EEG Correlates of Different Types of Anxiety in 14 - to 15-Year-Old Teenagers

E. V. Éismont,[1] T. A. Aliyeva,[1] N. V. Lutsyuk,[1] and V. B. Pavlenko[1]

Neirofiziologiya/Neurophysiology, Vol. 40, Nos. 5/6, pp. 448-456, September-December, 2008.

Received October 17, 2008.

We studied peculiarities of the spectral characteristics of electroencephalogram (EEG) in 14- to 15-year-old teenagers with dissimilar levels of different types of anxiety. These levels were estimated using Spielberger–Khanin's questionnaire and Prikhozhan's scale of personal anxiety; the latter allowed us to estimate different types of anxiety (self-appraisal, interpersonal, school, and "magic," related to a fear of mystic phenomena). In teenagers with a high level of some types of anxiety, we observed lower values of the spectral power density (SPD) of the alpha rhythm, sensorimotor rhythm (12-15 Hz), and beta1 rhythm, as well as a somewhat lower modal frequency of the alpha rhythm, as compared with the respective indices in teenagers of the same age with low estimates of anxiety. Analysis of EEG correlates of different types of anxiety showed the following. A high level of school anxiety correlated with low ratios of the SPDs of the alpha3/theta rhythms, sensorimotor rhythm/theta activity, and beta1/theta rhythms. In teenagers with high indices of self-appraisal anxiety, we found low values of the alpha-rhythm modal frequency. High levels of interpersonal anxiety estimated using Prikhozhan's scale and of personal anxiety estimated by Spielberger correlated with low values of the SPD of the alpha2 rhythm. High indices in the scale of "magic" anxiety were related to decreased values of the modal frequencies of the alpha1 and alpha3 rhythms, a low SPD of the alpha rhythm (8-13 Hz), and to lower ratios of the SPDs of the alpha2/theta rhythms. Therefore, we found that spectral characteristics of EEGs in 14- to 15-year-old teenagers with a high level of one particular type of anxiety or another (school, self-appraisal, interpersonal, or "magic") can, even at a relatively low level of general personal anxiety, significantly differ from some aspects from spectral characteristics of EEGs of teenagers with low values in analogous scales of anxiety.

Keywords: electroencephalogram, test systems (questionnaires) by Spielberger and Prikhozhan, anxiety, particular types of anxiety, teenagers.

INTRODUCTION

Psychophysiological studies carried out within the last years pay more and more attention to the mechanisms of anxiety because abnormally increased anxiety plays a significant role in the pathogenesis of a number of serious mental disorders [1-4]. There are two meanings of the term "anxiety" that should probably be clearly differentiated from each other. In the first meaning, anxiety is an emotional feeling of discomfort related to expectation of probable trouble, to foreboding (justified or false) of future danger; it correlates with certain autonomic manifestations. Thus, anxiety (alarm) is a definite emotional *state* significantly influencing psychologically motivated behavior of an individual. At the same time, anxiety (uneasiness) is a stable *property*, a feature of personality or of temperament [5] (in Slavic languages, the above terms are separate: "trevoga" and "trevozhnost'"). In some cases, this property is classified as situative anxiety characterized by such emotions as psychological tension, agitation, and preoccupation related to definite life situations. The state of situative anxiety is evoked as an emotional reaction to a certain stress situation and is reflected in the characteristics of behavior; it is limited in time. On the other hand, anxiety is exclusively understood as a characteristic of the personality. Personal anxiety is qualified as a stable individual characteristic reflecting the internal level of pre-occupation of a subject to anxiety. High personal anxiety supposes that the respective subject is characterized by a constant trend toward perception

[1] Vernadskii Tavricheskii National University, Simferopol', Autonomic Republic of Crimea, Ukraine.
Correspondence should be addressed to E. V. Éismont (e-mail: jema07@crimea.edu),
T. A. Aliyeva (e-mail: chadess@mail.ru),
N. V. Lutsyuk (e-mail: biofeedback@bk.ru), or
V. B. Pavlenko (e-mail: pavlenkovb@crimea.edu).

of an unwarrantably extended multitude of situations as necessarily dangerous and by responding to these situations by a hypertrophied reaction of anxiety.

