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Developmental Features of the Formation of the Brain Bioelectrical Activity in Children with Remote Consequences of a Perinatal Lesion of the CNS: I. Spontaneous Activity

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Abstract—Investigation of the brain bioelectrical activity in children with remote consequences of perinatal CNS pathology showed that the typical "mature" EEG of young schoolchildren of the risk group has some specific features, which reflect a CNS lesion of a predominantly hypoxic origin. This specific temporal EEG pattern combines the mature basic (α) rhythm with slow and sharp activities. Sufficient compensatory possibilities of the CNS and their adequacy to increasing loads at school form a basis for efficient individual adaptation. Learning problems arise in the course of a child's development when compensation is insufficient because of a severe brain lesion or slower spontaneous rehabilitation, which is related, in particular, with the rigidity of brain mechanisms determining the complete maturation of the biorhythm structure necessary for the efficient integrative activity of the brain.

It is known that the number of children with somatic and neurological pathology in mass preschool institutions and schools is increasing yearly, steadily decreasing the general index of children's health [1–3]. This poses the physiological problem of predicting the efficiency of adaptation to current developmental loads on the basis of investigation of the functional state of a child, primarily, of his or her CNS, its compensatory possibilities, and their adequacy to the intensity of developmental loads.

The EEG is considered to be an integrative index of the functional state of the CNS. To date, a wide range of EEG studies of healthy children at rest and during exposure to various loads have been performed [4–12]. In spite of the differences in methodological approaches to the analysis and interpretation of the EEG data, the authors of these works emphasize common developmental features of the formation of the brain electrical activity. These features include gradual acceleration of cortical rhythms and replacement of the slow δ and θ oscillations by regular α activity with the focus in the parietooccipital regions of the brain cortex. Most authors use indices of α-rhythm maturity for estimating the maturity of the whole biorhythmic structure in growing children, the α-rhythm formation being considered as a functional mechanism integrating neural centers into a single system that provides for complex behavior [9, 11, 13, 14].

Nowadays, the growing proportion of children with learning problems in mass educational institutions [15–23] (including children with residual organic pathology [24–37]) is stimulating neurophysiological investigations of functional disorders of the brain with the use of EEG parameters. A predominance of slow forms of activity and the regular appearance of paroxysms, including those of epileptiform character, have been described in clinical studies of the bioelectrical brain activity in children with consequences of perinatal lesions of the CNS [5, 38, 39]. Initially, no correlation between the character of pathological changes in the bioelectrical activity and features of academic progress was found in EEG studies of children of the risk group [5, 8]. More recently, sophisticated neurophysiological and neuropsychological examinations of children and analysis of school problems have led researchers to the conclusion that every dysontogenetic disorder is characterized by a certain type of deficiency in basic neural substrates of mental activity [15–23], e.g., by immaturity of the morphological and functional organization of the cortex or subcortical and brainstem structures (including disorders associated with heterochronous maturation of brain structures) or by developmental disorders caused by prenatal or perinatal organic lesions of the brain. Moreover, the underdevelopment or lesion of individual brain structures and a CNS dysfunction against the background of their sufficient maturity may underlie similar disorders [40, 41]. This fact makes it problematic to determine the form of efficient intervention in the course of a therapeutic and/or pedagogical process.

The goal of this work was to study the developmental features of the formation of the structure of the bio-

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Table 1. Developmental changes in typological EEG features (a longitudinal study)

EEG type (incidence, %), $N = 77$	Preschoolers	Schoolchildren
High-voltage ($N = 55$)		
with spatially organized α rhythm	82	93
without regional differences	18	7
Low-voltage ($N = 22$)		
with spatially organized α rhythm	45	64
without regional differences	55	36

electrical brain activity in children who had suffered perinatal CNS lesions of different origins.

METHODS

All subjects were divided into two groups. Group 1 was formed of 78 first-grade pupils (aged from 7 to 8 years) of a common primary school, who were taught according to the basic or gymnasium programs (three or four years of education) and were examined once. Group 2, of longitudinal observation, included 77 children subjected to repeated EEG examination from the ages of 3–4 to 8–10 years. The children were examined from two to six times within the observation period. In total, 195 examinations were performed. The overwhelming majority of children were examined in connection with their complaints of increased fatigability, occasional headaches, sleep disorders, and learning problems. In the anamnesis, the children had perinatal encephalopathy and/or hyperexcitability syndrome, muscular dystonia syndrome, hypertensive–hydrocephalic syndrome, or risk factors of a perinatal CNS lesion (a prolonged anhydrous period during labor, cyanosis, etc.).

The EEG was recorded using a 16-channel EEG recorder (Medicor) in the frequency band 1–70 Hz at rest and under functional loads (photostimulation with the frequency 1–20 Hz and 2-min hyperventilation). Electrodes were located by the International 10–20 System; monopolar (in reference to an earlobe electrode) and bipolar leads were used. An EEG fragment (2–4 min) recorded at rest was analyzed according to the principles of EEG structural analysis [18]. EEG indices proposed for 7- to 8-year-old children [18] were used as normative. In particular, for successfully learning children, dominance of the regular α rhythm with a frequency of 8–10 Hz and acquisition of the photostimulation frequency in this band were considered to represent an age-related normal pattern of a mature EEG. The maturity of the regulatory brain structures is manifest, as a rule, in the absence of paroxysmal activity at this age. EEGs with sharpened α activity, lower frequencies of the rhythms at rest, poorer acquisition of the photostimulation frequency, and paroxysmal activity were described as characteristic of the mature EEG in 6- to 7-year-old children and the EEG in 7- to 8-year-old children with learning problems. Children with moderate academic success occupy an intermediate position between these groups with respect to the above EEG features.

As an additional feature of the electrical activity of the brain, we used the amplitude. In the baseline EEG, the amplitude was described as low at <50, high at 50–100, and excessively high at >100 μV.

