Reflection of Anxiety in the Characteristics of Evoked EEG Potentials in 10- to 11-Year-Old Children

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Neirofiziologiya/Neurophysiology, Vol. 41, No. 6, pp. 513-521, November-December, 2009.

Received September 11, 2009.

We studied the peculiarities of the amplitude/time parameters of evoked EEG potentials (EPs) and event-related potentials (ERPs) in 10- to 11-year-old children characterized by low and high anxiety levels. The latter levels were estimated using the scale of the manifest anxiety test of Prikhozhan and projective techniques ("House–Tree–Person," HTP, and the Lüscher color test). For children with a high anxiety level, the amplitudes of the following EP components and ERPs were lower than those in low-anxiety children of the same age: P1 (predominantly in the occipital region of the left hemisphere), P2 (in the right occipital region), and P300 wave (in different loci of both hemispheres). In high-anxiety children, we also more frequently observed increased amplitudes of the N2 component in the left parietal and right occipital regions. High-anxiety individuals were characterized by longer latencies of component P1 (mostly in the right frontal and left central regions) and, at the same time, shorter latencies of component N1 (in the parietal and occipital regions of the left hemisphere and also in the right temporal region). Thus, we found that the amplitude/time characteristics of a few EP components and ERPs in children with high anxiety levels differ statistically significantly from the parameters of corresponding EPs/ERPs in individuals of the same age but with low anxiety levels.

Keywords: EPs, wave P300, anxiety, children, Prikhozhan's questionnaire, "House–Tree–Person" test Lüsher's test.

INTRODUCTION

The problem of abnormally high personal anxiety is extremely urgent in modern life. Different aspects of this problem have been studied by a number of neuropsychologists, psychophysiologists, and neurophysiologists. A high level of personal anxiety correlates with a high variety of cognitive, affective, and behavioral peculiarities of humans [1]. An excessive increase in the anxiety level promotes the development of a variety of clinical/subclinical forms of neurological and mental disorders (panic attacks, phobias, depressions, etc.) [2]. At present, a few researchers emphasize that the number of children and teenagers with increased anxiety levels (furtheron, high-anxiety) has increased noticeably [3].

High anxiety in children can have no clear obvious manifestations, but its consequences are rather serious. It is sufficient to mention the high risks of development of psychosomatic diseases and of the formation of addictive and delinquent behavior in teenagers. A high anxiety level influences not only the emotional and behavioral spheres but also the cognitive sphere. Thus, it is natural to believe that such a situation in children will negatively affect realization of the functions of thinking, memory, voluntary attention, and, correspondingly, the formation of different abilities and skills and learning success in school. This is why research into the phenomenon of high anxiety developed within the prepubertal period is of especially high importance.

Methods of objective estimation of the electrical activity of the brain, including recording of evoked EEG potentials (EPs), begin to play a more and more important role in the study of cerebral mechanisms underlying higher mental functions and in the objective diagnostics of the state of cognitive and emotional spheres of personality. In many publications, the term EP is attributed to discrete EEG potentials elicited by the presentation of definite external stimuli and being in sufficiently strict time relations with the latter. A group of EEG potentials that are specifically related to some phenomena of the behavioral and/or cognitive activity and do not necessarily correlate directly

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with external stimuli is usually qualified as event-related potentials, ERPs [4]. In the English-language literature, there is a trend toward general avoidance of the term “EP,” and all discrete EEG potentials correlating with any events, both external (action of stimuli) and internal ones, are qualified as ERPs. We shall not specially discuss this question because this is out of the scope of our study. We would like only to note that some aspects typical of the ERPs can be manifested in a majority of the EP components elicited by sensory (in our case, acoustic) stimulation; these components (among them, even early ones) can hardly be called “purely sensory” EEG phenomena. At the same time, late components of such EPs (under our conditions, the P300 wave) can be qualified as ERPs with no reservations.

It was reported that the characteristics of an N1 EP component strictly related to primary processing of sensory information demonstrate, at the same time, a noticeable correlation with emotional strain; the amplitude of this wave is greater in subjects with high anxiety levels [5]. Typical changes in the amplitude/time parameters of a “classic” ERP, the P300 wave, were observed in the case of high-anxiety/phobic disorders [6, 7].

