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Study on Human's Working Memory for Short-term Stationing in Plateau Airport

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***Abstract*:** The purpose of this study was to investigate the change of working memory for several special occupation group such as airline pilots' and rescuer team who exposure to high altitude with 3,600m for several days and the improvement of cognitive function by diffusion type of oxygen supply during sleepiness. Twenty male volunteers aged between 25 and 35 were recruited. The first group of 10 participants were measured their spatial attention reaction time both in high and low perceptual load task after 1 hour entering the 3,600m altitude plateau and the same time of the second day, the third day and the fourth day. The second group of 10 participants was randomly divided into the oxygen group with diffusion types of oxygen supply during sleep and the exposure group, and the same tasks as the first group were measured in the above 4 time point. The results showed that the reaction time, accuracy and sensitivity of working memory was significantly declined when participant entering into the plateau ($P<0.001$). With the adaptation to the plateau environment in the short term, the speed can be alleviated to some extent, but there were no significant improve in accuracy and sensitivity. Moreover, the study also found that the use of oxygen during sleep through diffuse oxygen supply has a certain improvement effect on the recovery of verbal working memory speed, accuracy and sensitivity of spatial working memory under high altitude environment.

1. Introduction

The plateau has the characteristics of low oxygen, low pressure, dry and cold climate, high wind speed, increased solar radiation and ultraviolet radiation. China's plateau area accounts for more than 33% of the country's total area, concentrated in Yunnan, Sichuan and Tibet Autonomous Region in the southwest of China. China is the country with the most plateau airports. Statistics show that there are 16 high-altitude airports with 2560 meters and above in China. Among the top 10 highest plateau airports in the world, China occupies 8 places, among which Yading Airport is the highest plateau airport in the world at an altitude of 4,411 meters. At the same time, with the continuous economic development of western China, the demand for plateau airport transportation is increasing. Many airlines have increased the operation route to plateau airport, and some airlines are also considering and trying to add a highland base station, where pilots can carry out short-term plateau flight work.

However, compared with the general airport operation, the difficulty of the high high altitude route operation is greatly increased. On the one hand, the aircraft performance is sharp reduced, the terrain conditions of the plateau airport are complex, and the clearance conditions are poor, which puts forward higher requirements for the basic piloting skills and other comprehensive competence to the flight crew. On the other hand, with the increase of altitude, the partial pressure of oxygen in the air decreases, the partial pressure of oxygen in human blood decreases, the blood oxygen content and the blood oxygen saturation decrease, resulting in hypoxia, which lead to different degrees of effects on the physical, and also affect the cognitive ability to a certain extent. Sustained exposure to high altitude leads to cognitive decrement, such as impairment in attention, memory, judgment, and emotion[1]. Therefore, the problem of plateau safety flight is not only a worldwide problem, but also an urgent aviation safety problem in our country.

As a core cognitive capability, working memory may be influenced by high altitude conditions. Working memory(WM) is a system used for temporary storage and processing of limited information, providing the necessary temporary storage space and processing required information for complex tasks. At least two types of working memory systems have been identified, processing verbal information (verbal working memory) and spatial information (spatial working memory)[2].The hippocampus and the limbic system, critical brain regions involved in WM, are more sensitive to low oxygen levels[3]. According to the study of Maiti et al., apoptosis of neurons in hippocampus, cortex and striatum may lead to reduced spatial memory ability in animals under acute altitude hypoxia environment[4]. Acute high-altitude exposure affects memory capacity, including working memory, short-term memory, and long-term memory. Crow and Kelman(1971) tested 86 subjects and found that the short-term memory ability of the subjects would be impaired when the altitude reached 3658 m[5]. Bartholomew et al. (1997) tested the short-term memory ability of 72 pilots at altitudes of 606m, 3788m, and 4545m. The study found that only when the altitude reached 4,545m, the pilots' short-term memory ability decreased significantly[6]. From the above results, it can be seen that the lowest altitude for the occurrence of short-term memory impairment is about 3500 m. There are also many other studies that have found that verbal and visual short-term memory ability and recall are impaired at 2,500 meters[7-9]. Yan et al. (2011) investigated the spatial working memory of Han people growing up at high altitudes with fMRI and found that there was no difference in accuracy between the two groups, except that the average reaction time of the high altitude group was slightly longer than that of the low altitude group. Although the volume of gray matter in the frontal lobe decreased in the high-altitude group, the BOLD signal in the frontal lobe did not decrease significantly, and the activation of the cerebellar cone and temporal lobe increased, indicating that the high-altitude group utilized the frontal lobe and more attention resources in a wider range when completing the spatial working memory task, so as to maintain a higher level of attention to compensate for the defects of visual spatial structure[10] . Ma et al. (2019) determine the neurocognitive basis underlying the effects of long-term high altitude exposure on working memory of verbal and spatial n-back tasks. Behavior and ERPs result indicated that high altitude had a different effect on verbal and spatial 2-back task performance[11].

