure to high altitude a vasoconstriction response occurs in the pulmonary arterial vessels causing increased pulmonary pressure and altered blood flow distribution in the lung. The advantage to this response is a larger surface area for O₂–CO₂ gas exchange due to the blood movement into the upper portion of the lungs. This could be a disadvantage if the increased pressure overwhelms the vasoconstrictive mechanism; some of the small arterioles and capillaries are susceptible to leakage during surges of pressure, resulting in interstitial and alveolar edema. It has been hypothesized that the same
membrane lipid metabolites (leukotrienes) responsible for hypoxic vasoconstriction may also alter membrane permeability and contribute to pulmonary edema formation (Milledge, 1984; Schoene, 1987a). A person maladapted to altitude may not have a strong mechanism for hypoxic vasoconstriction to protect the capillaries from the pressure surges (Auerbach, 1978). Unlike pulmonary edema, cerebral edema is generated in another way. Hypoxia in the brain causes a severe vasodilatation. The blood flow to the brain is normally controlled by a flow regulating mechanism before it reaches the small susceptible vessels. A dilation of the cerebral vessels occurs to help reduce blood flow velocity and pressure. If the regulating mechanisms are not responsive enough, the pressure continues to build and is transmitted to the capillary beds resulting in edema (Hyers, Scoggin, Will, Grover, & Reeves, 1978).

In summary, the acute hypoxic pulmonary vasoconstriction response has to be present to maintain maximum arterial oxygenation by diverting blood flow to more ventilated apical areas of the lungs. Hypoxia causes vasodilation in the brain and without proper blood pressure regulation with increased blood flow the brain may become susceptible to vascular leakage (Grover, 1980; Grover, Wagner, McMurtry, & Reeves, 1982).
Environmental Symptoms Questionnaire

The Environmental Symptoms Questionnaire III (ESQ III) used in this study is made up of questions that cover many of the symptoms of AMS. Some of the questions seem more directly related to AMS than others. The more pertinent questions that reflect the major symptoms of AMS have been examined and justified. These were not definitive causes, but broad inferences made from a number of observed physiological adjustments at altitude (Sampson et al., 1983).

The ESQ III divides AMS into two categories, AMS-cerebral (AMS-C), and AMS-respiratory (AMS-R). In the factor analysis the two categories of AMS are computed by weighing certain questions that relate specifically to cerebral functions and to respiratory function. For clarification the questions are categorized below: (The full questionnaire is in Appendix A).

AMS-C

1. Lightheadedness
2. Headache
4. Dizzy
5. Faint
6. Vision
7. Coordination off
19. Feel weak
24. Sick to stomach
52. Loss of appetite
53. Feel sick
54. Feel hungover

AMS-R

2. Headache
8. Short of breath
9. Hard to breath
10. Hurts to breath
17. Stomach cramps
22. Back aches
23. Stomach aches
24. Sick to stomach
46. Nose stuffed
48. Nose bleeds
58. Couldn’t sleep
65. Depressed

The AMS condition described as high altitude pulmonary edema (HAPE) and high altitude cerebral edema (HACE) were
introduced briefly. These two severe conditions have been found in the later progression of AMS. Houston elucidated the conditions of AMS, HAPE, and HACE when he wrote, "Altitude illness is a single entity which can be manifest in several different forms or combinations. Until recently we spoke of AMS, HAPE, HACE, and retinal hemorrhage (RH) thinking of them as separate entities although all were caused by oxygen lack. It has become clear that these rarely exist alone: The victim usually shows a great deal of one condition and some of the others" (Wohns, 1981).

The most common early symptom of AMS reflected by a headache is associated with unequal pressure in the brain. Singh, Khana, and Roy (1969) concluded that headache symptoms at high altitude were the result of increased cerebrospinal pressure of 60 to 210 mm of water during their illness. In a study by Klatzo, cited by Wohns (1981) the author identified the two types of cerebral edema which cause the increase cerebral pressure; vasogenic and cytotoxic edema. Wohns hypothesized that the first sign of AMS is initiated by an intracranial vasodilation in the cerebral and/or meningeal vessels. As hypoxic stress becomes more intensified, plasma leakage occurs and the first stage of HACE is recognized (vasogenic edema). The leakage becomes worse in the cerebellum and hippocampus. Increased pressure develops and relates directly with decreased levels of consciousness, lightheadedness, dizziness and fainting. (Note: All these symptoms are
questions weighted in the ESQ III analysis under AMS-C). At this time the cytotoxic edema occurs, possibly induced by changes in the cell environment which appears to be from the vasogenic response (Wohns, 1981). Another observation reported by Hackett and Roach (1987) was that the intracranial pressure is caused by blood engorgement of the brain for an extended period of time, thus increasing the chance of edema formation.

Singh, et al., (1969) documented that patients with tumors and above-normal intracranial pressure exhibit vision impairment as well as ataxia. Their research concluded vision impairment may also be attributed to engorged retinal veins. Analogous conditions seen in patients with AMS-C may result in similar vision impairment.

In a study of 840 army troops in the Himalayas at altitudes between 3350 and 5480 m, Singh et al., (1969) observed that the most common symptoms were headache, nausea, loss of appetite, mental impairment, and pain in the abdomen. Olive and Waterhouse (1979) explained these reactions as being referable to the central nervous system, although they stated that this is not the sole reason for the symptoms.

Another theory for the increased cerebral edema focuses on the bio-electrical potentials of the cell which control the sodium pump (Wohns, 1980). According to the theory the pump becomes altered due to oxygen deficiency.
Via the renin-angiotensin pathway, sodium is retained and water enters the cell causing abnormal expansion. Although these explanations are attractive, Dalessio (1980) has shown that patients with raised intracranial pressure sometimes have no headaches.

Homeostasis of body fluid has been examined extensively in an attempt to find the etiology of AMS. The research suggests that diuresis and hemoconcentration may be the beneficial responses, while a retention of salt and water is detrimental. The hemoconcentration not only gives a quick increase in hematocrit but a rise in oncotic pressure which could help to counter hydrostatic (vasogenic) edema formation in the lungs or brain. On the other hand retention of salt and water could contribute to problems with pulmonary and cerebral edema. HAPE and HACE are two conditions which have led researchers to look into the renin-aldosterone system as an answer to the complicated mechanism for fluid retention and it's consequences. The renin-aldosterone system is an integral part of the process through which edema is elevated or alleviated (Jones, & Delamare, 1979; Milledge et al.,1983a,1984; Slater & Jowett, 1977). The elevation in fluid may be a factor in producing both AMS-C and AMS-R. Thus, headache which may be the first sign of fluid imbalance, is seen as a question on the ESQ III in both categories of AMS.
Several theories (Milledge et al., 1983a) have been proposed to explain how the renin-aldosterone system adjusts or maladjusts to altitude in relationship to AMS. One explanation is that the exposure to altitude causes hypoxia which immediately stimulates release of renin from the juxtaglomerular apparatus of the kidney. Renin then converts angiotensinogen to angiotensin I. Angiotensin I is converted to a vasoactive octapeptide, angiotensin II, by the angiotensin-converting enzyme (ACE) located in the endothelial tissue of the lungs. Besides being a vasoconstrictor, angiotensin II acts via a receptor mechanism on the adrenals to release aldosterone, which in turn acts on the renal tubules to retain sodium (Milledge et al., 1983b, 1983c, 1984). Sodium retention implies a shift of fluid from intracellular to extracellular space and a renal retention of water (Milledge et al., 1983c). One adjustment to blunt the aldosterone effect, so that increased fluids and cell expansion don’t reach dangerous levels, is to inhibit ACE activity (Milledge et al., 1983b). The inhibition of ACE is only postulated, although Leuenberger, Stalcup, Mellins, Greenbaum, and Turino (1978) showed that hypoxia in dogs resulted in the inhibition in ACE. Milledge (1984) theorized that a failure to lower ACE activity with hypoxia results in increased susceptibility to AMS.

The second theory of aldosterone control is the introduction of the enzyme aminopeptidase which is involved
in the degradation of angiotensin II. Without angiotensin II stimulating the adrenal cortex to release aldosterone, sodium is not retained and pressure caused by increased water is alleviated (Milledge et al., 1983a).