The number of studies focused on the correlations between the anxiety level and the peculiarities of EPs and ERPs in children is at present rather limited. In particular, the question on the relation between the EP and ERP parameters recorded within the framework of the go/no go paradigm (one of the most effective in EP studies) and the level of anxiety in children estimated using direct psychological testing has not been examined. Considering all the above-mentioned, in our study we tried to elucidate the dependence between the amplitude/time characteristics of EPs and ERPs recorded using the above paradigm (go/no go) in 10- to 11-year-old children and the level of anxiety in these subjects. The practical aspect of such a work is obvious; we tried to identify a set of parameters that can serve as an objective correlate in the identification of children with an increased level of anxiety.

METHODS

Thirty-one reasonably healthy 10- to 11-year-old children (among them 15 boys and 16 girls) took part in the study. Twenty-eight subjects were dextrals, while three subjects were sinistrals. Thus, the proportion of sinistrals was rather small, and the parameters of EPs and ERPs of this subgroup are hereafter analyzed together with the indices of all the other children.

A two-stimulus go/no go paradigm was used for recording the EPs and ERPs; the ERP-2 software used in the tests was developed by V. Arbatov. Thirty pairs of auditory stimuli were presented to the tested subjects; these were two tonal segments of dissimilar frequencies with 2-sec-long intrapair and 4-sec-long interpair intervals. Pairs of the stimuli were presented in a randomized order with a similar (close to 50%) probability of arrival of both high- and low-frequency tones. The task proposed to the subject was the following. The subject should press a button with the leading hand after presentation of the second signal in a pair of stimuli of identical frequency, either low or high. The latency of the motor reaction should not exceed a standard value. At the same time, the subjects were asked not to react to the signal pairs if the stimulus tones were different. The initial standard latency was set at 380 msec, but later on, after the first and all other subsequent reactions of the subject, the latency value was calculated as the median of the values of all sensorimotor reactions of the subject demonstrated in the preceding realizations. Thus, the standard time of reaction was individual because it was a value calculated separately for the tested subject, and it was changed in the course of the task performance. After each pressing of the button, the calculated value of the pre-set latency was compared with the current value of the latency shown by the subject. If this value was smaller than the standard value or equal to it, the task was considered to be successfully performed; in other cases, it was qualified as a failure. Such a technique allows us to automatically “tune up” the difficulty of the task performance to each subject; this approach within the framework of EP recording seems more correct to us, as compared with the case where the standard latency is taken as a fixed value [10]. Probably, such an approach is also preferable when compared with the estimation of the standard time of the reaction as the mean for all reactions of the subject; in our case, the effects of extremum (maximum and minimum) values of the reaction times shown by the subject were eliminated to a considerable extent.

The subject was provided with a feedback signal informing about the successful/unsuccessful performance of the task; correspondingly, a vertical or a horizontal bar was presented on a light-emitting diode matrix.

The technique of EP recording was routine; a computerized complex including an encephalograph, a laboratory interface, and a PC was used. The potentials were recorded from leads F3, F4, C3, C4, P3, P4, T3, T4, O1, and O2 according to the 10-20 system. Connected contacts placed above the *proc. mastoidei* served as a reference electrode.

The EP components P1, N1, P2, N1-P2 (vertex potential), and N2 were recorded after presentations of all warning (the first ones in the pair) signals, and the P300 potential was recorded after presentation of all visual feedback signals. The maxima of the analyzed EP components were found within the limits of 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 P300, 250 to 500 msec after signal presentations. Other details of recording and measurement/calculation of the EP and ERP characteristics were described earlier [10].

The levels of anxiety in children were estimated using the scale of the manifest anxiety test of Prikhozhan and two projective techniques, "House–Tree–Person" (HTP) and Lüscher's color test.

