

Measuring Balance at High Altitudes

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Abstract

Aims: Due to hypoxia and hypobaric conditions at high altitudes, oxygen saturation decreases. Ataxia might occur and the ability to maintain balance is challenged. This study aimed to determine whether a new balance assessment test, the Zur Balance Scale (ZBS) is sensitive enough to detect changes in balance at high altitudes. *Methods:* Seven healthy men, 30-64 years of age, volunteered to participate. During a 14-day journey to Mt. Everest Base Camp, Nepal, they underwent a series of balance evaluation procedures daily, using the ZBS and the single-leg balance test. In addition, physiological tests included pO₂ saturation (%), systolic and diastolic blood pressure (mmHg) and heart rate (pulse/min). Data on balance were collected at 4 different altitudes (2,610 m, 3,300 m, 4,400 m, and 4,950 m). *Results:* ZBS scores decreased significantly ($P < 0.0001$) at higher altitudes. Heart rate was increased at higher altitudes, while systolic and diastolic blood pressure and pO₂ saturation decreased. *Conclusions:* Poor balance control could contribute to risk of falls from high altitudes and might result in injury or death. The ZBS detected changes in balance at high altitudes.

Keywords: High altitude, Balance, Blood pressure, Heart rate, Oxygen saturation

Introduction

High altitude conditions can cause impairment in balance control that could result in falls, injury or death [1] and might trigger abnormal gait such as ataxia [2, 3] and severe headaches. These symptoms can occur due to hypoxia [4] and hypobaric phenomena, and to oxygen saturation, which decreases as altitude

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increases [5, 6]. Leptin is a biomarker in the neuroendocrine system that helps regulate homeostasis and appetite. Hypoxia, cold temperatures and hypobaric conditions affect blood leptin levels [7, 8]. This constellation of symptoms, known as Acute Mountain Sickness (AMS), occurs when the body is exposed to elevations of 2,500 m above sea level and higher. The percentage of individuals affected by altitude-related symptoms vary; thus, the incidence of AMS depends on the rate of ascent, altitude and health and age of the individual [9, 10]. Although 3-week exposure to moderate altitude had a favorable short-term effect on the cardiovascular system in patients with metabolic syndrome insulin resistance, other benefits of moderate altitude have not been reported [11]. Increased ataxia and imbalance at high altitudes were not related to AMS [12]. Changes in balance at high altitudes may also be a result of central nervous system disorders, and therefore might result in impaired balance control. Reports on the association between poor balance and hypoxia at high altitudes (>3,500 km) in open space conditions are lacking. Most measurements of balance and height have been done under laboratory conditions. However, actual field tests can provide accurate information regarding real-life situations.

The Zur Balance Scale (ZBS) is a new, validated clinical tool with no ceiling effect that is easy to conduct and inexpensive [13]. The ZBS was designed to cover the three physiological systems related to balance control: visual, vestibular, and somatosensory. Its major advantages are that it is portable, short and simple to administer (i.e., it takes approximately five minutes to complete the test and to analyze the results). Equipment needed for the test is a half-cylinder of Styrofoam 60 cm long x 18 cm wide x 9 cm high, a stop watch for measuring time in seconds and a metronome set at 60 Hz (1 beat per second). The Styrofoam density is 30 kg/m³ and it is covered tightly with a piece of stretchable fabric.

This study assessed whether changes in balance control occur at different altitudes and analyzed the correlation between physiological parameters and balance control at different heights among healthy adults climbing to the Everest base camp. We hypothesized that balance control would become increasingly impaired as altitude increased. The study outcomes may have implications for commercial flight passengers and crew, military forces, trekkers, and people with known risk of falling.

Methods

This was an observational, double-blinded study. Data were collected five times during 10 climbing days in September 2013.

Participants

Seven healthy men, ages 47-64 years with normative body mass index (BMI) values, and two Nepalese Sherpas (30 and 33 years of age) volunteered to participate in the study. All participants had no symptoms (score equal zero) when the AMS questionnaire was administered at the beginning of the study.

Data Collection and Variables

The following tests were administered to all participants at each altitude: AMS questionnaire [14], the Single-Leg Balance (SLB) test [15] and the Zur Balance Scale (ZBS) [13], and four physiological assessments (pO₂ saturation (%), systolic and diastolic blood pressure (S/DBP) (mmHg) and heart rate (pulse/min)). The total time required to finish all tests was up to 10 minutes. Tests and participant testing were administered in randomized order. Each day's tests were recorded separately to avoid comparisons with the previous results and to prevent bias.