Ventilation is important in the study of AMS because it is the one factor that can compensate for the reduced PO$_2$ levels by adjusting the oxygen transport system. If the oxygen transport system can minimize the O$_2$ loss at the tissue level the overall hypoxic effect would be reduced. This modification is accomplished by the process of hyperventilation stimulated by various chemoreceptors (Dempsey, & Forster, 1982). Acclimatization is the process by which the arterial, cerebrospinal fluid (CSF) and brain interstitial fluid (ISF) pH are balanced with ventilation to provide adequate oxygen to the tissue.

Lahiri et al. (1984) stated that the mechanism by which ventilation reached this balance is less understood today than what was previously believed. While theories are inconsistent regarding the maladaptation in the ventilatory acclimatization response via the chemoreceptors, it is possible this could be a significant contributor to trigger AMS. To elucidate further, an example of maladapted ventilation occurs during sleep at altitude. Ventilation during sleep is reduced despite the increase in PCO$_2$ and decrease in PaO$_2$ (Reeves et al., 1987). King and Robinson (1972) looked at the sleep response and concluded that the severity of AMS is related to the ventilatory
responsiveness to hypoxia. Most high altitude climbers wake up in the morning with increased AMS symptoms presumably from the low ventilatory response to hypoxia during sleep. Powles (1982) studied similar sleep states and was unable to confirm a relationship between AMS severity and ventilatory responsiveness during sleep to hypoxia. King and Robinson (1972) concluded that sleep states do have merit in the determination of AMS. A prophylaxis, acetazolamide, has been shown to alleviate AMS symptoms by stimulating ventilation during sleep via carbonic anhydrase inhibition causing bicarbonate diuresis and subsequent metabolic acidosis (Hultgren, 1983; Grover, 1980; Hackett & Roach, 1987). These prophylaxis findings support the theory that an increased ventilatory response does alleviate AMS symptoms. The amelioration of AMS-R by administration of acetazolamide provides evidence that a correlation exists between breathing responses and AMS.

**AMS and Pre-climb Predictors**

The parameters for the pathology of AMS have been established in the previous subsections. The ESQ III has been used to determine the degree of AMS the subject experienced during high altitude excursions by relating certain symptoms with AMS. It is known that AMS is not a result of one mechanism in the adaptation process, but a multitude of physiological changes interacting upon each other to elicit a potentially harmful response in the form
of AMS. Considering the complexity of interaction, the measurements taken in this study: (a) fitness level, (b) percent body fat, (c) age, and (d) blood pressure, must be used in combination to encompass more than one functional aspect of AMS. This section reviews the studies that include pre-climb measurements and how they are associated with the physiological functions of AMS-C and AMS-R.

Acute Mountain Sickness has been observed to occur less frequently with increased age (Hackett et al., 1976). The actual mechanism and/or environmental conditions associated with this observation were not documented. One of the possible explanations is that older people, between the ages of 35 to 70 years, have already begun normal life changes, including decreased metabolism, decreased muscle mass, and certain alterations in chemical processes (Sharkey, 1979).

Fitness level is directly related to the body's ability to take in, transport, and utilize oxygen (Sharkey, 1979). These factors are important at altitude where $O_2$ pressure is low and energy is limited. A body that is aerobically trained has enhanced the aerobic pathways resulting in more efficient fat and carbohydrate utilization. An untrained person, even with a genetically high fitness level, is hampered in fat utilization because the metabolic pathway is not as aerobically efficient. Hence the assumption is made that a person's ability to burn fat effectively at high altitude enhances the ability
to spare glycogen (Young et al., 1985). Without this glycogen sparing effect, high altitude trekkers need to consume high carbohydrate foods, otherwise they can expect to use protein in the form of muscle tissue as an energy source. Picon-Reategui (1961) found that those individuals that were active at sea level incurred a minimal loss of muscle at high altitude as compared to the inactive.

Guilland and Klepping (1983) measured fitness level of five climbers and then related the subjects' nitrogen balance at various altitudes. The researchers reported that at an altitude of 4800 m only the highest fit subject, with a relative VO\text{\textsubscript{2}} of 59.8 ml·kg\textsuperscript{-1}·min\textsuperscript{-1}, maintained a positive nitrogen balance. The next highest fitness level was 48.2 ml·kg\textsuperscript{-1}·min\textsuperscript{-1} indicating, in this case, the large fitness difference may be responsible for the different use of energy sources. The sample was small, and the question still remains whether a negative nitrogen balance has a deleterious effect on the subject in reference to AMS. Surks et al. (1966) reported that muscle proteins were reduced at 4300 m thus concluding muscle protein was used as an energy source. Rennie and Joseph (1970) found a correlation between the proteinuria and the degree of hypoxia. Considering hypoxia is the direct result of AMS this presents a question whether the breakdown of protein is an important factor in the genesis of AMS. Contradictory results by Winterborn, Bradwell, Chesner and Jones (1987) found no correlation between proteinuria and
hypoxia or $P_{\text{O}_2}$. Other studies have ruled out fitness level as a factor in acquiring AMS (Green & Stockley, 1979; Hackett, 1978; Wright & Fletcher, 1987). These discrepancies between fitness level and AMS need to be resolved before establishing preclimbing programs that include fitness training as a preventative measure of AMS.

Mechanisms other than those mentioned for loss of body fat in relationship to AMS cannot be omitted. They are as follows: increased mobilization of free fatty acid (FFA) from caloric restriction, hypoxic stimulation of norepinephrine which mobilizes FFA, and impaired lipid absorption at high altitude (Guilland & Klepping, 1983).

Blood pressure has been examined in very few studies in its relationship with AMS. Singh et al. (1969) reported in 840 treated cases of AMS elevated blood pressures above 160 systolic and 100 diastolic, and low blood pressure below 110 systolic and 75 diastolic were more apt to contract AMS. Mathew, Gopanathan, Purkayastha, Gupta, and Nayar (1983) reported conflicting data, observing no relationship between AMS and blood pressure. This study chose to include blood pressure as a predictor because of the ease of administration and because of the study conducted by Singh et al. (1969).
CHAPTER 3

METHODOLOGY

Subject Selection

Thirty six males and 4 females who signed on with Genet Expeditions to climb Mt. McKinley were selected as subjects for this study. Genet Expeditions advertised in various outdoor magazines to attract potential clientele. The advertisements were addressed to both experienced and inexperienced climbers. Genet Expeditions has a reputation for getting clients to the top of McKinley, as well as an outstanding safety record. The subjects in the study were scheduled to climb via the West Buttress Route.

Introduction of Subjects to the Study

The subjects were given a concise orientation on the general purpose and procedures of the study. Each group was informed of the research study's investigation of pre-climb factors for the purpose of determining a procedure to predict the propensity to acquire AMS. Genet Expeditions had informed them of the study before arrival in Talkeetna, Alaska, and of the testing to be conducted the morning
before their flight to the Kahiltna Glacier at the base of Mt. McKinley. Subjects were informed that the tests would be administered prior to meals, coffee, or cigarettes. All subjects were advised, prior to arrival, to come dressed in sneakers and light running gear. Data collection adhered to the following protocol:

1. General explanation of the study.
2. Filling out the general questionnaire.
3. Instructions on filling out the ESQ III.
5. Step test.
6. Percent body fat estimation.

All subjects were asked to record any medication they ingested during the climb.

**Variable Test Measurements**

**Step Test**

The equipment for this test included two 8 foot long benches, one 15 3/4" high for men and one 13" high for women. The heights were based on the step test developed by Sharkey (1979). Other items used in the testing were a cassette player and a cassette tape with complete instructions for self administration (Appendix C). Four people were tested at a time. Each individual was weighed and requested to sit and rest for 10 minutes. During that time the purpose of the step test was explained to them as
well as the procedure. A pre-test pulse rate was taken to assure the subjects were relaxed. A demonstration of the test was given to help reduce anxiety about an unfamiliar test or any confusion with the instructions on the tape.

