

# Impacts of Mild and Moderate Acute Hypoxia on Visual Contrast Sensitivity

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## Research

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# Abstract

**Introduction:** Acute hypoxia could hamper the visual performance during the aviation. In the study, we aimed to investigate the effects of acute hypoxia on the contrast sensitivity (CS) and the color contrast sensitivity (CCS).

**Methods:** 12 healthy volunteers (aged 20-22 years old) were selected for CS and CCS examination at altitude of 300m, 3000m and 4500m by applying the hypobaric cabin to simulate acute hypoxia (3000m in height = mild hypoxia; 4500m = moderate hypoxia). All data were collected after the heart rate and the blood oxygen saturation became stable, and were analyzed by the paired student's t-test.

**Results:** The CS at the spatial frequency of 1.5 Cpd was significantly increased at the altitude of 3000m ( $P<0.05$ ), while CS at the higher spatial frequencies was not significantly affected. The CS of 1.5 and 3.0 Cpd was increased at the altitude of 4500m ( $P<0.05$ ), while the CS of higher spatial frequency did not change significantly. With the increased degree of hypoxia, the overall CCS was increased with a statistical difference at 4500m ( $P<0.05$ ). The CCS of the temporal superior and inferior quadrants were significantly affected ( $P<0.05$ ), while those in other quadrants were significantly changed.

**Conclusions:** Mild and moderate acute hypoxia could affect the CS in the low spatial frequency. With the increased degree of acute hypoxia, CCS deteriorates with the temporal quadrant more vulnerable to be affected.

## Introduction

Acute hypoxia is a serious problem during aviation activities. In the aviation of helicopter aviation, acute hypoxia is widespread among pilots. Hypoxia in aviation is usually prevented by use of pressure cabins or supplementary oxygen. However, hypoxia in unpressurised aircraft would happen when aircrew do not use oxygen. Previous studies have indicated that acute hypoxia influences human performance, of which visual function is the most sensitive<sup>[1]</sup>. McFarland, etc. showed that human sensitivity to light was reduced, with the dark adaptation time extended at the altitude of about 2200 m<sup>[2]</sup>. The visual contrast sensitivity (CS) and color contrast sensitivity (CCS) are very important part of vision, which are useful during detecting and distinguishing objects<sup>[3-5]</sup>. Connolly, etc showed that the CS and CCS were affected at the altitude of about 3000 m<sup>[6-8]</sup>. However, the detail changes of the CS and the CCS has not been clearly illustrated during acute hypoxia.

In the study, we aimed to investigate the detailed change of acute hypoxia on the CS and CCS by applying the hypobaric cabin to simulate the environment of acute hypoxia. The work would help to set up the basis for flight personnel to protect the visual functions during acute hypoxia.

## Methods

10 young healthy men, aged  $20.25 \pm 0.45$ , were selected. There were no congenital color vision deficiency. They were the recruits and passed the physical examination before. We just selected the male sample in the current study. Their best corrected visual acuity (BCVA) was 1.0. No history of ocular diseases was reported among them. They had no smoking history, and had never entered the plateau before. All the procedure and research plan were approved by the Institutional Review Board (IRB).

All the 10 subjects were tested the CS and CCS insides the hypobaric altitude chamber at the altitude of 300m (the actual altitude of the city where the research was performed), 3000m (mimicking the mild hypoxia) and 4500m (mimicking the moderate hypoxia). At each altitude, the heart rate and blood oxygen saturation of each subject were examined. All data were collected after the heart rate and the blood oxygen saturation became stable.

Detection of CS was performed at spatial frequency of 1.5, 3, 6, 12, and 18 Cpd, respectively using the vision tester (G901, Shanghai water precision instruments co., LTD). The CSC examination was performed through a computer aided color vision system Chromates to detect the threshold. The distance of the detection screen was 33 cm. Different degrees of CCS randomly appear on four quadrants, radian of the screen. The CCS is increased until the its threshold did not change and reach a stable level. The system automatically gives the corresponding CCS threshold for each quadrant and for the total area.

For all statistical analyses, all data in different altitudes were expressed as the mean  $\pm$  standard error (S.E.). Data from every two altitudes were analyzed by paired-sample T test using the SPSS software (version 16.0, Chicago, IL, USA), respectively. A *P* value less than 0.05 was considered statistically significant.

