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NEUROPHYSIOLOGICAL INVESTIGATIONS OF THE FEATURES OF THE STATE AND PHYSIOLOGICAL ACTIVITY OF SOME STRUCTURES OF THE STRIOPALLIDUM AND THALAMUS IN VARIOUS FORMS OF PARKINSONISM

V. A. Ilyukhina, N. Yu. Kozhushko, and V. B. Bokarius

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The results of many years of investigations of the features of the functional state and physiological activity of some structures of the striopallidum (Cd, GP, Put) and thalamus (VP, VL, CM) as links in the brain systems of the organization of mental and motor activity in patients with various forms of parkinsonism are presented in generalized form. The possibilities for the use of various types of ultraslow physiological processes to study the brain mechanisms of the activational and emotional states, with more precise definition of the role of structures of the striopallidal complex in the formation of systems supporting these types of mental activity in parkinsonism, are reviewed.

The development in the second half of the 20th century of investigations into the role of structures of the striopallidal complex in the formation of the integrative functions of the central nervous system has expanded previously existing views regarding their participation in the organization of motor activity, the mechanisms of attention, memory, perception, the emotions, thinking and other types of adaptive activity of animals and man [6, 19]. Fundamental data regarding the principles and mechanisms of their involvement in the systems supporting simple and complex forms of mental and motor activity have been obtained by N. P. Bekhtereva and her school over the last 30 years through benign direct and prolonged contact with the cortex and subcortical formations of the human brain [3-5, 18].

Many years of investigations into the neurophysiological mechanisms of persistent pathological states of the brain of parkinsonian patients have made it possible to accumulate a great deal of factual material on the features of the state and physiological activity of structures of the striopallidum (Cd, GP, Put) and some thalamic structures (VP, VL, CM) which are among the stereotaxic targets in the treatment of this disease.

The main results of the investigations of the Laboratory of the Physiology of the States of the Brain and Organism, Institute of Human Brain, Russian Academy of Sciences, which reveal the features of the ongoing state and contribution of structures of the striopallidum and thalamus to the organization of mental and motor activity in patients with various forms of parkinsonism are presented in this paper.

METHODS

A comprehensive approach was used which affords the possibility of obtaining mutually complementary data on the features of the dynamics of the functional state and physiological activity of structures of the striopallidum (Cd, GP, Put) and thalamus (VP, VL, CM) at rest and during mental and motor activity [3]. An analysis was made, as applied to the aims of the investigation, within the framework of this approach, of various types of ultraslow physiological processes (the ω-potential, ε-, τ-, and ζ-waves) in parkinsonian patients using long-term intracerebral electrodes.

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The dynamics of the ultraslow physiological processes of the deep structures were recorded in the resting state, during spontaneous activity and the occurrence of emotional experiences, and during the performance of psychological and motor tests [11]. The psychological tests included: 1) tests for the activation of involuntary and voluntary attention during the performance of different types of mental and motor activity; 2) tests for short-term memory, in particular, the Binet test; 3) motor tests in the form of the flexing of the upper and lower extremities on command in limited time intervals; and 4) emotional tests: the Sacks–Sydney sentence completion test was used at the first stage. Such tests were used later whose structure approximated conversation in form; in these the patient was asked to answer in greater detail, without time limitations, questions that were emotionally significant for him (family, illness, former work, etc.).

As the work with a patient proceeded, from investigation to investigation, a sphere of problems and questions was delineated in relation to which the patient responded most willingly; this demonstrated the degree of his interest in one or another topic of conversation. These questions subsequently made up the main part of the program of work with the patient.

Concurrently with the recording of the ultraslow physiological processes of the deep brain structures, the commensurable temporal characteristics of the indices of galvanic skin activity (tonic and dynamic constituents, respectively, in the range from 0 to 0.05 Hz and from 0.05 to 0.5 Hz) and the dynamics of the average frequency of the cardiac contractions of the pneumogram were recorded. The principles of the comprehensive method of investigations, analysis and interpretation of the data obtained are set forth in detail in the papers of V. A. Ilyukhina and colleagues [8, 9, 11, 12].

