Spectral-Coherent Characteristics of EEG Alpha Rhythm in Different Efficiency of Visual Spatial Task Performance in Humans

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Translated from *Byulleten' Eksperimental'noi Biologii i Meditsiny*, Vol. 153, No. 5, pp. 546-550, May, 2012
Original article submitted March 5, 2011

We studied spectral-coherent characteristics of EEG alpha rhythm in 26 students demonstrating different performance efficiency in visual spatial tasks of the same difficulty. More close coherence of biopotentials in the alpha EEG frequency band was observed between the occipital, parietal, central, and temporal areas in both hemispheres of the brain. The results of the experiments showed that different performance efficiency in visual spatial task of the same difficulty was associated with different levels of biopotential synchronization in the EEG alpha frequency band.

Key Words: *memorization efficiency; alpha rhythm; spectral power; coherence*

The frontothalamic system of selective attention plays an important role in the spatial image perception. Many published reports discuss the relationship between EEG alpha-rhythm and this system facilitating the interaction of brain structures during cognitive activity [4,7]. Alpha-rhythm plays an important role in the integration of brain structures during sensory and cognitive activities by forming a dynamic basis of their functional interaction [5].

According to classical concept proposed by M. N. Livanov [2], the phenomenon of synchronization reflects the state of the brain cortex, when irradiation of the excitatory processes is facilitated. Synchronization, temporal concordance of the processes, reflects mutual tuning of nerve structures ensuring also the possibility of their working cooperation. Coherence coefficient (Kcoh) is a quantitative measure of synchronization. Coherence is an objective systemic criterion reflecting spatiotemporal functional relationships of different areas of the brain cortex. The coherence of different EEG ranges reflects the degree of functional connectivity and coordination of neuronal ensembles in different areas of the brain cortex.

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It was hypothesized that the coordination of different rhythmogenic mechanisms during information processing can be organized as follows. During voluntary attention, the rhythmogenic structures of the thalamus controlled by the frontothalamic system and tuning them to the solution of the current cognitive task from the functional interaction basis the brain structures at the macro level (*i.e.* individual projection and associative areas and subcortical structures) via alpha-rhythm synchronization [4]. It has been also demonstrated that alpha-rhythm spectral power parameters are less important than analysis of inter-regional synchronization of alpha-potentials in the study of difficult sensory tasks performance in humans [6]. Considering this hypothesis, we assumed that different efficiency of the cognitive process should be associated with different synchronization of alpha-band biopotentials. Here we studied the dynamics of biopotential coherence in EEG alpha-range in humans with different performance efficiency of visual spatial tasks of the same difficulty.

MATERIALS AND METHODS

The study included 80 students (males, 18-21 years); the participants signed informed consent for participation in the experiments.

The examinee sat in a darkened room without extraneous stimuli at the monitor (17") at a distance of 60-70 cm. He was asked to memorize a sequence and location of 6 signals (1-cm circles). The sequence was presented twice for 30 sec. After that, the examinee was asked to reproduce the sequence by clicking the next expected circle on the monitor. According to the instruction, the goal of the examinee was to predict with maximum accuracy the location of the next signal. The examinee was presented 10 similar sequences of similar difficulty differing by the signal location and ordering.

The following parameters were analyzed for each examinee: the number of precise predictions of the locations of the next signal (<1.5 cm from the center) and the number of errors in the sequence (prediction of the next signal in a site close to any other signal, but not to the correct one).

We choose two sequences of similar difficulty (i.e. the performance efficiency by the analyzed parameter did not differ for these sequences for the whole group). However, individual analysis revealed a group of examinees (*N*=26) demonstrating different performance efficiency in the tasks of similar difficulty. Here we present the results of analysis of spectral-coherent characteristics of EEG in this group of examinees.

EEG was recorded in three experimental situations: in the absence of extraneous stimuli in a quiet awake state with eyes open (40 sec) and closed (40 sec) and during memorizing of the sequence (30 sec).

