MMA Memo 191: Feasibility Study of the Use of the White Mountain Research Station (WMRS) Laboratory to Measure the Effects of 27% Oxygen Enrichment at 5000 m Altitude on Human Cognitive Function

J.B. West, F.L. Powell and A.M. Luks

Division of Physiology

School of Medicine, UCSD

Abstract

The NRAO MMA radiotelescope will be situated at an altitude of approximately 5000 m and numerous studies have shown that this altitude impairs cognitive function, including causing more rapid fatigue, more arithmetical and other types of errors, reduced short-term memory, impaired hand-eye coordination, lower productivity, and changes of mood. All these alterations are caused by oxygen deprivation (hypoxia). We propose to add oxygen to the air-conditioning of the control room to raise the oxygen concentration from 21 to 27%. This is equivalent to reducing the altitude of the facility to 3200 m, which is easily tolerated. The feasibility of measuring the effects of oxygen enrichment on cognitive function was tested at the University of California White Mountain Research Station (altitude 3800 m) where the conditions for ambient air breathing at 5000 m were simulated by reducing the oxygen concentration in the room from 21 to 18%. A comprehensive package of cognitive tests was tested. A full scale investigation will be carried out in the summer of 1998.

Background

The NRAO MMA will be situated at an altitude of approximately 5000 m in north Chile. Personnel will stay at about 2400 m and commute daily to the telescope.

Numerous studies have shown that an altitude of 5000 m impairs cognitive function (for a review see Ward et al., 1995, pp. 325-343). The major changes to be expected include lower productivity, more rapid fatigue, more arithmetical and other types of errors, reduced short-term memory, and changes of mood. All these alterations are caused by oxygen deprivation (hypoxia). Therefore improving the partial pressure of oxygen (Po_2) in the atmosphere should improve cognitive efficiency.

One way of increasing the Po_2 in the air is to add oxygen to the room ventilation. It has been shown that relatively small degrees of oxygen enrichment provide a major advantage. For example, every 1% of enrichment (for example, increasing the O_2 concentration from 21 to 22%) reduces the equivalent altitude by 300 m. (The equivalent altitude is that which has the same inspired Po_2.) Therefore raising the oxygen in the control room of the MMA facility by 6% (from 21 to 27%) is equivalent to reducing the altitude of the site to 3200 m. This altitude is easily tolerated and will produce very little cognitive impairment, especially as the personnel will have some acclimatization to 2400 m.

The feasibility of oxygen enrichment was demonstrated in the summer of 1997 at the WMRS laboratory, altitude 3800 m, where a room was maintained with an oxygen concentration of 24%. In this case the equivalent altitude was reduced from 3800 m to 2900 m. No technical difficulties were encountered. The oxygen enrichment was obtained from two AirSep New Life oxygen concentrators which each produced 5 liters per minute of 90% oxygen. Each of these devices requires only 350 watts and costs less than $1,500. The oxygenated room was used as a dormitory for two subjects and a double blind study showed that they had an improved quality of sleep by both objective and subjective measurements, had fewer symptoms of acute mountain sickness the following day and, most interesting of all, had higher levels of oxygen in their arterial blood the following day when they were breathing ambient air. The explanation of this last finding may be that their control of ventilation was altered following reduction of their sleep disordered breathing during the night as a result of the oxygen enrichment.

It is clearly desirable to document what features of cognitive function will be improved by 6% oxygen enrichment at 5000 m. Unfortunately there is no laboratory at this altitude in the U.S. However, it is potentially feasible to study the effects of oxygen enrichment at 5000 m on cognitive function at the WMRS laboratory (altitude 3800 m) if the room oxygen concentration is reduced to 18% by nitrogen enrichment. Furthermore, if the air in the WMRS laboratory is enriched to 23%, this is equivalent to 27% oxygen in the air at 5000 m.

