Correlation of the Characteristics of Evoked EEG Potentials with Individual Peculiarities of Attention in Children

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We studied correlations of the main parameters of evoked EEG potentials (EP) with individual characteristics of attention in children and teenagers. One hundred and one healthy children (dextrals) took part in the tests. Among them, 26 and 30 children were 5 to 7 and 10 to 12 years old, while the third age group included 45 teenagers (15 to 16 years old). We recorded EP and measured the time of a sensorimotor reaction in the following experimental paradigm. Its program provided automated presentation of a pair of acoustic signals, preliminary and imperative; the subject had to perform a motor reaction, pushing a button with the right thumb, with a minimum delay after the second stimulus. Visual feedback signals informed the subject about the successful or inadequate performance of the reaction (time of reaction was shorter than or exceeded a limit value). Indices characterizing the level of attention were estimated using "Find and delete" and "Schulte's tables" techniques. A well-manifested N2 component of the EP related to the preliminary signal was a specific feature in the group of 5- to 7-year-old children, while the contingent negative variation (CNV) preceding the motor reaction was poorly developed in this group. The best characteristics of attention in these and older (10 to 12 years old) children were typical of subjects with maximally expressed N1-P2 waves. In teenagers, the best attention was typical of subjects with the highest-amplitude P1 and P2 components, CNV, and P300 wave and with the lowest amplitude of the N1 component.

Keywords: evoked potentials, event-related potentials, attention, time of reaction.

INTRODUCTION

Studies of the mechanisms of voluntary attention are highly important because the level of attention is a factor that to a great extent determines the cognitive abilities of the human individual and the efficiency of his/her activity. The development and application of techniques that allow one to obtain maximally objective characteristics of attention typical of the individual are undoubtedly valuable in both the fundamental and applied aspects.

At present, electroencephalographic approaches are actively used in complex studies of cognitive, mental, and neurophysiological processes. Recording of evoked EEG potentials (EP), in addition to recording of a "classic" current EEG, is extensively used for visualization of the dynamics of the electrical activity of the human brain related to the above-mentioned processes. Medium- and long-latency EP components, in particular those classified as event-related potentials, ERP (in particular contingent negative variation, CNV, and potential P300), are considered most informative from the aspect of interpretation of information processing at the level of the higher CNS structures. Significant correlations between the parameters of the EP components and those of cognitive and motor processes in the norm and in pathology were found in a few studies [1-3]. Recording of EP is extensively used in clinical and scientific practice; this is related to the high temporal resolving ability of such methods and to the fact that the respective results can be easily reproduced and that the technique of EP recording is relatively simple.

The importance of studies of processes providing such a characteristic as attention is emphasized by

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the following circumstance. There is no formalized system of diagnostic criteria allowing the researcher to adequately estimate the level of development of this property both in healthy children and in children with attention deficit combined with hyperactivity. In particular, some authors emphasized that previous studies in this aspect were mostly based on the analysis of behavioral characteristics and did not examine the electrophysiological correlates of attention [4]. Clarke and others emphasized that at present there is practically no objective criteria of the attention deficit and hyperactivity syndrome. Diagnostic approaches in the above cases are subjective and are frequently based on observations of the parents of a child. This, in turn, supposes that the parent possesses sufficiently adequate knowledge on the age norms of the normal development and behavior of the child; it is probably not worth emphasizing that in many cases the situation is quite opposite [5].

Yet, extensive application of objective physiological techniques for the analysis of attention has begun [6-16]. Recently, some papers describing the pattern of EP recorded during realization of attention-related tasks were published. In most such studies, however, only adult subjects were tested. Thus, it is obvious that using the respective experimental paradigms in studies of cognitive processes in children will not only help in understanding the process of development of attention but will also allow researchers to elucidate the causes of attention disorders in children [4] and to propose measures for the correction of deviations of the mentioned cognitive function [9, 11, 17].

