THE STUDY OF THE HYPOXIA AND HYPOBARISM EFFECTS CORRELATED WITH THE SATURATION LEVEL OF OXYGEN IN ARTERIAL BLOOD AT PILOTS DURING FLIGHT

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Abstract*: The physiological answer of the human body under pressure such as the one generated by flying, where numerous stimuli act simultaneously upon the pilot, has begun being studied and researched since the beginning of 1918. Meanwhile, the studies have proved crucial in enhancing the flight security, in the limitations of the accidents through a better adjustment capacity, a timely intervention of the body to compensate the effects generated by the variations of the atmospheric pressure, of temperature, of the body oxygen level and of the effects caused by accelerations, vestibular and visual illusions. The study is meant, on the one hand, to point out to what degree hypoxia and hypobarism affect the function of the correct body oxygen intake, that is its implications at the mental status level and the pilot's capacity of taking the right decision during the flight, and on the other hand, the explanation in terms of statistics of the measured experimental data.*

Keywords*: hipoxia, hypobarism, pulse-oximetry, bar chamber, physiological parameters.*

1. THE EFFECTS OF HYPOXIA ON RESPIRATION

The decrease of the barometric pressure (Pb) at altitudes causes the diminution of oxygen partial inspiration pressure and of oxygen alveolar partial pressure that is arterial blood oxygen partial pressure. Hypoxia causes a stimulation of the arterial, carotid and aorta chemo receptors, whose growth of potential transmission action generate a ventilation growth. Actually, hypoxic stimulation of chemo receptors starts causing a significant hyperventilation only when the oxygen partial pressure in the arterial blood becomes lower than 75 mmHg, a value which is specific to the healthy patient who is at an altitude of 2500m. This fact explains the absence of the ventilation reaction up to an altitude of 200-2500m, the level which causes progressively augmenting hyperventilation depending on the altitude [1].

Hypocapnia induced by hyperventilation reduces the difference of the partial pressure of oxygen between the air inspired and the alveolar gas, diminishing the hyperventilation answer to the hypoxia. As regards to the role of hypocapnia in the ventilation command, central arterial chemo receptors stimulation by the carbodyoxide this is mediated firstly by the sensitivity at the arterial blood pH and also cephalic – rachidian liquid and secondly by the cerebral interstitial liquid [1].

Hyperventilation, characterized by increasing respiratory flow per unit time, appears as a reflex response, associated to the nerve altitude hyper excitability.It is triggered after a period of approx. 1-2 hours at altitudes of 0-2000 m, in a few minutes between 2500 and 3000 m high and almost instantly at altitudes above 5000 m, and once installed, it increases rapidly until it gets stabile at a maximum level, characterizing the state of hypoxic acclimatization of respiration. The amplification of hyperventilation not only determines the appropriate reduction of vital capacity (respiratory volume VR), which is reduced by 4 to 7% at altitudes of 1500-2000 m, 10-15% at altitudes of 4000-5000 m and 20-25% at heights exceeding 6000-7000m, but also modifies the respiratory exchange of the two gasses, components of air (O2 and CO2), by the downside of their partial pressure not only from inspired air (pO2 and pCO2), but also in alveolar air (pA pAO2 and CO2), considering the that the value of 30 mmHg of pAO2 is the maximum allowed, that untrained people can reach at the altitudes of approx. 5000 m [2,3].

2. PRESENTATION OF THE MEDHOD USED

Conducting this research involved the collaboration with the Institute of Aviation and Space Medicine of Bucharest, where military and civilian pilots have the annual medical examination in order to receive the medical opinion for flight.

The hypoxia and hypobaric state will be induced to the aeronavigant staff, subject to the study in process through a pressure chamber, connected to a computerized system that allows real-time monitoring of several physiological parameters. The created conditions (hypoxia and hypobarism) are similar to those existing at the altitude of 5500 m. This altitude is considered relevant to the study, knowing that the occurrence of changes caused by hypoxia appear with the altitude of 3600m. Tracking physiological parameters will be performed on a time period corresponding to 1050 seconds, from the beginning of test.