Reactions of the autonomic nervous system are most frequently examined as physiological correlates of anxiety. In particular, the dependence of characteristics of the cardiac rhythm on the intensity of preoccupation to anxiety and, respectively, on the anxiety level in adult tested subjects is obvious [6]. The recording of autonomic reactions related to the development of the state of anxiety is a necessary component of the techniques used in the so-called lie detectors. At the same time, the reflections of anxiety in the characteristics of phenomena related to the CNS activity have been also studied. In tests with the analysis of spectral characteristics of EEG recorded at a high anxiety level in individuals with panic disorders, an abnormally high level of theta activity with numerous repetitive epileptiform discharges was observed [7]. The above state also correlated with a decrease in the intensity of interhemisphere functional interactions in the frontal cortical regions and increases in the coefficients of the interhemisphere asymmetry in the delta, theta, and beta ranges with domination of these rhythms in the temporal regions of the right hemisphere [8]. In the case of phobic disorders in adult subjects, considerably higher powers of beta oscillations in EEG samples recorded from the right temporal and lateral prefrontal regions were found [9]. According to the authors' opinion, these facts support the hypothesis on mostly right-side activation of the anterior cortical regions within the periods of increased situative anxiety and confirm the statement that modifications of EEG within the periods of high-anxiety/phobic states are related to manifestations of negative emotional reactions.

According to the findings of Knyazev et al. [10], high anxiety, trends toward the development of depression, and somatic complaints with no organic basis were observed in children with predomination of right-hemisphere desynchronization in the alpha2, alpha3, and beta1 ranges. In this case, however, the anxiety level was estimated using questionnaires filled by parents and teachers and not by the children themselves.

At present, analysis of anxiety in children and teenagers includes not only estimation of general levels of situative and personal anxiety, but also differentiation of the types of the latter, e.g., interpersonal anxiety, school anxiety, and also "magic" anxiety (related to fear of darkness, fear of the influence of forces "beyond," attention to "omen signs," etc.) [5]. Specificities of the EEG patterns in children with a predominance of different types of anxiety practically have not been studied. Our study was aimed at analyzing the spectral characteristics of EEG in healthy 14- to 15-year-old teenagers with low and high levels of different types of anxiety.

METHODS

Twenty-nine practically healthy 14- or 15-year-old teenagers, 16 boys and 13 girls, pupils of the middle school, were involved in the tests.

Recording and analysis of EEG were carried out according to generally accepted techniques using a computerized set including an encephalograph, a laboratory interface, and a computer. As a working program, EEG Mapping 3 (programmer E. Zinchenko) was used. EEG potentials were recorded monopolarly by frontal (F3 and F4), central (C3 and C4), temporal (T3 and T4), parietal (P3 and P4), and occipital (O1 and O2) leads, according to the 10-20 international system. Joined contacts fixed above the mastoid processes served as a reference electrode. The cut frequencies of low- and high-frequency filters were, respectively, 1.5 and 35 Hz, and the digitization frequency of EEG signals was 250 sec^{-1}. The signals were processed using fast Fourier transform, and smoothing according to the Blackman technique was applied.

Tests included recording of background EEG in the state of motor rest with the eyes closed and open. Spectral compositions of EEG were calculated separately for the samples with closed and open eyes. Each analyzed sample of continuous recording was 60 sec long. Values of the square root of the density of distribution of the spectral power within the respective frequency range and indices of spectral power density (SPD, μV/Hz) were considered indices characterizing the spectral power of one EEG component or another. The following ranges and subranges were differentiated in the EEG composition: theta (4-8 Hz), alpha1 (8-9.5 Hz), alpha2 (9.5-11 Hz), alpha3 (11-13 Hz), sensorimotor rhythm, SMR (12-15 Hz), beta1 (16-20 Hz), and beta2 (21-30 Hz). Modal frequencies of the alpha subranges were measured as the mean frequency of the respective subcomponent of the alpha frequency component demonstrating the maximum amplitude in 20-25 2.56-sec-long segments of recording. We also calculated ratios of the SPDs of the following ranges and subranges: alpha/theta, SMR/theta, beta1/theta, and beta2/theta.

The levels of anxiety were estimated using the following

techniques. For estimation of the levels of situative and personal anxiety of the tested subjects, the technique of Spielberger adapted by Khanin [11] was used. Within the framework of this technique, a questionnaire including 20 statements relating to the development of the state of anxiety at one definite external circumstance or another and 20 statements allowing one to characterize the level of anxiety as a stable property of the individual was proposed. Answers to these groups of questions determine the reactive (or situative) and personal anxiety, respectively. The total index for each subscale (situative and personal anxiety) can vary within a 20 to 80 points; the greater this index, the higher the level of anxiety of the respective type.