The technical and methodological basis of the comprehensive investigations was the method of polyelectroneurography, which ensures artifact-free simultaneous multichannel recording of the various types of ultraslow physiological processes from the depths of the brain, the surface of the human head and body [7].

The results of many years of repeated investigations of the ultraslow physiological processes of the deep structures of 74 patients with various forms of parkinsonism are generalized in this paper.

INVESTIGATION RESULTS AND DISCUSSION

The features of the cerebral underpinnings of psychoemotional, vegetative, and motoric disturbances in various forms of parkinsonism have been revealed through the generalization of the results of analysis of the ultraslow physiological processes of the investigated structures of the striothalamocortical system (Cd, GP, Put, VP, VL, CM). It has been established that, among other factors, the neurophysiological bases of the hyposthenic form of the asthenoneurotic manifestations of the psychoemotional, vegetative, and motor disturbances in patients with the akinetic–rigid form of parkinsonism are revealed:

– in the narrowing of the boundaries of the variations of the ω-potential of structures of the thalamus (VL) and striopallidum (Cd, GP) in the presence of stability of fixed states; this has suggested a sharp limitation in their functional plasticity [10, 11, 14, 16];

– in the slight manifestation and dissemination of low-amplitude, irregular, aperiodic τ- and ε-waves in the same subcortical structures; this revealed limitations in their functional activity [10, 11, 21];

– in the presence of low-voltage regular ζ-waves with a period of 2-4 sec in the deep structures investigated, as well as in the lead from the surface of the head, as a manifestation of the irradiation of the respiratory rhythm in pathologically altered cortical–subcortical–stem interrelationships [2, 10, 11, 15, 20];

– in the substantial limitation of the manifestations of the properties of the caudate nucleus as a modulating structure in the organization of activational and emotional states, its disengagement from the support of motoric functions and short-term memory [10, 11, 16];

– in the substantial limitation of the properties of polyfunctionality of the globus pallidus and the ventrolateral nucleus of the thalamus, especially in relation to their participation as links in the cerebral systems supporting voluntary movements [10, 11].

In patients with the tremulous–rigid form of parkinsonism, the following were the neurophysiological basis of the psychoemotional instability, with a tendency toward fits of passion, of the primarily sympathoadrenal directionality of the vegetative disturbances, and of the predominance of forced involuntary movements at a frequency of 4-6/sec, of the local and generalized type:

– a substantial expansion of the boundaries of the variations of the ω-potential of the structures of the thalamus (VL) and striopallidum (Cd, GP) in the presence of its instability over the course of short time intervals; this characterized the destabilization of the state of the structures under investigation [10, 11, 16, 21];