The scale of the manifest anxiety test proposed by Prikhozhan [11] is designed for estimation of the anxiety level as a relatively stable characteristic in 7- to 12-year-old children. A questionnaire used in this technique includes 53 questions related to the sphere of behavior and feelings of the child. The latter can answer this question in a binary mode, either positively or negatively. The answers are estimated in points. The greater the final index obtained by summation of the points in all questions, the higher the measured anxiety estimate for the child.

When using the projective HTP technique [12], the subject should draw, as well as possible, a house, a tree, and a person. Each proposed object is drawn on a separate part of the sheet. This method allows the researcher to obtain a quantitative estimate of the anxiety level in points depending on the presence or absence in the picture of definite qualitative details (e.g., a cloud, a clearly expressed dashing of some parts, intensely colored hairs of the person shown, etc.). These details, within the framework of the above technique, are considered as being correlated with an anxiety-related complex of symptoms.

The Lüscher's test is based on individual emotional perception of different colors. When using this test, the subject is asked to classify colors in eight presented cards in order of this preference. According to the selection, each color is designated by a number; then, using a special formula, the estimate of the anxiety level for the subject is calculated in points [13].

Data of the electrophysiological study and indices of the psychological tests were treated using standard techniques of variational statistics. The presence/absence of correlations and the intensity of the latter were characterized based on calculations of the coefficients of range correlation by Spearman. To estimate the significance of differences between groups, we used the Mann–Whitney test.

RESULTS AND DISCUSSION

Our study included calculation of mean estimates of the levels of anxiety within the examined group using all the above separate techniques of psychological testing. Depending on the obtained means, the subjects were classified into subgroups with low and high indices according to each test. Individuals with minimum to mean (inclusive) values were included in the low-anxiety group, while subjects with indices exceeding the mean intragroup value were classified as high-anxiety individuals (Table 1). Differences in the anxiety levels between boys and girls did not reach the level of significance; therefore, children regardless of sex were included in the above subgroups of low- and high-anxiety persons.

When the children were divided according to the scale of Prikhozhan's manifest anxiety test, the following pattern was observed. High-anxiety individuals were characterized by significantly higher values of the amplitude of the vertex potential N1-P2 (in F3, $P = 0.010$; F4, $P = 0.014$; C3, $P = 0.012$; C4, $P = 0.016$; P3, $P = 0.028$; and T3, $P = 0.004$) and

TABLE 1. Estimates of the Anxiety Levels (Points) Estimated using Different Techniques in the Examined Group of 10- to 11-Year-Old Children ($n = 31$) and also in the Subgroups of Children with Low and High Anxiety Levels

Methods for estimation of the anxiety level	All tested children (n=31)	Low-anxiety individuals	High-anxiety individuals
Manifest anxiety test of Prikhozhan	15.45 ± 1.26	10.29 ± 0.87 (n = 17)	21.71 ± 1.20 (n = 14)
House–Tree–Person (HTP) test	4.40 ± 0.38	3.31 ± 0.25 (n = 21)	6.70 ± 0.55 (n = 10)
Lüscher's test	4.13 ± 0.50	2.73 ± 0.23 (n = 22)	7.56 ± 0.88 (n = 9)

Footnote. Means ± s.e.m. are shown.

by smaller latencies of the N1 (in P3, $P = 0.015$; O1, $P = 0.047$; and T4, $P = 0.038$). The latter peculiarity, however, was combined with greater values of the latency of component N2 (in leads F3, $P = 0.016$, and O1, $P = 0.013$), as compared with the analogous indices in low-anxiety children of the same age. Correlation analysis showed the existence of a negative correlation between the anxiety level estimated by Prikhozhan and the latencies of potential N1 (in P3 and T3, $P = 0.050$ in both cases; T4, $P = 0.001$, and O1, $P = 0.003$) but failed to detect statistically significant correlations between the estimate of the anxiety level within the framework of the mentioned test and the latency values for oscillation N2 and the amplitude of the vertex potential N1-P2.

When the subjects were divided into two groups according to the anxiety level estimates in the HTP test, differences between the EP patterns typical of children with dissimilar values of this index were also found. Figure 1 shows examples of the averaged EPs in two children significantly differing from each other in the anxiety level determined using the above test. As can be seen, the subject with a high anxiety estimate demonstrated considerably lower amplitudes of components P1, N1, and P2, while the amplitude of component N2 in this individual was greater than that in a low-anxiety boy of the same age.

