FEATURES OF BIOELECTRIC ACTIVITY OF THE RETROSPLENIAL CORTEX

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Human brain is one of the most difficult organs to study. The possibility of developing the technologies that have sufficient scientific accuracy and economic accessibility and never violate the moral and ethical standards of human society is of great interest. The study was aimed to study the possibility of assessing the retrosplenial cortex (RSC) structures' activity based on the EEG analysis of brain activity in the alpha frequency range in 36 healthy volunteers with an average age of 29.1 years, no acute central nervous system disorders or exacerbation of chronic central nervous system disorders, severe traumatic brain injuries, mental disorders or epilepsy. Significant source localizations were obtained by solving the EEG inverse problem that could be used for identification of the cerebral retrosplenial cortex structures' bioelectric activity. The use of such technology will allow us to expand the scope of the research focused on assessing the brain functional activity in both research and clinical centers, thereby paving the way for understanding the features of the brain structures' activity in physiologically normal conditions and in individuals with mental disorders caused by various functional alterations in the brain.

Keywords: electroencephalography, mathematical methods, retrosplenial cortex, bioelectrical activity of the brain

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ОСОБЕННОСТИ БИОЭЛЕКТРИЧЕСКОЙ АКТИВНОСТИ РЕТРОСПЛЕНИАЛЬНОЙ КОРЫ ГОЛОВНОГО МОЗГА

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Головной мозг человека представляет собой один из самых сложных для исследования органов. Огромный интерес представляет возможность разработки технологий, обладающих достаточной научной точностью и экономической доступностью при полном соблюдении морально-этических норм человеческого сообщества. Целью работы было изучить возможность исследования активности структур ретросплениальной коры (RSC) на основе ЭЭГ-анализа биоэлектрической активности головного мозга в альфа-диапазоне частот у 36 здоровых добровольцев возрастом в среднем 29,1 года, не имевших острых и хронических заболеваний центральной нервной системы в стадии обострения, тяжелых черепномозговых травм, психических заболеваний и эпилепсии. Получены статистически достоверные локализации источников с помощью решения обратной ЭЭГ-задачи, позволяющие использовать их для идентификации биоэлектрической активности структур ретросплениальной коры головного мозга. Применение данной технологии позволит расширить объем исследований функциональной активности головного мозга как в научных, так и клинических учреждениях, создав условия для понимания особенностей работы мозговых структур в условиях физиологической нормы и при наличии психических заболеваний, основу которых составляют различные функциональные изменения головного мозга.

Ключевые слова: электроэнцефалография, математические методы, ретросплениальная кора, биоэлектрическая активность головного мозга

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Human brain is one of the most difficult organs to study, which is due to the features of human anatomy, the need to comply with ethical standards, and the economic component of the use of advanced functional visualization methods: computed tomography (CT), positron emission tomography (PET), and magnetic resonance imaging (MRI). That is why the possibility of developing the research technologies that have sufficient scientific accuracy and economic accessibility and do not violate moral and ethical standards of modern society is of great interest.

Electroencephalography (EEG), developed in the beginning of the previous century, but given a new impulse with the development of mathematical data processing systems, has become one such technology [1–3].

In terms of EEG, brain activity is a combination of rhythmic phenomena reflecting the changes in the summed total of postsynaptic potentials. Alpha activity that is currently considered to be associated with the visual analyzer or visual cortex (VC) (Brodmann's areas 17, 18, 19) activity represents the most prominent and commonly recorded EEG phenomenon [4]. Occupying almost the entire occipital lobe, it produces strong occipital rhythmic activity with the frequency of 8–14 Hz that vanishes with eye opening; its association with the visual cortex shows conclusively that there are rhythmic phenomena associated with the activity of other neural analyzers, the mu and kappa rhythms that have specific stimuli and do not respond to eye opening [5–9]. However, a number of studies [10, 11] have revealed alpha-activity heterogeneity in individuals with borderline disorders and mental deviations manifested in the form of alpha rhythm multimodality. This raises the question of possible perceptual alterations in such individuals. At the same time it has been found [12] that not the visual cortex can be the source of such heterogeneity, but rhythmic activity in the posterior areas of the cingulate cortex, the structure belonging to the retrosplenial cortex (RSC).

The study of the RSC is of interest due to its direct involvement in complex cognitive processes, such as spatial cognition, analysis and error correction for current sensory states with internal representations of the environment [13]. Occupying the posterior part of the cingulate cortex (Brodmann's areas 26, 29, 30, 23, 31) [14], this area is linked to the anterior thalamic nuclei, entorhinal and parietal cortex, subiculum and hippocampus [15, 16, 17], which determines its key role in the processes underlying spatiotemporal orientation (human self-determination and navigating in the surrounding space). Changes in the RSC activity may be the earliest signs of dementia [18], which has been confirmed by clinical trials [19–21]. Furthermore, the RSC is associated with memory and attention [22–24], as well as with knowledge of the world [24, 25]. The RSC is closely related to the visual stimuli encoding by the visual cortex [26] and to formation of personal orientation towards a specific goal [27–29]. This view is confirmed by the presence of structural links between the RSC and the prefrontal cortex, parahippocampal areas, hippocampus, anterior thalamic nuclei, and parietal cortex [30, 31]. The functional neuroimaging studies have shown that the RSC structures respond more strongly during virtual or imaginary navigating compared to other tasks [32–34]. Thus, according to current research, the RSC is a major area of the cerebral cortex that is associated with cognitive and mental functions. The RSC extensive study will make it possible to acquire new data on the features of the brain functional activity at the earliest stages of the disease development.

The study was aimed to demonstrate the possibility of assessing the RSC activity based on the analysis of the EEG alpha waves in order to determine the features associated with various relaxed wakefulness states.

METHODS

Study design

According to modern literature, the RSC is primarily an area responsible for spatial positional orientation (and possibly temporal orientation). That is why its EEG identification becomes possible during the periods when the RSC structures produce rhythmic activity in the conditions of afferent stimuli disconnected from the systems controlling body position in space, the main of which is proprioceptive system. Therefore, a matched study involving EEG recording of alpha waves became the main functional test. During the test the subject, who was in the relaxed wakefulness state, was seated in a chair (active proprioceptive system) or was lying in bed before falling asleep (a fragment of EEG recording with the same length as the first recording was extracted that showed strong occipital alpha activity before fragmentation), when his/her proprioceptive system was minimally involved. This functional test was selected based on the clinical phenomenon "falling sensation when falling asleep". Primary data were recorded with the digital electroencephalography system (Medical Computer Systems; Zelenograd, Russia). The analog-to-digital converter sampling rate was 500 Hz, and the signal filtering input parameters were 0.03–70 Hz. Electrodes were placed on the scalp according to the international 10–20 settlement system. The electrode positions were refined by performing linear measurements with subsequent adjustment of the electrode spatial arrangement standard tables. This electrode settlement system was selected due to the fact of the increasing number of the recording artifacts associated with exposure to physical and technological environmental factors in the multichannel system [35].

