Modifications of EEG Activity Related to Perception of Emotionally Colored, Erotic, and Neutral Pictures in Women during Different Phases of the Ovulatory (Menstrual) Cycle

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We studied modifications of EEG activity related to perception of visual stimuli (pictures) of the International Affective Picture System (IAPS) in women during different phases of the ovulatory (menstrual) cycle. We found that the woman's brain is most intensely activated by both emotionally negative and positive visual stimuli during the follicular phase of the ovulatory cycle, while such activation is minimum during ovulation *per se*. Upon the action of neutral stimuli, cerebral activation was the most intense during the lutein phase (compared with that within other phases); manifestations of activation were concentrated in the right hemisphere. Cognitive and emotional components of perception of affective pictures were expressed to a greatest extent in the course of viewing positive stimuli during the follicular phase. Perception of emotionally pleasant stimuli during other phases was accompanied by lateralization of activation of sensory and analytical processes in the left hemisphere during the ovulatory phase and in the right hemisphere within the lutein phase. The viewing of emotionally negative pictures during the follicular phase led to a rise in the power of theta oscillations in the left frontal region and also to depression of the alpha activity in central/parietal parts of the left hemisphere, which can result from aggravation of anxiety and verbally shaped disturbing ideas upon the action of such stimuli. Presentation of erotically colored visual stimuli caused the most intense changes in the EEG, which depended on the phases of the ovulatory cycle, during post-stimulation time interval but not during the viewing of pictures itself.

Keywords: EEG components, spectral power, ovulatory (menstrual) cycle, affective images.

INTRODUCTION

It is known that alterations of the level of sex hormones in women throughout the ovulatory (menstrual) cycle influence noticeably the pattern of reactions of the organism to both biologically and socially significant stimuli [1, 2]. Changes in the levels of estrogen and progesterone throughout the ovulatory cycle are capable of modulating the level of anxiety, pain sensitivity, and practically all cognitive functions, including the ability to learn, memory, the level of attention, etc. [3-5]. This can be explained in the following manner: Sex hormones acting on their specific receptors located in cerebral structures, such as the amygdalar complex, hypothalamus, hippocampus, and anterior cingulate gyrus, are capable of modifying the functional state and even the structural characteristics of these centers via genome- and non-genome-mediated pathways. In turn, such subcortical structures modulate the functional activity of different cortical parts, including the orbitofrontal cortex [1, 6]. It is very important to note that subcortical structures, which are targets for the action of sex hormones, create in the brain a system of formation of emotional responses to all sorts of stimuli [7]. Fluctuations of the levels of sex hormones throughout the ovulatory cycle are capable of modifying the characteristics of reactions of these structures to emotiogenic influences. Thus, it is logical to expect that one and the same stimulus presented during different phases

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of the ovulatory cycle will be perceived in different manners. Results obtained in studies with the use of modern techniques for neurovisualization of the human brain confirmed such a concept in general. It was demonstrated that reactions to erotically colored stimuli in women are noticeably altered depending on the phases of the ovulatory cycle [8]. At the same time, it should be noted that the physiological mechanisms underlying these distinctions remain little studied. In addition, the question remains: What are the dynamics of processes in various cerebral parts in the course of perception of positive, negative, neutral, or erotically colored visual stimuli by women during different phases of the ovulatory cycle? Unfortunately, the use of neurovisualization cannot help in answering this question, since the corresponding techniques are characterized by a relatively low spatial/temporal resolution. This shortcoming is eliminated in the case of EEG recording, because such a technique allows one to estimate neurophysiological processes in various cerebral regions within a millisecond range.

It can be expected that the analysis of changes in the electrical activity of the woman's brain in the course of viewing positive, negative, erotically colored, and neutral visually presented pictures during different phases of the ovulatory cycle will allow one to come closer to the interpretation of neurophysiological mechanisms underlying the specificity of reactions of women to presentation of visual stimuli (pictures) of various types during successive phases of cyclic changes in the hormonal background.

