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FUNCTIONAL RELATIONSHIPS OF THE CEREBRAL CORTEX WITH SUBCORTICAL STRUCTURES IN EMOTIONALLY STRESSFUL CONDITIONS

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Abstract:

Multidirectional and stable changes in phase shifts and cross-correlation coefficients of the cortical and subcortical stress rhythms occur under conditions of repeated irregular photostimulation, especially in the initial periods. Thus, cross-correlation functional connections, characterized by changes in the spatio-temporal relationships of the brain structures (posterior nuclei of the hypothalamus, reticular formation, and visual projection zones of the cerebral cortex), can be one of the indicators of the formation of stress. By using the parameters mentioned above, we can solve many issues related to the central mechanisms of stress. Our results show that functional connections between the cortical projection area and subcortical structures decrease under stress conditions, while connections between subcortical structures increase. We furthermore found that these EEG changes correlated with autonomic reactions in animals. Thus, these changes may lie based on 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.

Keywords: EEG, spatiotemporal analysis, emotional stress, cross-correlation, phase shifts.

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, 4, 5]. In recent years, the most common stress factors such as urbanization, scientific and technological progress, increased pace of life, and information overload have been joined by the recent pandemic, which has further increased the level of emotional stress [6]. Of particular interest are long-term negative emotions, the accumulation of which can lead to the development of neurotic conditions, and cardiovascular diseases, which are the most dangerous for the body [8]. In recent years, many studies have been conducted to assess stress and its effect on the body [3]. Most research on stress and emotional states uses peripheral signals such as respiratory rate, pulse, pressure, etc. [7, 9]. Many researchers have studied EEG and peripheral signals separately, but so far little attention has been paid to the correlation of these indicators [2]. 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 assessment.

Purpose: Study of changes in the EEG potentials of the brain's cortex and subcortical structures based on cross-correlation coefficients and phase shifts in emotionally stressful conditions.

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 6 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, and A.P. - 9 mm, L - 2 mm, H - 7 mm for the reticular formation. Photostimulations with an 8 Hz frequency and 10–30 ms duration were used. The intervals between the stimuli were irregular in order to create an emotionally stressful condition. The EEG was recorded on an NS-Neurosoft multichannel electroencephalograph and then analyzed on a computer using the automated statistical processing software Neuro-Stat. Cross-correlation analysis was conducted in 4 periods: background—before stimuli, at the time of stimuli, in the intervals between them, and after stimuli.

RESULTS AND DISCUSSION

Correlation analysis software was performed on 20-second sections of the EEG recording for each analysis. Animals remained continuously tensed under conditions of irregular photostimulation with respect to time. The first (2–10) flashes of light were 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 and posterior hypothalamus were mainly synphasic with a phase shift of 2–5 ms.

