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FREQUENCY VARIATION OF ALPHA-BAND OSCILLATIONS ON THE ELECTROENCEPHALOGRAM OF HEALTHY SUBJECTS

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Abstract. ***Introduction.*** Alpha activity is the dominant rhythm of the brain, formed by 14–16 years of age with an individual stable frequency for each person, on average about 10 Hz. Fluctuations of the alpha range, on the one hand, reflect the activity of inhibition processes in the brain, on the other hand, are associated with the potential ability of the brain to cognitive activity. ***The aim of the study*** was to investigate the peculiarities of the frequency characteristics of the alpha rhythm and its representation in occipital electroencephalogram (EEG) recording points in a population of practically healthy adults in the north-west of Russia. ***Materials and methods.*** EEG was registered in practically healthy adult population of St. Petersburg (n=106), 62 women and 44 men. The mean age of the subjects was 44.5 (SD=17.7). EEG was recorded according to the International system “10-20”. The software and hardware complex “Mizar-EEG-202” (Russia) was used in the work. Statistical processing was carried out in SPSS program, version 27. ***Results.*** Reduction of the average frequency of alpha rhythm in occipital leads of both hemispheres up to 9 Hz, reduction of its representation in occipital leads up to 13–15% was established. Decrease of alpha rhythm frequency is more characteristic for young age (less than 40 years) — 8.83±0.21 Hz. ***Conclusion***. New peculiarities of functional activity of the brain in the form of alpha rhythm frequency reduction and loss of its dominance in occipital leads have been revealed, which is considered as a change in inhibitory activity of the brain and related disturbance of sensory processing of signals.

Keywords: electroencephalography, alpha rhythm, alpha activity, human brain biorhythms, bioelectrical brain activity, cognitive brain activity https://doi.org/10.56871/RBR.2025.52.46.002

ЧАСТОТНАЯ ВАРИАТИВНОСТЬ КОЛЕБАНИЙ АЛЬФА-ДИАПАЗОНА НА ЭЛЕКТРОЭНЦЕФАЛОГРАММЕ ЗДОРОВЫХ ЛЮДЕЙ

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Резюме. ***Введение.*** Альфа-активность является доминирующим ритмом головного мозга, формируется к 14–16 годам с индивидуальной стабильной частотой для каждого человека в среднем около 10 Гц. Колебания альфа-диапазона, с одной стороны, отражают активность процессов торможения в головном мозге, с другой стороны, связаны с потенциальной способностью головного мозга к когнитивной деятельности. ***Цель исследования —*** изучение особенностей частотных характеристик альфа-ритма и его представительство в затылочных точках регистрации электроэнцефалограммы (ЭЭГ) в популяции практически здорового взрослого населения Северо-Запада России. ***Материалы и методы.*** Регистрировали ЭЭГ у практически здоровых взрослых жителей г. Санкт-Петербурга (n=106), из них 62 женщины, 44 мужчины. Средний возраст обследованных составил 44,5 года (SD=17,7). ЭЭГ регистрировали по стандартной международной схеме «10-20». В работе использовался программно-аппаратный комплекс «Мицар-ЭЭГ-202» (Россия). Статистическая обработка проводилась в программе SPSS, версия 27. ***Результаты.*** Установлена редукция средней частоты альфа-ритма в затылочных отведениях обоих полушарий до 9 Гц, уменьшение его представительства в затылочных отведениях до 13–15%. Снижение частоты альфа-ритма более характерно для молодого возраста (менее 40 лет) — 8,83±0,21 Гц. ***Выводы***. Выявлен ряд особенностей функциональной активности головного мозга в виде редукции частоты альфа-ритма и утраты его доминирования в затылочных отведениях, что расценивается изменением тормозной активности головного мозга и связанным с этим нарушением сенсорной обработки сигналов.

Ключевые слова: электроэнцефалография, альфа-ритм, альфа-активность, биоритмы мозга человека, биоэлектрическая активность мозга, когнитивная активность мозга

INTRODUCTION

A hundred years have passed since Hans Berger (1873–1941), the pioneer of modern electroencephalography (EEG), defined alpha activity as a rhythmic component of the EEG with a frequency ranging between 8 and 12 Hz, and noted that alpha oscillations have maximum amplitude in the occipital region of the cortex and decrease in amplitude when the eyes are opened and during various cognitive tasks [1]. Many decades have been devoted to studying the mechanisms of alpha rhythm generation and their frequency-amplitude characteristics. Currently, these issues have received less attention, giving way to quantitative studies with complex computer analysis [2, 3].