Monopolar EEG by the "10-20" system was recorded using a Neiron-Spektr encephalograph in occipital (O2, O1), parietal (P4, P3), central (C4, C3), frontal (F4, F3), and temporal (T4, T3) leads. Common reference electrodes were fixed on the ear lobules. Filtration band was 0.5-45.0 Hz, time constant 0.3 sec.

The artifacts caused by eye movements were identified by the typical shape and spatial distribution and excluded from the analysis using available software functions (in particular, automatic detection of artifacts with visual control).

Spectral analysis of EEG using a Fourier transform algorithm was performed using Neiron-Spektr software. Power density spectra in the range of 0.5-35.0 Hz were calculated. The analysis epoch was 4 sec, sampling rate 200 Hz, rejection ratio 50 Hz. The absolute power (μV^2) and the mean intra- and interhemispheric coherence coefficients (with a 50% shift) in the alpha range (8-10 Hz) were calculated for all possible channel combinations. The data were processed statistically using Statistica 6.0 software. Significance of differences of the analyzed parameters in students of the selected group was evaluated using breakdown and one-way ANOVA. Significance of changes in the parameters in different experimental situations in this group of students was evaluated using *t* test for related samples.

RESULTS

Alpha-rhythm spectral power significantly decreased in comparison with the initial values in the parieto-occipital areas of the cortex during both successful and unsuccessful memorization (Fig. 1). It should be noted that alpha-rhythm spectral power in the right occipital lead decreased to 12.98±1.71 μV^2 (*vs.* initial 25.20±4.52; $p<0.05$) during successful memorization and to 8.32±1.38 μV^2 ($p<0.01$) during unsuccessful memorization. Hence, desynchronization of alpha potentials in comparison with the baseline was less pronounced in case of successful memorization. Taking into account the facts that the coefficient of alpha-rhythm depression is increased in individuals incapable of complete memorization [1] and that the degree of alpha-rhythm depression during mental load reflects the individual level of nonspecific activation and correlates with the rate of memorization, in particular, with the rate of learning [3], we can assume that in our experiments incomplete memorization of a "unsuccessful" sequence was associated with an excess of unspecific activation effects.

Analysis of Kcoh showed that synchronization of cortical activity at the EEG alpha-rhythm frequency between several cortical areas significantly increased in comparison with baseline values during both successful and unsuccessful memorization (Table 1). For more demonstrative presentation of the detected differences in Kcoh for EEG alpha-band biopotentials in the examined individuals we constructed a topographic scheme of coherent relationships of biopotentials. The scheme shows only the relations between the cortical areas where Kcoh of alpha-range biopotentials at

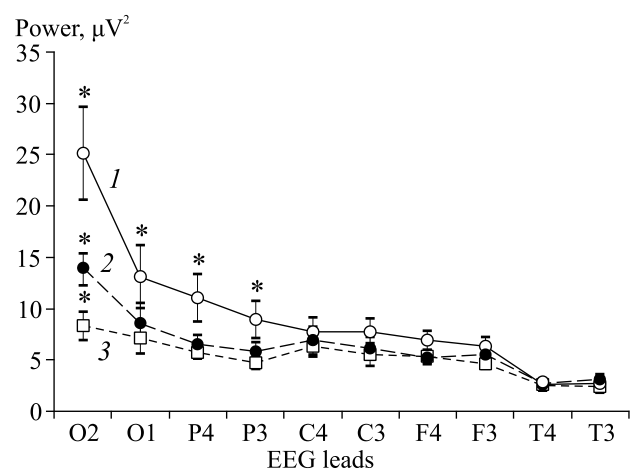

Fig. 1. Spectral power of EEG alpha-rhythm at the baseline (*1*) and during successful (*2*) and unsuccessful (*3*) memorization of signal sequences. *$p<0.05$ in comparison with baseline.

