Letter to the Editor

A Computerized Evaluation of Sensory Memory and Short-term Memory Impairment After Rapid Ascent to 4280 m*

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To evaluate the effect of acute high-altitude exposure on sensory and short-term memory using interactive software, we transported 30 volunteers in a sport utility vehicle to a 4280 m plateau within 3 h. We measured their memory performance on the plain (initial arrival) and 3 h after arrival on the plateau using six measures. Memory performance was significantly poorer on the plateau by four of the six measures. Furthermore, memory performance was significantly poorer in the acute mountain sickness (AMS) group than in the non-AMS group by five of the six measures. These findings indicate that rapid ascent to 4280 m and remaining at this altitude for 3 h resulted in decreased sensory and short-term memory, particularly among participants who developed AMS.

High plateaus have special natural features, such as hypobaria, hypoxia, and cold. These can affect the brain's cognitive and neuropsychological functions, including reflection, perception, attention, and memory[1-2]. Individuals who initially enter a high altitude plateau, particularly those who rapidly ascend without adaptability exercises, are more susceptible to acute mountain sickness (AMS). Cognitive ability declines rapidly following rapid ascent to high altitudes, particularly at an altitude of >4000 m, eventually resulting in a significant reduction in occupational and other cognitive skills, even in people without serious acute altitude sickness[3-4].

Here, we transported 30 male volunteers in a sport utility vehicle (SUV) from the plain to Shengli Daban within 3 h. Shengli Daban is a mountain pass in the Tianshan Mountains of the Xinjiang Autonomous Region of northwest China with an altitude of 4280 m. The characteristics of the volunteers were (mean±SD): age (years)=25.2±1.9; education (years)=16.2±1.0; height (cm)=178.7±4.2; weight (kg)=74.7±7.7, and body mass index (BMI, kg/m^2)=23.4±2.1. The altitude of their permanent residence was <800 m and they had no high-altitude exposures (≥2500 m) during the past year. They were all healthy with no history of asthma, rhinitis, allergies, or serious illness, such as a cardiovascular abnormality or pulmonary dysfunction. They had no serious history of motion sickness, and their BMI conformed to the standard BMI of Chinese people (18-25 kg/m^2). The Ethics Committee of Urumqi General Hospital of the PLA approved the study (2014-0001), which was conducted in accordance with the Declaration of Helsinki.

AMS was assessed by the Lake Louise Scoring system (LLS)[5-6], using a self-report questionnaire. The questionnaire was completed by participants upon arrival at the plateau and 3 h after their arrival. The Lake Louise AMS questionnaire includes questions regarding five of the following different symptoms: headache; gastrointestinal problems (anorexia, nausea, or vomiting); fatigue or weakness; dizziness or light headedness; and difficulty sleeping. The response to each item is scored from 0 (absence of symptoms) to 3 (severe symptoms); the total score ranges from 0 (no signs of AMS) to 15 (maximum). Because the volunteers did not stay overnight, the section of the questionnaire concerning difficulty sleeping was eliminated. Each participant's score on the self-report questionnaire was calculated according to the LLS. Volunteers having headache symptoms and a score of ≥3 were diagnosed as having AMS. The results indicated that none of the participants had AMS immediately after

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their rapid ascent to the altitude of 4280 m, but after 3 h, the mean AMS score was 1.40±1.22, and the incidence of AMS was 23.33% (7/30). The most common symptoms were gastrointestinal problems (anorexia, nausea, or vomiting) with 43.33% (13/30) of the participants reporting at least one gastrointestinal symptom. Other common symptoms included dizziness or light headedness (12, 40%), headache (11, 36.67%), and fatigue or weakness (6, 20%). These findings suggest that continuous plateau hypoxia during the 3 h on the plateau, rather than acute high-altitude exposure (i.e., rapid ascent to 4280 m within 3 h), was the primary cause of the induced AMS.

Heart rate (HR), arterial oxygen saturation (SaO_2), and blood pressure (BP) were measured using portable instruments on the plain, after arriving on the plateau and after 3 h at high altitude. Table 1 shows that, compared to the plain phase, HR and diastolic blood pressure (DBP) increased in all the participants after 3 h on the plateau (P<0.001 and P<0.05, respectively), and SaO_2 decreased (P<0.001). Systolic blood pressure (SBP) increased slightly; however, the difference was not statistically significant. There were no statistical differences in HR, SaO_2, or BP (data not shown) between initial arrival on the plateau (4280 m altitude) and after 3 h on the plateau.

We divided the participants into an AMS group and a non-AMS group to compare the physiological measures taken on the plain and after 3 h on the plateau (Table 1). The results showed that HR was higher (P<0.05) and SaO_2 was lower (P<0.01) in the AMS group than in the non-AMS group. SBP and DBP were slightly higher in the AMS group; however, the difference was not statistically significant. These results suggest that after continuous high altitude anoxia, HR and SaO_2 were correlated with AMS to a certain degree. In particular, AMS was more likely to occur in persons with significantly increased HR accompanied by significantly decreased SaO_2.

To evaluate the effect of acute high-altitude exposure on cognitive ability, we independently developed an interactive memory-testing software. This testing software consisted of six tests, and the detailed processes were as follows:

1. A visual digit-span test (V-DST) and an auditory digit-span test (A-DST) were used to evaluate sensory-memory capacity. The participant was instructed to memorize a random digit string that was displayed or played on the laptop within a specified time, and the number of random digits was gradually increased. Next, the participant entered the memorized digit string into a textbox within a specified time. The computer recorded the number of random digits correctly reported by each participant.

2. A paced visual serial addition test (PVSAT) and a paced auditory serial addition test (PASAT) were used to evaluate short-term memory. Computer-generated random double-digits were displayed or played one after another on the laptop within a specified time. Next, the participant had to add the two most recent numbers and enter the sum into a blank textbox. This cycle was repeated 45 times and the computer recorded the number of correct additions for each participant and calculated the percentage of correct responses.

