NEUROPHYSIOLOGICAL ASSESSMENT OF SPEECH FUNCTION IN INDIVIDUALS HAVING A HISTORY OF MILD COVID-19

Gulyaev SA ✉, Voronkova YuA, Abramova TA, Kovrazhkina EA

Federal Center for Brain and Neurotechnologies of Federal Medical and Biological Agency, Moscow, Russia

Establishing a link between the objective research data and the thought process is one of the major issues of modern neurophysiology. The study was aimed to find an opportunity to perform objective analysis of the causes of cognitive impairment in individuals having a history of mild novel coronavirus infection by solving the inverse EEG problem. A total of 38 COVID-19 survivors were assessed, who had returned to work. The control group included 33 healthy individuals. EEG was recorded using a 128-channel system with an average reference. The data obtained were subjected to the EEG microstate segmentation and converted using the algorithm for solving the inverse EEG problem implemented in the sLORETA software package. In individuals with no history of COVID-19 being in a state of relaxed wakefulness, the component of rhythmic activity within Brodmann area 47, responsible for perception and realization of music, was found in all classes of EEG microstates ($0.01 < p < 0.05$; χ^2-test). Auditory-speech load was characterized by rhythmic activity within areas 22, 23, 37, 39, 40, 44, 45, and 47. In individuals having a history of novel coronavirus infection being in a state of relaxed wakefulness, rhythmic activity within areas 22, 37, 39, 40 was detected. Under auditory-speech load, there was rhythmic activity within areas 37, 39, and 41 ($p < 0.05$; χ^2-test). Thus, alterations in realization of speech function in the form of the disordered sequence of switching on the main language centers were revealed in COVID-19 survivors.

Keywords: novel coronavirus infection, EEG, inverse problem solution

Author contribution: Gulyaev SA — data analysis, manuscript writing, editing; Voronkova YuA, Abramova TA — data acquisition; Kovrazhkina EA — editing.

Compliance with ethical standards: the study was approved by the Ethics Committee of the Federal Center for Brain and Neurotechnologies of FMBA (protocol № 148-1 dated June 15, 2021). All the subjects took part in the experiment on a voluntary basis with no extra benefit. The experiment was studied by employees of the Federal Center for Brain and Neurotechnologies of FMBA within the limits of scientific work conducted by the institution with no third party funding.

✉ **Correspondence should be addressed:** Sergey A. Gulyaev
Ostrovitianova, 1, str. 10, Moscow, 117997, Russia; sergruss@yandex.ru

Received: 24.03.2022 **Accepted:** 04.05.2022 **Published online:** 25.05.2022

DOI: 10.47183/mes.2022.016

НЕЙРОФИЗИОЛОГИЧЕСКОЕ ИССЛЕДОВАНИЕ РЕЧЕВОЙ ФУНКЦИИ У ЛИЦ, ПЕРЕНЕСШИХ ЛЕГКУЮ ФОРМУ COVID-19

С. А. Гуляев ✉, Ю. А. Воронкова, Т. А. Абрамова, Е. А. Ковражкина

Федеральный центр мозга и нейротехнологий Федерального медико-биологического агентства, Москва, Россия

Одной из наиболее важных проблем современной нейрофизиологии является установление связи между данными объективных исследований и мыслительным процессом. Целью исследования был объективный анализ причин развития когнитивных дисфункций у лиц, перенесших легкую форму новой коронавирусной инфекции, с помощью технологии решения обратной ЭЭГ-задачи. Проведено обследование 38 человек, перенесших COVID-19 и вернувшихся к выполнению профессиональных обязанностей. Контрольную группу составили 33 здоровых человека. ЭЭГ регистрировали с помощью 128-канальной системы с усредненным референтом. Полученные данные сегментировали с выделением отдельных ЭЭГ-микросостояний и преобразовывали с помощью алгоритма решения обратной задачи ЭЭГ, реализованном в пакете прикладных программ sLORETA. У лиц, не болевших COVID-19, в состоянии пассивного расслабленного бодрствования во всех классах ЭЭГ-микросостояний присутствует компонент ритмической активности 47-го поля Бродмана, ответственного за восприятие и реализацию музыки ($0{,}01 < p < 0{,}05$; χ^2-test). Слухоречевая нагрузка характеризовалась появлением ритмической активности над полями 22, 23, 37, 39, 40, 44, 45 и 47. У переболевших новой коронавирусной инфекцией в состоянии пассивного расслабленного бодрствования ритмическая активность была зарегистрирована над полями 22, 37, 39, 40. При слухоречевой нагрузке ритмическая активность выделялась над полями 37, 39 и 41 ($p < 0{,}05$; χ^2-test). Таким образом, у лиц, перенесших COVID-19, выявлены изменения реализации речевой функции в виде дезорганизации последовательности включения основных речевых центров.

Ключевые слова: новая коронавирусная инфекция, ЭЭГ, решение обратной задачи

Вклад авторов: С. А. Гуляев — анализ данных, написание текста, оформление; Ю. А. Воронкова, Т. А. Абрамова — получение данных; Е. А. Ковражкина — оформление.

