Dependence of Autonomic and Behavioral Reactions to Pain-Related Emotional Stress on Individual Typological Characteristics of the Autonomic Nervous System

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It was found that autonomic and behavioral reactions to pain-related emotional stress in the miners of deep coal mines depend on the individual typological characteristics of their autonomic nervous system. The normotonics with an initially high sympathetic and parasympathetic activity were characterized by low resistance to stress-inducing factors, while high resistance to emotional stress was typical of the subjects with the parasympathetic type of autonomic nervous system. The greatest shifts in autonomic indices were observed in the stress-anticipation period rather than on direct exposure to pain stimulus.

Key Words: *emotional stress; autonomic nervous system; myocardium*

Emotional stress is considered to be partly responsible for the increasing incidence of cardiovascular diseases. The unfavorable effects of negative emotions on the cardiovascular system have been confirmed by numerous data. Experimental studies on animals showed that acute and chronic stress affects myocardial mitochondria by changing their energy production, ion transport, intracellular concentration of catecholamines, and electrolytes and changes the myocardial ultrastructure [6,10,12]. The concept of individual resistance to stress which emphasizes the role of behavior in the development of myocardial dysfunction [9,13] is of considerable importance for both theoretical and preventive medicine. It was found that stress-induced activation of the sympathetic adrenal system contributes to the development of arterial hypertension, cardiac rhythm dysfunction and ventricular fibrillation, while the moderate predominance of parasympathetic effects prevents structural deformations in the myocardium [8,11].

In recent years, the dependence of myocardial dysfunction on the genetically determined individual typological characteristics of the autonomic nervous system has attracted growing attention [3,5,7]. In the present study we investigated the resistance to emotional stress in individuals with different functional states of the autonomic nervous system.

MATERIALS AND METHODS

The study involved 106 coal miners aged from 30 to 45. It was performed under clinical conditions in two stages. The background autonomic tone was determined at the first stage using the pharmacological tests with cholinergic (kalymin and atropine) and adrenergic (obsidan and isadrin) drugs, active orthostatic test, and Ashner's test [3]. Heart rate (HR) and arterial pressure (AP) were recorded in a lying position to calculate the Kerdo index. The pharmacological tests were conducted in the morning no less than 2 h after breakfast. According to the obtained indices, the autonomic functional states were classified into six groups: normotonia with low (1), moderate (2) and high (3) activity of the adrenergic (A) and cholinergic (C) systems, i.e., A1C1, A2C2 and A3C3; sympathotonia with A2C1, A3C2 and A3C1, and parasympathotonia (vagotonia) with A1C2, A2C3 and A1C3 [4]. The sub-

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jects with the extreme variants of the autonomic state were then selected from the studied population: normotonics with low (A1C1) and high (A3C3) activity of both autonomic parts and vagotonics and sympathotonics with predominant cholinergic (A1C3) or adrenergic (A3C1) effects on the myocardium. Triplicate examination showed persistence of autonomic responses in the majority of the miners.

At the second stage the miners were tested for motor coordination under normal and stressful conditions using the Rupp coordimeter. After the initial training without painful stimulation, the subjects were informed that their mistakes will be punished by electroshock. The number of errors and the total error time were recorded during both variants of the test. The heart rhythm (100-120 *R-R* intervals), arterial pressure (AP), respiratory rate (RR) and heart rate (HR) were recorded before (background) and during the test. In some cases blood and urine samples were obtained before and after testing to determine the concentrations of catecholamines, 5-hydroxytryptamine, and histamine and acetylcholinesterase activity.