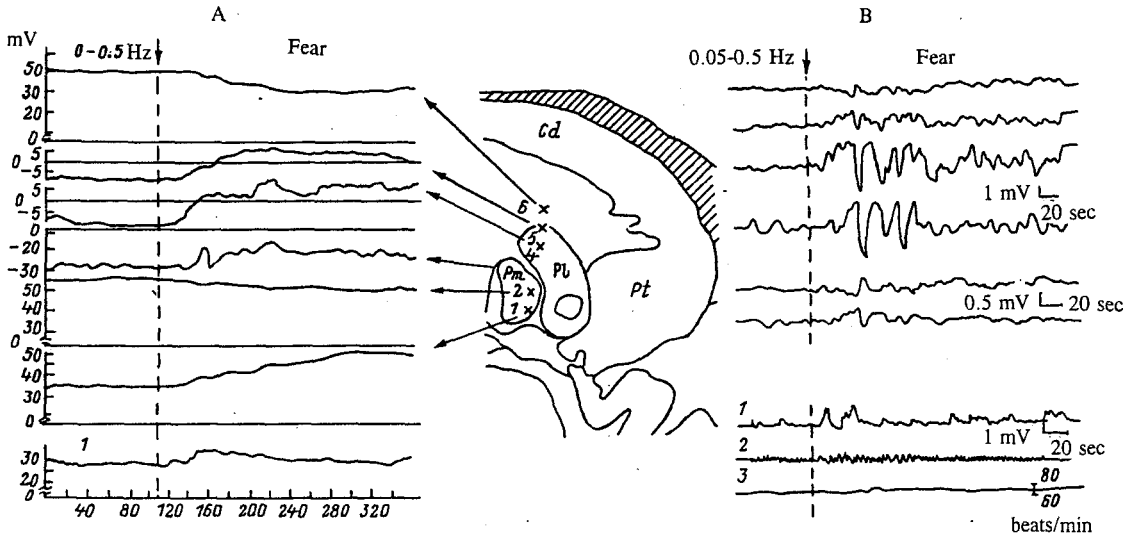

Fig. 1. Features of the dynamics of various types of ultraslow physiological processes of the globus pallidus during the spontaneous development of the emotion of fear in connection with the sensation of lack of air. A) The dynamics of ultraslow physiological processes in the frequency range from 0 to 0.5 Hz. Along the abscissa [sic]: magnitude of the ω-potential, mV. The pickups of the ω-potential from different zones of the globus pallidus are designated by arrows. Lower curve, dynamics of the steady potential of the millivolt range in the palmar–dorsum lead in the frequency band from 0 to 0.6 Hz (tonic constituent of the galvanic skin activity). B) The dynamics of ultraslow physiological processes in the frequency range from 0.05 to 0.5 Hz in the same zones of the globus pallidus. 1) The dynamic constituent of the galvanic skin activity in the dorsum–palmar lead in the frequency band from 0.05 to 0.5 Hz; 2) pneumogram; 3) average frequency of the cardiac contractions, beats/min. Vertical line in A and B, moment of the occurrence of the emotional reaction.

– prevalence and stability of high-amplitude τ- and ε-waves, with a tendency toward regularity; this suggested metabolic and neurohumoral strain [1];

– the presence of low-voltage regular ζ-waves with a period of 2-4/sec [sic] in the deep structures and in the lead from the surface of the head as a manifestation of irradiation of the respiratory rhythm in the presence of pathological changes in the cortical–subcortical–stem interrelationships [2, 11, 15, 20];

– the manifestation of emotiogenic properties of the caudate nucleus and the ventrolateral nucleus of the thalamus during the realization of all types of activity, including the activation of attention, short-term memory, and during the development of emotional reactions and voluntary motoric functions [11, 14, 16];

The results of these investigations expand existing ideas regarding the morphofunctional, principal, polymorphic, regulatory disturbances which are manifested in differences in the pathological changes in the psychoemotional sphere, and in vegetative and motoric disturbances in various forms of parkinsonism [13].

In revealing the role of the striopallidal and thalamic structures in the formation of the specific features of the pathological changes in adaptive behavior in patients with different forms of parkinsonism, the data obtained confirm the key role of these structures in the cerebral support of the realization of goal-directed behavioral acts.

Investigation of the ultraslow physiological processes of the cortex and subcortical formations in parkinsonian patients during the realization of mental and motor activity has made it possible to define more precisely the causal interrelatedness of the disturbances that are taking place in attention, mnestic functions, and emotional disturbances, and of the features of the participation of structures of the thalamus and striopallidum in the formation of the cerebral systems supporting these types of mental activity. Thus, according to the data of the dynamics that are being reproduced of the ζ-waves, a substantial limitation has been found in parkinsonian patients of the participation of structures of the striopallidum (Cd, GP) and thalamus (VL,

VP, CM) (in 22% of the areas of the number investigated) in the cerebral systems supporting the activation of voluntary and involuntary attention, a limitation which is comparable with the disturbance in its stability and productivity, [17].

It is characteristic that substantial variations in the latent periods of the evoked dynamics of the ζ-waves (0.2-4.6 sec), with a tendency toward their prolongation during numerous repeated performances of tests, were observed in the presence of stability (nonextinguishability) of the ζ-waves that are being reproduced in those zones of the globus pallidus, caudate nucleus, and thalamic structures in which they were detected during the activation of attention.