Соблюдение этических стандартов: исследование одобрено этическим комитетом ФЦМН ФМБА России (протокол № 148-1 от 15 июня 2021 г.). Все лица приняли участие в эксперименте на добровольных началах, без дополнительного поощрения. Исследования эксперимента проводили сотрудники ФГБУ ФЦМН ФМБА России в рамках научной работы учреждения без привлечения сторонних средств.

✉ **Для корреспонденции:** Сергей Александрович Гуляев
ул. Островитянова, д. 1, стр. 10, г. Москва, 117997, Россия; sergruss@yandex.ru

Статья получена: 24.03.2022 **Статья принята к печати:** 04.05.2022 **Опубликована онлайн:** 25.05.2022

DOI: 10.47183/mes.2022.016

Establishing a link between the objective research data and the thought process is one of the major issues of modern neurophysiology. Currently, activity in the neural structures of the brain is studied by functional brain imaging methods, such as functional magnetic resonance imaging (fMRI) and positron emission tomography (PET), and neurophysiological techniques based on the electroencephalography/magnetoencephalography (EEG/MEG) studies in various modalities (continious or discrete EEG). All these methods have disadvantages, resulting in difficulties in data interpretation. Thus, functional brain imaging methods detect the major changes in the neuronal activity over a rather long period of time. Regardless of the almost direct temporal relationship with brain activity, continious EEG/MEG is so complex and diverse that it is unable to precisely answer the question, which neural structures are responsible for its formation. In case of discrete recording widely used to study the neural structures responses to external stimuli (evoked potential (EP) tests), this method provides information on the nervous tissue direct response to the selected stimulus, which makes it impossible to study brain fuction as a whole even in case of recording long-latency EPs, resulting in determining recognition of a particular stimulus [1].

Thus, to study cognitive processes, a method is required for selection of different variants of continious activity, which can currently be implemented by using clustering algorithms [2] with subsequent conversion of the results through solving the inverse EEG problem [3–5].

These studies are of particular interest in individuals having disorders that result in mild cognitive impairment, which is difficult to diagnose by common clinical assessment methods. The post-COVID syndrome observed in people having a history of novel coronavirus infection (COVID-19), even the mild form, is of interest as an example of the specific case of such disorder.

According to the current logic, the impact of COVID-19 on the central nervous system (CNS) is beyond question: like other coronaviruses, it can invade the CNS via both hematogenous and neuronal pathways. However, the virus is quickly neutralized, that is why there is usially no clinically significant damage to brain matter or meninges [6, 7]. At the same time, the reports of COVID-19-associated neurological manifestations show that cerebral symptoms, such as headache and dizziness (13.1–16.8% of cases), together with anosmia and hypogeusia/ageusia (up to 83% of observations) are most common in patients with novel coronavirus infection [8]. Cerebrovascular events are registered in 2–17%, and seizure in 1% of cases (similar to their prevalence in the population). This suggests that these secondary disorders result from hypoxia and electrolyte imbalance, as well as from the effects of the products of immune response. The rodent and neuronal cell culture studies have demonstrated viral RNA invading cells and subsequent massive deaths of neurons [9]. However, clinical reports of the direct damage to brain matter in the form of encephalitis are rare [10–12]. Nevertheless, autopsy of those who died from COVID-19 [13–16] revealed viral RNA transcripts in the tissue of cranial nerves in 40% of cases, as well as viral proteins in endothelial cells of the olfactory bulb. The main neurological manifestations of COVID-19 are represented by cerebral simptoms and/or damage to specific cranial nerves; it is necessary to exclude other causes in case of any structural brain tissue changes.

The nature of neuropsychiatric disorders observed in about 25% of patients with COVID-19 remains poorly understood. According to some reports, anxiety disorders/phobias (8.5–28.8%) and depression (9.5–16.5%) are the most common. However, in patients with severe COVID-19, these could be attributed not to the effects of the virus itself, but to stress related to the fact of infection, isolation, stay in the intensive care unit, fear of death or further development of various complications [17].

Under these circumstances, diagnostic methods capable of objectifying clinical manifestations are of some interest. However, meta-analysis of EEG recordings obtained from 308 patients with COVID-19 revealed non-specific changes in the majority of cases; paroxysmal EEG activitiy was detected in 20.3% of cases, the confirmed seizures and status epilepticus were observed in 2.05% [18]. Other authors, who had explained specific changes in EEG by the condition severity, hypoxia-ischemia, and the resulting secondary neurological disorder, reached almost the same conclusion [19].

These findings are entirely to be expected: regardless of the direct routes of invading the nervous tissue, the effects of COVID-19 are characterized by diffuse processess with no focal destruction of nerve cells, accompanied by bioelectrical brain activity alterations associated with various neuropsychiatric syndromes. That is why objectifying such “cerebral” alterations requires the use of slightly different methods.

The study was aimed to find an opportunity to perform objective analysis of the causes of cognitive impairment in individuals having a history of mild COVID-19 by EEG and solving the inverse neurophysiological problem.

