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BRIEF REPORT

Ataxia at Altitude Measured on a Wobble Board

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Objective.—To establish a simple measure of ataxia for use at high altitude.

Methods.—Twenty healthy subjects took part in a trek to 5005 m. At 5 different altitudes on the route, they undertook a balance test using a wobble board. The primary objectives were to investigate disturbances of ataxia at altitude and to correlate any observed disturbances with acute mountain sickness (AMS) scores. Secondary outcomes were correlations with cerebral regional oxygenation, pulse oximetry, and age.

Results.—After a short learning curve, the wobble board test was found to be reproducible. Subjects over 31 years of age were significantly less steady than younger subjects. Subjects suffering acute mountain sickness scored significantly worse on the wobble board test, although scores did not correlate with a specific question on unsteadiness. A positive test defined as equal to or more than 2.5 contacts over 2 minutes gave a predictive value for acute mountain sickness of 66.7% at 4650 m and 100% at 5005 m. Cerebral regional oxygenation in 9 subjects at 5005 m correlated with the wobble board test ($r = 0.73$; $p < .05$), whereas pulse oximetry did not.

Conclusions.—The wobble board may be a useful adjunct in quantitating ataxia in the field. A positive result may indicate the presence of AMS and may be a useful clinical measure of cerebral hypoxia but should be correlated with other clinical features.

Key words: altitude, ataxia, cerebral regional oxygenation, HACE, wobble board

Introduction

Ataxia refers to a disturbance in the smooth performance of voluntary motor acts and may affect the limbs, the trunk, or the gait. Ataxia or imbalance describes the inability to maintain an upright position while stationary or during movement. Ataxia is an important clinical feature of acute mountain sickness (AMS), not only increasing the risk of having accidents but also providing an indication that the common, relatively benign form of AMS is progressing to potentially fatal high-altitude cerebral edema (HACE).[1] Symptoms of ataxia were noted in 25 of 42 (60%) subjects suffering from HACE and were noted as a physical sign in a similar percentage.[2] The Lake Louise self-assessment questionnaire for AMS does not specifically address the issue of ataxia, and we have previously suggested appropriate amendments.[3] Our observations in studies of AMS are that the symptom of unsteadiness is commonly reported before any disturbance of the heel-to-toe walking test. The only question that may have some relevance to ataxia relates to the presence or absence of dizziness/light-headedness, but such symptoms are nonspecific. A question on coordination was included in the cerebral AMS (AMS-C) part of the environmental symptoms questionnaire, and on factor analysis, incoordination was rated higher than dizziness.[4] Although ataxia is partly assessed by the heel-to-toe walking test portion of the Lake Louise clinical assessment protocol,[5] this is a relatively insensitive measure of ataxia and, there is no clinical assessment that satisfactorily grades the severity of impaired balance. We therefore attempted to develop a more sensitive objective test of ataxia that might be useful in identifying patients at risk of progressing from AMS to more serious HACE.

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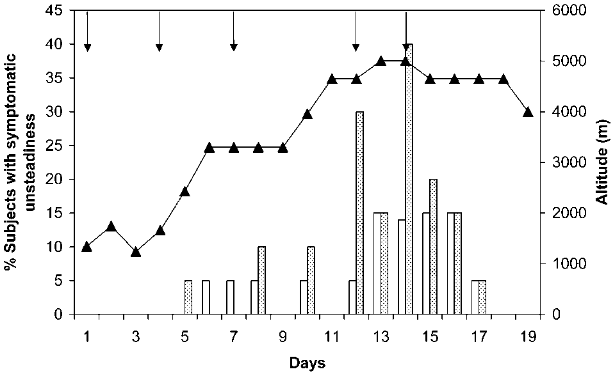

Figure 1. Altitude profile is shown in black triangles over the 19 days of the trek. The days of wobble board tests are indicated by arrows. The proportion of subjects with self-reported symptomatic unsteadiness is shown in the vertical columns, with the morning questionnaire as white bars and the evening questionnaire as stippled bars.

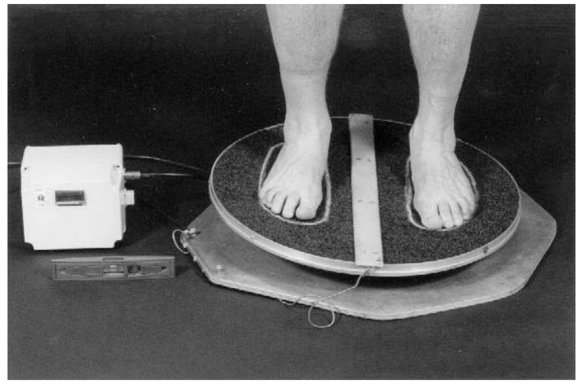

Figure 2. Wobble board equipment in use.

