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M. Chernykh, Ph.D student, I. Zyma, Dr Hab.
Taras Shevchenko National University of Kyiv, Kyiv, Ukraine

PECULIARITIES OF INFORMATION TRANSFER WITHIN FUNCTIONAL CORTICAL NETWORKS DURING EMOTIONAL FACE PERCEPTION

Aim: The research aimed to study and model the emotion-related activity of functional networks within the human brain cortex using power spectrum density and detrended phase transfer entropy methods. Attention was focused on revealing alterations in cognitive mechanisms, caused by presentation of neutral human faces as rare stimuli among faces with either negative or positive expression. Methods: EEG-data was recorded during the perception and processing of neutral human facial expressions, presented among positive and negative faces in two series of images, alongside with resting state with open and closed eyes, which was further analyzed using power spectrum density and detrended phase transfer entropy methods. Results: Specific EEG-bands (θ and β) were chosen for the analysis based on their prominent role in memory- and emotion-related mechanisms. The topography of the spectral power density corresponded to the generally accepted ideas describing perception and visual stimuli processing mechanisms. The phase transfer entropy method was not sufficient to analyze resting state data. The results of the analysis performed using the phase transfer entropy method revealed the problems of neutral faces differentiation when presented in a positive emotional context. Simultaneously, enhanced processes of motivational coding and self-reflection were observed during the presentation of neutral faces in a negative emotional context. These results corresponded with the data obtained in our previous ERP-based study. Conclusions: Phase transfer entropy and spectral power density have demonstrated their effectiveness in analyzing the mechanisms of emotional visual stimuli processing mediated in different cortical areas.

Keywords: EEG; Emotion; Facial expression; Functional network.

Introduction. Human facial expressions are complex multi-dimensional visual stimuli, which provide the brain with a wide range of characteristics to process. The current study focused on the activity in and β bands of EEG data, as θ- and β- band oscillations directly reflect such cognitive processes as retrieval and actualization of memory [1], emotional excitement and other consciousness-driven processes [2]. Thus, changes in power spectrum density in these bands were measured, and effective connectivity was modeled using phase transfer entropy (phase TE).

There is a hypothesis that the brain has an internal model of the external world, which functions under Bayesian system principles while processing sensory input so that experience-modified response is elicited [3]. In our previously conducted ERP study, we have revealed that the stimuli' valence, which creates the emotional context for the target neutral expressions, affects perception. This effect is signified in the increase of attention level and memory processes [4]. To reveal and quantify "causal" or directional inter-areal phase-phase interactions during emotion perception, a new information theory-based approach of phase transfer entropy (phase TE) was used, as phase synchronization of neuronal-based oscillations has been suggested to determine the coordination and integration of anatomically distributed information processing [5].

Phase synchronization and amplitude correlations are functionally independent phenomena [6] and reveal different neural network functioning aspects. Besides, the importance of phase-derived information in neuronal processes is highlighted by studies showing that phase-based grouping can encode more information than the amplitude-based one in both visual and auditory [7] processing. This marks the oscillatory phase as a reflection of neuronal synchronization and a robust information transmitter between neural ensembles. The phase-derived information flow from one cortical region to another cannot be estimated using phase synchrony metrics [8], which, by their nature, are not able to reveal spatial orientation.

Phase transfer entropy (phase TE) [9] is a reformulation of the Wiener principle within the framework of information theory (IT) [10]. Like Granger's causality, TE assesses whether the past of the original and target time series affects predicting the target time series's future. Contrariwise, phase TE compares conditional probabilities using the Kulbak-Leibler divergence. If signal X triggers the signal Y, then the probability density of the future Y, due to its past, must be different from the probability density of the future Y due to the past of both X and Y. Besides, unlike Granger's causality (and dynamic causal modeling), the phase TE is model-free as it does not carry any assumptions about the signal structure.

Phase TE can be a good indicator for analyzing phase-based connections and detecting directional interactions in broadband MEG / EEG sensor and source signals. However, the calculation of phase TE for individual tests requires a large amount of continuous data, which can be problematic in the case of a temporary task-related connection. The method can also be used for continuous data analysis with the help of several techniques of state space reconstruction.

This research aimed to study and model the effect of positive and negative faces on the perception and processing of target neutral faces. To do so, we focused our attention on determining the spectral power density and establishing causal relationships within θ- and β-bands, which play a unique role in human cognitive activity. Theta oscillations generated in the limbic system are considered the "emotional" band of the human brain. Thus, this activity reflects the cognitive component of the emotional reaction [11]. Besides, according to modern ideas, the increase of θ-activity in the anterior cortical areas can be assessed as a marker of enhanced activation, accompanied by inner attention and positive emotional experience [12]. Slow θ-oscillations are associated with memory-related processes and awareness, while high-frequency θ-oscillations reflect cognitive activity's emotional background. At the same time, β-band today is mainly associated with various aspects of brain function, from simple sensory responses (visual, auditory, somatosensory, etc.) to higher cognitive functions such as sensory memory, mechanisms of visual attention regulation, movement, emotional states, and execution of cognitive or creative tasks [13].