METHODS

Eighteen women, 18 to 21 years old, students of the Taras Shevchenko National University (Kyiv, Ukraine), took part in the tests. According to the data of anamnestic survey and medical cards, regular (throughout the year) menstrual cycles (27 to 35 days long) were observed in these women. All tested persons were reasonably healthy, did not suffer earlier from neurological or mental diseases, and did not take hormonal contraceptives. Each woman took part in the tests three times, during the follicular phase (2nd to 4th day of the menstrual cycle), ovulatory phase (12th to 16th day), and lutein phase of the ovulatory cycle (21st to 25th day of the menstrual period). The presence and duration of ovulation in each woman were estimated according to the pattern of crystallization of the content of saliva according to the data of test microscopy (certificate of the Ministry of Public Health of Ukraine, No. 817/2002). This technique is based on the following phenomenon: During ovulation (with a maximum concentration of estrogens in the blood), crystallization of dried samples of saliva looking like "leaves of fern" is observed under a microscope. The corresponding official testing confirmed a rather high reliability of such tests.

In all women throughout each examination, we recorded EEG using the following protocol: 3-min-long recording in the resting state (with the eyes closed); presentation of visual stimuli on a screen of the PC monitor, namely (i) a set of pictures capable of inducing positive emotions, for 1.5 min, (ii) neutral stimuli, for 1.5 min, (iii) erotically colored pictures, for 1.5 min, and (iv) pictures capable of inducing negative emotions, for 1.5 min; and the second 3-min-long interval in the resting state (with the eyes closed). Between each series of presentations of pictures with positive, negative, erotic, or neutral contents, we recorded 1.5-min-long EEG segments in the course of alternate presentation of repeated empty gray-colored pictures. As pictures with the corresponding contents, we used photographs from the catalog of the International Affective Picture System (IAPS) [9]. Presentations of a separate picture (photograph) in the series lasted 6 sec each.

EEGs were recorded monopolarly using a diagnostic complex, Neuron-Spectr (Neurosoft, Russia); a contact on the ipsilateral ear lobe was used as the reference electrode. Electrodes were positioned according to the international system 10-20 in 14 symmetrical points of the head surface: mid-frontal (F3/F4), lateral frontal (F7/F8), central (C3/C4), anterior temporal (T3/T4), posterior temporal (T5/T6), parietal (P3/P4), and occipital (O1/O2).

For the analysis of EEG, we used only artifact-free segments of recordings that were preliminarily selected in the course of visual analysis. With the use of the Fourier fast transform, we estimated the spectral powers (μV^2) for the following frequency ranges: theta (4.0 to 7.9 Hz), alpha (8.0 to 12.9 Hz), low-frequency beta (13.0 to 19.9 Hz), and high-frequency beta (20.0 to 35.0 Hz). The analyzed epoch was 2.56 sec long, segments of overlapping were 1.28 sec, and the bandwidth of the amplification/recording tract was from 1.0 to 35 Hz. In addition, we calculated the coefficient of activation (CA) as a ratio of the power of oscillations of the total beta range and the power of the alpha range.

Statistical analysis of the data was performed using STATISTICA 7.0 software (Statsoft, USA, 2004). Since distributions of the experimental data

obtained in our study did not correspond to a normal law (by the Liliefor test), we used the nonparametric Wilcoxon criterion of sign ranks for the comparison of interdependent samplings. For the control of statistical hypotheses, the critical level of significance of intergroup differences P was taken as 0.05.

RESULTS AND DISCUSSION

According to the results of analysis of the cerebral electrical activity of women in the resting state (with the eyes closed) within different phases of the menstrual cycle, interphase differences in EEG activity within the examined group were observed only in the right hemisphere and, thus, demonstrated a clear interhemisphere asymmetry (Fig. 1). Within the ovulatory phase, the power of alpha oscillations in the occipital zone of this hemisphere (O2) was lower than that within the follicular and lutein phases. The powers of theta oscillations dropped during the lutein phase in the occipital (O2) and central (C4) zones, as compared with those during the ovulatory phase in the occipital (O2) and temporal (T4) parts in comparison with the corresponding values within the follicular phase. During the lutein phase, the power of the high-frequency beta subcomponent decreased in the right frontal part (F4). Our data agree in general with the findings of other researchers who reported that the intensity of EEG activation in women during the premenstrual period is minimal just in the frontal cortical parts [10].

