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ORIGINAL RESEARCH

Association of Cognitive Performance with Time at Altitude, Sleep Quality, and Acute Mountain Sickness Symptoms

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Objective.—It is well documented that cognitive performance may be altered with ascent to altitude, but the association of various cognitive performance tests with symptoms of acute mountain sickness (AMS) is not well understood. Our objective was to assess and compare cognitive performance during a high-altitude expedition using several tests and to report the association of each test with AMS, headache, and quality of sleep.

Methods.—During an expedition to Mount Everest, 3 cognitive tests (Stroop, Trail Making, and the real-time cognitive assessment tool, an in-house developed motor accuracy test) were used along with a questionnaire to assess health and AMS. Eight team members were assessed pre-expedition, postexpedition, and at several time points during the expedition.

Results.—There were no significant differences ($P > .05$) found among scores taken at 3 time points at base camp and the postexpedition scores for all 3 tests. Changes in the Stroop test scores were significantly associated with the odds of AMS ($P < .05$). The logistic regression results show that the percent change from baseline for Stroop score ($\beta = -5.637$; $P = .032$) and Stroop attempts ($\beta = -5.269$; $P = .049$) are significantly associated with the odds of meeting the criteria for AMS.

Conclusions.—No significant changes were found in overall cognitive performance at altitude, but a significant relationship was found between symptoms of AMS and performance in certain cognitive tests. This research shows the need for more investigation of objective physiologic assessments to associate with self-perceived metrics of AMS to gauge effect on cognitive performance.

Key words: cognitive performance, hypoxia, altitude, AMS, cognition, expedition

Introduction

Moderate hypoxia has been shown to induce changes in visual, motor, somatosensory, and mental function. Performance in intelligence tests, reaction time, speech comprehension, hand steadiness, and visual contrast discrimination are some of the mental functions that have been shown to be negatively affected.[1–3] Hypoxia affects individuals' ability to perform word association tests along with causing abnormal test responses.[4] The effects of hypoxia go as far as inducing auditory and visual hallucinations[5] and have even been documented to induce feelings of depersonalization and out of body experiences.[6] Visual function changes with hypoxia include narrowing of the visual field and vision blurring, with worsening levels of hypoxia causing failure of the entire retina and total loss of vision.[7–9]

Over the years, stories of climbers not being able to perform simple mental tasks have become part of the literature documenting cognitive changes at altitude. Although it is well known that cognitive performance is impaired with altitude ascent, the exact nature and timing of these changes are not clear. Each year altitude-related hypoxia affects thousands of aviators, both military and civilian, and causes complications in rapid high-altitude troop deployments.[10] In addition, many workers at extreme altitudes, and even recreational climbers and tourists, experience acute mountain sickness (AMS). Assessing possible cognitive degradation with altitude ascent is

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complex due to the multitude of factors that accompany altitude ascent. Lack of sleep, headache, and AMS with accompanying symptoms can all affect cognition, and isolating their effect from actual hypoxia can be difficult.[11]

In the literature, a variety of different tests have been used to detect cognitive function changes with hypoxia and/or altitude. These tests focus on observing changes in motor and executive function, memory, response time, and hand−eye coordination. The sheer variety of tests available to researchers, along with the inherent variability within tests, may be a reason why there is debate in the literature on whether cognitive degradation occurs at certain elevations.[11–15] Additional complications are added when taking into account variation in individual physiology. The difficult nature of field expeditions and the possible differences with controlled environmental chamber studies also does not help with the consistency of results. Hence, the focus of this research expedition was to assess degradation in cognitive performance by using multiple tests and to examine the relationship to the physiologic consequences of high altitude, specifically AMS, headache, and quality of sleep.

Several tests, such as the Stroop Color-Word and the Trail Making test, have been "grandfathered in" as standards for testing cognitive function. We decided to take a fresh approach and design a real-time cognitive assessment tool (RCAT) to examine changes in motor executive function, specifically speed, hand−eye coordination, and response time. The objective was to use the test in tandem with other tests normally used for altitude performance and to determine which tests were possibly better suited for detection of the specific symptoms accompanying altitude exposure. The test is designed to take advantage of progress in mobile technology with the intention of future deployment and use in the field (See online Supplementary Appendix for more information).

In the present expedition to Mount Everest Base Camp (5500 m/17,300 ft), cognitive function was examined alongside changes in physiology that occur with altitude. The first objective was to use Stroop, Trail Making, and the RCAT to examine any changes in cognitive function that occur with graded exposure to altitude. The second objective was to use continuous monitoring to examine AMS, headache, and quality of sleep. The third objective was to report the association of each cognitive performance test with AMS, headache, and quality of sleep.

Methods

SUBJECTS

During the course of the expedition 8 subjects were monitored and tested. The experimental procedures were approved by the Mayo Clinic Institutional Review Board, and each subject provided written informed consent prior to participation. Subject demographics were as follows (mean ± SD): age 35 ± 10 years, height 181 ± 5 cm, weight 86 ± 8 kg, body mass index 26 ± 2 kg/m^2. Before this expedition, 4 of the 8 subjects had experienced high altitude of 2500–3500 m or greater.

STUDY DESIGN

Figure 1 shows the ascent timeline to Everest Base Camp as well as the other altitudes along the trek at which expedition testing was performed. All members were tested before the climb, at 3 time points at base camp, and upon return. To minimize the effect of learning, subjects were asked to perform each test for approximately 20 minutes before collecting the baseline data.

COGNITIVE TESTING

Three tests were used to evaluate cognitive performance. In each session, all tests were administered in a randomized sequence with a maximum of a 1-minute break in between tests. Subjects were asked to take 3 of each test type and were isolated during gameplay to minimize the effect of distractions.

Stroop Color-Word test

In this test, subjects are asked to identify the color of the text and associate it with the proper text that spells the answer. Colors and text often contradict each other to increase confusion and demand more focus from the subject. The version we programmed for use on Android tablets lasted for 1 minute and awarded 1 point for a correct response and subtracted 1 point for an incorrect response. The data we tracked documented each choice and reported patterns in the errors made (eg, incorrect

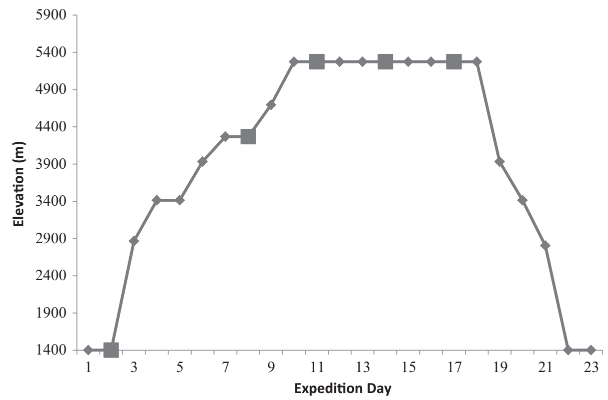

Figure 1. Ascent timeline for the expedition from Kathmandu to base camp and back. Testing days are marked by large squares and trek days by small diamonds. The posttesting was done in the United States after the expedition.