Despite the fact that studies of the anomalies of ontogenetic development in children are extensive and urgent, the problem of the attention disorders remains insufficiently studied, and the results obtained are frequently contradictory, poorly systematized, and are not adopted to the needs of practicing specialists. This is why we believed that electrophysiological studies where indices of the current EEG and EP are correlated with psychological characteristics of attention of the subjects are rather expedient. This, in particular, allowed us to evaluate EEG correlates corresponding to the development of functions of the CNS in children and teenagers and to their individual characteristics of attention.

METHODS

Healthy children (dextrals) constituted the studied population (n = 101), including three age groups. Group 1 consisted of 26 children (5 to 7 years old, 13 boys and 13 girls), group 2 included 30 children (10 to 12 years old, 15 boys and 15 girls), while 45 teenagers (15 to 16 years old, 35 boys and 10 girls) formed group 3.

We recorded EP in the paradigm of measuring the time of a simple sensorimotor reaction with presentation of two signaling acoustic stimuli, preliminary and imperative, using a loudspeaker. The interval between presentation of paired signals was varied by the experimenter in a randomized manner within a 5 to 15 sec range. As a first signal, we used a 100-msec-long tonal stimulus (frequency 2,000 Hz). The second, imperative, signal was also a tonal stimulus, but its frequency was 1,000 Hz; it was presented with a 2-sec-long interval after the preliminary signal and was terminated by the tested subject by pushing the button.

Information about the successful *vs* wrong performance of the test was presented to the subject as visual feedback signals on a photodiode indicator board. These 100-msec-long signals were switched on with a 1-sec-long interval after the imperative signal. A vertical bar indicated the successful performance of the task (time of reaction did not exceed 180 msec in groups 2 and 3 and 250 msec in the youngest group 1). If the time was greater, a horizontal bar indicated the wrong performance.

The EP were recorded using an automated set (including an encephalograph, an interface, and a computer) using a routine technique. As a working program, we used the ERP software developed by A. Sukhinin. The following components of the EP related to the perception of the preliminary acoustic signal were analyzed: P1, N1, P2, N1-P2 (a vertex potential), and N2. These fluctuations are generally considered mid-latency components of the acoustic EP [1]. We also analyzed the CNV, which reflects processes of mental concentration and preparation for the performance of a behavioral act, and the P300 wave related to the perception of the visual feedback signal allowing the person to evaluate the result of the task performance. Potentials were recorded monopolarly from C3 and C4 points; it is known that all the above-mentioned components, including those qualified as ERP, are well manifested in the central recording sites [2, 3, 10]. Interconnected electrodes fixed above the mastoid processes served as a reference electrode. For EP recording, two channels of the encephalograph were modified to provide a 10 sec time constant. The upper limit of the waveband of the recording system was 30 Hz, and the digitalization frequency was 100 sec^{-1}.

In the course of the experiment, the subject was sitting in a convenient armchair in a dark shielded chamber. A 5 × 5 cm photodiode indicator board positioned at a 1.5 m distance from the subject at the level of his/her eyes was used as the tool for presentation of the visual feedback signals produced by the computer. To minimize the artifacts related to involuntary eye movements, the tested subject tried to fix the gaze on a photodiode in the center of the board. A contact button (for pushing with the thumb) was in the right hand of the subject.

The experiment was carried out in a game/competition mode. The working cycle was preceded by several training realizations. The working recording time was 10 to 15 min. Within such a segment, it was possible to select off-line 20-25 sufficiently qualitative realizations for group-1 children (5 to 7 years old) and 30-35 realizations for teenagers. Samples with potential amplitudes exceeding 100 μV were considered artifact-containing and, thus, were excluded from the analysis.