METHODS

Main group

A total of 38 COVID-19 survivors were assessed, who had returned to work. Inclusion criteria: all subjects were right-handed; no history of severe traumatic brain injury and mental disorders; the age of the subjects was 38.6 ± 2 years. Exclusion criteria: smoking; taking pharmacologically active substances due to chronic disorder.

All the participants were working people who had a relevant special educational background. A total of 35 (92%) individuals were employed at the time of the study. The majority of volunteers, 37 individuals (97%), lived in families. None of the subjects were disabled. The majority of subjects, 35 individuals (92%), were right-handed.

Neuropsychological testing was performed using the Montreal Cognitive Assessment score (MoCA), which was chosen due to scope of its coverage of various cognitive functions and sensitivity compared to other scores for detection of mild to moderate cognitive impairment [20]. However, the testing results defined the average score of 26 (variation 3, minimum score 25, maximum score 28), which confirmed no cognitive impairment.

T1- and T2-weighted MRI scans in the suppression and diffusion modes revealed alterations in only two subjects (5% of all cases). In the first case, the findings were represented by chronic cerebral venous sinus thrombosis, and in the second case these were represented by small vessel disease. Both findings were not associated with the history of COVID-19.

Control group

A total of 33 healthy people were enrolled who had volunteered to take part in the experiment. Their age ranged between 19–60 years; the average age was 32.37 ± 9.44 years; the volunteers' educational background was equivalent to that of the subjects in the index group.

General characteristics of methods

The eyes-closed resting state EEG was recorded in the darkened room using the 128 channel HydroCel-128 system (Magstim; USA) with an average reference, combined with the EGI-GES-300 bioamplifier (Magstim; USA). The resulting signal was converted into a digital form by discrete sampling with a sampling rate of 500 Hz, thus allowing to eliminate signal distortion in the frequency range of 1–250 Hz. The signal bandwidth with the applied 50-Hz notch filter was 0.5–70 Hz, which made it possible to integrate the main ranges of interest. No recording was performed within a minute after connecting a volunteer to the device in order to eliminate movement-related artifacts resulting from the subject's maladaptation.

Impedance, the total resistance of the neural interface electrodes, was maintained within 10 kOhm. It was

Table 1. Comparative characteristics of the class 1–6 EEG microstate duration in controls

	Class 1		Class 2		Class 3		Class 4		Class 5		Class 6	
	m	SD	m	SD	m	SD	m	SD	m	SD	m	SD
Resting state	0,02	0,01	0,02	0,01	0,03	0,01	0,02	0,01	0,03	0,01	0,02	0,01
Task state	0,04	0,01	0,04	0,01	0,04	0,01	0,04	0,01	0,05	0,01	0,04	0,01
p (*t*-test)	< 0,001		< 0,001		< 0,001		< 0,001		< 0,001		< 0,001	

Note: m — mean; SD — standard deviation.

continuously monitored throughout the study in accordance with the manufacturer's instructions.

A pool of functional tests included recording the eyes-closed resting state EEG that was considered the resting-state bioelectrical activity, and recording EEG under auditory-speech load (listening to a short story in the subject's native language). This made it possible to obtain environmental changes defined by activation of only one cognitive function with the relatively well understood architecture of cortical processing in accordance with the modern two-stream hypothesis [21].

The results were further processed and analyzed. Other electrical devices that created spurious electromagnetic emissions were turned off to minimize signal artifacts; we also controlled impedance of the interface, maintained room temperature, minimized facial muscle artifacts. The data pool obtained was filtered with the 1–70 Hz wide band filter. Standardization of electrode positioning to obtain single EEG electrode space and separation of the signal into independent components allowing one to remove various artifacts of physical and biological origin, that had not been eliminated from the EEG signal at the first stage, were performed. Subsequently, microstate segmentation of the EEG signal was performed by k-means clustering or the adhesion-spraying method to define six microstate classes taking into account variability of the classes 5 and 6 [22–24]. The final phase of research included analysis of the EEG source localization for each of the distinguished EEG microstate classes in accordance with the method by R. Pascual-Marqui with the use of the algorithm for solving the inverse EEG problem implemented in the sLORETA software package [25, 26].

The findings provided information on both the resting state and task state bioelectrical brain activity. Six classes of EEG microstates were assessed separately taking into account the following characteristics: 1) microstate duration, seconds; 2) microstate occurrence per second; 3) EEG microstate contribution to the total energy of the scalp field (coverage). The main cortical area was defined for each case of the EEG microstate sequence and for each EEG microstate class in accordance with the Brodmann's map.

Statistical data processing

Statistical processing of the results was performed using the GNU-PSPP software package for GNU OC Linux Mate 10.10 (Canonical ltd.; UK). Statistical analysis included the following steps: the data were tested for reliability or internal consistency by the Cronbach's alpha method ($0.05 < \alpha < 0.5$), after that factor analysis was used to define the main factors for further analysis. The results were compared using t-test to define the significance of changes due to the influence of the selected factor in one of the study groups and one-way analysis of variance (ANOVA) to define the influence of individual factors on different comparison groups. Pearson's chi-squared test (χ^2) was used to assess changes in the groups were the results obtained were in the form of qualitative characteristics. A single degree of freedom was used for all calculations; the accepted significance level was $\alpha > 0.05$.