Materials and methods. Forty students of Taras Shevchenko National University of Kyiv (21 females, aged 18-24, mean=21) were presented with two series of images, during which EEG was recorded. Data was also obtained during resting state with both closed and open eyes. The image demonstration procedure and recording of the cerebral cortex's induced activity were performed using the software and hardware complex "Neurocom" (KhAI Medica, Kharkiv, Ukraine) according to a specially created template. Electrodes were applied to the scalp following the international "10-20%" system.

Stimuli were selected from the International Affective Pictures System (IAPS) [14]. In the stimulation program, positive (average values of emotional valence: M = 6.94, SD = 1.42 to M = 8.03, SD = 1.13) and negative (average values of emotional valence M = 4.22, SD = 1.64 to M = 5.84, SD = 1.62) emotional faces were chosen as frequent stimuli. Rare stimuli included neutral emotional faces with valence varied from M = 4.22, SD = 1.64 to M = 5.84, SD = 1.62.

Emotional stimuli were shown in an arbitrary pattern in which the likelihood of a rare stimulus (n=100) appearance was 30%. and β bands were subdivided as follows: θ -1 (4.1, 5.8) Hz, θ -2 (5.9, 7.4) Hz, β-1 (13, 19.9) Hz, β-2 (20, 30) Hz. For the subbands selected, power spectrum density analysis was conducted, which was then displayed in the topographical maps of activation. PTE method was applied to reveal the effective cortical neural networks involved in stimuli processing.

Transfer entropy (TE) is an information-theoretical measure that follows from the theory of information exchange to estimate conditional transition probabilities between two paired processes that develop over time.

The dPTE coefficient for the two cortical areas was calculated as the sum of the values of the PTE coefficients in both directions

$$\text{dPTE}= \frac{PTExy}{PTExy+PTEyx}$$

The values of the dPTE criterion vary within [-0.5: 0.5]. The criterion was implemented based on the Brainstorm software package.

In order to compare the phase transfer entropy method to the existing methods of a quantitative assessment of human brain activity during cognitive activation, the spectral power density was calculated based on the fast Fourier transformation. This characteristic is the de facto standard measure of the strength of oscillation activity, which has been widely used in the study of cortical activity. Each EEG channel's spectral power density in each frequency band during each trial was calculated using the Welch period method [15]. The obtained values in the corresponding frequency range were normalized relative to the maximum value for emotional load and background, after which a map of the topographic distribution of the corresponding values was plotted on the scalp surface.

Results and discussion. The nature of the distribution of power spectrum density during resting state with both closed and open eyes can be described according to the general framework of the human brain's functioning in the absence of an urgent external task, brought out by the action of so-called default neural networks. Namely: increased power in θ1 and θ2 subbands in frontal (55.7 μV^2 / Hz and 54.6 μV^2 / Hz, respectively), occipital (55.3 μV^2 / Hz with eyes closed and 53.1 μV^2 / Hz with eyes open in θ1; 54.8 μV^2 / Hz with eyes closed and 53.4 μV^2 / Hz with eyes open in θ2 eyes) and parieto-central areas (maximum values up to 55.8 μV^2 / Hz in θ1 and 54.8 μV^2 / Hz in θ2) reflected the processes associated with memory, emotional manifestations, passive scanning of information (Fig. 1).

At the same time, the resting-state oscillations in β-band were characterized by a somewhat different topographic distribution: increased power of β1-oscillations was concentrated in the occipital regions of the cortex during the trial with closed eyes. However, eyes opening caused the spread of generalized activation around the cortex, thus covering not only occipital (up to 48.6 μV^2 / Hz) but also parietal, central, and frontal areas of the cortex (maximum values registered for frontal areas – 48.4 μV^2 / Hz), with right-hemisphere lateralization in temporal regions (up to 48.5 μV^2 / Hz in the temporal area of the right hemisphere). As for the β2 frequency subband, the distribution of the increased oscillatory power in the occipital (up to 44.3 μV^2 / Hz), parietal (up to 43 μV^2 / Hz), and frontal (up to 44.3 μV^2 / Hz) areas of the cortex during resting state with closed eyes narrowed to the frontal regions (up to 44.1 μV^2 / Hz) after opening the eyes (Fig. 1).

