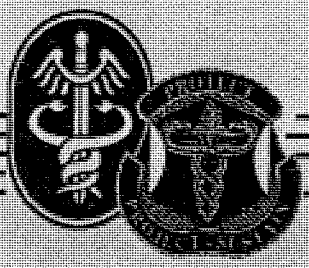
U.S. ARMY RESEARCH INSTITUTE OF ENVIRONMENTAL MEDICINE



TECHNICAL NOTE NO. TN04-05
DATE March 2004
AD A423388

ALTITUDE ACCLIMATIZATION GUIDE

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED

U.S. ARMY MEDICAL RESEARCH AND MATERIEL COMMAND

DISCLAIMERS

The views, opinions and/or findings in this publication are those of the authors, and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	March 2004	USARIEM Technical Note

4. TITLE AND SUBTITLE
Altitude Acclimatization Guide

5. FUNDING NUMBERS

6. AUTHOR(S)
S.R. Muza, C.S. Fulco, A. Cymerman

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Thermal & Mountain Medicine Division
U.S. Army Research Institute of Environmental Medicine
Kansas Street
Natick, MA 01760-5007

8. PERFORMING ORGANIZATION REPORT NUMBER
TN04-05

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Same as #7 above.

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Rapid ascent of low altitude residents to altitudes above 6,000 ft (1,600 m) increases individual susceptibility to altitude illness and decreases physical and cognitive work performance. Altitude acclimatization allows Soldiers to decrease their susceptibility to altitude illness and optimize physical and cognitive performances for the altitude to which they are acclimatized. Altitude acclimatization consists of physiological adaptations that develop in a time-dependent manner during continuous or repeated intermittent exposure to hypoxia. The purpose of this guide is to provide the user with quantitative estimations of the health and performance decrements as a function of altitude, the degree of improvements in health and performance resulting from altitude acclimatization, and several methods for inducing altitude acclimatization.

14. SUBJECT TERMS
hypoxia, altitude sickness, physical performance, cognitive performance

15. NUMBER OF PAGES
17

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unclassified

USARIEM TECHNICAL NOTE TN04-05

ALTITUDE ACCLIMATIZATION GUIDE

Stephen R. Muza
Charles S. Fulco
Allen Cymerman

Thermal & Mountain Medicine Division

March 2004

U.S. Army Research Institute of Environmental Medicine, Natick, MA
Natick, MA 01760-5007

TABLE OF CONTENTS

Introduction 1
High Altitude and Hypoxia 1
Health and Performance at High Altitude 3
Altitude Acclimatization 6
Staging / Slow Ascent Profiles 8
Intermittent Altitude (Hypoxic) Exposures 11
Monitoring and Assessing Altitude Acclimatization 12
Supportive Interventions 13

LIST OF FIGURES

FIGURE PAGE

1 Relationship between altitude, arterial oxygen partial pressure and arterial oxygen saturation in unacclimatized personnel. Categorizing altitudes is based on the physiologic responses to hypoxia. 2
2 Effects of altitude, acclimatization state, and acetazolamide on prolonged, high intensity, submaximal physical performance. Regression lines represent best fit of available performance data. Standard Deviations range from 5%-10%. 5
3 Recommended staging altitude and duration combinations to produce effective altitude acclimatization. Staging according to this guidance will reduce AMS incidence to 0%-10% at altitudes up to 3,500 m, and to 10%-30% at altitudes between 3,500-4,300 m during subsequent rapid ascents. To use, select desired staging altitude, then move to the right to determine exposure duration. 9
4 Recommended slow ascent profiles to produce effective altitude acclimatization. These slow ascents profiles will reduce AMS incidence by about 50% at altitudes above 2,500 m in initially unacclimatized personnel. 10

LIST OF TABLES

TABLE PAGE

1 Estimated AMS incidence and severity in unacclimatized personnel rapidly ascending to specified altitudes from below 1500 m. AMS incidence and severity will be increased by performing physical work at altitude. 3
2 Estimated physical performance for tasks of different durations at moderate to very high altitudes in unacclimatized (initial) and acclimatized (> 1 wk altitude residence) personnel not taking acetazolamide. 6
3 Resting SaO_2 values for unacclimatized and acclimatized personnel at high altitudes. Mean value and (range). 7
4 Recommend intermittent hypoxic exposure procedures to induce altitude acclimatization in personnel based at low altitude. 11

INTRODUCTION

Rapid ascent of low altitude residents to altitudes above 6,000 ft (1,600 m) increases individual susceptibility to altitude illness and decreases physical and cognitive work performance. Altitude acclimatization allows Soldiers to decrease their susceptibility to altitude illness and optimize physical and cognitive performances for the altitude to which they are acclimatized. Altitude acclimatization consists of physiological adaptations that develop in a time-dependent manner during continuous or repeated intermittent exposure to hypoxia. The purpose of this guide is to provide the user with quantitative estimations of the health and performance decrements as a function of altitude, the degree of improvements in health and performance resulting from altitude acclimatization, and several methods for inducing altitude acclimatization.