During the first phase of processing physical artifacts were minimized. For that the by-standing electrical devices that generated parasitic electromagnetic fields were switched off, and the interface impedance was controlled. The temperature in the room was also adjusted, and parasitic muscle movements were minimized whenever possible, which reduced the biological artifacts' intensity.

During the second phase the data pool obtained was through standardization of basic assembly to create a common electrode space, as well as to artifact removal via extraction of independent signal components. This made it possible to purify the native signal of various physiological artifacts that had not been eliminated by filtration.

During the third phase the EEG signal segmentation was performed to extract individual EEG microstates by using the procedure implemented in the sLORETA software package (v. 20210701 University of Zurich; Switzerland) involving allocating eight classes of individual microstates (conventional I–IV [36] and four extra ones (V and VIII) taking into account their variability). The final phase of the study involved solving the EEG inverse problem for each of the allocated EEG microstate classes using the EEG inverse problem solution algorithm implemented in the sLORETA software package. The results provided information about eight variants of sources of individual EEG microstates in accordance with the Brodmann area atlas (based on the atlas by the Montreal Neurological Institute (MNI)).

Patients

A total of 36 healthy volunteers of different ages, who submitted informed consent, were assessed. Among them 19 individuals were under the age of 30 years, while 17 were over the age of 30 years. The average age of the subjects was 29.1 years, (Mo — 10 years, Me — 26 years, 1st quartile —18 years, 1st quartile — 33 years). The average age of the subjects under the age of 30 years was 17.4 years (standard deviation — 1.7 years, Mo – 10 years, ME — 18 years, 1st quartile — 12.3 years, 3rd quartile — 23.3 years). The average age of thesubjects over the age of 30 years was 43.3 years (Mo — 31 years, Me — 34.5 years, 1st quartile — 31 years, 1st quartile — 55.8 years).

All the subjects were through EEG test involving assessing the background activity of the brain in the relaxed wakefulness state with the eyes closed performed when the subject was in a sitting position and the same test performed when the subject was lying down (the onset of physiological sleep was controlled), since in healthy people the RSC activity is represented by the development of the phenomenon "falling sensation when falling asleep" observed before falling asleep or when lying in bed with the eyes closed. It is associated with the sense of spatial disorientation described as flying and/or falling down before falling asleep [37]. This makes it possible to use this phenomenon as a physiological test for extraction of the RSC activity during the experiment.

Table 1. Pairwise comparison of the alpha activity frequency characteristics (Hz) in occipital and parietal areas in the relaxed wakefulness state in the sitting position (observation № 1) and in the relaxed wakefulness state when lying down before falling asleep (observation № 2) (Student's *t*-test, KS-test norm < 0.01)

Region	O1		O2		P1		P2	
Observation	1	2	1	2	1	2	1	2
M	10.3	10.3	10.3	10.3	10.3	10.1	10.3	10.1
σ	0.7	1	0.7	1	0.8	0.9	0.8	0.9
Mo	10	9.5	10	9	10	9.5	10	9.5
Me	10.2	10.4	10.2	10.3	10.2	9.8	10.2	9.8
p t-Student	1		0.8		0.2		0.1	

Inclusion criteria: no history of acute nervous system disorder; no exacerbation of chronic disorder; no history of severe traumatic brain injury, mental disorder, epilepsy.

Clinical assessment was performed in the La Salute Clinic in accordance with the cooperation agreement between the La Salute Clinic and the National Research Nuclear University MEPhI (№ 09-01/23 of 09 January 2023).

Statistical analysis

The results obtained were processed in accordance with the guidelines [38] using PSPP (GNU software ver. 1.6.2-g78a33a) for OC Linux Mate (v. 10.10, GNU-GPL licence). Calculation involved pairwise comparison of the EEG inverse problem solution results obtained for eight EEG microstates using the Kolmogorov-Smirnov test (KS-test) for normality; calculation of Student's *t*-test for samples with normal distribution and Wilcoxon signed-rank test for related samples with non-normal distribution. The same degree of freedom was used, the significance level was set as $\alpha < 0.05$.

RESULTS

The analysis of occipital and parietal alpha activity performed in the general group revealed the decrease in alpha activity frequency before falling asleep, but there were no significant differences in the values of the general group (Table 1) and individuals under the age of 30 years (Table 2). In contrast, in the group of subjects over the age of 30 years the decrease in alpha activity frequency observed before falling asleep was significant (Table 3).

When studying individual EEG microstates in the alpha range, heterogeneity of the alpha activity sources associated with the changes in the subject's state was revealed in the general group (Table 4). Thus, in the sitting position the rhythmic phenomena were generated mainly by Brodmann's areas 17, 18, and 19, which represented the expected alpha activity produced by the visual cortex structures functioning in the "idle" mode. Persistence of these indicators when lying down (without the emergence of significant differences) also suggested the visual cortex response to eye closing, however, when lying down, the recorded alpha activity source shifted to the Brodmann's areas 23, 29, 30, and 31 characterizing the RSC structures.

Assessment of the age-related features of this response showed that individuals under the age of 30 years demonstrated significant differences in alpha rhythm production, since when sitting in the relaxed wakefulness state, alpha activity was produced by the VC structures (Brodmann's areas 17, 18, and 19), while prior to falling asleep the RSC became the source of alpha activity (Brodmann's areas 23, 29, 30, and 31). A reliable RSC response was observed in individuals over the age of 30 years, while the VC structures showed no significant differences before falling asleep (Table 5).

DISCUSSION

The findings have shown that even the assessment of the brain rhythm frequency characteristics makes it possible to determine that alpha rhythm recorded during conventional EEG tests is not a stable parameter determining the "basic" characteristics of brain activity in humans. Alpha activity represents the group of rhythmic phenomena showing significant differences in individuals over the age of 30 years having fully developed brain structures.

However, the shift of alpha activity source between the visual cortex and retrosplenial cortex (clinically manifesting in the phenomenon "falling sensation when falling asleep") is clear in individuals under the age of 30 years that can be considered as involvement of the larger number of brain structures in implementation of higher nervous functions and the need for integration of their activity.