The rheoencephalogram (REG) was used for evaluating cerebral hemodynamics in the children of group 1 [32, 33, 36, 42]. The REG was recorded with a 4 RG-2M instrument bilaterally in the frontal- and occipital-mastoid leads at rest and during head rotation. REG recording supplements transcranial Doppler ultrasonography with characteristics of pulse volume in the internal carotid artery area (ICAA) and the vertebrobasilar area (VBA). The REG data were compared to the age norm [43, 44]. The index of reaction of vessels to a functional load (a single deep inspiration) allowed us to estimate the state of autoregulatory reactions of the vascular resistive area; these reactions maintain optimal blood flow under unstable environmental conditions [45].

RESULTS AND DISCUSSION

In group 1 of 7- to 8-year-old children, the learning progress was characterized by marks of 4 and 5 (on a five-point scale) in 86% of subjects. The marks of the remaining pupils were 3 or 4 or varied from 2 to 5. The causes responsible for such poor progress included specific disorders of the formation of school skills (dysgraphia, dyslexia, or attention deficit syndrome) and insufficient maturity of certain mental functions. The normal EEG pattern with the regular 8- to 10-Hz α rhythm was revealed in only nine children (14.1%), independently of their academic progress. The rhythm acquisition reaction in the frequency band of 8–10 Hz was observed in 3.8% of cases. In the remaining children, regular sharpened α activity predominated in the parietooccipital areas of the brain cortex and was combined with θ activity (both irregular and including groups of high-voltage θ waves), sharp waves, and sharp wave–slow wave complexes (Figs. 1a, 1b, 2b).

To study developmental changes in the brain electrical activity, we performed a longitudinal EEG examination of children of the risk group (group 2) over several years. We studied the EEG amplitude and characteristics of the spatially organized α activity. As seen from Table 1, 82% of the children displayed a high-voltage EEG and a spatially organized regular α rhythm with a frequency from 7–8 to 10 Hz (Fig. 2). As in group 1, the EEG α activity in these children was combined with slow and/or sharpened forms. Low-voltage EEG patterns with a spatially organized α activity were revealed in only 45% of the children. The EEG positive dynam-

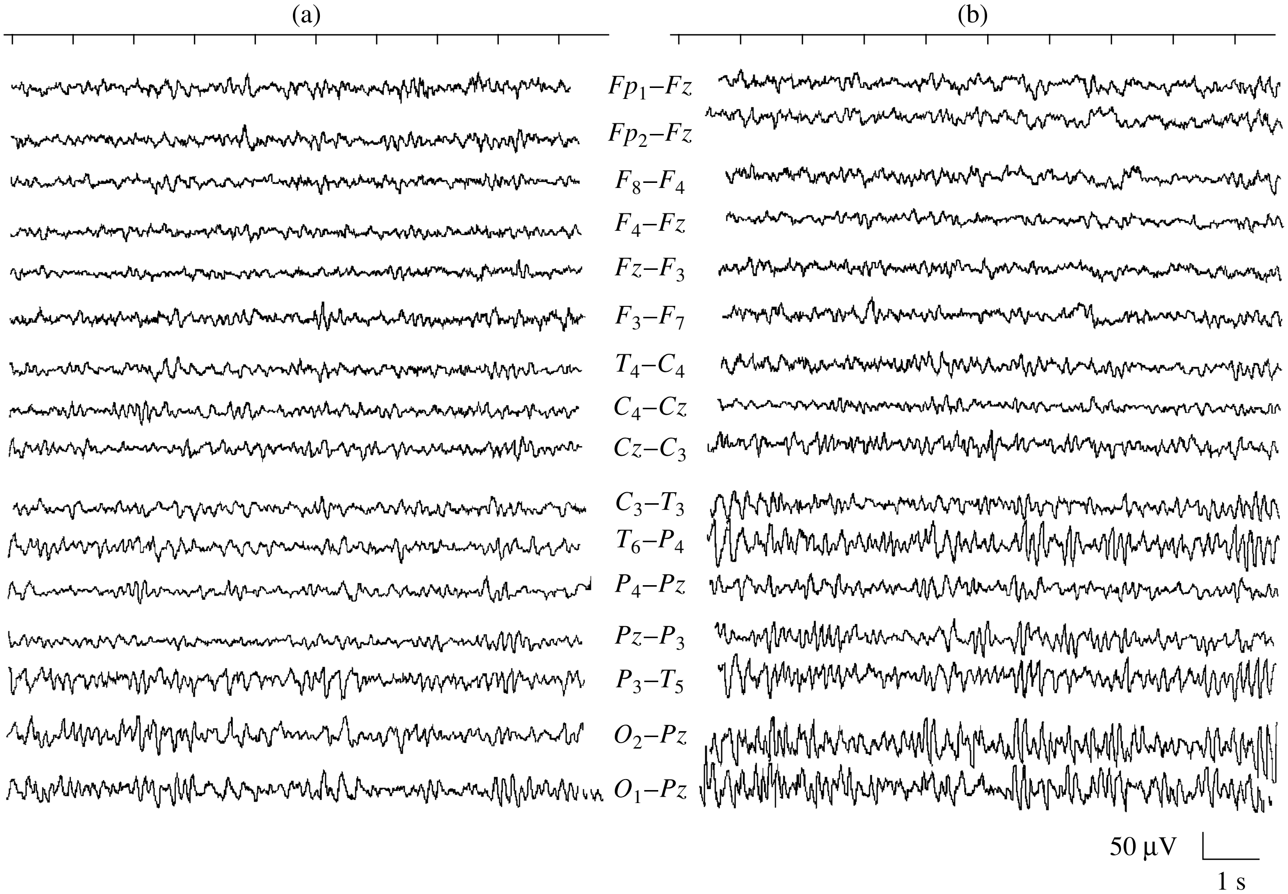

Fig. 1. EEG features of children with consequences of perinatal pathology of the CNS (fragments of spontaneous activity): EEGs of (a) Denis B., 7 years old (a pupil of a gymnasium, excellent marks, program 1–3), and (b) Nadya A., 7 years old (a pupil of a common school, good and excellent marks, program 1–4). Here and in Figs. 2 and 3, bipolar leads are designated in the center and calibration bars are at the bottom right.

ics associated with the growth of children to school age was characterized by a change from the initially predominant dysrhythmic EEG activity to an irregular activity combined with groups of α waves with a modified shape in the occipital cortical area; the EEG amplitude remained low. In other words, the type of a low-voltage irregular EEG with characteristic dysrhythmia and a disorganized (or still lacking organization?) type of cortical rhythmicity did not change drastically (Fig. 3). However, the type of a high-voltage EEG (Fig. 2) changed at various ontogenetic stages; as a rule, the changes agreed with characteristics of maturity for a given age with respect to the frequency and spatial organization of the basic rhythm [6]. A longitudinal study of healthy children has also shown the preservation of a typological EEG pattern independent of the academic progress [46].