Therefore, the resulting picture can be explained using existing literature data on these subbands' properties: traditionally, β1-subband is associated with external attention, cognition per se, while β2-oscillations are considered to reflect internal awareness, maintaining the status quo of brain activity. That is why topographic maps obtained in different resting-state trials can be juxtaposed with each other.

It is also worth noting that the obtained topographic maps of activation-related changes in power generally corresponded to the widely accepted visual stimuli processing framework. Namely: high-power foci in the prefrontal and fronto-central regions of the cortex in θ1 (up to 61 μV^2 / Hz), θ2 (up to 62.7 μV^2 / Hz) and β2 (up to 50.7 μV^2 / Hz) subbands, were accompanied with high values of oscillation power in the frontal, central, parietal and right-hemisphere occipital regions (values ranged from 48.2 μV^2 / Hz to 60 μV^2 / Hz) in β1-subband (Fig.1).

Concerning the results obtained by the detrended phase transfer entropy analysis in the processing of resting-state records with both closed and open eyes, it should be noted that the values of dPTE in such conditions were close to zero. This fact once again confirms the hypothesis of this method's effectiveness for analyzing only the states associated with cognitive activity. The connections formed within functional neural networks are shown in Fig.2 (dPTE$\geq$0.2).

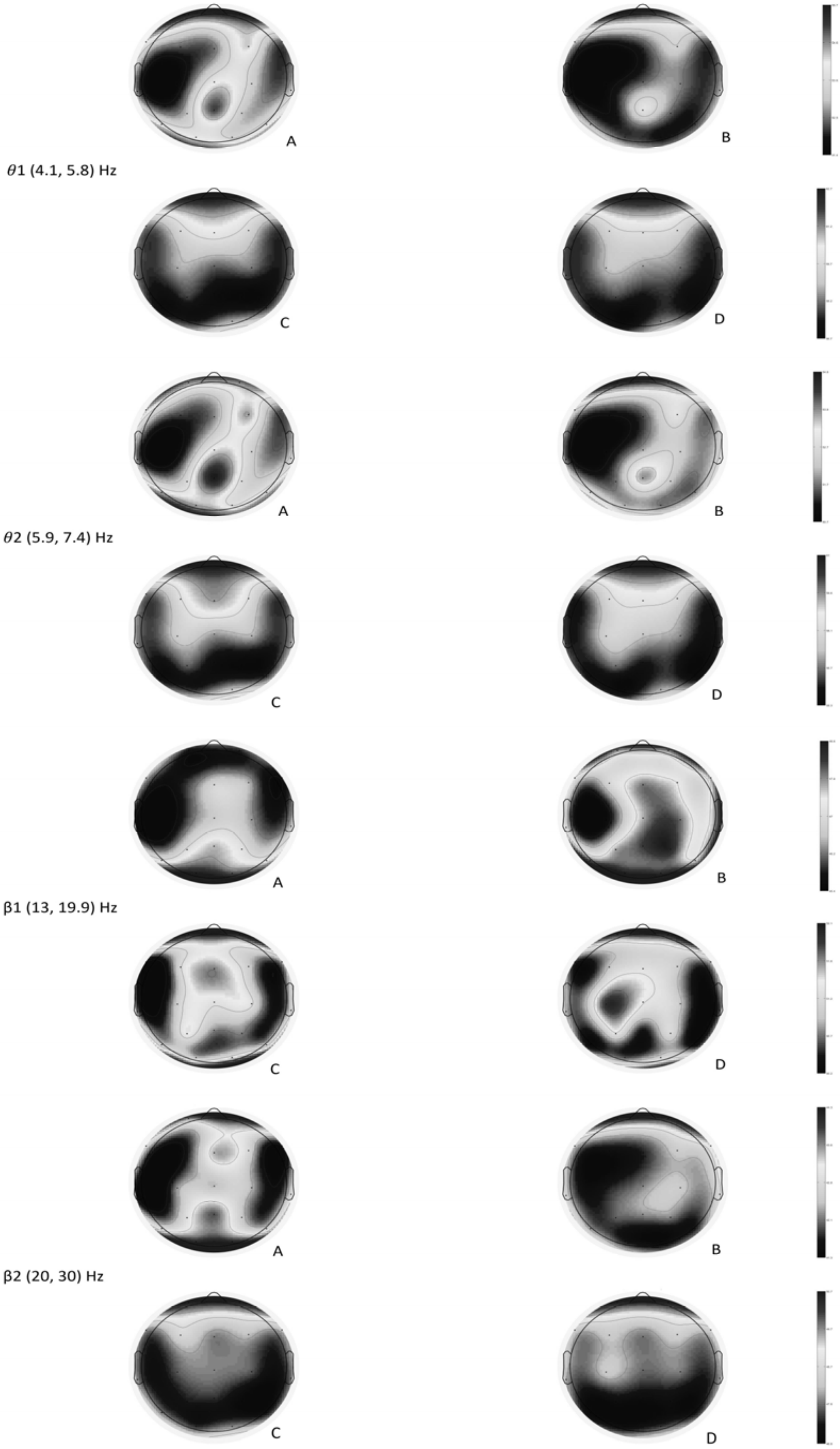

Fig. 1. Topographical distribution of the activation changes in the spectral power density:
A – resting with closed eyes; B- resting state with open eyes; C – demonstration of neutral stimuli in a positive context;
D – demonstration of neutral stimuli in a negative context