Cardiac and respiratory function and oximetry pulse level will be constantly monitored, the values recording being achieved as follows:

- at T_0 = time prior to the start of the test (ground);
- at T_1 = at 130 sec., corresponding to the altitude of 5500 m;
- at T_2 = at 550sec., prior to physical effort;
- at T_3 = at 700sec., after physical effort (running on a conveyor belt);
- at T_4 = at 1050sec., before descending.

3. PROTOCOL STUDY. STATISTICAL ANALYSIS

- Bar chamber samples were performed between 8:30-12:30 am in similar conditions, rest and nutrition prior.
- Test for „simulated flight” lasted 18 minutes.
- The „cension” was performed at a speed of 40m/s up to 5500m altitude (temperature and humidity within limits of comfort).
- In the 10th minute a sample application was performed consisting of a physical running on treadmill for 20s, with a speed of 2m/s.
- The „Descent” was performed at a constant speed of 30m/s.
- During the hypoxia exposure, there were monitored on-line: ECG, oxygen saturation, altitude, temperature and humidity.
- The lot subject of the study was composed of 13 subjects, pilots with an average age of 22 years (Table 1).

Table 1 The value of pulse-oximetry during the bar chamber test

No. crt.	The value of pulse-oximetry during the test				
	Soil level $T_0 = 0$	5500 meters $T_1 = 130s$	Before effort $T_2 = 550s$	After effort $T_3 = 700s$	Before descent $T_4 = 1050s$
1	98	94	81	78	83
2	96	88	75	73	74
3	97	94	77	80	86
4	97	86	82	76	80
5	97	89	84	78	78
6	98	96	83	83	81
7	95	86	74	78	85
8	95	90	78	68	75
9	96	91	77	75	77
10	97	92	77	78	74
11	96	97	83	81	81
12	96	92	81	80	76
13	97	90	88	85	89
m_a	96,5	91,1	80	77,9	79,9

4. INTERPRETATION OF TEST RESULTS WITH BAR CHAMBER

- The arithmetic average of pulse-oximetry values measured at soil level (norm bar conditions is 96.5% O_2.
- At a 5500 meters height and 130 seconds of hypoxia from the beginning of the test a decrease of pulse-oximetry is established at an arithmetic average of 91.1% O_2, 5.4 units lower than the T_0 average.
- Before the undertaking of the physical effort, at 550 seconds of exposure to hypoxia a decrease of pulse-oximetry is established at an arithmetic average of 80% O_2, 16.5 units lower

than the T_0 average and 11.1 units lower than T_1.

- After the undertaking of the physical effort „20 seconds” running on a treadmill, at 700 seconds of exposure to hypoxia a decrease of pulse-oximetry is established at an arithmetic average of 77.9% O_2, 18.6 units lower than the T_0 average and 2.1 units lower than T_2.
- Before the decrease, at T_4 = 1050 seconds exposure to hypoxia equaling the value for 5500 meters, the average value of pulse-oximetry is 79.9% O_2, 16.6 units lower than T_0 and 2 units lower than T_3.

The last record, taken at 1050 seconds (17.5 minutes) from the beginning of the test shows an increase of oxygen concentration in the blood based on the adapting measures taken by the organism to the condition of hypoxia.

The arithmetic average of pulse-oximetry is 79.9% O_2 with a 2 unit increase.

There hasn't been a slower adapting process to hypoxia of the organism in the cases when the subjects of the test were smokers (4 subjects) as compared to non-smokers. The age of the subjects, as well as the shorter period of time of their being smokers did not significantly influence their capacity to resist hypoxia for a limited period of time.

Fig. 1 shows the evolution of pulse-oximetry values recorded for the whole group that has been studied, as well as the oxygen saturation depending on the time.