Thus, the EEG types described for the children of groups 1 and 2, including pupils with successful learning, did not correspond to the age-related criteria of EEG maturity in healthy children with good academic progress [18].

Assessment of the functional state of the CNS by the indices of the cerebral blood flow revealed the following features in the children of the risk group. In group 1, the children were examined once and a sufficient cerebral blood flow in both vascular basins at rest and in response to a load was found in only 5.1% of cases. At rest, a deficit of the pulse volume (A Ω) in the VBA was revealed in 34.6% of the children, which was combined with a deficit in the ICAA in 7.6% of the children.

Table 2. Features of the functional state of children of the risk group with remote consequences of a perinatal CNS lesion

Complaints (incidence, %), $N = 77$	Low-voltage EEG type, $N = 22$	High-voltage EEG type, $N = 55$
Anxiety, excitation, restlessness	55	51
Undue fatigability	36	41
Sleep disorders	41	45
Emotional instability	59	51
Learning problems	36	20

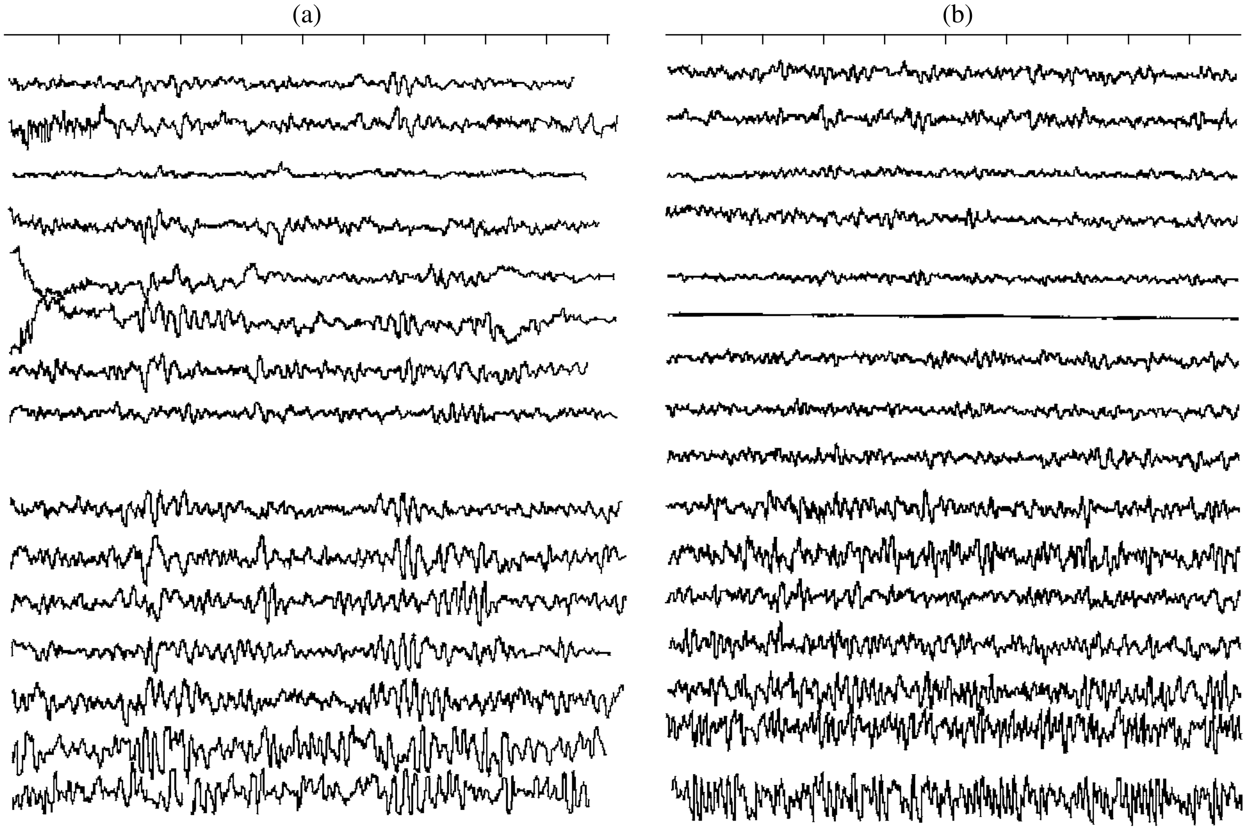

Fig. 2. Developmental changes in the EEGs of children with consequences of perinatal pathology of the CNS as revealed in a longitudinal study (fragments of spontaneous activity): EEGs of Nastya N. (a pupil of a gymnasium, excellent marks, program 1–3) at the ages of (a) 3 and (b) 7 years.

Under a load (head rotation), the proportion of children with a deficit in the VBA increased more than twofold (to 74.4%) and the pulse volume decreased by 30–80% as compared to the initial A Ω (the normal acceptable decrease is 20%). This circumstance either decreased the initially sufficient blood flow to the level of a deficit or aggravated the initial vascular insufficiency. In 43.6% of the children of group 1, the changes were combined with a decrease in the reactivity of vessels of the resistive area to the functional load, which pointed to exhaustion of the regulatory mechanisms maintaining optimal blood flow.