Interhemispheric features of the involvement of the striopallidal and thalamic structures in question in the formation of the cerebral systems of the activation of voluntary attention have been found. It has been established on the basis of identified differences in the latent periods and in the types of evoked dynamics of the ζ-waves, that the structures of the right hemisphere support primarily the brief and monotonic component of the activation of attention, whereas the formations of the left hemisphere are more sensitive to the modulation of activating influences [17].

As the investigations of N. P. Bekhtereva [3-5] and V. M. Smirnov [18] which revealed the principles and mechanisms of the formation of the cerebral systems supporting emotional reactions and states of man developed, the features of the dynamics of different types of ultraslow physiological processes (the ω-potential, ε-, τ-, and ζ-waves) of the deep structures during the development of negative and positive emotions in parkinsonian patients were analyzed.

As is known, one of the current aspects in the investigation of the cerebral mechanisms of the emotions is the search for neurophysiological correlates of the activational and emotional states. The approach we have chosen has been oriented toward isolating the neurophysiological equivalents, over the time course of the ultraslow physiological processes, of the activational reactions, and of the emotional experiences proper, with further investigation on this basis of the role of the striopallidal and thalamic structures in the formation of the cerebral systems supporting mental activity in parkinsonian patients. One of the characteristic features of the cerebral support of the activational and emotional states identified during investigations in parkinsonian patients was an increase in the number of thalamic and striopallidal structures involved, and an increase in the amplitude of the evoked changes in the ultraslow physiological processes as deeper emotional contact between the investigator and the patient was established.

The potentialities of polyneurographic investigations with simultaneous recording of different types of ultraslow physiological processes of the cortex and deep structures, of the stable and dynamic constituent of the ultraslow potentials in the dorsum-palm lead, and of the pneumogram and average frequency of the cardiac contractions made real a more detail analysis of the contribution of the structures of the striopallidum, thalamus, and other structures in the formation of the cerebral systems of the activational processes and of emotional experiences proper.

An example is presented in Fig. 1 of the results of a polyneurographic investigation of the dynamics of the ω-potential of various zones of the globus pallidus in combination with the stable constituent of the potential of the millivolt range in the dorsum-palm lead, the galvanic skin activity (A). Changes in the ultraslow fluctuations of the potentials in the frequency band from 0.05 to 0.5 Hz, in combination with the dynamic constituent of the galvanic skin activity in the dorsum−palm lead (in the same frequency band), were recorded simultaneously with the ω-potential of the same zones, and with the pneumogram and the average frequency of cardiac contractions (B), in a patient with the tremulous−rigid form of parkinsonism at the moment of the spontaneous appearance in him of the feeling of fear in connection with the sensation of shortness of breath.

As can be seen in Fig. 1, at the moment the sensation of shortness of breath appeared, a weakly expressed activational component in the brain structures in the form of a monophasic, low-amplitude ζ-wave corresponded to the short-latency physical changes in the galvanic skin activity (Fig. 1B). Shifts in the ω-potential, variously directed in terms of sign, develop immediately after it with a latent period of 20-25 sec in all of the investigated zones without return to the initial level, and practically concurrently (Fig. 1A). Against this background, with a latent period of 5-15 sec, a burst of high-amplitude rhythmical activity, including ζ- and τ-waves, arises selectively in two zones of the globus pallidus (Fig. 1B). A long-period ε-wave, on which low-voltage regular ζ-waves are superimposed, appears right after this burst in the same zones (Fig. 1B).

