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Energy metabolism of the brain in the inhabitants of the arctic zone, depending on the prevalence of vegetative tonus

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Abstract. The study of the physiological mechanisms of human acclimatization to extreme climatic conditions seems to be an urgent task in the current socio-economic conditions of the development of the Arctic territories. The purpose of the study is to determine cerebral energy metabolism in young people in the Arctic region with a different initial autonomic tone. Cerebral energy consumption and heart rate variability were studied in 103 young people (mean age 19 ± 0.22) constantly residing in Arkhangelsk. Research of the energy metabolism of the brain was carried out using the direct current (DC) potential recorded from the scalp. The study of the vegetative regulation of heart rhythm was carried out by cardiac rhythmography with registration of the background electrocardiogram at rest. High values of DC potential were registered in frontal cortex in the group of participants with a predominance of sympathetic nervous system influences. In the group of participants with a predominance of the effects of the parasympathetic nervous system, an increased level of constant potential in occipital cortex, with a decrease DC potential in the temporal and the frontal areas.

1. Introduction

The unique geographical location of the Arctic region and its natural resources are of great interest to the global community. However, the development of the Arctic territories requires not only the introduction of advanced innovative technologies, but also to attract additional human resources. Extreme climatic conditions of the Arctic have a direct and indirect impact on the human body. From the direct impact of extreme climatic conditions, the human body is well protected by modern technologies. However, techniques and technologies that prevent the indirect influence of the environment on the human body are absent. Thus, the study of issues related to the reactions of the organism to the stress factors of the Arctic zone becomes interesting and relevant [1].

Acclimatization reactions of the organism to new external conditions, as a rule, have a compromise nature, that is, ensuring the effective functioning of some physiological systems occurs due to a decrease in the efficiency of functioning of others. Part of the reserves of organs and body systems during an abrupt climate change is involved in the processes aimed at the formation of adaptive reactions of homeostasis. With constant exposure to severe climatic factors, the correct functioning of the body is achieved through certain changes in almost all life support systems. The impact of a number of negative climatic and environmental factors is summarized, exacerbating the stress of all functional systems of the body. At the initial stage of acclimatization to the specific conditions of the Arctic, an urgent, but incomplete set of protective-compensatory reactions is realized, implemented through the increased use of functional reserves. At this stage, the destruction of the old intersystem interactions and the restructuring of the central processes of regulation, in particular, the intersystem



coordination of respiration and circulation occurs. Long stay at this stage increases the risk of developing diseases. The excess of the norm of functional reserves is evidenced by the strengthening of compensatory reactions, the limitation of acclimatization reactions of respiration and blood circulation, which determines an unfavorable prognosis for the further functioning of the body.

Achievement of acclimatization in the conditions of the Arctic region is carried out primarily by restructuring the body's energy metabolism. The human body moves to an energy-saving level of regulation. The brain has no reserves of energy substrates, as a result of which the question arises about the energy supply of the central nervous system during the transition of the whole organism to an energy-saving mode. At the initial stage of acclimatization, including the stressful effects of extreme climatic conditions, activation of the sympathetic nervous system occurs causing catabolic reactions that provide the body with the necessary energy during the restructuring of the body during energy costs[2].

Thus, the study of cerebral energy-exchange processes with different types of vegetative regulation of heart rhythm with acclimatization to the conditions of the Arctic is of particular interest.

2. Materials and research methods

The study involved 103 people (45 boys and 58 girls aged 19–20) who were born and permanently reside in the Arctic region. At the initial stage of the study, the initial vegetative tone was determined by cardiac rhythmography with recording of the background electrocardiogram (ECG) in a state of relative rest (after preliminary rest in a sitting position) using the Varicard hardware and software complex: standard deviation of the average duration of RR intervals (SDNN); the square root of the mean square difference of consecutive RR intervals (RMSSD); The percentage of consecutive RR intervals, the difference between which exceeds 50 ms (pNN50,%). The increase in temporal parameters of heart rate variability was regarded as an increase in parasympathetic influences (GP), decline as activation of sympathetic influences (GS).

The activity of the autonomic nervous system divisions was differentiated using the spectral characteristics of the cardiac rhythm, which were calculated using the fast Fourier transform method. Heart rate parameters were evaluated in three frequency ranges: high-frequency oscillations (2–10 s, 0.4–0.15 Hz), HF (ms²), which characterize the effect of the parasympathetic division of the autonomic nervous system; low-frequency vibrations (10–30 s, 0.15–0.04 Hz), LF (ms²), reflecting mainly the activity of the sympathetic part; ultra-low-frequency oscillations (more than 30 s, 0.04–0.003 Hz), VLF (ms²), which characterize the degree of connection between autonomous segmental levels of blood circulation regulation and supersegmental ones. The total power of the TF spectrum (ms²) was also estimated and the sympathetic parasympathetic index LF / HF was calculated, reflecting the balance of sympathetic and parasympathetic activity [3].