Thus, the children of group 1 were characterized by specific features of the electrical brain activity and cerebral blood flow. Parameters of cortical spontaneous bioelectrical activity in the band of the basic rhythm were unstable: α-rhythm fragments, slower waves of the θ band, and sharpened waves occurred simultaneously in posterior areas of the cortex. Moreover, we observed a significant drop of the pulse flow in the VBA at rest and/or under the functional loads.

With such functional parameters of the brain, sufficient learning ability in the children with remote consequences of perinatal lesions of the CNS was maintained, probably, owing to preserved blood flow in the ICAA (in 92.4% of the children) and self-regulatory mechanisms of the resistive area (56.4%). Presumably, it is compensatory possibilities of a child's brain and plasticity of its vascular system under conditions of a certain working schedule that allow considerable progress in performance of the main age-related task (learning). Such compensation is adequate until the load exhausts the functional reserves of the body under exposure to strong environmental stress factors [36]. Upon exhaustion, the above disorders of the cerebral hemodynamics and CNS functional state (according to the EEG data) lead to increased fatigue after lessons, occasional headaches, sleepiness, restlessness, sleep disorders, etc. In other words, the latent vascular insufficiency manifests itself clinically [44].

Comparative analysis of the complaints and the features of the spontaneous EEG revealed a similarity of complaints for children with different EEG types (Table 2). The most distinct differences between these types were in the incidence of learning problems such as dysgraphia, dyslexia, restlessness, and distraction, observed alone or as components of attention deficit hyperactivity disorder. As seen from Table 2, such learning problems tended to predominate in the children with low-voltage, poorly organized (immature)

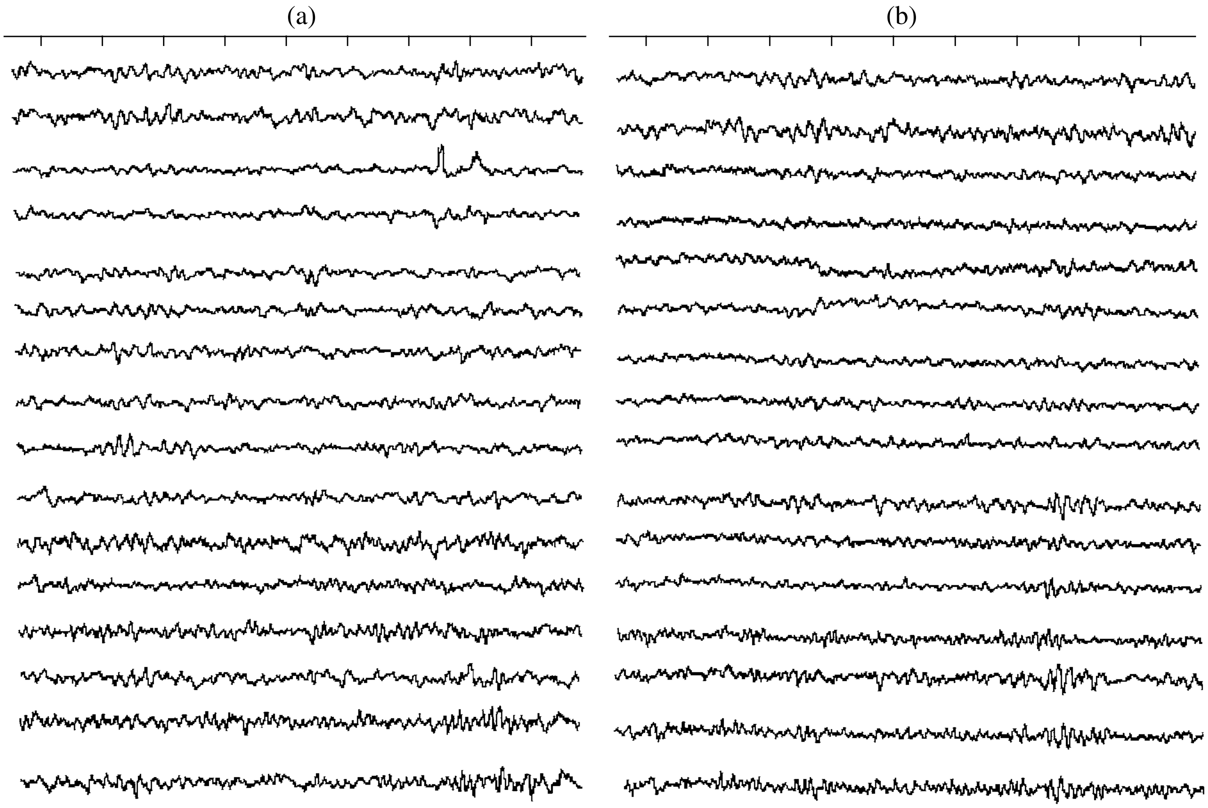

Fig. 3. Developmental changes in the EEGs of children with consequences of perinatal pathology of the CNS as revealed in a longitudinal study (fragments of spontaneous activity): EEGs of Sasha B. (a pupil of a common school, poor progress, program 1–4) at the ages of (a) 5 and (b) 7.5 years.

EEGs as compared to the children with high-voltage EEGs. Probably, brain mechanisms of the formation of the mature structure of cortical rhythms in children of the risk group are relatively rigid and, with growth, cannot provide a sufficient basis for the performance of complex integrative activities (including learning).

A thorough neuropsychological examination of first-grade pupils of common schools showed that up to 73% of children display immaturity of some higher mental functions (HMFs). For the most part, these are children of the risk group, with consequences of perinatal CNS lesions and possible brain morphofunctional immaturity, the influence of which in actual practice turns out to be more significant as compared to psychological readiness for learning at school [47, 48]. In this connection, the results of our study are informative. Investigations of school problems in children show that, to solve them, researchers must look for their primary causes, among which pre- and perinatal disorders (in particular, perinatal encephalopathy of a hypoxic or ischemic origin) are most important [15–23].