3. A picture recall test was used to evaluate sensory memory ability. A set of 20 pictures was simultaneously displayed on the laptop screen. After 20 s, all of the pictures disappeared and the participant had to type the name of each picture he remembered into a blank textbox. The computer recorded the number of pictures correctly recalled by each volunteer and calculated the percentage of correctly recalled pictures.

Table 1. Effect of High Altitude on Various Physiological Variables

Variables	Sea Level Mean±SD	4280 m Pateau after 3 h Mean±SD	AMS at 4280 m Pateau after 3 h	
			No (n=23)	Yes (n=7)
HR (beats/min)	71.13±4.26	84.03±3.50***	83.30±3.48	86.43±2.44$^{\#}$
SaO_2 (%)	98.10±1.01	86.74±2.04***	87.30±1.89	84.89±1.38$^{\#\#}$
SBP (mmHg)	117.07±6.99	119.43±10.06	118.30±10.44	123.14±8.30
DBP (mmHg)	71.87±6.12	74.43±8.48*	72.91±7.68	79.43±9.68

Note. $^{*}P$<0.05, $^{**}P$<0.01, and $^{***}P$<0.001 compared with the sea level. $^{\#}P$<0.05, $^{\#\#}P$<0.01, and $^{\#\#\#}P$<0.001 compared with the non-AMS group.

4. A picture recognition test was used to evaluate visual short-term associative memory. Twenty pictures and their names were displayed for 5 s one after another on the laptop screen. Next, the 20 pictures were displayed without their names one after another on the laptop screen. The participant was instructed to enter the name of the displayed picture into a blank textbox. The computer recorded the number of pictures that were correctly named by each participant and calculated the percentage of correctly named pictures.

The statistical results for all the participants in the six memory tests on the plain and after 3 h on the plateau (4280 m altitude) are shown (Table 2). The A-DST, PVSAT, PASAT, and picture recognition test scores decreased significantly from the plain to the plateau (P<0.05, P<0.01, P<0.01, and P<0.001, respectively). However, the V-DST and picture recall test scores only slightly decreased from the plain to the plateau, and no statistical difference was found. The V-DST, A-DST, PVSAT, PASAT, and picture recognition test scores were significantly lower (P<0.05, P<0.05, P<0.01, P<0.05, and P<0.05, respectively) for the AMS group than for the non-AMS group. The picture recall test scores were slightly lower in the AMS group; however, this difference was not statistically significant. These results indicate that 3 h after a rapid ascent to high altitude, the level of auditory memory and audiovisual short-term memory decreased in all the study participants; however, there was no significant change in visual memory. The level of audiovisual memory and short-term memory decreased in the seven volunteers who developed AMS, suggesting that continuous plateau hypoxia not only induces AMS but also results in an obvious decrease in cognitive brain functions, including decreased sensory memory and short-term memory decline.

This study had numerous limitations. Qualified volunteers were plain residents who had not visited any plateau of ≥2500 m in the past 1 year. However, during the screening of volunteers, it was found that six volunteers had crossed Shengli Daban once or twice in their lives (note that it is necessary to pass through Shengli Daban to get to Korla from Urumqi by land). Therefore, these six volunteers did not fear mountain altitudes. In contrast, volunteers who had never experienced mountain altitudes may have had fears or concerns about such altitude, which may have affected their cognitive and neuropsychological functioning[7]. Moreover, although volunteers with a history of severe motion sickness were excluded from the study, five volunteers complained of motion sickness when they were almost at the 4280 m altitude. This could have been due to the bumpy, rough road and the high driving speed. Symptoms of motion sickness could have affected the self-reported symptoms of AMS[8]. At Shengli Daban (4280 m altitude), the ground is covered with snow, the temperature is -8 °C, and the wind is about at level 5; these cold factors may induce or exacerbate AMS[9]. Therefore, the occurrence of AMS cannot be completely attributed to acute high-altitude exposure and plateau hypoxia. However, fear, symptoms of motion sickness, the cold, and gale-force winds may also be important for the development or exacerbation of AMS and may affect cognitive functions.

In conclusion, our findings indicate that rapid ascent to an altitude of 4280 m within 3 h in an SUV can result in increased HR, decreased SaO_2, and increased DBP. After 3 h at this altitude, the levels of sensory memory and short-term memory decreased, particularly in participants who developed AMS.

Table 2. Effect of High Altitude on Sensory Memory and Short-term Memory Function

Variables	Sea Level Mean±SD	4280 m Plateau after 3 h Mean±SD	AMS at 4280 m Plateau after 3 h	
			No (n=23)	Yes (n=7)
V-DST	7.60±1.13	7.27±1.05	7.52±0.95	6.43±0.98$^{\#}$
A-DST	7.17±1.29	6.50±1.22*	6.78±1.13	5.57±1.13$^{\#}$
PVSAT (%)	70.67±9.68	64.52±8.72**	66.76±7.83	57.14±7.78$^{\#\#}$
PASAT (%)	71.70±9.61	66.07±9.82**	68.41±8.66	58.41±10.08$^{\#}$
Picture Recall test (%)	45.83±12.94	42.33±9.44	43.70±10.03	37.86±5.67
Picture Recognition test (%)	57.17±14.00	47.00±9.43***	48.91±9.29	40.71±7.32$^{\#}$

***Note*.** $^{*}P$<0.05, $^{**}P$<0.01, and $^{***}P$<0.001 compared with the sea level. $^{\#}P$<0.05, $^{\#\#}P$<0.01, and $^{\#\#\#}P$<0.001 compared with the non-AMS group.

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