The previously reported guidelines were used to develop a common method for statistical analysis [27].

RESULTS

Comparative characteristic of EEG microstates recorded during realization of speech function

Comparison of the EEG misrostate characteristics under functional load using the paired *t*-test showed the following: in controls engaged in listening or active speech production, all three major indicators (duration, occurrence, and coverage) were significantly ($p < 0.05$) different from those obtained in a state of relaxed wakefulness. At the same time, in COVID-19 survivors, there were no such differences in the characteristics of bioelectrical activity between the resting state and the situation of auditory-speech load. In the vast majority of comparisons,

Table 2. Comparative characteristics of the class 1–6 EEG microstate duration in individuals having a history of novel coronavirus infection

	Class 1		Class 2		Class 3		Class 4		Class 5		Class 6	
	m	SD	m	SD	m	SD	m	SD	m	SD	m	SD
Resting state	0,04	0,02	0,04	0,02	0,04	0,01	0,05	0,02	0,04	0,02	0,05	0,01
Task state	0,04	0,02	0,04	0,02	0,04	0,01	0,04	0,01	0,05	0,01	0,04	0,02
p (*t*-test)	> 0,5		0,4		> 0,5		> 0,5		0,02		> 0,1	

Note: m — mean; SD — standard deviation.

Table 3. Comparative characteristics of the class 1–6 EEG microstate occurrence in controls

	Class 1		Class 2		Class 3		Class 4		Class 5		Class 5	
	m	SD	m	SD	m	SD	m	SD	m	SD	m	SD
Resting state	6,18	3,43	6,57	3,48	5,65	3,91	5,66	3,93	5,71	4,09	5,40	3,80
Task state	3,88	0,00	3,88	0,00	3,88	0,00	3,88	0,00	3,87	0,01	3,88	0,00
p (*t*-test)	< 0,01		< 0,001		0,01		0,01		0,01		0,02	

Note: m — mean; SD — standard deviation.

Table 4. Comparative characteristics of the class 1–6 EEG microstate occurrence in individuals having a history of novel coronavirus infection

	Class 1		Class 2		Class 3		Class 4		Class 5		Class 6	
	m	SD	m	SD	m	SD	m	SD	m	SD	m	SD
Resting state	3,88	0,00	3,88	0,01	3,88	0,00	3,88	0,00	3,88	0,00	3,88	0,01
Task state	3,88	0,01	3,88	0,00	3,88	0,00	3,88	0,01	3,88	0,01	3,63	0,95
p (*t*-test)	> 0,5		0,4		> 0,5		> 0,5		0,4		0,2	

Note: m — mean; SD — standard deviation.

the differences were nonsignificant ($p > 0.3$). Significant differences ($p = 0.02$) were revealed during assessment of the class 5 EEG microstate coverage only (Tables 1–6).

Microstates source analysis by solving the EEG inverse problem

The sources of distinct EEG microstates were assessed using the algorithm for solving the inverse EEG problem. However, the algorithm is based on defining the power of scalp potentials, since this parameter defines not the excitatory functional area, but the areas producing rhythmic activity, thus forcing us to use the general term “activity” that represents the area of interest for the algorithm to be used, but is not equivalent to the term “excitation of nervous tissue”.

However, the gradual transition from excitation of nerve centers to production of rhythmic activity was indicative of activity in distinct neuronal areas associated with the studied function realization. This made it possible to distinguish two main sequences, typical for cortical structures that produced rhythmic activity both in the state of relaxed wakefulness and under auditory-speech load, and locate the data obtained in accordance with the Brodmann’s map of cortical areas (see Figure).

The findings showed that no rhythmic activity was registered in controls within major Brodmann areas forming a cortical representation of speech (39, 40 and 44, 45), however, the components of rhythmic activity in the Brodmann area 47 responsible for perception and realization of music were found in all classes of EEG microstates. The auditory-speech load was characterized by rhythmic activity within areas 22 (class 2), 23 (class 6), 37 (classes 3–6), 39, 40 (classes 3–6), 44 (classes 3, 4 and 6), 45 (class 6), and 47 (class 5), which formed the following centers: center responsible for perception of noise, Wernicke's area, Broca's area, and center responsible for perception of music. This was in line with the common perceptions of the speech function realization via dorsal stream of the dual stream model of speech processing.

However, other sequences of the recorded rhythmic patterns within the recorded classes of EEG microstates were found in COVID-19 survivors (see Figure), along with the reduced total number of EEG microstates involved in realization of speech function.

Thus, no rhythmic activity within Brodmann area 47 typical for controls was revealed in the state of relaxed wakefulness. At the same time, rhythmic activity was revealed within areas 22 (classes 1, 5, 6), 37 (class 3), 39, 40 (all classes of EEG microstates). Under auditory-speech load, rhythmic activity was detected within areas 37 (classes 1 and 3), 39 (classes 4, 5, 6), and 41 (class 6).

DISCUSSION

The study of bioelectrical brain activity made it possible to substantially enhance the capabilities of EEG method and improve the accuracy of results, especially in the context of using a multichannel high density EEG system.

