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THE EFFECT OF HYPOXIA ON THE CRITICAL FLICKER FUSION THRESHOLD IN PILOTS

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Abstract

Objectives: Human reactions to environmental changes have been the subject of numerous investigations related to pathophysiology, aviation psychology, aviation, and sports. The present study aimed at evaluating the perception of light stimulus via the Critical Flicker Fusion threshold (CFF) measurements among aviation pilots. **Materials and Methods:** The study was carried out under hypoxic conditions corresponding to 5000 m altitude, for a period of 30 min, without the use of supplemental oxygen. Fourteen volunteer pilots, 23–30 years of age, were examined in the hypobaric chamber (HC). The measurements were performed at normobaria and at the initial and final phase of hypoxia. Heart rate (HR) and blood oxygen saturation (SaO_2) were monitored. **Results:** The high altitude hypoxia was found to produce a decrease in the CFF threshold F(3.39) = 3.207, $p < 0.05$, and SaO_2 F(3.39) = 52.651, $p < 0.001$, as well as HR increase F(3.39) = 7.356, $p < 0.001$. The results indicate that the higher the decrease in SaO_2 under hypoxic conditions, the higher the decrease in CFF $r = .567$ $p < 0.05$. Likewise, the higher the increase in HR, the higher the decrease in CFF $r = –0.491$ $p < 0.05$. **Conclusions:** Under hypoxic conditions, the perceptual ability of the pilots is gradually decreasing. This has been confirmed by the findings of the physiological examinations. The authors express an opinion that it would be advisable to introduce CFF measurement into the hypobaric chamber tests as it allows individual assessment of the pilot's perceptual ability under conditions of incomplete physiological compensation of the high altitude hypoxia.

Key words:
Hypoxia, CFF, Physiological examination

INTRODUCTION

The evaluation of the effects of lowered air pressure on the perceptual abilities of humans has been the subject of numerous studies related both to psychology and pathophysiology. Apart from their scientific value, such investigations are of practical importance in such disciplines as aviation or sports [1–5].

Hypoxia affects mainly the sensory receptors and the CNS [6–8]. Among the several functional disorders due to hypoxia, the following should be mentioned: physical and mental fatigue, somnolence, decreased muscular strength, impaired precision of movement, and coordination disorders [4,9]. These disorders are increasing in proportion to the demand for oxygen and intensify with the duration of hypoxia. In several reports assessing the functions of the human organism at various altitudes, the tolerance of hypoxia was found to depend not only on the duration of staying at a given altitude but mainly on the level of individual adaptation [7,10,11].

In available literature, there are numerous studies employing the Critical Flicker Fusion threshold (CFF) technique. These studies concern mainly the effect of the perceptual load, anxiety level and age on CFF threshold [12–14]. CFF measurement also determines individual response to emotional stimulation, physical exhaustion and fatigue [5,15–20].

An influence of a short-term staying at an altitude ranging from 4000 m to 8000 m was investigated only in a few studies, concerning mainly the physiological and psychological effects [3,4,11,21]. The available literature lacks reports on the application of CFF measurements in routine tests of hypoxia tolerance during the pilots' examinations.

The present study aimed at investigating what effect the high altitude hypoxia may have on the pilot's perceptual

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ability and what is the relationship between these changes and selected physiological variables (blood oxygen saturation and heart rate).

MATERIALS AND METHODS

Study population and procedures

Fourteen active-duty pilots, aged 23–30 years, volunteered to take part in the experiment that was to be performed in the hypobaric chamber. The volunteering pilots were previously examined by the Central Aeromedical Board and declared as fit to fly. Each participant was informed in detail of the project methodology, safety measures, and profile of exposure in the hypobaric chamber. The study protocol was approved by the Ethical Committee at the Military Institute of Aviation Medicine and an informed consent was obtained from each participant prior to the experiment.