At the same time, after 30 years the neural centers are likely to acquire marked specialization, especially the brain's parietal and RSC structures. Specialization manifests itself in the changes of parietal alpha rhythm and the recording of rhythmic

Table 2. Pairwise comparison of the alpha activity frequency characteristics (Hz) in occipital and parietal areas in the relaxed wakefulness state in the sitting position (observation № 1) and in the relaxed wakefulness state when lying down before falling asleep (observation № 2) in individuals under the age of 30 years (Student's *t*-test, KS-test norm < 0.01)

Region	O1		O2		P1		P2	
Observation	1	2	1	2	1	2	1	2
M	10.3	10.7	10.3	10.6	10.2	10.3	10.2	10.3
σ	1	1.4	1	1.4	1.2	1.3	1.2	1.3
Mo	9.6	10.5	9.6	10.5	8.2	9.5	8.2	9.5
Me	10	10.6	10	10.6	10	10.5	10	10.5
p t-Student	0.357		0.525		0.789		0.857	

Table 3. Pairwise comparison of the alpha activity frequency characteristics (Hz) in occipital and parietal areas in the relaxed wakefulness state in the sitting position (observation № 1) and in the relaxed wakefulness state when lying down before falling asleep (observation № 2) in individuals over the age of 30 years (Student's *t*-test, KS-test norm < 0,01)

Region	O1		O2		P1		P2	
Observation	1	2	1	2	1	2	1	2
M	10.3	9.8	10.3	9.8	10.5	9.8	10.5	9.8
σ	0.8	0.9	0.8	0.9	0.8	0.9	0.8	0.9
Mo	10.2	9	10.2	9	10.5	9	10.2	9
Me	10.2	9.6	10.2	9.6	10.4	9.6	10.4	9.6
p t-Student	0.07		0.1		0.02		0.02	

Table 4. The data on the rate of EEG activity recording (%) over certain Brodmann fields acquired by solving the EEG inverse problem for the model of eight individual EEG microstates in the general group (Wilcoxon signed-rank test, KS-test norm > 0.5)

Subject's position	Brodmann areas 23, 29, 30, 31	Brodmann areas 17, 18, 19
Sitting	18.3%	34.2%
Lying down	41.7%	25.0%
p (*t*-Wilcoxon)	0.01	0.4

Table 5. Age-related features of the rate of EEG activity recording (%)over certain Brodmann fields acquired by solving the EEG inverse problem for the model of eight individual EEG microstates in various age groups (Wilcoxon signed-rank test, KS-test norm > 0.5)

RSC (Brodmann areas 23, 29, 30, 31)		
Age	1–30 years	> 30 years
Sitting	7.4%	12.5%
Lying down	28.7%	19.8%
p (*t*-Wilcoxon)	0	0.05
VC (Brodmann areas 17, 18,19)		
Sitting	20.1%	15.6%
Lying down	27.1%	23%
p (*t*-Wilcoxon)	0.03	0.5

activity produced by the RSC structures; according to our observations, these can be considered as related phenomena.

The use of advanced mathematical methods for EEG signal analysis enables clear differentiation of alpha activity and determining the sources in various brain structures [39]. Under the conditions of targeted functional load this makes it possible to link repetitive EEG recording fragments to the activity of certain neural networks of the brain [40, 41] involved in production of alpha activity not only by the cerebral visual cortex structures [42–49]. Such observations can be considered as formation of stable links and growing significance of visual cortex as the main source of information in individuals over the age of 30 years, including information about the position of the body in space, as previously reported for other cortical areas [50–52].

Thus, alpha activity identified when performing conventional EEG tests is not the common “basic” rhythm typical for brain structures, but the combination of several rhythms with similar frequency and amplitude characteristics. The above bioelectric activity is produced by various brain structures, particularly the RSC, which is confirmed by conclusions of several studies [5–9] suggesting the alpha rhythm cortical origin. This makes it possible to re-interpret the findings of the studies [53] showing heterogeneity of alpha rhythm spectra in individuals with various mental deviations, as well as the results of earlier studies [54], especially that focused on the multimodal alpha rhythm variants.

CONCLUSIONS

The use of the brain bioelectric activity frequency analysis within the framework of conventional technology is not an effective method for assessment of higher nervous functions. Modern EEG tests require using the combination of mathematical methods for extraction of individual EEG microstates and EEG inverse problem solution, thereby making it possible to obtain a simple and cost-effective tool for assessment of the brain structures’ functional activity. The use of such technology will allow us to expand the scope of the research focused on assessing the brain functional activity in both research and clinical centers, thereby paving the way for understanding the features of the brain structures’ activity in physiologically normal conditions and in individuals with mental disorders.

References

1. Delorme A, Makeig S. EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. J Neurosci Methods. 2004; 134 (1): 9–21. Available from: https://doi.org/10.1016/j.jneumeth.2003.10.009.

PMID: 15102499.