Comparative analysis of the changing characteristics of EEG microstates also confirmed the functional changes in bioelectrical activity, which were based on the changes in the patterns of activity in distinct groups of neurons. Thus, the lack of changes in the EEG microstate coverage in healthy individuals and COVID-19 survivors showed preserved neural structures involved in realization of functions. However, the differences in duration and occurrence of distinct classes of EEG microstates demonstrated the functional connectivity disruption, which, according to a number of authors, was indicative of mismatch in the joint activity of separate neural networks [23, 24].

An almost complete regression of variability in the EEG microstate occurrence in the COVID-19 survivors, detected in all the specified classes, was of particular interest. We considered this phenomenon a crude manifestation of low compensatory ability being the sequelae of the disease in such people.

However, the most complete characteristics of bioelectrical changes in the COVID-19 survivors were shown when solving the inverse EEG problem, which made it possible to detect

Table 5. Comparative characteristics of the class 1–6 EEG microstate coverage in controls

	Class 1		Class 2		Class 3		Class 4		Class 5		Class 6	
	m	SD	m	SD	m	SD	m	SD	m	SD	m	SD
Resting state	17%	14%	19%	13%	17%	14%	16%	15%	18%	16%	13%	12%
Task state	17%	3%	17%	4%	16%	3%	17%	3%	18%	4%	16%	4%
p (*t*-test)	0,8		0,4		0,6		0,9		0,9		0,2	

Note: m — mean; SD — standard deviation.

Table 6. Comparative characteristics of the class 1–6 EEG microstate coverage in individuals having a history of novel coronavirus infection

	Class 1		Class 2		Class 3		Class 4		Class 5		Class 6	
	m	SD	m	SD	m	SD	m	SD	m	SD	m	SD
Resting state	17%	7%	15%	7%	17%	6%	17%	6%	16%	6%	18%	6%
Task state	15%	6%	17%	7%	17%	5%	16%	8%	20%	3%	15%	7%
p (*t*-test)	> 0,5		> 0,4		> 0,5		> 0,5		0,02		0,1	

Note: m — mean; SD — standard deviation.

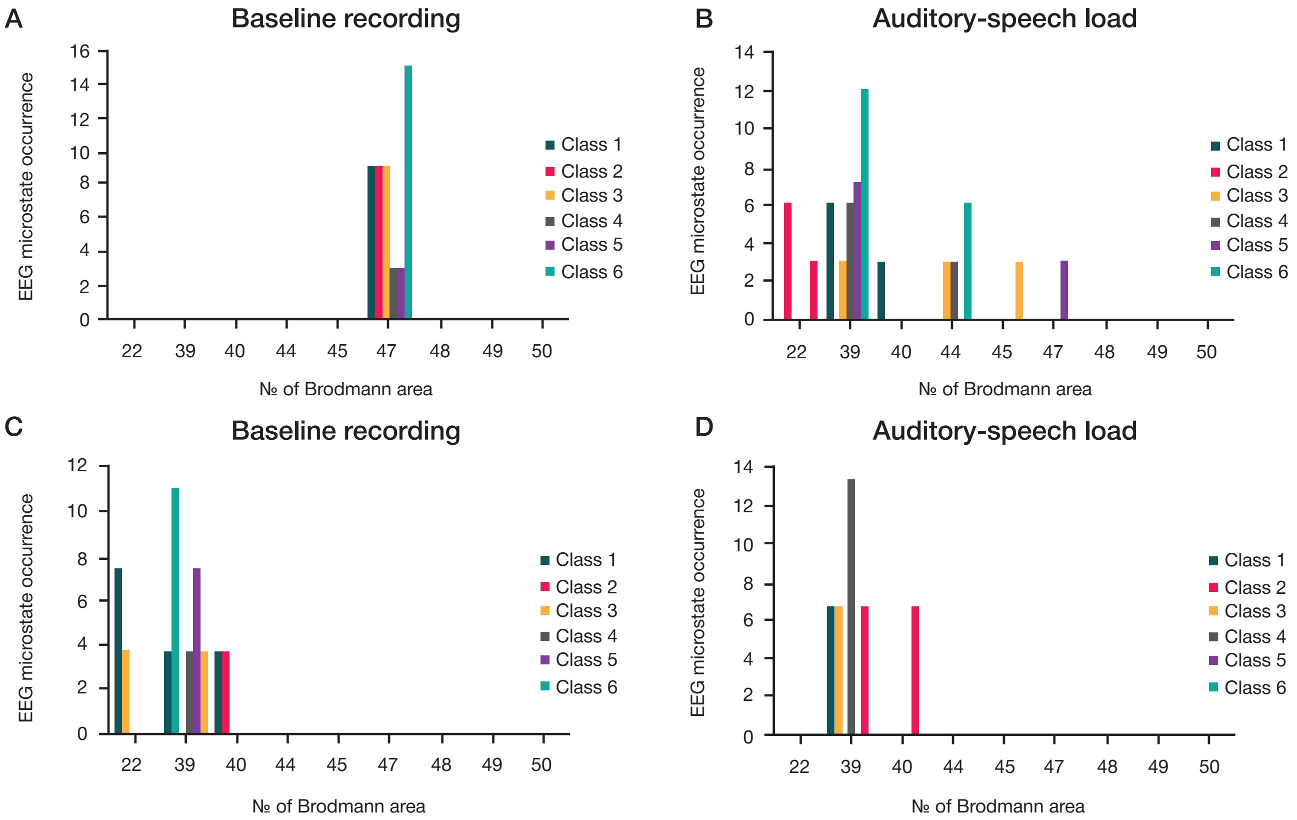

Fig. Rhythmic activity occurrence in accordance with the Brodmann area in controls (**A**, **B**) and individuals having a history of novel coronavirus infection (**C**, **D**) in the state of relaxed wakefulness and under auditory-speech load; p < 0.05 (χ^2-test)

