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Heart Rate Variability in Exposure to High Altitude Hypoxia of Short Duration

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The objective of the study is to attempt an evaluation of heart rate (HR) and heart rate variability (HRV) regulatory mechanisms in the presence of autonomous nervous system (ANS) components in transient exposure to high altitude hypoxia.

During 24 hrs including a stay in hypobaria, the participants had their HR continuously recorded using the Holter method. The following parameters were calculated at rest and during the stay in a thermobarochamber: spectral power in low frequency bands (LF) 0.04–0.15 Hz and high frequency bands (HF) 0.15–0.5 Hz, and the sympathetic-parasympathetic balance index LF/HF.

Under hypobaric conditions, a decrease in mean spectral power of R-R intervals was noted within both frequency ranges, compared with the study performed in normobaria. The observed differences were larger at daytime.

heart rate variability hypoxic hypoxia autonomic nervous system

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1. INTRODUCTION

High altitude hypoxia occurs during flights and during stays in the mountains. Although modern aircraft are designed to protect flying personnel and passengers from the effect of hypoxia (oxygen apparatus and pressurised cockpits), there is a potential risk of exposure to hypoxia and decompression under emergency conditions (Heimbach & Sheffield, 1985).

Exposure to high altitude hypoxia of short duration is included in aeromedical examinations of pilot candidates and aircrew members. The range of such examinations is different in different countries and the interpretation of results—apart from defining the Time of Useful Consciousness (TUC)—is often limited to a description of the psychophysical state.

As far as tolerance of high altitude hypoxia is concerned, the efficiency of regulatory mechanisms and the circulatory system is of particular importance (Ernsting, Sharp, & Harding, 1994; Frisancho, 1975; Krasney, 1994; Ward, Milledge, & West 1989). Spectral analysis of ECG signal R-R intervals is a convenient method of non-invasive assessment of the mechanisms involved, especially the autonomous nervous system (ANS).

Heart rate variability (HRV) depends on the sympathetic-parasympathetic balance, adjusting heart rate (HR) to changeable environmental

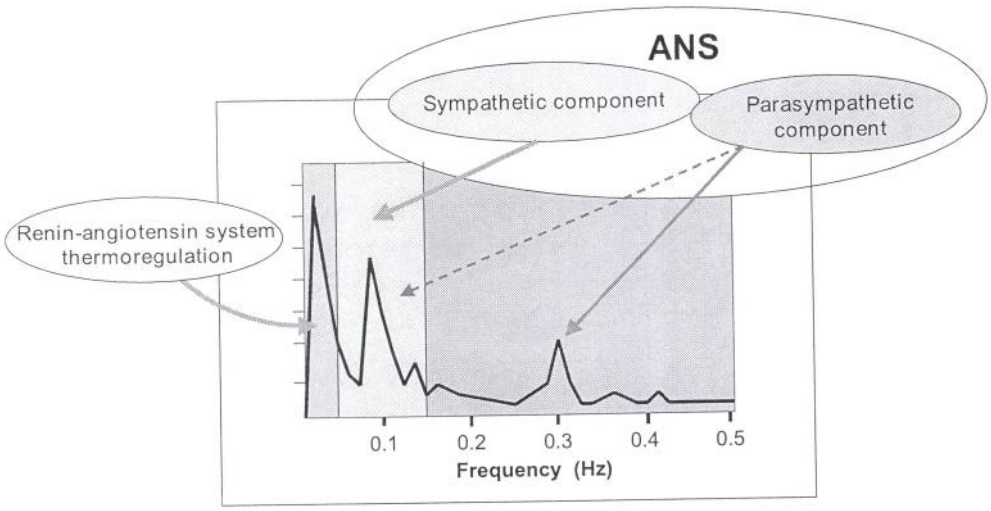

Figure 1. Physiological interpretation of spectral analysis R-R intervals results. *Notes.* LF—low frequency (0.04–0.15 Hz), HF—high frequency (0.15–0.5 Hz).Vertical axis: Power (a.u.)

factors (Hayano et al., 1993; Hughson, Yamamoto, McCullough, Sutton, & Reeves, 1994; Ravenswaaij-Arts, Kollee, Hopman, Stoelinga, & Geijn, 1993). The analysis of HR variability is considered an effective method of assessing the circulatory system control, as it enables a distinction between the sympathetic and parasympathetic components of the ANS (Hayano et al., 1993; Ravenswaaij-Arts et al., 1993).