2. Martínez-Cancino R, Delorme A, Truong D, Artoni F, Kreutz-Delgado K, Sivagnanam S, et al. The open EEGLAB portal Interface: High-Performance computing with EEGLAB. Neuroimage. 2021; 224: 116778. Available from: https://doi.org/10.1016/j.neuroimage.2020.116778. Epub 2020 Apr 11. PMID: 32289453; PMCID: PMC8341158.
3. Tadel F, Bock E, Niso G, Mosher JC, Cousineau M, Pantazis D, et al. MEG/EEG Group Analysis With Brainstorm. Front Neurosci. 2019; 13: 76. Available from: https://doi.org/10.3389/fnins.2019.00076. PMID: 30804744; PMCID: PMC6378958.
4. Jasper H, Penfield W. Electrocorticograms in man: effect of voluntary movement upon the electrical activity of the precentral gyrus. Archiv für Psychiatrie und Nervenkrankheiten. 1949; 183: 163–74.
5. Lopes Da Silva FH, Storm Van Leeuwen W. The cortical source of the alpha rhythm. Neurosci Lett. 1977; 6 (2-3): 237–41. Available from: https://www.doi.org/10.1016/0304-3940(77)90024-6.
6. Klimesch W. α-Band oscillations, attention, and controlled access to stored information. Trends Cogn Sci. 2012; 16 (12): 606–17. Available from: https://www.doi.org/10.1016/j.tics.2012.10.007.
7. Klimesch W. EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. Brain Res Brain Res Rev. 1999; 29 (2-3): 169–95. Available from: https://www.doi.org/10.1016/s0165-0173(98)00056-3.
8. Klimesch W, Sauseng P, Hanslmayr S. EEG alpha oscillations: the inhibition-timing hypothesis. Brain Res Rev. 2007; 53 (1): 63–88. Available from: https://www.doi.org/10.1016/j.brainresrev.2006.06.003.
9. Klimesch W, Doppelmayr M, Hanslmayr S. Upper alpha ERD and absolute power: their meaning for memory performance. Prog Brain Res. 2006; 159: 151–65. Available from: https://www.doi.org/10.1016/S0079-6123(06)59010-7.
10. Ivanov LB. Spektr moshhnosti ehlektroehncefalogrammy: oshibki i praktika primeneniya (lekciya pervaya). Medicinskij alfavit. 2021; (39): 45–52. Dostupno po ssylke: https://doi.org/10.33667/2078-5631-2021-39-45-52. Russian.
11. Lydon EA, Nguyen LT, Shende SA, Chiang HS, Spence JS, Mudar RA. EEG theta and alpha oscillations in early versus late mild cognitive impairment during a semantic Go/NoGo task. Behav Brain Res. 2022; 416: 113539. DOI: 10.1016/j.bbr.2021.113539. Epub 2021 Aug 17. PMID: 34416304.
12. Rusiniak M, Lewandowska M, Wolak T, Pluta A, Milner R, Skarźyński H. Mozliwości i problemy jednoczesnych rejestracji EEG-fMRI--badanie rytmu alfa [The possibilities and limitations of simultaneous EEG-fMRI registration--the alpha rhythm study]. Przegl Lek. 2015; 72 (11): 616–9. PMID: 27012118. Polish.
13. Alexander AS, Place R, Starrett MJ, Chrastil ER, Nitz DA. Rethinking retrosplenial cortex: Perspectives and predictions. Neuron. 2023; 111 (2): 150–75. Available from: https://doi.org/10.1016/j.neuron.2022.11.006. Epub 2022 Dec 1. PMID: 36460006.
14. Todd TP, Fournier DI, Bucci DJ. Retrosplenial cortex and its role in cue-specific learning and memory. Neurosci Biobehav Rev. 2019; 107: 713–28. Available from: https://doi.org/10.1016/j.neubiorev.2019.04.016. Epub 2019 May 2. PMID: 31055014; PMCID: PMC6906080.
15. Trask S, Fournier DI. Examining a role for the retrosplenial cortex in age-related memory impairment. Neurobiol Learn Mem. 2022; 189: 107601. DOI: 10.1016/j.nlm.2022.107601. Epub 2022 Feb 22. PMID: 35202816.
16. Olsen GM, Ohara S, Iijima T, Witter MP. Parahippocampal and retrosplenial connections of rat posterior parietal cortex. Hippocampus. 2017; 27 (4): 335–58. Available from: https://doi.org/10.1002/hipo.22701. Epub 2017 Jan 16. PMID: 28032674.
17. Sugar J, Witter MP, van Strien NM, Cappaert NL. The retrosplenial cortex: intrinsic connectivity and connections with the (para) hippocampal region in the rat. An interactive connectome. Front Neuroinform. 2011; 5: 7. Available from: https://doi.org/10.3389/fninf.2011.00007. PMID: 21847380; PMCID: PMC3147162.
18. Dillen KNH, Jacobs HIL, Kukolja J, von Reutern B, Richter N, Onur ÖA, Dronse J, Langen KJ, Fink GR. Aberrant functional connectivity differentiates retrosplenial cortex from posterior cingulate cortex in prodromal Alzheimer's disease. Neurobiol Aging. 2016; 44: 114–26. Available from: https://doi.org/10.1016/j.neurobiolaging.2016.04.010. Epub 2016 Apr 22. PMID: 27318139.
19. Squire LR, Genzel L, Wixted JT, Morris RG. Memory consolidation. Cold Spring Harb Perspect Biol. 2015; 7 (8): a021766. Available from: https://doi.org/10.1101/cshperspect.a021766. PMID: 26238360; PMCID: PMC4526749.
20. de Sousa AF, Cowansage KK, Zutshi I, Cardozo LM, Yoo EJ, Leutgeb S, Mayford M. Optogenetic reactivation of memory ensembles in the retrosplenial cortex induces systems consolidation. Proc Natl Acad Sci U S A. 2019; 116 (17): 8576–81. Available from: https://doi.org/10.1073/pnas.1818432116. Epub 2019 Mar 15. PMID: 30877252; PMCID: PMC6486739
21. Auger SD, Maguire EA. Retrosplenial Cortex Indexes Stability beyond the Spatial Domain. J Neurosci. 2018; 38 (6): 1472–81. Available from: https://doi.org/10.1523/JNEUROSCI.2602-17.2017. Epub 2018 Jan 8. PMID: 29311139; PMCID: PMC5815348.
22. Mitchell AS, Czajkowski R, Zhang N, Jeffery K, Nelson AJD. Retrosplenial cortex and its role in spatial cognition. Brain Neurosci Adv. 2018; 2: 2398212818757098. Available from: https://doi.org/10.1177/2398212818757098. PMID: 30221204; PMCID: PMC6095108.
23. Corcoran KA, Yamawaki N, Leaderbrand K, Radulovic J. Role of retrosplenial cortex in processing stress-related context memories. Behav Neurosci. 2018; 132 (5): 388–95. Available from: https://doi.org/10.1037/bne0000223. Epub 2018 Jun. 7. PMID: 29878804; PMCID: PMC6188831.
24. Milczarek MM, Vann SD. The retrosplenial cortex and long-term spatial memory: from the cell to the network. Curr Opin Behav Sci. 2020; 32: 50–56. Available from: https://doi.org/10.1016/j.cobeha.2020.01.014. PMID: 32715030; PMCID: PMC7374566.
25. Mitchell AS, Czajkowski R, Zhang N, Jeffery K, Nelson AJD. Retrosplenial cortex and its role in spatial cognition. Brain Neurosci Adv. 2018; 2: 2398212818757098. Available from: https://doi.org/10.1177/2398212818757098. PMID: 30221204; PMCID: PMC6095108.
26. Powell A, Connelly WM, Vasalauskaite A, Nelson AJD, Vann SD, Aggleton JP, et al. Stable Encoding of Visual Cues in the Mouse Retrosplenial Cortex. Cereb Cortex. 2020; 30 (8): 4424–37. Available from: https://doi.org/10.1093/cercor/bhaa030. PMID: 32147692; PMCID: PMC7438634.
27. Fischer LF, Mojica Soto-Albors R, Buck F, Harnett MT. Representation of visual landmarks in retrosplenial cortex. Elife. 2020; 9: e51458. Available from: https://doi.org/10.7554/eLife.51458. PMID: 32154781; PMCID: PMC7064342.
28. Fournier DI, Monasch RR, Bucci DJ, Todd TP. Retrosplenial cortex damage impairs unimodal sensory preconditioning. Behav Neurosci. 2020; 134 (3): 198–207. DOI: 10.1037/bne0000365. Epub 2020 Mar 9. PMID: 32150422; PMCID: PMC7244381.
29. Mao D, Molina LA, Bonin V, McNaughton BL. Vision and Locomotion Combine to Drive Path Integration Sequences in Mouse Retrosplenial Cortex. Curr Biol. 2020; 30 (9): 1680–8.e4. Available from: https://doi.org/10.1016/j.cub.2020.02.070. Epub 2020 Mar 19. PMID: 32197086.
30. Morris R, Pandya DN, Petrides M. Fiber system linking the mid-dorsolateral frontal cortex with the retrosplenial/presubicular region in the rhesus monkey. J Comp Neurol. 1999; 407 (2): 183–92. Available from: https://doi.org/10.1002/(sici)1096-9861(19990503)407:2<183::aid-cne3>3.0.co;2-n. PMID: 10213090.
31. Clark BJ, Simmons CM, Berkowitz LE, Wilber AA. The retrosplenial-parietal network and reference frame coordination for spatial navigation. Behav Neurosci. 2018; 132 (5): 416–29. Available from: https://doi.org/10.1037/bne0000260. Epub 2018 Aug 9. PMID: 30091619; PMCID: PMC6188841.
32. Aggleton JP, Yanakieva S, Sengpiel F, Nelson AJ. The separate and combined properties of the granular (area 29) and dysgranular (area 30) retrosplenial cortex. Neurobiol Learn Mem. 2021; 185: 107516. DOI: 10.1016/j.nlm.2021.107516. Epub 2021 Sep 3. PMID: 34481970.
33. Epstein RA, Parker WE, Feiler AM. Where am I now? Distinct roles for parahippocampal and retrosplenial cortices in place