Before analyzing our own experimental data on the effects exerted by pictures with emotional loading on the EEG characteristics in women during different phases of the ovulatory cycle, it should be noted that, according to a neurologic model described by Heilman [7], perception of emotiogenic stimuli consist, in general, of three components. These components are provided by the functioning of different cerebral structures. First, an emotional stimulus (pleasant or unpleasant) is evaluated subjectively under the action of the presented stimuli. In such evaluation, the frontal cerebral parts play the leading role; excitation of the left frontal cortex predominates during evaluation of positive stimuli, while excitation of the right hemisphere predominates during the action of negative ones. Second, an activation support of perception of emotional signal (arousal) is realized. It is believed that emotional arousal is mediated mostly by the involvement of the parietal cerebral parts in the control of influences of activating cerebral systems. Finally, third, an emotional experience, under certain conditions, produces a motor component, which can be

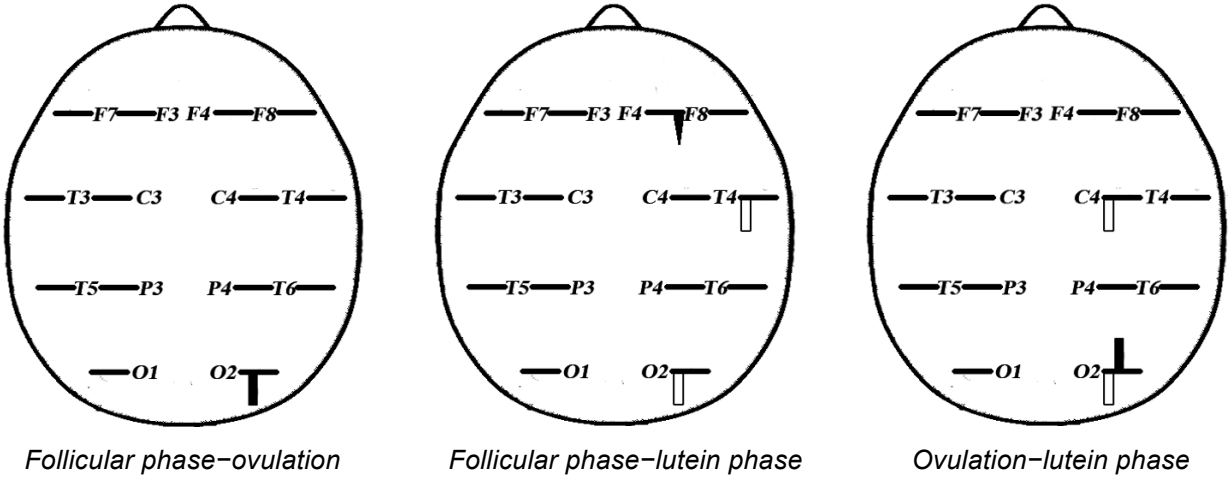

Fig. 1. Topomaps of differences between the values of medians of the spectral powers (SPs) of EEG frequency components (rhythms) observed in the examined groups of women (n = 18) within various phases of the ovulatory cycle. Horizontal line shows the absence of significant difference between the SP values in the corresponding records within two phases of the ovulatory cycle indicated under the topomaps; rectangles and upward- or downward-directed triangles show cases of significantly higher or smaller ($P < 0.05$) values of SP medians of different-frequency EEG components within the latter of the above-mentioned phases compared with those in the former phase. Open and filled rectangles show differences between the mean SPs of oscillations of the theta and alpha ranges, respectively; filled triangles show the difference between SPs of the high-frequency beta EEG subrange.