The objective of this study was to investigate disturbances of ataxia that occur at altitude and to correlate any observed disturbances with AMS and with symptoms of dizziness/light-headedness. Secondary endpoints of the study were to assess whether age was a factor in impaired balance arising at altitude, and whether there were any correlations with cerebral regional oxygenation and pulse oximetry studies. We designed an experimental protocol using a wobble board as a way of investigating balance.

Methods

Six healthy subjects (3 males and 3 females) aged 25–46 years undertook a reproducibility study of results between tests at sea level on four separate occasions, 2–3 days apart. Twenty different healthy subjects (16 males, 4 females) aged 21–61 years (median 33 years) who took part in a trekking expedition to an altitude of 5005 m in the Kanchenjunga region of Nepal (route profile; Figure 1) were recruited for this study. The subjects were all members of the Birmingham Medical Research Expeditionary Society (BMRES), traveling to altitude as part of a research expedition. No subject was excluded for any reasons. Initial recruitment was at sea level. A medical questionnaire pretrek revealed no subjects with known coordination problems. At altitudes below 3300 m, subjects were free of any symptoms of unsteadiness. Throughout the trek no prophylactic drugs against AMS were taken. Five subjects, however, were given acetazolamide to treat AMS between 4650 m and 5005 m. The drug was taken 12–18 hours before the wobble board test at 5005 m. No alcohol was allowed in the 12 hours before a test, and subjects were warm and well hydrated during testing.

All subjects completed Lake Louise questionnaires every morning and evening. Subjects were considered to be suffering from AMS at any given altitude if the questionnaire score was 3 or more before the wobble board test was done at that altitude. At the same time, a separate BMRES questionnaire assessing 23 different symptoms was completed, and question 3 (‘‘I have been unsteady on my feet’’) was scored (0, not at all; 1, slight; 2, moderate; 3, quite a lot; or 4, extreme).

WOBBLE BOARD

A wobble board consisting of a flat board (diameter 53 cm) with a half sphere (diameter 15 cm) glued to the center of the undersurface was modified by attaching a metal strip to the inferior surface of the circumference. The board was placed on a flat metal plate checked for horizontal position with a spirit level. The combined weight of board and plate was 6 kg. The metal strip and plate were connected by a single electrical circuit to a battery-powered recording box (weight 1 kg) that recorded the duration of contact of the metal strip with the metal plate to the nearest 0.1 second (Figure 2). Each contact was marked by a buzzer sound so that the person supervising the test could record the number of contacts. The equipment was used in a covered area (mountain hut or tent) in which one could stand, so that environmental distractions of coldness, noise, sunlight, and distracting movement could be kept to a minimum.

Subjects removed footwear and stood on the board with their feet astride the central point. Foot outlines were drawn on the board to ensure a standard position 25 cm apart. Subjects kept their eyes open and were encouraged to fix visually on a distant point. When balance had been achieved, observations were then made for three separate 1-minute periods, separated by ap-

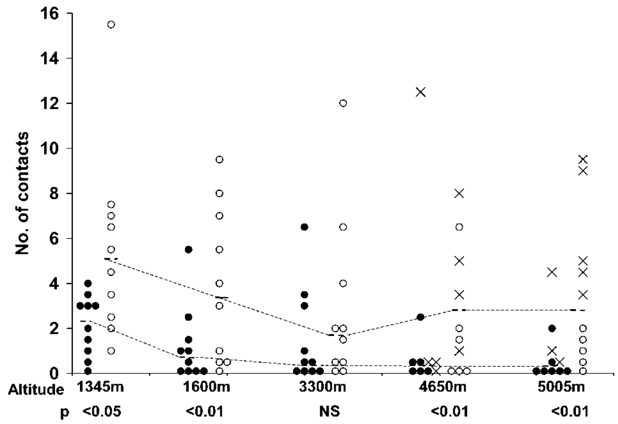

Figure 3. Wobble board (number of contacts) results at different altitudes. At each altitude, the *p* values refer to the difference between the younger (31 years of age or less, closed circles) compared with older (over 31 years of age, open circles) subjects. The crosses refer to subjects with AMS at 4650 m and 5005 m.

proximately 1 minute of rest. Subjects were asked to keep the board horizontal and were allowed to use their arms to maintain balance to simulate normal walking conditions. Subjects were familiarized with the test at sea level before departure and were assessed on five occasions during the trek: at 1345, 1660, 3300, 4650, and 5005 m (Figure 3). Because of difficulties in familiarizing and testing all subjects at the same time at sea level, 1345 m was used as the first assessment point and was considered still low enough not to play any part in symptoms or signs of AMS.