In general, the subgroup of the children with high estimates of the anxiety level obtained using the above testing technique showed statistically significantly lower amplitudes of oscillations P1, P2, and wave P300 and a significantly higher mean amplitude of potential N2 than the respective indices in the low-anxiety individuals (Fig. 2). The mean amplitude of the vertex potential N1-P2 was also significantly smaller in the high-anxiety subgroup, as compared with such value in the low-anxiety children subgroup (in leads P4 and O2, $P = 0.025$ in both cases). At the same time, we found no significant statistical difference for the amplitude of the N1 component between the low-anxiety and high-anxiety children and no correlation of this parameter with the anxiety level.

We should also note that subjects of the subgroup demonstrating high estimates of the anxiety level determined by the HTP technique showed a significantly longer average time of reaction in the go/no-go test ($P = 0.025$), as compared with the analogous value in the low-anxiety children subgroup. In the latter subgroup, the mean latency of the reaction was 370.8 ±

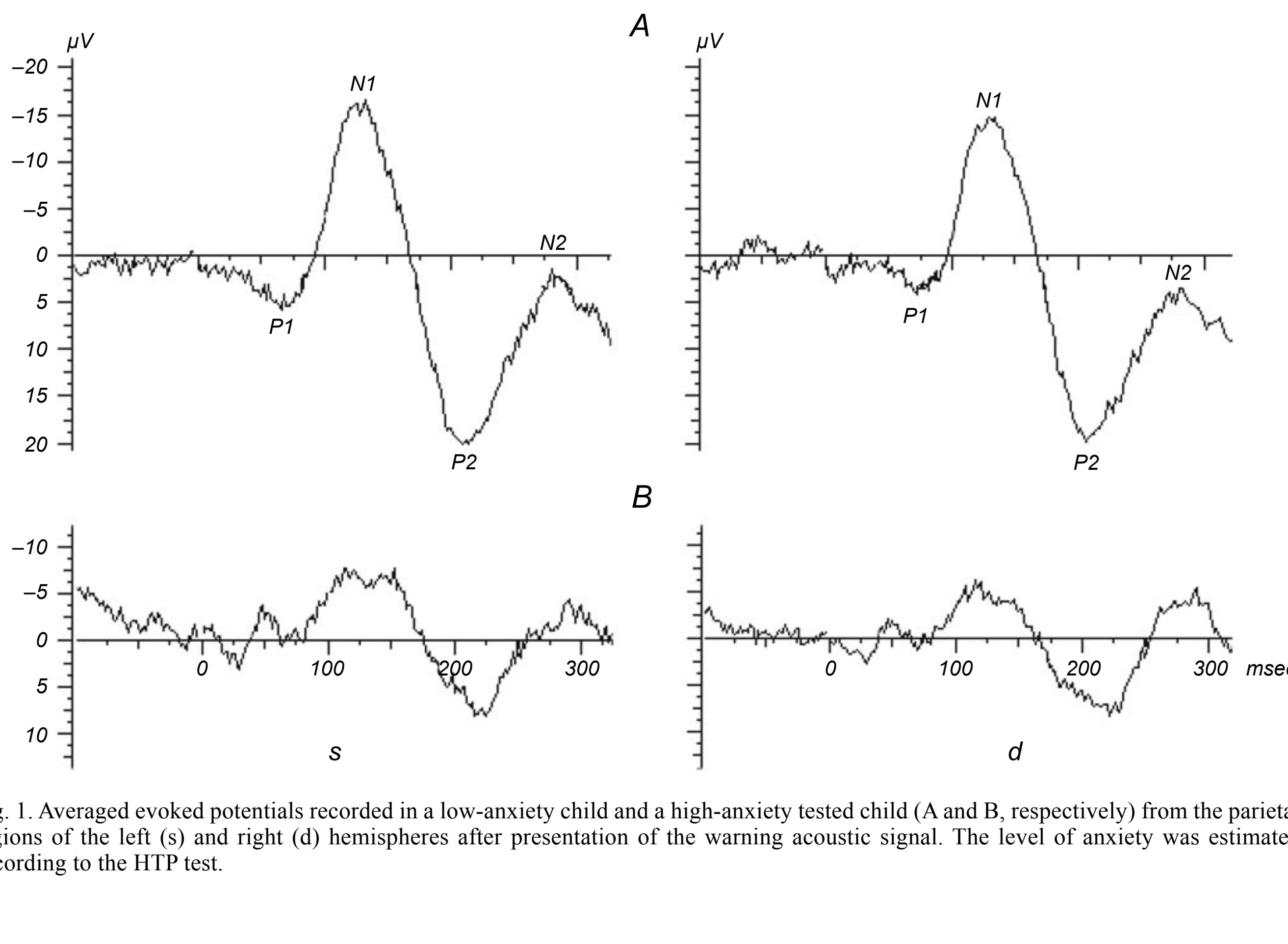

Fig. 1. Averaged evoked potentials recorded in a low-anxiety child and a high-anxiety tested child (A and B, respectively) from the parietal regions of the left (s) and right (d) hemispheres after presentation of the warning acoustic signal. The level of anxiety was estimated according to the HTP test.