Psychological testing of 5- to 7-year-old children (group 1) was based on the use of a "Find and delete" technique (presentation of tables with simple symbol figures) [18]. The following characteristics of attention were calculated: (i) coefficient of accuracy, CA, of the task performance (ratio of the number of deleted symbols to that needed to be deleted), and (ii) coefficient of intellectual efficiency (CE, product of the coefficient of accuracy and total number of reviewed symbols). It is evident that the higher the values of the above coefficients, the better the level of development and efficiency of attention in the given tested person.

A "Schulte's tables" technique [19] was used for estimating the stability of attention and dynamics of the working abilities of children of groups 2 and 3. It is believed that the mean normative time of task performance for a single table is 40 to 50 sec for teenagers and 80 to 90 sec for 10- to 12-year-old children. A clearly uneven pattern of time indices (when the data for all five tables are compared for one tested subject) is indicative of increased fatigue/exhaustion or of slowing down of the "work in" process. According to the above-mentioned technique, we calculated the following characteristics of attention: (i) work efficiency (WE, the mean time necessary for one table), (ii) "working-in" (WI, an index equal to the ratio of the time of work with the first table to the mean time necessary for one table), and (iii) mental stability (MS, an empirical index equal to the ratio of the time of work with the fourth table to the mean time of work with one table). It is obvious that the lower the values of WE, WI, and MS, the better the level of attention characterizing the given subject.

The data of the electrophysiological study and the indices of physiological testing were processed using standard techniques of variation statistics. The levels of correlation between the indices were estimated according to Spearman's coefficients of range correlation.

RESULTS AND DISCUSSION

The general pattern of the examined EP components recorded in the course of tests for the time of a simple sensorimotor reaction with a preliminary notice is illustrated in Figs. 1 and 2, and diagrams of their amplitudes are shown in Figs. 3 and 4.

The CNV was poorly manifested in 5- to 7-year-old children (group 1; Fig. 1A). In children of this age group, a relatively greater negativity of the EP components developing with a 200 to 400 msec latency was the main peculiarity of the EP related to the preliminary signal. This feature resulted in the generation of a better-manifested N2 wave (Fig. 2A). Our observations agree with the results of studies of Johnstone et al. [20]. In adults, a high-amplitude N2 component is generated after presentation of novel unusual stimuli and is related to such phenomena as "commutation of curiosity" and identification of complex unusual signals [21]. In children younger than 10 years, the appearance of the N2 component is related to presentation of standard and target stimuli as well. In such a case, this wave is believed to reflect the "width of focus" of attention and weak concentration of the latter, and the magnitude of this fluctuation decreases with age [20].

The results of analysis of correlations between the EP characteristics, time of reaction, and indices characterizing attention, which were typical of group 1, are illustrated in Table 1 (in this and other tables, only the cases where the correlation was significant are shown).

The positive correlation between the interspike magnitude N1-P2 (vertex potential) and CA can be indicative of a better development of the cerebral mechanisms providing concentration of attention in children with a greater N1-P2 magnitude. Negative correlation between the CNV amplitude and time of reaction, probably, supports the statement that CNV can be considered an electrographic manifestation of