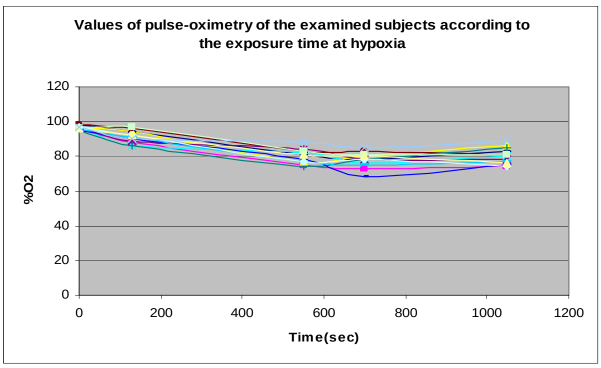

Fig. 1 Values of pulse-oximetry of the studied subjects

As a conclusion, the average arithmetic values for pulse-oximetry are the following:

T_0 = 96.5% O_2;

T_1 = 91.10% O_2 (-5.4) compared to To;

T_2 = 80% O_2 (-16.5) compared to To;

T_3 = 77.90% O_2 (-18.6) compared to To;

T_4 = 79.90% O_2 (-16.6) compared to To.

If the SaO_2 values between 94-100% represent an optimum saturation of the Hb in O_2, values between 93-88% represent mild hypoxemia, 88-83% represents average hypoxemia, and those lower than 83% stand for acute hypoxemia, the conclusion is obvious, that flying at altitudes of 5500m (without an oxygen mask) even with activation of the compensatory mechanisms specific to the human body, can lead to aeronautical accidents caused by changes in the mental function.

Below, the main precision statistical indicators are presented: standard correction, standard deviation, variation quotient, and standard error.

The values for oxygen saturation for the whole group of subjects are presented in charts 2 and 3in various phases of the study. Also, these charts contain values for standard deviations as well.

It is known that the sum of apparent correction must equal zero [5,7]:

$$\sum_{i=1}^{n} c_i = 0 \qquad (1)$$

Where: $c_i = \bar{\nu} - \nu_i$; c_i - apparent correction; $\bar{\nu}$ - average frequency; ν_i - individual frequency of subject i.

The standard deviation is calculated according to the relation (2):

$$s_0 = \sqrt{\frac{\sum_{i=1}^{n} c_1^2}{n-1}} \qquad (2)$$

Where: $\sum_{i=1}^{84} c_i^2 = c_1^2 + c_2^2 + c_3^2 + ... + c_{84}^2$

$$s_0 = \sqrt{\frac{278,92}{12}} = 4,8 \text{ at } T_0$$

$$s_1 = \sqrt{\frac{145,69}{12}} = 3,5 \text{ at } T_1$$

$$s_2 = \sqrt{\frac{196}{12}} = 4 \text{ at } T_2$$

$$s_3 = \sqrt{\frac{228{,}92}{12}} = 4{,}4 \text{ at } T_3$$

$$s_4 = \sqrt{\frac{278{,}92}{12}} = 4{,}8 \text{ at } T_4$$

Knowing *the standard deviation* that is the individual answers spreading towards the average, a measure of determination *precision* is represented.

The variation coefficient is expressed by the relation [7]:

$$CV\% = \frac{s_x}{\bar{x}} \cdot 100 \qquad (3)$$

In our case:

$$CV_0\% = \frac{s_{T0}}{\bar{\nu}_{T0}} \cdot 100 = \frac{4{,}8}{96{,}50} \cdot 100 = 4{,}97\%$$

for: $T_0 = 0$ sec;

$$CV_1\% = \frac{s_{T1}}{\bar{\nu}_{T1}} \cdot 100 = \frac{3{,}5}{91{,}15} \cdot 100 = 3{,}8\%$$

for: $T_1 = 130$ sec;

$$CV_2\% = \frac{s_{T2}}{\bar{\nu}_{T2}} \cdot 100 = \frac{4}{80} \cdot 100 = 5\%$$

for: $T_2 = 550$ sec;

$$CV_3\% = \frac{s_{T3}}{\bar{\nu}_{T3}} \cdot 100 = \frac{4{,}4}{77{,}92} \cdot 100 = 5{,}6\%$$

for: $T_3 = 700$ sec;

$$CV_4\% = \frac{s_{T4}}{\bar{\nu}_{T4}} \cdot 100 = \frac{4{,}8}{79{,}92} \cdot 100 = 6\%$$

for: $T_4 = 1050$ sec.