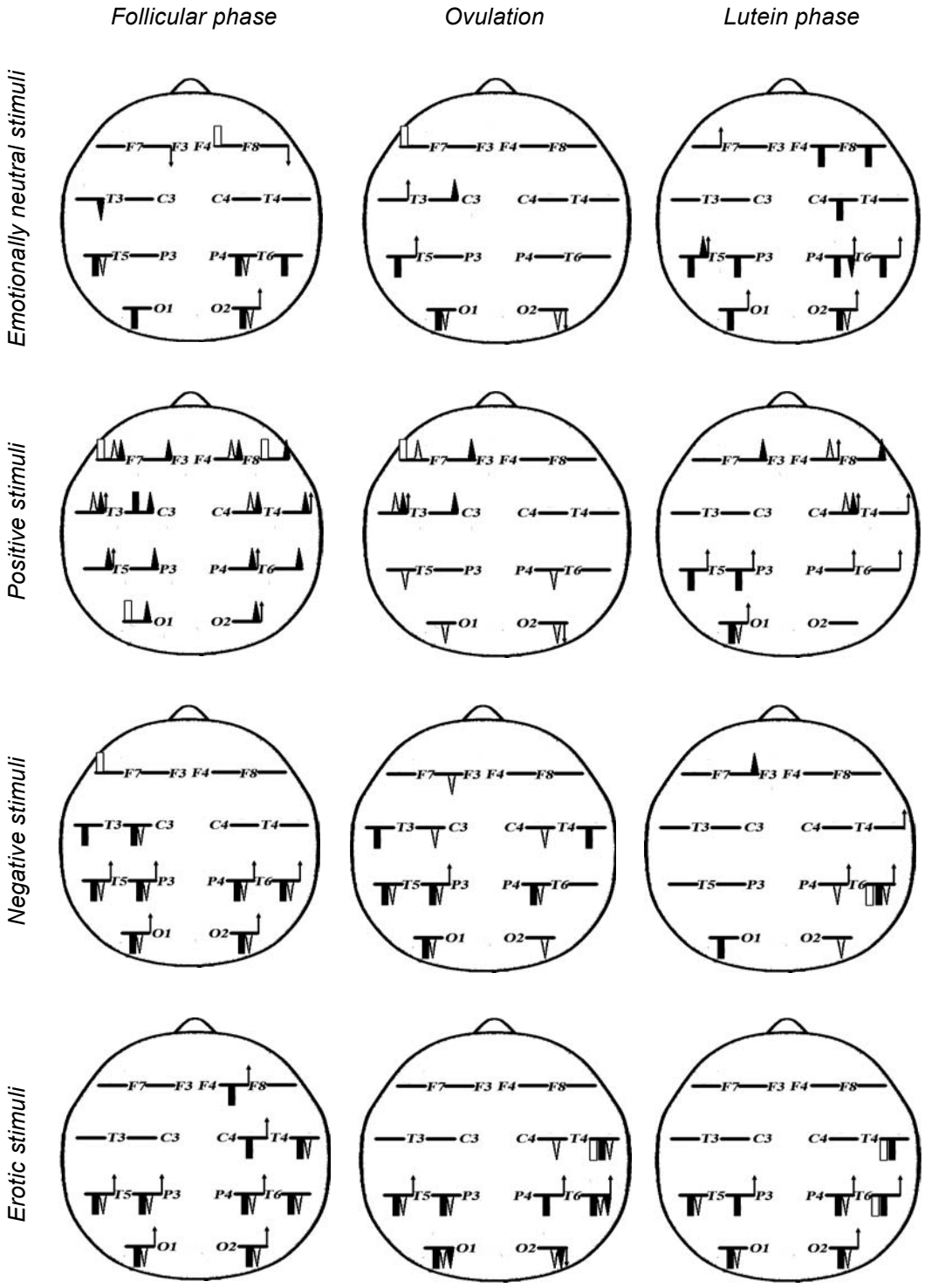

Fig. 2. Topomaps of differences between the values of medians of the spectral powers (SPs) of EEG frequency components and also those between the values of the coefficient of activation (CA) observed in the examined groups of women within various phases of the ovulatory cycle (indicated above). The mean intragroup values of medians of the SPs and CA under conditions of presentation of neutral and emotionally colored images of the IAPS set (indicated at the left side) were compared with those in the case of presentation of "empty" visual image stimuli. Designations the same as in Fig. 1. Arrows and open triangles indicate cases of significant differences between the values of the CA and SPs of the low-frequency EEG beta subrange, respectively. Other designations the same as in Fig. 1.

manifested in the removal from certain stimulus or in the approach toward another stimulus. Such reactions are controlled predominantly via the influences of the orbitofrontal cortex and right parietal part on the limbic structures and basal ganglia.

Since the examined women in our study passively viewed the presented pictures and realized no motor reaction upon the action of these visual stimuli, we *a priori* believe that changes recorded under such conditions are related mostly to the neocortical parts that provide evaluation of both the sign of the stimulus and the activating component of its perception.

As can be seen from the experimental data presented in Fig. 2, viewing of emotionally colored pictures with different contents is accompanied by specific rearrangements of cerebral electrical activity, which manifest a clearly pronounced dependence on phases of the ovulatory cycle in women.

In the course of viewing neutral pictures, the power of alpha oscillations in the left occipital/temporal parts (O1/T5) decreased during all phases of the ovulatory cycle. This phenomenon is quite expected, since it is generally known [11] that there is a relation between depression of the alpha rhythm and the development of activating processes in cortical zones related to the analysis of visual stimuli. During the follicular phase, viewing of the above pictures was accompanied by additional activation of the parietal/occipital/temporal parts. This can indicate that symmetrical posterior occipital parts of the neocortex are involved in the analysis of such pictures against the background of a simultaneous decrease in the activation in the frontal loci (F3 and F8). This circumstance seems to be quite natural, since the above