Correlations between Characteristics of Evoked EEG Potentials Recorded in a Go/No-Go Paradigm and Indices of Attention in Children

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We studied correlations of the parameters of evoked EEG potentials (EPs) with the indices of attention in 30 children (12 years old). The EP were recorded in a two-stimulus go/no-go paradigm; the time of reaction was also measured. The indices of attention were measured using a Burdone test (correction trial) and Schulte's tables. Optimum characteristics of attention were found in children with high amplitudes of the P2 component, P300 wave, and contingent negative deviation, low amplitudes of the N2 component, and small values of the latencies of the P1–N1–P2 complex.

Keywords: evoked potentials, go/no-go paradigm, attention, time of reaction.

INTRODUCTION

The necessity for studying the level of development of attention in children and teenagers is to a great extent determined by the existence of problems related to rather frequent disorders of attention in the above age groups. The attention deficit/hyperactivity syndrome is now one of the most widespread disorders. Such an attention disorder is observed in 5 to 20% of the entire population of children and teenagers [1]. Diagnostic criteria that allow one to estimate the level of development of attention both in healthy children and those suffering from attention deficit have still not been developed to a satisfactory extent. This is why we examined the correlations between the components of evoked EEG potentials (EP) and the indices of voluntary attention in children of middle school age.

It is believed that relatively long-latency EP components (P1, N1, P2, N2), contingent negative deviation (CND), and P300 potential are the most informative electrographic phenomena with respect to information processing at the level of higher CNS structures. It was demonstrated that the characteristics of these potentials correlate with cognitive processes and disorders of the latter [2-4]. An earlier study [5] demonstrated the existence of correlations between the characteristics of EPs and the attention indices under conditions of measurement of the time of a simple sensorimotor reaction with presentation of two signal stimuli. In the study described below, we examined the correlations between the EP characteristics measured within the framework of a go/no-go paradigm and the indices of attention. We believe that realization of go/no-go tests with parallel recording of EPs allows us to more differentially diagnose the level of development of voluntary attention and to estimate such an index as impulsivity; such tests should be considered preferred compared to corresponding measurements under conditions of estimation of the time of a simple sensorimotor reaction.

METHODS

Thirty healthy 12-year-old children, 15 boys and 15 girls, were examined in the course of the tests.

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A modification of the two-stimulus go/no-go paradigm was used for recording of the EP complex [6, 7]. Pairs of the stimuli, a warning stimulus and a stimulus initiating or forbidding the motor response, were presented. The subject prepared to perform the response after the warning stimulus and pushed a button after the permitting stimulus (a go trial) or declined to push after the forbidding stimulus (a no-go trial). Our modification of the paradigm differed from others in such a feature. In addition to the warning stimulus and the stimulus, which permitted or forbade a motor response, we presented a feedback signal informing the subject on the correct or erroneous performance of the task (a vertical or a horizontal bar shown on an indicator board, respectively).

Thirty pairs of acoustic tone stimuli of different frequencies (high/high, high/low, low/low, and low/high) were presented to the tested children; intrapair and interpair intervals were 2 and 4 sec long, respectively. These low- and high-frequency stimuli (400 and 1,000 Hz) were 200 msec long. Pairs of the stimuli were presented in a randomized order with a nearly equal (close to 50%) probability of presentation of the low and high tones. The subjects were to push the button with the right hand with a time of reaction (TR) shorter than 380 msec when pairs of high-frequency or low-frequency stimuli were presented and should perform no reaction in the case of pairs of signals of different frequencies. Among 30 pairs of stimuli, 13 to 17 pairs were significant (permitting reaction).

Estimates of the correctness of the performance of the two-stimulus test were measured. We calculated the number of missed significant pairs of stimuli (low/low and high/high); these errors were considered to be related to inattention. The number of erroneous reactions after insignificant pairs forbidding pushing of the button (low/high or high/low) characterized the errors related to impulsivity. In addition, the mean TR value was measured for each subject.

