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Acute mountain sickness in athletes with neurological impairments

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Abstract—Acute mountain sickness (AMS) is a symptom complex noticed commonly among high altitude travelers. The occurrence of AMS depends on multiple factors that have been studied extensively. However, AMS in individuals with neurological impairments has not been considered in detail. A total of 168 subjects, including active controls, inactive controls, and those with spinal cord injury (SCI), multiple sclerosis, and traumatic brain injury (TBI), were studied at the National Veterans Winter Sports Clinic in Snowmass, Colorado, from 2007 to 2009 for the occurrence of AMS. Lake Louise Score was used to quantify symptoms. A higher than anticipated occurrence of AMS (42.85%) among the study population was noted, with significantly higher Lake Louis Scores among athletes with neurological impairments. Disability group, prior history of AMS, and prior occurrence of headache at high altitude could be used as predictors for the development of AMS symptoms. More research is warranted specifically targeting the interaction between factors affecting AMS and the pathophysiology of neurological impairments like SCI and TBI to further our understanding about prophylactic medications and treatments for AMS, especially because many military personnel with neurological impairments continue on Active Duty.

Key words: acute mountain sickness, altitude sickness, AMS, disability, Lake Louis Score, multiple sclerosis, neurological impairments, paraplegia, spinal cord injury, sports, tetraplegia, traumatic brain injury, veterans.

INTRODUCTION AND BACKGROUND

Acute mountain sickness (AMS) is a symptom complex characterized by headache and at least one of the following: nausea/vomiting, fatigue, dizziness, and difficulty sleeping; it appears 6–12 h after arrival at high altitude (HA) and usually resolves within 1–3 d [1]. The occurrence of AMS or HA illness (HAI) depends on multiple factors like study population [1–3], geographic region [4–6], individual susceptibility [1,6–7], rate of ascent to altitude [1,3], absolute height achieved [1,4], and height at which the individual resides/lives before beginning the climb [1,8–9].

Although the multiple factors just mentioned have been evaluated individually in various studies, the occurrence of

Abbreviations: AMS = acute mountain sickness, ANCOVA = analysis of covariance, HA = high altitude, HAI = high altitude illness, LLS = Lake Louise Score, MS = multiple sclerosis, NVWSC = National Veterans Winter Sports Clinic, SCI = spinal cord injury, TBI = traumatic brain injury.

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AMS in individuals with neurological impairments has not been an important topic of focus. Because an increased number of military personnel with neurological impairments like traumatic brain injury (TBI), spinal cord injury (SCI), and polytrauma are returning to Active Duty and being deployed to HA environments, flying in nonpressurized aircraft, and participating in HA sporting events as part of rehabilitation, an in-depth analysis to study the occurrence of AMS in this population was done at the 2007 National Veterans Winter Sports Clinic (NVWSC) in Snowmass, Colorado (elevation of 2,470–3,813 m). Dicianno et al. published the findings from this pilot study in 2008 [10]. While no differences were found among control subjects and subjects with various neurological impairments with respect to occurrence of AMS, more subjects were needed to make a definitive conclusion. The study did, however, show that AMS in individuals with disabilities due to neurological impairments was at least as common and as severe as in those without disabilities, with the most common symptoms being fatigue and weakness, similar to what has been reported in other studies [4].

While the pathogenesis of AMS is still unclear, multiple studies have explained the series of adjustments the body goes through to meet the hypoxemic challenge at HA. This process, defined as acclimatization, has two distinct systems:

1. Increase in altitude causes the barometric pressure to fall, thereby decreasing the reduction of partial pressure of oxygen, causing hyperventilation and respiratory alkalosis. The body compensates for this alkalosis by excreting bicarbonates in the urine within 24–48 h of exposure to HA [11–12].
2. In addition, cerebral vasodilatation accompanied by alterations in the blood-brain barrier secondary to the altitude-induced hypoxemia and an increase in vascular hydrostatic pressure also occur among HA travelers [13]. These combined effects lead to cerebral edema. The ability to compensate for this edema greatly varies with every individual [1,11–12], depending on the ability of his or her spinal cord to expand and accommodate for the additional fluid [14].