The rationale for these numbers is as follows. At 5000 m (barometric pressure P_B 420 torr) the inspired Po_2 equals 0.2093 (420 - 47) = 78 torr. (Note that the inspired Po_2 is equal to the fractional concentration of oxygen (0.2093) multiplied by the barometric pressure less 47, which is the water vapor pressure.) At 3800 m (P_B 487 torr), the inspired Po_2 equals 0.18 (487 - 47) = 79 torr. For oxygen enrichment at 5000 m with a room oxygen concentration of 27%, the inspired Po_2 equals 0.27 (420 - 47) = 101 torr. At 3800 m with a room oxygen concentration of 23%, the inspired Po_2 equals 0.23 (487 - 47) = 101 torr.

Experimental Studies

The objective was to determine the feasibility of measuring the effects of oxygen enrichment on cognitive function at a simulated altitude of 5000 m using the WMRS facility.

Initially we planned to provide the nitrogen enrichment in the WMRS lab from liquid nitrogen tanks. Special valves allow the nitrogen to be vented at the appropriate rate. This is similar to the arrangement used in one of the facilities in north Chile where oxygen enrichment is being carried out with liquid oxygen tanks.

However, Dr. John Severinghaus of UCSF came up with the idea of reversing the AirSep machines to provide nitrogen instead of oxygen. There is no convenient attachment for the nitrogen-rich effluent when the molecular sieves are being purged. However, in effect, we placed the AirSep machines in the room and vented the oxygen that they produced to the outside. In fact, the machines were not actually in the room but in a gas-tight box just outside the room, and the box was connected to the room with large ports and fans. The result was that the oxygen concentration in the room was kept at 18%.

In order to simulate the oxygen enrichment at 5000 m altitude it was necessary to maintain the oxygen concentration in the WMRS lab at 23%. This was easily done by connecting the AirSep machines in the usual way.

An unexpected difficulty was obtaining subjects for the simulated 5000 m study. The main reason was that we felt it important that the subjects acclimatize to 3800 m for a couple of days before being taken to 5000 m. An altitude of 5000 m can be uncomfortable if the subject comes straight from sea level, and our Human Subjects Committee, who had to agree to the protocol, quite reasonably insisted that the subjects spend two days at the WMRS lab first. However since the 5000 m simulation test took an additional two days because we wanted to study the same subject with and without oxygen enrichment, this meant that they had to spend 5 days at the lab, including traveling time. In spite of a great deal of effort including broadcasts over the radio in Bishop, we only succeeded in enlisting 4 subjects.

The subjects spent about 1 hours at 5000 m prior to carrying out the cognitive test package which itself lasted about 1 hours. The subjects were measured on three occasions. The first testing session was conducted in the ambient air at the WMRS lab. This was partly to familiarize the subject with the package and also to get a baseline value. The subjects were then tested in 18% oxygen and 23% oxygen on two separate days and the ordering was randomized. The subjects were not aware of the oxygen concentration of the room. The tests were designed by Dr. Igor Grant and his colleagues in the Department of Psychiatry at UCSD. They are listed at the end of this report in the Appendix.

In this feasibility study, no significant differences were detected between the measurements at simulated 5000 m, with and without oxygen enrichment. This was perhaps disappointing, but the main object of the study was to demonstrate the feasibility of measuring cognitive function at a simulated altitude of 5000 m at the WMRS laboratory. In addition, 4 subjects is a very small number.

Several points came up as a result of these studies. One is that although it is well documented that people make more errors at high altitude, it has also been found that if a person concentrates hard for a relatively short time, he or she can do a test accurately. In other words, sitting a subject down in front of a test, which he sees as a challenge, prompts him to concentrate much more than he does during a normal working day. It is possible that this test package, which is mainly used in clinical work to determine the cognitive status of people with alcoholism, drug dependence, and perhaps neurological lesions, may not be the best package for our work. Another potential problem with the tests is that there is a learning curve and the subjects improved as they became more familiar with the tests.