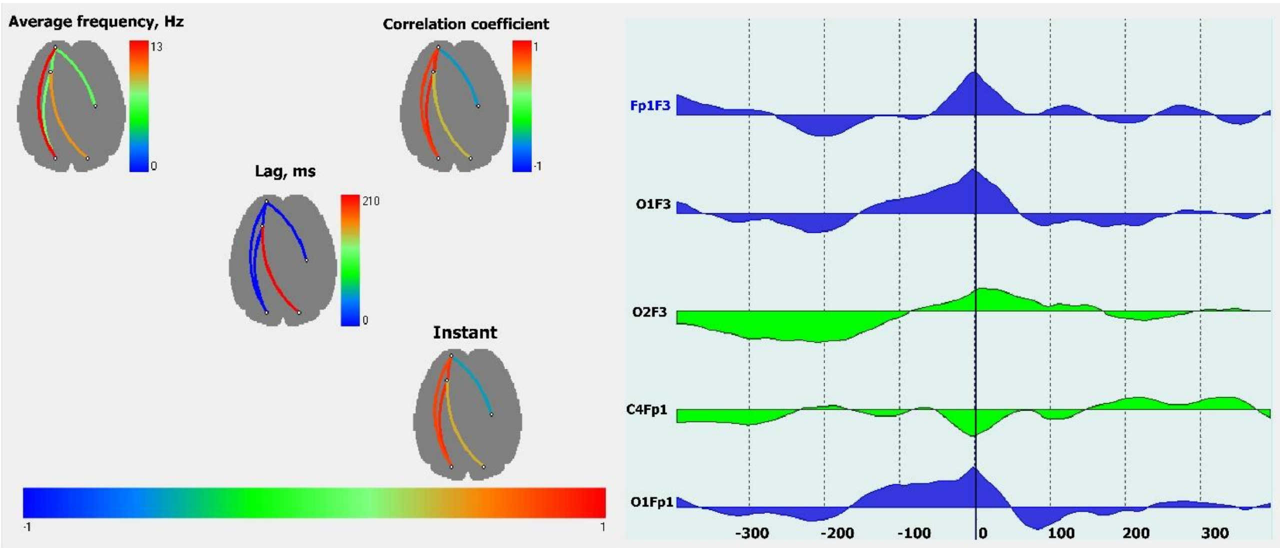

Figure 1. The cross-correlogram obtained after computer analysis of EEG waves in a background.

The connections between the posterior hypothalamus (F3) and the reticular formation (Fp1) were weak: the cross-correlation coefficient was 0.52, and the phase shift was 33 ms. Functional relationships between the hypothalamus (F3) and the visual cortex (O1, O2) determined by the cross-correlation coefficient were on average between 0,8-0,9 (Figure 1, Table 1).

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

Pair	Frequency (Hz)	Lag (ms)	Cross-correlation coefficient
Fp1F3	16.9	33	0.52
O1Fp1	16.3	3	0.92
O2Fp1	18.8	5	0.80
O1F3	21.4	33	0.52
O2F3	21.3	3	0.92

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 (O1, O2) was 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 were between 0.95-0.99, and the phase shift was reduced to a minimum of 5 ms. In rabbits, these changes were observed throughout the experiment, especially in the initial periods of the orientation-exploratory response (Figure 2, Table 2). (All data were analyzed in the ANOVA Statistical Software using the Mann-Whitney test; the processing results are presented in Fig. 3).

Table 2. The cross-correlation coefficient data obtained immediately after the stimuli.

Pair	Frequency (Hz)	Lag (ms)	Cross-correlation coefficient
Fp1F3	4	5	0.95
O1F3	0	15	0.67
O2F3	13.9	10	0.65
O1Fp1	10.5	5	0.95
O2Fp1	21.3	15	0.67

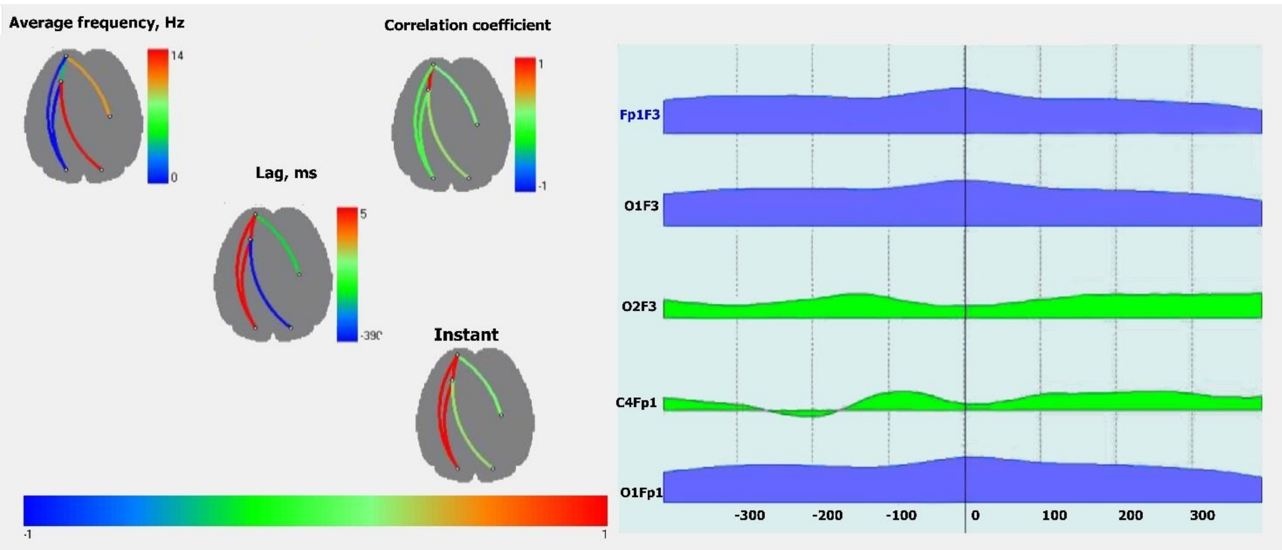

Figure 2. The cross-correlogram obtained immediately after the stimuli.