Application of the Holter method for continuous ECG recording allows the gathering of information about heart bioelectric activity under conditions of the natural living and working environment. The application of an adequate method of mathematical and statistical analysis of the recorded signal, enables not only existing pathology to be recognized but also circulatory system regulatory mechanisms to be evaluated. Hypoxia tolerance tests, constituting a part of aeromedical studies in Poland, usually include a 30-min staying in an altitude chamber (AC) at the simulated altitude of 5000 m above sea level.

The objective of this study was to attempt to evaluate the role of ANS sympathetic and parasympathetic components in heart rate (HR) regulatory mechanisms in clinically healthy subjects, during a 30-min exposure to high altitude hypoxia at the simulated altitude of 4500 m above sea level (in AC). Spectral analysis of ECG signal R-R intervals was used to ascertain the role of ANS in HR regulation.

2. MATERIAL AND METHODS

Six healthy males aged 25–28 volunteered for the study. During the experiment and the preceding day, the participants did not take any medication, drink coffee or alcohol, or smoke tobacco.

On the study day, ECG Holter monitoring was performed, using MR-4500 recorders manufactured by Oxford Medical Systems (the United Kingdom). The devices recorded two ECG leads during 24 hrs. Twenty-four-hour ECG monitoring was performed twice for all participants during different days. The study consisted of six 30-min cycles of staying in AC at the simulated altitude of 4500 m. The first cycle started at about noon. The next cycles were repeated every 4 hrs, namely, at 4:00 p.m., 8:00 p.m., midnight, 4:00 a.m., and 8:00 a.m.

After a few days' break, a 24-hr ECG record was repeated in the already described AC study scheme, but exposure to high altitude was simulated as pressure in AC corresponded with the altitude of Warsaw

(namely, about 115 m above sea level, denoted as "0" level) termed normobaria. During exposure to hypoxia and normobaria, the participants rested in the sitting body position. On the preceding day and between subsequent cycles, the participants made a detailed record of their activity during the day. In AC, the person controlling the time course made the measurement after synchronising his or her own watch time with the time of the participants' ECG records.

An analysis of HR time and frequency was made, with a 3-min analysis of the ECG record. During exposure to hypoxia, an analysis was made of the ECG segment recorded after 30 min of exposure. During each phase of the study, the following parameters were determined:

1. mean R-R interval in the analysed ECG segment;
2. standard deviation from the R-R mean value (SDNN);
3. percentage of differences between succeeding R-R intervals, larger than 50 ms (pNN50);
4. spectral power (in ms^2) in two frequency bands: low frequency (LF): 0.04–0.15 Hz and high frequency (HF): 0.15–0.5 Hz;
5. sympathetic-parasympathetic balance index LF/HF.

An analysis of the recorded ECG signal was conducted using Medilog-Excel system software made by Oxford Medical Systems. Values of the listed parameters, calculated after a 30-min stay at the altitude of 4500 m were compared with measurement values obtained during daytime or nighttime control experiments. The non-parametric Wilcoxon's test was applied to check the significance of differences between the obtained results.

3. RESULTS

After a 30-min stay at the altitude of 4500 m, significant differences in mean R-R interval, the SDNN index, and the variability index pNN50 were found, as compared to control values obtained at 0 level, during the active daytime phase. The mean value of R-R interval under control conditions was 823 $\pm$ 62 ms, whereas in AC it decreased to 756 $\pm$ 35 ms ($p < .05$). The SDNN mean value decreased from 96 $\pm$ 14.4 ms to 73.8 $\pm$ 8.7 ms ($p < .05$), whereas the mean value of pNN50 index decreased from 33.1 $\pm$ 9.2% to 15.5 $\pm$ 8.9% ($p < .01$).