The EPs were recorded using standard techniques (a set including an encephalograph, an interface, and a computer); the working program "ERP-2" was developed by V. Arbatov. Potentials were monopolarly recorded from F3, F4, C3, C4, P3, P4, T3, T4, O1, and O2 leads, according to the 10-20 system. Connected contacts above the *proc. mastoidei* served as a reference electrode. Signals were digitized at 500 sec^{-1}. Two additional channels of the encephalograph (C3 and C4 leads) were used to record the CND; these channels were modified to expand the frequency band of amplifiers.

The general pattern of the complex of averaged EPs accompanying the performance of the go/no-go test by one of the subjects is shown in Fig. 1. The components P1, N1, P2, N1-P2 (a vertex potential), and N2 were considered long-latency components of the exogenous auditory EPs and recorded at presentations of each warning (first in the pair) signal; the frequency band of amplifiers in these cases was 0.53 to 70 Hz. The P300 potential was recorded at presentations of all visual feedback signals, with the same frequency band of amplifiers. The CND generated within an interval between presentations of two stimuli (warning and imperative ones) and reflecting the processes of preparing for the behavioral act were recorded using a 0.016 to 70 Hz frequency band. In the course of analysis of all components of the EP complex, all realizations were averaged, including those where the task was performed erroneously (missing of the significant pair of stimuli, erroneous pushing after presentation of the insignificant pair, or a TR greater than the limit value). Thus, all realizations with no artifacts (usually, 25 to 27 of 30) were averaged.

The maxima of the analyzed EP components corresponded to the following time intervals: P1, 50 to 100 msec; N1, 100 to 150 msec; P2, 150 to 250 msec; N2, 200 to 300 msec, and P3, 250 to 500 msec after presentation of the signal. The amplitudes of the following CND phases were measured: an integral CND (CND_i), within 300 to 2,000 msec from presentation of the first signal in the pair of stimuli; an orientation CND (CND_o), within 300 to 1,000 msec from the first signal in the pair; and a terminal CND (CND_t) reflecting the readiness to the stimulus-related reaction, within 1,000 to 2,000 msec from the moment of the first signal in the pair.

Indices of attention were estimated using the following techniques. Such indices as "efficiency of the work," "involvement in the work," and "mental stability" were measured using Schulte's tables. According to this system of testing [8], the smaller the values of these indices, the more perfect the level of attention.

To measure the "efficiency of attention" and "accuracy of attention" indices, we used a version of Burdone's correction test [9]. Children were asked to cross out within a 5-min-long period the symbols "K" and "P" (letters of the cyrillic alphabet) distributed randomly among other letters of the alphabet. The indices were calculated in the following way. "The efficiency of attention" index was characterized by the number of symbols analyzed within the above time interval, and the "accuracy of attention" was equal to the ratio of the number of correctly crossed symbols and the number of symbols that should be crossed out (%). It is obvious that the higher values of the above indices, the more developed and effective the attention of the subject.

Numerical indices of the electrographic phenomena and data of the psychophysiological tests were processed using standard statistical approaches. To characterize correlations, we used Spearman's coefficient of range correlation.

Other details of the experiments (including calculation of the attention indices with the use of Schulte's tables) were described earlier [5].

RESULTS AND DISCUSSION

The mean TR in the studied group of children was 348.8 ± ± 14.7 msec (hereafter we show the means ± s.e.m.). In boys, the mean TR was 315.8 ± 12.1 msec, while in girls this index was noticeably longer (381.9 ± ± 18.4 msec).

The "efficiency of attention" index in boys was 850 ± ± 32 symbols; "accuracy of attention," 94.0 ± 0.9%; "efficiency of the work," 51.6 ± 3.2 sec, "involvement in the work," 1.02 ± 0.05; "mental stability," 0.99 ± ± 0.04; "errors of missing the significant stimuli," 0.9 ± 0.6; and erroneous (incorrect) reactions, 12.2 ± ± 5.3. In girls, the corresponding set of indices was as follows: 815.0 ± 27.1 symbols, 96.5 ± 0.5%, 44.2 ± ± 1.2 sec, 1.03 ± 0.04, 0.99 ± 0.04, 0.3 ± 0.03, and 7.9 ± 3.2. These data show that girls performed the test tasks somewhat more slowly than boys, but concentration of attention was better in girls.