the disrupted sequences of the rhythmic activity registration within distinct brain structures and their association with the Brodmann's map of cortical areas.

According to the results, impaired speech fuction realization manifested itself in the disrupted information flow through the ventral stream and impaired communication between the areas within Wernicke's area and Broca's area (dorsal stream), which resulted in communication disorders in the form of impaired perception of new information and difficulties in implementing the decisions.

This is probably associated with the effects of COVID-19 on the neuronal structures, including those mediated by immunopathological processes, previously reported in experimental studies [19].

CONCLUSIONS

1. Individuals having a history of novel coronavirus infection who have returned to work after convalescence show objective changes in bioelectrical brain activity associated with unexplored mechanisms, underlying functional damage to neural networks, involved in realization of the higher brain functions. 2. Recovery of general EEG characteristics in people having a history of novel coronavirus infection occurs over a long period of time (at least six months), which provides the basis for dysfunction known as post-COVID syndrome. 3. The results of solving the inverse EEG problem showed that COVID-19 survivors demonstrated alterations in realization of speech function in the form of the disordered sequence of switching on the main language centers. The study has shown that in people having a history of novel coronavirus infection, cognitive impairment undermining restoration of professional skills persists over a long time (up to six months). Such disorders are difficult to differentiate by clinical and brain imaging methods only, that is why recording and verification of these processes require developing the new multimodality neurophysiological assessment procedures.

References

1. Qi G, Zhao S, Ceder AA, Guan W, Yan X. Wielding and evaluating the removal composition of common artefacts in EEG signals for driving behaviour analysis. Accid Anal Prev. 2021; 159: 106223. DOI: 10.1016/j.aap.2021.106223. Epub 2021 Jun 10. PMID: 34119819.
2. Dittman Z, Munia TTK, Aviyente S. Graph Theoretic Analysis of Multilayer EEG Connectivity Networks. Annu Int Conf IEEE Eng Med Biol Soc. 2021; 2021: 475–9. DOI: 10.1109/EMBC46164.2021.9629514. PMID: 34891336
3. 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.
4. 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. DOI: 10.1186/1743-0003-5-25. PMID: 18990257; PMCID: PMC2605581.
5. Hecker L, Rupprecht R, Tebartz Van Elst L, Kornmeier J. ConvDip: A Convolutional Neural Network for Better EEG Source Imaging. Front Neurosci. 2021; 15: 569918. DOI: 10.3389/fnins.2021.569918. PMID: 34177438; PMCID: PMC8219905.
6. Escaffre O, Borisevich V, Rockx B. Pathogenesis of Hendra and