The scale developed by Prikhozhan [12] for estimation of different types of anxiety in 13- to 16-year-old teenagers was also used in our tests. This scale includes four subscales estimating anxiety related to the situations of communication (interpersonal anxiety) to educational situations (school anxiety), to the subject's own personality (self-appraisal anxiety), and anxiety related to the influence of irrational mystic fears ("magic" anxiety). The questionnaire contains 40 questions relating to different situations and circumstances. The tested persons must answer to what extent one proposed situation or another is unpleasant to him/her and can evoke nervousness and fears. Each answer is estimated by a corresponding number of points, from one to four. The result of summation of estimates by all subscales is interpreted as an index of the general level of anxiety.

Data of the electrophysiological study and indices of the psychological tests were quantitatively treated using standard techniques of variational statistics. To estimate the significance of differences between groups, we used Mann–Whitney's test.

RESULTS AND DISCUSSION

In our study, we calculated the mean value of the each index (level of the type of anxiety) within the entire examined group. Depending on the obtained mean values, the tested teenagers were divided into subgroups, with comparatively low and high indices in the certain scale (subscale) of anxiety. Individuals demonstrating a value of the anxiety index in one scale or another from the minimum to the mean (inclusive) were classified as low-anxiety teenagers, while subjects with the indices higher than the mean intragroup value were considered high-anxiety teenagers (Table 1).

Classification of the teenagers according to the level of personal anxiety estimated by Spielberger's questionnaire showed that, in the subgroup of subjects with a low level of this type of anxiety, EEG samples recorded with the eyes closed were characterized by significantly higher SPDs of the alpha2 rhythm (leads F3, F4, O1, and T3, $P < 0.05$), alpha3 oscillations (leads F4 and C3, $P < 0.05$), and SMR(leads F4, C3, C4, P4, O2, and T3, $P < 0.05$), as compared with the respective indices in high-anxiety subjects. The greatest number of significant intergroup differences was observed in the SPD of the SMR (Fig. 1). As is believed, this rhythm represents an EEG component close in its nature to the "classic" alpha rhythm but recorded mostly within the sensorimotor cortical regions. According to the published data [13], the power of this rhythm shows a high level of correlation with the indices of intellect.

As was mentioned [14], the examined age interval of development of children is characterized in most cases by the process of stabilization of a dominating rhythm of the electrical activity in all neocortical regions. Because of this, the alpha rhythm becomes the predominant form of activity in both anterior and posterior areas of the cortex. In this case, oscillations corresponding to a higher limit of the alpha frequency range are the highest in amplitude, and they are combined with low-amplitude activity of the beta1 subrange. Therefore, our findings demonstrate that teenagers with a mild level of personal anxiety (according to Spielberger's questionnaire) to a greater extent corresponded to the age norm of spectral EEG characteristics.

It should be noted that the number of statistically significant differences between the EEG characteristics classified according to the level of situative anxiety of the subjects (by Spielberger) was rather limited. In particular, in teenagers with a low level of situative anxiety the modal frequencies of the alpha1 rhythm in the right upper frontal area and of the alpfa3 rhythm in the right parietal region were significantly ($P < 0.05$) higher than those in high-anxiety tested subjects. According to Farber [14], the examined ontogenetic stage of children is characterized by some increase in the modal frequency of alpha oscillations. Thus, the frequency characteristics of EEG of low-anxiety teenagers to a greater extent corresponded to those of the EEG of adult subjects; at the same time, some signs of immaturity of the alpha rhythm were observed in high-anxiety teenagers.