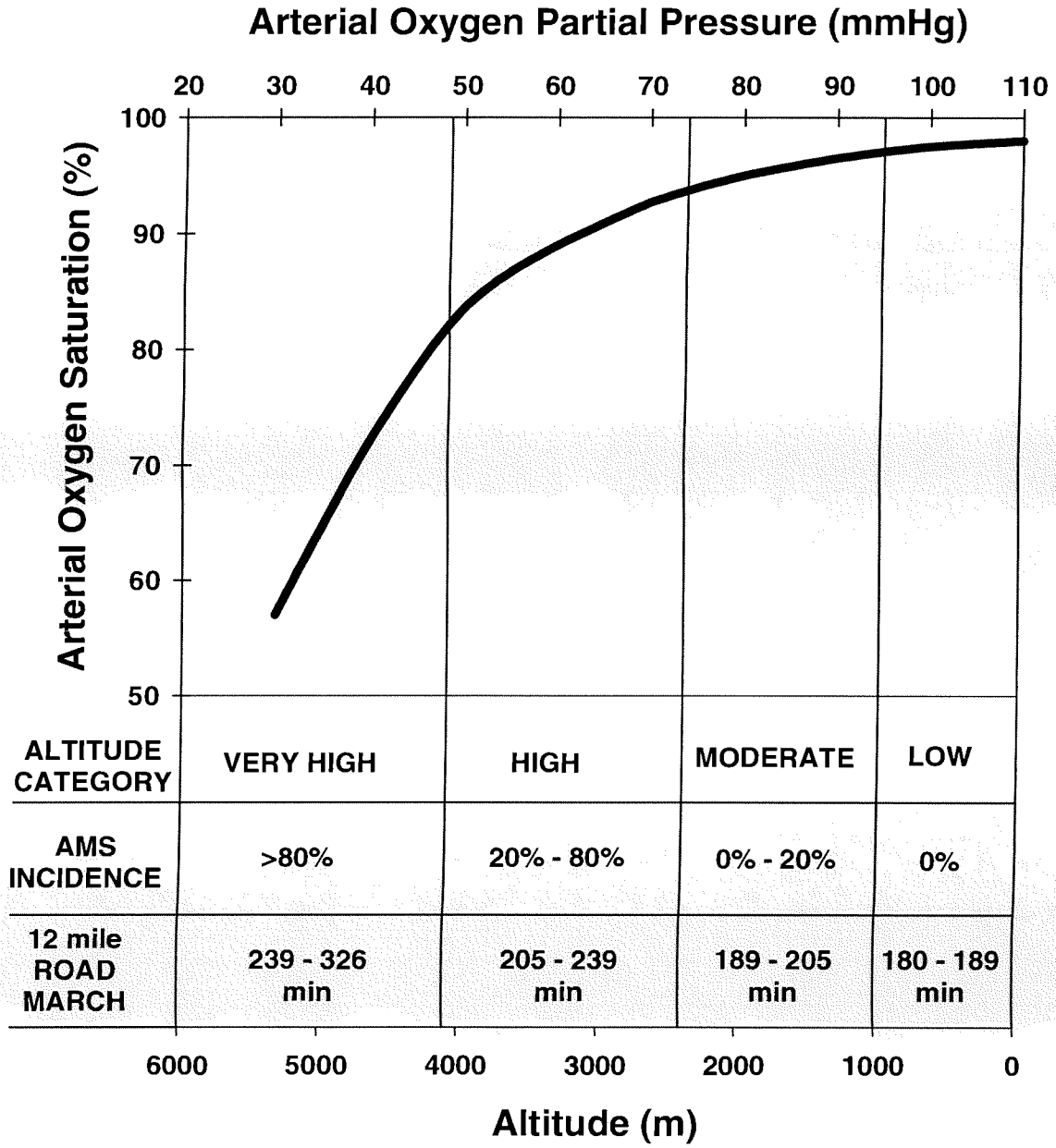
HIGH ALTITUDE AND HYPOXIA

Decreased oxygen availability in the ambient air is the only environmental stress unique to high terrestrial altitudes. It lowers the oxygen supply to body tissues which causes altitude illness, the decline in physical and mental performances, and may exacerbate preexisting medical conditions.

There is a curvilinear reduction in the ambient barometric pressure with increasing altitude. The physiologic significance of decreased barometric pressure is related to the concomitant reduction in the partial pressure of oxygen (hypobaric hypoxia). Although oxygen makes up approximately 21% of the atmosphere at all altitudes, the progressive decrease in partial pressure of oxygen means there is less actual oxygen (i.e., a lower molecular concentration) compared to sea level available for respiration.

The relationship of decreased oxygen availability to altitude illness and performance decrements provides a classification of altitude exposure based on arterial oxygen content and its physiologic effects (Figure 1). The information presented in Figure 1 is for unacclimatized low-altitude residents that have rapidly ascended (<6 h) from low altitude. This figure illustrates that with ascent to increasing altitudes, the risk of developing altitude illness (e.g., Acute Mountain Sickness) and experiencing an aerobic work performance decrement is inversely proportional to the resting arterial oxygen saturation (SaO_2). Because of the relationship between arterial partial pressure of oxygen and hemoglobin, significant decrements in resting SaO_2 do not emerge until the altitude exceeds ~2,400 m. Although the resting SaO_2 is well preserved up to ~2,400 m, the drop in arterial partial pressure of oxygen decreases the diffusion of oxygen from the lungs to the blood and then from the blood to the cells. This decrease in oxygen diffusion rate becomes apparent during physical activities as an arterial oxygen desaturation at altitudes as low as 1,000 m. Thus, physical work performance (e.g., 12 mile road march) is decremented at altitudes slightly greater than 1,000 m, even though resting SaO_2 is near sea-level values.

Figure 1. Relationship between altitude, arterial oxygen partial pressure and arterial oxygen saturation in unacclimatized personnel. Categorizing altitudes is based on the physiologic responses to hypoxia.