The second phase of the study included the assessment of cerebral energy processes using neuroenergy mapping - the method of functional neuroimaging of the neurophysiological processes of the brain. This method is based on the registration of the level of direct current potential (DC potentials).

This kind of potential characterizes the slow electrical activity of the brain. In the absence of reserves of energy substrates, the intensification of brain activity leads to an increase in cerebral blood flow and, as a result, to the deformation of the vascular wall by the blood flow, accompanied by a change in the electrical characteristics of the vessels and capillaries. These potentials can be registered when electrodes are located along large vessels, such as the inferior vena cava, middle cerebral artery, or sagittal sinus. In addition to blood flow, this type of potential is influenced by the state of acid-base balance on both sides of the blood-brain barrier (BBB). The resulting potential difference at the BBB boundary depends on the intensity of energy metabolism in the nervous tissue adjacent to the capillaries, since with increasing energy metabolism with intensive work of nerve cells, hydrogen ions are formed, and a potential difference arises due to the difference in the concentration of hydrogen ions in the blood and nervous tissue. The slow electrical activity arising at the BBB boundary in the integrated form can be registered on the surface of the head [4,5].

Registration of DC potentials was carried out monopolarly using silver chloride electrodes with a controlled potential difference of 1 mV and a DC amplifier with an input resistance of 100 k Ω . The reference electrode was mounted on the wrist of the left hand. Active electrodes were located on the head in the frontal, central, occipital regions along the sagittal line and the parasagittal in the right and left temporal regions according to the international scheme 10–20. Registration was carried out 5 minutes after applying the electrodes with gaskets moistened with a saturated solution of NaCl. During registration, control of skin resistance was performed.

The study was conducted strictly in the morning, with complete physical and psychological rest, 1–1.5 hours after a meal in compliance with all ethical and legal norms. Written informed consent was obtained from all participants in accordance with the principles of the Helsinki Declaration. Statistical analysis of the results was performed using SPSS-20 software products from IBM for Windows. The test for normal distribution was carried out by a Kolmogorov-Smirnov test. In the case of a normal distribution of variables, parametric methods were used for independent samples (t-Student). The results of parametric data processing methods were presented as mean (M) and mean error (m). For all the above results, the differences were considered significant at a level of $p < 0.05$.

3. Results and discussion

Comparative analysis of level of DC potentials distribution values revealed some peculiarity of energy consumption in the cerebral cortex of residents of the Arctic region depending on the vegetative tonus (Table 1). So, in young people GS, DC potentials values in all five monopolar leads above the standard values of the average band. The minimum deviation from the standard is recorded in the left temporal region.

Table 1 - The distribution of the DC potentials level of brain in young people with different autonomic tone, living in the Arctic region ($M \pm m$), mV.

Indicator	sympathetic activation group (GS) (n = 30)	parasympathetic activation group (GP) (n = 21)
Monopolar values		
Fz	14,28 $\pm$ 2,28	10,58 $\pm$ 2,02
Cz	17,23 $\pm$ 1,94	17,82 $\pm$ 2,30
Oz	13,16 $\pm$ 2,25	15,86 $\pm$ 2,06
Td	12,04 $\pm$ 2,12	9,37 $\pm$ 1,70
Ts	10,78 $\pm$ 2,12	9,49 $\pm$ 1,36
Sum	67,49 $\pm$ 9,27	63,12 $\pm$ 7,61
Interelectrode potential difference		
Td-Ts	1,25 $\pm$ 1,36	-0,12 $\pm$ 1,32
Fz-Cz	-2,95 $\pm$ 1,82	-7,24 $\pm$ 2,11
Fz-Oz	1,11 $\pm$ 2,14	-5,28 $\pm$ 2,07
Fz-Td	2,24 $\pm$ 0,12	1,21 $\pm$ 1,79
Fz-Ts	3,49 $\pm$ 1,94	1,09 $\pm$ 1,94
Cz-Oz	4,06 $\pm$ 1,59	1,96 $\pm$ 1,83
Cz-Td	5,19 $\pm$ 1,35	8,45 $\pm$ 1,84
Cz-Ts	6,45 $\pm$ 1,34	8,33 $\pm$ 1,94
Oz-Td	1,13 $\pm$ 1,57	6,49 $\pm$ 1,84
Oz-Ts	2,38 $\pm$ 1,69	6,37 $\pm$ 1,51
Mean and deviations from mean		
Xcp	13,49 $\pm$ 1,85	12,62 $\pm$ 1,52
Fz-Xcp	0,78 $\pm$ 1,43	-2,04 $\pm$ 1,34
Cz-Xcp	3,73 $\pm$ 0,85	5,20 $\pm$ 1,28
Oz-Xcp	-0,33 $\pm$ 1,13	3,23 $\pm$ 1,15
Td-Xcp	-1,46 $\pm$ 0,96	-3,26 $\pm$ 1,00
Ts-Xcp	-2,71 $\pm$ 0,94	-3,13 $\pm$ 0,98

In the GP, the potential level in the temporal leads, on the contrary, is lower than the standards (Fig. 1), which indicates minimization of the energy processes in these parts of the brain.