Classification of the subjects into subgroups according to the level of general anxiety estimated by Prikhozhan's scale shows that EEG samples recorded

TABLE 1. Estimates of Different Types of Anxiety in the Examined Group of 14- to 15-Year-Old Teenagers and in Their Subgroups with Low and High Levels of Anxiety

Type of anxiety	Entire group (n=29)	Low-anxiety teenagers	High-anxiety teenagers
Test system of Spielberger			
Situative	34.31 ± 1.31	30.22 ± 0.79 (n = 18)	41.00 ± 1.94 (n = 11)
Personal	40.00 ± 1.38	34.56 ± 0.92 (n = 16)	46.69 ± 1.37 (n = 13)
Test system of Prikhozhan			
Interpersonal	12.00 ± 0.93	8.83 ± 0.53 (n = 18)	17.18 ± 1.13 (n = 11)
Self-appraisal	11.07 ± 0.70	8.20 ± 0.59 (n = 15)	14.14 ± 0.60 (n = 14)
School	10.24 ± 1.05	6.35 ± 0.56 (n = 17)	15.75 ± 1.94 (n = 12)
"Magic"	9.21 ± 1.24	4.76 ± 0.58 (n = 17)	15.50 ± 1.62 (n = 12)
General estimate	42.52 ± 3.04	31.72 ± 1.20 (n = 18)	60.18 ± 3.73 (n = 11)

Footnote. Means ± s.e.m. are shown.

with the eyes closed in teenagers with a low general anxiety level were characterized by higher values of the modal frequency of the alpha3 rhythm in the right temporal region ($P < 0.05$), of the beta1 SPD in the left occipital region ($P < 0.05$), and of the ratio of the beta1/theta SPDs in the right occipital lead ($P < 0.05$), as compared with the respective indices in individuals distinguished by high general anxiety. Recording of EEG with the eyes open (i.e., in the state of EEG desynchronization) showed that teenagers with a low level of general anxiety had higher values of the theta-rhythm and SMR SPDs (in the O2 lead, $P < 0.05$), of the beta1 SPD (leads O1, $P < 0.05$, and O2, $P < 0.01$), and of the beta2 SPD (leads O1 and O2, $P < 0.05$).

When we divided the subjects into subgroups depending on the level of school anxiety estimated by Prikhozhan, we found that EEG samples recorded with the eyes open in teenagers with a low level of this type of anxiety showed higher values of the SPD of the alpha3 rhythm (in leads F4, O1, and O2, $P < 0.05$), SMR (in leads F4 and O1, $P < 0.05$, and in lead O2, $P < 0.01$), and beta1 rhythm (leads F4, P4, O2, and T3, $P < 0.05$; lead O1, $P < 0.01$) (Fig. 2). In addition, teenagers with low estimates of school anxiety demonstrated higher values of the SPD ratios alpha3/theta (leads P4 and O1, $P < 0.05$; O2, $P < 0.01$), SMR/theta (lead P4, $P < 0.05$; lead O2, $P < 0.01$), beta1/theta (leads F4, P4, T3, and O2, $P < 0.05$), and beta2/theta (leads F4, P4, T3, and O2, $P < 0.05$).

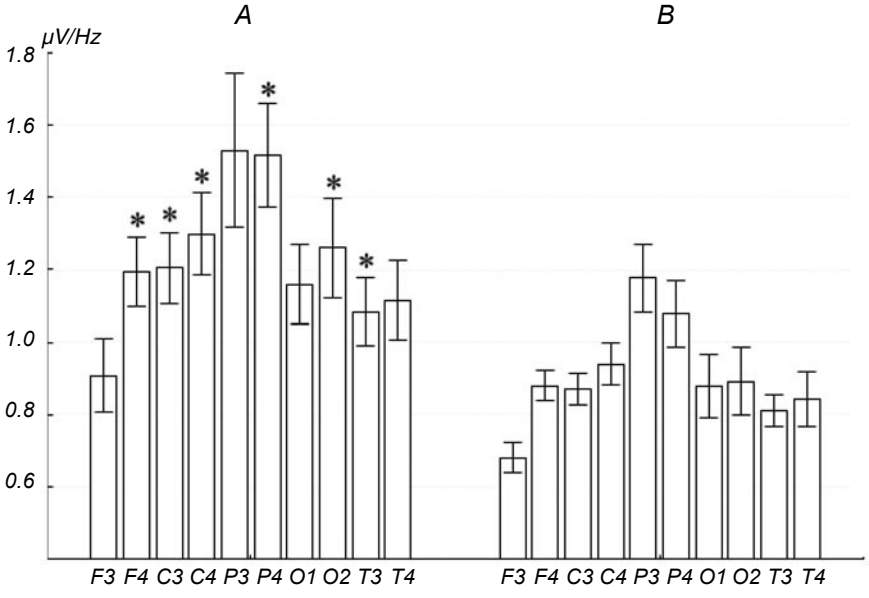


Fig. 1. Diagrams of indices of the spectral power density (SPD) of the sensorimotor rhythm in subgroups of low-anxiety and high-anxiety teenagers (A and B, respectively; estimation by the questionnaire of Spielberger). EEG was recorded with the eyes closed. Means ± s.e.m. are shown. EEG leads are indicated below the diagrams. Vertical scale) SPD, μV/Hz. Asterisks show cases of significant differences between the subgroups ($P < 0.05$).