Although there have been some previous studies on the effects of mild to moderate acute hypoxia on working memory, the results have been quite different. In particular, there is a lack of short-term evidence for changes in cognitive function after exposure to high-altitude hypoxic environments within one weeks. The purpose of this study was to investigate the effects of hypoxia on working memory during short-term stay at plateau airport of 3600m high altitude. The effect and mechanism of hypoxia on working memory in short term were investigated by measuring the 2-back tasks of volunteers entering into plateau for 3 days.

2. Experiment

2.1. Subjects

The subjects were 20 healthy male volunteers from Beijing, with education above secondary school and age between 30-40 years old. The subjects were asked to sign an "informed consent form" before the experiment. All subjects had normal naked eye vision or corrected vision, no color blindness, color weakness and other eye diseases, and no history of neurological or brain surgery.

2.2. Stimuli

In this study, 2-back tasks were used to measure Working Memory(WM) performance. The researchers showed the subjects a continuous sequence of stimuli that asked them to indicate whether the current image was the same or different from the previous two stimuli (Figure 1).

The stimuli were 12 capital letters ,including A to L, that would appear at one of 12 positions, each of which was at the tip of one of six equidistant radii of an imaginary circular array, 2 or 6 cm from the screen center. The stimulus occupied between 3 °and 4.5 °of the visual angle on either side of the visual midline. The white stimuli were presented against a black background on a computer screen, with horizontal and vertical visual angles less than 5° .

In this study, the verbal and spatial 2-back tasks involved the same stimuli, and the requirements were distinguished only by the task, providing different instructions to the subjects before each task began. In the verbal WM task, participants were asked to remember only the name of the letter, while in the spatial WM task, participants were instructed to remember the location of the letter only.

Sufficient practice (five minutes for each participant) was provided to make sure that all participants had understood the requirement and had been familiar with the task. In the practice and formal test, each trial consisted of the following sequence(see Fig. 1). At the first, a fixation cross were presented continuously on the computer screen, which remained on the screen for a random time interval ranging from 200ms to 400ms. Next, a capital letter serving as the target stimulus was presented for 300ms. The subjects were asked to judge if the target match or non-math by pressing left or right button in keyboard. The next stimulus would appear after 1500ms if no response was provided. Match and non-match stimuli presented randomly and each occurred in 50% of the trials. The accuracy and reaction time of each trial were recorded by computers.

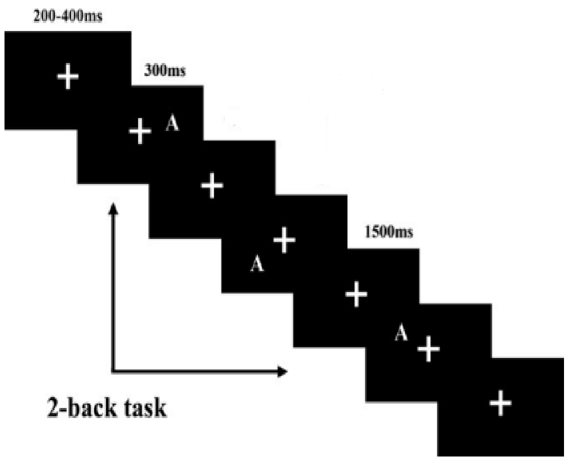

Figure1: The procedure and the stimuli of this 2-back task

2.3. Procedure

The experiment was administrated by two small teams for 10 subjects each.