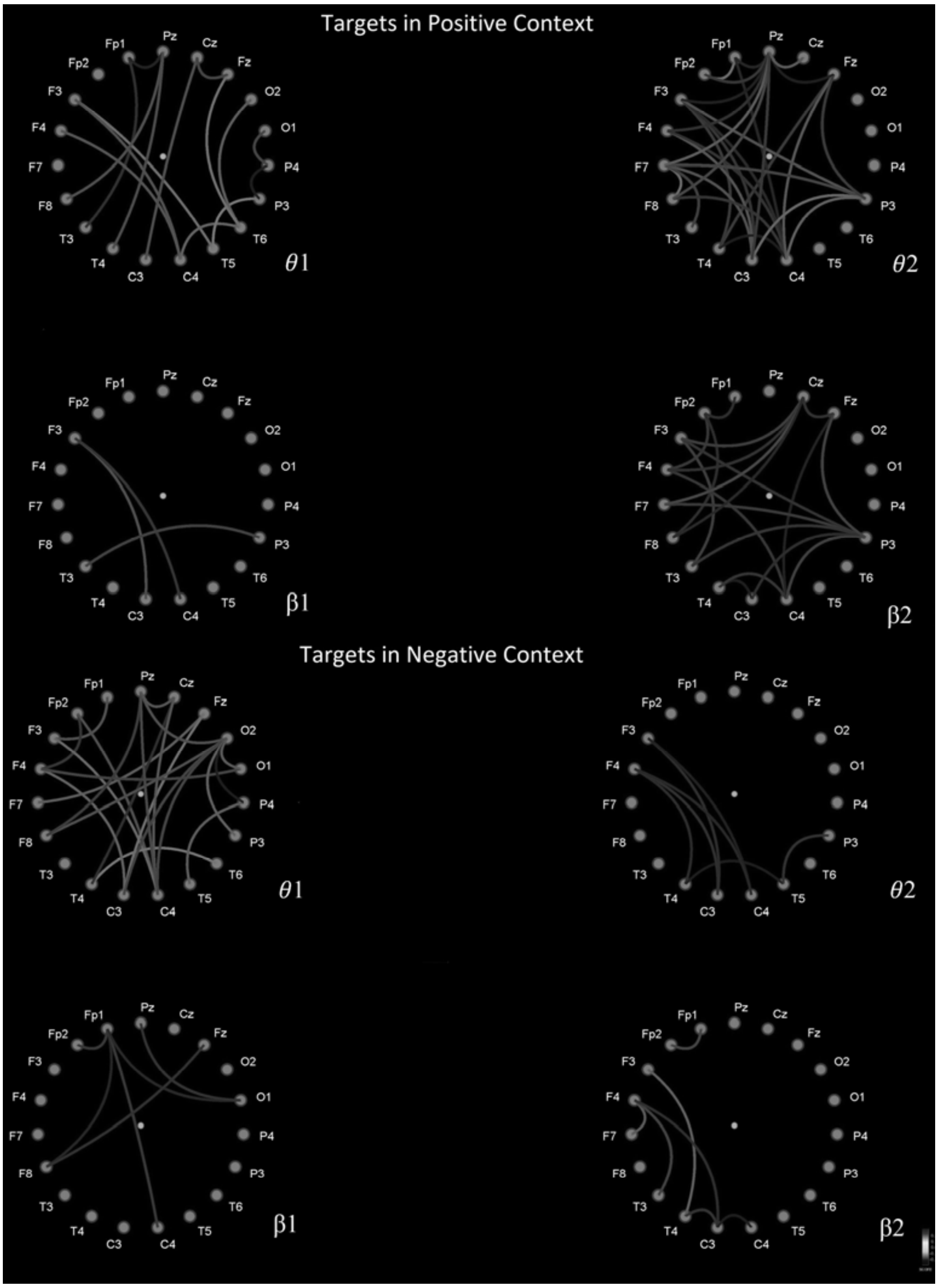

Fig. 2. Distribution of functional causal connections during neutral stimuli demonstration in an emotional context

The topography of PSD activation changes corresponded with prevailing views on visual stimuli perception and processing mechanisms. In both θ1- and θ2-subbands, extensive networks of effective connections during the processing of neutral faces in a positive emotional context were formed. However, in θ1-subband, it was generalized when in θ2-subband prominent activation nodes were formed in frontal, central, and parietal cortical areas in both hemispheres. As for neutral stimuli in a negative context, well-established nodes of activation in the left parietal and the cortex's central regions in θ2-subband were observed (Fig.2).