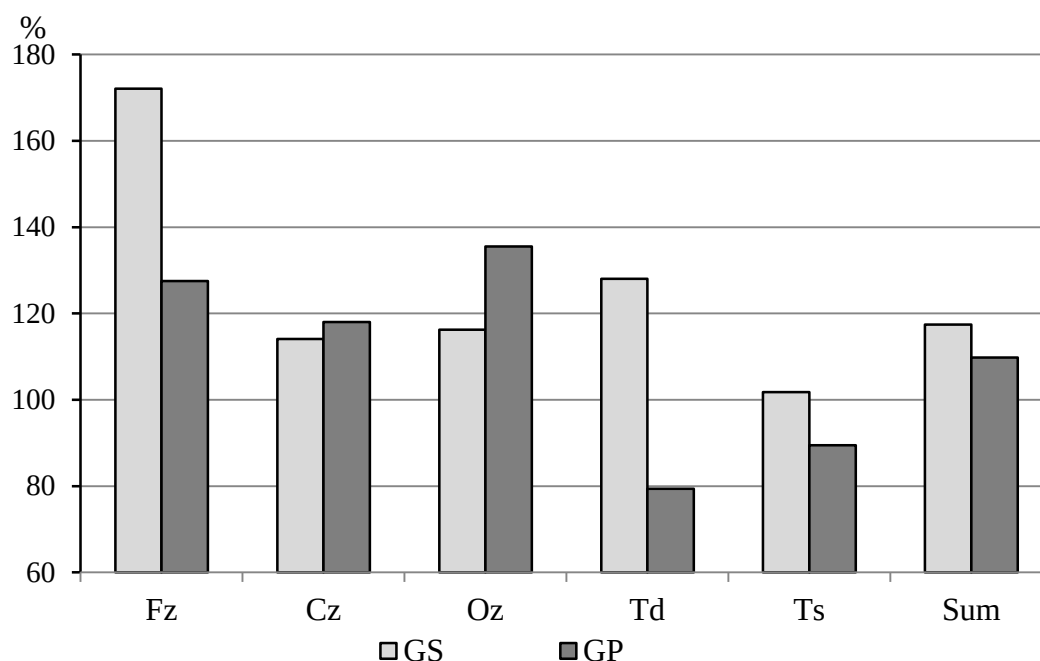


Figure 1 - The distribution of DC potentials level in young people of the Arctic zone of the Russian Federation in % relative to the standard values of DC potentials indicators in middle-aged residents.

Intergroup comparison indicates the predominance of energy processes in the frontal regions of the brain in GS, which is reflected in high values of DC potentials in the frontal lead and positive values of local (Fz-X) and interelectrode gradients of DC potentials. In the GP, on the contrary, increased intensity of energy processes is recorded in the occipital abduction with a sharp drop in the level of potential in the temporal calves and the reduction of energy consumption in the frontal area.

The values of the inter-temporal potential difference, which characterize inter-hemispheric asymmetry of the brain in this method, are noteworthy. In the GS, the difference is $Td - Ts = 1.25$ mV, which indicates the dominance of the activity of the right hemisphere. In the GP, this difference is negative $Td - Ts = -0.12$ mV and has a value of less than one millivolt, which may indicate a close inter-hemispheric interaction with a slight predominance of the activity of the left hemisphere.

The total values of DC potentials in the GS were 4.37% higher than in the GP. In the GP, the values of DC potentials in the occipital departments are highlighted.

4. Conclusion

Thus, the results of neuroenergetical mapping suggest that the neurophysiological mechanisms in the cerebral cortex of individuals with different types of predominance of autonomic CNS tone also have a different character. In the group of participants with a predominance of sympathetic influences of the central nervous system, high values of DC potentials were recorded in the frontal and right temporal departments. Functional restructuring in the process of acclimatization is usually associated with the activation of the right hemisphere. High values of energy consumption of the frontal divisions may indicate a significant stress in the control functions and high centralization of regulatory processes.

In the group of participants with a predominance of the effects of the parasympathetic nervous system, an increased intensity of energy processes is recorded in the occipital lead, with a decrease in the level of constant potential in the temporal leads and a decrease in energy consumption in the frontal areas.

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