For example, it has been established that alpha rhythm depression can be caused not only by the presentation of recognizable stimuli, but also before their presentation, if the subject knows that he will soon be presented with a task that requires a solution [4]. In children and adults, a decrease in alpha rhythm power is observed when anticipating tactile and visual stimuli. At the same time, variability in anticipatory alpha lateralization (a change in the left-right asymmetry of alpha rhythm distribution) in subjects was associated with a single training session. This relationship was more pronounced in adults than in children and was not evident for auditory stimuli. Anticipation is proposed as a developmental bridge connecting neurology, behavior, and cognitive abilities, with anticipatory EEG oscillations discussed as quantitative and potentially flexible indicators of stimulus prediction [5]. At the same time, the power of alpha oscillations in the background and during the anticipation of a stimulus that is to follow is significantly higher in people capable of effective self-control and lower in patients with impulsive personalities [6].

The theory of functional suppression asserts that a reduction in alpha band power provides control of attention by selectively suppressing neural representations that are not relevant to the task at hand. This assumption has been well supported by decades of correlational studies showing attention-related changes in alpha power topography in anticipation of task-related stimuli, and is a viable theory of how attention influences sensory processing, namely through changes in alpha power in sensory areas prior to stimulus onset [7].

When performing tasks involving the comparison of two different stimuli, an interesting dynamic change in alpha power is observed, showing that the alpha rhythm increases at the beginning and in the middle of the presentation of stimuli for comparison. When presenting short stimuli, the alpha rhythm power generally increases throughout the analysis period, whereas for long stimuli, on the contrary, it decreases. This may indicate a weakening of the evaluation process if it is prolonged [8]. In the analysis of visual stimuli, higher alpha frequencies were associated with improved segmentation of visual events over time, while lower alpha frequencies were associated with improved temporal integration [9].

Based on the hypothesis of the separation of a whole family of alpha rhythms, it has been shown that alpha rhythms with specific frequency intervals are specific to the modality of sensory signals. Thus, alpha rhythms with a frequency of 7–9 Hz are related to somatosensory sensitivity, those with a frequency of 9–12 Hz to visual analysis, and those with a frequency of 12–13 and 7–9 Hz to auditory perception. Dipole sources of alpha rhythm with a specific frequency equivalent to the frequencies indicated are recorded addressively in the primary sensory area of the cortex [10]. Changes in the power of the alpha signal on electrodes O1 and O2 during intermittent photostimulation allow for a quantitative assessment of cortical hyperexcitability, which can be used in epilepsy and other diseases [11].

However, it is not only sensory models of central nervous system (CNS) functioning that are associated with alpha rhythms on EEG. For example, one study showed an increase in the average power of the alpha rhythm in the contralateral areas of the motor cortex proportional to the increase in grip strength in stroke patients during rehabilitation exercises, which may be important for assessing the progress of rehabilitation measures in patients [12].

Attempts to link task performance with changes in alpha rhythm have so far been unsuccessful. For example, a study by our colleagues showed that the correlation between the grades received by students and the frequency of alpha rhythm was very weak. However, when comparing the individual activity indicators of the left and right hemispheres, it was found that in most of the test groups of “excellent” and “poor” students, the alpha rhythm amplitude in the left hemisphere prevailed: in 71% of successful students and in 69% of less successful students. In addition, the alpha rhythm amplitude in the left and right hemispheres was greater in successful subjects than in less successful ones [13]. A number of authors suggest approaching the presentation of the material being studied on an individual basis, linking its temporal characteristics to the individual EEG rhythm frequency. It has been shown that individual frequency engagement of the brain leads to faster learning of visual identification tasks (i.e., detecting targets hidden in background clutter) compared to engagement that does not match the individual's alpha frequency [14].

Quantitative EEG analysis is a suitable tool for assessing mental fatigue. An increase in alpha rhythm power has been shown during prolonged tasks in individuals who met the criteria for greater fatigue. In children in a similar situation, an increase in alpha rhythm power is associated with behavioral disorders when performing excessive mental tasks [9].