Nipah virus infection in humans. J Infect Dev Ctries. 2013; 7 (4): 308–11. Available from: https://doi.org/10.3855/jidc.3648.
7. Wang GF, Li W, Li K. Acute encephalopathy and encephalitis caused by influenza virus infection. Curr Opin Neurol. 2010; 23 (3): 305–11. Available from: https://doi.org/10.1097/wco.0b013e328338f6c9.
8. Roy D, Ghosh R, Dubey S, Dubey MJ, Benito-León J, Kanti Ray B. Can Neurological and Neuropsychiatric Impacts of COVID-19 Pandemic. J Neurol Sci. 2021; 48 (1): 9–24. Available from: https://doi.org/10.1017/cjn.2020.173
9. Song E, Zhang C, Israelow B, Lu-Culligan A, Prado AV, Skriabine S, et al. Neuroinvasion of COVID-19 in human and mouse brain. J Exp Med. 2021; 218 (3): e20202135. Available from: https://doi.org/10.1084/jem.20202135
10. Moriguchi T, Harii N, Goto J, et al. A first case of meningetis/encephalitis associated with SARS-Coronavirus-2. Int J Infect Dis. 2020; 94: 55–58. Available from: https://doi.org/10.1016/j.ijid.2020.03.06
11. Ye M, Ren Y, Lv T. Encephalitis as a clinical manifestation of COVID-19. Brain Behav Immun. 2020; S0889–1591 (20): 30465–7. Available from: https://doi.org/10.1016/j.bbi.2020.04.017.
12. Duong L, Xu P, Liu A. Meningoencephalitis without respiratory failure in a young female patient with COVID-19 infection in Downtown Los Angeles, early April 2020. Brain Behav Immun. 2020; 87: 33. Available from: https://doi.org/10.1016/j.bbi.2020.04.024.
13. Helms J, Kremer S, Merdji H, Clere-Jehl R, Schenck M, Kummerlen C, et al. Neurologic Features in Severe COVID-19 Infection. N Engl J Med. 2020; 382 (23): 2268–70. Available from: https://doi.org/10.1056/NEJMc2008597.
14. Puelles VG, Lütgehetmann M, Lindenmeyer MT, Sperhake JP, Wong MN, Allweiss L, et al. Multiorgan and Renal Tropism of COVID-19. N Engl J Med. 2020; 383 (6): 590–2. Available from: https://doi.org/10.1056/NEJMc2011400.
15. Solomon IH, Normandin E, Bhattacharyya S, Mukerji SS, Keller K, Ali AS, et al. Neuropathological Features of Covid-19. N Engl J Med. 2020; 383 (10): 989–92. Available from: https://doi.org/10.1056/NEJMc2019373.
16. Troyer EA, Kohn JN, Hong S. Are we facing a crashing wave of neuropsychiatric sequelae of COVID-19? Neuropsychiatric symptoms and potential immunologic mechanisms. Brain Behav Immun. 2020; 87: 34–39. Available from: https://doi.org/10.1016/j.bbi.2020.04.027
17. Rogers JP, Chesney E, Oliver D, et al. Psychiatric and neuropsychiatric presentations associated with severe coronavirus infections: a systematic review and meta-analysis with comparison to the COVID-19 pandemic. Lancet Psychiatry. 2020; 7 (7): 611–27. Available from: https://doi.org/10.1016/S2215-0366(20)30203-0.
18. Kubota T, Gajera PK, Kuroda N. Meta-analysis of EEG findings in patients with COVID-19. Epilepsy Behav. 2021; 115: 107682. Available from: https://doi.org/10.1016/j.yebeh.2020.107682.
19. Petrescu AM, Taussig D, Bouilleret V Electroencephalogram (EEG) in COVID-19: A systematic retrospective study. Neurophysiol Clin. 2020; 50 (3): 155–65. Available from: https://doi.org/10.1016/j.neucli.2020.06.001.
20. Pinto TCC, Machado L, Bulgacov TM, Rodrigues-Júnior AL, Costa MLG, Ximenes RCC, et al. Is the Montreal Cognitive Assessment (MoCA) screening superior to the Mini-Mental State Examination (MMSE) in the detection of mild cognitive impairment (MCI) and Alzheimer's Disease (AD) in the elderly? Int Psychogeriatr. 2019; 31 (4): 491–504. Available from: https://doi.org/10.1017/S1041610218001370.
21. Mishkin M, Ungerleider LG. Contribution of striate inputs to the visuospatial functions of parieto-preoccipital cortex in monkeys Behav Brain Res. 1982; 6 (1): 57–77. Available from: https://doi.org/10.1016/0166-4328(82)90081-x.
22. 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.
23. Michel CM, Koenig T. EEG microstates as a tool for studying the temporal dynamics of whole-brain neuronal networks: A review. Neuroimage. 2018; 180 (Pt B): 577–93. Available from: https://doi.org/10.1016/j.neuroimage.2017.11.062.
24. Van De Ville D, Britz J, Michel CM. EEG microstate sequences in healthy humans at rest reveal scale-free dynamics Proceedings of the National Academy of Sciences. 2010; 107 (42): 18179–84; Available from: https://doi.org/10.1073/pnas.1007841107.
25. 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
26. Vitali P, et al. Integration of multimodal neuroimaging methods: a rationale for clinical applications of simultaneous EEG-fMRI Funct Neurol. 2015. PMID: 26214023.
27. 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.