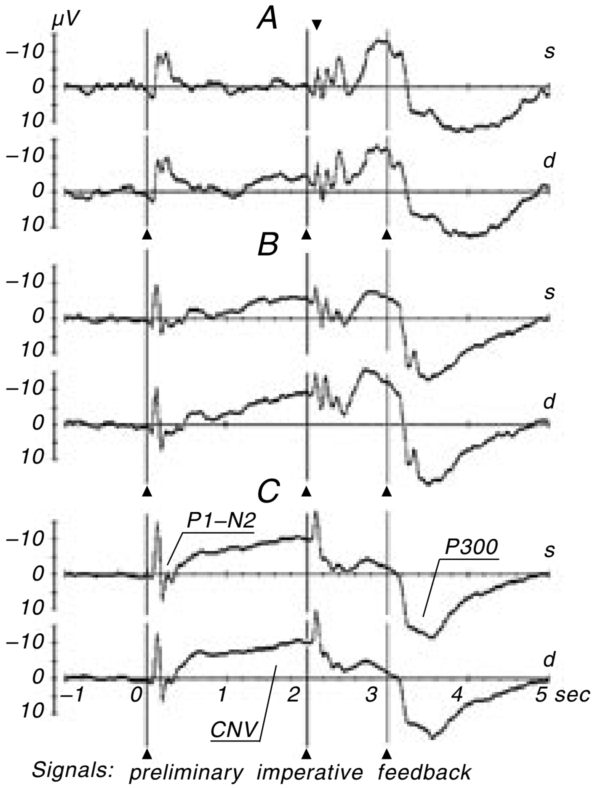

Fig. 1. General pattern of the complex of averaged evoked and event-related potentials elicited under conditions of the performance of the task for the time of sensorimotor reaction in 5- to 7-, 10- to 12-, and 15- to 16-year-old children (A, B, and C, respectively). Realizations are averaged for all subjects of the respective age group. P1-N2 are components of the EP related to the preliminary acoustic signal, CNV is the contingent negative variation, and P300 is the positive wave related to the perception of the visual feedback signal. Upper and lower traces of each fragment are potentials recorded from the left (s) and right (d) hemispheres. The moment of pushing a button is indicated above the traces. Moments of presentation of acoustic preliminary and imperative signals and of a visual feedback signal are shown below.

the processes of preparing for the motor reaction. The correlation between the time of reaction and CNV recorded from the left hemisphere can be determined by the following fact. In 5- to 7-year-old children, elements of voluntary attention are developing and begin to be involved in the performance of the task, and these elements are known to be based mostly on the resources of the left hemisphere.

The significant negative correlation between the amplitude of the P300 wave in the left hemisphere and the CE was somewhat unexpected. Usually, it is believed that a high amplitude of the P300 in the respective experimental situation is indicative of high cognitive resources of the brain [1, 2, 16]. At the

TABLE 1. Coefficients of Correlation between the Amplitudes of EP Recorded from the Left (s) and Right (d) Brain Hemispheres and Indices of the Reaction Time in 26 Group-1 Children (5 to 7 Years Old)

EP amplitude	Time of reaction	“Coefficient of accuracy”	“Coefficient of efficiency”
N1-P2$_d$	–0.02	0.47*	0.30
CNV$_s$	–0.47*	0.03	0.33
P300$_s$	0.15	–0.11	–0.45*

Footnote. Asterisks show cases where coefficients of correlation were significant ($P < 0.05$).

same time, the greatest P300 potentials were observed in those children who showed relatively low results in the experimental test. This situation is, probably, related to the great frequency of reception of negative feedback signals by these subjects. Attention to such signals should be rather high, and this resulted in an additional growth of the P300 wave.

In 10- to 12-year-old children, the CNV was manifested more clearly than that in younger children (Fig. 1B). Components of the EP complex related to presentation of the preliminary acoustic signal were recorded with no significant slow negative shift, and this resulted in a decrease of the N2 component (Fig. 2B).

The results of correlation analysis of the EP characteristics and indices of attention in group 2 are shown in Table 2. The positive correlation between the amplitude of P1 in the right hemisphere and the WI shows that the greater the amplitude of this component, the slower is the involvement of the child in work with Schulte’s tables. This fact, however, also shows that such children possess certain mental reserves allowing them to increase the rate of work with each subsequent table. The optimum index for the stability of attention was shown by subjects with greater amplitudes of the N1 component in the left hemisphere. The amplitudes of P2 and N1-P2 components, which relate to the perception of the preliminary signal, negatively correlated with the WE index. The greater amplitudes of these components correspond to the ability of the subject to rapidly perform the cognitive task and, consequently, to a high level of development of voluntary attention. Our results agree with the data of studies of acoustic EP in children of different ages under conditions of the old-ball paradigm. These experiments showed that the amplitude of the P2 component increases with age,