Regarding alpha rhythm lateralization, it can be added that when our attention shifts to the left or right, the balance of waves in the left and right hemispheres of the brain changes. This is especially true for the pattern of electrical activity known as the alpha wave [15]. This asymmetry is thought to reflect the concentration of one side of the brain on relevant input, while the other suppresses distractions from the environment [16]. The asymmetry of EEG alpha power in the frontal lobes of the brain has been actively studied over the past 30 years as a potential marker of emotional and motivational states. However, most studies are based on prolonged manipulations in which participants are placed in situations that provoke anxiety. A relatively small number of studies have examined alpha asymmetry in response to briefly presented emotionally charged stimuli. For example, threatening images and faces caused a redistribution of alpha power with the formation of right asymmetry [17]. Frontal alpha asymmetry has been studied since the late 1970s as a neural correlate of emotion regulation and motivational processes. It is often considered a reflection of individual differences in positive or negative emotionality and a predisposing factor for approach or avoidance motivational processes. Moreover, frontal alpha asymmetry changes over time, and how it changes over time depends on individual experience and development [18].

It has been proven that the decrease in alpha power in the occipital-parietal region is not a passive consequence of activation, but serves to improve perceptual sensitivity and increases the amount of information that can be deciphered from patterns of neural activity. In addition, fluctuations in the alpha band immediately before stimulus presentation modulate the accuracy of subsequent responses. Taken together, it has been shown that the dynamics of fluctuations in the alpha band modulate sensory signals of interest more strongly than noise [19].

It has been shown that creative thinking, as well as the performance of creative tasks, has clear electrographic biomarkers. Neurophysiological studies note high synchronization of the alpha rhythm in people engaged in creative interpretation of events. However, other high-frequency components, in addition to the alpha band, such as beta and gamma, can also be used for assessment. Interestingly, during divergent thinking, the subjects demonstrated alpha synchronization along with beta and gamma desynchronization, a more pronounced shift in the spectral power of the alpha signal to the left hemisphere. During convergent thinking, the opposite pattern was observed: desynchronization of the alpha rhythm and an increase in the beta and gamma rhythms, which allows us to take a fresh look at the complex physiological features of the creative process [20].

Scientists have discovered that at a young age, around 18–20 years old, a turning point occurs: before this age, the spectral power in the alpha range increases on average in healthy subjects, and after this age, probably due to functional inhibition, there is a decrease in alpha rhythm power, especially in its low-frequency part, which may indicate a marker of the maturation of empathic abilities [21].

No significant differences in spectral power in the alpha band have been described at the occipital electrodes (O1 and O2), but spectral power in the alpha band may be reduced at the temporal and parietal electrodes. There was also a tendency toward a decrease in the individual frequency of alpha episodes, which is more characteristic of people who suffer from periodic headaches [22].

A number of authors argue that computer analysis of EEG with the addition of artificial intelligence can reliably prove schizophrenic thinking in psychiatric patients [23].

In comprehensive methods of psychophysiological assessment of humans, technologies can be applied that allow for the objective identification of emotional responses to questions using artificial intelligence and programmable neural networks, which are primarily used to analyze recorded EEG [24].

In people with specific speech disorders, the spectral power of the alpha rhythm was statistically significantly lower than in healthy individuals in the area of the left temporal (T5) and occipital electrodes (O1, O2) when their eyes were closed. With their eyes open, the subjects demonstrated significantly lower spectral power of the alpha rhythm in the left temporal (T3, T5), parietal (P3, Pz), and occipital electrodes (O1, O2) [25].

Patients with cognitive impairment show an imbalance between cortical inhibition and excitation, including changes in alpha band activity (in some cases leading to epileptiform activity), and these changes correlate well with established biomarkers of neurodegeneration and cognitive impairment [26]. It has been shown that the neurophysiological mechanisms of synchronization of brain neural oscillations, which regulate cortical excitation, are reflected in the alpha rhythm index. The latter decreases in elderly people with moderate cognitive impairment and is accompanied by an increase in the delta band index [27].

Thus, a large body of contemporary research over the past five years has been devoted to changes in alpha rhythm during sensory and motor manifestations of CNS functioning using complex computer analysis methods. The study of the basic characteristics of the alpha rhythm at rest, especially using classical methods (frequency, amplitude, indices), is considered unpromising, long known, and well established. However, descriptions of such characteristics, often used as normative, serving as a starting point for comparison with patient data, may be outdated. We thought it would be promising to conduct a new study, processing information about the analysis of basic alpha rhythm indicators on the EEG of healthy subjects in the modern world.