recognition. J Neurosci. 2007; 27 (23): 6141–9. Available from: https://doi.org/10.1523/JNEUROSCI.0799-07.2007. PMID: 17553986; PMCID: PMC6672165.

34. Spiers HJ, Maguire EA. Thoughts, behavior, and brain dynamics during navigation in the real world. Neuroimage. 2006; 31 (4): 1826–40. Available from: https://doi.org/10.1016/j.neuroimage.2006.01.037. Epub 2006 Apr 11. PMID: 16584892.
35. Tamburro G, Fiedler P, Stone D, Haueisen J, Comani S. A new ICA-based fingerprint method for the automatic removal of physiological artifacts from EEG recordings. PeerJ. 2018; 6: e4380. DOI: 10.7717/peerj.4380. PMID: 29492336; PMCID: PMC5826009.
36. Lehmann D, Strik WK, Henggeler B, Koenig T, Koukkou M Brain electric microstates and momentary conscious mind states as building blocks of spontaneous thinking: I. Visual imagery and abstract thoughts. Int J Psychophysiol. 1998; 29 (1): 1–11. Available from: https://doi.org/10.1016/s0167-8760(97)00098-6.
37. Schacter DL, Crovitz HF. "Falling" while falling asleep: sex differences. Percept Mot Skills. 1977; 44 (2): 656. DOI: 10.2466/pms.1977.44.2.656. PMID: 866074.
38. Sarter M Fritschy JM Reporting statistical methods and statistical results in EJN. Eur J Neurosci. 2008; 28 (12): 2363–4. Available from: https://doi.org/10.1111/j.1460-9568.2008.06581.x.
39. Ivanov LB. Spektr moshhnosti po ehlektroehncefalogramme: oshibki i praktika primeneniya (lekciya vtoraya). Dispersionnyj analiz ehlektroehncefalogrammy po Rosmanu. Medicinskij alfavit. 2022; (9): 38–43. Available from: https://doi.org/10.33667/2078-5631-2022-9-38-43. Russian.
40. Croce P, Quercia A, Costa S, Zappasodi F. EEG microstates associated with intra- and inter-subject alpha variability. Sci Rep. 2020; 10 (1): 2469. Available from: https://doi.org/ 10.1038/s41598-020-58787-w.
41. Poskanzer C, Denis D, Herrick A, Stickgold R. Using EEG microstates to examine post-encoding quiet rest and subsequent word-pair memory. Neurobiol Learn Mem. 2021; 181: 107424. Available from: https://doi.org/ 10.1016/j.nlm.2021.107424.
42. Pascual-Marqui RD, Michel CM, Lehmann D. Segmentation of brain electrical activity into microstates: model estimation and validation. IEEE Trans Biomed Eng. 1995; 42 (7): 658–65. Available from: https://doi.org/10.1109/10.391164.
43. Milz P, Pascual-Marqui RD, Lehmann D, Faber PL. Modalities of Thinking: State and Trait Effects on Cross-Frequency Functional Independent Brain Networks. Brain Topogr. 2016; 29 (3): 477–90. Available from: https://doi.org/ 10.1007/s10548-016-0469-3.
44. Seitzman BA, Abell M, Bartley SC, Erickson MA, Bolbecker AR, Hetrick WP. Cognitive manipulation of brain electric microstates. Neuroimage. 2017; 146: 533–43. Available from: https://doi.org/10.1016/j.neuroimage.2016.10.002.
45. Mishra A, Englitz B, Cohen MX. EEG microstates as a continuous phenomenon. Neuroimage. 2020; 208: 116454. Available from: https://doi.org/ 10.1016/j.neuroimage.2019.116454. Epub 2019 Dec 10.
46. Milz P, Faber PL, Lehmann D, Koenig T, Kochi K, Pascual-Marqui RD. The functional significance of EEG microstates--Associations with modalities of thinking. Neuroimage. 2016; 125: 643–56. Available from: https://doi.org/ 10.1016/j.neuroimage.2015.08.023.
47. Pascual-Marqui RD, Esslen M, Kochi K, Lehmann D. Functional imaging with low-resolution brain electromagnetic tomography (LORETA): a review. Methods Find Exp Clin Pharmacol. 2002; 24 Suppl C: 91–5. PMID: 12575492.
48. Grech R, Cassar T, Muscat J, Camilleri KP, Fabri SG, Zervakis M, et al. Review on solving the inverse problem in EEG source analysis. J Neuroeng Rehabil. 2008; 5: 25. Available from: https://doi.org/ 10.1186/1743-0003-5-25.
49. Neuner I, Arrubla J, Werner CJ, Hitz K, Boers F, Kawohl W, et al. The default mode network and EEG regional spectral power: a simultaneous fMRI-EEG study. PLoS One. 2014; 9 (2): e88214. Available from: https://doi.org/ 10.1371/journal.pone.0088214
50. Vukovic N, Hansen B, Lund TE, Jespersen S, Shtyrov Y. Rapid microstructural plasticity in the cortical semantic network following a short language learning session. PLoS Biol. 2021; 19 (6): e3001290. Available from: https://doi.org/10.1371/journal.pbio.3001290. PMID: 34125828; PMCID: PMC8202930.
51. Hubert V, Beaunieux H, Chételat G, Platel H, Landeau B, Viader F, Desgranges B, Eustache F. Age-related changes in the cerebral substrates of cognitive procedural learning. Hum Brain Mapp. 2009; 30 (4): 1374–86. Available from: https://doi.org/10.1002/hbm.20605. PMID: 18537110; PMCID: PMC2935916.
52. Just MA, Keller TA. Converging measures of neural change at the microstructural, informational, and cortical network levels in the hippocampus during the learning of the structure of organic compounds. Brain Struct Funct. 2019; 224 (3): 1345–57. Available from: https://doi.org/10.1007/s00429-019-01838-4. Epub 2019 Feb 6. PMID: 30725233.
53. Nunez PL, Wingeier BM, Silberstein RB. Spatial-temporal structures of human alpha rhythms: theory, microcurrent sources, multiscale measurements, and global binding of local networks. Hum Brain Mapp. 2001; 13 (3): 125–64. Available from: https://doi.org/10.1002/hbm.1030. PMID: 11376500; PMCID: PMC6872048.
54. Rodriguez-Larios J, ElShafei A, Wiehe M, Haegens S. Visual working memory recruits two functionally distinct alpha rhythms in posterior cortex. eNeuro. 2022; 9 (5): ENEURO.0159-22.2022. DOI: 10.1523/ENEURO.0159-22.2022. Epub ahead of print. PMID: 36171059; PMCID: PMC9536853.