In individuals with neurological impairments, multiple changes within the central nervous system following injury may potentially affect these processes. For instance, individuals with SCI have central canal expansion and loss of uniform cellular arrangement and thickening of the wall of the canal [15–16] and those with TBI and multiple sclerosis (MS) have alterations in the blood-brain barrier [17–18]. In addition, the cardiovascular and metabolic alterations secondary to these neurological impairments (SCI, TBI, and MS) involving the autonomic nervous system [17–19] could hinder the compensatory mechanisms, causing an increase in the severity of the symptoms, particularly in those with tetraplegia because they may experience autonomic dysreflexia.

With this background, the study was extended to the 2008 and 2009 NVWSC at Snowmass, Colorado, with the following specific aims:

1. To compare the occurrence of AMS in a population of athletes with neurological impairments to physically active and physically inactive control subjects at HA. We hypothesized that the occurrence and severity of AMS in individuals with neurological impairments would be higher than in the control groups.
2. To compare the occurrence of AMS in athletes based on their disabilities. We hypothesized that among individuals with neurological impairments, individuals with tetraplegia from SCI would have a higher occurrence than the other disability groups.

Further, no clinical feature or test has been shown to predict an individual's susceptibility to developing AMS at HA with any reliability [3]. Based on previous studies [2–3] and our experience with studying AMS in the past, we conducted an analysis to evaluate the factors that could have a clinically significant predictive capacity for high Lake Louise Score (LLS).

METHODS AND STATISTICS

Similar to the previous study in 2007 [10], we recruited registered athletes, trainers, and volunteers from the registration exposition, medical staff meeting, and dining facilities at the 2008 and 2009 NVWSC. A similar protocol used to obtain the preliminary data in 2007 [10] was followed. Inclusion criteria were being between the age of 18 and 80 and belonging to one of the following categories: (1) physically active controls: those trainers, volunteers, or individuals with visual impairments who were participating in sports activities and had no other disabilities; (2) physically inactive controls: those trainers, volunteers or individuals with visual impairments who were not physically participating in sports activities and had no disabilities; and (3) athletes with disabilities: those registered athletes who defined themselves as having a physical disability or who used assistive technology for mobility or self-care. There

were no exclusion criteria. However, before participating in the NVWSC, applicants are screened by a medical team for any medical condition that would present a danger to the participant. Examples of these conditions include unstable angina, severe cardiomyopathy, renal failure requiring hemodialysis, severe pulmonary fibrosis, and new-onset seizure disorder.

Subjects who met the eligibility criteria were asked to complete a medical and demographics survey as well as the questionnaire to measure the LLS (**Appendix**, available online only) [20] on day 1 of enrollment, followed by one LLS questionnaire on each of the next 2 consecutive days. In addition, we performed a retrospective chart review of the medical charts of all individuals who presented at the clinic, recording the number of general visits, the number of visits that resulted in a diagnosis of AMS, and the disability type. We also collected the number of alcoholic drinks the subjects consumed each day because this had not been collected in the prior study.

Diagnostic Criteria

AMS was defined as scoring at least 3 on the LLS, plus the presence of a headache and at least one of the following symptoms: change in appetite, nausea/vomiting, fatigue, weakness, dizziness or light-headedness, or difficulty sleeping [1,4,10]. Subjects were encouraged to report only symptoms that were new or different from baseline. Subjects who were diagnosed with AMS based on this questionnaire were referred to the medical area for further medical evaluation. The severity of the AMS was described as mild, moderate, and severe if the LLS scores were 3, 4–5, and 6 or more, respectively, after the basic AMS criteria were met [10].

Statistical Analysis

The overall occurrence of AMS in the entire study population and in each group was calculated based on the number of subjects who met the diagnostic criteria for AMS on at least one LLS on any of the 3 d. We also tallied the number of people receiving a diagnosis of AMS in the medical area for comparison. The base altitude from which subjects traveled was determined by using a database of U.S. Census Bureau information that links zip codes to altitudes (http://www.zipdatafiles.com, TPS Products and Services, Inc; New Castle, California). All alpha levels were set to 0.05 a priori. IBM SPSS Statistics 19 (IBM Corp; Armonk, New York) was used for all statistical analyses.