The first team of 10 subjects were longitudinal tested working memory task three times respectively as follow: the 1hours after entering into plateau(about 10am in local time), the same time in the second day and the third day. And then the result of 2-back task in flatland as baseline also be collected.

The second team of 10 participants were also longitudinal administrated the same task in the same three times after into the plateau. Beside, in order to explore the influence of oxygen supply, 10 participants were divided into two groups randomly with double blind. One group of 6 participants were supplied by diffusion types of oxygen with 96% oxygen concentration in the sleepiness time during 9 pm to 7am. While the other group of 4 participants were exposed to hypoxia as usual.

2.4. Stastic anlysis

Reaction times (RTs) and accuracy were online recorded and the measures about speed and accuracy were calculated by the median RTs of correct trails and accuracy ratio for all the subjects.

The signal detection measure Sensitivity(d') was also calculated using the formulas (1),where z(H) and z(FA) mean the Normal transformation of the hit (i.e. correct match trials in this study) and false alarm(i.e. error non-match trials in this study) rates to z-scores[12]. The variable *d'* represents a measure of the perceptual sensitivity in different conditions.

$$d' = \mathrm{z(H)} - z(FA) \quad (1)$$

The short-term changes of working memory after entering the plateau were analyzed by the first batch of total 10 subjects' data. The RTs , ACC and d' were used for data analysis respectively, and were analyzed by means of mixed-model analysis of variance (ANOVA) using the F statistic. The independent variables were testing time (3 days in plateau and control in plain) and task type (verbal WM and spatial WM) as within-subject factor for a 4×2 repeated measured design. LSD (Fisher Least Significant Difference) test method was used for post-event comparison of all levels of differences within variables.

To further investigate whether oxygen supply during sleep improved working memory, the second batch of 10 subjects was randomly assigned to either the oxygen or the exposure group, using a mixed three-factor design. The RTs , ACC and d' were used for data analysis, and were analyzed by ANOVA respectively. The independent variables were testing time (3 days in plateau and control in plain) and task type (verbal WM and spatial WM) as within-subject factors, and oxygen conditions (Hypoxic exposure and Oxygen supply)for a 4×2×2 repeated measured design. LSD (Fisher Least Significant Difference) test method was used for post-event comparison of all levels of differences within variables.

3. Rusult

3.1. The RTs results

As described in Table1, the reaction time when participants entering into plateau for 1 hour were significantly longer than they were in the plaint, and then the reaction time gradually decreased significantly on the second day and the third days whether the verbal WM task or the spatial WM task. The ANOVA revealed significant main effects of testing time [F (3, 27) = 111.62, p < 0.001, η^2=0.925] and task type [F (1, 9) = 77.94, p < 0.001, η^2=0.896], which the verbal WM has longer reaction time than spatial WM in each condition.

Considering the oxygen supply effect, the ANOVA in spatial 2-back task revealed significant main effects of testing time [F (3, 24) = 39.56, p < 0.001, η^2=0.832] . There are no significant main effects of oxygen supply [F (1, 8) = 1.42, p >0. 1, η^2=0.151] , even the difference between oxygen or the exposure group in each testing time.

Table 1: Mean and standard deviation of response time (RT) accuracy rate (ACC)and sensitivity(d') (M ± SE)

		RT	ACC	d'
spatial WM	**1hour**	956.07±106.35	0.76±0.05	1.41±0.3
	2th day	877.2±79.94	0.77±0.05	1.47±0.3
	3rd day	825.74±70.6	0.77±0.04	1.52±0.26
	Control	707.57±51.67	0.87±0.05	2.42±0.66
verbal WM	**1hour**	1001.38±103.13	0.83±0.04	1.93±0.33
	2th day	931.22±79.27	0.85±0.03	2.06±0.27
	3rd day	862.38±62.86	0.88±0.04	2.38±0.41
	Control	753.28±51.36	0.89±0.03	2.45±0.32