The features of the brain bioelectrical activity (its maturity or immaturity) revealed in the children of the risk group and associated with school problems can be interpreted in terms of the level of CNS lesions [49–51]. Thus, pathological development more often causes a lesion of subcortical brain structures, which have a relatively short period of maturation. When compensatory mechanisms are insufficient, subcortical structures maintaining the optimal tone of the brain cortex can remain defective in the later ontogenetic period. Such a defect leads to complaints testifying to emotional lability, mental exhaustion, and attention disorders. The term immaturity is more frequently applied to the frontal cortical areas, i.e., the tertiary fields of analyzers with a longer period of postnatal development. In pedagogical practice, the above features of brain development demand individual approaches to children in order to attain the necessary results in teaching the basic school program by relying on intact units of the system determining the HMFs [52].

There are relatively few studies describing the correlations between features of the cortical rhythms, HMFs, and parameters of the cerebral blood flow [31, 35, 44], although the dependence of the functional state of the brain cortex on the system of blood supply needs no proof. In earlier studies of children with remote consequences of a perinatal CNS lesion, we described a correlation of EEG changes (alternation of the α rhythm with slow and sharpened forms of activity in the posterior cortical areas (Figs. 1, 2)) with disorders of the cerebral hemodynamics in areas supplied by the vertebral arteries in children of the risk group [32, 33, 36, 53]. It is known that remote complications of birth injuries occur more frequently in children with natal spinal traumata than in children with natal brain injuries [44]. Cerebral hemodynamics gradually improves in a growing child owing to the development of collaterals providing a retrograde blood flow from the area supplied by the carotid arteries via the circle of Willis. Our studies confirmed that the transition from preschool to school age is accompanied by a developmental increase in the pulse volume in the VBA (alleviation of the initial deficit). However, as schooling starts, vertebrogenous effects on the cerebral blood flow increase in incidence; i.e., the blood flow in the VBA under a load becomes deficient because of compression of the vertebral arteries [33, 36]. Latent vascular insufficiency associated with a high incidence of pathologies of the craniovertebral junction, subluxations, and instability of the cervical part of the spinal cord in children of the risk group becomes frank when mental and physical loads at school increase beyond the compensatory possibilities [44, 54]. This situation is typical for children now, under conditions of highly intense school studies associated with a sitting at a desk for periods exceeding hygienic norms [1–3]. In such cases, a further increase in the level of functioning of the vascular system is associated with exhaustion of functional reserves and overexertion of the central regulatory mechanisms [55, 56]. It stands to reason that the cerebral asthenia syndrome is considered to be one of the most important factors of school dysadaptation [57].

Our approach to assessment of the CNS functional state was validated in practice. Thus, in cases of parents' complaints of school problems of their children with remote consequences of perinatal CNS lesions, the above EEG pattern was considered to indicate instability of the functional state of posterior areas of the brain cortex and to result from a disorder of hemodynamics in the VBA. The disorder was confirmed by REG examination or Doppler ultrasonography. These data were reinforced by X-ray, neurosonographic, or magnetic resonance examination of the cervical part of the spinal cord. In this context, the term EEG syndrome seems to be most applicable [26, 58, 59]. For example, additional examination of the child whose EEG is presented in Fig. 1a showed instability of the cervical part of the spinal cord and a decrease in the pulse volume in the ICAA and VBA at rest by 25 and 15%, respectively. Head rotation decreased the pulse volume in the VBA by 35%, but the reactivity of vessels to the load remained sufficient. Examination of the child whose EEG is presented in Fig. 1b revealed a rotational subluxation of the cervical vertebra C1 to the right, extension of the cervical lordosis, and symptoms of improper junction of the posterior arch of the C1 vertebra with the occipital bone (fixation). REG examination revealed a decrease in the pulse volume during head rotation by 35% of the initially sufficient level, which was combined with a decrease in the vessel reactivity to the load. Discussion of this aspect of the problem is beyond the scope of this paper, but it is undoubtedly important for predicting the success of children's adaptation at school in the case of timely efficient intervention in the pathological process.

What is the mechanism of correlations between the features of the EEG pattern described for the children of the risk group and disorders of cerebral hemodynamics? The parietooccipital localization of the most evident changes in the α activity may be associated with the fact that EEG changes accompanying a drop in the cerebral blood flow (circulatory hypoxia) are most dramatic at the borders of vascular basins [60]. Many experimental and clinical studies have focused on the correlation of slow EEG frequencies with hypoxic states [61–65]. A break of the initial interrelations between EEG components and the functional nucleus of the α rhythm and an increased contribution of the θ activity to the EEG pattern can be an informative marker of a decrease in the individual threshold of brain tolerance to hypoxia [59]. There is evidence of the adaptive role of EEG slow waves in hypoxia [60]. It can be suggested that, before the adult structure of biorhythms is formed (i.e., before the EEG is "overgrown" by the α rhythm [61]), the EEG of a child preserves traces of problems experienced by the brain in hypoxia, inherent in the majority of complications of the pre- and perinatal periods [66]. It is possible that the coexistence of immature rhythms and fragments of the regular basic (α) rhythm in the EEG reflects the process described.

Markers of maturity, which were described by Lukashevich *et al.* [18] and proved to be informative in multiple studies [19, 22, 23, 29, 30], can probably be considered as a certain rigid, formal structure. Plasticity of the child's brain, enabling compensation for immaturity or natal damage of some structures, can facilitate development of other functional formations of the brain. The structural features of the brain electrical activity observed in the children of the risk group should be considered not only in terms of maturity and immaturity but also in terms of CNS functional instability, which substantially depends on the circulation system. In our opinion, a classification of children's EEGs by the factors mentioned should also include the amplitude, which characterizes the overall level of electrogenesis. There is evidence that amplitude modulations of the EEG determine the synchrony of changes in most components of the EEG frequency spectrum because such modulations are a direct reflection of the control, synchronization, and regulation in the nervous and other body systems, as well as intersystem interactions [67].