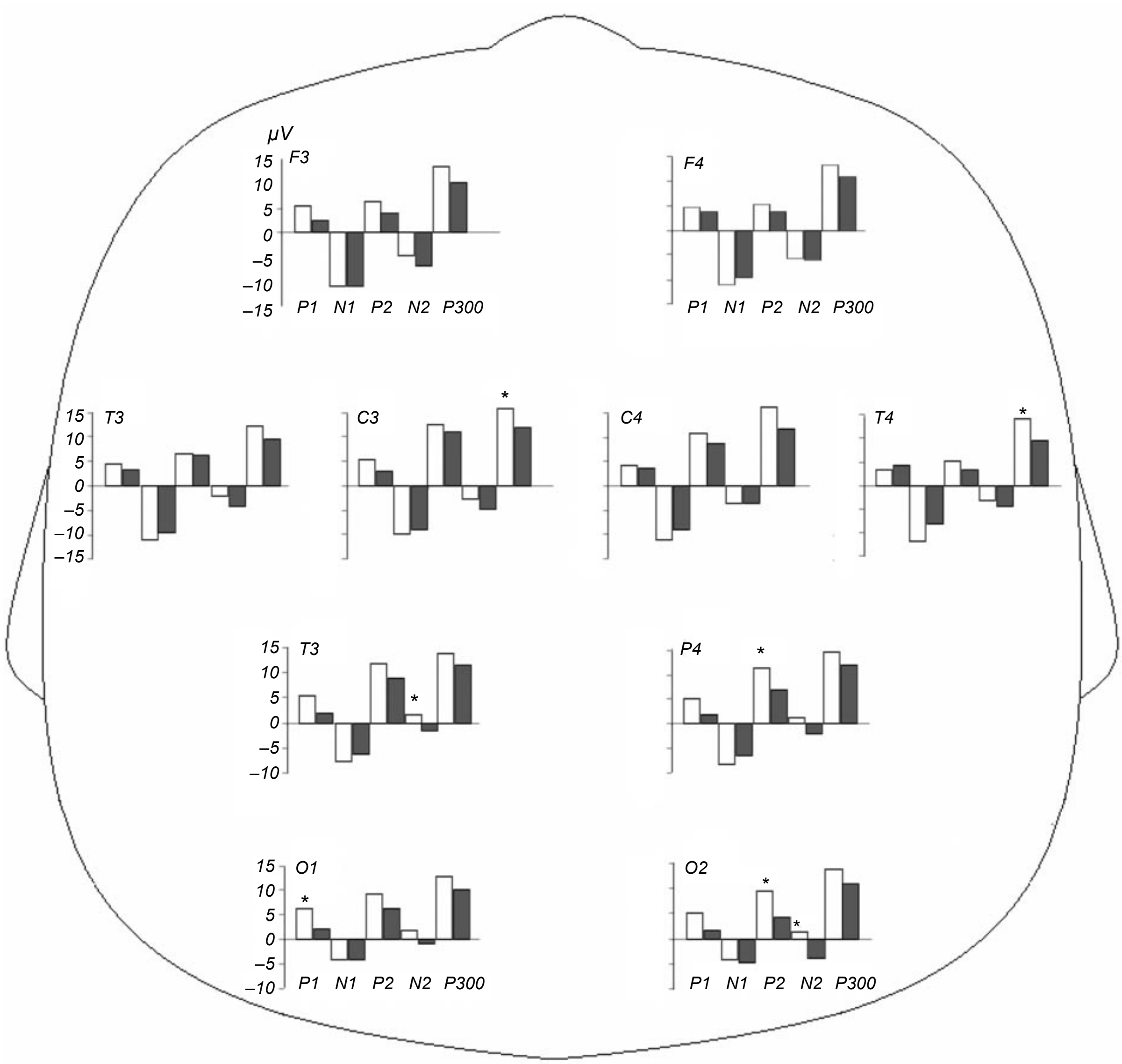

Fig. 2. Diagrams of the mean amplitudes of the components of evoked potentials and wave P300 in the subgroups of low- and high-anxiety children (open and filled columns, respectively). Classification into the subgroups according to the results of HTP test. The components are shown below the horizontal scale. Vertical scale, their amplitude (μV). Asterisks show cases of significant differences between the subgroups of low- and high-anxiety children ($P < 0.05$). F3, F4, T3, T4, C3, C4, P3, P4, O1, and O2 are designations of the leads according to the 10-20 system.

± 21.5 msec, while the same index in the high-anxiety group (according to the results of the above-mentioned projective test) reached 471.9 ± 37.2 msec (means ± ± s.e.m. are shown).

As can be seen, the regularities found for the amplitude of the N1-P2 vertex potential in the groupings classified according to Prikhozhan's scale did not coincide with the respective trends in the subgroups divided using the HTP technique. In the first case, the considered index was greater in the subgroup of high-anxiety individuals, while in the second case the subgroup of low-anxiety children showed greater values. It should, however, be mentioned that differences between the mean amplitudes of the N1-P2 vertex potential in low- and high-anxiety subjects were observed in the leads differing from those demonstrating such dissimilarities in the case of the use of Prikhozhan's questionnaire.

Correlation analysis showed that there is a negative dependence between the HTP estimates of the anxiety level and the amplitude parameters of the P1 component (in leads C3, $P = 0.032$; P3, $P = 0.026$; and O1, $P = 0.050$), P2 component (in O2, $P = 0.007$), and P300 wave (in F3, $P = 0.040$, and