By the condition of verbal 2-back task, the ANOVA revealed significant main effects of testing time [F (3, 24) = 46.04, p < 0.001, η^2=0.852] and marginal significant main effects of oxygen supply [F (3, 24) = 39.56, p = 0.092, η^2=0.832]. The one factor ANOVA for each testing time revealed that the person slept in the room with diffusion types of oxygen supply would show a significant improve in the reaction speed of verbal 2-back task in the second day [F (1, 9) = 8.31, p < 0.05] and third day [F (1, 9) = 6.09, p < 0.05] after entering into plateau (see Table 2, Figure 2)

Table 2: Reaction time of spatial and verbal 2-back for oxygen and exposure group for 3 days at plateau(M ±SE)

	Spatial WM		Verbal WM	
	Exposure	**Oxygen**	**Exposure**	**Oxygen**
1hour	968.84±22.97	952.66±26.76	996.1±22.69	987.38±91.03
2th day	874.43±64.78	832.39±114.35	936.84±61.81	797.39±70.26
3rd day	824.46±80.75	689.34±113.14	865.72±89.52	735.5±59.77
Control	708.26±69.94	659.8±97.47	758.78±80.77	679.08±98.8

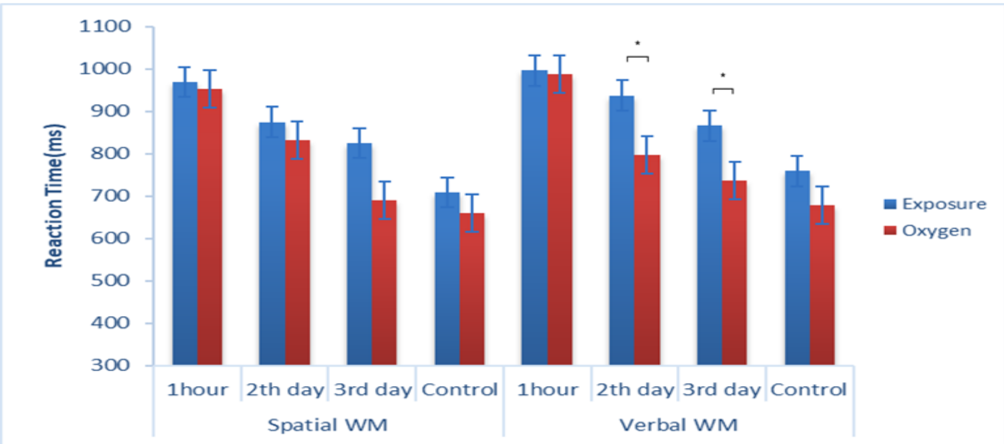

Figure2: The RT change of spatial2-back and verbal 2-back of 3 days in the paltaeu for oxygen and expusure group

3.2. The ACC results

The accuracy of working memory were also shown in Table 1. The ANOVA revealed significant main effects of testing time [F (3, 27) = 161.39,p < 0.001, η^2=0.947] and task type [F (1, 9) = 177.99, p < 0.001, η^2=0.952], which the verbal WM has more accuracy rate than spatial WM. Post hoc analysis by LSD on testing time revealed the accuracy after 1 hour entering into high altitude environment was significant lower than control condition, and then somewhat increase in the next 2 days. There was also a significant interaction of testing time × task [F=33.69, p < 0.001, η^2=0.789], the post hoc analysis showed that the difference of accuracy change between spatial 2-back task and verbal 2-back task, which the spatial task are more affected by high altitude hypoxia.