The step test protocol on the cassette kept the instructions standardized for all subjects. To determine the fitness level or the predicted maximal oxygen consumption, the body weight, post-test pulse rate, and age were entered into the fitness calculator (Appendix D) and recorded on the subjects general questionnaire form (Appendix B). The step test was chosen due to lack of other equipment and its ability to test many people in a short period of time as well as its close simulation to mountain climbing.

The step test has been correlated highly with treadmill protocols of r=.77 (Heyward, 1984) thus justifying this test for the determination of fitness level.

Skin Fold Measurements (% Body Fat)

Skin fold thicknesses were measured with a Harpendun caliper. Skin fold thicknesses were measured at the chest, abdomen, and thigh for males, and the triceps, suprailiac, and thigh for females (Baum & Baum, 1981). All measurements were taken on the dominant side of the body. The formulas used to calculate total body density were derived by Jackson and Pollock (1979). The male body
density (MBD) equation has a correlation of $r = 0.905$ to hydrostatic weighing and a standard error of 0.0077. $X_1$ is the sum (in mm) of chest, thigh and abdomen skinfolds of males. $X_3$ is the age in both formulas.

$$MBD = 1.1093800 - 0.0008267 (X_1) + 0.0000016 (X_1)^2 - 0.0002574 (X_3)$$

(1)

The formula to determine the female body density (FBD) has a slightly lower correlation, $r = 0.74$ and a standard error of 0.0086 (Heyward, 1984). $X_2$ is the sum (mm) of triceps, thigh and suprailiac skinfolds. The computation is illustrated below:

$$FBD = 1.0994921 - 0.0009929 (X_2) + 0.0000023 (X_2)^2 - 0.0001392 (X_3)$$

(2)

The percentage of body fat was determined using Siri’s formula (1954), which has been found to be applicable at high altitude by Bharadwaj et al., (1977). The formula is:

$$\text{Estimation of percent fat} = \left( \frac{4.950}{BD} - 4.50 \right) \times 100$$

(3)

**Blood Pressure**

Blood pressure was determined on an aneroid sphygmomanometer and monitored with a stethoscope. Blood pressure was taken in the sitting position following the
procedures of the American Heart Association (American Heart Association, 1980).

**Environmental Symptoms Questionnaire III**

**Procedures.** All subjects were given three ESQ III forms marked with the altitude at which it was to be filled out. They were enclosed in a waterproof ziplock bag with a pencil. Each subject read the questionnaire to make sure the instructions were clear. The guides for each expedition were asked to remind the subjects to fill in the questionnaires at the appropriate altitudes before the day's climb. The questionnaires were collected by the guides and turned into the Genet Expedition office and sent to the University of Montana.

The instrument that was used in this study was the ESQ III designed at the U.S. Army Research Institute of Environmental Medicine in Natick, Massachusetts. The resultant product from the ESQ III is the degree AMS. The questionnaire has been used in number of research studies, and proved to be a valid instrument when checked against a physical and oral exam by experienced medical personnel in the field of altitude research (Sampson et al., 1983).

**Questionnaires' method of statistical analysis.** The questionnaire contains factor analysis in the development of a subjective measurement scale. By analyzing the intercorrelations of individual responses to a broad array of symptom questions, the factor analysis reveals symptom
complexes indicative of the altitude stress. In this way the analysis provides a means that best represents AMS stress experiences. The factor labels for AMS in conjunction with cerebral and respiratory AMS are; acute mountain sickness-cerebral (AMS-C) and acute mountain sickness - respiratory (AMS-R). All the symptom questions relating to AMS-C and AMS-R have been assigned a factor weight. The weights and computational formulas for determining the severity of AMS-C and AMS-R are seen in Appendix E and F, respectively. The results from the computational formulas provide a severity AMS score to use in determining "sick" versus "not sick" climbers. The reliability coefficient alphas for AMS-C is $r = 0.774$ and for AMS-R is $r = 0.816$.

Another general information questionnaire was filled out before flying into the Kahiltna Glacier at the base of Mt. McKinley (Appendix B). This questionnaire was used to record age, socioeconomic status, lifestyle, test measurements, keep track of names and for potential future exploratory studies.

**Statistical Design**

**Pearson Product-Moment Correlation**

Before combining the prediction variables in a discriminant analysis, a determination between the relationship of individual variable means and AMS-C and AMS-R was conducted using the Pearson product method. The
Pearson correlation measures the linear correlation between two variables. The purpose for conducting a Pearson correlation was to determine how well the data approximates a linear relationship. The variables with high correlations would provide information concerning the effect of increased altitude on those variables. The concern here is not distinguishing between group means, but the relationship between altitude sickness and the total means at 4328 m.

**Analysis of Variance**

The subjects have been labeled Group 1 (not sick) or Group 2 (sick), in each category of AMS. The purpose of calculating the analysis of variance was to determine the variability between the group means of each variable in its respective category of AMS. The results determine the significance of the variability and provide insight on how altitude may play a role in the difference.

**Discriminant Analysis**

The objective of the statistical design was to determine whether certain factors combined in such a way can accurately predict whether or not a person is at high risk of acquiring AMS. Multivariate statistical methods provide a means of allowing us to simultaneously consider how each of these factors help in predicting the degree of AMS. As previously stated, the ESQ III provides us with a factor score of degree AMS-C and AMS-R. Thus for one given
altitude, two analyses must be performed for both types of AMS. Two analyses were examined on the not sick group and the sick group at 4328 m, as the data collected fit the assumptions of the discriminant analysis best. Those assumptions included a maximum difference between groups, and an adequate number of subjects to delineate that difference.

To begin with, a discrimination must be determined between sick and not sick. The method derived by Sampson et al., (1983) in his development of the ESQ III was to separate sick from not sick according to the answers on the ESQ III. Once the factor scores were calculated, Sampson et al. used a statistical formula to separate the sick from the not sick. Due to the small sample number in this study a bimodal separation was employed. This separation is determined by graphing the subjects factor scores on the X axis and the frequency those scores appeared on the Y axis. In this fashion a pattern develops; Group 1 (not sick) and Group 2 (sick) bunch to opposite sides of the graph. The most central point between these two groups is the point of division. Question number 53, "I feel sick", on the ESQ III, may be used cautiously to check the reliability of the division. For example, if a large percent of those that said they were sick were separated into the non-sick group the point of division may need some adjustment to find the optimal point. In his study Sampson et al. (1983) used this technique to check the prediction accuracy of his
statistical procedure for dividing Group 1 and Group 2 and found AMS-C was 98.6% accurate and AMS-R was 92% accurate.

The statistical method employed in this study, a discriminant analysis, weighed and linearly combined the factors: fitness level, percent body fat, age and blood pressure. This was done in a manner to maximize their differences so that the groups were as statistically distinct as possible (Klecka, 1980). The purpose is to be able to "discriminate" between sick and not sick via the measured prediction factors. The equations attempt to form linear combinations of the factors which were written in a standardized fashion using weight coefficients for those factors. The following is an example of the general form the equation takes:

$$Y' = d_0 + d_1*x_1 + d_2*i*x_2 + \ldots + d_p*x_p$$

where $Y'$ is the predicted single discriminate score obtained from the original set of measurements, $d_0$ is the constant, $x_1, \ldots, x_p$ the prediction variables and $d_1, \ldots, d_p$ are the coefficients which produce the desired characteristics in the function (Klecka, 1980). The multivariate problem has thus been reduced to a problem involving only one variable. The discriminant function can be illustrated by axes in geometric space. Within that spatial dimension the weighted coefficients act to identify variables most apt to
contribute to the differentiation along the respective function.

The Statistical Package for Social Sciences (SPSSx) was used for this analysis (SPSSx, 1986). The program selected the discriminant variables and entered them into the analysis on the basis of their discriminatory power, i.e. the higher the weight the greater the discriminatory power. Therefore, the program chose the variable that best discriminates between sick and not sick. The second discriminatory variable was selected which best improved the value to discriminate. If a variable was chosen that reduced the discriminative power, it was removed. This exploratory method of selection provides a means of finding the right combinations of variables.

Once the discriminate score was calculated a probability score was assigned to the factor combination which most accurately predicts AMS. It also provided a cut-off point for the discriminant score from which the subjects fall below (sick) or above (not sick).