The subjects were examined in the hypobaric chamber: under conditions of normobaria and lowered air pressure corresponding to 5000 m altitude, for a period of 30 min, without the use of supplemental oxygen. Before the onset of hypobaric chamber tests, a training in the use of the FLIM device (Schuhfried, Austria) for CFF measurements was carried out. The subjects had to report the moment when the flickering light was perceived as a constant light. The flicker fusion frequency ranged from 25 Hz to 60 Hz. The physical characteristics of the light stimulus were as follows: diameter 1.2; luminance 270 cd/m^2; wavelength 655 nm.

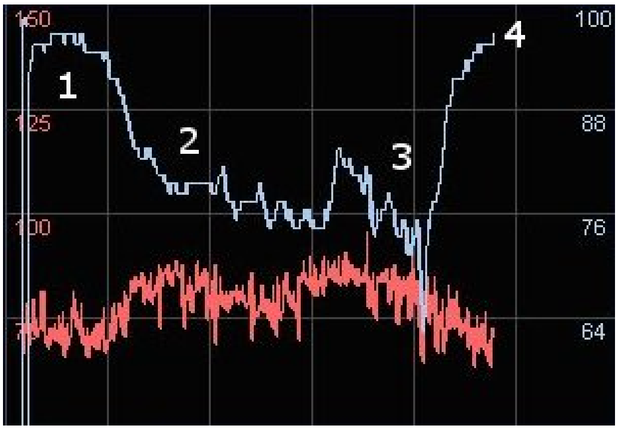

Fig. 1. Changes in the physiological parameters (SaO$_2$ and HR) throughout the study.

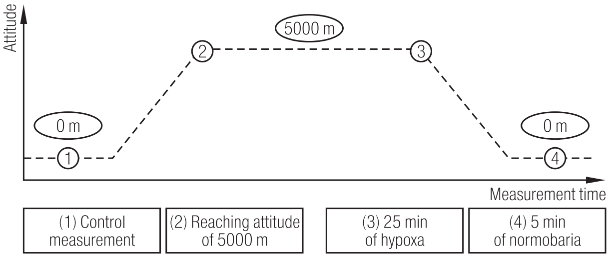

Fig. 2. Measurement scheme.

Each series of HC tests comprised four CFF measurements. Blood oxygen saturation (SaO$_2$) heart rate (HR) and chamber pressure were monitored. Fig. 1 displays the changes in the study parameters.

All the CFF measurements were performed at the following time-points:

1. Before the onset of lowering air pressure in HC: control measurements (baseline value).
2. After reaching altitude of 5000 m (at 10th min since the onset of experiment).
3. After 25 min of hypoxia exposure.
4. After 5 min of normobaria.

STATISTICAL ANALYSIS

The purpose of the statistical analysis was to assess the effect of the high altitude exposure on blood oxygen saturation, heart rate and critical flicker fusion threshold. The data were analyzed by *one-way repeated measures* ANOVA and Tukey's test for multiple comparisons. Moreover, to estimate the relationship between SaO$_2$, or HR, and the CFF threshold, the Pearson's correlation coefficient was calculated. We have assumed partial η^2 as a measure of the effect. Partial $\eta^2 = 0.01$ represents little effect; partial $\eta^2 = 0.06$, medium effect; and partial $\eta^2 = 0.14$, considerable effect [22]. The differences were considered significant at $p < 0.05$.

RESULTS

All the recorded parameters, including HC pressure, were expressed as absolute values in a tabular form, and analyzed with statistical methods.

Table 1. Analysis of the effect of hypoxia on the CFF threshold, SaO_2 and HR

Variable	Time-points																F	p	η^2
	1				2				3				4						
	Control measurement (baseline value)				Reaching altitude of 5000 m (10 min of testing)				25 min of hypoxia				5 min of normobaria						
	mean	SD	min	max	mean	SD	min	max	mean	SD	min	max	mean	SD	min	max			
Critical flicker fusion (CFF) threshold	35.97	3.23	32	42	35.32	2.76	31	40	34.91	2.51	32	40	36.28	3.33	33	42	3.207	$p < 0.05$	0.198
Blood oxygen saturation (SaO_2)	96.85	0.94	95	98	81.57	6.91	72	97	79.85	5.28	71	93	94.85	3.63	83	98	52.651	$p < 0.001$	0.802
Heart rate (HR)	82.85	15.64	95	98	90.92	16.3	63	126	89.57	17.27	61	120	79.42	14.43	59	102	7.356	$p < 0.001$	0.361

The changes in HC pressure affected the CFF value $F(3.39) = 3.207$; $p < 0.05$; $\eta^2 = 0.198$. CFF decreased significantly with the decreasing air pressure. In addition, post hoc comparisons were performed using the Tukey's test. As expected, VF in measurements 1 and 4 was significantly higher than in measurements 2 ($p < 0.05$) and 3 ($p < 0.06$).