Baseline Analysis

The participants were divided into three groups: (1) active control, (2) inactive control, and (3) athletes with disabilities. Chi-square or Fischer exact tests were used to calculate the differences between the groups in terms of baseline demographic or medical variables that were ordinal or nominal. Kruskal-Wallis or analysis of variance tests were used to compare groups with respect to other baseline variables that were continuous, such as age, average number of times in the last year the subject traveled to HA, and average home altitude.

Level I Analysis

An analysis of covariance (ANCOVA) test was used to analyze the differences across the subgroups with respect to the average LLS, the occurrence or number of cases diagnosed, duration of symptoms, number of severe cases, and median number of days between arrival at the clinic and the time when the participant completed the first LLS. We factored in any baseline variables that were significantly different across the subgroups. A post hoc analysis was performed to determine where differences in subgroups occurred.

Level II Analysis

The participants were divided into six groups: (1) active control, (2) inactive control, (3) TBI, (4) paraplegia, (5) tetraplegia, and (6) MS. The same parameters as in the level I analysis were used to evaluate for differences in baseline values and in main outcome variables, again using ANCOVA statistics with similar post hoc analyses.

Level III Analysis

To predict an individual's susceptibility for developing AMS, we performed a regression analysis to evaluate possible factors that could have a significant clinical predictive capacity for high LLS. Age, sex, type of disability, prior history of HAI, and occurrence of headache in HA in the past were considered as the predictor variables. Kendall tau-b was used to identify possible correlations between these factors and LLS averaged over 3 d. Based on this correlation analysis, a backward regression analysis was performed to build a model to predict the average LLS for travelers with neurological impairments to HA.

Alcohol Analysis

A Pearson correlation analysis between the number of drinks consumed by each individual in a particular day

and the LLS for the same day was performed to study whether there was any relationship between alcohol consumption and LLS.

RESULTS

Subjects

Overall, there were 1,130 participants in the 2007, 2008, and 2009 NVWSC, of which 125 (11.06%) were females. A total of 178 subjects expressed interest in this study. Two subjects did not complete the informed consent document, but the remaining 176 individuals who had agreed to participate in the study completed the informed consent document. However, 8 subjects had participated in the study for more than 1 yr, and hence, only the data from their first year of participation were included. Of these 168 subjects, 54 (32.14%) were females and 114 (67.86%) males. A total of 135 (80.35%) of the 168 subjects were U.S. veterans. Racial/ethnic distribution was 112 (66.7%) Caucasian, 27 (16.1%) African American/Black, 12 (7.1%) Hispanic, 5 (3%) American Indian, 3 (1.8%) Asian American, and 9 (5.4%) more than one ethnicity. **Table 1** shows the disability types of all the participants in the NVWSC each year. Twenty-one amputees participated in the study, eight of whom had a secondary diagnosis of TBI and, hence, were grouped along with the TBI subgroup. The remaining 13 amputees were grouped with the active controls.

Analysis

After the exclusion of the repeat data, data from 168 subjects were analyzed. The subgroups differed with respect to age and sex in both levels of analysis (**Tables 2** and **3**). Autonomic dysreflexia was also present in some of the participants with tetraplegia. All subjects traveled to the NVWSC in less than 1 d, and most began participating in sporting events 24 h after arrival.

A total of 72 (42.85%) subjects met the diagnostic criteria for AMS, with 22 (13.09%) being diagnosed with severe illness. There were significant differences in the average LLS (mean ± standard deviation) among the active controls (1.2 ± 1.1), inactive controls (1.7 ± 1.7), and athletes with disabilities (2.4 ± 1.9) in the level I analysis (p = 0.01) (**Table 4**). The post hoc analysis showed that the average LLS was significantly higher in athletes with neurological impairments than in the active controls (p = 0.01) and inactive controls (p = 0.04). There was a trend for the paraplegia group to have the highest LLSs, but there were no statistically significant differences in the average LLSs among the subgroups in the level II analysis. Also, there were no significant differences in the total AMS scores, number of cases diagnosed, the duration of symptoms, number of severe cases, or median days from arrival to completion of the first LLS among subject groups in level I or level II analyses (**Table 5**). Overall, fatigue and headache were the most commonly reported symptoms (**Table 6**).