The SPSSx package also provided a classification system that determined the predictability of the derived equation. In essence it analyzed the division and determines how many correct and incorrect predictions were made in each group.

The hypothesis of a significant relationship existing between the combined prediction variables and the ability to acquire AMS was accepted at the .05 level (p < .05).
CHAPTER IV

RESULTS AND DISCUSSION

Results

Five expedition groups totalling 40 subjects, 36 males and 4 females, were measured for their fitness level, percent body fat, age, and blood pressure at sea level before attempting the summit of Mt. McKinley. The 40 climbers age ranged from 20 to 70 years old and their climbing experience ranged from 0 to 18 years. The fitness levels ranged from 39 to 67 ml·kg⁻¹·min⁻¹ with a mean of 52.4 ml·kg⁻¹·min⁻¹. The fitness ratings adapted by Sharkey (1979) consider a score between 50 and 54 ml·kg⁻¹·min⁻¹ excellent fitness, taken from a large sample and compared to the average American. Body fat estimates ranged from 5 to 29 percent with a mean of 12.77 percent. The average percent fat for men between the ages of 20 and 50 is as follows: (Sharkey, 1979)

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Percent Fat</th>
</tr>
</thead>
<tbody>
<tr>
<td>18-22 years</td>
<td>12.5 percent fat</td>
</tr>
<tr>
<td>23-29 years</td>
<td>14.0 percent fat</td>
</tr>
<tr>
<td>30-40 years</td>
<td>16.5 percent fat</td>
</tr>
<tr>
<td>40-50 years</td>
<td>21.0 percent fat</td>
</tr>
</tbody>
</table>

This information reveals the average of the 40 subjects in this study are more fit and less fat than the
average American at an equivalent age. Although the minimum range on fitness at 39 ml·kg⁻¹·min⁻¹ for this group is considered a fair level and the maximum percent body fat is considered obese, the median however is more fit and less fat than the mean. The measures for central tendency and variability are presented in Table 1.

Table 1.

Measures of Central Tendency and Variability for Prediction Factors for AMS.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fitness (ml·kg⁻¹·min⁻¹)</td>
<td>52.4</td>
<td>7.91</td>
<td>39-67</td>
</tr>
<tr>
<td>Body Fat (%)</td>
<td>12.77</td>
<td>5.21</td>
<td>5-29</td>
</tr>
<tr>
<td>Age (years)</td>
<td>35.95</td>
<td>10.49</td>
<td>20-70</td>
</tr>
<tr>
<td>BPS (systolic BP)</td>
<td>128.73</td>
<td>8.31</td>
<td>128-148</td>
</tr>
<tr>
<td>BPD (diastolic BP)</td>
<td>78.45</td>
<td>7.01</td>
<td>58-95</td>
</tr>
</tbody>
</table>

N = 40

The measurements of fitness, percent fat, age and BP taken at sea level were the basis for statistical analyses, which determined the effect these variables had on AMS-C and AMS-R. As the subjects gained in altitude, they began to separate into two groups: Group 1 (not sick) and Group 2 (sick). The remainder of this section concerns the differences between Group 1 and Group 2 under the category
of AMS-C and AMS-R. As discussed briefly under Questionnaires' method of statistical analysis, the division of sick versus not sick was done in a bimodal fashion. The factor scores made up the X axis and the frequency of subjects receiving certain factor scores made up the Y axis. These bimodal distributions can be seen in the bar graphs in Figures 1 and 2. The division was chosen at the point between two distinct groups of subjects. For example in Figure 1, AMS-C, the majority of Group 1 subjects had a factor score of less than 0.6 and Group 2 had a score of greater 0.6. Therefore 0.6 was chosen as the dividing point between sick and not sick.

The factor score which determined the degree of AMS, was calculated by the answers on the Environmental Symptoms Questionnaire III (ESQ III). The average factor scores of all 40 climbers were recorded at each altitude. The means for the factor scores at 2590 m, 3475 m, 4328 m and 5242 m were .121, .265, .668, and 1.380 for AMS-C, respectively. The AMS-R factor scores for the increased elevations were .201, .474, .810, and 1.287 for each altitude respectively. A comparison of AMS-C and AMS-R at each altitude is found in Table 2.
Figure 1. AMS-C group division
Figure 2. AMS-R group division
Table 2.

**AMS-C & AMS-R Factor Score Means at Selective Altitudes.**

<table>
<thead>
<tr>
<th>Altitudes</th>
<th>2590m</th>
<th>3475m</th>
<th>4328m</th>
<th>5242m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sickness</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AMS-C</td>
<td>.121</td>
<td>.265</td>
<td>.668</td>
<td>1.380</td>
</tr>
<tr>
<td>AMS-R</td>
<td>.201</td>
<td>.474</td>
<td>.810</td>
<td>1.287</td>
</tr>
</tbody>
</table>

In AMS-C it was not until the 4328 m level that the average factor score means were above the cut-off point (> .6) for separating sick from not sick, while AMS-R factor score means were below the cut-off point by a small margin. This is important in the analysis of the group factor scores when compared to altitude (Table 3), as more subjects lend stability to the results. When the group factor score means are compared with the number of subjects in each of those group means, the best distribution of subjects, between groups, is at the 4328 m elevation. For example, in AMS-C the percentage for group 1 and group 2 respectively is 70% and 30% at the 4328m level. The nearest to that is group 1 and group 2 at the 3475m level at 85% and 15% respectively (Table 4).

The group means for the factor scores also illustrate the gradual increase in degree altitude illness of both AMS-C, and AMS-R, as one moves to higher altitudes (Table 3). Figure 3 is a graphic illustration of this relationship.
Table 3.

Group Factor Score Means.

<table>
<thead>
<tr>
<th>Sickness</th>
<th>Altitudes</th>
<th>2590m</th>
<th>3475m</th>
<th>4328m</th>
<th>5242m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AMS-C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 1</td>
<td>.06</td>
<td>.136</td>
<td>.276</td>
<td>.383</td>
<td></td>
</tr>
<tr>
<td>Group 2</td>
<td>.803</td>
<td>.99</td>
<td>1.58</td>
<td>1.61</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AMS-R</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 1</td>
<td>.18</td>
<td>.33</td>
<td>.36</td>
<td>.69</td>
<td></td>
</tr>
<tr>
<td>Group 2</td>
<td>1.44</td>
<td>1.25</td>
<td>1.19</td>
<td>1.64</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.

The Number of Subjects in the AMS Groups at the Four Altitudes.

<table>
<thead>
<tr>
<th>Altitude</th>
<th>2590m</th>
<th>3475m</th>
<th>4328m</th>
<th>5242m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of Subjects</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AMS-C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 1</td>
<td>37</td>
<td>34</td>
<td>28</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>(92.5%)</td>
<td>(85%)</td>
<td>(70%)</td>
<td>(7.5%)</td>
</tr>
<tr>
<td>Group 2</td>
<td>3</td>
<td>6</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>(7.5%)</td>
<td>(15%)</td>
<td>(30%)</td>
<td>(32.5%)</td>
</tr>
<tr>
<td>Missing</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>(0%)</td>
<td>(0%)</td>
<td>(0%)</td>
<td>(60%)</td>
</tr>
<tr>
<td>AMS-R</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 1</td>
<td>39</td>
<td>34</td>
<td>29</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>(97.5%)</td>
<td>(85%)</td>
<td>(72.5%)</td>
<td>(15%)</td>
</tr>
<tr>
<td>Group 2</td>
<td>1</td>
<td>6</td>
<td>11</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>(2.5%)</td>
<td>(15%)</td>
<td>(27.5%)</td>
<td>(25%)</td>
</tr>
<tr>
<td>Missing</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>(0%)</td>
<td>(0%)</td>
<td>(0%)</td>
<td>(60%)</td>
</tr>
</tbody>
</table>
Figure 3. Group mean factor scores at selected altitudes.
The major purpose of this study was to determine if a significant relationship existed between the prediction variables and the degree of AMS and then combine those relationships and analyze whether significant correlations can be found in those subjects suffering from AMS. The line graphs in Figures 4-8 illustrate the prediction variables means and their relationship to altitude. Each variable has been divided into Group 1 and Group 2 means. For example, Figure 4 shows the average fitness for Groups 1 and 2, AMS-C, at 3475 m as 53.21 and 47.83 ml·kg⁻¹·min⁻¹, respectively. These graphs represent the differences between groups and categories of AMS. The margin of difference between groups gives a practical indication of whether the difference was significant.