The decrease in HC pressure brought about a significant decrease in blood oxygen saturation (SaO_2) $F(3.39) = 52.651$; $p < 0.001$; $\eta^2 = 0.802$. In the Tukey's test, SaO_2 in measurements 1 and 4 was significantly higher than in measurements 2 and 3; $p < 0.001$.

Heart rate was found to increase with the decreasing HC pressure $F(3.39) = 7.356$; $p < 0.001$; $\eta^2 = 0.361$. The Tukey's test revealed that in measurements 1 and 4, this parameter was significantly lower than in measurements 2 and 3; $p < 0.02$.

To estimate the relationship between blood oxygen saturation, or heart rate, and the Critical Flicker Fusion threshold, Pearson's correlation coefficients were calculated. The results indicated that in the control measurement no significant relationship could be noted between $SaO_{2,}$ or HR, and CFF.

The hypoxic conditions were obtained at 25th min of testing. Therefore, an assumption was made that pilots may differ in the resistance to hypoxia and that an indicator of individual resistance would be the difference between blood oxygen saturation and heart rate at the 25th min since the onset of testing (baseline value).

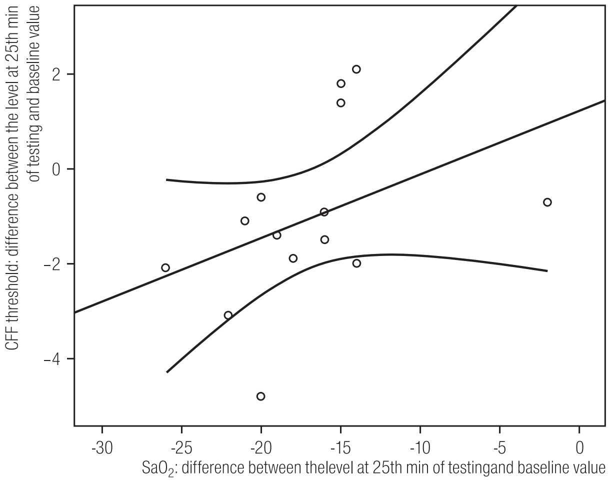

Fig. 3. Correlation plot demonstrating the relationship between the changes in SaO_2 and CFF during hypoxic conditions.

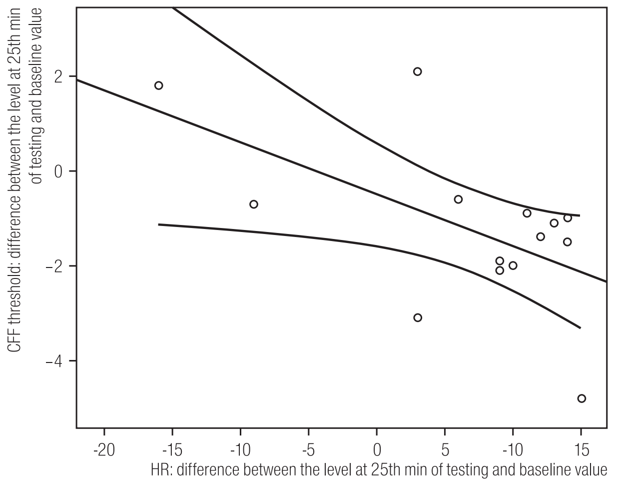

Fig. 4. Correlation plot demonstrating the relationship between the changes in HR and CFF during hypoxic conditions.

The results indicate that the higher the decrease in SaO_2 under hypoxic conditions, the higher the decrease in CFF threshold r = 0.567, $p < 0.05$ [Fig. 3]. Likewise, the higher the increase in heart rate, the higher the decrease in CFF threshold r = –0.491, $p < 0.05$ [Fig. 4].