HEALTH AND PERFORMANCE AT HIGH ALTITUDE

Rapid ascent to altitudes above 8,000 ft (2,500 m) increases individual susceptibility to altitude illness. The primary altitude illnesses are Acute Mountain Sickness (AMS), High Altitude Pulmonary Edema (HAPE), and High Altitude Cerebral Edema (HACE). Additionally, many individuals develop a sore throat and bronchitis that can produce disabling, severe coughing spasms. The following is a brief description of these illnesses. For a more detailed description of altitude illness, their diagnoses and treatment, medical personnel should review the SOF Medical Handbook: Environmental and Occupational Medicine.

AMS is the most common form of altitude illness. AMS is a short-lived (2-7 days) illness similar to an alcoholic "hangover." AMS symptoms include headache, nausea, fatigue, and lightheadedness. AMS develops within the first 6-24 hrs of altitude exposure, and its incidence and severity increases in direct proportion to ascent rate and altitude (Table 1). Individual AMS susceptibility is currently not predictable from any measurements made at low altitude. However, prior history of AMS is the single best predictor of future susceptibility to AMS under similar ascent conditions. For all individuals, sustained physical exertion early in the altitude exposure substantially increases AMS incidence and severity.

Table 1: Estimated AMS incidence and severity in unacclimatized personnel rapidly ascending to specified altitudes from below 1500 m. AMS incidence and severity will be increased by performing physical work at altitude.

ALTITUDE	INCIDENCE (%)		
	MILD	MODERATE	SEVERE
2,130 m (7,000 ft)	20%-40%	0%-10%	0%
3,050 m (10,000 ft)	20%-30%	10%-20%	0%-10%
3,660 m (12,000 ft)	10%-40%	30%-40%	10%-20%
4,270 m (14,000 ft)	10%-30%	30%-60%	20%-30%
5,500 m (18,000 ft)	0%	10%-20%	>70%

The best methods for reducing AMS susceptibility are altitude acclimatization and minimizing physical exertion at high altitudes. Methods for developing altitude acclimatization will be described later. If altitude acclimatization is not possible, pharmacologic prophylaxis (~75% reduction in symptom severity) is available with acetazolamide, a carbonic anhydrase inhibitor. Acetazolamide induces a mild metabolic acidosis via bicarbonate diuresis, which stimulates breathing and increases arterial oxygen content to ameliorate the hypoxemia. Additional benefits include the mild diuresis that may reduce the development of edemas, which is the likely basis for all altitude illnesses. The adverse side-effects of acetazolamide include paraesthesis (tingling sensation), potential dehydration, and decreased aerobic endurance performance. Several studies have demonstrated that 1000 mg acetazolamide per day

will produce about a 25% decrease in endurance performance, at low and high altitudes. Thus, prophylaxis with high doses of acetazolamide will impair prolonged physical performance at all altitudes. Current guidance recommends limiting acetazolamide to individuals with known susceptibility to AMS, and/or using lower doses (250 - 500 mg per day) for rapid ascents to altitudes below 4000 m.

HACE is a potentially fatal, although not common illness (usually less than 2% of persons ascending above 3,660 m). HACE is an exacerbation of unresolved, severe AMS and most often occurs in people who have AMS symptoms and continue to ascend. If left untreated, HACE can progress to coma and death in 12 hrs or less. Prevention of HACE is the same as for AMS.

HAPE is a potentially fatal, although not common illness (usually less than 10% of persons ascending above 3,660 m). Individuals making repeated ascents and descents above 3,660 m may have an increased susceptibility to HAPE. Prevention of HAPE is similar to that of AMS. However, in lieu of acetazolamide, persons with prior history of HAPE may take a vasodilator such as nifedipine (20 mg sustained release every 8 hrs). Recent research suggests that sildenafil and inhaled beta agonists, such as salmeterol, may also provide prophylaxis for HAPE.

During ascent to altitude, the progressive decline in the oxygen partial pressure causes a decline in maximal aerobic exercise performance. However, submaximal physical activities require the same amount of oxygen uptake at altitude as needed at sea level. Thus, expressed in relative terms, the oxygen uptake required for a submaximal physical activity now represents a greater proportion of the reduced maximal oxygen uptake. Thus, submaximal physical performance is also impaired at altitude (Figure 1: Road March example). Furthermore, at a given altitude, the magnitude of the performance decrement will not be constant, but will vary in proportion to the duration of the activity. For example, high intensity exercise tasks lasting 2-5 min, 20-30 min, and >1 hr at sea level will average about 5%, 12%, and 30% longer, respectively, at an altitude of 3,000 m. These estimates were derived from highly trained athletes or research subjects who had been living and training at altitude for greater than 10 days.

The effects of altitude, acclimatization state, and acetazolamide on prolonged, high-intensity, submaximal, physical performance are illustrated in Figure 2. The magnitude of the physical work performance decrement varies in proportion to the altitude. Note that at all altitudes, submaximal physical performance is impaired by acetazolamide (1000 mg per day). On the other hand, acclimatization improves physical performance. For example, at an altitude of 3,000 m, altitude acclimatization can improve submaximal physical performance by ~20% over the unacclimatized individual, and by ~45% over the unacclimatized individual on high dose acetazolamide prophylaxis. Thus, altitude acclimatization sufficient to eliminate or reduce acetazolamide dosage will substantially improve submaximal physical performance at high altitudes. Table 2 shows the estimated percentage increases in physical performance times to complete tasks of various durations during initial altitude exposure

and after 1 week of altitude acclimatization. The data in Table 2 do not include the effects of acetazolamide.