An analysis of variance (ANOVA) was performed to determine whether significant difference existed between groups for like variables. With the significant level set at \( p < .05 \), Group 1 mean scores for fitness of 54.1 ml·kg⁻¹·min⁻¹ was significantly different from the mean score of 48.3 ml·kg⁻¹·min⁻¹ for Group 2. No other mean score differences between Group 1 and Group 2 for the variables age, percent body fat, BPS, and BPD were found to be significant. The \( p \) values for the variables are listed in Table 5.
Figure 4. Sea level fitness group means at selected altitudes illustrating the differences between the not sick and sick.
Figure 5. Percent body fat group means at selected altitudes depicting differences between the not sick and the sick.
Figure 6. Age group means at selected altitudes illustrating the differences between the not sick and the sick.
Figure 7. Systolic blood pressure means at selected altitudes showing the differences between the not sick and the sick.
Figure 8. Diastolic blood pressure means at selected altitudes illustrating the differences between the not sick and the sick.
A Pearson product-moment correlation on fitness level, % body fat, age and BP as they relate to both AMS-C and AMS-R at 4328 m is shown in Table 6. Fitness had a moderate/low correlation of \(-0.42, p < 0.01\) and \(-0.31, p < 0.05\) for AMS-C and AMS-R, respectively.

Fitness and its relationship to AMS correlated significantly better than the other variables. The final goal however was to generate a regression equation using a combination of contributing variables to increase the correlational relationship. The \(-0.42\) and \(-0.31\) correlation for fitness \((p < 0.05)\), AMS-C and AMS-R respectively in the Pearson product would suggest fitness is the primary contributor for predicting AMS. The other variables' \(r\) values for AMS-C are as follow: percent body fat, \((0.113)\), age, \((0.111)\), BPD, \((0.167)\), BPS, \((0.082)\) and for AMS-R they are in the following order: age, \((0.088)\), percent fat, \((0.06)\), BPD & BPS, \((0.009)\) (Table 6).
Table 5.

The Group Means and the Significance Difference Between the Group Means (Analysis of Variance) for the Test Variables at 4328m.

<table>
<thead>
<tr>
<th>Group Means</th>
<th>Age</th>
<th>Fitness</th>
<th>% Fat</th>
<th>BPS</th>
<th>BPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMS-C 4328m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 1 mean</td>
<td>34.82</td>
<td>54.14</td>
<td>13.59</td>
<td>127.6</td>
<td>77.93</td>
</tr>
<tr>
<td>p value =</td>
<td>.305</td>
<td>.0314</td>
<td>.1278</td>
<td>.23</td>
<td>.45</td>
</tr>
<tr>
<td>(Analysis of Variance)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(S.D.)</td>
<td>9.23</td>
<td>7.39</td>
<td>5.77</td>
<td>8.25</td>
<td>5.78</td>
</tr>
<tr>
<td>(S.E.)</td>
<td>1.74</td>
<td>1.31</td>
<td>.91</td>
<td>1.47</td>
<td>.99</td>
</tr>
<tr>
<td>Group 2 mean</td>
<td>38.58</td>
<td>48.33</td>
<td>10.84</td>
<td>131.7</td>
<td>79.75</td>
</tr>
<tr>
<td>(Analysis of Variance)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(S.D.)</td>
<td>13.05</td>
<td>7.89</td>
<td>5.21</td>
<td>8.31</td>
<td>7.01</td>
</tr>
<tr>
<td>(S.E.)</td>
<td>3.77</td>
<td>2.28</td>
<td>.85</td>
<td>2.38</td>
<td>1.10</td>
</tr>
<tr>
<td>AMS-R 4328m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 1 mean</td>
<td>35.14</td>
<td>54.21</td>
<td>12.86</td>
<td>128.88</td>
<td>79.13</td>
</tr>
<tr>
<td>p value =</td>
<td>.434</td>
<td>.017</td>
<td>.867</td>
<td>.475</td>
<td>.879</td>
</tr>
<tr>
<td>(Analysis of Variance)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(S.D.)</td>
<td>8.75</td>
<td>7.10</td>
<td>4.93</td>
<td>7.90</td>
<td>5.36</td>
</tr>
<tr>
<td>(S.E.)</td>
<td>1.62</td>
<td>1.32</td>
<td>.91</td>
<td>1.47</td>
<td>1.00</td>
</tr>
<tr>
<td>Group 2 mean</td>
<td>38.09</td>
<td>47.64</td>
<td>12.54</td>
<td>131.5</td>
<td>79.8</td>
</tr>
<tr>
<td>(Analysis of Variance)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(S.D.)</td>
<td>14.43</td>
<td>8.27</td>
<td>6.16</td>
<td>9.55</td>
<td>10.54</td>
</tr>
<tr>
<td>(S.E.)</td>
<td>4.35</td>
<td>2.49</td>
<td>1.86</td>
<td>2.88</td>
<td>3.18</td>
</tr>
</tbody>
</table>
Table 6.

A Pearson Product-Moment Correlation of the Prediction Factors Versus AMS-C and AMS-R at 4328 m.

<table>
<thead>
<tr>
<th></th>
<th>AMS-C 4328 m</th>
<th>AMS-R 4328 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>.111</td>
<td>.088</td>
</tr>
<tr>
<td>Fitness</td>
<td>-.420**</td>
<td>-.313*</td>
</tr>
<tr>
<td>% Fat</td>
<td>-.113</td>
<td>-.060</td>
</tr>
<tr>
<td>BPS</td>
<td>.082</td>
<td>-.009</td>
</tr>
<tr>
<td>BPD</td>
<td>.167</td>
<td>-.009</td>
</tr>
</tbody>
</table>

* $p < .05$
** $p < .01$

The discriminant analysis refined these rough estimates in a more sophisticated manner. It was done in a stepwise fashion and eliminated each variable which detracted or did not add to the strength of the relationship between AMS and the prediction variables. Fitness, percent fat, and age were chosen as the contributory variables for AMS-C with respective correlations of 0.51, 0.35, 0.24 at $p < .01$. AMS-R's chosen variables were fitness and percent body fat with respective correlations of 0.84, 0.06 at $p < .05$ (Table 7).
Table 7.

A Discriminant Analysis on the Prediction
Variables for AMS-C and AMS-R at 4328m.

<table>
<thead>
<tr>
<th>Variables accepted</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMS-C **</td>
<td></td>
</tr>
<tr>
<td>Fitness</td>
<td>0.51</td>
</tr>
<tr>
<td>% Fat</td>
<td>0.35</td>
</tr>
<tr>
<td>Age</td>
<td>0.24</td>
</tr>
<tr>
<td>AMS-R *</td>
<td></td>
</tr>
<tr>
<td>Fitness</td>
<td>0.85</td>
</tr>
<tr>
<td>% Fat</td>
<td>0.06</td>
</tr>
</tbody>
</table>

*  \( p < 0.05 \)
**  \( p < 0.01 \)

The result of the discriminant analysis also determined the discriminant coefficients for predicting AMS-C and AMS-R at 4328 m in a prediction formula (Table 8). These prediction equations are based on data at the 4328 m elevation. The resulting correlation between AMS-C and the three variables at 4328 m using the prediction equation is .58 with a significance of \( p = 0.0018 \). The second prediction equation derived for AMS-R resulted in a correlation of .44 at a significance level of \( p = 0.0225 \) using the variables fitness and percent fat.
Table 8.