Undoubtedly, a number of attendant factors associated with the selection of children for the test group should be taken into account in interpreting the results obtained for the children with consequences of perinatal CNS lesions. The question of homogeneity of clinical and normative samples in such studies is rather complicated [26]. Thus, on the one hand, the children of our sample had no mental retardation and went to common schools; i.e., they had a sufficient level of HMF development. On the other hand, it was not a screening study because the examination was initiated by the parents with their regular complaints of the children's health and learning problems. It is also worth noting that introduction of a new assessment system, utilizing arbitrary symbols as marks or lacking any marks, for first-year pupils in place of the common five-point scale makes the discrimination of children by their academic progress to a certain extent arbitrary and temporary. A more definite prognosis of success in school adaptation is possible only at a higher academic load.

CONCLUSIONS

(1) A longitudinal study of the spontaneous brain electrical activity in children with consequences of a perinatal CNS lesion revealed polar EEG types. The first type involves a regular high-voltage activity with spatially organized rhythms and regular ontogenetic changes and corresponds to age-related characteristics of the maturity of the biorhythmic structure. The second type involves a low-voltage disorganized activity and does not change substantially with age, which points to a relative rigidity of the brain mechanisms providing for complete maturation of the biorhythmic structure or to immaturity of the integration systems.

(2) An EEG pattern combining fragments of the basic α rhythm and slow and/or sharpened forms of activity was revealed in the parietooccipital and posterotemporal cortical areas of children of the risk group, which points to instability of the mechanisms regulating the CNS functional state. The formation of this EEG pattern was related to hypoxia resulting from impaired cerebral hemodynamics, predominantly in the vertebrobasilar area.

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REFERENCES

1. Zelinskaya, D.I., On the State of Health of Children of Russia, *Shkola Zdorov'ya*, 1995, vol. 2, no. 2, p. 5.
2. Antropova, M.V., Borodkina, G.V., Kuznetsova, L.M., *et al.*, Mental Working Ability and the State of Health of Junior Schoolchildren Taught according to Different Pedagogical Systems, *Fiziol. Chel.*, 1998, vol. 24, no. 5, p. 80.
3. Zavadenko, N.N., Petrukhin, A.S., Manelis, N.G., *et al.*, School Dysadaptation: A Psychoneurological and Neuropsychological Study, *Vopr. Psikhol.*, 1999, no. 4, p. 21.
4. Shepoval'nikov, A.N., On the Development of Brain Bioelectrical Activity in Children in the First Months of Life, *Extended Abstract of Cand. Sci. (Med.) Dissertation*, Leningrad, 1963.
5. Kaubish, V.K., On the Problem of Electroencephalographic Criteria of the Norm and Pathology in Children, *Tr. Leningrad. Nauchno-Issledovatel'skogo Psikhonevrologich. Inst. im. V.M. Bekhtereva*, Leningrad, 1967, vol. 44, p. 112.
6. Farber, D.A. and Alferova, V.V., *Elektroentsefalogramma detei i podrostkov* (Electroencephalogram of Children and Adolescents), Moscow: Pedagogika, 1972.
7. Dumermuth, D., *Electroencefalographie in Rindesalter*, Stuttgart: Thieme, 1976.
8. *Current Practice of Clinical Electroencephalography*, Daly, D., and Padley, T., Eds., New York: Raven, 1990.
9. Farber, D.A. and Dubrovinskaya, N.V., Functional Organization of the Developing Brain: Age-Related Features and Some Regularities, *Fiziol. Chel.*, 1991, vol. 17, no. 5, p. 17.
10. Farber, D.A. and Vil'davskii, V.Yu., Heterogeneity and Developmental Changes in the α Rhythm of the Electroencephalogram, *Fiziol. Chel.*, 1996, vol. 22, p. 5.
11. Vedeneeva, L.S., Soroko, S.I., and Shepoval'nikov, A.N., Features of the Statistical Structure of Interactions among Main EEG Components in Children of the School Age, *Fiziol. Chel.*, 1998, vol. 24, no. 1, p. 5.
12. Rozhkov, V.P. and Soroko, S.I., Formation of the Interaction between the Wave Components of the Main EEG Rhythms in Children of the First Five Years of Life, *Fiziol. Chel.*, 2000, vol. 26, no. 6, p. 5.
13. Bekshaev, S.S., Soroko, S.I., and Vasilevskii, N.N., Regularities Underlying the Maintenance of the Dynamic Stability of the Human EEG Frequency Bands, *Fiziol. Chel.*, 1988, vol. 14, no. 4, p. 545.
14. Peresleni, L.I., Rozhkova, L.A., and Ryabchikova, N.A., On the Neurophysiological Mechanisms of Attention Disorders in Children, *Zh. Vyssh. Nerv. Deyat. im. I.P. Pavlova*, 1990, vol. 40, no. 1, p. 37.
15. Sokolova, L.V., Specific Features of the EEG Spectral Characteristics in Children with Reading Problems, *Fiziol. Chel.*, 1991, vol. 17, no. 5, p. 125.
16. Peresleni, L.I. and Rozhkova, L.A., Psychophysiological Mechanisms of Attention Deficit in Children of Different Ages with Learning Problems, *Fiziol. Chel.*, 1993, vol. 19, no. 4, p. 5.
17. Alferova, V.V. and Kudryakova, T.A., Spatial Organization of the Bioelectrical Activity of the Brain in Children with Learning Problems, *Fiziol. Chel.*, 1994, vol. 20, no. 5, p. 151.
18. Lukashevich, I.P., Machinskaya, R.I., and Fishman, M.N., Dynamics of the Functional State of the Brain in Junior Schoolchildren with Learning Problems, *Fiziol. Chel.*, 1994, vol. 20, no. 5, p. 34.
19. Lukashevich, I.P., Machinskaya, R.I., and Fishman, M.N., The Role of the Regulatory Brainstem Regions in the Functional Maturation of the Brain Cortex in 7- to 8-Year-Old Children, *Fiziol. Chel.*, 1996, vol. 22, no. 1, p. 63.
20. Dubrovinskaya, N.V., Neurophysiologist at School, *Shkola Zdorov'ya*, 1996, vol. 3, no. 1, p. 24.