Thus, complex neurophysiological changes in the ultraslow physiological processes which are associated with the mechanisms of the activation of attention (short-latency monophasic ζ-waves) and of changes in the general level of activation of the zones under investigation (shifts in the ω-potential), are detected during the development of the negative emotion of fear within the limits of a single brain structure (GP); these are associated with the switching on of compensatory-adaptive mechanisms which support the restoration of the respiratory rhythm (the burst of high-amplitude rhythmical activity); and finally, with the emotional experiences proper (long-period focal ε-waves). A similar principle of complexly organized

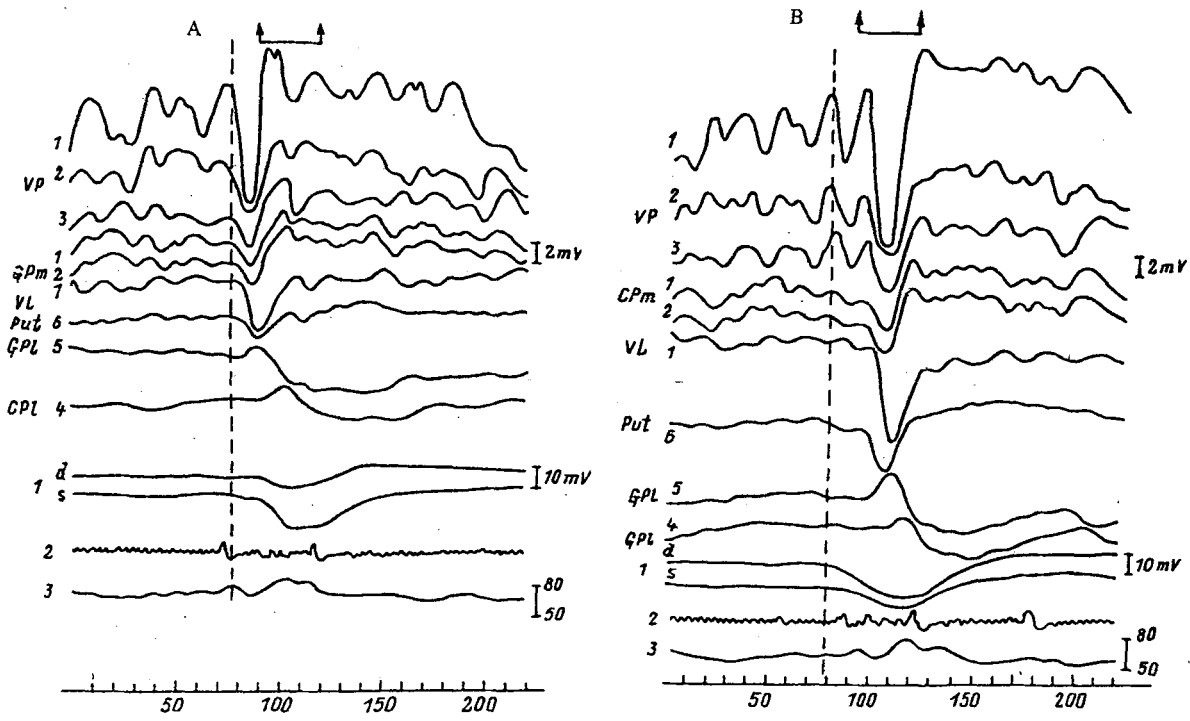

Fig. 2. Features of the dynamics of ultraslow physiological processes of deep structures of the right hemisphere during the development of negatively (A) and positively (B) tinged emotion. Vertical broken line, the moment of addressing the question to the [female] patient. Arrows above, bounded by a straight line, time of the [female] patient's answer. Horizontal line below, time scale. Designations on the right, magnitudes of the waves of the calibration signal of the amplitude of the waves. 1) Stable difference of the potentials of the millivolt range in the dorsum–palmar lead (tonic constituent of the galvanic skin activity) of the right (d) and left (s) hand. 2) Pneumogram; 3) average frequency of the cardiac contractions, beats/min. designations of brain structures: VP, posteroventral nucleus of the thalamus; VL, ventrolateral nucleus of the thalamus; GP, globus pallidus; GPl, lateral segment, GPm, medial segment, Put, putamen. 1-5) Reference numbers of the zones investigated within the limits of the structure.

changes in time and space in the neurodynamics during the development of the emotions is also observed when ultraslow physiological processes are recorded simultaneously from many brain structures.