The data on *R-R* intervals were subjected to spectral and correlation analyses [1]. The index of tension (IT), that characterizes the stress level in the autonomic nervous structures controlling the heart activity was calculated from the following formula:

$$IT=A_{mo}/2Mo\times\Delta X$$

were ΔX is the variation amplitude, calculated from the original data, *Mo* and *Amo* are the mode and its amplitude. The powers of low-frequency (LFSP) and high-frequency (respiratory) components were determined from the heart rhythm power spectrum. Their ratio was taken as the index of centralization which reflects the involvement of supraspinal autonomic centers in the regulation of myocardial activity. Another index measuring the impact of higher autonomic centers on cardiac regulation is the autocorrelation coefficient which was determined within the first shift of the dynamic series of *R-R* intervals. The Cildebrandt's coefficient was calculated as the HR/BF ratio. The data were analyzed statistically using Student's *t*-test.

RESULTS

Background AP and BF were similar in all the subjects while their HR and hormonal level were different. In accordance with the primary selection, vagotonic bradicardia (HR=57±1.3 beat/min) was typical of the subjects with A1C3 and sympathotonia (HR=88±1.7 beat/min) of the subjects with A3C1, while the normotonics with A3C3 and A1C1 occupied the intermediate position. The mean hormonal indices in all the individuals were within the physiological limits. The highest concentrations of catecholamines (both adrenaline and noradrenaline) were revealed in the A3C3 subjects, the lowest ones were shown by the A1C3 individuals. The level of histamine corresponded to the upper limit of the norm, while the activity of acetylcholinesterase was near the lower limit.

The HR, AP, and RR indices varied differently during the coordimetric session without electroshock. Their deviations from the background values varied considerably, being dependent on the autonomic state. Thus, HR increased by 25% in the vagotonics ($p<0.05$), by 6 and 7% in the normotonics with A3C3 and A1C1, respectively, and remained almost unaffected (2%) in the sympathotonics. The A3C3 and A3C1 subjects exhibited significant increases in the RR values, but showed no noticeable shifts in the chronotropic heart function. As a result, the Gildebrand's coefficient decreased by 34% (A3C3) or 51% (A3C1), which is indicative of disturbed cooperation between the activities of the cardiovascular and respiratory systems and is considered as the first sign of emotional tension

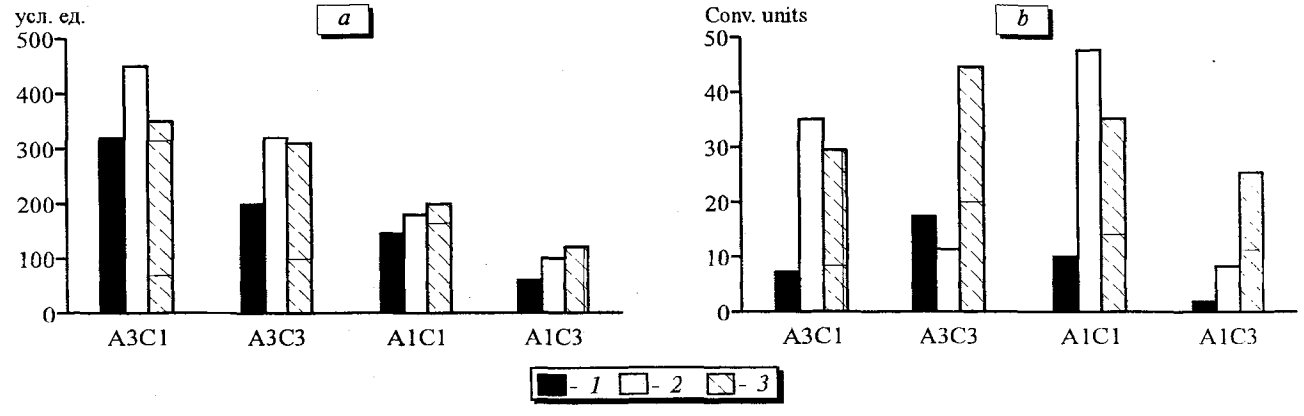

Fig. 1. Changes in the indices of tension (*a*) and centralization (*b*) with respect to the individual typological characteristics of the autonomic nervous system induced by emotional pain-related stress. Here and in Fig. 2: (1) background; (2) coordimetry without electroshock; (3) coordimetry with electroshock.