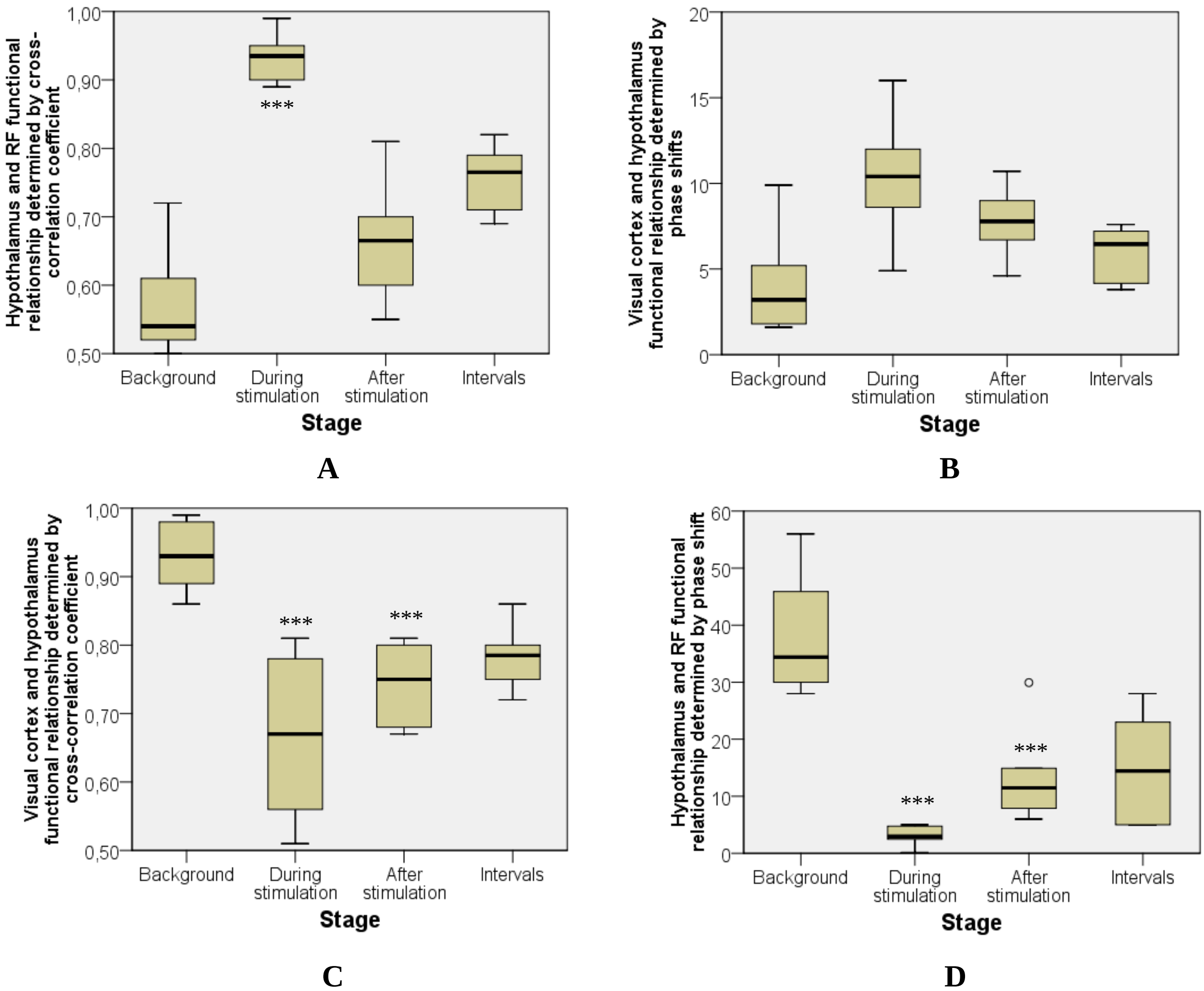

Figure 3. Results of cross-correlation analysis of functional connections between various brain structures under conditions of emotional stress (irregular photostimulation).
Note: A and C- cross-correlation coefficients; B and D - phase shifts.