During the study conducted at night, no significant difference was found for the R-R interval under control conditions and at the altitude of 4500 m. The value of mean R-R interval under control conditions was 795 ± 86 ms, and after a 30-min exposure to hypoxia—786 ± 30 ms. A statistically significant decrease of values was observed for both SDNN indices (0 level—98 ± 32.8 ms, altitude 4500 m—78.3 ± 13.6 ms, ($p < .05$) and pNN50 (0 level 19.5 ± 5.2%, altitude 4500 m 12.6 ± 4.3%, $p < .05$). Table 1 presents the results of the HRV time domain analysis.

TABLE 1. Parameters of Temporal Analysis, Describing Heart Rate Variability at the Altitudes of 0 and 4500 m: Mean R-R Interval, Standard Deviation From the Mean R-R Interval Value in the ECG Segment Under Study (SDNN) and the Percentage of Differences Between Subsequent R-R Intervals Exceeding 50 ms (pNN50)

Time of Study	Group ($n = 6$)	Parameters of Time Domain ($x \pm SD$)		
		R-R (ms)	SDNN (ms)	pNN50 (%)
Daytime	0 level	823 ± 62	96.0 ± 14.4	33.1 ± 9.2
	4500 m	756 ± 35	73.8 ± 8.7	15.5 ± 8.9
	$p <$	.05	.01	.01
Night	0 level	795 ± 86	98.0 ± 32.8	19.5 ± 5.2
	4500 m	786 ± 30	78.3 ± 13.6	12.6 ± 4.3
	$p <$	*ns*	.05	.05

During exposure to high altitude hypoxia at daytime, spectral analysis of HRV in the participants showed a statistically significant ($p < .05$) decrease in spectral power in the high frequency (HF) band: 0.15–0.5 Hz.

Under control conditions, namely, at 0 altitude, the mean spectral power within this frequency band was 1704 ± 688 ms^2, whereas in AC it was 847 ± 481 ms^2 at the altitude of 4500 m above sea level.

In the low frequency (LF) band (0.04–0.15 Hz), the decrease of spectral power mean value during a stay at the altitude of 4500 m above sea level, as related to 0 level values, both at night and daytime, was statistically insignificant. At daytime, LF spectral power was 4281 ± 1720 ms^2 at 0 level and at night—3815 ± 1738 ms^2. After exposure to hypoxia at daytime it was 3295 ± 1577 ms^2 and 2907 ± 505 ms^2 at night.

No statistically significant differences were found in LF/HF index values during the control study and the AC study. The results of spectral analysis have been compared in Table 2.

TABLE 2. Frequency Analysis Parameters of R-R Intervals at the Altitudes of 0 and 4500 m. Spectral Power Within Low Frequency (LF: 0.04–0.15 Hz) and High Frequency (HF: 0.15–05 Hz) Range and Sympathetic-Parasympathetic Balance LF/HF Index

Time of Study	Group ($n = 6$)	Spectral Power ($x \pm SD$, ms^2)		
		LF	HF	LF/HF
Daytime	0 level	4281 ± 1720	1704 ± 688	3.39 ± 2.55
	4500 m	3295 ± 1577	847 ± 481	4.64 ± 2.80
	$p <$	*ns*	.05	*ns*
Night	0 level	3815 ± 1738	1229 ± 983	3.97 ± 1.78
	4500 m	2907 ± 505	872 ± 504	3.23 ± 0.64
	$p <$	*ns*	*ns*	*ns*

