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Functional relationships of the cerebral cortex with subcortical structures in emotional stressful conditions

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Abstract. Studying central mechanisms of stress, which is assuming more an emotional aspect, is among the topical problems of modern neurophysiology and medicine. Having created complex conditions of adaptive behavior, rapid scientific and technological growth has required processing a huge flow of different information related to biological functions and social activity of human beings. According to WHO experts, in 70% of all cases emotional stress leads to various diseases including hypertension, myocardial infarction, stroke, atherosclerosis, as well as development of neurotic conditions, psychiatric disorders and disruption of normal adaptation of humans to social conditions of life. Many researchers have studied EEG and peripheral signals separately, but little attention has been paid to the correlation between these indicators. To date, issues related to the central mechanisms of stress and their relationship with autonomic functions have not been fully studied. The EEG cross-correlation analysis we have chosen is more advanced because, unlike conventional EEG analysis, it provides detailed information about the connections between brain structures in spatio-temporal relationships.

1 Introduction

Among the current problems of modern medicine and neurophysiology is the study of the central mechanisms of negative emotions, the level of which increases from year to year [1-3]. In recent years, the most common stress factors such as urbanization, scientific and technological progress, increased pace of life, information overload have been joined by the recent pandemic, which has further increased the level of emotional stress [4]. Of particular interest are long-term negative emotions, the accumulation of which can lead to the development of neurotic conditions, cardiovascular diseases, which are the most dangerous for the body [5]. In recent years, many studies have been conducted to assess stress and its effect on the body [6]. Most research on stress and emotional states uses peripheral signals such as respiratory rate, pulse, pressure, etc. [7, 8]. Many researchers have studied EEG and peripheral signals separately, but so far little attention has been paid to correlation of these

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indicators [9]. So far, issues related to the central mechanisms of stress and their correlation with autonomic functions have not been fully investigated. The research methodology we have chosen (EEG cross-correlation analysis) is more advanced, since, unlike conventional EEG analysis, it provides detailed information about the connections between brain structures in a spatio-temporal assessments. We aimed to study the changes in EEG potentials of the brain's cortex and subcortical structures based on cross-correlation coefficients and phase shifts in emotional stressful conditions.

2 Materials and Methods

Experiments were carried out in compliance with the principles of the “European Convention” for the protection of vertebrate animals that are used for experimental and scientific purposes (Strasbourg 1986) and the resolution of the 1st National Congress on Bioethics (Kyiv 2001).
Experiments were conducted on 5 immobilized rabbits with chronically implanted electrodes using the stereotaxic atlas of coordinates A.P. - 2.5 mm, L - 1.5 mm, H - 11.8 mm for the posterior nuclei of the hypothalamus, A.P. - 9 mm, L - 2 mm, B - 7 mm for the reticular formation. Photostimulations with the 8 Hz frequency and 10-30 ms duration were used. The intervals between the stimuli were irregular in order to create an emotional stressful condition. EEG was recorded on the multichannel electroencephalograph Neuron-Spectr-5 EEG devise (Neurosoft, Ivanovo, Russia), then analyzed on a computer using automatized statistical processing software Neuro-Stat program. Cross-correlation analysis conducted in 3 periods: background - before stimuli, at the time of stimuli and in the intervals between them.

3 Results and Discussion

For each analysis, correlation analysis software was performed on 10-second sections of the EEG recording. Animals remained continuously tense under conditions of irregular photostimulation with respect to time. The first (2-10) flashes of light accompanied by emotional stress, which was confirmed by changes in autonomic indicators: the pulse rate increased in the electrocardiogram. The animals were anxious both during the stimuli and during the intervals between them, because under these conditions it was not possible to foresee the moment of application of the stimuli. Data obtained before exposure to photostimulation showed that the slow waves of EEG potentials in the visual cortex (O1) and posterior hypothalamus were with a phase shift of 395 ms. The connections between the posterior hypothalamus (F3) and the reticular formation (Fp1) were weak: the cross-correlation coefficient was 0,61, and the phase shift was – 105 ms. Functional relationships between the hypothalamus (F3) and the visual cortex (O1, O2) determined by the cross-correlation coefficient were on average between 0,8-0,4 (Table 1, Figure 1).

Table 1. The cross-correlation coefficient data obtained in a background in rabbit N#1.

Pair	Lag (ms)	Cross-correlation coefficient
Fp1F3	-105	0,61
F3 O1	395	0,86
F3 O2	-190	-0,4

Against this background, the irregular use of photostimulation was accompanied by emotional stress, which caused an increase in phase shifts between the posterior nuclei of the hypothalamus and the visual projection zone, disrupting the synphase between the structures. The delay between the posterior hypothalamus (F3) and the visual cortex (O2) was clearly increased, and the delayed structure was the visual cortex with a phase shift of 365 ms. The cross-correlation coefficient decreased from an average of 0,80 to 0,23. On the contrary, the connections between the posterior hypothalamus (F3) and the reticular formation (Fp1) determined by the cross-correlation coefficient was between 0,91-0,75 and the phase shift reduced till 0 ms. In rabbits, these changes were observed throughout the experiment, especially in the initial periods of the orientation-exploratory response (Figure 2, Table 2).