Figure 2. Effects of altitude, acclimatization state, and acetazolamide on prolonged, high intensity, submaximal physical performance. Regression lines represent best fit of available performance data. Standard Deviations range from 5%-10%.

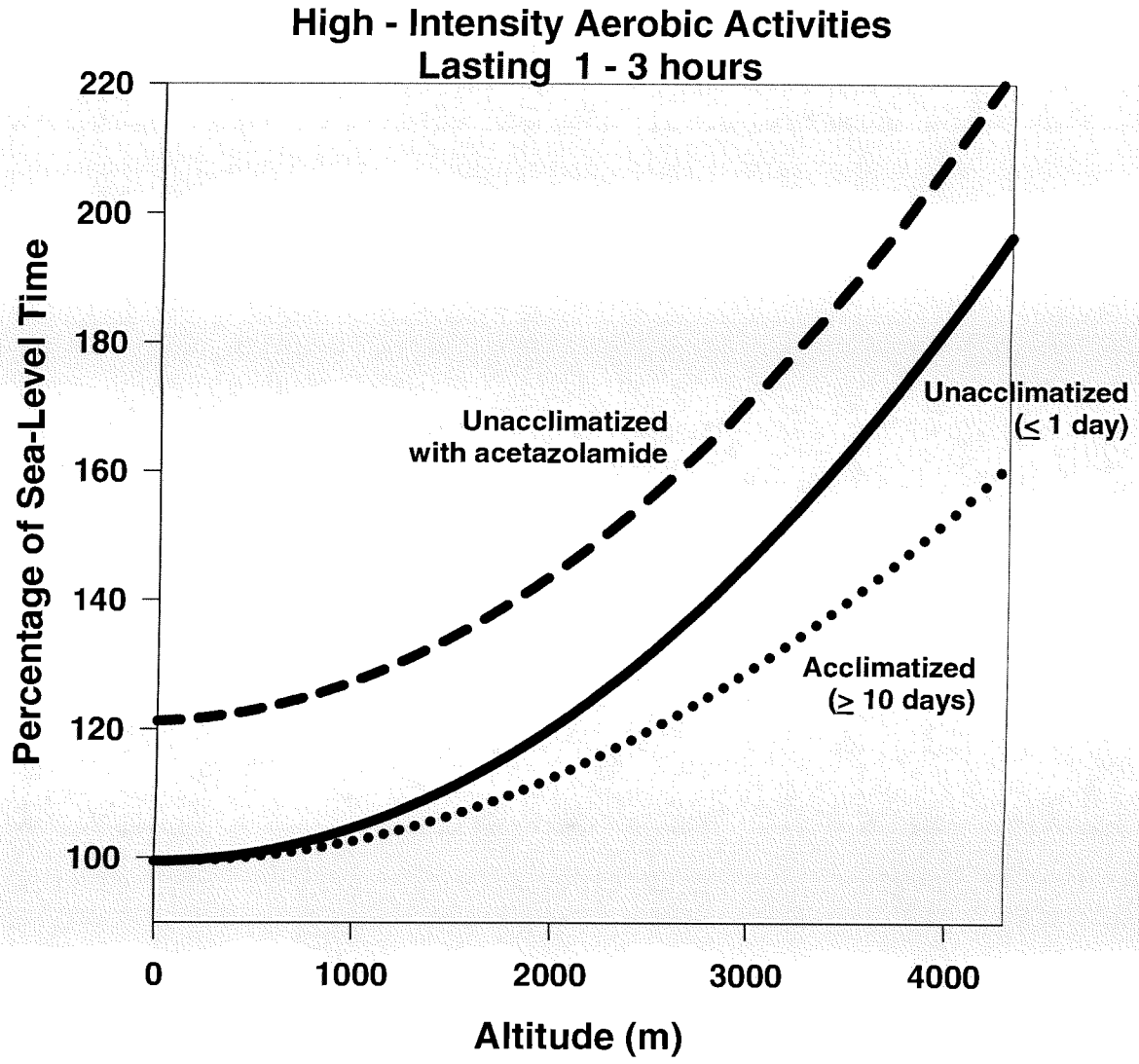


Table 2. Estimated physical performance for tasks of different durations at moderate to very high altitudes in unacclimatized (initial) and acclimatized (> 1 wk altitude residence) personnel not taking acetazolamide.

ALTITUDE	% INCREASE IN TIME TO COMPLETE TASKS RELATIVE TO SEA LEVEL							
	Tasks < 2 min		Tasks 2 - 5 min		Tasks 10 -3 0 min		Tasks > 3 hrs	
	Initial	> 1 wk	Initial	> 1 wk	Initial	> 1 wk	Initial	> 1 wk
1,220 m (4,000 ft)	0	0	2	0	4	1	7	3
2,130 m (7,000 ft)	0	0	7	2	11	3	18	10
3,050 m (10,000 ft)	0	0	12	5	20	9	40	20
3,960 m (13,000 ft)	2	0	18	9	45	20	65	45
4,880 m (16,000 ft)	2	0	50	25	90	60	200	90

With increasing altitudes, hypobaric hypoxia can negatively impact the senses, mood, psychomotor, and cognitive tasks. The "threshold" altitude for each of these psychological consequences varies. Vision, particularly dark adaptation, is the first sense affected by hypoxia, with some effects seen at altitudes as low as 1,220 to 1,520 m. Auditory thresholds are relatively insensitive to altitudes below 5,000 m. At altitudes above 3,000 m, mood states are altered, with personnel becoming less friendly, less clear-thinking, and sleepier. Reaction times are significantly longer, starting at ~3,000 m altitude, with further slowing in an altitude-dependent manner. Finally, decrements in cognitive performance (problem solving, pattern recognition, memory recall, etc.) appear to have a threshold altitude of about 3,000 m. Few military-specific psychomotor tasks have been evaluated at high altitude. However, marksmanship accuracy is decreased (~10%-15%) during the first 24 hrs of altitude exposures to as low as 2,700 m. All measures of mood, psychomotor, and cognitive task performance improve with the duration of the altitude exposure and appear to return to baseline values by after ~2 days at altitudes below 5,000 m.