Blinding

This was a double blind study. Despite the fact that participants knew they were ascending to altitude, they were not aware of their test results. For anonymity and confidentiality, data were analyzed after concluding the journey. Participants were asked not discuss their tests during the trek. Data were only available to the statistician, who was also blinded to the assessments.

Questionnaire for Acute Mountain Sickness (AMS)

The Lake Louise scoring system is a short, self-report questionnaire that was used to assess symptoms of AMS. It includes questions on headache, gastrointestinal symptoms, fatigue and/or weakness, dizziness/lightheadedness and sleeping difficulties [14].

The AMS questionnaire consists of 2 sections, a self-reported questionnaire and a clinical assessment form. A diagnosis of AMS requires the presence of the main symptom of headache and at least 1 additional symptom. Scores of 3 to 5 on the questionnaire indicate mild AMS and scores of 6 or more indicate severe AMS [16].

Balance Control

Balance control was assessed with the Single-Leg Balance (SLB) test [15], and the Zur Balance Scale (ZBS) [13]. Both are valid for assessing balance control. For both tests, the participant stands two meters from the fixed target of a 5 x 5 cm X marked at eye level ($\pm 30^\circ$). A solid support (such as a chair or table) is placed next to the participant for safety and confidence, while the examiner stands in front and to the side. Participants are barefoot and stand with hands on hips when ready to start. Each condition is performed twice and measured with a stop watch. The better of the two trials is recorded for analysis.

Single Leg Balance (SLB)

This test was first performed with eyes open (EO) and then with eyes closed (EC), hands on hips. The participant is required to stand unassisted on one foot, while the other foot does not touch the ground. The time from when one foot is flexed off the floor until it touches the ground or the standing leg, or when an arm leaves the hips is measured in seconds. The test was conducted twice and the better of the two trials was analyzed. The maximum score is achieved by maintaining balance while standing on one foot for 10 seconds, although scores were normalized to percentages. The dominant leg was used for data collection [17].

Zur Balance Scale (ZBS)

The Zur Balance Scale (ZBS) is conducted while participants stand in Romberg or tandem stance on the floor or on a small half-cylinder of Styrofoam covered tightly with a stretchable piece of fabric while completing a series of four tasks (eyes open, eyes closed, horizontal head movements and vertical head movements). Each combination of stance and task comprises a different condition (Cond), for a total of ten conditions evaluated in the ZBS [13]. The ability to maintain balance for a maximum of 10 seconds is measured for each condition.

Physiological Parameters

The four physiological assessments pO_2 saturation (%), systolic and diastolic blood pressure (mmHg) and heart rate (pulse/min) were measured using a finger-held pulse oximeter (Tensortip Vital Signs Monitor (VSM) (CNOGA Co., Israel). All measurements were recorded before the balance tests and after 2-3 hours of rest. The time required to conduct the physiological tests was approximately 3 minutes.

Timeline for Assessments

Each participant was assessed five different times (T1-T5). Baseline assessment (T1) was taken before departure to Katmandu, Mt. Everest, Nepal (i.e., under normal oxygenation and barometric conditions) or at 1200 m above sea level for one of the Nepalese Sherpas. The second Sherpa joined the group at T2. Additional assessments from all participants were taken at altitudes T2-T5 (T2 = day 3 at 2,610 m (Phakding), T3=day 5 at 3,330 m (Namche), T4 = day 8 at 4,400 m (Dingboche), T5 = day 9 at 4,950 m (Lobuche). The exact altitudes and the elevation at each day of walking were measured by the Forerunner® 630 watch (Garmin Ltd., Schaffhausen, Switzerland).

Ethical Considerations

The study was approved by the Institutional Review Board of the University of Haifa (no. 255/13). Information about the study procedure was given to all participants, who provided signed informed consent.

Statistical Analysis

In order to examine the differences in measurement of various parameters along five altitude points, we employed a one-way mixed-model repeated-measures analysis of variance (ANOVA) with 1 within participant variable (altitude). The variance matrix was determined to be unstructured. Contrast analysis was used to compare successive altitudes. A P-value of 0.05 was considered significant. Statistical analysis

was performed using SAS for Windows, version 9.4.