Analysis of the correlations between latent periods of the EP components and the "errors of missing of the significant stimuli" index is illustrated by

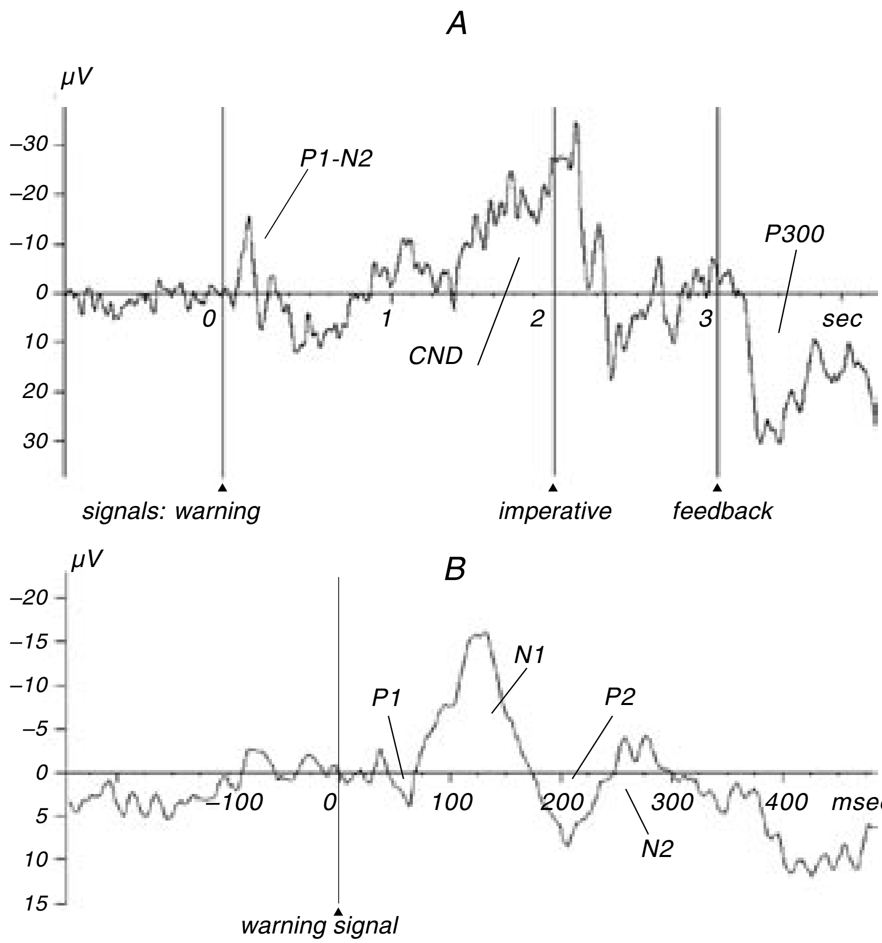

Fig. 1. General pattern of a complex of the averaged evoked potentials (EPs) recorded from the central region of the left hemisphere under conditions of the go/no-go test performed by one of the tested subjects (A) and potentials elicited by presentation of a warning acoustic signal (B). Averaging of 27 trials. P1, N1, P2, and N2 are components of the EPs related to the warning acoustic signal; CND) the contingence negative deviation; P300) the wave related to perception of the feedback signal. Moments of presentations of the acoustic warning and imperative signals and feedback signal are shown below.