O2, $P = 0.044$). In other words, higher values of the amplitudes of these potentials tended to be typical of the individuals with lower anxiety indices. For the amplitude of potential N2, a positive correlation with the anxiety level was found (in leads P3, $P = 0.017$, and O2, $P = 0.026$), i.e., greater amplitudes of this component were in general typical of the children with higher anxiety estimates. There was no negative correlation of the magnitude of the vertex potential N1-P2 with the anxiety level estimated with the use of the above-mentioned test (similarly to the absence of positive correlations of this index with the anxiety level measured by Prikhozhan's scale).

When classifying the children with respect to the anxiety indices estimated with Lüscher's test, we found the following. High-anxiety children, according to this test, were characterized by significantly longer latencies of component P1 (in leads F3, $P = 0.030$; F4, $P = 0.004$; C3, $P = 0.013$; P4, $P = 0.012$; T3, $P = 0.022$; and O2, $P = 0.025$) and by shorter latencies of oscillations P2 (in F4, $P = 0.020$; F3, and C4, $P < 0.034$), as compared with the analogous indices in low-anxiety children. A positive correlation was found for Lüscher's estimates of the anxiety level and latency values of the P1 potential (in leads F4, $P = 0.033$; C3, $P = 0.031$; and O1, $P = 0.046$). At the same time, we found no significant correlation between the values of the P2 latency and the anxiety level in this test.