Detecting the impact of oxygen supply, The ANOVA analysis conducted on the spatial 2-back task revealed significant main effects of testing time [F (3, 24) = 31.79, p < 0.001, η^2=0.799],with significant lower accuracy in high altitude conditions comparing with control . Although there was no significant main effects of oxygen supply [F (1, 8) = 0.09, p >0.1, η^2=0.011], we found a marginal significant interaction of testing time × oxygen supply[F (3, 24) = 2.56, p =0.079, η^2=0.243]. Further analysis showed somewhat improvement in the second and the third day (post hoc analysis contrast to control condition , P>0.1) for the group with oxygen supply in sleep time. On the other hand, in the verbal 2-back task condition, the ANOVA analysis demonstrated significant main effects of testing time [F(3, 24)=26.59,p<0 .001, η^2=0 .769], without main effects of oxygen supply and any other interactions (see table3) .

Table 3: accuracy rate of spatial2-back and verbal 2-back for oxygen and exposure group for 3 days at plateau(M ± SE)

	Spatial WM		**Verbal WM**	
	Exposure	**Oxygen**	**Exposure**	**Oxygen**
1hour	0.75±0.04	0.74±0.07	0.83±0.05	0.83±0.03
2th day	0.76±0.04	0.79±0.09	0.84±0.06	0.84±0.05
3rd day	0.77±0.03	0.82±0.09	0.86±0.07	0.87±0.04
Control	0.87±0.04	0.87±0.06	0.88±0.05	0.88±0.04

3.3. The d' resutlts

We also analyzed the signal detection measure Sensitivity(d') computed by formulas (1)(see Table 1). The ANOVA revealed significant main effects of testing time [F (3, 27) = 94.83, p < 0.001, η^2=0.913] and task type [F (1, 9) = 71.11, p < 0.001, η^2=0.888], which the verbal WM has more sensitivity than spatial WM in each condition. The testing time × task type interaction was found to be significant [F (3, 27) = 19.08, p < 0.001, η^2=0.680] . Post hoc analysis revealed that the sensitivity change with time after entering into plateau differed significantly between the spatial 2-back task and the verbal 2-back task, with the spatial task being more susceptible to high altitude hypoxia. .

Further analysis on the impact of oxygen supply, a 4×2×2 ANOVA revealed significant main effects of testing time [F (3, 24) = 68.79, p < 0.001, η^2=0.888] and task type [F (1, 8) = 8.16, p < 0.05, η^2=0.505], which the verbal WM has more sensitivity than spatial WM in each condition. Moreover, there were significant interaction of testing time × task type [F (3, 24) = 14.32, p < 0.001, η^2=0.642] and significant interaction of testing time× task type ×oxygen[F (3, 24) = 3.08, p < 0.05, η^2=0.278]. Considering the spatial 2-back task, the ANOVA revealed significant main effects of testing time [F (3, 24) = 3.69, p < 0.05, η^2=0.315] and significant interaction of testing time ×oxygen supply[F (3, 24) = 50.21, p < 0.001, η^2=0.863]. By contrast, the ANOVA on the condition of verbal 2-back task revealed significant main effects of testing time [F (3, 24) = 68.61, p < 0.001, η^2=0.896] without the interaction of testing time ×oxygen supply [F (3, 24) = 0.16, p > 0.1, η^2=0.019]. The post hoc analysis revealed a slight improvement in spatial 2-back task on the second and third day (in contrast to the control condition, P>0.1) for the group receiving diffusion types of oxygen supply during sleep(see Table 4).

Table 4: sensitivity(d') of spatial2-back and verbal 2-back for oxygen and exposure group for 3 days at plateau(M ± SE)

	spatial WM		**verbal WM**	
	Exposure	**Oxygen**	**Exposure**	**Oxygen**
1hour	1.38±0.27	1.37±0.67	1.92±0.35	1.99±0.32
2th day	1.4±0.25	1.72±0.68	2.02±0.45	2.06±0.39
3rd day	1.51±0.22	2.03±0.8	2.27±0.59	2.3±0.4
Control	2.38±0.44	2.48±0.88	2.45±0.5	2.44±0.45