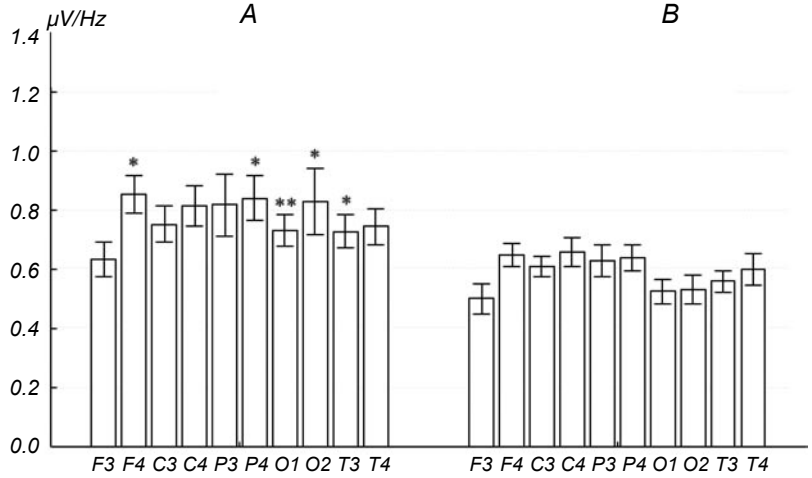


Fig. 2. Diagrams of indices of the spectral power density of the beta1 rhythm of EEG recorded with the eyes open in teenagers with low (A) and high (B) indices of school anxiety. One and two asterisks show cases of significant differences between subgroups A and B with $P < 0.05$ and $P < 0.01$, respectively. Other designations are similar to those in Fig. 1.

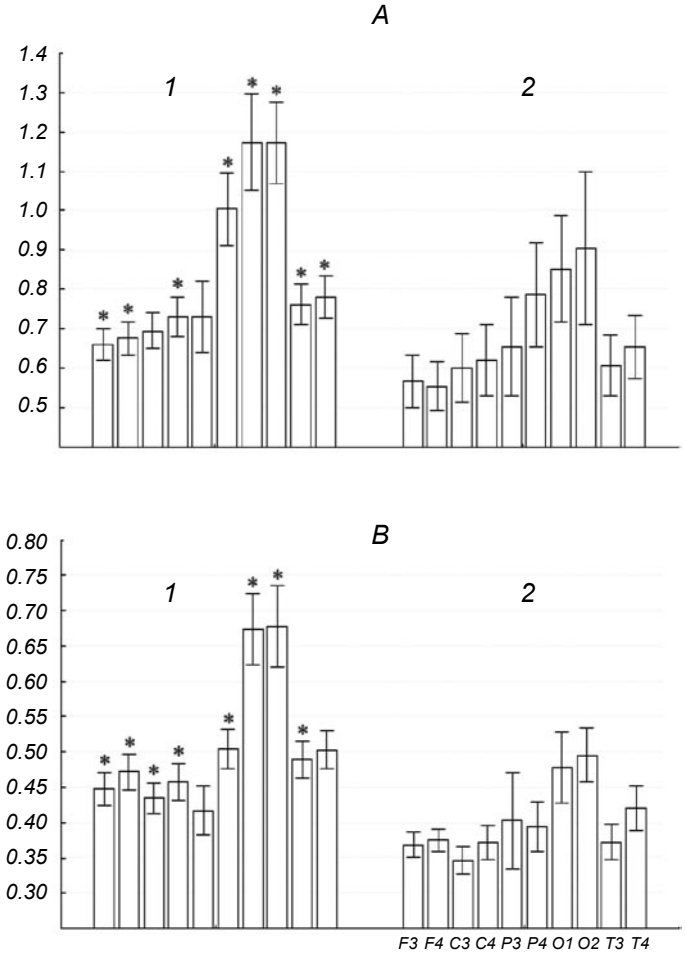


Fig. 3. Diagrams of mean ratios of the spectral power densities (SPDs) of the alpha3 and theta rhythms (A) and those of the beta1 and theta rhythms (B) in teenagers with low (1) and high (2) indices of school anxiety. EEG was recorded with the eyes closed. Vertical scale) Ratio of SPDs. Other designations are similar to those in Fig. 1.