It is possible that other tests might be more appropriate for these measurements. At the present time we are preparing for a NASA Spacelab Neurolab experiment to take place in April 1998 where we are teamed with a group who are studying sleep during the mission. Our colleagues under Dr. Charles Czeisler of Harvard Medical School, have an automated series of cognitive function tests specifically designed to study the effects of sleep deprivation. These tests are given frequently to the astronauts and there is no learning curve. Furthermore the emphasis is not so much on accuracy but the time taken to complete the tests, and this may be a better measure of the problems associated with working at 5000 m. A further advantage of this package is that it is highly automated and the subject carries out the whole test package using a laptop PC which both presents the information and automatically records the results. We are in the process of assessing this set of tests before the definitive study of the effects of oxygen enrichment at 5000 m which we plan to carry out in the summer of 1998.

Acknowledgements

Dr. Igor Grant was responsible for the preparation of the psychometric tests.

Reference

Ward, M.P., J.S. Milledge and J.B. West. High Altitude Medicine and Physiology, 2nd edition. London, Chapman and Hall, 1995.

Appendix

Package of Tests of Cognitive Function

Story Memory Test: This is a measure of short-run and immediate-term memory. On this tests, subjects listened to a 1 minute story on a tape recorder. At the conclusion of the recording, they were asked to repeat the story back to the examiner. The Learn Rate is a measure of how many details of the story they remembered. The higher the learn rate score, the better the performance. Subjects were also asked to repeat the story again after a one hour delay. The %-Loss compares their performance on this second task with the performance when they first heard the story (%Loss = [Score on first repetition - score on delayed repetition] score on first repetition). The lower the %-loss score the better the performance.

Digit Vigilance: This is a test of the subject's ability to concentrate. Subjects were presented a two-page document filled with numbers from 0 to 9 randomly arranged in rows. They were asked to cross out every number "6" they saw on the two pages as quickly as possible without making any mistakes (crossing out the wrong number or missing a 6). They received two scores for this test: (1) Time: the time in seconds it took them to complete the task. The lower the score, the better the performance; (2) Errors: the number of mistakes. Fewer errors signified better performance.

Peg Board: This is a test of manual dexterity. Subjects were presented a peg board with 25 holes. They were asked to place a set of pegs in the holes as quickly as possible. The time to complete this task was recorded for the dominant and non-dominant hand. The lower the score the better the performance.

Finger Tapping: This is a test of fine-motor skills. Subjects were asked to tap as quickly as they could with their index finger on a special finger-tapping board. Subjects tapped for 10 seconds. Multiple trials were performed and the average performance on those trials was calculated. The number presented in the data set is the average number of taps over all trials conducted. The higher the score, the better the performance. This was done for the dominant and non-dominant hand.

PASAT: This is test of the subject's ability to concentrate. On this test, subjects heard a series of 200 numbers on a tape recorder and were asked to perform a particular operation with each number they heard. There was a maximum of 196 operations to perform. The score presented in the data table is the total number of correctly executed operations. The higher the score, the better the performance.

Digit Symbol: This is a test of the subject's ability to learn. Subjects were presented with a list of numbers from 1 to 9. Each number had an associated symbol. For example,. the number 1 had the symbol ">" while the number 2 had the symbol "[". After seeing the coding scheme, they were presented with a list of 92 randomly arranged numbers between 0 and 9. They were then given 90 seconds to write down the symbol that corresponded to each number. The score reported is the number of correct pairs completed in the allotted time.

Trails B: This is a test of the subject's ability to concentrate. Subjects are asked to complete a "connect the dots" type puzzle. Rather than simply drawing lines from 1 to 2 to 3 and so on, however, subjects were required to draw lines from 1 to A to 2 to B to 3 to C. This is much more confusing than the simple version. The reported score is the time required to complete the connection of all the dots. The faster the time, the better the performance.

CALCAP: This test is a measure of reaction times. Numbers were flashed on a computer screen in front of the subject. On the "Simple" version of the test, subjects were asked to hit a special key on they key pad as soon as they saw a number on the screen. On the "Sequential" version of the test, subjects were asked to hit the special key as soon as they saw two numbers flashed in sequence (e.g. hit the key after they see 12 or 56, but not after they see 14 or 58). Two scores are reported for each version of the test: (1) Mean Reaction Time, the average of their response time each time they were supposed to strike the key pad (the lower the mean reaction time, the better the performance; (2) Z-score: a measure of how their performance compared to a population of healthy subjects (the higher the score the better the performance).