CONCLUSION

Our results showed that during stressful conditions, 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.

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ФУНКЦИОНАЛЬНЫЕ СВЯЗИ КОРЫ МОЗГА С ПОДКОРКОВЫМИ СТРУКТУРАМИ В ЭМОЦИОНАЛЬНО-СТРЕССОВЫХ УСЛОВИЯХ

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В условиях повторных нерегулярных фотостимуляций, особенно в начальные периоды, происходят разнонаправленные и устойчивые изменения фазовых сдвигов и коэффициентов взаимной корреляции коркового и подкоркового стрессового ритма. Таким образом, кросс-корреляционные функциональные связи, характеризующиеся изменением пространственно-временных взаимоотношений анализируемых структур мозга, могут быть одним из индикаторов формирования стресса. С помощью упомянутых выше параметров мы можем решить многие вопросы, связанные с центральными механизмами стресса. Наши результаты показывают, что в условиях стресса функциональные связи между корковой проекционной зоной и подкорковыми структурами снижаются, тогда как связи между подкорковыми структурами возрастают. Кроме того, мы обнаружили, что эти изменения ЭЭГ коррелируют с вегетативными реакциями у животных. Таким образом, эти изменения могут лежать в основе центрального механизма стресса, а результаты изменения ЭЭГ-активности коры головного мозга и параметров кросс-корреляции в задних ядрах гипоталамуса и ретикулярной формации могут позволить проводить профилактические мероприятия необходимые для снижения эмоционального напряжения.

Ключевые слова: ЭЭГ, пространственно-временной анализ, эмоциональный стресс, математический анализ мозговых волн, кросс-корреляция, фазовые сдвиги.

EMOSİONAL GƏRGİN VƏZİYYƏTLƏRDƏ BEYİN QABIĞININ QABIQALTI STRUKTURLARLA FUNKSİONAL ƏLAQƏLƏRİ

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Təkrarlanan qeyri-müntəzəm fotostimulyasiya şəraitində, xüsusilə ilkin dövrlərdə, qabıq və qabıqaltı stress ritminin faza sürüşmələrində və kross-korrelyasiya əmsallarında çox istiqamətli və sabit dəyişikliklər baş verir. Beləliklə, təhlil edilən beyin strukturlarının məkan-zaman əlaqələrində dəyişikliklərlə xarakterizə olunan kross-korrelyasiya funksional əlaqələri stressin formalaşmasının göstəricilərindən biri ola bilər. Yuxarıda qeyd olunan parametrlərdən istifadə edərək, stressin mərkəzi mexanizmləri ilə bağlı bir çox sualları həll edə bilərik. Nəticələrimiz göstərir ki, stress şəraitində qabıq proyeksiya sahəsi ilə qabıqaltı strukturlar arasında funksional əlaqələr azalır, qabıqaltı strukturlar arasındakı isə əlaqələr güclənir. Bundan əlavə, biz EEQ dəyişikliklərinin heyvanlarda avtonom reaksiyalarla əlaqəli olduğunu aşkarladıq. Beləliklə, bu dəyişikliklər stressin mərkəzi mexanizminin əsasını təşkil edə bilər və beyin qabığının EEQ aktivliyindəki dəyişikliklərin nəticələri, eləcə də hipotalamusun arxa nüvələri ilə retikulyar formasiyanın kross-korrelyasiya parametrləri emosional gərginliyi azaltmaq üçün zəruri olan profilaktik tədbirlərin həyata keçirilməsinə imkan verə bilər.

Açar sözlər: EEG, məkan-zaman analizi, emosional stress, beyin dalğalarının riyazi təhlili, kross-korrelyasiya, faza sürüşmələri

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