Литература

1. Delorme A, Makeig S. EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. J Neurosci Methods. 2004; 134 (1): 9–21. Available from: https://doi.org/10.1016/j.jneumeth.2003.10.009. PMID: 15102499.
2. Martínez-Cancino R, Delorme A, Truong D, Artoni F, Kreutz-Delgado K, Sivagnanam S, et al. The open EEGLAB portal Interface: High-Performance computing with EEGLAB. Neuroimage. 2021; 224: 116778. Available from: https://doi.org/10.1016/j.neuroimage.2020.116778. Epub 2020 Apr 11. PMID: 32289453; PMCID: PMC8341158.
3. Tadel F, Bock E, Niso G, Mosher JC, Cousineau M, Pantazis D, et al. MEG/EEG Group Analysis With Brainstorm. Front Neurosci. 2019; 13: 76. Available from: https://doi.org/10.3389/fnins.2019.00076. PMID: 30804744; PMCID: PMC6378958.
4. Jasper H, Penfield W. Electrocorticograms in man: effect of voluntary movement upon the electrical activity of the precentral gyrus. Archiv für Psychiatrie und Nervenkrankheiten. 1949; 183: 163–74.
5. Lopes Da Silva FH, Storm Van Leeuwen W. The cortical source of the alpha rhythm. Neurosci Lett. 1977; 6 (2-3): 237–41. Available from: https://www.doi.org/10.1016/0304-3940(77)90024-6.
6. Klimesch W. α-Band oscillations, attention, and controlled access to stored information. Trends Cogn Sci. 2012; 16 (12): 606–17. Available from: https://www.doi.org/10.1016/j.tics.2012.10.007.
7. Klimesch W. EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. Brain Res Brain Res Rev. 1999; 29 (2-3): 169–95. Available from: https://www.doi.org/10.1016/s0165-0173(98)00056-3.
8. Klimesch W, Sauseng P, Hanslmayr S. EEG alpha oscillations: the inhibition-timing hypothesis. Brain Res Rev. 2007; 53 (1): 63–88. Available from: https://www.doi.org/10.1016/j.brainresrev.2006.06.003.
9. Klimesch W, Doppelmayr M, Hanslmayr S. Upper alpha ERD and absolute power: their meaning for memory performance. Prog Brain Res. 2006; 159: 151–65. Available from: https://www.doi.org/10.1016/S0079-6123(06)59010-7.
10. Иванов Л. Б. Спектр мощности электроэнцефалограммы: ошибки и практика применения (лекция первая). Медицинский алфавит. 2021; (39): 45–52. Доступно по ссылке: https://doi.org/10.33667/2078-5631-2021-39-45-52.
11. Lydon EA, Nguyen LT, Shende SA, Chiang HS, Spence JS, Mudar RA.

EEG theta and alpha oscillations in early versus late mild cognitive impairment during a semantic Go/NoGo task. Behav Brain Res. 2022; 416: 113539. DOI: 10.1016/j.bbr.2021.113539. Epub 2021 Aug 17. PMID: 34416304.