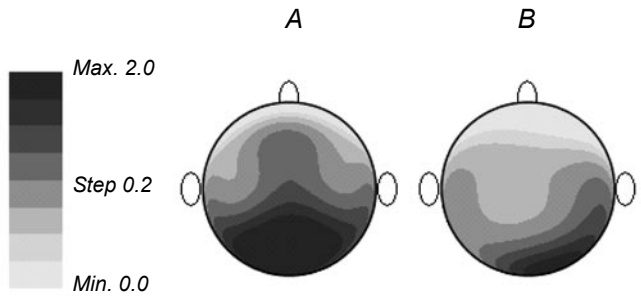
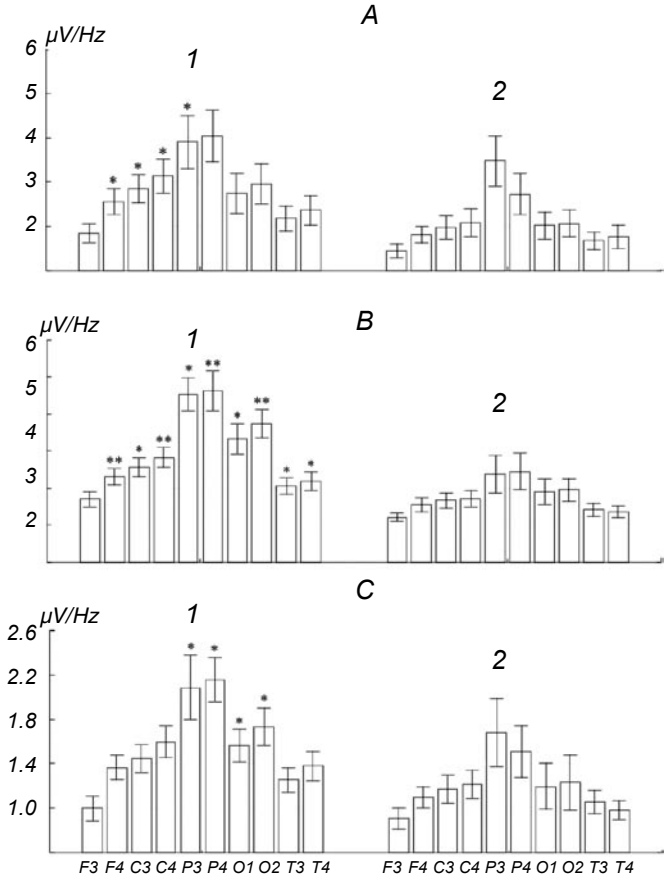


Fig. 4. Topograms of the values of ratios of the spectral power densities of the alpha2 and theta rhythms in two teenagers with low (A) and high (B) levels of interpersonal anxiety. EEG was recorded with the eyes closed. Calibration scale for the values of ratios alpha2/theta, arbitrary units, is shown at the left.



When EEG was recorded with the eyes closed, the following results were obtained. Teenagers with low indices in the school anxiety subscale showed significantly higher values of the modal frequency of the alpha2 rhythm (in lead F3, $P < 0.01$, and in T3, $P < 0.05$). For these subjects with low school anxiety, higher values of the following SPD ratios were typical, as compared with the respective values in high-anxiety children: alpha2/theta (in F4, P4, and O1, $P < 0.05$), alpha3/thets (in F3, F4, C4, P4, O1, O2, T3, and T4, $P < 0.05$; Fig. 3A), SMR/theta (in F4, P4, O1, O2, T3, and T4, $P < 0.05$), and beta1/theta (in F3, C4, P4, O1, and O2, $P < 0.05$, and in F4, C3, and T3, $P < 0.01$; Fig. 3B).