We believe that the use of the projection techniques (HTP and Lüscher's test) allows researchers to obtain more objective, in general, estimates of the anxiety level in children than application of Prikhozhan's questionnaire; correspondingly, peculiarities of the interrelations between the above index and EP characteristics are detected more adequately. Such a conclusion is based on the general opinion that evaluation of the psychological peculiarities of individuals of the examined groups and of comparable age groups using projective methods is more objective than that using verbal questionnaires. A clear trend toward selection of such answers to the questions, which seem more socially acceptable for the tested subject (especially for a child), is a significant problem in interviewing with verbal test systems. In children, such a trend can be indicative of a desire to look better in the eyes of a highly authoritative adult subject (such a situation is also clearly visible in a part of the adult community). At the same time, projective methods propose relatively nonstructurized tasks, i.e., tasks permitting nearly unlimited diversity of the possible answers, which will not be considered by the tested person as correct or erroneous, socially acceptable or *vice versa*. The sphere of fantasy in an individual can be manifested rather freely because he/she is provided only with general short instructions. Because of the same reason, test tasks and stimuli are usually vague and not single-valued. According to the central hypothesis used for the construction of such tasks, the mode of perception and interpretation of the test material by the individual should reflect fundamental aspects of functioning of his/her mental sphere. As is supposed, the projective test materials reflect the specificities of the thinking process, necessities, anxiety, conflicts, etc. typical of the given tested individual. These tests are believed to detect also hidden, suppressed, or nonrealized sides of the personality's character. In psychology, results of the projective tests are frequently considered to be the most reliable [14]. At the same time, it should be recognized that the basis of interpretation of the results obtained by projective tests is conventional to a greater or lesser extent ("according to the existing opinion, one peculiarity or another should necessarily be interpreted precisely in a strictly definite way"). It can be supposed that, because of the different levels of objectivity of the results obtained using different tests, classification of the children into low- and high-anxiety subgroups using the HTP technique provided estimation of a greater number of significant differences between the EP components than classification of the subjects according to Prikhozhan's scale.

In should also be noted that there was practically no correlation between the estimates of the anxiety level evaluated, on the one hand, by Prikhozhan's test and, on the other hand, by the HTP and Lüscher's tests. It seems probable that this discrepancy is related to the fact that the aspects of anxiety detected with the use of the verbal *vs* projective techniques differ considerably from each other. Verbal tests probably reflect, to a greater extent, those sides of anxiety that are mentally realized by the individual, while projective methods mostly reflect the nonrealized anxiety aspects.

Information on the relations between the EP/ERP parameters and the anxiety level remains rather limited (especially in children); this circumstance makes interpretation of the data obtained in our study and their comparison with the results of other researchers relatively difficult. As was reported, patients suffering from panic disorders demonstrate higher amplitudes of the N2 component, as compared with those in healthy subjects [1]. This fact is interpreted by the authors as proof in favor of changes in "early" processing of sensory information in the case of panic disorders (i.e., abnormally high anxiety). The tests carried out in our laboratory showed that the amplitude of the N2 component in 5- to 7-year-old children is, on average, higher than that in 10- to 12-year-old children. At the same time, this parameter in 15- to 16-year-old teenagers was lower than in the latter children group. It was supposed that a progressive decrease in the N2 amplitude with increase in the age is related, to a considerable extent, to the development of the mechanisms of selective attention. It was hypothesized that, with aging, detection of the relevant information begins to be performed within the earlier stages of information processing corresponding in time to generation of the N1 and P2 components. Therefore, it can be supposed that processing of sensory information in high-anxiety children (characterized in our study by smaller, in general, amplitudes of the P1 and P2 components and higher amplitudes of the N2 potential, as compared with the respective indices in low-anxiety children of the same age) is performed somewhat more slowly, and high-anxiety children demonstrate "less mature" EP parameters. The statement that high-anxiety children process the incoming sensory information with a lesser efficiency is supported by the fact that the mean time (delay, latency) of the sensorimotor reaction is significantly longer in these individuals than that in the low-anxiety children. Greater values of the latency of the P1 component were found in our study in the high-anxiety children tested, as compared with this parameter in low-anxiety ones. Chernyi [16], when examining adult healthy subjects, found positive correlations of the levels of situative and personal anxiety estimated by Spielberger's test with the values of this EP component.