DISCUSSION

Routine examinations of pilots in the hypobaric chamber at the Military Institute of Aviation Medicine include an assessment of resistance to hypoxia under air pressure conditions corresponding to the altitude of 5000 m. The findings of these examinations have shown that in the pilots susceptible to hypoxia, the cardiovascular and respiratory parameters reveal changes indicating an approaching loss of consciousness. These individuals show a significant increase in HR and a rapid decrease in SaO_2 in the critical phase, which was confirmed in our study. Despite the small number of subjects, the level of r-Pearson's coefficient between the study variables and the effect [22] was significant enough.

In our study, both these parameters showed a similar direction of changes but the values indicating poor tolerance of hypoxia were not obtained. The changes observed at both the initial and terminal phase of hypoxia indicated a gradually increasing physiological dysfunction that rapidly receded when the normobaric conditions returned. However, in spite of this dysfunction, a satisfactory tolerance of hypoxia, consistent with effective standards, was noted in all the examined pilots.

It should be emphasized that a pilot who has passed the hypobaric chamber tests, corresponding to 5000 m altitude, will be exposed during the flight to various environmental and work-related hazards including changeable environmental conditions, considerable physical and mental effort, fatigue from long-lasting flights, stress, and emotional strain. In our study, both the flight time and altitude examined were in the range of incomplete physiological compensation, i.e. over 4000 m. Therefore, the pilot's tolerance of hypoxia depended on the functional capability of the physiological compensation system. However, at the altitude of 5000 m, the effectiveness of the compensation mechanisms is limited. Blood oxygen saturation depends mainly on the partial pressure of oxygen and only to some extent on the pulmonary ventilation. A decrease in SaO_2 affects the heart rate, thus having impact on the cardiovascular and respiratory functions. Pilot performance depends largely on the perception of visual stimuli. Therefore, we have employed the CFF measurements to assess the pilot's perceptual ability under conditions of the high altitude hypoxia. An advantage of this method is the possibility to evaluate threshold changes in response to a varying pulsation of the light stimulus.

Some authors emphasized the advantages of CFF assessment [1,12] as an objective, quantitative, and important method for measuring alertness and arousal, The CFF test makes it possible to determine the degree of CNS fatigue and cortical arousal. The results of the studies indicating that an exhausting physical exercise increases the CFF threshold are particularly interesting [1,12]. Their authors suggest that the changes in CFF frequency result in an increased sensorial susceptibility and cortical arousal. Our study revealed reverse findings, namely a decrease in the CFF threshold and blood oxygen saturation. The main effect of hypoxia at the altitude of 5000 m seems not to be the physical workload or fatigue but the hypoxia-induced changes in CNS functions. This finding is consistent with our main assumption that hypoxia exerts an effect on the Critical Flicker Fusion threshold in pilots.

Several studies on the consequences of short-term staying at high altitudes ranging from 4000 m to 8000 m concerned mainly the physiological effects evaluated using different methods. The studies by Benedek et al. [21] on visual contrast sensitivity at the altitude of 5000 m are of particular interest. After a 30-min exposure to hypoxia, the authors noted changes in blood oxygen saturation that were consistent with our own results.

Our study focused also on determining the level of visual perception as a part of assessment of individual resistance to hypoxia. The wide range of results reflecting varying responses of pilots to hypoxic conditions indicates a necessity for such an individual approach.

CONCLUSIONS

1. The physiological parameters monitored during the HC tests indicate a progressing decrease in the pilot's perceptual ability under hypoxic conditions at the altitude of 5000 m.
2. The increasing high altitude hypoxia, reflected in the changes in heart rate and blood oxygen saturation, leads to a decrease in the critical flicker fusion frequency.
3. It is advisable to introduce the CFF measurements into the scope of the hypobaric chamber tests for pilots as it allows individual assessment of the perceptual ability under incomplete physiological compensation of the high altitude hypoxia. It can be of value in disputable cases of health condition assessments of candidate pilots.

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