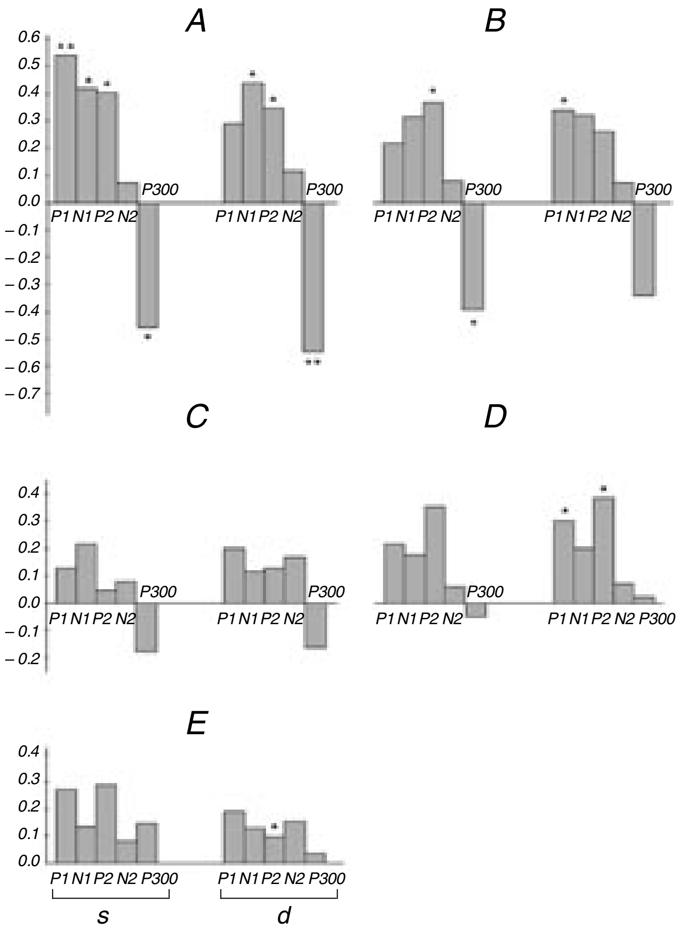

Fig. 2. Mean values of the coefficients of correlation of the "errors of missing of significant stimuli" index with the peak latencies of evoked potentials recorded from the frontal (A), central (B), temporal (C), parietal (D), and occipital (E) zones of the left (s) and right (d) hemispheres in the group of 30 children (12 years old). One and two asterisks show significance levels for the correlation coefficients, $P < 0.05$ and $P < 0.01$, respectively. Other designations are the same as in Fig. 1.

Fig. 2. Positive correlations show that subjects with insufficient concentration of attention are characterized by greater values of the peak latencies of P1, N1, and P2 waves. The latent periods of the P300 wave in the frontal regions of both hemispheres and in the central region of the left hemisphere negatively correlated with the above index. Therefore, correlation analysis shows that, in general, subjects with well-concentrated attention are characterized by smaller latencies of the P1-N2 complex and greater values of the P300 latency.

We should note that a number of experimenters, when recording EPs in the odd-ball paradigm, obtained opposite results [10-12]; a higher level of development of cognitive processes correlated with small values of the P300 latency generated after presentation of a target stimulus. As is known, recording of the so-called endogenous EP components (event-related potentials, ERPs) produced in response to rare target signals presented against the background of relatively frequent perception of non-target signals is a key aspect of the above-mentioned paradigm. It should be taken into account that, within the framework of the classic odd-ball paradigm, the P300 wave reflects the process of appraisal of the signal resulting in the formation of the conclusion, to perform the motor act or not to perform it. Thus, the relatively small values of the latency of the P300 potential are indicative of the ability of the individual to rapidly process the information. At the same time, the P300 potential within our experimental paradigm developed to presentation of the feedback signal. Therefore, the latency of the P300 in this case characterized the time necessary for realization and appraisal of the results of the test. It is obvious that when the latency of the P300 wave is shorter, the information on the results of the action of the subject, which is obtained via the feedback signal and used for correction and calculation of the attention resources addressed to realization of the task, is used less perfectly. Subjects with shorter latencies of the above wave are less disposed to the analysis of the feedback information and less effectively distribute their mental resources.

All the EP components under study were most clearly manifested in the central leads. The diagram of the amplitudes of the components of EPs recorded in these leads is shown in Fig. 3A. When recorded from the central region of the left hemisphere, the amplitude of the P2 wave related to perception of the warning signal negatively correlated with the "efficiency of the work" index and, consequently, positively correlated with the level of voluntary attention (B). Our findings agree with the data on the auditory EP in children of different ages (recording under conditions of the odd-ball paradigm). According to this study [13], the amplitude of P2 positively correlates with the level of maturity of the brain. Such a dependence was also found when EP were recorded within the framework of the paradigm of a simple sensorimotor reaction [5].