ALTITUDE ACCLIMATIZATION

Altitude acclimatization allows Soldiers to decrease their susceptibility to altitude illness and achieve optimal physical and cognitive performance for the altitude to which they are acclimatized. Furthermore, altitude acclimatization has no negative side effects and will not harm health or physical performance upon return to low altitude. Altitude acclimatization consists of physiological adaptations that develop in a time-

dependent manner during continuous or repeated intermittent exposure to hypoxia. Among the major adaptations encompassing altitude acclimatization are increases in pulmonary ventilation and improvements in oxygen transport, delivery, and metabolism.

During altitude exposure, pulmonary ventilation increases in a time-dependent fashion. At altitudes >1,500 m, ventilation increases over the first 7-9 days at that altitude, with the majority of the increase completed by the fifth day. Table 3 contains mean resting SaO_2 for unacclimatized and acclimatized subjects at a range of altitudes. Due to the shape of the oxyhemoglobin disassociation curve, resting SaO_2 is not a sensitive measure of ventilatory acclimatization below 3,048 m. On the other hand, following ventilatory acclimatization, SaO_2 during physical exertion is sustained at a higher level, thus improving submaximal physical performance. Unacclimatized individuals with a resting SaO_2 at or below the mean value for that altitude have a greater risk for developing AMS than individuals with resting SaO_2 above the mean value.

Table 3. Resting SaO_2 values for unacclimatized and acclimatized personnel at high altitudes. Mean value and (range).

Altitude (m)	2,438	3,050	3,660	4,270
Unacclimatized	94% (90%-97%)	91% (85%-96%)	85% (75%-93%)	81% (72%-93%)
Acclimatized	94% (91%-98%)	92% (88%-97%)	91% (86%-97%)	89% (81%-95%)

Within the first few days of high-altitude exposure, plasma volume decreases resulting in a hemoconcentration that elevates hematocrit and/or hemoglobin concentration. The rapid reduction in plasma volume elevates the arterial oxygen content, thus reducing the demand for blood flow to supply needed oxygen. Erythropoietin levels are elevated within the first few hrs of exposure to altitudes greater than 2,000 m. However, red blood cell volume does not increase the first 1-2 weeks of altitude residence, and significant increases in red blood cell volume are only seen during high altitude exposures exceeding 16-20 days. One consequence of the elevated erythropoietin levels is a reduction in blood iron levels. Thus, personnel exposed to hypoxia should take some form of iron supplementation.

Altitude acclimatization also improves oxygen transfer between the blood and skeletal muscle by a reduction in the diffusion distance and an increase in intracellular myoglobin. Energy substrate metabolism during exercise is also affected by altitude acclimatization, with an increased preference for carbohydrate.

Taken together, these physiological adaptations increase oxygen delivery to the cell by elevating arterial oxygen content, enhancing oxygen transfer, and optimizing substrate metabolism efficiency. The result is reduced susceptibility to altitude illness and improved sustained physical and cognitive performances.

STAGING / SLOW ASCENT PROFILES

The goal of staged ascent protocols is to promote development of altitude acclimatization while averting the adverse consequences of rapid ascent to high altitudes. The following staging guidance was developed using AMS incidence and symptom severity as the sole outcome measure. That is, these staging recommendations will significantly reduce AMS incidence and severity. The effectiveness of these staging profiles on improving physical work performance at high altitudes has not been established.