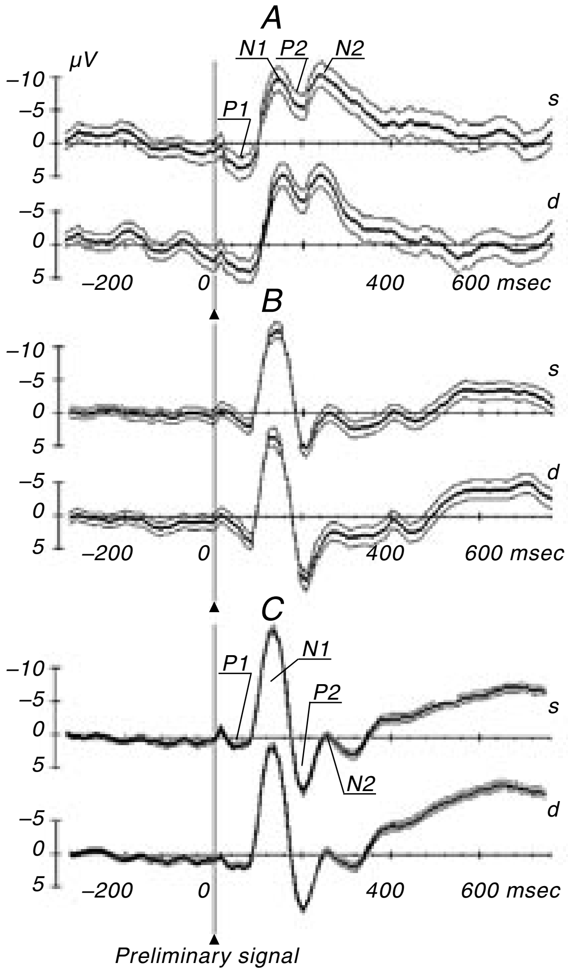

Fig. 2. General pattern of averaged evoked EEG potentials (EP) elicited by presentation of an acoustic preliminary signal in the course of the performance of the task for the time of reaction in 5- to 7-, 10- to 12-, and 15- to 16-year-old children (A, B, and C, respectively). Realizations are averaged for the respective age groups. Thin bars show s.e.m. values. P1, N1, P2, and N2 are EP components. Other designations are the same as in Fig. 1.

and this index can, to a certain extent, reflect the level of maturity of the brain [20, 22].

In 15- to 16-year-old teenagers (group 3), the CNV, P300, and components of the EP complex generated after presentation of the preliminary signal were manifested most clearly (Figs. 1C, 2C, and 3). Data on the correlation analysis of the indices of EP and characteristics of attention in this group are shown in Table 3. The amplitudes and latencies of the positive EP components (P1 and P2) and those of the vertex potential in general (i.e., components related to the perception of the preliminary acoustic signal)

TABLE 2. Coefficients of Correlation between Parameters of EP Recorded from the Left (s) and Right (d) Brain Hemispheres and Indices of Attention in 30 Group-2 Children (10 to 12 Years Old)

EP parameters	"Work efficiency"	"Working in"	"Mental stability"
Amplitude of $P1_d$	–0.08	0.47**	–0.15
Amplitude of $N1_s$	–0.20	0.09	–0.46**
Peak latency of $N1_s$	–0.16	0.01	–0.42*
Amplitude of $P2_s$	–0.42*	0.27	0.08
Amplitude of $N1\text{-}P2_s$	–0.40*	0.21	–0.20

Footnotes. $^{**}P < 0.01$. Other designations are the same as in Table 1.

correlated with the WE indices. The greater amplitudes and higher rates of increase of these components corresponded to the ability of the subject to perform more rapidly a cognitive task and, correspondingly, to a higher level of voluntary attention.