OXYGENATION

Measurements of peripheral oxygen saturation (Ohmeda oximeter) and cerebral regional oxygenation[6] were undertaken on 9 randomly chosen subjects from the group at 5005 m. All measurements were made under cover of tent or mountain hut. Reflected near-infrared cerebral spectroscopy (NIRS) uses light in the NIR spectrum (650–1100 m) and, similar to pulse oximeters and mixed venous oximeters, uses the principles of light transmission and absorption to measure concentrations of oxygenated (HbO_2) and deoxygenated ($HbDO_2$) hemoglobin and total hemoglobin (Total Hb) in cerebral tissue. The cerebral regional oxygen saturation (rSO_2) was derived from HbO_2/Total Hb $\times$ 100. Continuous noninvasive NIRS was performed using a Critikon 2020 monitor (Johnson and Johnson Medical, Newport, UK), with the sensor positioned over a standard point in the frontoparietal region and held in place with a pressure bandage around the forehead to ensure good waveforms throughout the measurements.

STATISTICS

Within-subject comparisons were made using paired *t*-tests, and between-subject comparisons were made using the Wilcoxon rank sum test.

Results

Duration and Number of Contacts

The duration of contact and the number of contacts in any given test were highly correlated ($r = 0.92$; $p < .0001$). The number of contacts has therefore been used when relating wobble board results to other measurements.

REPRODUCIBILITY

The first of the three readings of all tests at sea level and at altitude was significantly higher than the second and third readings; for example, during the altitude study, the mean number of contacts (SD) was 5.0 (5.9) at the first reading, which was higher than 2.6 (3.6) at the second reading and 2.7 (3.4) at the third reading ($p < .001$). The second and third readings were not significantly different, and for further analysis the mean of these two readings was used. The mean number of contacts (SD) on repeated testing on alternate days at sea level fell from 4.4 (2.4), to 2.1 (1.4), to 1.8 (1.6), to 0.5 (0.6). The number of contacts was less than 1.5 in all subjects by the fourth successive test.

EFFECT OF AGE

The number of contacts increased with increasing age ($r = 0.48$; $p < .05$). Subjects over 31 years of age were significantly unsteadier on the wobble board (mean number of contacts, 3.79; SD, 3.5) than those aged 31 years or under (mean, 1.52; SD, 2.2) ($p < .001$). Older subjects were unsteadier at each altitude except at 3300 m (Figure 3).

EFFECT OF ALTITUDE

Wobble board results improved, comparing results at 1345 and 1660 m (mean number of contacts 3.77 [SD 3.4] vs. 2.58 [SD 2.97]; $p < .05$, paired *t*-test), but thereafter, mean results were not affected by ascent to higher altitude (3300 m, 2.23 [SD 3.1]; 4650 m, 2.26 [SD 3.34]; and 5005 m, 2.25 [SD 2.89]).

Predictive values for acute mountain sickness (AMS)

No. of contacts		*4650 m*		*5005 m*	
+Test	*−Test*	*Positive (%)*	*Negative (%)*	*Positive (%)*	*Negative (%)*
>0.5	0	53.8	85.7	57.1	100.0
≥1.0	≥0.5	55.5	72.7	63.6	88.8
≥1.5	≥1.0	50.0	72.7	75.0	83.3
≥2.0	≥1.5	57.1	69.2	75.0	83.3
≥2.5	≥2.0	66.7	71.4	100.0	85.7
≥3.0	≥2.5	80.0	73.3	100.0	85.7
≥7.01	<7.01	100.0	66.7	100.7	66.7

CLINICAL QUESTIONNAIRES AND EXAMINATION AT ALTITUDE

The Lake Louise question on dizziness/lightheadedness was scored positive by 4 subjects at 4650 m (number of contacts 12.5, 6.5, 0.5, 0.5), compared with 16 subjects scoring negative (mean number of contacts, 1.95 [SD 2.7]) and was scored positive by 2 subjects at 5005 m (number of contacts, 4.5 and 0.5).

Five subjects scoring positive to the specific question on unsteadiness in the BMRES questionnaire at 4650 m did not perform differently (number of contacts: mean, 4.62 ± 5.1 SD) than those with no unsteadiness (mean, 1.41 ± 2.3) ($p > .05$, Wilcoxon rank sum test). Similarly, the 6 subjects scoring positive on the question at 5005 m did not perform differently (number of contacts, 3.77 ± 3.3 SD) than those with no unsteadiness (mean, 1.57 ± SD 2.5 $p > .05$). No subjects were unsteady using the heel-to-toe test at 4650 m, and only 2 subjects (number of contacts 9.0 and 4.5) were unsteady on heel-to-toe testing at 5005 m.