21. Gorbachevskaya, N.L., Zavadenko, N.N., Yakupova, L.P., *et al.*, Electroencephalographic Study of Hyperactivity in Children, *Fiziol. Chel.*, 1996, vol. 22, no. 5, p. 49.
22. Machinskaya, R.I., Lukashevich, I.P., and Fishman, M.N., Changes in Electrical Brain Activity in 5- to 8-Year-Old Children in Norm and Learning Problems, *Fiziol. Chel.*, 1997, vol. 23, no. 5, p. 5.
23. Bezrukikh, M.M., Machinskaya, R.I., and Sugrobova, G.A., Differential Influence of the Functional Maturity of the Cortex and Regulatory Brain Structures on Characteristics of Cognitive Activity in 7- to 8-Year-Old Children, *Fiziol. Chel.*, 1999, vol. 25, no. 5, p. 14.
24. Shan'ko, G.G., Korol', E.A., and Shal'kevich, V.B., Neurological Disorders and EEG Features in Children Who Had Heat Cramps in Infancy, *Zh. Nevrol. Psikhiatr. im. S.S. Korsakova*, 1980, vol. 80, no. 10, p. 1465.
25. Gorbachevskaya, N.L., Yakupova, L.P., Kozhushko, L.F., and Simernitskaya, E.G., Neurobiological Backgrounds of School Dysadaptation, *Fiziol. Chel.*, 1991, vol. 15, no. 5, p. 72.
26. Gorbachevskaya, N.L., Yakupova, L.P., Kozhushko, L.F., *et al.*, Topographic EEG Mapping in Children's Psychiatry, *Fiziol. Chel.*, 1992, vol. 18, no. 6, p. 40.
27. Rozhkov, V.P., Assessment of Pathological Changes in Children's EEG, *Detsk. Nevrol.* (St.Petersburg), 1994, no. 1, p. 47.
28. Peresleni, L.I., Mastyukova, E.M., Rozhkova, L.A., and Fotekova, T.A., Clinical, Physiological, Psychological, and Pedagogic Analyses of the Structure of the Deficit of Cognitive Activity in Three Different Cases of Speech Pathology, *Zh. Nevrol. Psikhiatr. im. S.S. Korsakova*, 1996, vol. 96, no. 2, p. 49.
29. Lukashevich I.P., Fishman, M.N., and Machinskaya, R.I., Investigation of the Neurophysiological Mechanisms of Mental Retardation in Children: EEG Structural Analysis, *Fiziol. Chel.*, 1998, vol. 24, no. 1, p. 16.
30. Lukashevich I.P., Machinskaya, R.I., Shklovskii, V.M., Role of the Right- and Left-Hemispheric Structures in Speech and Memory Formation in Children, *Fiziol. Chel.*, 2002, vol. 28, no. 6, p. 52.
31. Chiron, C., Pinton, F., Masure, M.C., *et al.*, Hemispheric Specialization Using SPECT and Stimulation Tasks in Children with Dysphasia and Dystrophia, *Dev. Med. Child Neurol.*, 1999, vol. 41, no. 8, p. 512.
32. Kozhushko, N.Yu., and Matveev, Yu.K., Clinical and Physiological Aspects of School Problems in Children with Remote Consequences of Perinatal Encephalopathy, in *Neiroimmunologiya* (Neuroimmunology), St. Petersburg, 2002, p. 132.
33. Kozhushko, N.Yu., Matveev, Yu.K., and Kudzilov, D.B., Study of the Specific Changes in the Functional State of Children with Remote Consequences of CNS Perinatal Pathology at the Start of Schooling, in *Kolebatel'nye protsessy gemodinamiki. Pul'satsiya and fluktuatsiya serdechno-sosudistoi sistemy* (Oscillatory Processes of Hemodynamics: Pulsation and Fluctuation in the Cardiovascular System), Miass, 2000, p. 140.
34. Fishman, M.N., Functional State of the Cortex and Regulatory Brainstem Structure in Children with Developmental Speech Disorders, *Fiziol. Chel.*, 2001, vol. 27, no. 5, p. 30.
35. Shklovskii, V.M., Lukashevich, I.P., Machinskaya, R.I., *et al.*, Some Pathogenetic Mechanisms of Disorders of Speech Development in Children, *Defektologiya*, 2001, no. 2. p. 20.
36. Ilyukhina, V.A., Kozhushko, N.Yu., Matveev, Yu.K., and Shaitor, V.M., Main Factors of a Decrease in Stress Resistance in 6- to 8-Year-Old Children with Remote Consequences of Perinatal CNS Pathology at the Transition to the School Period of Life, *Fiziol. Chel.*, 2002, vol. 28, no. 3, p. 5.
37. Kiroi, V.N., Ermakov, P.N., Belova, E.N., and Samoilova, T.G., EEG Spectral Characteristics of Junior Schoolchildren with Learning Problems, *Fiziol. Chel.*, 2002, vol. 28, no. 2, p. 20.
38. Zislina, N.N., Opelinskii, E.S., and Reidenboim, M.G., Study of the Functional State of the Brain in Children with Developmental Delay by Electroencephalography Data, *Defektologiya*, 1972, no. 3, p. 9.
39. Kruk, E.V., *Tserebrastenicheskie sostoyaniya u detei doshkol'nogo vozrasta* (Cerebrasthenic States in Preschool Children), Kiev: Zdorov'ya, 1990.
40. Bezrukikh, M.M., School Difficulties as a Problem of Age Periodization, in *Fiziologiya razvitiya cheloveka* (Physiology of Human Development), Moscow, 2000, p. 94.
41. Peresleni, L.I. and Rozhkova, L.A., Psychophysiological Mechanisms of Learning Difficulties as Problems of Diagnostics and Correction, in *Fiziologiya razvitiya cheloveka* (Physiology of Human Development), Moscow, 2000, p. 332.
42. Kozhushko, N.Yu. and Matveev, Yu.K., Features of the CNS Functional State and Cerebral Hemodynamics in Children with Remote Consequences of a Perinatal Brain Lesion of a Hypoxic–Ischemic Origin, in *Neiroimmunologiya* (Neuroimmunology), St. Petersburg, 2001, p. 142.
43. Zenkov, A.R. and Ronkin, M.A., *Funktsional'naya diagnostika nervnykh boleznei* (Functional Diagnostics of Nervous Diseases), Moscow, 1991, p. 423.
44. Ratner, A.Yu., *Pozdnie oslozhneniya rodovykh povrezhdenii nervnoi sistemy* (Late Consequences of Birth Injury of the Nervous System), Kazan: Kazan Gos. Univ., 1990.
45. Gaidar, B.V., Diagnostic and Prognostic Values of the Indices of Reactivity of the Brain Vessels in the Acute Period of a Craniocerebral Injury, *Extended Abstract of Cand. Sci. (Med.) Dissertation*, Leningrad, 1984.
46. Gorbachevskaya, N.L. and Kozhushko, L.F., Dynamics of the EEG Formation in Boys and Girls of the School Age (Results of Nine-Year Observation), *Zh. Nevrol. Psikhiatr. im. S.S. Korsakova*, 1990, vol. 90, no. 8, p. 75.
47. Semago, N.Ya., New Approaches to Correctional Work with Children with Different Types of Deviant Development, *Defektologiya*, 2000, no. 1, p. 66.
48. Novikova, G.R., State of the Higher Mental Functions in Children Entering the First Grade of a Common School (Results of Neuropsychological Examination), *Defektologiya*, 2000, no. 2, p. 51.
49. Lebedinskaya, K.S., *Osnovnye voprosy kliniki i sistematiki zaderzhki psikhicheskogo razvitiya detei* (Main Problems of Clinic and Systematics of Mental Retardation in Children), Moscow, 1982.