Discriminant Function Coefficients

<table>
<thead>
<tr>
<th></th>
<th>AMS-C</th>
<th>AMS-R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>-0.0357</td>
<td>N/A</td>
</tr>
<tr>
<td>Fitness</td>
<td>0.142</td>
<td>0.153</td>
</tr>
<tr>
<td>Fat</td>
<td>0.202</td>
<td>0.114</td>
</tr>
<tr>
<td>(Constant)</td>
<td>-8.745598</td>
<td>-9.47294</td>
</tr>
</tbody>
</table>

The resulting prediction equations 1 and 2 for AMS-C and AMS-R respectively, are as follows:

\[
Y^1 = -8.745598 + (-0.0357 \times \text{AGE}) + (0.142 \times \text{FIT}) + (0.2023 \times \text{FAT}) \\
\text{(4)}
\]

\[
Y^2 = -9.472942 + (0.1530 \times \text{FIT}) + (0.11389 \times \text{FAT}) \\
\text{(5)}
\]

where \(Y^1\) equals the discriminant score designating sick or not sick for AMS-C. The discriminant score for AMS-C of less than \(-0.4468\) designates sick and any score higher designates not sick. \(Y^2\) or the AMS-R discriminant score was divided at less than \(-0.34\) as being sick or greater than \(-0.3401\) as being not sick.

Comparing the people who became sick at the altitude 4328 m as defined earlier with factor scores greater than .6 for AMS-C and greater than 1.0 for AMS-R and the results of the prediction formula provided a way to classify the
predicted results. For example, in Table 9 under AMS-C, 28 cases were known to be in Group 1 (not sick), estimated from the bimodal group division pictured in Figure 1. From the prediction equation, 23 were predicted not to get sick before ascent. The 5 incorrect predictions results in an 82.1% success rate for correct predictions. The correct predictions for AMS-R was 67.5%. Caution should be followed in that the estimation of the original group division adds more error to the results than can be seen in the statistics.

Table 9.

The Classification System for Known and Predicted AMS Subjects.

<table>
<thead>
<tr>
<th>Sick Categories</th>
<th># Cases</th>
<th>Predicted Not Sick</th>
<th>Predicted Sick</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMS-C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 1 (not sick)</td>
<td>28</td>
<td>23</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(82.1%)</td>
<td>(17.9%)</td>
</tr>
<tr>
<td>Group 2 (sick)</td>
<td>12</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(16.7%)</td>
<td>(83.3%)</td>
</tr>
<tr>
<td>AMS-R</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 1</td>
<td>29</td>
<td>20</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(69%)</td>
<td>(31%)</td>
</tr>
<tr>
<td>Group 2</td>
<td>11</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(36.4%)</td>
<td>(63.6%)</td>
</tr>
</tbody>
</table>

Discussion

Fitness Level and Percent Body Fat

The results of the significant difference between fitness group means of 54.1 and 48.3 ml·kg⁻¹·min⁻¹ and the
Pearson Product Correlation of -0.42 at (p < .01) between fitness and AMS-C indicate fitness plays an important role in preventing AMS. Contrasting results were reported by Green and Stockley (1979); Hackett (1978); Wright and Fletcher (1987), who declared that fitness had no relationship to AMS. One of the possible explanations for the discrepancy could be due to Green's small sample size (n=17) and the different methods employed by the other researchers for control of acclimatization.

The subjects who climbed were found to have a low/moderate negative correlation between percent body fat and fitness of -0.43, (p = .003) (Table 6). The implication is, the leaner the person is the higher the fitness level. One of the paradoxical findings that has been reported by several researchers is that lean climbers tend to lose more body fat because of their efficiency to utilize fat (Harvey, Chettle, & James, (1979); Surks et al., 1966).

In this study the group mean for percent body fat at 4328 m was 13.59% fat level for the not sick and a mean of 10.84% body fat level for the sick group. The difference in percent body fat between groups were relatively small, but nonetheless, Group 1 had more energy reserve than Group 2 (sick), in the form of fat, and they were not as affected by AMS. There have been no studies that correlate a high fitness level at altitude and the increased ability to utilize fat.
In this study the results suggest that the highly fit climbers, happened to have higher percent fat values (13.59%) than the less fit (10.84%) and were less prone to AMS. One of the explanations may be that unfit climbers derive their primary energy source from glycogen stores. Young et al. (1982) reported a general glycogen sparing effect in climbers at high altitude, but no comparison was made between fitness levels and the ability to spare glycogen. The process of using up glycogen stores could account for AMS symptoms, resulting in fatigue and the catabolism of muscle protein for energy. The use of muscle tissue causes an imbalance in the fluid state of the body because the protein catabolism results in dehydration to rid the body of metabolic wastes. (Katch, Katch & McArdle, 1981). A concomitant dehydration affect of a water shift from intravascular to intracellular as a result of a maladapted ACE response in the angiotensin pathway may end in more severe AMS symptoms (Hackett et al., 1981). Hackett (1978) classified dehydration as an enhancer of AMS symptoms. Bradwell and Delamere (1986) found above 3000 m that protein breakdown correlates well with the degree of hypoxia and the height attained. If the less fit tend to break down protein at an earlier stage, do they become more hypoxic and thus more susceptible to AMS? Further, is the less efficient use of oxygen in protein breakdown quantitative enough to cause a more advanced hypoxic condition? Possibly, but a more accepted theory is the
fluid balance is disturbed resulting in pulmonary edema which increases hypoxia due to decrease oxygen exchange.

Another possible result of protein catabolism is the effects of the by products on AMS susceptibility. It is feasible that the waste by-products could change the permeability status of the cell membrane (Winterborn et al., 1987) thus promoting fluid imbalance or leakage into extracellular space. If this is a possibility, it may explain some of the symptoms of AMS caused by excess edema (HACE & HAPE). In review of the literature Milledge et al. (1983) maintains fluid balance is one of the main components in the genesis of AMS.

Milledge (1986) maintained the hypoxic ventilatory response (HVR) determines whether a person will reduce his or her risks of acquiring AMS. This concept is simple. A rapid HVR will result in increased $O_2$ saturation. A question to be investigated is how does a person achieve a rapid HVR? Is it possible to increase the response by increasing fitness level or is it a genetic trait only?

Elite athletes found to have difficulty with AMS at high altitude were shown to have a blunted HVR. Shoene (1982) discovered that these world class female middle and long distance runners were unable to maintain adequate oxygenation at high altitude. Successful and highly fit high altitude climbers however, with rapid HVR's maintained adequate oxygenation at the same height. In this case, an athlete of world class caliber has trained extensively in
her sport. Is this blunted response, which enhances her sea level performance but interferes with her high altitude performance, an adapted or trained response? Fitness in the case of elite runners seems to promote AMS but the climbers who trained specifically for their activity had a beneficial response. Is it possible to take a population such as the subjects in this study and train them to respond more adequately to high altitude?

All these possibilities dealing with various relationships to fitness level are mostly speculation because very few studies include fitness levels of their subjects. This study's evidence suggested that a significant relationship exists between fitness and AMS. Schoene's results for one, help distinguish those populations with similar fitness levels relative to their sport but different specificity of training and thus a different response to altitude (Schoene, 1982).

**Age**

A poor correlation for age of $r = .11$ ($p > .05$) for AMS-C and $r = .08$ ($p > .05$) for AMS-R, using the Pearson product correlation at 4328 m suggested that age alone is a poor predictor of AMS. The group means in this study for age at the 4328 m level for Group 1 was 34.8 years and Group 2 was 38.6 years (AMS-C). AMS-R Group 1 was 35.1 years and Group 2 was 38.0 years. In the review of the literature Hackett (1976) observed a negative correlation revealing that older
individuals were less apt to suffer AMS symptoms. No correlations were cited. The present study found older individuals were more prone to AMS. Hackett's sample was a potpourri of all trekkers and climbers alike passing through Pheriche Nepal, the conditions for acclimatization were not as controlled, and he used a different instrument to measure AMS. All these factors could explain the contrasting results; yet from the large population his observations seemed representative of that particular sample and region.

Although the correlation for both categories of AMS as related to age were insignificant alone, the use of age does contribute to the significance in the discriminant analysis for AMS-C.

A possible explanation for the older individuals being more susceptible to AMS, providing higher fitness is related to decrease risk in AMS, is fitness and its relationship to age. Age and fitness were reported by Sharkey (1979) to be related due to loss of muscle fiber in the later years of life and decreased muscle mass is directly related to fitness level. The 4 year difference in age between Groups 1 & 2 makes this conjecture.