EFFECT OF AMS

At 4650 m, the 8 subjects with AMS had a greater number of contacts on the wobble board (4.3 ± SD 4.63) compared with those with no AMS (1.09 ± SD 1.82) ($p < .01$, Wilcoxon rank sum test). At 5005 m, the 8 subjects with AMS had a greater number of contacts on the wobble board (4.50 ± SD 3.29), compared with those with no AMS (1.98 ± SD 3.3) ($p < .01$ Wilcoxon rank sum test). The predictive value of the wobble board test for AMS is shown in Table 1.

RELATIONSHIP TO CEREBRAL OXYGENATION

Cerebral regional oxygenation measured in 9 subjects at 5005 m correlated with the number of contacts on the wobble board ($r = 0.73$; $p < .05$), but peripheral oxygenation did not correlate with the wobble board test result.

Discussion

Active balance, as defined by maintaining equilibrium while moving,[7] is essential to trekkers and climbers in mountainous terrain. Normal balance function is reliant on complex central mechanisms that result in coordinated neurologic and musculoskeletal interactions. Different inputs are received via the vestibular, visual, and somatosensory systems, and normal posture is maintained through the vestibulo-spinal and vestibulo-ocular motor reflexes that are integrated by the cerebellum, pons, and midbrain. Higher cortical functions, notably attention, volition, and memory are also necessary to maintain balance. We attempted to devise a test of ataxia that was largely independent of higher cortical function and learning effects.

It has been shown that static balance deteriorates with hypobaric hypoxic conditions as low as 2438 ft,[8] and the importance of ataxia is recognized by the inclusion of the heel-to-toe test in the clinical assessment of AMS.[5] However, the results in our study show that the heel-to-toe test is relatively insensitive, and a simple quantitative test of ataxia applicable to field conditions is required. The wobble board proved easy to use at high altitude, with the equipment being simple and reliable in use. This included the battery, which was in a protective box to protect against coldness. The improvement in results we observed early in the trek probably reflected a learning effect. We were not able to determine in this small group whether older subjects took longer to learn the technique, but repeated testing in subjects taken from a wide age range showed complete mastery by the fourth test, and results at the four altitudes above 1345 m were stable.

No subjects undertaking the wobble board test were taking regular medications that would affect balance. It is particularly important to note that acetazolamide was not used prophylactically for AMS but had been given to five subjects for management of AMS at 5005 m. Acetazolamide is known to improve intermittent episodes of ataxia that occur in individuals with defined ion-channel mutations.[9,10] Furthermore, magnetic resonance spectroscopy in untreated individuals with episodic ataxia type 2 shows an increased pH in the cerebellum and cerebrum that is normalized following acetazolamide therapy.[11]

Older subjects would be expected to have greater subclinical ataxia at sea level than younger subjects, because aging is associated with hair cell loss and selective neuronal loss that particularly affects the Purkinje cells of the cerebellar vermis,[12] vestibular nuclear neurons, and primary vestibular neurons[13]. Previous large-scale studies have shown a clear deterioration of balance with increasing age.[14] The wobble board test we devised was sufficiently difficult in older subjects, but for younger subjects, it will need modifications so that all subjects score positively under normal conditions.

The design of the study did produce limitations in the eventual analysis of the results. The number of participants was limited by the size of this expedition party. The number of altitude elevations at which measurements could take place was small, and the frequency of testing was probably not high enough. This limited the statistical power in analyzing results and lessened the possibility of making more conclusive statements. In addition, the wide age range (21–61 years) exposed a difference in difficulty in performing the test across the ages. Whether this affected the results is difficult to ascertain, as all participants found that a high level of concentration was required to perform. In addition, for practical reasons, we designed the test procedure to have a time period of 60 seconds. We have not performed other studies to know whether this is the optimal length of time for the test. Last, as in the case of other studies at altitude, the difficulty in our ability to control environmental factors at altitude may have affected the test results.

Ataxia assessed by this wobble board is probably related to AMS. One study at altitude showed that oxygenation did not improve ataxia but did improve AMS symptoms and scores, indicating that ataxia may not correlate with AMS, using current scoring systems.[15] Larger numbers are required to overcome the limitations of self-assessment scores and the range of symptoms included in the Lake Louise questionnaire.

Conclusions

We conclude that the wobble board test was easy to use but was shown to have some limitations with a learning curve and a distinct effect of age on the results. A positive result may indicate the presence of AMS, but whether wobble board scores are truly predictive of AMS requires further studies with more regular measurements in a larger number of subjects.

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