pictures possessed no emotional loading; the frontal parts responsible for evaluation of the significance of stimuli are involved in the analysis of such stimuli to a lesser extent. Within the ovulation phase, left-hemisphere activation of the temporal/central zones was mostly observed. During the lutein phase, viewing of neutral pictures was accompanied by the most topographically extensive depression of the alpha rhythm and a rise in the CA. Such changes were found in the frontal, central, parietal, and occipital zones.

In the course of viewing positive pictures, first, an increase in the power of the high-frequency beta subrange typical of the action of only such a type of pictures was observed. Such an increase probably functionally reflects a cognitive component of perception. Second, the dynamics of changes in the power of different ranges of EEG activity in the course of viewing pictures of the above type in different phases of the ovulatory cycle demonstrated the most significant distinctions. In this case, the most extensive (according to the number of involved cerebral zones) modifications were observed during the follicular phase. Within this phase, the power of the high-frequency beta subrange increased in all the studied zones, while the power of low-frequency beta oscillations increased in the frontal, left temporal, and right central zones. In addition, theta oscillations in the left occipital and symmetrical posterior frontal zones (F7 and F8) were intensified within the follicular phase. It seems probable that these shifts are related to the emotional component of perception of such pictures.

It should be mentioned that, during ovulation, viewing of emotionally positive pictures caused opposite modifications of the high- and low-frequency subcomponents of the beta range. Increase in the power of the high-frequency beta subcomponent in the left frontal-temporal cortical zone was accompanied within this period by a decrease in the intensity of low-frequency beta oscillations in the occipital zones.

In general, the maximum rearrangement of EEG rhythms induced by the viewing of pictures with positive emotional contents was observed in the left hemisphere; this fact agrees with the concept of the predominant role of this hemisphere in the processing of "pleasant stimuli." It should be noted that, during the ovulatory phase, viewing of such pictures was accompanied by the smallest changes in the CA, as compared with those observed within other phases of the ovulatory cycle (this coefficient increased only in the left temporal lead).