12. Rusiniak M, Lewandowska M, Wolak T, Pluta A, Milner R, Skarźyński H. Mozliwości i problemy jednoczesnych rejestracji EEG-fMRI--badanie rytmu alfa [The possibilities and limitations of simultaneous EEG-fMRI registration--the alpha rhythm study]. Przegl Lek. 2015; 72 (11): 616–9. PMID: 27012118. Polish.
13. Alexander AS, Place R, Starrett MJ, Chrastil ER, Nitz DA. Rethinking retrosplenial cortex: Perspectives and predictions. Neuron. 2023; 111 (2): 150–75. Available from: https://doi.org/10.1016/j.neuron.2022.11.006. Epub 2022 Dec 1. PMID: 36460006.
14. Todd TP, Fournier DI, Bucci DJ. Retrosplenial cortex and its role in cue-specific learning and memory. Neurosci Biobehav Rev. 2019; 107: 713–28. Available from: https://doi.org/10.1016/j.neubiorev.2019.04.016. Epub 2019 May 2. PMID: 31055014; PMCID: PMC6906080.
15. Trask S, Fournier DI. Examining a role for the retrosplenial cortex in age-related memory impairment. Neurobiol Learn Mem. 2022; 189: 107601. DOI: 10.1016/j.nlm.2022.107601. Epub 2022 Feb 22. PMID: 35202816.
16. Olsen GM, Ohara S, Iijima T, Witter MP. Parahippocampal and retrosplenial connections of rat posterior parietal cortex. Hippocampus. 2017; 27 (4): 335–58. Available from: https://doi.org/10.1002/hipo.22701. Epub 2017 Jan 16. PMID: 28032674.
17. Sugar J, Witter MP, van Strien NM, Cappaert NL. The retrosplenial cortex: intrinsic connectivity and connections with the (para) hippocampal region in the rat. An interactive connectome. Front Neuroinform. 2011; 5: 7. Available from: https://doi.org/10.3389/fninf.2011.00007. PMID: 21847380; PMCID: PMC3147162.
18. Dillen KNH, Jacobs HIL, Kukolja J, von Reutern B, Richter N, Onur ÖA, Dronse J, Langen KJ, Fink GR. Aberrant functional connectivity differentiates retrosplenial cortex from posterior cingulate cortex in prodromal Alzheimer's disease. Neurobiol Aging. 2016; 44: 114–26. Available from: https://doi.org/10.1016/j.neurobiolaging.2016.04.010. Epub 2016 Apr 22. PMID: 27318139.
19. Squire LR, Genzel L, Wixted JT, Morris RG. Memory consolidation. Cold Spring Harb Perspect Biol. 2015; 7 (8): a021766. Available from: https://doi.org/10.1101/cshperspect.a021766. PMID: 26238360; PMCID: PMC4526749.
20. de Sousa AF, Cowansage KK, Zutshi I, Cardozo LM, Yoo EJ, Leutgeb S, Mayford M. Optogenetic reactivation of memory ensembles in the retrosplenial cortex induces systems consolidation. Proc Natl Acad Sci U S A. 2019; 116 (17): 8576–81. Available from: https://doi.org/10.1073/pnas.1818432116. Epub 2019 Mar 15. PMID: 30877252; PMCID: PMC6486739
21. Auger SD, Maguire EA. Retrosplenial Cortex Indexes Stability beyond the Spatial Domain. J Neurosci. 2018; 38 (6): 1472–81. Available from: https://doi.org/10.1523/JNEUROSCI.2602-17.2017. Epub 2018 Jan 8. PMID: 29311139; PMCID: PMC5815348.
22. Mitchell AS, Czajkowski R, Zhang N, Jeffery K, Nelson AJD. Retrosplenial cortex and its role in spatial cognition. Brain Neurosci Adv. 2018; 2: 2398212818757098. Available from: https://doi.org/10.1177/2398212818757098. PMID: 30221204; PMCID: PMC6095108.
23. Corcoran KA, Yamawaki N, Leaderbrand K, Radulovic J. Role of retrosplenial cortex in processing stress-related context memories. Behav Neurosci. 2018; 132 (5): 388–95. Available from: https://doi.org/10.1037/bne0000223. Epub 2018 Jun. 7. PMID: 29878804; PMCID: PMC6188831.
24. Milczarek MM, Vann SD. The retrosplenial cortex and long-term spatial memory: from the cell to the network. Curr Opin Behav Sci. 2020; 32: 50–56. Available from: https://doi.org/10.1016/j.cobeha.2020.01.014. PMID: 32715030; PMCID: PMC7374566.
25. Mitchell AS, Czajkowski R, Zhang N, Jeffery K, Nelson AJD. Retrosplenial cortex and its role in spatial cognition. Brain Neurosci Adv. 2018; 2: 2398212818757098. Available from: https://doi.org/10.1177/2398212818757098. PMID: 30221204; PMCID: PMC6095108.
26. Powell A, Connelly WM, Vasalauskaite A, Nelson AJD, Vann SD, Aggleton JP, et al. Stable Encoding of Visual Cues in the Mouse Retrosplenial Cortex. Cereb Cortex. 2020; 30 (8): 4424–37. Available from: https://doi.org/10.1093/cercor/bhaa030. PMID: 32147692; PMCID: PMC7438634.
27. Fischer LF, Mojica Soto-Albors R, Buck F, Harnett MT. Representation of visual landmarks in retrosplenial cortex. Elife. 2020; 9: e51458. Available from: https://doi.org/10.7554/eLife.51458. PMID: 32154781; PMCID: PMC7064342.
28. Fournier DI, Monasch RR, Bucci DJ, Todd TP. Retrosplenial cortex damage impairs unimodal sensory preconditioning. Behav Neurosci. 2020; 134 (3): 198–207. DOI: 10.1037/bne0000365. Epub 2020 Mar 9. PMID: 32150422; PMCID: PMC7244381.
29. Mao D, Molina LA, Bonin V, McNaughton BL. Vision and Locomotion Combine to Drive Path Integration Sequences in Mouse Retrosplenial Cortex. Curr Biol. 2020; 30 (9): 1680–8.e4. Available from: https://doi.org/10.1016/j.cub.2020.02.070. Epub 2020 Mar 19. PMID: 32197086.
30. Morris R, Pandya DN, Petrides M. Fiber system linking the mid-dorsolateral frontal cortex with the retrosplenial/presubicular region in the rhesus monkey. J Comp Neurol. 1999; 407 (2): 183–92. Available from: https://doi.org/10.1002/(sici)1096-9861(19990503)407:2<183::aid-cne3>3.0.co;2-n. PMID: 10213090.
31. Clark BJ, Simmons CM, Berkowitz LE, Wilber AA. The retrosplenial-parietal network and reference frame coordination for spatial navigation. Behav Neurosci. 2018; 132 (5): 416–29. Available from: https://doi.org/10.1037/bne0000260. Epub 2018 Aug 9. PMID: 30091619; PMCID: PMC6188841.
32. Aggleton JP, Yanakieva S, Sengpiel F, Nelson AJ. The separate and combined properties of the granular (area 29) and dysgranular (area 30) retrosplenial cortex. Neurobiol Learn Mem. 2021; 185: 107516. DOI: 10.1016/j.nlm.2021.107516. Epub 2021 Sep 3. PMID: 34481970.
33. Epstein RA, Parker WE, Feiler AM. Where am I now? Distinct roles for parahippocampal and retrosplenial cortices in place recognition. J Neurosci. 2007; 27 (23): 6141–9. Available from: https://doi.org/10.1523/JNEUROSCI.0799-07.2007. PMID: 17553986; PMCID: PMC6672165.
34. Spiers HJ, Maguire EA. Thoughts, behavior, and brain dynamics during navigation in the real world. Neuroimage. 2006; 31 (4): 1826–40. Available from: https://doi.org/10.1016/j.neuroimage.2006.01.037. Epub 2006 Apr 11. PMID: 16584892.
35. Tamburro G, Fiedler P, Stone D, Haueisen J, Comani S. A new ICA-based fingerprint method for the automatic removal of physiological artifacts from EEG recordings. PeerJ. 2018; 6: e4380. DOI: 10.7717/peerj.4380. PMID: 29492336; PMCID: PMC5826009.
36. Lehmann D, Strik WK, Henggeler B, Koenig T, Koukkou M Brain electric microstates and momentary conscious mind states as building blocks of spontaneous thinking: I. Visual imagery and abstract thoughts. Int J Psychophysiol. 1998; 29 (1): 1–11. Available from: https://doi.org/10.1016/s0167-8760(97)00098-6.
37. Schacter DL, Crovitz HF. "Falling" while falling asleep: sex differences. Percept Mot Skills. 1977; 44 (2): 656. DOI: 10.2466/pms.1977.44.2.656. PMID: 866074.
38. Sarter M Fritschy JM Reporting statistical methods and statistical results in EJN. Eur J Neurosci. 2008; 28 (12): 2363–4. Available from: https://doi.org/10.1111/j.1460-9568.2008.06581.x.
39. Иванов Л. Б. Спектр мощности по электроэнцефалограмме: ошибки и практика применения (лекция вторая). Дисперсионный анализ электроэнцефалограммы по Росману. Медицинский алфавит. 2022; (9): 38–43. Available from: https://doi.org/10.33667/2078-5631-2022-9-38-43.
40. Croce P, Quercia A, Costa S, Zappasodi F. EEG microstates associated with intra- and inter-subject alpha variability. Sci Rep. 2020; 10 (1): 2469. Available from: https://doi.org/ 10.1038/s41598-020-58787-w.
41. Poskanzer C, Denis D, Herrick A, Stickgold R. Using EEG microstates to examine post-encoding quiet rest and subsequent word-pair memory. Neurobiol Learn Mem. 2021; 181: 107424. Available from: https://doi.org/ 10.1016/j.nlm.2021.107424.
42. Pascual-Marqui RD, Michel CM, Lehmann D. Segmentation of brain electrical activity into microstates: model estimation and validation. IEEE Trans Biomed Eng. 1995; 42 (7): 658–65.