TABLE 1. Kcoh between the Studied Cortical Areas in Examinees at the Baseline and during Successful and Unsuccessful Memorization of the Sequences

Lead pairs	Baseline	Successful memorization	*p*	Unsuccessful memorization	*p*
F3-T3	0.54±0.02	0.59±0.04	0.266007	0.53±0.03	0.763179
F4-T3	0.37±0.02	0.41±0.03	0.095876	0.39±0.02	0.215396
C3-T3	0.67±0.01	0.71±0.02	0.191385	0.67±0.03	0.510266
C4-T3	0.41±0.02	0.48±0.02	**0.013449**	0.42±0.03	0.237383
T4-T3	0.36±0.02	0.42±0.02	**0.003594**	0.41±0.03	**0.013688**
P3-T3	0.67±0.02	0.71±0.03	0.193912	0.69±0.02	0.289292
P4-T3	0.41±0.02	0.47±0.02	**0.002618**	0.45±0.02	**0.024499**
O1-T3	0.54±0.02	0.60±0.02	**0.045994**	0.58±0.04	0.053563
O2-T3	0.37±0.02	0.43±0.02	**0.001947**	0.41±0.03	**0.015989**
F4-F3	0.65±0.02	0.63±0.02	0.427854	0.62±0.03	0.350008
C3-F3	0.82±0.02	0.86±0.02	0.101083	0.82±0.02	0.941760
C4-F3	0.56±0.02	0.56±0.02	0.883091	0.55±0.03	0.584034
T4-F3	0.38±0.02	0.44±0.02	0.107145	0.38±0.03	0.838381
P3-F3	0.63±0.02	0.72±0.02	**0.008365**	0.64±0.03	0.267802
O1-F3	0.46±0.03	0.52±0.03	0.115216	0.47±0.03	0.509187
O2-F3	0.38±0.03	0.38±0.03	0.899020	0.37±0.03	0.950817
P4-F3	0.42±0.02	0.48±0.02	**0.003631**	0.46±0.03	**0.041818**
F4-C3	0.54±0.02	0.54±0.02	0.651469	0.54±0.03	0.632955
C4-C3	0.64±0.02	0.63±0.02	0.954393	0.65±0.03	0.688465
T4-C3	0.43±0.02	0.48±0.02	**0.007118**	0.45±0.03	0.050445
P4-C3	0.54±0.02	0.60±0.02	**0.008458**	0.59±0.03	**0.013818**
P3-C3	0.85±0.01	0.89±0.01	**0.038643**	0.86±0.02	0.207652
O1-C3	0.61±0.02	0.67±0.02	**0.034164**	0.63±0.03	0.212393
O2-C3	0.41±0.02	0.47±0.02	**0.009782**	0.42±0.02	0.232024
F4-P3	0.43±0.02	0.43±0.02	0.625345	0.44±0.02	0.476966
C4-P3	0.55±0.02	0.58±0.02	0.138981	0.55±0.03	0.415322
T4-P3	0.43±0.02	0.51±0.02	**0.004247**	0.46±0.03	0.073521
P4-P3	0.61±0.02	0.67±0.02	**0.026035**	0.64±0.03	0.078597
O1-P3	0.82±0.01	0.82±0.01	0.505553	0.82±0.02	0.795850
O2-P3	0.51±0.02	0.58±0.02	**0.004413**	0.56±0.03	**0.012753**
F4-O1	0.38±0.02	0.38±0.02	0.975864	0.36±0.03	0.626585
C4-O1	0.43±0.02	0.47±0.02	0.054379	0.44±0.03	0.307878
P4-O1	0.56±0.02	0.62±0.02	**0.027290**	0.58±0.03	0.193559
T4-O1	0.42±0.02	0.49±0.02	**0.002065**	0.45±0.02	**0.030178**
O2-O1	0.60±0.02	0.66±0.03	**0.011919**	0.65±0.03	**0.033470**
C4-F4	0.81±0.02	0.81±0.03	0.796156	0.82±0.02	0.576526
T4-F4	0.53±0.02	0.56±0.04	0.169770	0.55±0.03	0.184206
P4-F4	0.61±0.02	0.65±0.03	**0.048142**	0.66±0.03	**0.018138**
O2-F4	0.48±0.02	0.50±0.03	0.870724	0.46±0.04	0.499408
T4-C4	0.70±0.02	0.71±0.02	0.232051	0.71±0.03	0.312760
P4-C4	0.82±0.02	0.87±0.01	**0.008211**	0.85±0.01	**0.029910**
O2-C4	0.58±0.02	0.68±0.02	**0.004149**	0.61±0.02	0.061893
T4-P4	0.72±0.02	0.76±0.03	0.149741	0.72±0.03	0.815671
O2-P4	0.83±0.02	0.86±0.02	0.200861	0.83±0.02	0.842273
T4-O2	0.61±0.02	0.65±0.03	0.319793	0.61±0.03	0.741620