Of the 1,130 participants at the NVWSC, there were 548 visits to the medical treatment area (**Table 7**). There were 348 unique athletes who visited the medical treatment area, and 22 (6.32%) were diagnosed with AMS. Diagnoses of those receiving treatment were SCI (eight), TBI (four), visual impairment (two), amputations (two), and other (three). Patients received treatment with oxygen, hydration, nonsteroidal anti-inflammatory drugs, acetaminophen, acetazolamide, and dexamethasone, depending on their severity of symptoms. No one had to return to low altitude because of the symptoms.

Three variables, the presence of a neurological impairment, prior history of AMS, and prior history of occurrence of headache at HA, had significant positive correlations with average LLS and were considered for the regression analysis (**Table 8**). The significant F values for both the models indicated a high overall fit of the model for this data. The models also met all the assumptions of a multiple regression, indicating this model could be generalized to a larger population (**Table 9**).

No significant correlation was found in the correlation analysis performed to study the relationship between alcohol consumption and LLS.

Table 1.
Medical conditions of all 2007–2009 National Veterans Winter Sports Clinic participants.

Disability	No. of Athletes			
	2007	2008	2009	Total
Traumatic Brain Injury	50	64	73	187
Spinal Cord Injury	144	144	135	423
Stroke	5	15	12	32
Visual Impairment	58	54	75	187
Amputation	69	63	53	185
Multiple Sclerosis	36	40	25	101
Other	12	29	27	68

Note: Several participants carried >1 diagnosis.

Table 2.
Subject group demographics, based on athletes with disabilities as one subgroup.

Variable	Active Controls (*n* = 19)	Inactive Controls (*n* = 39)	Athletes with Disabilities (*n* = 110)	*p* -Value
Age, Mean ± SD (yr)	53.42 ± 12.94	50.64 ± 11.84	45.93 ± 11.8	0.03*
Female, *n* (%)	14 (25.9)	17 (31.5)	23 (42.6)	<0.001*
Past Medical History, *n* (%)				
Hypertension	4 (21.1)	12 (30.8)	30 (27.3)	0.74
Hypercholesterolemia	6 (31.6)	10 (25.6)	36 (32.7)	0.71
Heart Disease	1 (5.3)	0	8 (7.2)	0.22
Autonomic Dysreflexia	NA	NA	3 (7.9)	0.001*
Peripheral Vascular Disease	1 (5.3)	1 (2.6)	7 (6.3)	0.66
Any HAI	6 (31.6)	5 (12.8)	18 (16.4)	0.19
Sought Treatment for HA, *n* (%)	4 (2.1)	3 (7.7)	17 (15.4)	0.33
Taking Prophylactic Medication, *n* (%)	0	2 (5.1)	6 (5.4)	0.48
Headaches at HA, *n* (%)	10 (52.6)	15 (38.5)	37 (33.6)	0.28
Traveled to HA in Last 2 mo, *n* (%)	6 (31.6)	13 (33.3)	45 (40.1)	0.58
Times in Last Year Traveled to HA, Mean ± SD	0.7 ± 1.1	0.9 ± 1.8	0.5 ± 0.8	0.25
Home Altitude (m), Mean ± SD	538.7 ± 664.0	371.4 ± 539.8	363.5 ± 623.9	0.11

*Statistically significant difference.
HA = high altitude, HAI = high altitude illness, NA = not applicable, SD = standard deviation.

Table 3.
Subject group demographics, based on athletes with disabilities and subgroups based on their neurological impairment.