Figure 2 presents the comparison of spectral powers of R-R intervals for one participant exposed to hypoxia during daytime activity (4:00 p.m.). The spectra denoted by letters describe HRV at the moment of reaching the altitude of 4500 m (A, B) and descending (D, E), respectively: the first 3 min—A, D, the last 3 min—B, E. Spectrum C corresponds with the role of the ANS components in HR regulation after 30-min adaptation to the altitude of 4500 m. The dotted fragment of spectra corresponds with the LF band of 0.04–0.15 Hz. The spectrum height within this band is related to arterial blood pressure, the function of baroreceptors. The plain part of spectra within the HF range (0.15–0.5 Hz) informs us about vagus nerve activity. In Figure 2, the lowest spectral power within the HF range can be noted, during a stay at 4500 m, accompanied by a power increase within the LF band.

Figure 3 presents the effect of hypoxia on spectral power in LF and HF bands (the same participant as in Figure 2) at the time of night rest (4:00 a.m.). Letter A denotes the spectrum characterised by high power value for 0.2 Hz frequency, which is associated with the increased activity of parasympathetic ANS component at night rest time. After a 30-min stay at the altitude of 4500 m, the decrease in spectral power is observed within both analysed bands. Figures 2 and 3 compare the power of the spectra of R-R intervals during different phases of a stay in AC for the same participant, exposed twice to altitude hypoxia: during daytime activity (4:00 p.m.) and at night rest time (4:00 a.m.).

Comparison of spectra, calculated from the sequence of R-R intervals, recorded during a simulated and real study in AC at the altitude of 4500 m in one of the participants, is presented in Figure 4. The effect of a 30-min

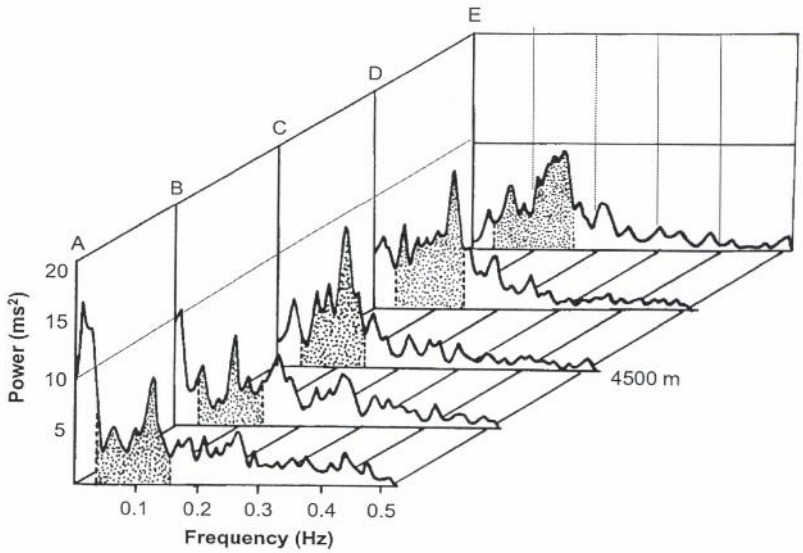

Figure 2. Spectra of R-R intervals power during different phases of a stay in an altitude chamber for the same participant, exposed twice to altitude hypoxia: at daytime activity (4:00 p.m.). *Notes.* A—first 3 min of ascending to the altitude of 4500 m, B—last 3 min of ascending to the altitude of 4500 m, C—after 20-min adaptation to the altitude of 4500 m, D—first 3 min of descending, E—last 3 min of descending.