Results

Balance Parameters

The higher the participants climbed, the length of time (in seconds) they were able to maintain their balance, as measured by the ZBS, significantly decreased (Figure 1). At sea level, the mean ZBS score was 87% and at 2,600 meters, the mean score decreased to 80%. At 4,400 and 4,950 meters the ZBS score decreased to 77% ($P < 0.001$). SLB decreased, although the difference was not significant (Figure 2). At sea level, the mean SLB score was 70% and at 2,600 meters, the mean score decreased to 67%. At 4,400 it decreased to 55% and at 4,950 meters, the SLB score decreased to 53% ($P < 0.651$, NS) standard deviation (± 21.2 -25.6).

One participant acquired AMS at 4,950 meters and was evacuated by helicopter. He was accompanied by the primary investigator.

Physiological Parameters

Table 1 demonstrates the physiologic parameters at different altitudes. As altitude increased, participants' saturation decreased. Thus, at 0 m, the mean pO₂ saturation was 97.8%, while at 4950 m, the mean pO₂ saturation was 89.6%. Likewise, systolic and diastolic blood pressure decreased significantly as altitude increased. Heart rate increased in proportion to altitude.

Table 1. Physiological parameters at different altitudes

Altitude (m) N = Participants	0 (N = 6)	2610 (N = 7)	3300 (N = 7)	4400 (N = 6)	4950 (N = 7)	P-value
Physiological parameters						
Saturation pO ₂ (%)	97.8 ± 1	93.4 ± 4.3	95.1 ± 2.8	91.3 ± 1.2	89.6 ± 3.3	0.0007
Systolic BP (mmHg)	122.7 ± 8.1	107 ± 17.7	106.6 ± 17	98.5 ± 21.4	98 ± 15.7	<.0001
Diastolic BP (mmHg)	75.5 ± 9.6	67.3 ± 9.9	68.9 ± 12.4	61.7 ± 10.1	63.9 ± 8.6	<.0001
Heart rate (pulse/min)	67.1 ± 8.5	74.6 ± 18.9	67.7 ± 10.3	76 ± 19.8	74.4 ± 11.4	0.0154

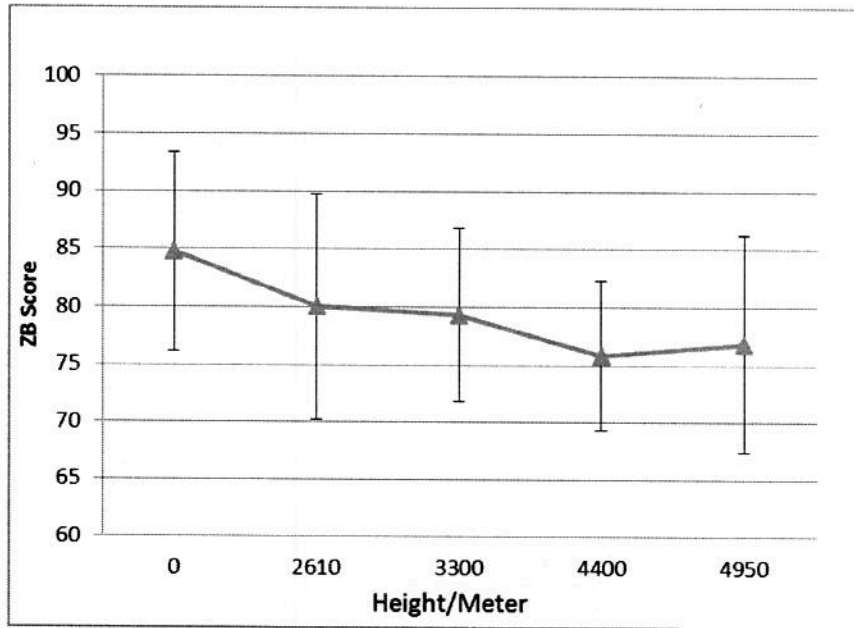


Figure 1. Number of seconds balance was maintained during the Zur Balance Score (ZBS) testing at different altitudes.