Variable	Active Controls (*n* = 19)	Inactive Controls (*n* = 39)	TBI (*n* = 29)	Paraplegia (*n* = 38)	Tetraplegia (*n* = 28)	MS (*n* = 15)	*p*-Value
Age (yr), Mean ± SD	53.42 ± 12.94	50.64 ± 11.84	41.67 ± 13.87	47.39 ± 11.28	46.64 ± 11.51	48.53 ± 6.72	0.03*
Females, *n* (%)	14 (73.7)	17 (43.6)	4 (13.8)	7 (18.4)	4 (14.3)	8 (53.3)	<0.001*
Past Medical History, *n* (%)							
Hypertension	4 (21.1)	12 (30.8)	8 (27.6)	9 (23.7)	12 (42.9)	1 (6.7)	0.19
Hypercholesterolemia	6 (31.6)	10 (25.6)	10 (34.5)	14 (36.8)	9 (32.1)	3 (30.0)	0.84
Heart Disease	1 (5.3)	0	3 (10.3)	3 (7.9)	2 (7.1)	0	0.32
Autonomic Dysreflexia	NA	NA	NA	3 (7.9)	NA	NA	0.001*
Peripheral Vascular Disease	1 (5.3)	1 (2.6)	4 (13.8)	2 (5.3)	1 (3.6)	0	0.47
Any HAI	6 (31.6)	5 (12.8)	3 (10.3)	10 (26.3)	4 (14.3)	1 (6.7)	0.21
Sought Treatment for HA, *n* (%)	4 (2.1)	3 (7.7)	5 (17.2)	8 (21.1)	4 (14.3)	0	0.25
Taking Prophylactic Medication, *n* (%)	0	2 (5.1)	4 (13.8)	2 (5.3)	2 (7.1)	0	0.50
Headaches at HA, *n* (%)	10 (52.6)	15 (38.5)	8 (27.6)	15 (39.5)	9 (32.1)	5 (33.3)	0.61
Traveled to HA in Last 2 mo, *n* (%)	6 (31.6)	13 (33.3)	13 (44.8)	16 (42.1)	11 (39.3)	5 (33.3)	0.89
Times in Last Year Traveled to HA, Mean ± SD	0.7 ± 1.1	0.9 ± 1.8	0.4 ± 0.7	0.6 ± 1.1	0.5 ± 1.1	0.5 ± 0.7	0.61
Home altitude (m), Mean ± SD	538.7 ± 664.0	371.4 ± 539.8	281.3 ± 532.6	166.8 ± 263.1	262.9 ± 481.3	744.2 ± 951.7	0.15

*Statistically significant difference.
HA = high altitude, HAI = high altitude illness, MS = multiple sclerosis, NA = not applicable, SD = standard deviation, TBI = traumatic brain injury.

Table 4.
Acute mountain sickness (AMS) statistics for each group.

Variable	Active Controls (*n* = 19)	Inactive Controls (*n* = 39)	Athletes with Disabilities (*n* = 110)	*p*-Value
Average LLS, Mean ± SD	1.2 ± 1.1	1.7 ± 1.7	2.4 ± 1.9	0.01*
Cases Diagnosed, No. (%)	8 (42.1)	14 (35.9)	50 (45.4)	0.58
Duration of AMS Symptoms, No. of d (Range)	1 (1–2)	1 (1–3)	1 (1–3)	0.48
Severity, No. (%)	1 (5.3)	3 (7.7)	24 (21.8)	0.14
Days Subjects at Clinic when Completed First LLS, Median (Range)	1 (0–3)	2 (0–4)	2 (0–4)	0.08

*Statistically significant difference.
LLS = Lake Louise Score, SD = standard deviation.

Table 5.
Acute mountain sickness (AMS) statistics for each subgroup, based on neurological impairments in athletes.

Variable	Active Controls (*n* = 19)	Inactive Controls (*n* = 39)	TBI (*n* = 29)	Paraplegia (*n* = 38)	Tetraplegia (*n* = 28)	MS (*n* = 15)	*p*-Value
Average LLS, Mean ± SD	1.2 ± 1.1	1.7 ± 1.7	2.4 ± 2.0	2.6 ± 1.9	2.2 ± 2.1	2.0 ± 1.8	0.06
Cases Diagnosed, No. (%)	8 (42.1)	14 (35.9)	13 (44.8)	21 (55.3)	10 (35.7)	6 (40.0)	0.58
Duration of AMS Symptoms, No. of d (Range)	1 (1–2)	1 (1–3)	2 (1–3)	1 (1–3)	1 (1–3)	1.5 (1–3)	0.56
Severity, No. (%)	1 (5.3)	3 (7.7)	6 (20.7)	8 (21.1)	4 (14.3)	2 (13.3)	0.41
Days Subjects at Clinic when Completed First LLS, Median (Range)	1 (0–3)	2 (0–4)	1 (1–4)	1 (0–3)	1 (1–3)	1 (0–4)	0.09

LLS = Lake Louise Score, MS = multiple sclerosis, SD = standard deviation, TBI = traumatic brain injury.