When subgroups of the subjects with different levels of self-appraisal anxiety were analyzed, we found that values of the modal frequency of the alpha2 rhythm of EEG recorded with the eyes closed were higher in low-anxiety teenagers. This was observed in leads F3, F4, and O2 ($P < 0.05$) and also in P4, T3, and O1 ($P < 0.01$). The SPD of the theta rhythm in leads C3 and P4 was greater ($P < 0.05$) in high-anxiety individuals. Samples of EEG recorded with the eyes open showed no significant differences between teenagers with low and high levels of self-appraisal anxiety from this aspect.

Teenagers with low interpersonal anxiety were characterized by higher modal frequencies of the alpha1 (in leads P4, O1, and O2, $P < 0.05$) and alpha3 (in leads F4 and T3, $P < 0.05$) components of EEG recorded with the eyes closed. In addition, teenagers with low estimates of interpersonal anxiety had greater values of the alpha2 SPD (in leads F4, C3, C4, O2, and T4, $P < 0.05$) and greater alpha2/theta ratios (in leads P4, O1, O2, and T4, $P < 0.05$) of EEG recorded with the eyes closed. As an example, we show topograms of EEG of two subjects considerably differing from each other in their levels of interpersonal anxiety (Fig. 4). As can be seen, the teenager with low anxiety (by this subscale) was characterized by noticeably greater alpha2/theta SPD ratios mostly in the occipital, parietal, and central areas.

Teenagers forming the subgroup with a low level of interpersonal anxiety showed relatively higher values

Fig. 5. Diagrams of indices of the spectral power densities of the alpha1, alpha2, and alpha3 rhythms (A-C, respectively) in teenagers with low (1, $n = 17$) and high (2, $n = 12$) levels of "magic" anxiety. Other designations are similar to those in Fig. 1 and 2.

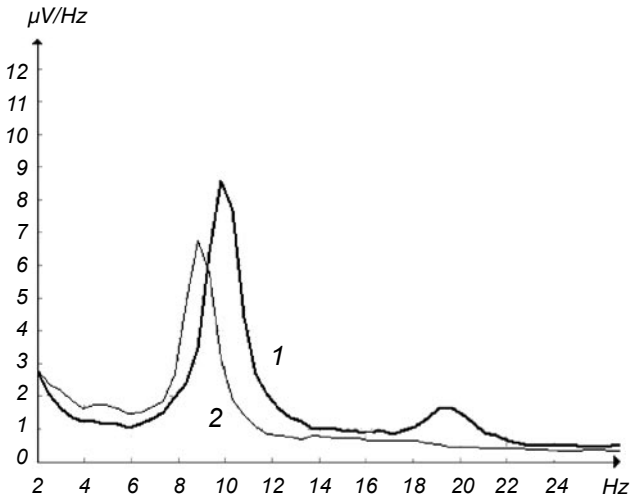


Fig. 6. Averaged spectral characteristics of EEG recorded with the eyes closed (left-hemisphere occipital lead) in two teenagers significantly differing from each other in the level of "magic" anxiety. 1 and 2) Spectra of EEG of teenagers with a low and a high estimate in the above scale. Abscissa) Frequency, Hz; ordinate) spectral power, μV/Hz.

of the SPDs of the following rhythms; theta (C4, O2, and T4, $P < 0.05$), alpha2 (O2 and T4, $P < 0.05$), beta1 (O2 and P4, $P < 0.05$), and beta2 (C4 and P4, $P < 0.05$) in EEGs recorded with open eyes.

Classification of the subjects into subgroups depending on the level of "magic" anxiety showed the following. EEG samples of individuals with high levels of this type of anxiety (related to fear of the "forces of the other world," "getting the evil eye," darkness, bad omens, etc.), when recorded with the eyes closed, were distinguished, on average, by lower SPDs of the alpha1, alpha2, and alpha3 rhythms (Fig. 5) and of the beta1 rhythm (in leads P4 and O1, $P < 0.05$, and in lead O2, $P < 0.01$). These teenagers also showed lower values of the alpha2/theta SPD ratio (in leads F3, F4, C4, P4, T3, and T4, $P < 0.05$, while in O1 and O2, $P < 0.01$), as compared with the corresponding values in teenagers with a low level of "magic" anxiety. In addition, subjects with high levels of anxiety of this type were characterized by low modal frequencies of the alpha1 rhythm (in F3, C3, C4, O1, and O2 $P < 0.05$in F3 and P4, $P < 0.01$) and alpha3 oscillations (in C4, P4, O2, T3, and T4, $P < 0.05$; in O1, $P < 0.01$). An example is shown in Fig. 6; these are EEG spectra of two teenagers significantly differing from each other in the level of "magic" anxiety. As can be seen, a teenager with a higher estimate of this type of anxiety showed a lower modal frequency of the alpha rhythm, as compared with the analogous index in a low-anxiety subject. As is known, values of the frequencies of spectral peaks of subranges of the alpha rhythm increase somewhat with age [10]. The above-described peculiarity is another proof in favor of the statement that EEGs of low-anxiety teenagers to a greater extent correspond to the age norm than EEGs of high-anxious subjects of the same age.