50. Markovskaya, I.F., Clinical and Neuropsychological Basis of Diagnostics and Correction of Mental Retardation in Children, in *Kliniko-geneticheskoe i psikhologicheskoe izuchenie i korrektsiya anomalii psikhicheskogo razvitiya u detei* (Clinical and Genetic Study and Correction of Abnormal Mental Development in Children), Moscow, 1991, p. 51.

51. Adrianov, O.S., Kesarev, V.S., and Borisenko, O.V., Structural Reorganization of the Human Brain Cortex in Perinatal and Early Postnatal Ontogeny, in *Mozg i povedenie mladentsa* (Infant Brain and Behavior), Moscow: IPAN, 1993, p. 34.

52. Semenovich, A.V., Umrikhin, S.O., and Tsyganok, A.A., Neuropsychological Analysis of Poor Academic Progress in Pupils of Common Schools, *Zh. Vyssh. Nerv. Deyat. im. I.P. Pavlova*, 1992, vol. 42, no. 4, p. 655.

53. Kozhushko, N.Yu., Matvejev, Yu.K., Kudsilov, D.B., and Fyodorova, M.A., Peculiarities of Damage of CNS Functional State and Cerebral Hemodynamics at the Children with Consequences of Perinatal Encephalopathy, *J. Obstetr. Women's Diseases*, 1999, vol. 48, p. 87.

54. Vetrile, S.T., Kolesov, S.V., Es'kin, N.A., *et al.*, Vascular Disorders in Craniovertebral Pathology in Children and Adolescents, *Zh. Nevrol. Psikhiatr. im. S.S. Korsakova*, 2002, no. 5, p. 6.

55. Meerson, N.Z., Adaptive Reactions of an Injured Organism, in *Fiziologiya adaptatsionnykh protsessov* (Physiology of Adaptive Processes), Moscow: Nauka, 1986, p. 481.

56. Baevskii, R.M., A Problem of Health and Norm: The Viewpoint of a Physiologist, *Klin. Med.*, 2000, no. 4, p. 59.

57. *Shkol'naya dezadaptatsiya: emotsional'nye i stressornye rasstroistva u detei i podrostkov* (School Dysadaptation: Emotional and Stress-Related Disorders in Children and Adolescents), Moscow, 1995.

58. Troshin, V.M., Modern Methodological Approaches to Application of Quantitative and Qualitative EEG Criteria in Clinic of a Craniocerebral Injury, in *Neirodinamika cherepno-mozgovykh travm* (Neurodynamics of Craniocerebral Injuries), Gorky, 1984, p. 11.

59. Zhirmunskaya, E.A., *V poiskakh ob"yasneniya fenomenov EEG* (In Search for Explanations of the EEG Phenomena), Moscow: NPF Biola, 1996.

60. Prior, P.F., *Monitornyi kontrol' funktsii mozga* (Monitoring of Brain Functions), Moscow: Meditsina, 1982 (Russian translation).

61. Walter, G., *The Living Brain*, London: Pelikan Books, 1966.

62. Soroko, S.I. and Dimarov, R.M., Individual Features of Changes in Brain Bioelectrical Activity and Hemodynamics under Exposure to Experimental and High-Altitude Hypoxia, *Fiziol. Chel.*, 1994, vol. 20, no. 6, p. 16.

63. Malkin, V.B. and Gippenreiter, E.B., Acute and Chronic Hypoxia, in *Problemy kosmicheskoi biologii i meditsiny* (Problems of Space Biology and Medicine), Moscow: Nauka, 1977, p. 35.

64. Aleksandrov, M.V., Ivanov, A.O., Kosenkov, N.I., and Lutsyk, M.A., Influence of Hypoxic Hypoxia on the Spontaneous Activity of the Human Brain, *Fiziol. Chel.*, 2001, vol. 27, no. 6, p. 58.

65. Burykh, E.A., Nesterov, S.V., Soroko, S.I., and Volkov, N.Yu., Relationships between Cerebral Blood Flow Dynamics and Bioelectrical Activity of the Human Brain in Experimental Acute Hypoxia, *Fiziol. Chel.*, 2002, vol. 28, no. 6, p. 24.

66. Badalyan, L.O., Zhurba, L.G., and Timoshina, O.V., *Detskii tserebral'nyi paralich* (Infantile Cerebral Palsy), Kiev, 1983.

67. Bondar', A.T. and Fedotchev, A.I., On the Question of the Amplitude Modulation of the Human EEG, *Fiziol. Chel.*, 2000, vol. 26, no. 4, p. 18.