AIM

To study the characteristics of alpha rhythm frequency responses and their distribution across the convexity surface in a population of practically healthy adults in North-West Russia.

MATERIALS AND METHODS

The functional diagnostics department of St. Petersburg State Budgetary Healthcare Institution "Psychoneurological Dispensary No. 1" conducted a study of practically healthy residents of St. Petersburg (n=106), including 62 women and 44 men, who underwent professional medical examinations. The average age of the subjects was 44.5 years (SD=17.7).

The EEG was recorded according to the standard international "10-20" scheme using the "Mitsar-EEG-202" software and hardware complex (Russia). A 16-channel EEG was recorded using bridge electrodes in physiological solution with a standard EEG helmet. The background EEG was recorded in conditions of muscle relaxation (in a dental chair), silence, darkness, and with eyes closed. The EEG was recorded in 16 monopolar leads (Fp1, F3, F7, C3, T3, T5, P3, O1, Fp2, F4, F8, C4, T4, T6, P4, O2) with a reference electrode at an electrically neutral point on the subject's cheekbone. Recording and analysis were performed using WinEEG 2.14 software at a speed of 30 mm/s, with a sensitivity of 50 μV/cm and a high-frequency filter (45–55 Hz) enabled to eliminate electro-tonic artifacts. Background recording was performed for at least 3 minutes, and a 10-second fragment was selected for analysis, which was as free as possible from various electrogenic and myogenic artifacts with a visually pronounced alpha rhythm dominant. Variants of EEG obtained without alpha rhythm manifestation, with beta-1 activity predominance, "flat EEG", as well as recordings with pathological graphoelements, were not included in the analysis. The frequency and amplitude of the alpha rhythm were calculated using quantitative EEG processing methods. We determined the spectral power in the alpha range using an algorithm built into the WinEEG program. Automatic software calculation was performed with the following settings: analysis epoch duration of 4 s, epoch overlap of 50%, Hann time window, artifact removal for the average spectrum — polynomial trend of order 2, low-frequency signal with a power of more than 200 μV in the range from 0.5 to 1.25 Hz.

In most cases, the data obtained obeyed the law of normal distribution, so Student's t-test for independent samples was used for statistical data processing. The critical level of significance (p) in our work was taken to be 0.05. If the distribution differed from normal, Mann–Whitney criteria were used. In order to identify relationships between age, gender characteristics, and functional brain status, a correlation analysis was performed for all observations (n=106). Statistical processing was performed using SPSS version 27.

RESULTS

The results of the studies revealed (Table 1) that the average alpha rhythm frequency in the adult population ranges from 8.81±0.13 Hz (lead F8) to 9.37±0.17 Hz (lead C4) in the recorded leads. For occipital leads, the alpha rhythm frequency was 9.19±0.15 Hz and 9.04±0.14 Hz for the left and right hemispheres, respectively. A comparative analysis of our values with the data of a number of authors [28–31], who indicated an average alpha rhythm value of at least 10 Hz, showed significant differences at $p < 0.001$.

There was no significant difference in alpha rhythm frequency between men and women.

When studying EEG indicators in age groups, it was found that in young people (under 40 years of age), the alpha rhythm frequency in the left occipital lead O1 was 8.83±0.21 Hz, which is significantly lower ($p = 0.031$) than in older people (40 years and older) — 9.47±0.20 Hz. Correlation analysis showed a weak positive correlation between the alpha rhythm frequency in the O1 lead and age: $r = 0.245$ ($p < 0.05$).

The percentage representation of the alpha rhythm in the occipital leads was 13.59±1.24% and 13.90±1.19% for the left and right hemispheres, respectively (Fig. 1). No differences were found by gender or age (Table 2).

DISCUSSION

Our study identified a number of trends in the neurofunctional activity of the brain in residents of St. Petersburg. For example, there was a decrease in the average alpha rhythm frequency (Fig. 2) in the occipital leads of both hemispheres. The vast majority of researchers indicate an average alpha rhythm frequency of at least 10 Hz. A decrease in this indicator to 9 Hz indicates a restructuring of brain functional activity, possibly associated with an increase in information flows. We suggest that the current trend of an avalanche-like increase in sensory signals, including those from gadgets, leads to neural network overload and a decrease in alpha rhythm frequency.