We can consider that a variation coefficient under 10% indicates a small dispersion of the data, which means that the series is homogenous.

A coefficient between 10% and 30% indicates a medium dispersion and, more than 30% indicates a large dispersion. If the dispersion is large, the average is not a representative indicator.

As a conclusion, the values registered at different exposure times at hypoxia, indicate the existence of a small dispersion of the data, the series being homogenous.

In order to find out the measurements precision, we must calculate the average deviation of the average obtained values, that is the standard error:

$$E = \frac{S_x}{\sqrt{n}} \qquad (4)$$

Applied to our case, we obtain:

$$E_{T_0} = \frac{S_{T0}}{\sqrt{n}} = \frac{4{,}8}{\sqrt{13}} = \frac{4{,}8}{3{,}60} = 1{,}3$$

$$E_{T_1} = \frac{S_{T1}}{\sqrt{n}} = \frac{3{,}5}{\sqrt{13}} = \frac{3{,}5}{3{,}6} = 0{,}9$$

$$E_{T_2} = \frac{S_{T2}}{\sqrt{n}} = \frac{4}{\sqrt{13}} = \frac{4}{3{,}6} = 1{,}1$$

$$E_{T_3} = \frac{S_{T3}}{\sqrt{n}} = \frac{4{,}4}{\sqrt{13}} = \frac{4{,}4}{3{,}6} = 1{,}2$$

$$E_{T_4} = \frac{S_{T4}}{\sqrt{n}} = \frac{4{,}8}{\sqrt{13}} = \frac{4{,}8}{3{,}6} = 1{,}3$$

Table 2 The table of the individual pulse-oximetry values & the standard deviation

$\%O_2$ at T_1	Correction	Correction at square	Standard deviation	$\%O_2$ at T_1	Correction	Correction at square	Standard deviation	$\%O_2$ at T_1	Correction	Correction at square	Standard deviation
83	-3.08	9.47		94	-2.85	8.10		81	-1	1	
74	5.92	35.08		88	3.15	9.95		75	5	25	
86	-6.08	36.93		94	-2.85	8.10		77	3	9	
80	-0.08	0.01		86	5.15	26.56		82	-2	4	
78	1.92	3.70		89	2.15	4.64		84	-4	16	
81	-1.08	1.16		96	-4.85	23.49		83	-3	9	
85	-5.08	25.78	4.8	86	5.15	26.56	3.5	74	6	36	4
75	4.92	24.24		90	1.15	1.33		78	2	4	
77	2.92	8.54		91	0.15	0.02		77	3	9	
74	5.92	35.08		92	-0.85	0.72		77	3	9	
81	-1.08	1.16		97	-5.85	34.18		83	-3	9	
76	3.92	15.39		92	-0.85	0.72		81	-1	1	
89	-9.08	82.39		90	1.15	1.33		88	-8	64	
79.92		278.92		91.15		145.69		80		196	

Table 3 The table of the individual pulse-oximetry values & the standard deviation

$\%O_2$ at T_3	Correction	Correction at square	Standard deviation	$\%O_2$ at T_4	Correction	Correction at square	Standard deviation
78	-0.08	0.01	4.4	83	-3.08	9.47	4.8
73	4.92	24.24		74	5.92	35.08	
80	-2.08	4.31		86	-6.08	36.93	
76	1.92	3.70		80	-0.08	0.01	
78	-0.08	0.01		78	1.92	3.70	
83	-5.08	25.78		81	-1.08	1.16	
78	-0.08	0.01		85	-5.08	25.78	
68	9.92	98.47		75	4.92	24.24	
75	2.92	8.54		77	2.92	8.54	
78	-0.08	0.01		74	5.92	35.08	
81	-3.08	9.47		81	-1.08	1.16	
80	-2.08	4.31		76	3.92	15.39	
85	-7.08	50.08		89	-9.08	82.39	
77.92		228.92		79.92		278.92	

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