No stable network was observed for high-frequency oscillations in both trials, which corresponds with the concept of it as a marker of inward-directed attention. Simultaneously, in β1-subband, a more comprehensive network of causal connections with loci in parietal, frontal, and central regions was observed for target stimuli in positive context perception compared to the negative context.

Results obtained with phase TE during resting states with both closed and open eyes were generally close to zero, which supports the view that this analysis method is suitable for mapping brain networks associated with a specific cognitive task. However, utterly different connectivity patterns ($C \geq 0.2$, $p \leq 0.05$) were observed during stimuli demonstration, and they correlated well with the results of our ERP study [4].

Activation loci formed in θ2-subband (Fig.2) reflected memory retrieval processes, implicit encoding, differentiation, and integration of emotionally salient sensory information for positive context [16] and reflective mind notion and motivational significance encoding for negative context [17]. The endogenous self-referential processing of the CMS (cortical midline) has been related to an intrinsic virtual models generation, through which the brain forms an inferential knowledge about the structure of the environment. Moreover, well-pronounced connections among parietal regions of the cortex may manifest ongoing estimation of the person's social status depicted [18], which correlates with ERP late posterior negativity (1000 ms) in parietal areas, manifesting semantic component of stimuli perception. Differentiation problems (interference) and attention modulation were displayed through a vast network of connections in the β1-subband when neutral stimuli were presented in a positive context [19].

Conclusions. In sum, phase TE and PSD demonstrated their effectiveness in analyzing emotional visual stimuli processing mechanisms mediated by disparate cortical areas. Consequently, PSD distribution corresponded with conventional views on visual stimuli perception and processing mechanisms. Withal, phase TE demonstrated no efficiency in resting-state data analysis. Phase TE revealed difficulties in neutral faces differentiation in a positive emotional context, alongside. Moreover, increased self-reflection and motivational encoding were observed when neutral faces were presented in a negative emotional context.

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References

1. Gamma, alpha, delta, and theta oscillations govern cognitive processes / E. Başar, C. Başar-Eroglu, S. Karakaş et al. // International Journal of Psychophysiology. – 2001. – Vol. 39. – № 2-3. – P. 241–248, doi: 10.1016/s0167-8760(00)00145-8.

2. Identical event-related potentials to target and frequent stimuli of visual oddball task recorded by intracerebral electrodes / M. Kukleta, M. Brázdil, R. Roman et al. // Clinical Neurophysiology. – 2003. – Vol. 114. – № 7. – P. 1292–1297, doi: 10.1016/s1388-2457(03)00108-1.

3. Vuilleumier P. Distributed and interactive brain mechanisms during emotion face perception: Evidence from functional neuroimaging / P. Vuilleumier, G. Pourtois // Neuropsychologia. – Vol. 14. – P. 153–167, doi: 10.1016/j.neuropsychologia.2006.06.003.

4. Черних М. Вплив поточного контексту, створеного сприйняттям емоційно забарвлених виразів облич, на таргетне пред'явлення нейтральних зорових образів / М. Черних, І. Зима // Проблеми регуляції фізіологічних функцій. – 2018. – Т. 1, В. – 24. – С. 46.

5. Pastötter B. Distinct slow and fast cortical theta dynamics in episodic memory retrieval / B. Pastötter, K. Bäuml // NeuroImage. – 2014. – Vol. 94. – P. 155–161, doi: 10.1016/j.neuroimage.2014.03.002.

6. TRENTOOL: a Matlab open-source toolbox to analyse information flow in time series data with transfer entropy / M. Lindner, R. Vicente, V. Priesemann et al. // BMC Neuroscience. – 2011. – Vol. 12. – P. 119, doi: 10.1186/1471-2202-12-119.

7. Friston K. J. Functional and Effective Connectivity: A Review / K. J. Friston // Brain Connectivity. – 2011. – Vol. 1. – P. 13–36, doi: https://doi.org/10.1089/brain.2011.0008.

8. Schreiber T. Measuring information transfer / T. Schreiber // Physiological Review Letters. – 2000. – Vol. 85. – P. 461–464, doi: https://doi.org/10.1103/PhysRevLett.85.461.