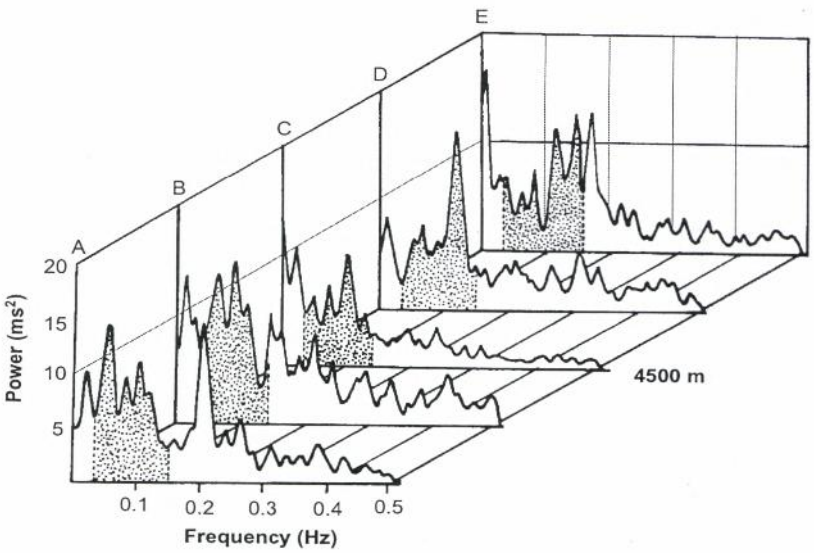

Figure 3. Spectra of R-R intervals power during different phases of a stay in an altitude chamber for the same participant, exposed twice to altitude hypoxia: at night rest time (4:00 a.m.). *Notes.* A—first 3 min of ascending to the altitude of 4500 m, B—last 3 min of ascending to the altitude of 4500 m, C—after 20-min adaptation to the altitude of 4500 m, D—first 3 min of descending, E—last 3 min of descending.

stay in AC at 4500 m can be observed, reflected by a significant decrease in power within the LF band during the daytime study (8:00 a.m.), as well as no difference during the night study (4:00 a.m.).

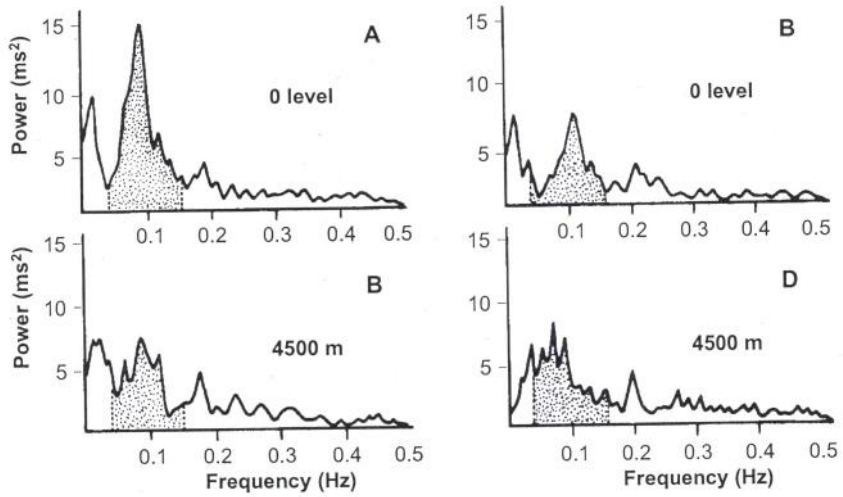

Figure 4. Spectra of R-R intervals power during a simulated (0 level) and real study in an altitude chamber at the altitude of 4500 m in one of the participants. *Notes.* A, B—8:00 a.m; C, D—4:00 a.m.

4. DISCUSSION OF RESULTS

The present study showed that under hypoxia conditions at the simulated altitude of 4500 m, there is an increase in HR, reflected by the shortening of R-R intervals, and a reduction of the range of the length of the R-R intervals, reflected by the lower value of SDNN and pNN50 indices. During daytime activity, the shortening of R-R intervals appeared to be greater than during night (the difference between mean intervals was 67 ms at daytime and 19 ms at night).

For all studies, a decrease in the mean power of the spectrum of R-R intervals, recorded under hypoxia conditions, within the range of LF and HF was observed, as related to control values at the 0 level.

The differences of spectral power values (at 0 level and at 4500 m) for both the HF and LF bands, are greater at daytime activity than at night rest time.