Note. Bold figures show significant differences between Kcoh during successful and unsuccessful memorization in comparison with the baseline values.

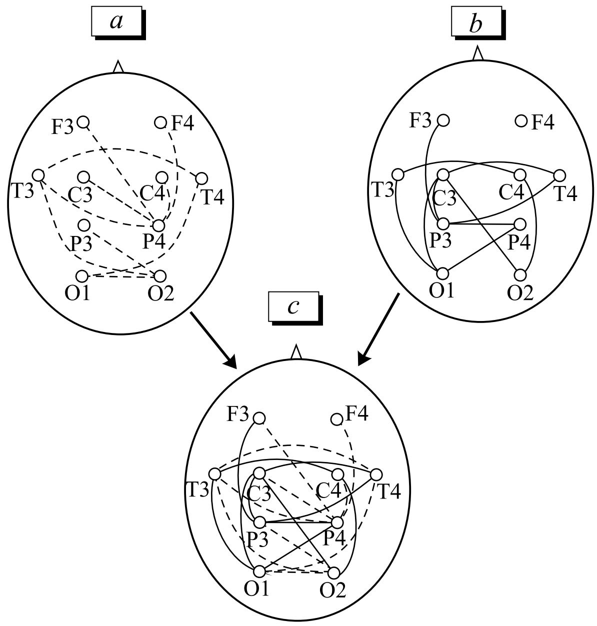

Fig. 2. Topographic distribution of coherent relations in the alpha-rhythm range with Kcoh above the baseline values. *a*) successful and unsuccessful memorization; *b*) additional relations that increased significantly only during successful memorization; *c*) general picture of coherent relations during successful memorization.

the stage of memorization significantly surpassed the initial values (Fig. 2). During both successful and unsuccessful memorization, we observed a significant increase in Kcoh between the areas T3-T4, P4-T3, O2-T3, P4-F3, P4-C3, O2-P3, T4-O1,O2-O1, P4-F4, P4-C4 in comparison with the baseline values (Fig. 2, *a*).

During successful memorization, apart from enhanced synchronization of biopotentials in the above specified areas we observed increased interactions of alpha-range biopotentials between some other cortical areas (C4-T3, O1-T3, P3-F3, T4-C3, P3-C3, O1-C3, O2-C3, T4-P3, P4-P3, P4-O1, O2-C4) (Fig. 2, *b*). We also observed an increase in interhemispheric synchronism of alpha-range potentials in comparison with the initial level. This fact can be interpreted as an evidence of specific interhemispheric interaction of biopotentials reflecting the involvement of the left-hemispheric mechanisms of information processing and analysis into memorization process. We present a scheme of topographic location of intra- and interhemispheric relations with Kcoh surpassing the baseline values during successful memorization (Fig. 2, *c*). It is evident that higher synchronism of EEG alpha-rhythm biopotentials during successful memorization facilitated information interaction between the right- and left-hemispheric areas in comparison with that during poor memorization.

Thus, we observed more close coherence of biopotentials in EEG alpha frequency range between the occipital, parietal, central, and temporal areas in both hemispheres of the brain. The results of our experiments showed that different performance efficiency of visual spatial task of the same difficulty was associated with different levels of biopotential synchronization in the EEG alpha frequency band.

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