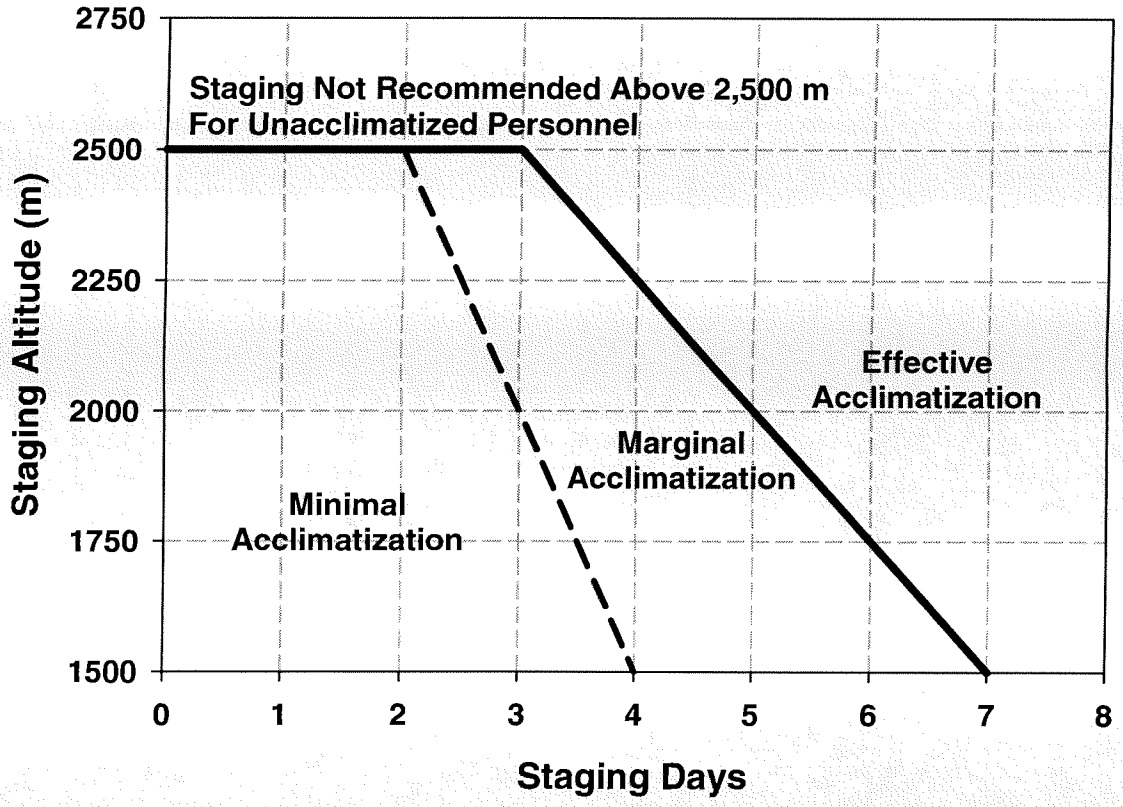
Figure 3 provides the recommended durations of staging exposure and staging altitudes that have proven effective in reducing AMS during subsequent ascents up to 4,300 m. The outcome metric for determining minimum effective staging profiles is a reduction of AMS incidence to 0%-10% at altitudes up to 3500 m and a reduction of AMS incidence to 10%-30% at altitudes between 3,500-4,300 m. By comparison, the estimated AMS incidence for unacclimatized personnel at 3,400 and 4,300 m are 50%-60% and 60%-85%, respectively. The chart also illustrates the minimal altitude exposure duration that will provide some beneficial acclimatization.

The recommended staging altitudes range from 1,500-2,500 m. Effective altitude acclimatization is not likely to develop at altitudes less than 1,500 m. On the other hand, the risk of developing AMS and other altitude illnesses increases rapidly in unacclimatized personnel ascending to altitudes greater than 2,500 m. Also, staging at altitudes higher than 2,500 m does not further decrease the length of the staging duration. Altitude staging profiles assume continuous altitude exposure for 3-7 days within the staging altitude range. To use this chart, you can enter the altitude that the personnel will stage at, then move to the right on the chart to determine the recommended exposure duration for that altitude. If personnel move within the recommended staging altitude range, a weighted-average altitude should be calculated to determine the appropriate exposure duration.

To ascend to altitudes above 4,300 m, staging can be repeated at progressively higher altitudes. As a general rule, at and above 3,500 m, staging 3 days provides significant protection against AMS during a rapid ascent up to 1,000 m above the staging altitude.

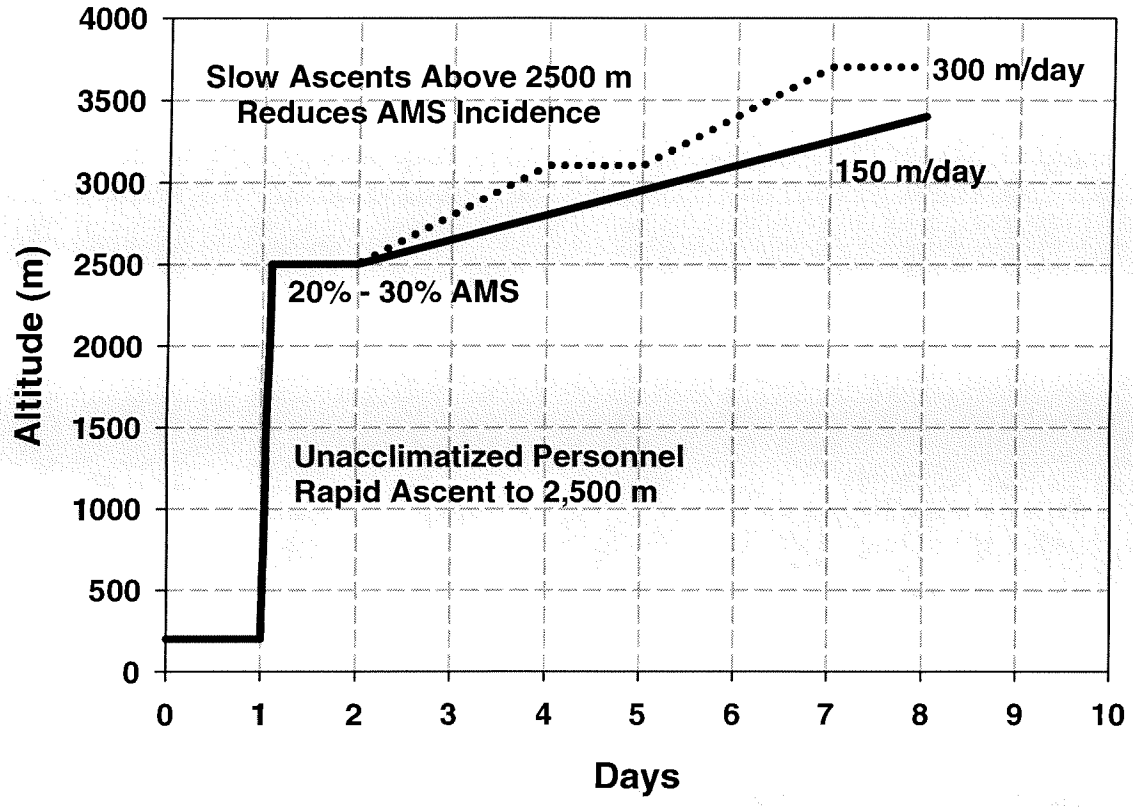
If improving physical performance at high altitudes is the principal goal, the staging guidance requires a few modifications. Current research suggests that doubling the staging durations at each altitude and including at least 1 hr of moderate intensity exercise (~60% maximum heart rate) each staging day will promote improved physical performance. The greatest physical performance improvements will be attained if the 1 hr exercise training can be conducted at altitudes above 2,000 m.