The results of a short exposure to high altitude hypoxia, related to the circulatory system, were analysed during other studies. For a 1-hr

stay in AC at the simulated altitude of 2000 m at different times during 24 hrs, some differences in HR response were shown. There was a smaller rise in HR compared to normobaria at night (3:00 a.m. and 6:00 a.m.; Heckman, Lobel, & Stegemann, 1982). A similar conclusion was drawn during the present study for the simulated altitude of 4500 m.

Spectral analysis was utilised for the evaluation of the activity of the ANS sympathetic and parasympathetic component in the regulation of the heart function during the study of exposure to high altitude hypoxia in mountain expedition members (Farinelli, Kayser, Binzoni, Cerretelli, & Girardier, 1994). During the early period of adaptation to high altitude (4300 m), after a 4–5 days' stay, a statistically significant lowering of the HF peak was observed, which was associated with vagus nerve activity (Hughson et al., 1994). The lowering of the LF peak—associated with ANS sympathetic activity—observed in the course of the adaptation to the altitude, may reflect a reduction of adrenergic receptors in the heart, or their expression, which is confirmed by experiments on animals living at high altitudes and altitudes close to sea level (Leon-Velarde et al., 1996). This phenomenon is reversible after the animals come back to lower altitude, the number of adrenergic receptors in their hearts again being normal for normobaric conditions.

REFERENCES

Ernsting, J., Sharp, G.R., & Harding, R.M. (1994). Hypoxia and hyperventilation. In J. Ernsting & P. King (Eds.), *Aviation medicine* (2nd ed., pp. 45–59). London: Butterworth-Heinemann.

Farinelli, C.C., Kayser, B., Binzoni, T., Cerretelli, P., & Girardier, L. (1994). Autonomic nervous control of heart rate at altitude (5050 m). *European Journal of Applied Physiology, 69*, 502–507.

Frisancho, A.R. (1975). Functional adaptation to high altitude hypoxia. *Science, 187*, 313–319.

Hayano, J., Taylor, J.A., Yamada, A., Mukai, S., Hori, R., Asakawa, T., Yokoyama, K., Watanabe, Y., Takata, K., & Fujinami, T. (1993). Continuous assessment of hemodynamic control by complex demodulation of cardiovascular variability. *American Journal of Physiology, 264*, H1229–H1238.

Heckman, C., Lobel, P., & Stegemann, L. (1982). Circadian variation in adaptation to high altitude. In G. Hildebrandt & H. Hensel (Eds.), *Biological adaptation* (pp. 117–120). Stuttgart, Germany: George Thieme Verlag.

Heimbach, R.D., & Sheffield, P.J. (1985). Protection in the pressure environment: Cabin

pressurization and oxygen equipment. In R.L. DeHart (Ed.), *Fundamentals of aerospace medicine* (pp. 110–131). Philadelphia: Lea & Febiger.

Hughson, R.L., Yamamoto, Y., McCullough, R.E., Sutton, J.R., & Reeves, J.T. (1994). Sympathetic and parasympathetic indicators of heart rate control at altitude studied by spectral analysis. *Journal of Applied Physiology, 77*(6), 2537–2542.

Krasney, J.A. (1994). A neurogenic basis for acute altitude illness. *Medicine and Science in Sports and Exercise, 26*, 195–208.

Leon-Velarde, F., Richalet, J.P., Chavez, J.C., Kacimi, R., Rivera-Chira, M., Palacios, J.A., & Clark, D. (1994). Hypoxia- and normoxia-induced reversibility of autonomic control in Andean guinea pig heart. *Journal of Applied Physiology, 81*, 2229–2234.

Ravenswaaij-Arts, C.M.A. van, Kollee, L.A.A., Hopman, J.C.W., Stoelinga, G.B., Geijn, H.P. van. (1993). Heart rate variability. *Annals of Internal Medicine, 118*, 436–446.

Ward, M.P., Milledge, J.S., & West, J.B. (1989). *High altitude medicine and physiology*. London: Chapman & Hall Medical.