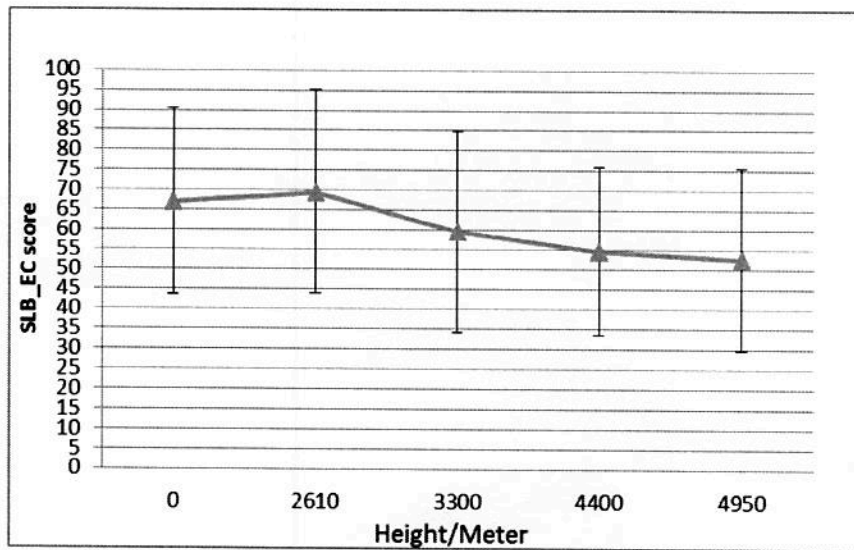


Figure 2. Number of seconds balance was maintained during the Single Leg Balance (SLB) test at different altitudes.

Discussion

This study investigated an important mechanism involving high altitudes and balance control. The findings confirm previous reports that changes in physiological parameters such as blood pressure and

heart rate occur at moderate-to-high altitudes. In addition, we found that balance control is compromised at moderate-to-high altitudes.

It is not surprising that healthy and relatively young persons who moved from sea level to high altitudes (>3,000 m) would require some

physiological adaptations, but these individuals should expect to reach a physical fitness that is approximately 70% of their fitness capacity at sea level after a few days [18].

It is known that hypoxia results in physiological and chemical changes such as Ca^{2+} intracellular influx, release of multiple neurotransmitters and alterations in the blood-brain barrier, which induce inflammation and brain edema [19]. These can result in headache, migraine, dizziness, nausea, sleep disorders (insomnia), fatigue, and instability [20]. Symptom intensity or severity varies according to ascent rate and altitude. High level functions such as memory, reaction time and psychomotor skills are affected at altitudes above 3,500 m, and more profoundly at greater altitudes 4,500 m [21]. However, Baumgartner et al. [22] found that these AMS symptoms are not the cause of balance impairment. Even after inhaling 3 liters of oxygen, balance instabilities did not improve, although symptoms of AMS decreased significantly.

Balance control is a peripheral and central multi-sensory task which includes vision, hearing, deep and superficial sensations, peripheral vestibular system (inner ear) and central nucleus of the vestibular system, which is located in the brainstem and collaborates with the cerebellum. The results of clinical tests showed decreased ability to maintain balance in stance positions [23]. Barometric pressure, falling ambient temperature, low humidity, wind speed and even high solar radiation can lead to balance instability and falls [24, 25]. The ZBS was specifically developed based on the function of the three main systems related to balance and as such, it provides accurate information about balance control, which is indirectly associated with the vestibular system. The ZBS test was found sensitive to detect changes as altitude increased. Changes in the SLB test were not statistically significant due to large deviations between the two repeated measures. More repetitions of the test might have resulted in significant differences. However, the study design included using the better of two trials in order to prevent motor learning, which would have affected the third trial.

High altitude activities such as mountaineering and climbing are popular. Yet, it is important that

climbers as well as clinicians recognize the effect of high altitude on balance control. Individuals who expose themselves to strenuous outdoor activities at high altitudes should be aware of the risk of impaired balance. Thus, one must bear in mind that the growing popularity of mountain climbing will potentially increase the number of injuries related to falls.

Limitations

Due to the small number of participants, the recommendations of this study are not necessarily generalizable. Data were collected only while ascending the mountain, and not while descending because the researcher had to accompany one of the participants who acquired AMS.

Conclusion

Results of this descriptive study showed that balance control becomes compromised as altitude increases. We demonstrated that changes in altitude affect balance stability as detected by the ZBS, but not by the SLB. We suggest that all climbers should be educated properly to identify pre-existing conditions of vestibular weakness, as well as to be aware of this phenomenon. People with a vestibular system disorder might not adapt well to high altitude environments and should not participate in unsupervised mountain climbing. Further studies are needed to identify risk factors for balance instability among high altitude climbers more precisely.

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Author Disclosure Statement

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