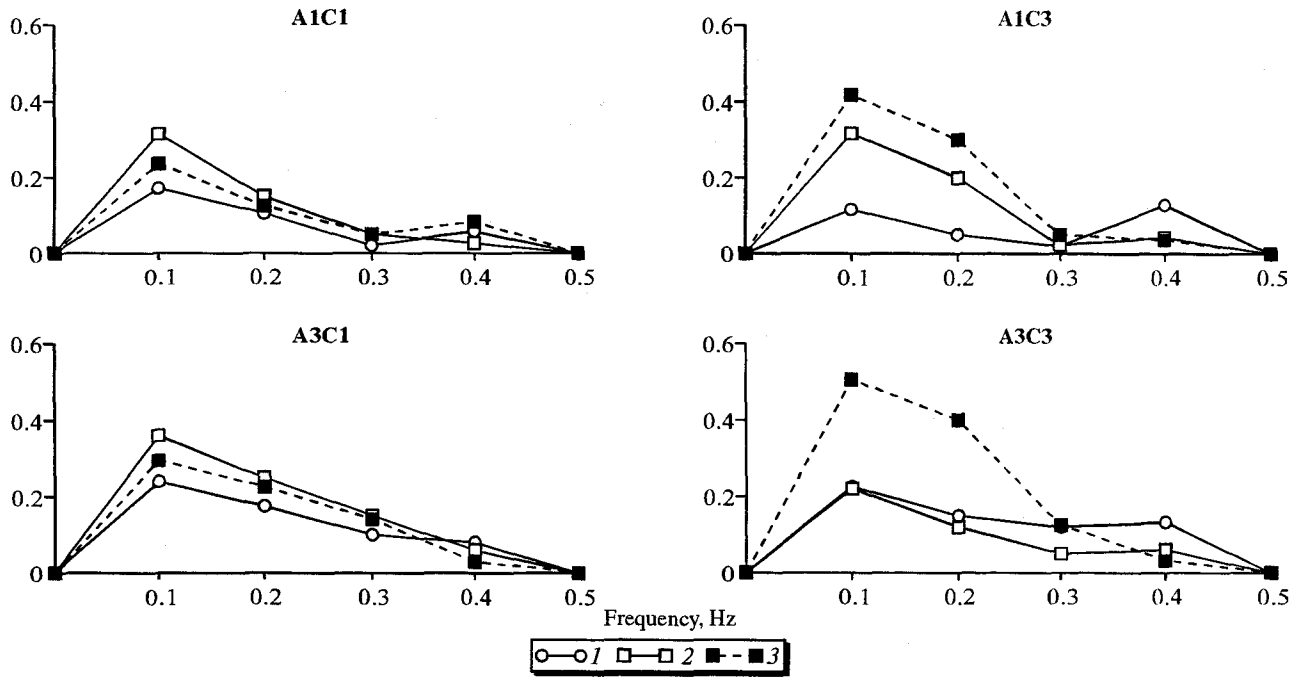

Fig. 2. The effects of pain-related emotional stress on the spectral characteristics of the cardiac rhythm in coal miners with different individual typological characteristics of the autonomic nervous system. Ordinate: spectral power, arb. units.

[14]. This conclusion was confirmed by the data on AP changes which were significant ($p<0.05$) only in these two groups: AP increased from 130/90 to 150/1225 mm Hg in the normotonics and from 140/90 to 160/100 in the sympathotonics.

Special attention was paid to changes in the autonomic regulation of heart rhythm, as they reflect the direct involvement of the nervous system in the regulation of myocardial activity.