Better characteristics of the stability of attention (smallest values of the index "mental stability") were found in subjects with the minimum latencies of the N1 component in central leads of the left and right hemispheres ($r = 0.43$, $P < 0.05$ and $r = 0.47$, $P < 0.05$, respectively).

The peak latency of the P2 component recorded from the right hemisphere in the central and temporal regions was in a positive correlation with the index "mental stability" (C4, $r = 0.4$, $P < 0.05$ and T4, $r = 0.48$, $P < 0.05$). The amplitude of the vertex N1-P2 potential recorded from the temporal region of the right hemisphere negatively correlated with the above index ("mental stability"; $r = -0.44$, $P < 0.05$), i.e., greater amplitudes of the vertex potential correlated with higher characteristics of the ability to work.

We found negative correlations of the amplitude of the N2 wave in the frontal and central parts of the right hemisphere and in the parietal region of the left hemisphere with such an index as the "accuracy of attention" (F4, $r = -0.44$, $P < 0.05$; C4, $r = -0.51$, $P < 0.01$; and P3, $r = -0.45$, $P < 0.05$). It is believed that the development of the N2 wave is related to the activity of the mechanisms responsible for selection of information. When selective attention is better developed, the amplitude of the above wave is lower [12, 14]. In addition, correlation of characteristics of the mentioned EP component with the processes of categorization of information was found in some studies. In particular, Oades [15] reported that the amplitude of N2 is related to categorization of the stimuli and drops with the development of concentration of attention. Thus, it is believed that some defocusing of attention is typical of individuals with a well-developed N2 wave.

Optimum characteristics of attention also correlated with greater amplitudes of the P300, CND_i, and CND_t in central leads of both hemispheres and with a greater amplitude of the P300 wave in the parietal region of the left hemisphere (P3, $r = -0.43$, $P < 0.05$). For EPs recorded from these leads, negative correlations of the above components with the "efficiency of work" index were typical (Fig. 3B). The greatest amplitude of the P300 fluctuation is known to be observed in those persons who perform the task better and are characterized by a higher cognitive maturity [16].

The CND_t is believed to be related to preparation for the motor act and to the activity of the mechanisms of pre-stimulus anticipating attention. The term "anticipation" determines pretuning, i.e., formation of a notion on the result of one process or another, which is created before actually reaching this result. The functional significance of this phenomenon is that it facilitates and accelerates identification of the target [13]. Processes of pretuning are controlled with the involvement of the prefrontal cortex, one of the crucial structures responsible for voluntary attention [17]. Thus, the above endogenous EP components (ERPs) can be considered the main objective