**Percent Body Fat**

Fat was found to be a contributing factor in the discriminant analysis in both categories of AMS. The correlation of percent fat to fitness, \( r = -0.43 \) (\( p < 0.01 \)),
revealed overlap with fitness in contributing to the prediction of AMS. In this study there were very few overfat subjects so the analysis dealt with percent fats that were within the normal range. No studies were found that contained any information dealing with percent fat and how it related to AMS, rather the emphasis was on fat utilization and glycogen sparing effects at altitude (Guilland & Klepping, 1983); Young et al., 1982).

**Blood Pressure**

Blood pressure did not play a role in the prediction of either form of AMS. However, as the subjects gained in altitude there was a noticeable increase in the significance of its role. The evidence by Singh (1969) at approximately 4300 m showed a significant correlation between AMS and blood pressures taken at sea level, above 160/100mmHg and below 110/75mmHg. The subjects in this study were all between these extreme ranges making a confirmation of his data impossible.

**Summary of Findings**

The results of the investigation are summarized as follows:

1) The climbing group was found to have a higher mean level fitness score of 54 ml·kg⁻¹·min⁻¹ than the mean level fitness score of the average American at 40–44 ml·kg⁻¹·min⁻¹.
2) The altitude of 4328 m was found to be the best elevation for the development of the prediction equation.

3) Progressive AMS symptoms were accounted for by increasing elevation.

4) The analysis of variance of like prediction factors demonstrated fitness level had the only significant difference between groups at $p = .0314$ (AMS-C) and $p = .017$ (AMS-R).

5) The Pearson product-moment correlation for fitness at 4328 m, resulted in a correlation of $-.42$ ($p = .003$) for AMS-C and AMS-R of $-.31$ ($p = .025$.)

6) The discriminant analysis for AMS-C at 4328m selected fitness, percent body fat and age as the contributing variables for the determination of a prediction equation significant at the $p = .0018$ level.

7) The discriminant analysis for AMS-R selected fitness and percent body fat as the contributing variables for determining the prediction equation at $p = .0225$. 
Summary

The primary purpose of this study was to determine whether AMS could be predicted by analyzing fitness level (ml·kg⁻¹·min⁻¹), percent body fat (%), age (years), and blood pressure (mmHg), prior to an ascent to high altitude. An ANOVA test was used to determine whether significant differences existed between the prediction variables for the not sick and sick groups. Fitness was found to contribute significantly to predicting AMS-C and AMS-R at an altitude of 4328 m. The relationship between fitness and AMS-C (r=-.42, p<.01) and AMS-R (r=-.31, p<.05) was an inverse one. The mean fitness levels for the not sick and sick were 54.1 and 47.3 ml·kg⁻¹·min⁻¹, respectively, which was significant at the p = .0314 level for AMS-C. AMS-R group mean differences were 54.1 ml·kg⁻¹·min⁻¹ (not sick) and 48.3 ml·kg⁻¹·min⁻¹ (sick), significant at the p = .017 level. Percent body fat, age and blood pressure were not significantly different for either AMS-C or AMS-R between the sick and not sick.
A discriminant analysis determined which variables optimized the significance of the test by choosing the variables with correlative values that most accurately predicted whether a climber would acquire AMS. In a stepwise fashion both blood pressures and age were eliminated from the AMS-C category at 4328 m, the remaining variables of fitness, percent body fat and age resulted in a moderate correlation of $r = 0.58$ ($p = 0.0018$). The discriminant analysis eliminated both blood pressures and age from the AMS-R category and the resulting $r$ of 0.43, was significant, ($p = 0.0225$).

Based on these findings, two equations (pg. 56) can be used prior to ascent to moderately predict the likelihood of acquiring AMS. The discriminant scores for $Y_1$ (AMS-C) in equation 4 and $Y_2$ (AMS-R) in equation 5 apply to AMS at 4328 m. The cut-off for $Y_1$ was less than $-0.44$ and denoted sick, above that score denoted not sick. The demarcation for $Y_2$ was below $-0.34$ as being sick and above $-0.34$ as being not sick. The findings in this study apply to AMS at 4328 m elevation.

**Conclusion**

Based upon the analysis of data at $p < 0.05$ the primary hypothesis can be accepted for both AMS-C and AMS-R at 4328 m. The combinations of fitness level, percent fat, and age were found to be most significant for predicting AMS-C. For AMS-R the variables that contributed most to the
prediction of AMS-R at 4328m were fitness and percent body fat.

The examination of the subproblem found a significant difference (p < .05) between the sick and not sick in the fitness levels of AMS-C and AMS-R. The other variables were not significant. Therefore the subproblem hypothesis of a difference between the sick and not sick was accepted as a significant difference occurred between fitness of the climbers that acquired AMS-C and AMS-R in contrast to those who did not.

The final summary of conclusions based upon the analysis of the data, from a population of 40 climbers with varying ranges of experience are as follows:

1) AMS-C at 4328 m can be reasonably predicted using the variables of fitness, percent body fat and age at r=.58, (p<.01).

2) AMS-R at 4328 m can be reasonably predicted using the variables of fitness and percent body fat at r=.43, (p <.05).

3) The level of fitness is inversely related to the occurrence of AMS-C and AMS-R at 4328 m.

Recommendations

The following are recommendations offered by the researcher for further related studies:

1) A study designed to establish whether fitness or training specificity can enhance the hypoxic
ventilatory response (HVR) that Schoene (1982) and Milledge (1986) maintained was a key factor in acquiring AMS.

2) A study designed to investigate whether specificity of training at sea level would help decrease the risk of acquiring AMS. Perhaps testing two groups; one group consisting of recreational runners, and another training with heavy backpacks while stair climbing to simulate climbing in the mountains.

3) Research is needed to examine whether fitness level affects muscle catabolism at altitude and determine whether muscle breakdown results in AMS.

4) Conduct a study to determine the effects of the prediction equation at other altitudes.

5) Design a study to investigate other variables: sex, type of aerobic training pre-climb, nutritional percentages of diet, personality, that may contribute to AMS-C and AMS-R.

6) Investigate whether contributing prediction variables change or predictability gets less accurate at higher altitude.
APPENDIX A

ENVIRONMENTAL SYMPTOMS QUESTIONNAIRE III
APPROXIMATE TEMPERATURE?

DIRECTIONS:
Cross out the number that is most applicable to the way you feel now.

HOW MUCH WATER CONSUMED IN THE LAST 24 HOURS?
APPENDIX B

GENERAL INFORMATION QUESTIONNAIRE
JAME:______________________________

ADDRESS:______________________________________________________

AGE:______ SEX______ EDUCATION___________________________(highest degree)

ANNUAL INCOME____________________

ALTITUDE OF RESIDENCE_____________ ft.

1) HAVE YOU EVER HAD ALTITUDE MOUNTAIN SICKNESS (AMS)?__________
   If so, what degree?________________________ (MILD, SEVERE, ETC.)