9. Kraskov A. Estimating mutual information / A. Kraskov, H. Stögbauer, P. Grassberger // Physical Review E. – 2004. – Vol. 69. – P. 1–16, doi: https://doi.org/10.1103/PhysRevE.69.066138.

10. Jensen O. Cross-frequency coupling between neuronal oscillations / O. Jensen, L. L. Colgin // Trends in Cognitive Science. – 2007. – Vol. 11. – № 7. – P. 267–269, doi: 10.1016/j.tics.2007.05.003.

11. Theta and gamma oscillations predict encoding and retrieval of declarative memory / D. Osipova, A. Takashima, R. Oostenveld et al. // Journal of Neuroscience. – 2006. – Vol 26. – № 28. – P. 7523–7531.

12. Özgören M. Beta in simple and complex cognitive processes / M. Özgören, A. Oniz // International Journal of Psychophysiology. – 2008. – Vol. 69. – № 3. – P. 192.

13. Stam C. J. Use of non-linear EEG measures to characterize EEG changes during mental activity / C. J. Stam, T. C. A. M. Van Woerkom, W. S. Pritchard // Electroencephalography and Clinical Neurophysiology. – 1996. – Vol. 99. – № 3. – P. 214–224.

14. Lang P. International Affective Picture System (IAPS): Technical Manual and Affective Ratings / P. Lang. – M. ; L. : The Center for Research in Psychophysiology, University of Florida, Gainesville, Fl, 1999.

15. Welch J. Cortical coordination dynamics and cognition / J. Welch // Trends in cognitive sciences. – 2001. – Vol. 5. – № 1. – P. 26–36.

16. Balconi M. Subliminal and supraliminal processing of facial expression of emotions: brain oscillation in the left/right frontal area / M. Balconi, C. Ferrari // Brain Science. – 2012. – Vol. 2. – P. 85–100, doi: 10.3390/brainsci2020085.

17. Similarities and differences in perceiving threat from dynamic faces and bodies. An fMRI study / M. E. Kret, S. Pichon, J. Grèzes et al. // Neuroimage. – 2011. – Vol. 54. – P. 1755–1762, doi: 10.1016/j.neuroimage.2010.08.012.

18. Selective attention modulates high-frequency activity in the face-processing network / K. Müsch, C. M. Hamamé, M. Perrone-Bertolotti et al. // Cortex. – Vol. 60. – P. 34–51. https://doi.org/10.1016/j.cortex.2014.06.006.

19. Paulmann S. Valence, arousal and task effects in emotional prosody processing / S. Paulmann, M. Bleichner, S. A. Kotz // Frontiers of Psychology. – Vol. 4. – P. 345, doi: 10.3389/fpsyg.2013.00345.

References (Scopus)

1. Başar E, Başar-Eroglu C, Karakaş S, Schürmann M. Gamma, alpha, delta, and theta oscillations govern cognitive processes. Int Journ of Psychophys. 2001; 39(2-3):241-248. DOI:10.1016/s0167-8760(00)00145-8.

2. Kukleta M, Brázdil M, Roman R, Jurák P. Identical event-related potentials to target and frequent stimuli of visual oddball task recorded by intracerebral electrodes. Clin Neurophys. 2003;114(7):1292-1297. DOI:10.1016/s1388-2457(03)00108-1.

3. Vuilleumier P, Pourtois G. Distributed and interactive brain mechanisms during emotion face perception: Evidence from functional neuroimaging. Neuropsychologia. 2006;14:153–167. DOI: 10.1016/j.neuropsychologia.2006.06.003.

4. Черних М, Зима І. Вплив поточного контексту, створеного сприйняттям емоційно забарвлених виразів облич, на таргетне пред'явлення нейтральних зорових образів. Проблеми регуляції фізіологічних функцій. 2018;1(24):46.

5. Pastötter B, Bäuml KT. Distinct slow and fast cortical theta dynamics in episodic memory retrieval. NeuroIm. 2014; 94:155-161. DOI:10.1016/j.neuroimage.2014.03.002.

6. Lindner M, Vicente R, Priesemann V, Wibral M. TRENTOOL: a Matlab open-source toolbox to analyse information flow in time series data with transfer entropy. BMC Neurosci. 2011;12: 119. DOI: 10.1186/1471-2202-12-119.

7. Friston KJ. Functional and Effective Connectivity: A Review. Brain Conn. 2011; 1:13–36. DOI: https://doi.org/10.1089/brain.2011.0008.

8. Schreiber T. Measuring information transfer. Phys Rev Lett. 2000;85:461–464. DOI:https://doi.org/10.1103/PhysRevLett.85.461.