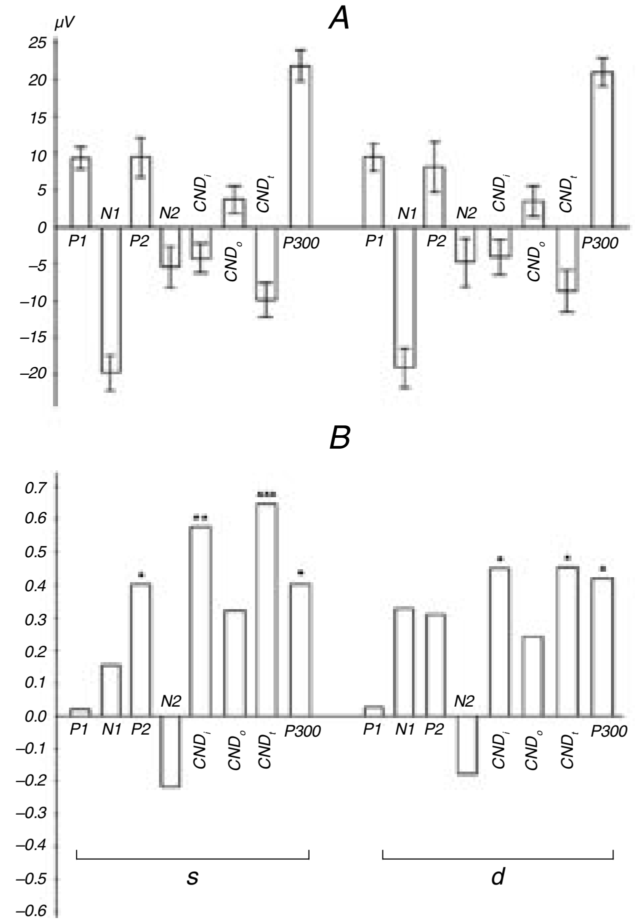

Fig. 3. Diagrams of the amplitudes of the EP components recorded from the central zone of the left (s) and right (d) hemispheres (A) and values of the coefficients of correlation (CCs) between this parameter and the level of development of voluntary attention (B) in 30 children. In A, means ± s.e.m. are shown. In B, the CCs for the EP amplitudes and "efficiency of the work" index; negative values of the CC are plotted upward, to illustrate a positive correlation of the EP amplitudes with the level of voluntary attention. One, two, and three asterisks show the cases with $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively. Other designations are similar to those in Figs. 1 and 2.

neurophysiological indices characterizing the level of development of voluntary attention and anticipation.

It should be emphasized that correlations of the parameters of CND and P300 with the characteristics of attention, which were found in our study, achieved statistical significance. This fact distinguishes our data from the results of our earlier measurements of the time of a simple sensorimotor reaction [5]. This feature can be explained in the following way. Within the framework of the go/no-go paradigm, the subject should selectively react to the presented pairs of stimuli. In some cases, he/she should initiate the motor act (push the button), while in other cases it is necessary to actively suppress the response, which has been just prepared. Such a task needs a greater involvement of the processes of voluntary attention. This approach differs from recording of EPs combined with the measurement of the time of a simple sensorimotor reaction; the latter technique does not allow the experimenter to diagnose features of selective attention of the subject to a full extent. Only the rate of cognitive processes can be estimated in such a mode more adequately. Yet, we should take into account that the central problems of attention disorders are related just to an insolvency or an insufficient development of the mechanisms of selection of definite programs and initiation *vs* suppression of their switching on. The latter situation is especially typical of persons with the attention deficit/hyperactivity syndrome [12, 14, 15].

Our experimental situation is close to the odd-ball but differs from it by a higher probability of presentation of the target signals requiring the performance of the motor reaction. This is why the used go/no-go paradigm determines certain stereotypization of the motor responses, which in turn needs especially significantly increased attention of the subject to avoid erroneous reactions to presentations of non-target signals. This circumstance allows us to interpret such an experimental situation as significantly related to the functioning of the frontal cortex [18]. Studies with the use of a tomographic technique showed that selective voluntary reactions initiated by a strictly definite feature of the object are based on activation of the frontal cortical regions, i.e., the structures controlling voluntary attention. This can be observed in the course of performance of both reactions of selection (go/no-go) and more complicate tasks, where features of the object, which attract attention, compete with nonrelevant features [19, 20]. Such an experimental strategy allows one to more adequately identify disorders of the control functions and to detect inattention and impulsivity related to the insufficiency of inhibition of sensory and cognitive actions and weakness of selective responsiveness to the appearance of relevant stimuli.

The results of our study show that indices of attention demonstrate definite correlations with the characteristics of EEG phenomena. The optimum features of attention were observed in children with maximum amplitudes of the P2 component, P300 waves, and CND, a minimum amplitude of the N2 component, and short latencies of the P1-N1-P2 complex. We believe that recording of EPs under conditions of the go/no-go paradigm possesses obvious advantages and can be rather effectively used for detection of objective indices characterizing attention-related processes. In particular, it allows one to diagnose the state of the sphere of attention in more detail than recording of EPs with measurement of the time of simple sensorimotor reactions.