Table 3 shows that the higher the amplitude of the N2 component, the lower the rate of work with Schulte's tables. The observed positive correlation of the N2 wave with the WE is, probably, indicative of the involvement of some compensatory mechanisms (additional neuronal populations) in a situation when satisfactory resolution of the task is necessary. Considering that the N2 component includes a "discoordination negativity," which reflects the manifestation of involuntary attention, individuals with clearly developed N2 waves can be characterized by domination of the involuntary attention components, as compared with voluntary ones.

The amplitudes of P300 waves in both hemispheres negatively correlated with the WE, i.e., the efficiency of attention in elder schoolchildren was greater when the P300 magnitude was higher. At the same time, the shorter latencies of the P300 waves correlated with the faster exhaustion of attention (greater MS values). This fact needs further examination.

The actual dependences between the EP characteristics and peculiarities of attention in one subject or another could be more complex because indices of attention are obviously interdependent with several components of the EP under study (even if correlation coefficients in these cases did not reach the significance levels). For example, not only the presence of a clear P2 component but also a well-developed CNV are certain indicators of rapid and effective working in the course of resolving the experimental task (Fig. 5). The minimum productivity in work with Schulte's tables (high values of the WE index) was observed in teenagers with poorly

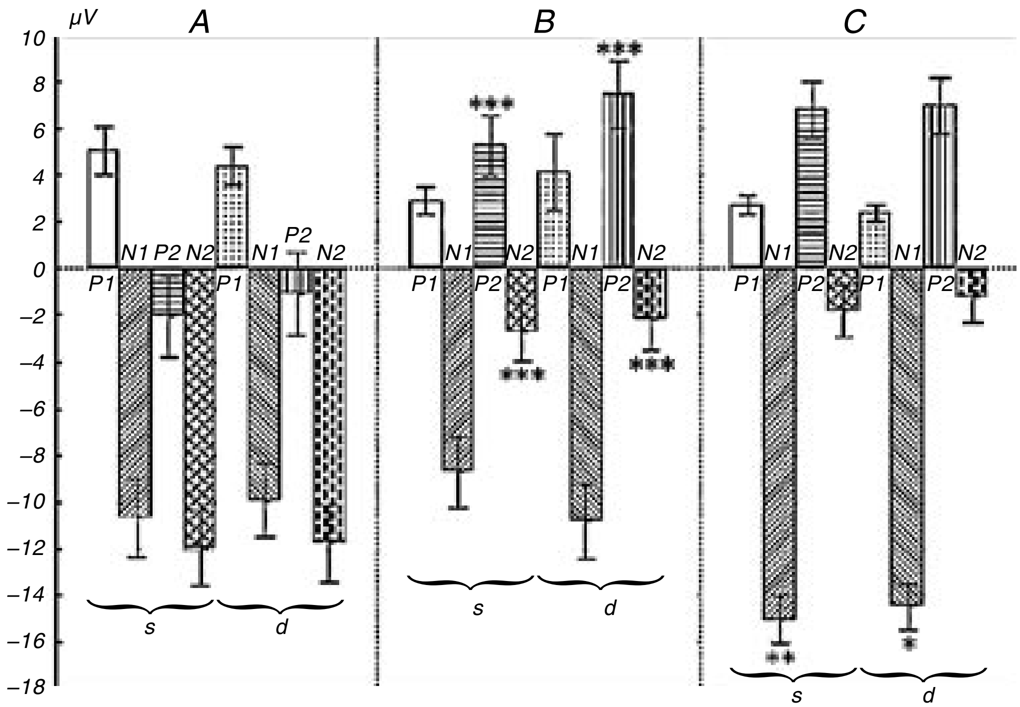

Fig. 3. Diagram of the amplitudes of the components of the evoked potentials (EP) related to perception of the preliminary acoustic signal in children of three age groups (A-C). A) Group 1 (5 to 7 years old), B) group 2 (10 to 12 years old), and C) group 3 (15 to 16 years old); *s* and *d* are left-side and right-side recordings, respectively. Means ± intergroup s.e.m. are shown. Asterisks indicate cases of significant differences from indices of the previous group; $^*P < 0.05$, $^{**}P < 0.01$, and $^{***}P < 0.001$.