Table 6.
Subjects in each subgroup reporting acute mountain sickness symptoms in Lake Louise Score questionnaire. Data shown as No. (%).

Symptom	Subgroup*					
	Active Controls (*n* = 19)	Inactive Controls (*n* = 39)	TBI (*n* = 29)	Paraplegia (*n* = 38)	Tetraplegia (*n* = 28)	MS (*n* = 15)
Headache	10 (52.6)	19 (48.7)	17 (58.6)	27 (71.1)	14 (50.0)	8 (53.3)
Gastrointestinal	2 (10.5)	9 (23.1)	8 (27.6)	14 (36.8)	5 (17.9)	6 (40.0)
Fatigue	11 (57.9)	21 (53.8)	19 (65.5)	23 (60.5)	17 (60.7)	10 (66.7)
Dizziness	3 (15.8)	12 (30.8)	11 (27.9)	15 (39.5)	11 (39.3)	3 (20.0)
Difficulty Sleeping	7 (36.8)	22 (56.4)	15 (51.7)	27 (71.1)	14 (50.0)	7 (46.7)

*n in each subgroup represents 100%.

Table 7.
Number of athletes who visited the medical area, with their disabilities, and treatment modalities for acute mountain sickness (AMS).

Variable	2007	2008	2009	Total
Visits in Medical Area				
Total No. of All Visits to Medical Area (Athletes, Volunteers, Trainers)	182	194	172	366
Total No. of Unique People Treated in Medical Area	161	153	135	449
Total No. of Unique People Diagnosed with AMS in Medical Area	7	6	9	22
Athletes in Medical Area				
Total No. of All Athlete Visits (Athletes Only)	150	149	145	444
Total No. of Unique Athletes Treated in Medical Area	133	113	111	357
Total No. of Unique Athletes Diagnosed with AMS in Medical Area	7	5	7	19
Average Age of Athletes Treated for AMS	54	42	49	145
Disabilities of Athletes Diagnosed with AMS in Medical Area: Tally No. for Each Category				
Traumatic Brain Injury	—	2	2	4
Spinal Cord Injury	4	1	3	8
Stroke	—	—	—	—
Visual Impairment	1	—	1	2
Amputations	—	1	1	2
Multiple Sclerosis	—	—	—	—
Other	2	1		3
Treatments Given: Tally No. for Each Category				
Oxygen	—	1	2	3
Hydration	3	2	2	7
Aspirin	—	—	—	—
Nonsteroidal Anti-Inflammatory Drugs	2	—	1	3
Acetaminophen	3	—	3	6
Return to Low Altitude	—	—	—	—
Acetazolamide	7	3	5	15
Dexamethasone	—	1	1	2

Table 8.
Pearson correlation coefficient for predictor variables.

Average LLS	Sex	Age	Category	h/o AMS	h/o Headache	Average LLS
Correlation Coefficient	0.01	–0.083	0.189	0.164	0.183	1
Significance (2-tailed)	0.878	0.133	0.003*	0.013*	0.006*	—

*Statistically significant difference.
AMS = acute mountain sickness, h/o = history of, LLS = Lake Louise Score.

Table 9.
Regression model (backward analysis) to predict average Lake Louise Score (LLS).