Figure 3. Recommended staging altitude and duration combinations to produce effective altitude acclimatization. Staging according to this guidance will reduce AMS incidence to 0%-10% at altitudes up to 3,500 m, and to 10%-30% at altitudes between 3,500-4,300 m during subsequent rapid ascents. To use, select desired staging altitude, then move to the right to determine exposure duration.



Slow ascent profiles are a variant of the staging profile, and are an option when staging is not possible for unacclimatized personnel ascending to altitudes greater than 2,500 m. Slow ascent profiles are not as effective as altitude staging profiles in reducing AMS incidence and severity above 2,500 m. Two examples of slow ascent profiles are illustrated in Figure 4. Recommended slow ascent profiles limit the ascent rate to 150-300 m per day and include a non-ascent day at 2-4 day intervals. Slow ascent profiles can be used with staging ascent profiles to effectively acclimatize to altitudes above 4,300 m. For example, after using a staged ascent profile from Figure 3, the acclimatized unit can rapidly ascend to 3,500 m with minimal risk of developing AMS. To ascend above 3,500 m, the unit can use one of the slow ascent profiles in Figure 4.

Figure 4. Recommended slow ascent profiles to produce effective altitude acclimatization. These slow ascents profiles will reduce AMS incidence by about 50% at altitudes above 2,500 m in initially unacclimatized personnel.



When altitude acclimatized personnel descend to low altitude, de-acclimatization begins. In well-acclimatized personnel, effective altitude acclimatization will be maintained for about 5-7 days at low altitude. It is possible that occasional exposures to high altitude will delay de-acclimatization, thus extending the duration of effective acclimatization in personnel based at low altitudes.

While staging and slow ascent protocols effectively induce acclimatization and reduce the incidence and severity of AMS, they are dependent on continuous residence at high altitudes to achieve these results. This "altitude residency" requirement reduces their utilization in special operations missions that exploit the world-wide air mobility capability of U.S. military forces to rapidly deploy to an area of operations on short notice.

INTERMITTENT ALTITUDE (HYPOXIC) EXPOSURES

The use of daily intermittent hypoxic exposures (IHE) in lieu of continuous residence at high altitudes is a recent approach to altitude acclimatization. Daily IHE can induce altitude acclimatization in personnel residing at low altitudes. Several studies have used IHE to induce altitude acclimatization prior to ascent to reduce susceptibility to altitude illness and enhance physical performance during rapid ascents to high altitude. Furthermore, these IHE altitude acclimatization studies achieved significant reductions in AMS and improved physical performance with reduced total exposure at altitude relative to chronic altitude residence. These initial findings suggest that IHE may be a more potent stimulus for acclimatization than continuous hypoxia.

IHE consists of short (1-12 h) daily exposures to high altitude either by hypobaric hypoxic or normobaric hypoxic exposures over a period of days to weeks. Normobaric hypoxia is produced by nitrogen dilution of air in a confined space (e.g., mask, hood, tent, or room). In general, three basic IHE procedures have emerged from this body of work. One IHE approach is to use relatively short (1.5-4 h) daily exposures to relatively high simulated altitudes (4,000-8,000 m) while the participant is resting but awake. The second IHE approach is to use relatively long (7-16 h) daily exposures to relatively moderate simulated altitudes (2,000-3,000 m), usually while the participant sleeps. The third IHE approach uses short (0.5-1.5 h) daily exposures to moderate altitudes (2,250-3,000 m) while the participants exercise trains at about 60% of their maximum heart rate. Using the first IHE approach, daily exposures greater than 1.5 hr for 6 or more days appear to induce ventilatory acclimatization. With the second IHE approach, daily exposures of 7-16 hr per day for 3 or more days also appear to induce ventilatory acclimatization. The development of ventilatory acclimatization should significantly reduce susceptibility to altitude illness and sustain cognitive performance. With the third IHE approach, at least 10 days of exercise training (1 h) during IHE is needed to significantly improve physical performance at altitude. Thus, taken together these studies clearly demonstrate that these IHE approaches are effective in inducing altitude acclimatization to very high altitudes without going to the mountain.

Table 4. Recommend intermittent hypoxic exposure procedures to induce altitude acclimatization in personnel based at low altitude.

ALTITUDE ACCLIMATIZATION OUTCOME	IHE DURATION (h)	IHE DAYS	IHE ALTITUDE (m)	ACTIVITY DURING IHE
AMS Reduction	>1.5	>6	4,000-4,500	Rest, awake
AMS Reduction	>7	>3	2,000-2,500	Rest, sleep
Aerobic Performance Enhancement	1	>10	2,500-3,000	Aerobic exercise @ 50%-60% HRmax

IHE procedures can be created using daily excursions to higher terrestrial altitudes, or within aircraft cabins. Personnel in unpressurized aircraft (i.e., helicopters) operating above 2,000 m experience IHE. Pressurized aircraft can be used to provide IHE if the cabin altitude is raised above 2,000 m. If personnel are awake, the cabin altitude can be raised above 2,500 m. However, if personnel are attempting to sleep, cabin altitudes should not exceed 2,500 m to avoid disrupting sleep. At present, the altitude acclimatization produced by 6-12 hrs exposure to 2,500 m altitude is not known. One study has found that 8 hrs exposure to about 2,500 m will initiate development of ventilatory acclimatization. Long exposures (>8 hrs) to altitudes above 3,000 m during air transport should be avoided to preclude development of AMS during the flight.