## Results

### 1. Heart rate and blood oxygen saturation

The heart beat rate of the volunteers tend to increase with degree of acute hypoxia, with a statistical difference at the altitude of 4500m ( $P < 0.05$ ). At the altitude of 3000m, the blood oxygen saturation was significantly affected compared to that of 300m ( $P < 0.05$ ). The blood oxygen saturation continued to be decreased at the altitude of 4500m, with a statistical difference compared to that of 300m ( $P < 0.05$ ) and 3000m ( $P < 0.01$ ). (Figure 1)

### 2. Contrast sensitivity

At the altitude of 3000m, the CS at the spatial frequency of 1.5 Cpd was significantly affected ( $P < 0.05$ ). Meanwhile, the CS of higher spatial frequencies did not change significantly at this altitude. At the altitude of 4500m, the CS of 1.5 and 3.0 Cpd was significantly elevated ( $P < 0.05$ ), while the change of higher spatial frequencies was not statistically significant ( $P > 0.05$ ). (Figure 2)

### 3. Color contrast sensitivity

The overall retinal CCS tended to be increased with degree of acute hypoxia, with a statistical difference at the altitude of 4500m ( $P < 0.01$ ). The CCS of the temporal superior and inferior quadrants was significantly affected ( $P < 0.05$ ), while the CCS of the other quadrants of retina was not significantly different ( $P > 0.05$ ). (Figure 3)

### Discussion

The retina is very susceptible to the influence of oxygen deprivation. Severe hypoxia, which happens in high altitudes, would definitely affect human's vision performance<sup>[9]</sup>. However, the effect of mild and moderate hypoxia on the visual function should not be neglected. The helicopter pilots would usually face this degree of hypoxia, which calls for great attention.

There are two kinds of subcortical visual processing channel, the large cell channel and the small cell channel. The large cell channel is composed of large retinal ganglion cells, which transmit the visual signal to the lateral geniculate body of large cell layer inside the brain center. The receptive field of these cells is big, which accept the visual information from multiple bipolar cells. The small cell channel is made up of small retinal ganglion cells, which signal transmission to the lateral geniculate body of small cell layer of the brain center for processing. These cells are mainly concentrated around the macula. Their receptive field is relative small and they accept information from single bipolar cell. The two channels deal with different types of information. The large cell channel deal with information of low spatial frequency, while the small cell channel is more sensitive generally to information of high spatial frequency and color signal<sup>[10, 11]</sup>.

Our experiment data showed that the contrast sensitivity of 1.5 Cpd was significantly decreased when the level was raised to 3000 m high, while the higher contrast sensitivity was not statistically changed. The higher contrast sensitivity, which was 1.5 ~ 3 Cpd, was decreased significantly when the level was raised to 4500 m. This indicated that the small cell channel dealing with the lower spatial frequency was more sensitive to hypoxia. Our results was somewhat in accordance with that of Pescosolido N et al, who found that Hypobaric hypoxia conditions in pilots reduced contrast sensitivity (1.95 log to 1.05 log) in a statistically significant result<sup>[12]</sup>. Besides, et al also argued that the contrast sensitivity significantly increased after 5, 10 and 15 min of hypoxic exposure in their study<sup>[13]</sup>.

As stated above, the color contrast sensitivity (CCS) belongs to the small cell channel transmission of visual information, which could help to distinguish visual color information<sup>[14, 15]</sup>. Our data showed that the CCS was increased with increased degree of hypoxia. Specially, the CCS of the temporal superior and inferior quadrants were more significantly affected. This implies that pilots might be better to use the nasal visual field to search for colored objects during hypoxia.

There were some limitations in our study. The light adaptation states were all the same for all the subjects. We measured the heart rate and the blood oxygen saturation, and conducted the study when

these indicators became stable. However, the respiratory was not measured in our study. We would try to record it in the future study. We did not measure the accommodation or the pupil size in our study, when conducting the visual testing.. We did not adjust the confidence for multiple pairwise comparisons which would be refined in future study. We did not measure the carbon dioxide to characterise respiratory conditions.

In conclusion, our study found that mild and moderate acute hypoxia tend to affect the CS in the low spatial frequency. Color contrast sensitivity deteriorates with the increased degree of acute hypoxia; of which the temporal quadrant were more likely to be affected.