When EEG was recorded with the eyes open, significant differences were also observed between the SPD values of the alpha2 rhythm in leads F4, C3, C4, P4, T4, and O2 ($P < 0.05$) of teenagers classified according to the level of "magic" anxiety; higher values of this index were found in low-anxiety individuals. The SPD of the theta rhythm in both central leads was also higher ($P < 0.05$) in teenagers with the low level of this type of anxiety.

As can be seen from the above description of our findings, the characteristics of the alpha rhythm showed the greatest number of cases of significant intersubgroup differences, while differences in the amplitude of theta oscillations were not so numerous. This fact can be interpreted using the concept of Knyazev and Slobodskaya [15]. According to the opinion of these researchers, the three oscillatory cerebral systems, which can be conventionally called the delta, theta, and alpha systems, are related predominantly to the three hierarchical systems of the brain, the brainstem system (a system of biological requirements), the limbic (an emotional) system, and the corticothalamic system. The latter is the cognitive system. The neocortex, in this case, provides mostly inhibitory control of the lower systems (limbic system and brainstem). The authors of the above concept proposed the hypothesis that the level of personal anxiety is determined mostly by the neocortical activities. Therefore, comparatively high amplitudes of the alpha rhythm and of its subcomponents, which are, according to our observations, typical of low-anxiety 14- to 15-year-old teenagers, can be related to the greater dominance of the cognitive sphere with respect to the emotional sphere in such subjects. Because of this, an individual with a relatively low anxiety level is capable of evaluating the environment (in the broad sense of the term) more adequately and impartially.

Considering our findings, we can, in general, conclude that levels of anxiety are in a definite manner reflected in the EEG pattern of teenagers (as well, obviously, of adults). In general, teenagers with a high level of one type (subtype) of anxiety or another were characterized by comparatively low levels of the SPDs of the alpha rhythm (8 to 13 Hz range), SMR, and beta1 rhythm, and also of relatively

low values of the modal alpha-rhythm frequency. High estimates of school anxiety correlated with low values of the alpha3/theta, SMR/theta, and beta1/theta SPD ratios. Low values of the alpha2 modal frequency were typical of teenagers with high indices of self-appraisal anxiety. High levels of interpersonal anxiety estimated by Prikhozhan and of personal anxiety estimated using Spielberger's questionnaire were reflected in low SPDs of the alpha2 rhythm. High indices in the scale of "magic" anxiety were related to relatively low values of the modal frequencies of the alpha1 and alpha3 subrhythms, SPD of the alpha rhythm in general (8-13 Hz), and to lower alpha2/theta SPD ratios.

Our findings allow us to postulate that, in some cases, diagnosing of personal anxiety only in general can show a quite moderate level of the latter, while differentiated estimation of the levels of various types/subtypes of anxiety related to different life spheres will demonstrate high indices for one or several particular type(s). Spectral characteristics of EEG in 14- to 15-year-old teenagers with a high level of one particular type of anxiety or another (school, self-appraisal, interpersonal, or "magic") combined with a mild level of general personal anxiety estimated by Prikhozhan demonstrated quite significant differences from spectral EEG characteristics of subjects of the same age having low values in the analogous anxiety scales.

It is logical to suppose that increased anxiety is based on the peculiarities of functioning of certain cerebral mechanisms related, in particular, to individual specific features of the aminergic systems and, from a broader aspect, to general characteristics of neuroendocrine (especially of adrenergic) regulation in a certain individual. These mechanisms are probably general, to a considerable extent, for each type of personal anxiety. At the same time, an individual profile of manifestation of separate types of anxiety in such an individual depends significantly on the specificities of the social environment this subject grows up in.

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