In the lutein phase, viewing of pictures with positive contents led to the development of a focus of activation localized in the right frontal/central parts (where the power of the high-frequency spectral components of EEG increased). In the left temporal/occipital zone, the alpha rhythm was suppressed. Such changes, according to the studies of EEG correlates of fMRT patterns [12], are indicative of intensification of attention-related processes. Taking into account that, in general, intensification of the beta activity correlates with the cognitive component of perception of visual pictures, we can conclude that the greatest tension and concentration in the course of viewing pictures with positive contents are typical of an interval of the follicular phase. Concurrently, perception of pleasant stimuli within other phases of the menstrual cycle was accompanied by lateralization of the activating support of sensory and analytical processes in the left (during the ovulatory phase) and right (during the

lutein phase) hemispheres, respectively.

Viewing of negatively colored pictures caused, in general, decreases in the power of the alpha activity and low-frequency beta oscillations in symmetrical occipital/temporal neocortical zones; these events obviously reflect activation of the visual associative areas of the cortex. Comparison of the dynamics of EEG changes in the course of viewing neutral and unpleasant pictures shows that perception of the latter more significantly decreased the power of oscillations of the low-frequency beta subrange during all the phases of the ovulatory cycle. Since the alpha and beta ranges of the EEG activity are usually considered to be opposite, to a considerable extent, in their functional contents [11], it cannot be ruled out that changes in the activity of the tonic controlling system of the neocortex were reflected in this situation. As a result, the power of broad frequency bands of the EEG spectrum can be modulated. The fact that viewing of pictures with negative emotional contents during all the phases of the ovulatory cycle caused a rise in the CA in the parietal cortical zones is intriguing. We believe that this fact can reflect more intense involvement of the activating cerebral systems [7], which is a quite natural phenomenon under conditions of the action of negative stimuli.

During the follicular phase, viewing of pictures with negative contents induced intensification of the theta activity in the left frontal zone (F7) and depression of alpha oscillations in the central/temporal parts of the left hemisphere. Our data agree with the findings obtained using positron-emission tomography. As was demonstrated in studies with the use of such a technique, expectation for an experimentally modeled danger is most frequently related to the activation of structures of just the anterior parts of the left hemisphere (orbitofrontal cortex, insular cortex, and anterior cingulate part) [13]. Depression of alpha oscillations in the central/parietal parts observed mostly in the left hemisphere can probably be explained by the influence of verbally mediated disturbing thoughts; this is the manifestation of anxiety and an attempt to decrease its level. Such a pattern of reaction to presentation of emotional stimuli is typical of persons with a high level of anxiety [14]. It is interesting that this pattern of reaction was observed in our studies just during the follicular phase of the ovulatory cycle, i.e., at the lowest concentrations of estrogen in the blood. Taking into account the effect of estrogens on the level of expression of serotonin receptors, on the synthesis of serotonin and its re-uptake by neural terminals, and on the monoamine oxidase-mediated destruction of serotonin [15], and also the well-known anxiolytic effect of this neurotransmitter, as well as the involvement of serotonergic neurons of the raphe nuclei in the modulation of the hippocampal theta rhythm [16], such a reaction to negative pictures during the follicular phase can be explained by the decrease in the activity of the serotonergic system, since the level of estrogens within this phase is minimal. During the follicular phase, the CA also increased in all the parietal/occipital/temporal zones.

During the ovulatory phase, changes in the power of oscillations of the alpha and low-frequency beta ranges were nearly symmetrical, with insignificant predominance in the left hemisphere. Similarly to what was observed upon viewing of pleasant pictures, we observed minimal activation of the neocortex during this phase, which is confirmed by a rise in the CA only at the left parietal lead (P3).