REFERENCES

1. E. V. Kasatikova, N. P. Larionov, and I. P. Bryazgunov, "A study of the distribution of the development of the attention deficit/hyperactivity syndrome and the respective indices of attention and risk factors in schoolchildren," *Pediatriya*, No. 5, 73-75 (1999).
2. V. V. Gnezditskii, *Evoked Brain Potentials in Clinical Practice* [in Russian], Publ. House of the Taganrog. Univ., Taganrog (1997).
3. É. M. Routman, *Evoked Potentials in Psychology and Psychophysiology* [in Russian], Nauka, Moscow (1979).
4. C. Miniussi, E. L. Wilding, J. T. Coull, and A. C. Nobre, "Orienting attention in time. Modulation of brain potentials," *Brain*, **122**, 1507-1518 (1999).
5. V. B. Pavlenko, N. V. Lutsyuk, and M. V. Borisova, "Correlation of the characteristics of evoked EEG potentials with individual peculiarities of attention in children," *Neurophysiology*, **36**, No. 4, 276-285 (2004).
6. V. A. Ponomarev, O. V. Kropotov, Yu. D. Kropotov, and Yu. I. Polyakov, "Desynchronization and synchronization of EEG in children evoked by stimuli switching on or prohibiting a sensorimotor reaction," *Fiziol. Cheloveka*, **36**, No. 3, 5-12 (2000).
7. Yu. D. Kropotov, V. A. Grin'-Yatsenko, L. S. Choutko, et al., "Treatment of children with attention disorder/hyperactivity syndrome using the technique of EEG biological feedback," *Ross. Vest. Perinatol. Pediat.*, No. 3, 37-40 (2002).
8. L. N. Kuleshova, *Attention. A Manual on General, Experimental, and Applied Psychology* [in Russian], Piter, Saint. Petersburg (2000).
9. E. I. Rogov, *A Manual for Practicing Psychologists in the Educational Field* [in Russian], VLADOS, Moscow (1995).
10. J. Polich, C. Ladish, and T. Burns, "Normal variation of P300 in children: age, memory span, and head size," *Int. J. Psychophysiol.*, **9**, 237-248 (1990).
11. J. Polich and A. Kok, "Cognitive and biological determinants of P300: an integrative review," *Biol. Psychol.*, **41**, 103-146 (1995).
12. R. J. Barry, S. J. Johnstone, and A. R. Clarke, "A review of electrophysiology in attention-deficit/hyperactivity disorder: II. Event-related potentials," *Clin. Neurophysiol.*, **114**, 184-198 (2003).
13. R. Naatanen, *Attention and Brain Functions* [in Russian], Publ. House of Moscow State Univ., Moscow (1998).
14. S. J. Johnstone, R. J. Barry, and J. W. Anderson, "Tomographic distribution and developmental time-course of event-related potentials in two subtypes of attention hyperactivity disorder," *Int. J. Psychophysiol.*, **42**, No. 1, 73-94 (2001).

15. K. D. Oades, "Frontal, temporal and lateralized brain function in children with attention-deficit hyperactivity disorder: a psychophysiological and neuropsychological viewpoint on development," *Behav. Brain Res.*, **94**, 83-95 (1998).
16. S. J. Johnstone, R. J. Barry, J. W. Anderson, and S. F. Coyle, "Age-related changes in child and adolescent event-related potential component morphology, amplitude and latency to standard and target stimuli in an auditory odd-ball task," *Int. J. Psychophysiol.*, **24**, No. 3, 223-238 (1996).
17. R. A. Sieb, "A brain mechanism for attention," *Med. Hypoth.*, **33**, 145-153 (1990).
18. H. S. Levin, K. A. Culhane, and J. Hartmann, "Developmental changes in performance on tests of purported frontal lobe functioning," *Dev. Neuropsychol.*, **7**, 377 (1991).
19. A. Dove, S. Pollmann, and T. Schubert, "Prefrontal cortex activation in task switching: an event related fMRI study," *Brain Res. Cogn. Brain Res.*, **9**, 103-119 (2000).
20. M. T. Banich, M. P. Milham, and R. A. Atchley, "Prefrontal regions play a predominant role in imposing an Attentional 'set': evidence from fMRI," *Brain Res. Cogn. Brain Res.*, **10**, 1-9 (2000).