TABLE 3. Coefficients of Correlation between Amplitudes/Latencies of EP Recorded from the Left (s) and Right (d) Brain Hemispheres and Indices of Attention in 45 Teenagers (15 to 16 Years Old)

EP parameters	“Work efficiency”	“Working in”	“Mental stability”
Amplitude of $P1_d$	–0.41**	0.11	–0.19
Latency of $P1_s$	–0.06	–0.32*	0.25
Amplitude of $P2_s$	–0.61***	–0.07	0.03
Amplitude of $P2_d$	–0.55***	–0.11	0.14
Amplitude of $N1\text{-}P2_s$	–0.45**	–0.15	0.26
Amplitude of $N1\text{-}P2_d$	–0.39**	–0.18	0.33*
Amplitude of $N2_s$	0.56***	0.23	–0.10
Amplitude of $N2_d$	0.38*	0.16	–0.19
Latency of $N2_s$	–0.36*	0.04	0.08
Amplitude of $P300_s$	–0.44**	0.14	–0.31*
Amplitude of $P300_d$	–0.46***	0.05	–0.21
Latency of $P300_s$	–0.25	0.29	–0.38**
Latency of $P300_d$	–0.18	0.24	–0.34*

Footnotes. $^{***}P < 0.001$. Other designations are the same as in Tables 1 and 2.

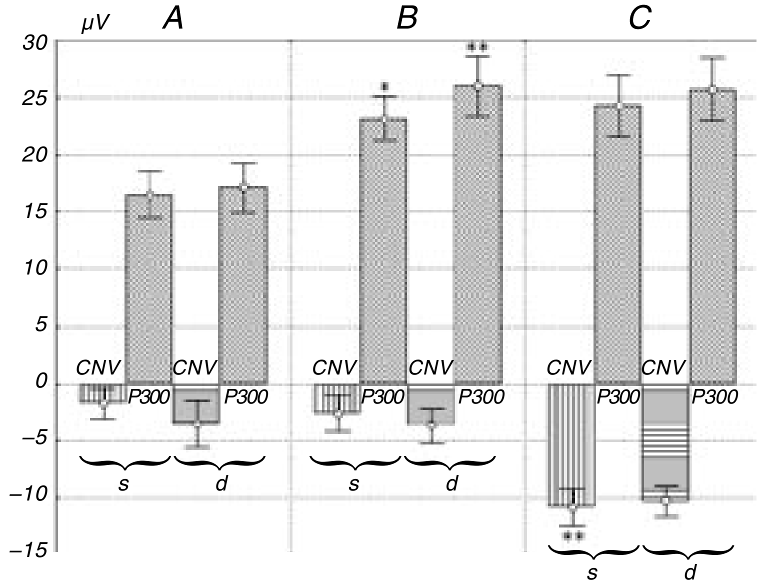

Fig. 4. Diagram of the amplitudes of the contingent negative variation (CNV) and P300 wave in children of three age groups (A-C). Designations are the same as in Fig. 3.

expressed and inverted EP waves. The correlation of high CNV amplitudes with optimum characteristics of attention is, probably, explained by the fact that the amplitude of this wave somehow reflects the levels of activity of the dopamine- and acetylcholinergic brain systems [23].

The above-described data allow us to present the age dynamics of the composition and characteristics of the complex of the EEG potentials (Figs. 1-4). The P1 and P2 components were sufficiently clearly manifested in all age groups, but a significant rise in the amplitude of P2 was evident with transition from 5-7 to 10-12 years. This is the reason for better manifestation of the vertex potential (N1 to P1 magnitude) in children of groups 2 and 3. According to the published data [15, 24], the P2 component reflects the process of inhibition of the activity in irrelevant channels of transmission of information, which “compete” for the attention resources and for further processing of this information. This is why we can suppose that effective mechanisms of coordination of information processing are intensely developed within the above time period.