As to the lutein phase, viewing of unpleasant pictures within this period caused zonal modifications of electrical activity, which differed from those during other phases. Viewing of pictures with emotionally unpleasant contents was accompanied by depression of the low-frequency beta activity in the right parietal/occipital zones against the background of a decrease in the power of oscillations of the alpha and theta ranges in the posterior temporal part (T6). Viewing of unpleasant pictures during this phase caused a rise in the CA only in the right temporal/parietal zones.

Viewing of unpleasant pictures during the lutein phase resulted also in an increase in the power of high-frequency beta subranges in the left frontal zone (F3), which can be indicative of attempts of the tested persons to provide conscious self-control of their emotional state. In the course of neurovisualization, such activation of the left prefrontal cortex was observed at conscious regulation of the emotional reactions to presentation of negative visual stimuli [17]. As a result, this conscious control is capable of totally decreasing the reactivity of the cortex with respect to negative stimuli. This can be related to the fact that, during the lutein phase, activation of the left frontal zone was accompanied by a significant decrease in the power of the alpha range only in the left occipital (O1) and right posterior temporal (T6) zones, while depression of the alpha rhythm during follicular and ovulatory phases covered the temporal/parietal/occipital zones.

Viewing of pictures with erotic contents was accompanied by a decrease in the power of the alpha and low-frequency beta ranges in the parietal/occipital and right temporal zones. Such a pattern was rather

similar to changes in the electrical activity induced by presentation of emotionally negative pictures (Fig. 2). In other words, emotiogenic stimulation by two different (in emotional/informational contents) drives causes rather similar EEG reactions. Based on such a uniformity of EEG alterations in the case where the presented emotional stimuli were rather different, we can hypothesize that the corresponding modifications of the EEG pattern reflect in this case mostly "energetic" support of specific cerebral reactions to emotionally colored information *per se*, with no relation to the sign of such information. It should be noted that presentation of erotic stimuli during the ovulatory phase additionally suppressed the low-frequency beta activity in the occipital zones and decreased the power of the theta activity in locus T4. During the lutein phase, such a decrease in the theta activity induced by erotic stimuli was found in the right temporal zones (T4 and T6).

Although the dynamics of changes in the powers of oscillations of the different-frequency EEG ranges in the course of viewing pictures with erotic contents were in general similar to alterations caused by viewing of emotionally unpleasant pictures, such changes were more expressed in the right temporal zone upon the action of erotic stimuli, while the respective shifts were more expressed in the left temporal zone upon the action of negative stimuli. It is interesting that our own data on the effects of erotically colored visual stimuli in women during different phases of the ovulatory cycle agree, on the whole, with the results obtained in studies of the effects of viewing of erotic visual pictures in men [18]. According to the data of the cited study, the viewing of erotic pictures activates in men the posterior temporal zones of the cortex, which correspond to the visual associative cortex and paralimbic parts (right islet and posterior frontal zone); it is believed that these zones are related to the processing of information with a high level of motivation. Activation also covered the left anterior part of the cingulate gyrus. As can be seen in Fig. 2, erotic visual stimuli, in contrast to stimuli of other types, induced rather generalized reactions within all phases of the ovulatory cycle. Frontal cortical zones, however, demonstrated no involvement under such conditions. It is logical to conclude that the activating component of perception, which triggers the emotiogenic cerebral structures independently of the sign of emotions, is precisely the leading factor in this case.

When beginning this study, we expected that most modifications of the EEG pattern related to the phases of the ovulatory cycle should be observed in women in the course of perception of just erotic stimuli. It is known that fluctuations of the levels of testosterone derivatives throughout the above-mentioned cycle influence significantly the perception of sexual stimuli in women [19, 20]. However, our data showed that the cerebral neurodynamics observed in the course of viewing pictures of this type during various types of the ovulatory cycle were characterized by the smallest specificity. Such a contradiction was, however, significantly removed after we analyzed changes in the EEG during a post-stimulus period. We found that the mentioned late alterations clearly correlate with the phases of the ovulatory cycle. Such changes were the most significant during just the ovulatory phase. After viewing an erotic picture, increases in the powers of the alpha and beta1 rhythms were observed in the posterior cortical zones. Intensification of the theta activity was observed in the right central and temporal zones, C4 and T4 (which was not characteristic of other post-stimulus periods). This, in general, can reflect a prolonged and stable emotiogenic effect of such stimuli just during the ovulatory phase. Within the time interval after viewing erotic pictures (presentation of "empty" pictures) during the lutein phase, we observed an increase in the power of the high-frequency EEG components (oscillations of both beta subranges) in the occipital zones (more expressed at the right). It has been reported that intensification of the beta activity in these cortical zones correlates with the reminiscence of certain unpleasant emotionally colored events; in women, intensification of the beta activity is, under such conditions, clearly pronounced in zone T6 [21].