Normobaric hypoxia is a relatively new approach to providing a hypoxic environment. Normobaric hypoxic systems are available from several commercial sources. Most systems consist of either small enclosed spaces such as tents or rooms, or a few us aviator style masks to deliver the hypoxic gas. The former systems are generally used to provide hypoxia during sleep, while the mask system is recommended by the manufacturer for short duration hypoxic exercise training. Whichever system is used, the participant's SaO_2 should be frequently monitored to ensure that the normobaric system is, in fact, producing the desired level of hypoxia.

It should be noted that the most common use of IHE has been to improve low altitude athletic performance by competitive athletes residing at low altitudes. This is a form of "live high, train low" that has proven effective in increasing low altitude, high-intensity, aerobic exercise performance by producing a natural "blood doping." For purposes of improving low altitude aerobic performance, the minimally effective IHE protocol is 16 hr daily exposures to 2,100-2,500 m altitude for at least 20 days. The approach most frequently used by athletes is to sleep and reside in a hypoxic room or tent for the majority of the day, but train in the normal low altitude environment.

MONITORING AND ASSESSING ALTITUDE ACCLIMATIZATION

Currently, there are no tests administered at low altitude that reliably assess an individual's altitude acclimatization state. The most objective and quantifiable assessment of altitude acclimatization is ventilatory acclimatization. However, in order to assess ventilatory acclimatization, the individual must be exposed to a high altitude or normobaric hypoxic environment during the measurement. A useful and practical measure of ventilatory acclimatization is resting SaO_2 by pulse oximetry (Table 3). However, any measurement of SaO_2 by pulse oximetry must be carefully conducted to eliminate possible aberrant results due to cold hands, physical movement artifact, talking, stimulation, voluntary hyperventilation, recent ingestion of food, caffeinated beverages, or recent exercise. A finger pulse oximeter placed on a cold finger will generally under-report the true SaO_2, while all other conditions will elevate the SaO_2 above its true resting value.

If personnel are at terrestrial altitudes greater than 2,000 m for several hours to days, the presence or absence of hypoxic symptoms (lightheadedness, dizziness, fatigue) or AMS is a useful measure of altitude acclimatization status. When possible, even during short missions to high altitudes, post-mission debriefings can be used to assess whether an individual experienced any symptoms of hypoxia or AMS. Generally, hypoxic and AMS symptoms rapidly decline as altitude acclimatization develops.

Written documentation of daily altitude exposure is the best, and at present, the only way to track unit acclimatization status. If units are deployed to terrestrial altitudes above 1,500 m, or passengers on aircraft with cabin altitudes greater than 2,000 m, then a log of their altitude-exposure duration can be used to assess their altitude acclimatization status using the information provided in Figure 3 and Table 4.

SUPPORTIVE INTERVENTIONS

In addition to the procedures described for inducing altitude acclimatization, maintaining adequate hydration levels and primarily consuming carbohydrates can improve physical performance and possibly decrease altitude illness susceptibility.

Dehydration significantly impairs physical performance and may increase susceptibility to AMS. The physical performance decrements produced by dehydration are most likely in addition to the impairments produced by hypoxia. Dehydration does increase the severity of hypoxic symptoms, such as lightheadedness and dizziness. Water requirements may be increased at high altitudes due to the increased loss of water through breathing and the diuresis produced by hypoxia and/or acetazolamide.

Carbohydrate is the most efficient fuel for optimizing physical performance at altitude. Recent research has indicated that a 6%-12% glucose or maltodextran solution in liquid form (e.g., 56 grams in 560 ml of water) ingested just before and periodically during moderate to intense physical activity improved endurance performance by 10%-25% at 4,300 m. Carbohydrate supplementation also maintains blood glucose levels and reduces perception of effort. Moreover, its ingestion after activity completion hastens recovery and replenished muscle glycogen stores. In addition to providing energy to power-prolonged and intense activity, ingesting carbohydrate in a liquid form assures a better hydration status by replacing much of the fluid volume lost due to sweating and increased ventilation.

A high carbohydrate diet at altitude also is recommended as an intervention to alleviate symptoms of AMS. A diet high in carbohydrate at altitude will stimulate ventilation and thus improve blood oxygenation. Since the severity of AMS is closely linked to low blood oxygen levels, increasing blood oxygen content via enhanced carbohydrate metabolism should lessen the symptoms of AMS. A high carbohydrate diet compared to a high fat or protein diet at altitude also is typically more palatable, digestible, and acceptable by all individuals.

Recent research has also determined that certain nutritional supplements are not effective in preventing altitude illness or enhancing physical performance. Ingestion of high doses of antioxidant vitamins or Ginkgo biloba does not effectively reduce AMS susceptibility. Furthermore, creatine supplementation during short, high-altitude exposures does not improve physical performance.

ACKNOWLEDGMENTS

The authors thank Judith Ensko and Shari Hallas for their assistance in preparing this document. This guide was produced with funding provided by the Special Operations Medical Technology Development Program through the U.S. Special Operations Command Biomedical Initiatives Steering Committee.