Our data related to the P300 amplitude are comparable with the results obtained by Gordeyev [17]. According to these findings, the amplitude of this ERP in adult subjects characterized by a high anxiety level is significantly lower than that in low-anxiety individuals. As is believed, the hippocampus, medial temporal lobe, frontal and parietal cortical regions, and also certain subcortical structures (nonspecific thalamic nuclei and brainstem reticular formation) are the main structures involved in the generation of the endogenous P300 potential. Simultaneously, these cerebral regions are also responsible for the formation of emotional/motivated behavior, cognitive functions, and, in the case of the development of anxiety disorders, for the pathogenesis of the latter. It was supposed that changes in the amplitude parameters of the P300 wave can serve as an objective neurophysiological marker of disorders in the cognitive and emotional sphere, which in high-anxiety personalities reflect functional disintegration of the limbico-reticular structures.

Individual peculiarities of the EP/ERP pattern are probably to a significant extent dependent on the level of development and state of the aminergic cerebral structures. The results of a few studies [18-20] allowed us to conclude that the systems of aminergic neurons to a considerable extent control the expression and time characteristics of the mid- and long-latency EP components. A few authors also emphasized that activation of the brainstem aminergic centers is one of the important factors responsible for generation of the "slow" cortical ERPs [21-24]. The peculiarities of functioning of the aminergic systems are partly determined genetically and, at the same time, are partly formed under the influence of ontogenetic experience; the especially important role of the latter in the early age (childhood) is emphasized [25, 26]. As was shown earlier [27], 10- to 12-year-old children with a high level of voluntary attention are characterized by higher amplitudes of the potentials P1, N1, P2, and N1-P2, as compared with the analogous parameters in children of the same age but with lower indices of this type of attention. Thus, differences in the amplitude/time parameters of EPs and ERPs found in our study in low- and high-anxiety children can be related (at least partly) to the peculiarities of functioning of the brain aminergic systems in these individuals. It should be taken into account that the anxiety level (high or low) is in a definite manner related to the peculiarities of neuroendocrine coupling. First of all, it correlates with the specificity of functioning of the hypothalamo-hypophyseal-adrenal axis; this specificity, in turn, significantly depends on the activity of the cerebral aminergic systems. Based on the above-mentioned facts and considerations, it is possible to conclude that higher amplitudes of the analyzed EP components in children correspond to some optimum level of functioning of the aminergic centers. It can also be supposed that decreased, in general, EP amplitudes in high-anxiety children (this was found in our study) reflect somewhat insufficient maturity and unbalanced functioning of the brainstem aminergic structures, as compared to what is observed in low-anxiety children of the same age.

The findings made in our study allow us to formulate the general conclusion that a low or high level of anxiety, as a feature of the child's personality, is reflected in a definite way in the characteristics of EPs and ERPs observed in this subject. Results obtained using different psychological methods of diagnosing the anxiety level were found to be contradictory in some aspects. This fact shows that further studies of the analyzed problem are needed. Taking into account the results of a comparison of different subgroups and those of correlation analysis, we can state with certainty that the increased level of anxiety in 10- to 11-year-old children is a reflection of relatively decreased amplitudes of the P1 component (predominantly in the left-hemisphere occipital region), the P2 component (in the right occipital region), and the P300 wave (in various loci of both hemispheres). In high-anxiety children, we also observed higher amplitudes of the N2 component in the left parietal and right occipital regions. High-anxiety individuals are, in general, characterized by greater values of the latency of the P1 component (predominantly in the right frontal and left central regions of the cerebral cortex); in this case, however, the latencies of the N1 oscillation are shorter in the parietal and occipital zones of the left hemisphere and also in the right temporal zone. The differences between the amplitude/time parameters of EPs/ERPs observed in low- and high-anxiety children can, to a definite extent, be related to the peculiarities of functioning of the aminergic cerebral systems in individuals belonging to the above subgroups.

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