Therefore, we stated that viewing of emotionally colored pictures of different contents is accompanied by rather specific rearrangements of cerebral electrical activity in women; such rearrangements demonstrate certain peculiarities depending on the phases of the ovulatory cycle. The minimal generalized activation of the brain (according to changes in the CA) in the course of viewing of both pleasant and unpleasant pictures was observed during the ovulatory phase where the estrogen concentration in the blood is maximal. Viewing of unpleasant and erotic pictures (samples of the IAPS set) related to the maximal level of arousal caused the most intense activating processes (according to the number of involved cortical zones) during the follicular phase (where the levels of both estrogen and progesterone are low). In studies using a tomography technique, it was demonstrated [1] that affective reactions to viewing of unpleasant pictures in women during the ovulation period are weakened, as compared with those during an earlier period of

the follicular phase. This is manifested in the weakest activation of the cortical and subcortical cerebral structures involved in the control of the level of arousal and initiation of neuroendocrine and affective reactions (central amygdala, periventricular and ventromedial hypothalamic nuclei, hippocampus, orbitofrontal cortex, and anterior cingulate gyrus). The authors of the cited study did not examine reactions to affective pictures during the lutein phase. According to the data obtained in other studies [22], the maximum stress-induced activation of the hypothalamo-hypophyseal axis was observed precisely within the lutein phase.

Numerous experimental proofs of the regulatory influences of circulatory estrogens on the release of hormones of the hypothalamo-hypophyseal-adrenal axis have been accumulated at present. These influences are mediated by estrogen beta receptors expressed in hypothalamic hormone-producing neurons [6]. Estrogens also influence the release of noradrenaline in the frontal cortex. It is believed that the anxiolytic effect of estrogens, which is based on a decrease in the release of noradrenaline and also in suppression of behavioral reactions typical of a stress response, is realized in such a mode. This circumstance can explain the fact that precisely during the ovulatory phase, i.e., during the maximum level of estrogens in the blood, viewing emotionally excitatory pictures is accompanied by the weakest activation of the cortex (according to changes in the CA). We believe that such decreased stress activation in response to emotiogenic stimulation during the ovulatory phase is behaviorally reasonable from the aspect of the possibility for realization of more resolute and effective behavioral strategies during this, the most favorable for fertilization, period.

Therefore, our study indicated that viewing affective pictures of various types activates the woman's brain to a greatest extent within the follicular phase of the ovulatory cycle and to a lesser extent during the ovulatory phase where the estrogen concentration in the blood is maximal. During the lutein phase, the maximum activation of the brain (compared with that within other phases) was caused by presentation of emotionally neutral stimuli; clear localization of such activation is observed in the right hemisphere. Cognitive and emotional components of perception of affective pictures predominate in the course of viewing positive stimuli during the follicular phase, while perception of these stimuli during other phases is accompanied by clear lateralization of activation related to sensory and analytical processes mostly in the left hemisphere during ovulation and in the right hemisphere during the lutein phase. Presentation of emotionally negative stimuli during the follicular phase intensifies the theta activity in the left frontal part and suppresses the alpha activity in central parietal parts of the same hemisphere. The above effects can be an electrographic correlate of anxiety under the action of such stimuli and verbally mediated anxious ideas.

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