9. Kraskov A, Stögbauer H, Grassberger P. Estimating mutual information. Phys Rev E. 2004;69:1–16. DOI:https://doi.org/10.1103/PhysRevE.69.066138.

10. Jensen O, and Colgin LL. Cross-frequency coupling between neuronal oscillations. Trends Cogn Sci. 2007; 11(7):267-269. DOI:10.1016/j.tics.2007.05.003.

11. Osipova D, Takashima A, Oostenveld R, Fernández G, Maris E, Jensen O. Theta and gamma oscillations predict encoding and retrieval of declarative memory. Journ of Neurosci. 2006; 26(28):7523-7531.

12. Özgören M, Oniz A. Beta in simple and complex cognitive processes. Intern Journ Psychophys. 2008;69(3):192.

13. Stam CJ, Van Woerkom TCAM, Pritchard WS. Use of non-linear EEG measures to characterize EEG changes during mental activity. Electroenceph Clin Neurophys. 1996; 99(3):214-224.

14. Lang P. International Affective Picture System (IAPS): Technical Manual and Affective Ratings.The Center for Research in Psychophysiology, University of Florida, Gainesville, Fl; 1999.

15. Welch J. Cortical coordination dynamics and cognition. Trends Cogn Sci. 2001;5(1): 26-36.

16. Balconi, M, Ferrari C. Subliminal and supraliminal processing of facial expression of emotions: brain oscillation in the left/right frontal area. Brain Sci. 2012;2:85–100. DOI: 10.3390/brainsci2020085.

17. Kret ME, Pichon S, Grèzes J, de Gelder B. Similarities and differences in perceiving threat from dynamic faces and bodies. An fMRI study. Neuroim. 2011; 54:1755–1762. DOI: 10.1016/j.neuroimage.2010.08.012.

18. Müsch K, Hamamé C M, Perrone-Bertolotti M, Minotti L, Kahane P, Engel AK. Selective attention modulates high-frequency activity in the face-processing network. Cortex. 2014; 60: 34–51. https://doi.org/10.1016/j.cortex.2014.06.006

19. Paulmann S, Bleichner M, Kotz SA. Valence, arousal and task effects in emotional prosody processing. Front Psychol. 2013;4:345. DOI: 10.3389/fpsyg.2013.00345.

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М. Черних, асп., І. Зима, д-р біол. наук
Київський національний університет імені Тараса Шевченка, Київ, Україна

ОСОБЛИВОСТІ ПЕРЕДАЧІ ІНФОРМАЦІЇ У ФУНКЦІОНАЛЬНИХ МЕРЕЖАХ КОРИ ПІД ЧАС СПРИЙНЯТТЯ НЕЙТРАЛЬНИХ ОБЛИЧ В УМОВАХ ЕМОЦІЙНОГО ВПЛИВУ

Дослідження спрямоване на вивчення та моделювання емоційної активності функціональних мереж у корі головного мозку людини з використанням методів щільності спектра потужності (PSD) і детрендової ентропії фазового перенесення (PTE). Увагу зосереджено на виявленні змін у когнітивних механізмах, спричинених поданням нейтральних людських облич як рідкісних стимулів серед зображень облич із негативним чи позитивним забарвленням. Дані ЕЕГ реєстрували під час сприйняття й оброблення зображень нейтральної міміки людини, представленої серед позитивних і негативних облич у двох серіях зображень, що було проаналізовано за допомогою методів щільності спектра потужності та детрендової ентропії фазового перенесення. Також зареєстровано і проаналізовано активність кори головного мозку у стані спокою з відкритими та закритими очима. Для аналізу обрано окремі ЕЕГ-діапазони (θ та β) на основі їх значень у когнітивних механізмах. Топографія спектральної щільності потужності відповідала загальноприйнятим ідеям, що описують механізми сприйняття й оброблення зорових подразників. Метод ентропії фазового перенесення не був ефективним для аналізу стану спокою. Результати аналізу, проведеного за допомогою методу ентропії фазового перенесення, виявили проблеми диференціації нейтральних облич, коли вони представлені в позитивному емоційному контексті. Під час презентації нейтральних облич в негативному емоційному контексті спостерігалися посилені процеси мотиваційного кодування та саморефлексії. Висновки: ентропія фазового перенесення та спектральна щільність потужності продемонстрували свою ефективність у аналізі механізмів оброблення емоційних зорових подразників, опосередкованих у різних зонах кори.

Ключові слова: ЕЕГ; емоції; вираз обличчя; функціональна мережа.