The N2 potential was maximally manifested in 5- to 7-year-old children. We believe that a drop in the N2 amplitude with growing up is related to the development of the mechanisms of selective attention. In the course of growing up, detection of the relevant information begins to be performed at the earlier stages of information processing; presumably, this occurs synchronously to generation of the N1 and P2 components. In younger children, the mechanisms of early selection are not fully developed. This is why imperfect (excessively broad) focusing of attention (weak concentration), insufficient detection of the relevant information, and distraction of attention are typical of 5- to 7-year-old children [9-11, 20]. In addition, some researchers emphasize the existence of interrelations between these EP components with processes of categorization. In particular, Oades [15] believes that the amplitude of the N2 component is related to categorization of the stimuli; the above parameter decreases with age in a parallel manner with increased abilities to concentrate attention. The developing ability to perform categorization reflects the capability of rapidly detecting the most significant information, with no attention to excessive, insignificant, or irrelevant information. Thus, it is probable that the capacity for categorization is strictly related to the development of concentration of attention.

The CNV is unstably recorded in 5- to 7-year-old children; this wave dominates in the right hemisphere. The amplitude of CNV increases in teenagers and reaches its maximum (being somewhat greater in the left hemisphere) in 15- to 16-year-old children.

The P300 potential also reaches the maximum amplitude in the eldest age group (in teenagers). Adequate use of information on the result of a separate event (in our case, a motor act) allows

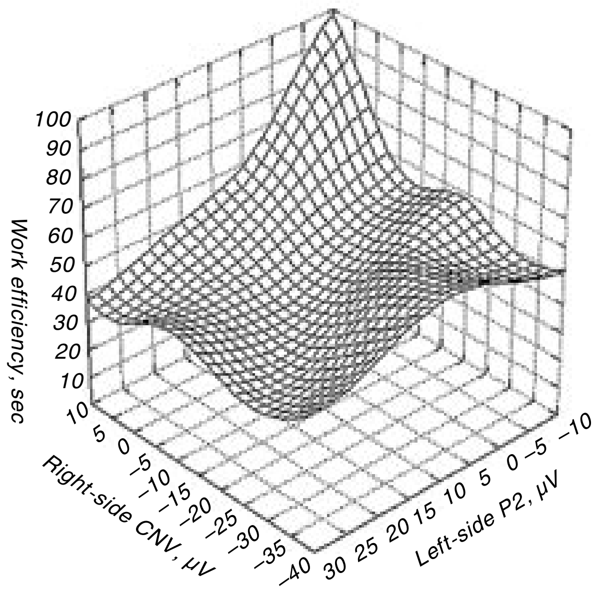

Fig. 5. Intercorrelations between the amplitudes of the contingent negative variation (CNV), component P2 of EP, and "work efficiency" index in 15- to 16-year-old teenagers. The correlation plane is plotted using the least-square technique.

the subject to provide the best efficiency of his/her activity. These mechanisms, however, reach a certain level of perfection only with growing up. Positive correlation of the P300 amplitude with characteristics of attention appeared only in elder teenagers. It seems that children only from this age begin to fully use the obtained information on the results of their actions for correction and integration of the mental efforts addressed to resolving an urgent task.

When recapitulating the above considerations, we can conclude that the development of the targeted behavior and corresponding resources of attention is a long-lasting process related to gradual improvement of different mechanisms of information processing. Each child's age is characterized by the development and domination of different mechanisms of attention, and this is reflected in the dynamics of interrelations between the parameters of EP and characteristics of attention. The development of these mechanisms with the growing up of a child provides earlier detection of the useful information from the informational continuum and better concentration of attention. This minimizes the load on the limited resources of the human mentality, makes faster information processing, and, consequently, allows the subject to more effectively resolve the behavioral tasks.

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