Литература

1. Qi G, Zhao S, Ceder AA, Guan W, Yan X. Wielding and evaluating the removal composition of common artefacts in EEG signals for driving behaviour analysis. Accid Anal Prev. 2021; 159: 106223. DOI: 10.1016/j.aap.2021.106223. Epub 2021 Jun 10. PMID: 34119819.
2. Dittman Z, Munia TTK, Aviyente S. Graph Theoretic Analysis of Multilayer EEG Connectivity Networks. Annu Int Conf IEEE Eng Med Biol Soc. 2021; 2021: 475–9. DOI: 10.1109/EMBC46164.2021.9629514. PMID: 34891336
3. 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.
4. 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. DOI: 10.1186/1743-0003-5-25. PMID: 18990257; PMCID: PMC2605581.
5. Hecker L, Rupprecht R, Tebartz Van Elst L, Kornmeier J. ConvDip: A Convolutional Neural Network for Better EEG Source Imaging. Front Neurosci. 2021; 15: 569918. DOI: 10.3389/fnins.2021.569918. PMID: 34177438; PMCID: PMC8219905.
6. Escaffre O, Borisevich V, Rockx B. Pathogenesis of Hendra and Nipah virus infection in humans. J Infect Dev Ctries. 2013; 7 (4): 308–11. Available from: https://doi.org/10.3855/jidc.3648.
7. Wang GF, Li W, Li K. Acute encephalopathy and encephalitis caused by influenza virus infection. Curr Opin Neurol. 2010; 23 (3): 305–11. Available from: https://doi.org/10.1097/wco.0b013e328338f6c9.
8. Roy D, Ghosh R, Dubey S, Dubey MJ, Benito-León J, Kanti Ray B. Can Neurological and Neuropsychiatric Impacts of COVID-19 Pandemic. J Neurol Sci. 2021; 48 (1): 9–24. Available from: https://doi.org/10.1017/cjn.2020.173
9. Song E, Zhang C, Israelow B, Lu-Culligan A, Prado AV, Skriabine S, et al. Neuroinvasion of COVID-19 in human and mouse brain. J Exp Med. 2021; 218 (3): e20202135. Available from: https://doi.org/10.1084/jem.20202135
10. Moriguchi T, Harii N, Goto J, et al. A first case of meningetis/encephalitis associated with SARS-Coronavirus-2. Int J Infect Dis. 2020; 94: 55–58. Available from: https://doi.org/10.1016/j.ijid.2020.03.06
11. Ye M, Ren Y, Lv T. Encephalitis as a clinical manifestation of COVID-19. Brain Behav Immun. 2020; S0889–1591 (20): 30465–7. Available from: https://doi.org/10.1016/j.bbi.2020.04.017.
12. Duong L, Xu P, Liu A. Meningoencephalitis without respiratory failure in a young female patient with COVID-19 infection in Downtown Los Angeles, early April 2020. Brain Behav Immun. 2020; 87: 33. Available from: https://doi.org/10.1016/j.bbi.2020.04.024.

13. Helms J, Kremer S, Merdji H, Clere-Jehl R, Schenck M, Kummerlen C, et al. Neurologic Features in Severe COVID-19 Infection. N Engl J Med. 2020; 382 (23): 2268–70. Available from: https://doi.org/10.1056/NEJMc2008597.
14. Puelles VG, Lütgehetmann M, Lindenmeyer MT, Sperhake JP, Wong MN, Allweiss L, et al. Multiorgan and Renal Tropism of COVID-19. N Engl J Med. 2020; 383 (6): 590–2. Available from: https://doi.org/10.1056/NEJMc2011400.
15. Solomon IH, Normandin E, Bhattacharyya S, Mukerji SS, Keller K, Ali AS, et al. Neuropathological Features of Covid-19. N Engl J Med. 2020; 383 (10): 989–92. Available from: https://doi.org/10.1056/NEJMc2019373.
16. Troyer EA, Kohn JN, Hong S. Are we facing a crashing wave of neuropsychiatric sequelae of COVID-19? Neuropsychiatric symptoms and potential immunologic mechanisms. Brain Behav Immun. 2020; 87: 34–39. Available from: https://doi.org/10.1016/j.bbi.2020.04.027
17. Rogers JP, Chesney E, Oliver D, et al. Psychiatric and neuropsychiatric presentations associated with severe coronavirus infections: a systematic review and meta-analysis with comparison to the COVID-19 pandemic. Lancet Psychiatry. 2020; 7 (7): 611–27. Available from: https://doi.org/10.1016/S2215-0366(20)30203-0.
18. Kubota T, Gajera PK, Kuroda N. Meta-analysis of EEG findings in patients with COVID-19. Epilepsy Behav. 2021; 115: 107682. Available from: https://doi.org/10.1016/j.yebeh.2020.107682.
19. Petrescu AM, Taussig D, Bouilleret V Electroencephalogram (EEG) in COVID-19: A systematic retrospective study. Neurophysiol Clin. 2020; 50 (3): 155–65. Available from: https://doi.org/10.1016/j.neucli.2020.06.001.
20. Pinto TCC, Machado L, Bulgacov TM, Rodrigues-Júnior AL, Costa MLG, Ximenes RCC, et al. Is the Montreal Cognitive Assessment (MoCA) screening superior to the Mini-Mental State Examination (MMSE) in the detection of mild cognitive impairment (MCI) and Alzheimer's Disease (AD) in the elderly? Int Psychogeriatr. 2019; 31 (4): 491–504. Available from: https://doi.org/10.1017/S1041610218001370.
21. Mishkin M, Ungerleider LG. Contribution of striate inputs to the visuospatial functions of parieto-preoccipital cortex in monkeys Behav Brain Res. 1982; 6 (1): 57–77. Available from: https://doi.org/10.1016/0166-4328(82)90081-x.
22. 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.
23. Michel CM, Koenig T. EEG microstates as a tool for studying the temporal dynamics of whole-brain neuronal networks: A review. Neuroimage. 2018; 180 (Pt B): 577–93. Available from: https://doi.org/10.1016/j.neuroimage.2017.11.062.
24. Van De Ville D, Britz J, Michel CM. EEG microstate sequences in healthy humans at rest reveal scale-free dynamics Proceedings of the National Academy of Sciences. 2010; 107 (42): 18179–84; Available from: https://doi.org/10.1073/pnas.1007841107.
25. 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
26. Vitali P, et al. Integration of multimodal neuroimaging methods: a rationale for clinical applications of simultaneous EEG-fMRI Funct Neurol. 2015. PMID: 26214023.
27. 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.