Model		Coefficients									
		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics				
		B	SE	Beta	*t*	Sig.	Tolerance	VIF	*F*	Sig.	Durbin-Watson
1	(Constant)	0.835	0.354		2.358	0.02			5.888	0.001[a]*	
	Category	0.186	0.056	0.25	3.295	0.001	0.986	1.014			
	h/o Headache	0.736	0.328	0.188	2.241	0.026	0.801	1.248			
	h/o AMS in Past	0.32	0.413	0.065	0.775	0.439	0.81	1.234			
2	(Constant)	0.85	0.353		2.409	0.017			8.552	<0.001[b]*	1.98
	Category	0.186	0.056	0.25	3.299	0.001	0.986	1.014			
	h/o Headache	0.846	0.295	0.217	2.863	0.005	0.986	1.014			

[a]Dependent variable: average LLS.
[b]h/o past AMS and headache.
*Statistically significant difference.
AMS = acute mountain sickness, h/o = history of, SE = standard error, Sig. = significance, VIF = variance inflation factor.

DISCUSSION

As with our previous study, there was an overall higher occurrence of AMS in the entire study population (42.85%), and within specific subgroups as compared with previously reported data (25.00%) within the same region [11,21]. Several factors may explain these findings. First, the majority of the study population included individuals with neurological impairments and the possible implications of the various pathophysiological process involved with these neurological impairments could affect the process of acclimatization, precipitating the symptoms of AMS. Second, the active and inactive controls had a high number of volunteers and staff who could have been more active than their baseline activity at lower altitudes by participating in events that may have been more physically demanding than hiking, climbing, and trekking, which were the sports commonly reported in previous literature. In addition, all our subjects had a rapid ascent and many participated in high intensity sporting events soon after arriving at HA.

Individuals with paraplegia trended toward having a higher occurrence of AMS (55.3%), higher LLS (2.6 ± 1.9), and more severe symptoms (21.1%) than the other subgroups (**Table 4**), although the results were not statistically significant. Our observation was that many of the athletes with paraplegia participated in some of the most physically demanding sports at the NVWSC as compared with those with tetraplegia and more heavily relied on upper-limb muscle groups for strength and endurance, which can increase aerobic exertion and may have made some symptoms more prevalent, which thereby could have caused an increase in their LLS. Also, the intrinsic fatigue of the muscles in patients with SCI [22] could have been aggravated by the physical exertion at HA, thereby causing an increase in the reporting of fatigue as a symptom and increasing average LLS.

Despite the 42 percent of the subjects in this study meeting diagnostic criteria, few sought medical treatment even after prompting. Most likely, many individuals may think the symptoms are self-limiting or may try to self-treat. Most symptoms fell into the mild range and lasted on average 1 to 2 d. Since only 22 individuals were diagnosed with AMS, we could estimate that possibly <2 percent of those with AMS symptoms sought treatment.

The significant findings from the regression analysis indicate that the three variables, the presence of a neurological impairment, prior history of occurrence of AMS, and prior occurrence of headache at HA correlate positively with the average LLS and could be used as predictors for the average LLS. Thus, clinicians should consider obtaining this information from the patient's history, particularly among individuals with neurological impairments traveling to HA. While there are no clear indications for prophylaxis, this information may help determine who will be more likely to have more symptoms.

LIMITATIONS

Although a large study population was recruited, the subjects within individual subgroups with the various disabilities were unevenly distributed, which could have contributed to the insignificant subgroup comparisons in the level II analysis. Also, because of the prescreening of participants before the NVWSC, the external validity of the study may have been limited to individuals without serious and unstable medical conditions.

While consumption of alcohol did not seem to confound the results, subjects may have underreported alcohol consumption. This study also did not account for the active medications the subjects were on, which may have multiple interactions with the cardiovascular and renal systems, both of which are actively involved in the process of acclimatization.

Although the regression model could be generalized for the larger population, only three variables could be accounted for from this study because of the size of the study population. More variables should be studied in future studies to evaluate for more accurate predictors for the LLS or for the occurrence of AMS itself.

CONCLUSIONS

While there were no differences among subject groups with respect to occurrence of AMS based on their disability, this study shows that LLS in athletes with disabilities due to neurological impairments is significantly higher than in those without disabilities. The most common symptoms reported are fatigue and headache. The occurrence may be underestimated or possibly underreported clinically because many do not seek treatment. Hence, individuals, specifically those with neurological impairments, should be carefully assessed with a detailed history to identify any predisposing factors, specifically prior history of AMS and prior occurrence of headache at high altitude.

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