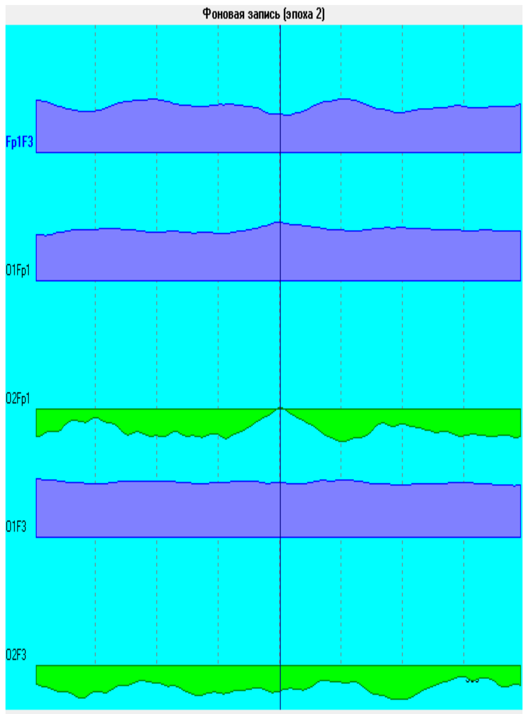


Fig.1. The cross-correlogram obtained after computer analysis of EEG waves in a background in rabbit N#1.

The delay between the posterior hypothalamus (F3) and the visual cortex (O1, O2) was clearly increased, and the delayed structure was the visual cortex with a phase shift of -390 ms. The cross-correlation coefficient decreased from an average of 0,92 to 0,65. On the contrary, the connections between the posterior hypothalamus (F3) and the reticular formation (Fp1) determined by the cross-correlation coefficient was between 0,91-0,75 and the phase shift reduced till 0 ms. In rabbits, these changes were observed throughout the experiment, especially in the initial periods of the orientation-exploratory response (Table 2, Figure 2).

Table 2. The cross-correlation coefficient data obtained immediately after stimuli in rabbit N#1.

Pair	Lag (ms)	Cross-correlation coefficient
Fp1F3	0	0,91
F3 O1	0	0,86
F3 O2	365	0,23

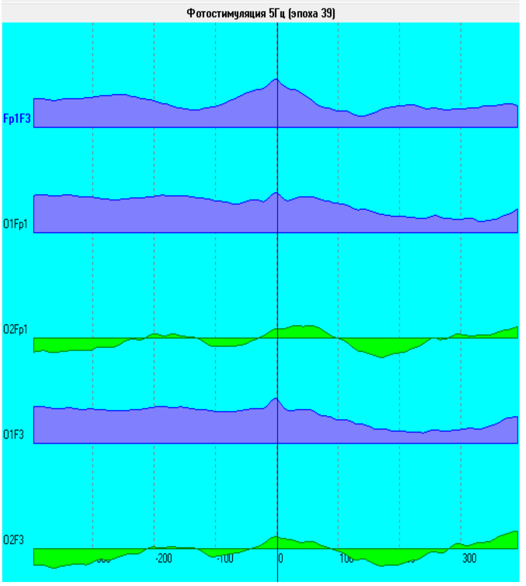


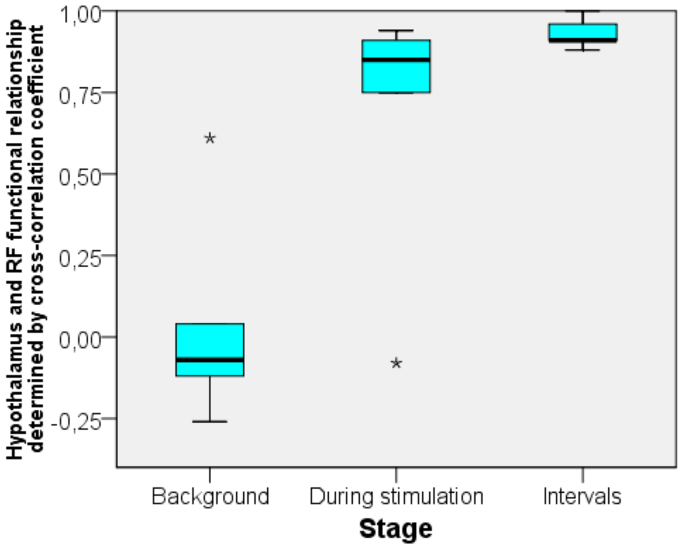
Fig.2. The cross-correlogram obtained immediately after stimuli in rabiit N#1.