The neurophysiological equivalents of two emotional reactions differing in sign are represented in Fig. 2. The first reaction (Fig. 2A) was associated with detailed recollections in response to a question as to whether difficulties has appeared in the [female] patient for the first time in playing the piano (the patient was a pianist). In this case, a synchronized positive ζ-wave appeared with a fairly short latent period (a second) in three zones of the posteroventral nucleus (VP 1-3), one zone of the ventrolateral nucleus of the thalamus (VL), two zones of the medial segment of the globus pallidus (GP 1-2), and in one zone of the putamen (Put 6). The maximally high amplitude of this wave (up to 15 mV) was found in VP 1. A synchronized negative ζ-wave appeared in the patient in the same structures at the beginning of the response to the questions; immediately after this the development of a long-period negative ε-wave is observed, the duration of which substantially exceeds the time of the verbal interaction with the patient. It is characteristic that dynamics of the ultraslow physiological processes, which are opposite in sign, and which are comparable with the directionality of the changes in the tonic constituent of the galvanic skin activity in the dorsum–palmar lead, are observed under the same conditions in the region of the lateral segment of the globus pallidus (GPl 5-4). It should be noted, however, that, despite the great intensity of the changes in the tonic constituent of the galvanic skin activity in the dorsum–palmar lead, they are substantially shorter in duration than the dynamics of the ω-potential in the globus pallidus.

In the second situation, in the absence of a negative component, in a conversation related to the musical tastes of the patient and her interest in the development of this topic, the cerebral equivalents of the activations and of the emotional experiences proper (in the form of a long-period negative ε-wave) in the investigated cerebral structures were more intense (Fig. 2B). The opposite character of the sign of the asymmetry of the dynamics of the tonic constituent of the galvanic skin activity of the right and left hands in both situations is also noteworthy.

The data obtained confirm the existing notions of the polyfunctionality of the investigated structures of the striopallidum and thalamus. At the same time, they disclose the specific features of the involvement of these structures in the cerebral mechanisms of the activational states and emotional experiences; this has fundamental significance for the understanding of their role in the integrative activity of the central nervous system of man.

The summarization of the results of numerous years of comprehensive neurophysiological investigations using various types of ultraslow physiological processes has shown the existence of a close association between the variability of the state of zones of cerebral structures and the features of their involvement as links in the cerebral systems supporting mental and motor activity. Review from these perspectives of the data obtained regarding the features of the state and physiological activity of the investigated structures of the striopallidum and thalamus in patients with different forms of parkinsonism has made it possible to uncover pathologically determined transformations of the properties of morphofunctionally associated brain structures. In particular, as a result of these investigations, differences were identified in the pathological changes in the state of one of the modulating formations of the brain, the caudate nucleus, in the form of limitations in functional activity, with its disengagement from the support of motor and mnestic functions in the akinetic–rigid form of parkinsonism, and, by contrast, in the form of its hyperactivity and in the manifestation of the properties of an emotiogenic structure, in the tremulous–rigid form of this disease.

It has been established that the properties of the globus pallidus and the ventrolateral thalamus, which also differ in the various forms of parkinsonism, vary in close relation to the differences in the pathological changes in state and in the physiological activity of the caudate nucleus.

In confirming the key role of the striopallidal structures under investigation in the organization of the adaptive behavior of man, the data obtained disclose the features of the formation of cerebral systems supporting compensatory–adaptive behavior in the morphofunctional disturbances in the striopallidal complex, and the thalamocortical system which is closely associated with it.

The identification of the neurophysiological correlates of the level of mental activation (based on the indices of the dynamics of the ω-potential), of the turning on of the mechanisms of the activation of attention (based on the typical changes in the ultraslow physiological processes in the range of the ζ-waves), and of the selective involvement of the cerebral structures in support of the emotional experiences proper (local ε-waves), is of fundamental significance for further investigations of the role of the caudate nucleus, globus pallidus, and other structures of the striopallidum and thalamus in the formation of the cerebral systems supporting the mental activity of man.

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