Irrespective of individual typological properties of the autonomic nervous system, all the subjects displayed an increased sympathetic adrenal effect on the myocardium (Fig. 1 and 2). At the same time, the extent of involvement of different regulatory levels was determined by the initial state of the autonomic system. In A3C3 normotonics, changes in heart activity originated largely from the activation of peripheral nervous structures, as evidenced by significantly (62%) increased IT without any shifts in LFSP, centralization index or correlation coefficient. The A1C1 subjects were characterized by markedly increased tone of the higher autonomic centers, which was manifested by increased LFSP and centralization index (of 84 and 50%, respectively, $p<0.001$) in combination with an insignificant increase in IT (of 29%). Both central and peripheral parts of the nervous system participated in the regulation of cardiovascular functions in the parasympathotonics, as indicated by a significant parallel increase in all the analyzed indices (LFSP by 270%, IT by 67%, $p<0.001$). The autonomic regulation of cardiac activity in sympathotonics was characterized by a moderate activation of suprapinal ergotropic structures.

These findings indicate that emotional stress developed as a result of the expectation of a possible painful punishment long before the application of the electroshock in the test protocol. It was manifested not only in the specific shifts of the autonomic correlates of the emotional tension, but also in behavioral reactions. Thus, increased centralization of the chronotropic cardiac function in the A1C1 and A1C3 individuals with initially low activity of the sympathetic nervous system was accompanied by a relatively high number of incorrect movements in the coordimetric test. On the other hand, the predominance of peripheral regulatory impacts was favorable for the reduction in the number of incorrect reactions.

No further changes in HR, AP and BF were revealed with the electroshock application in the coordimetric test schedule to punish every incorrect movement. This situation changed the relations between sympathetic and parasympathetic regulatory effects on the myocardium. The vagotonics showed further moderate activation of the sympathetic adrenal system: their IT and LFSP increased by 17% and 32%, respectively. The parasympathetic effects were intensified in the A1C1 normotonics and sympathotonics (their average IT and LFPS decreased by 15% and 21%, respectively) with a parallel decrease in the number of incorrect movements and the total error time. The myocardial effects of the punishment in the A3C3 normotonics implied pronounced centralization of the

cardiac chronotropic function with the involvement of higher ergotropic regulatory centers and dramatic increase in the effective concentration of catecholamines. During the test their index of centralization and LFSP increased 2.7 and 4.4 times, respectively ($p<0.001$), the concentration of adrenaline and noradrenaline was elevated 2 and 3.5 times, respectively ($p<0.001$). These changes were accompanied by decreased stability of movements.

Proceeding from P. K. Anokhin's theory of functional systems, it can be suggested that the adaptive mechanisms (an acceptor of action results) of the functional system providing the emotional and behavioral reactions to a stress-inducing factor in individuals with an initially high adrenergic and cholinergic activity were activated by the immediate exposure to this factor rather than during the preparatory period, which resulted in an excessive emotional tension. This was manifested in the considerably enhanced central regulatory effects on the myocardium and disintegrated activity of the cardiovascular and respiratory systems, on the one hand, and in the impaired emotional and behavioral reactions, on the other. At the same time, from the improved autonomic and behavioral indices in the other groups it can be concluded that timely formation of the afferent model of an emotional stimulus slows down or even prevents the development of stress.

Although well-balanced, the increase in the background activity of sympathetic and parasympathetic parts of the autonomic nervous system is likely to reduce the functional capacities not only of the nervous system, but also of the whole organism.

Thus, being warned about painful stimulation, the subjects experienced anxiety or so-called stress-anticipation syndrome [2,10]. During this period increased sympathetic adrenal effects on the myocardium were observed in all the subjects irrespective of the tone of their nervous system. At the same time, the repertoire of autonomic shifts and behavioral reactions in similar circumstances, as well as their dynamics, were determined by the individual typological characteristics of the autonomic nervous system. The high background level of adrenergic and cholinergic regulation of myocardial activity is probably the cause of emotional overstrain and decreased resistance to stress-inducing factors.

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