## Declarations

## Funding

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## Figures

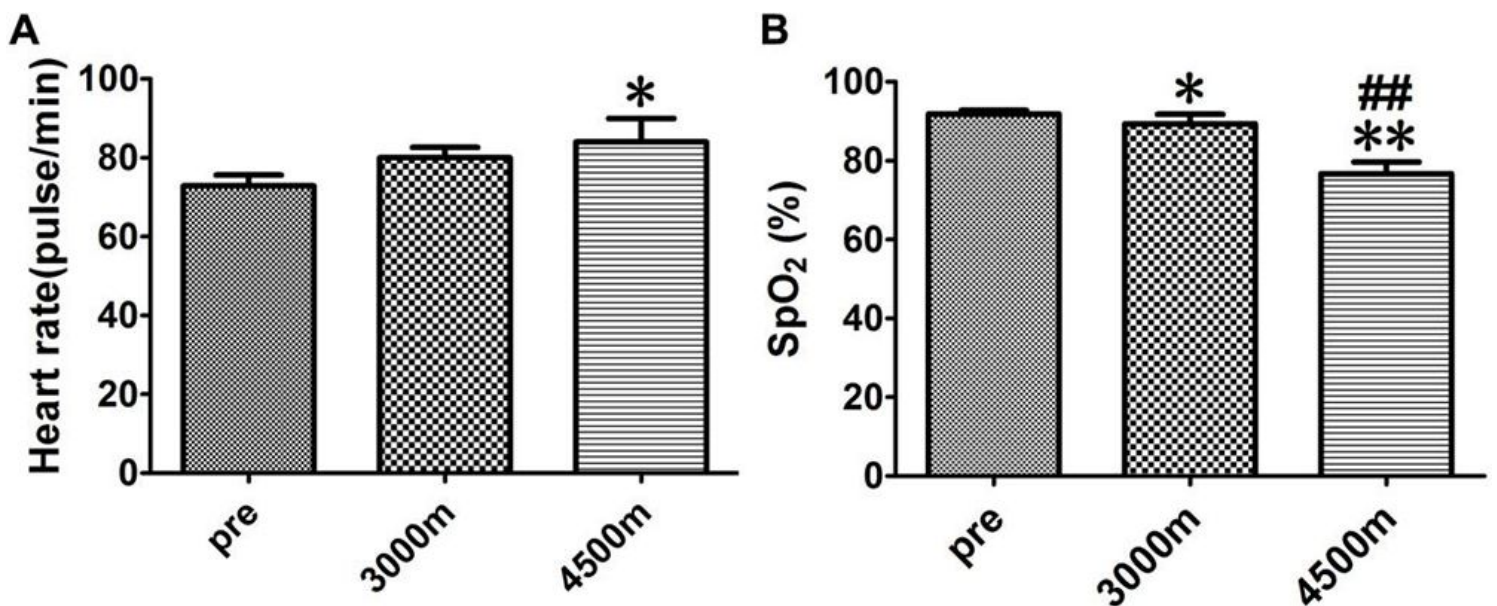


Figure 1

The effect of acute hypoxia on heart rate (A) and blood oxygen saturation (B). \*, \*\*P < 0.05, P < 0.01: v.s. the data of Pre (300m); ##P < 0.01 v.s. the data of 3000m.

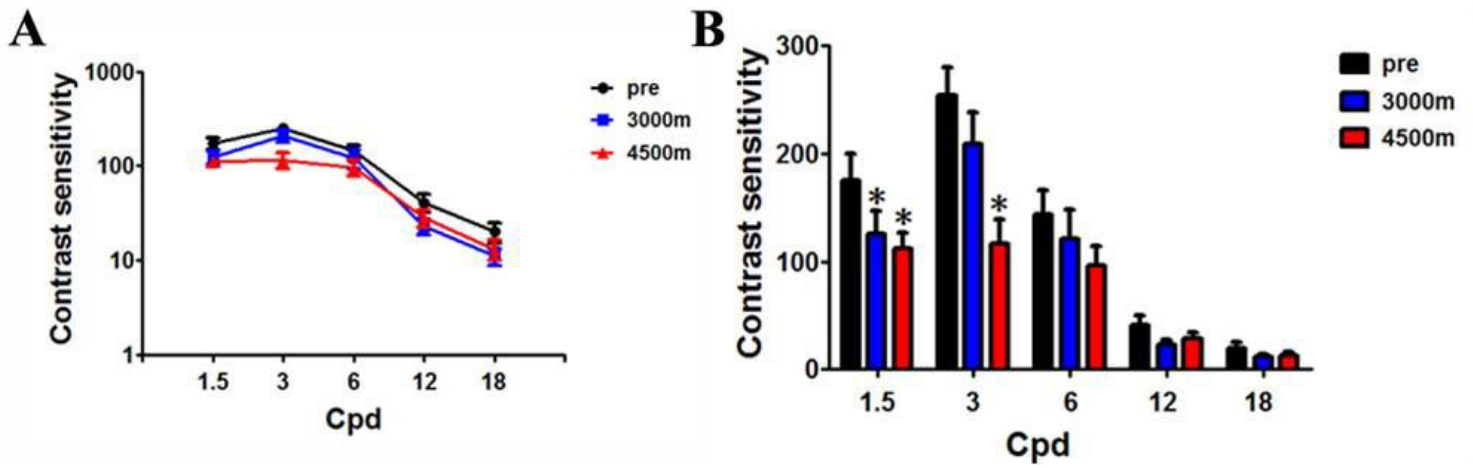


Figure 2

The effect of acute hypoxia on the contrast sensitivity. \* $P < 0.05$ , vs the data of pre.