2) CLIMBING EXPERIENCE__________________________MONTHS/YEARS

3) PURPOSE OF THE CLIMB?_______________________________________
   __________________________________________________________________

4) DO YOU SMOKE?_____________________________ HOW MANY PACKS A DAY?________

5) HOW DO YOU RATE YOURSELF IN THE FOLLOWING PERSONALITY SCALE? Circle #

   ____________________

6) DO YOU EXERCISE VIGOROUSLY ON A REGULAR BASIS?___________

7) WHAT ACTIVITIES DO YOU ENGAGE IN ON A REGULAR BASIS?__________
   __________________________________________________________________

8) IF YOU WALK, RUN OR JOG, WHAT IS THE AVERAGE # OF MILES PER WORKOUT?_______

9) HOW MANY MINUTES PER WORKOUT?_______________________________

10) HOW MANY WORKOUTS PER WEEK?______________________________

11) WHAT IS YOUR CURRENT WEIGHT?_________ WHAT WOULD YOU LIKE TO WEIGH?______

12) WHICH DO YOU EAT REGULARLY? (circle)
   a. breakfast  b. mid-morning snack  c. lunch  d. mid-afternoon snack
   e. dinner  f. after dinner snack

13) ON A STRENuous CLIMB OF MORE THAN 6 DAYS, IS IT MORE IMPORTANT TO EAT MORE
    PROTEIN, FATS OR CARBOHYDRATES? (circle one)

14) WHEN YOU SNACK, HOW MANY TIMES PER WEEK DO YOU EAT THE FOLLOWING?
    COOKIES.CAKES__________CANDY__________DIET SODA______SOFT DRINKS_____
    DOUGHNUTS________FRUIT______MILK______POTATO CHIPS______PEANUTS_____
    CHEESE AND CRACKERS______ICE CREAM__________OTHER____________

15) DO YOU CONSIDER POTATOES, PASTA, RICE AND OTHER COMPLEX CARBOHYDRATES,
    FATTENING?__________________

16) WHAT IS YOUR CHOLESTEROL LEVEL________mg.? (if you know it)

F.L. _______ % FAT._________ Chest________
B.P. _______ WT._________ Abdomen_______
                                 Thigh________
APPENDIX C

STEP TEST PROTOCOL
The protocol read as follows: "Please sit down. If you are wearing boots remove them now. Standard light weight shoes may be worn. Now relax, refrain from speaking, listen to the instructions, and rest for the next two minutes. The step test is a simple five minute test designed to measure physical fitness and to predict the ability to sustain arduous work. The test consists of stepping upon a 15 3/4" bench for men, and a 13" bench for women for five minutes at a pace of 90 beats per minute. Your post exercise pulse rate is taken, and through a calculation that adjusts for weight, age, and sex factors, your aerobic capacity is determined. More simply stated, the step test measures your ability to transport and utilize oxygen. For the best and most accurate results it is important that you follow the instructions very carefully. You should not take the test after meals, exercise, coffee, or cigarettes. Now rest...

Please approach the bench. Listen to metronome beat. On the command 'begin' you should step upon the bench and back to the floor keeping time with the metronome. You may change the lead leg during the test by resting that leg one beat and stepping upon the bench with the other. Ready? Begin. (Five minutes of metronome of 90 beats per minute.) STOP. Sit down. Begin counting now. (15 seconds of post-exercise pulse rate.) Stop."
APPENDIX D

FITNESS CALCULATOR
directions

1. Have subject rest 2 to 3 minutes before the test is not true test after exercise, meals, coffee, cigarette.

2. Start the metronome 100 beats per minute.

3. Have subject sit at one bench and back to floor sitting and with the metronome beat.

4. After five minutes of exercise, stop metronome and have subject sit down.

5. Count subject's pulse for 10 or 15 seconds (preferably 15 seconds) after the test and exercise.

6. Use pulse-exercise guide chart and body weight on calculator below to determine fitness score.

How to use the calculator

1. Enter body weight.
2. Locate pulse-exercise guide count in column.
3. Opposite pulse count, find fitness score.
4. Turn card over and area for score.
5. Find age-adjusted score opposite nearest age.
6. Enter adjusted fitness score and find physical fitness rating.

equipment needed

- Batta band
- 15" measuring tape for men
- 10" measuring tape for woman
- Metronome or other audible timing device such as a tone or a voice recording set or 60 beats per minute.
- Scale accurate to ± 1 ounce.
- Forms for recording ages and sex.

Physical Fitness Rating - Men

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>40-49</td>
<td>40</td>
</tr>
<tr>
<td>50-59</td>
<td>50</td>
</tr>
<tr>
<td>60+</td>
<td>60</td>
</tr>
<tr>
<td>70+</td>
<td>70</td>
</tr>
</tbody>
</table>

How to find fitness score:

1. Enter body weight.
2. Locate pulse-exercise guide count in column.
3. Opposite pulse count, find fitness score.
4. Find age-adjusted score opposite nearest age.
5. Enter adjusted fitness score and find physical fitness rating.

Physical Fitness Rating - Women

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>40-49</td>
<td>40</td>
</tr>
<tr>
<td>50-59</td>
<td>50</td>
</tr>
<tr>
<td>60+</td>
<td>60</td>
</tr>
<tr>
<td>70+</td>
<td>70</td>
</tr>
</tbody>
</table>

How to find fitness score:

1. Enter body weight.
2. Locate pulse-exercise guide count in column.
3. Opposite pulse count, find fitness score.
4. Find age-adjusted score opposite nearest age.
5. Enter adjusted fitness score and find physical fitness rating.
APPENDIX E

FACTOR WEIGHTS FOR AMS-C & AMS-R QUESTIONS FROM ESQ III
<table>
<thead>
<tr>
<th>Question # and Description</th>
<th>AMS-C</th>
<th>AMS-R</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Lightheaded</td>
<td>.489</td>
<td>-</td>
</tr>
<tr>
<td>2. Headache</td>
<td>.465</td>
<td>.312</td>
</tr>
<tr>
<td>4. Dizzy</td>
<td>.446</td>
<td>-</td>
</tr>
<tr>
<td>5. Faint</td>
<td>.346</td>
<td>-</td>
</tr>
<tr>
<td>6. Vision</td>
<td>.501</td>
<td>-</td>
</tr>
<tr>
<td>7. Coordination Off</td>
<td>.519</td>
<td>-</td>
</tr>
<tr>
<td>8. Short of Breath</td>
<td>-</td>
<td>.745</td>
</tr>
<tr>
<td>9. Hard to Breath</td>
<td>-</td>
<td>.763</td>
</tr>
<tr>
<td>10. Hurts to Breath</td>
<td>-</td>
<td>.734</td>
</tr>
<tr>
<td>17. Stomach Cramps</td>
<td>-</td>
<td>.516</td>
</tr>
<tr>
<td>19. Feel Weak</td>
<td>.387</td>
<td>-</td>
</tr>
<tr>
<td>22. Back Aches</td>
<td>-</td>
<td>.686</td>
</tr>
<tr>
<td>23. Stomach Aches</td>
<td>-</td>
<td>.744</td>
</tr>
<tr>
<td>24. Sick to Stomach</td>
<td>.347</td>
<td>.691</td>
</tr>
<tr>
<td>46. Nose Stuffed</td>
<td>-</td>
<td>.534</td>
</tr>
<tr>
<td>48. Nose Bleeds</td>
<td>-</td>
<td>.578</td>
</tr>
<tr>
<td>52. Lost Appetite</td>
<td>.413</td>
<td>-</td>
</tr>
<tr>
<td>53. Feel Sick</td>
<td>.692</td>
<td>-</td>
</tr>
<tr>
<td>54. Feel Hungover</td>
<td>.584</td>
<td>-</td>
</tr>
<tr>
<td>58. Couldn’t Sleep</td>
<td>-</td>
<td>.355</td>
</tr>
<tr>
<td>65. Depressed</td>
<td>-</td>
<td>.480</td>
</tr>
</tbody>
</table>
APPENDIX F

COMPUTATION OF INDIVIDUAL FACTOR SCORES FOR AMS-C & AMS-R
AMS-C = \((F_1/25.95)\times5\) Where \(F_1 = (V_1 \times .489) + (V_2 \times .465) + (V_4 \times .446) + (V_5 \times .346) + (V_6 \times .501) + (V_7 \times .519) + (V_{19} \times .387) + (V_{24} \times .347) + (V_{52} \times .413) + (V_{53} \times .692) + (V_{54} \times .584)\)

AMS-R = \((F_2/35.69)\times5\) Where \(F_2 = (V_2 \times .312) + (V_8 \times .745) + (V_9 \times .763) + (V_{10} \times .734) + (V_{17} \times .516) + (V_{22} \times .686) + (V_{23} \times .744) + (V_{24} \times .691) + (V_{46} \times .534) + (V_{48} \times .578) + (V_{58} \times .355) + (V_{65} \times .481)\)

(Note: \(V_1 = \text{question 1, Lightheaded(value 0-5)}; V_2=\#2 \text{ etc.}\)
REFERENCES


Cruz, J.C., Reeves, J.T., Grover, R.F., Maher, J.T., McCullough, R.E., & Cymerman, A. (1980). Ventilatory acclimatization to high altitude is prevented by CO2 breathing, Respiration, 39, 121-130.