Available from: https://doi.org/10.1109/10.391164.

43. Milz P, Pascual-Marqui RD, Lehmann D, Faber PL. Modalities of Thinking: State and Trait Effects on Cross-Frequency Functional Independent Brain Networks. Brain Topogr. 2016; 29 (3): 477–90. Available from: https://doi.org/ 10.1007/s10548-016-0469-3.
44. Seitzman BA, Abell M, Bartley SC, Erickson MA, Bolbecker AR, Hetrick WP. Cognitive manipulation of brain electric microstates. Neuroimage. 2017; 146: 533–43. Available from: https://doi.org/ 10.1016/j.neuroimage.2016.10.002.
45. Mishra A, Englitz B, Cohen MX. EEG microstates as a continuous phenomenon. Neuroimage. 2020; 208: 116454. Available from: https://doi.org/ 10.1016/j.neuroimage.2019.116454. Epub 2019 Dec 10.
46. Milz P, Faber PL, Lehmann D, Koenig T, Kochi K, Pascual-Marqui RD. The functional significance of EEG microstates--Associations with modalities of thinking. Neuroimage. 2016; 125: 643–56. Available from: https://doi.org/ 10.1016/j.neuroimage.2015.08.023.
47. Pascual-Marqui RD, Esslen M, Kochi K, Lehmann D. Functional imaging with low-resolution brain electromagnetic tomography (LORETA): a review. Methods Find Exp Clin Pharmacol. 2002; 24 Suppl C: 91–5. PMID: 12575492.
48. Grech R, Cassar T, Muscat J, Camilleri KP, Fabri SG, Zervakis M, et al. Review on solving the inverse problem in EEG source analysis. J Neuroeng Rehabil. 2008; 5: 25. Available from: https:// doi.org/ 10.1186/1743-0003-5-25.
49. Neuner I, Arrubla J, Werner CJ, Hitz K, Boers F, Kawohl W, et al. The default mode network and EEG regional spectral power: a simultaneous fMRI-EEG study. PLoS One. 2014; 9 (2): e88214. Available from: https://doi.org/ 10.1371/journal.pone.0088214
50. Vukovic N, Hansen B, Lund TE, Jespersen S, Shtyrov Y. Rapid microstructural plasticity in the cortical semantic network following a short language learning session. PLoS Biol. 2021; 19 (6): e3001290. Available from: https://doi.org/10.1371/journal.pbio.3001290. PMID: 34125828; PMCID: PMC8202930.
51. Hubert V, Beaunieux H, Chételat G, Platel H, Landeau B, Viader F, Desgranges B, Eustache F. Age-related changes in the cerebral substrates of cognitive procedural learning. Hum Brain Mapp. 2009; 30 (4): 1374–86. Available from: https://doi.org/10.1002/hbm.20605. PMID: 18537110; PMCID: PMC2935916.
52. Just MA, Keller TA. Converging measures of neural change at the microstructural, informational, and cortical network levels in the hippocampus during the learning of the structure of organic compounds. Brain Struct Funct. 2019; 224 (3): 1345–57. Available from: https://doi.org/10.1007/s00429-019-01838-4. Epub 2019 Feb 6. PMID: 30725233.
53. Nunez PL, Wingeier BM, Silberstein RB. Spatial-temporal structures of human alpha rhythms: theory, microcurrent sources, multiscale measurements, and global binding of local networks. Hum Brain Mapp. 2001; 13 (3): 125–64. Available from: https://doi.org/10.1002/hbm.1030. PMID: 11376500; PMCID: PMC6872048.
54. Rodriguez-Larios J, ElShafei A, Wiehe M, Haegens S. Visual working memory recruits two functionally distinct alpha rhythms in posterior cortex. eNeuro. 2022; 9 (5): ENEURO.0159-22.2022. DOI: 10.1523/ENEURO.0159-22.2022. Epub ahead of print. PMID: 36171059; PMCID: PMC9536853.