4. Discussion

4.1. High altitude impact on the working memeory

The results of this study indicated that the response speed, accuracy and sensitivity of complex working memory tasks, whether spatial or semantic tasks, are significantly affected by hypoxia after entering the plateau environment at an altitude of 3,600 meters for 1 hour. This discovery was similar to the studies by Wu et al. using low pressure oxygen cabin to explore the effect of acute hypoxia on cognitive efficiency, which found that the performance of all tests significantly decreased after exposure at altitude amount to 3600m[13]. Similar result also was found in Kelman(1971)'s study[5]. Whereas, some other studies[6,14] memory function would be impaired by hypoxia at the altitude of 4350m or above. Differences in these findings may be influenced by the complexity of the memory task. Wu et al.'s study using low pressure oxygen cabin[13] and our previous study based on the filed study in the plateau[15] have found that the performance of some simple attention task was not significantly reduced while that of some complex attention tasks was significantly affected. In this study, we used 2-back working memory task which is more complex and have high load to participants. Therefore, a certain degree of cognitive decline is also shown at an altitude of 3,600 meters in our study.

4.2. The short-term changes of working memeory

After entering the hypoxia environment at the plateau, the body will undergo a series of compensatory adaptive changes to hypoxia, which is called altitude acclimation and is an important natural way to alleviate the harm of hypoxia at the plateau [16]. Cognitive function is a response to brain function, depends on arterial oxygen content and cerebral blood flow (CBF). Studies have shown that when participants suddenly raised to 3,810m, the CBF increased by 24% and returns to normal after 3 to 5 days, showing considerable individual differences [17]. The results of the follow-up study on the soldiers in the plateau suggest that relatively simple cognitive tasks can be recovered within 1 week after entering the plateau region, while more complex cognitive tasks can be recovered within 1-2 weeks [18]. Our present study is based on the characteristics of pilots returning to the plateau for many times and staying at the plateau for a short time, to explore the short-term adaptive changes under the 3 days observation entering the plateau. The results of this study found that the reaction speed of working memory was alleviated to a certain extent on the third day after entering the plateau, but there was still a certain degree of damage compared with the control condition on the third day, while the accuracy and sensitivity of spatial tasks were alleviated slowly. This may also be related to the complex of working memory tasks. Our previous studies[15] also found that with the adaptation of individuals to the low-oxygen environment at the plateau, the cognitive ability can be improved, and the response to simple tasks can be relieved more quickly, and can almost recover to the normal level on the third day. For more complex tasks, the recovery speed is slower. And there's still some degree of damage.

4.3. The influence of oxygen supply to working memory

Sleep disorders caused by altitude hypoxia are a very common problem, manifested as sleep-disorganized breathing, longer wake time, decreased sleep quality, altered sleep structure, and reduced deep sleep and rapid eye movement time [19]. These sleep disorders further affect the cognitive function of the brain. The effect of altitude sleep disorder on cognitive function is more obvious in the early stage of entering altitude. Just as domestic studies have found that there is no difference in cognitive function among soldiers in different sleep quality groups who have lived in the Tibetan Plateau for more than one year, while for soldiers who have been in Tibet for less than three months, the scores of cognitive factors among different sleep quality groups have significant differences [20]. Therefore, improving sleep can help alleviate cognitive impairment, and providing diffuse oxygen during sleep is an effective measure. The results of our present study showed that individuals who were provided with diffuse oxygen during sleep, with oxygen levels up to the plain level, showed improvements in some working memory indicators of reaction time and accuracy or sensitivity indicators of spatial tasks. This result indicated that sleep oxygen can improve cognitive function to a certain extent, especially for the recovery of cognitive function in complex tasks, which is quite consistent with our previous studies[15].

5. Coulusions

In this 3 days short-term longitudinal study, participants' working memory were tested by b spatial 2-back task and verbal 2-back task when they entered into the plateau field. Then we reached the conclusions as followed: firstly, the performance of working memory was significantly declined after entering into the plateau with 3600m high altitude, whether the reaction time or the accuracy and sensitivity. Secondly, the reaction speed of working memory was alleviated to a certain extent on the third day after entering the plateau, without improving accuracy and sensitivity of spatial tasks. Thirdly, the use of oxygen during sleep through diffuse oxygen supply has a certain improvement effect on the recovery of verbal working memory speed, accuracy and sensitivity of spatial working memory under high altitude environment.

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