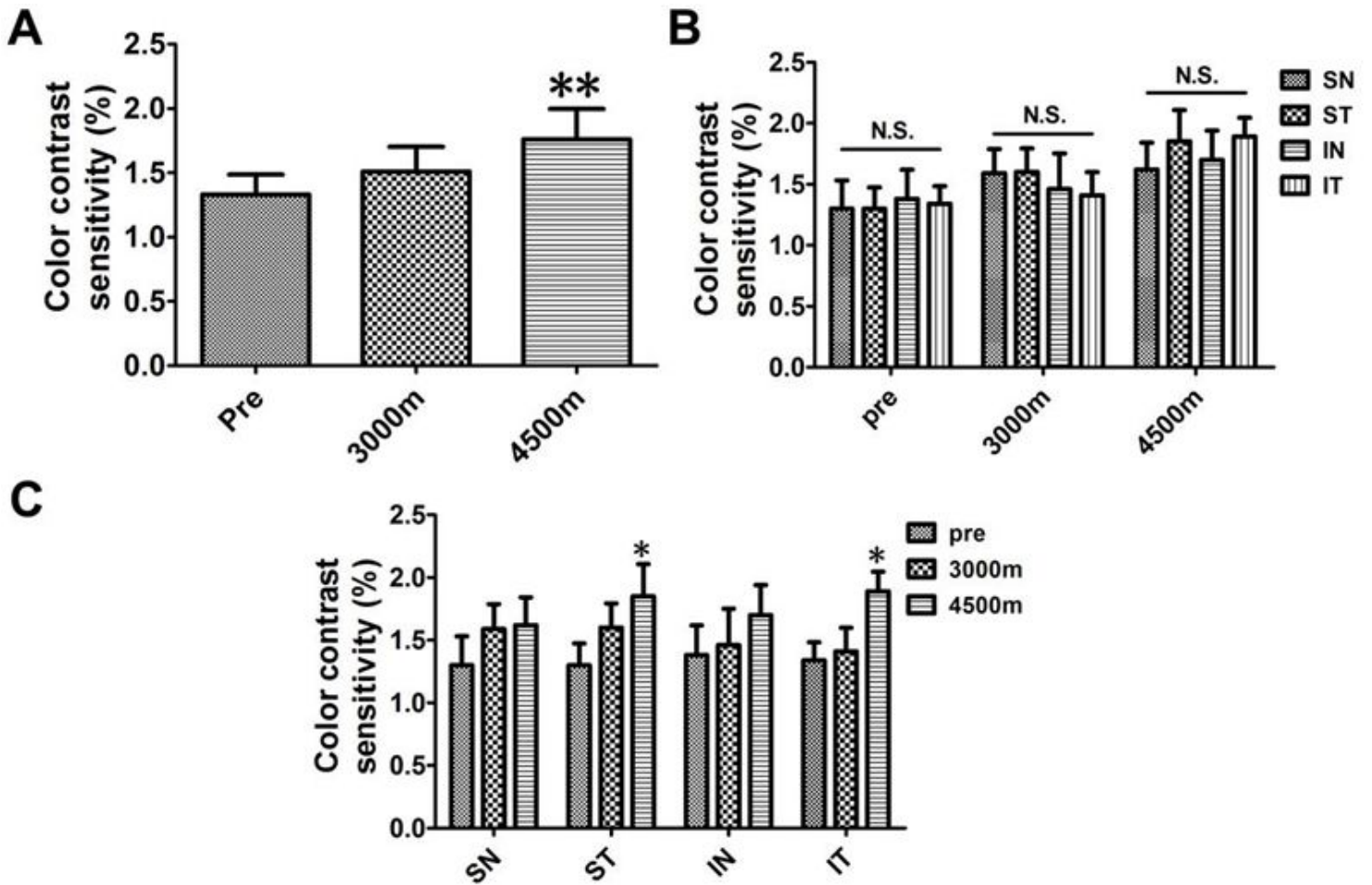


Figure 3

The effect of acute hypoxia on color contrast sensitivity. A: the general color contrast sensitivity threshold of different altitudes; B: the color contrast sensitivity threshold of each altitude on different quadrants; C: the color contrast sensitivity threshold of each quadrants on different altitude. \*, \*\* $P < 0.05$ ,  $P < 0.01$ : v.s.

the data of Pre (300m). SN: nasal quadrant; ST: superior temporal quadrant; IT: temporal quadrant; IN: nasal quadrant; N.S.: no statistical significance.