М. Черных, асп., И. Зима, д-р биол. наук
Киевский национальний университет имени Тараса Шевченко, Киев, Украина

ОСОБЕННОСТИ ПЕРЕДАЧИ ИНФОРМАЦИИ В ФУНКЦИОНАЛЬНЫХ СЕТЯХ КОРЫ ВО ВРЕМЯ ВОСПРИЯТИЯ НЕЙТРАЛЬНЫХ ЛИЦ В УСЛОВИЯХ ЭМОЦИОНАЛЬНОГО ВЛИЯНИЯ

Исследование направлено на изучение и моделирование эмоциональной активности функциональных сетей в коре головного мозга человека с использованием методов плотности спектра мощности и детрендовой энтропии фазового переноса. Внимание было сосредоточено на выявлении изменений в когнитивных механизмах, вызванных представлением нейтральных человеческих лиц как редких стимулов среди изображений лиц с отрицательной или положительной окраской. Методы: данные регистрировали при восприятии и обработке изображений нейтральной мимики человека, представленной среди эмоциональных лиц в двух сериях изображений, и проанализировали с помощью методов плотности спектра мощности и детрендовой энтропии фазового переноса. Также зарегистрированы и проанализированы активность коры мозга в состоянии покоя с открытыми и закрытыми глазами. Результаты: для анализа были выбраны отдельные ЭЭГ-диапазоны (θ и β) на основании их роли для когнитивных механизмов. Топография спектральной плотности мощности отвечала общепринятым идеям, описывающим механизмы восприятия и обработки зрительных раздражителей. Метод энтропии фазового переноса не был эффективным для анализа состояния покоя. Результаты анализа, проведенного методом энтропии фазового переноса, обнаружили проблемы дифференциации нейтральных лиц, когда они представлены в положительном эмоциональном контексте. Во время презентации нейтральных лиц в негативном эмоциональном контексте наблюдались усиленные процессы мотивационного кодирования и саморефлексии. Выводы: энтропия фазового переноса и спектральная плотность мощности продемонстрировали свою эффективность в анализе механизмов обработки эмоциональных зрительных раздражителей, опосредованных в различных зонах коры.

Ключевые слова: ЭЭГ; эмоции; выражение лица; функциональная сеть.

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L. Regeda, Ph.D stud., N. Bisko, Prof., G. Al-Maali, Ph.D.
M. G. Kholodny Institute of Botany, National Academy of Sciences of Ukraine, Kyiv, Ukraine

INFLUENCE OF *PHOLIOTA* SPP. (STROPHARIACEAE, BASIDIOMYCOTA) MYCELIAL BIOMASS ON SEED GERMINATION AND SEEDLINGS GROWTH OF *LEPIDIUM SATIVUM* L. AND *CUCUMIS SATIVUS* L.

Basidiomycetes represent a very diverse group of eukaryotic organisms in terms physiological parameters. Some organisms such as plants or fungi release certain secondary metabolites, which can affect the organisms around them. Some of the substances released by mushrooms could have effects on the growth and further development of nearby plants. Studies of fungi and their biologically active components have grown significantly, with the aim of potential introduction to various biotechnological processes.The allelopathic effect of Pholiota species has been investigated in this study. Mycelial biomass of seven screened Pholiota species were tested to study cucumber (Cucumis sativus L.) and lettuce (Lepidium sativum L.) seed germination and the sprouting growth. The results of our experiment showed that the biomass of the species of the genus Pholiota did not affect the germination of seeds of both plant species. 100% seed germination was recorded in both control and experimental samples. The addition of mycelial biomass of the Pholiota species led to a suppressive allelopathic effect, which affects seed germination, the length of the studied plant (both shoots and roots), as well as changes the morphology of the roots (pubescence, changes in lateral roots). The inhibitory effect on sprouting length was 8,6%-87,1% in the case of C. sativus and 42,2%-91,8% if specify for L. sativum in depence on Pholiota species. Allelopathic properties of Pholiota subochracea, where sprouting growth ratio did not exceed 12.9%, compared to the control group, should be noted. This result suggests that Pholiota mushrooms have a significant regulatory effect on lettuce and cucumber sprouting growth. The given results suggest that the studied species may play a significant role in relationships within ecosystems.

Keywords: mushroom allelopathy, Pholiota, sandwich method bioassay.

Introduction. Allelopathy includes all types of chemical interactions among plants and microorganisms. Allelochemicals influence patterns in features that affecting the vegetation communities, seed germination and the sprouting growth, plant defence nutrient chelation, prevent nutrient uptake of target plants and regulation of soil biota in ways that affect decomposition and soil fertility [5, 8, 18, 22].

Weeds account for not more than 1% of the total plant species on the earth, nevertheless they cause great problems to humankind by interfering in food production, health, economic stability, and welfare [20]. Moreover, as far as it is known, 255 weeds from 92 crops have become stable to 163 herbicides all over the world [9]. That is why the weed control issues demand new ways of solving.