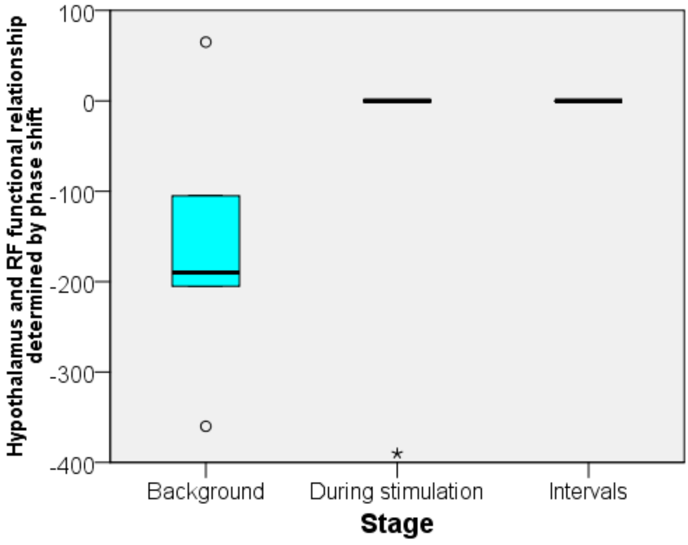
Our results show that during stressful condition the functional relationships between the cortical projection zone and subcortical structures consistently decrease, whereas relations between the subcortical structures increase. We furthermore found that these EEG changes correlated with autonomic reactions in animals.

Conclusion

Multidirectional and stable changes in phase shifts and cross-correlation coefficients of cortical and subcortical stress rhythm occur under conditions of repeated irregular photostimulation, especially during the initial periods. Thus, the cross-correlation functional relationships characterized by the changes of spatio-temporal relationships of the analyzed brain structures can be one of the indicators of stress formation. By the parameters mentioned above we can solve many issues related to the central mechanisms of stress. Our results show that during stressful condition the functional relationships between the cortical projection zone and subcortical structures consistently decrease, whereas relations between the subcortical structures increase (Figure 3).

We furthermore found that these EEG changes correlated with autonomic reactions in animals. Thus, these changes may lie on the basis of central mechanisms of stress and the results of changes in the EEG activity of the cerebral cortex and the cross-correlation parameters in the posterior nuclei of the hypothalamus and the reticular formation may allow preventive measures to be taken to affect these structures to reduce emotional stress. Thus, it is possible not only to prevent diseases, but also to protect human health in general


Hypothalamus and RF functional relationship determined by cross-correlation coefficient
1,00
0,75
0,50
0,25
0,00
-0,25
Background
During stimulation
Intervals
Stage


Hypothalamus and RF functional relationship determined by phase shift
100
0
-100
-200
-300
-400
Background
During stimulation
Intervals
Stage

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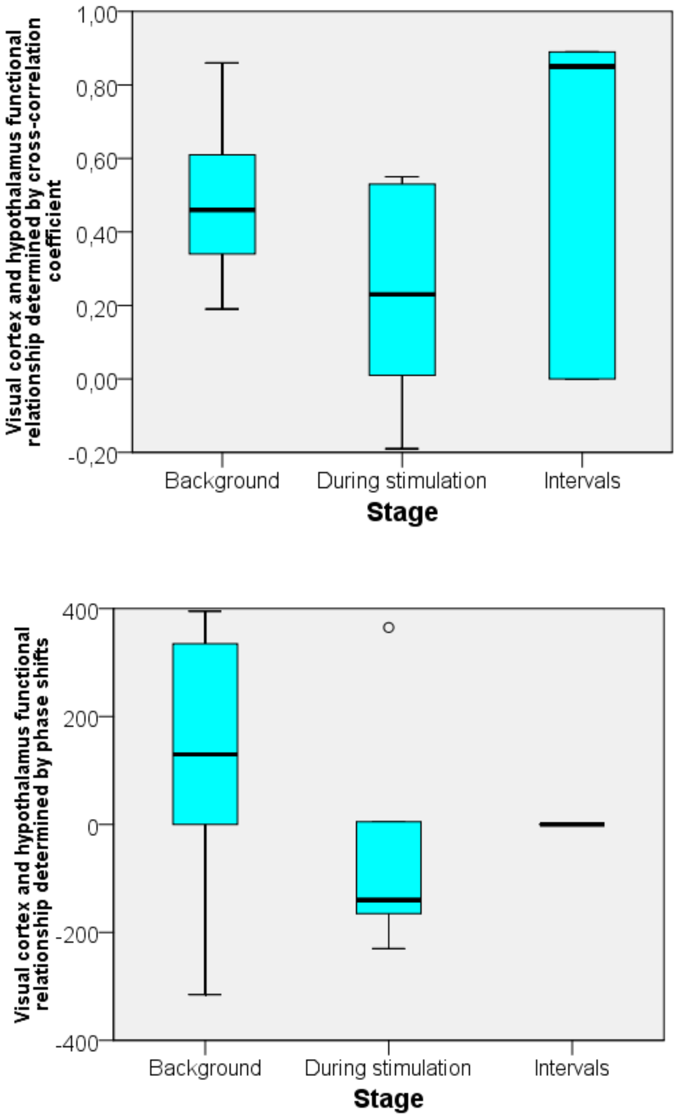

Figure 3. Statistical data obtained from 5 rabbits in the background, during photostimulations and in the intervals betweem stimuli.

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