There is a hypothesis that the frequency of the alpha rhythm reflects the level of "cognitive readiness", i.e., the

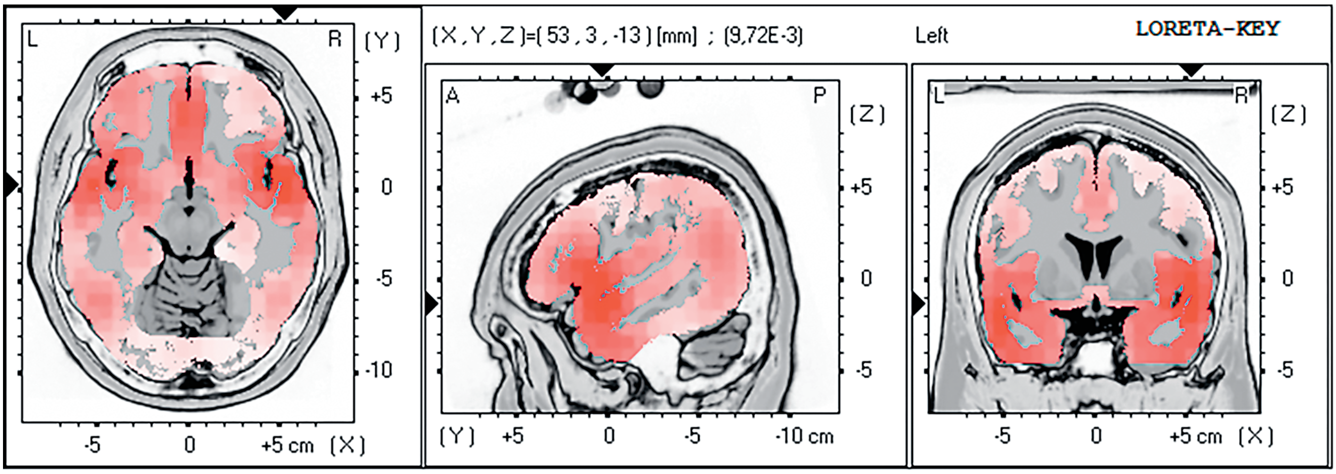

Fig. 1. **A 45-year-old man, diffuse distribution of alpha rhythm without dominance in occipital leads on SLoreta is seen**

Рис. 1. **ЭЭГ мужчины, 45 лет, видно диффузное распределение альфа-ритма без доминирования в затылочных отведениях на SLoreta**

Table 1

Comparative characterization of oscillation frequency in the alpha range (M±m)

Таблица 1

Сравнительная характеристика частоты колебаний в альфа-диапазоне (M±m)

Отведение / Lead	Частота альфа-ритма, Гц / Alpha rhythm frequency, Hz				
	все наблюдения / all observations n=106	женщины / women n=62	мужчины / men n=44	возраст <40 лет / age <40 years n=46	возраст ≥40 лет / age ≥40 years n=60
Fp1	8,91±0,15	8,77±0,18	9,10±0,25	8,86±0,20	8,95±0,21
Fp2	8,96±0,14	8,91±0,18	9,03±0,23	8,95±0,21	8,97±0,19
F3	9,11±0,17	9,02±0,22	9,24±0,25	9,07±0,25	9,15±0,22
F4	9,12±0,15	9,19±0,19	9,03±0,24	9,21±0,25	9,05±0,18
F7	9,19±0,17	9,18±0,22	9,19±0,28	9,08±0,24	9,27±0,24
F8	8,81±0,13	8,79±0,18	8,82±0,18	8,82±0,18	8,80±0,18
C3	9,04±0,16	9,04±0,21	9,05±0,23	8,90±0,21	9,16±0,22
C4	9,37±0,17	9,46±0,24	9,23±0,23	9,48±0,24	9,28±0,23
T3	8,93±0,14	9,05±0,18	8,76±0,20	8,98±0,24	8,89±0,16
T4	8,85±0,14	9,00±0,20	8,63±0,21	9,13±0,24	8,64±0,17
T5	8,83±0,15	8,82±0,19	8,85±0,24	8,61±0,19	9,00±0,21
T6	9,13±0,17	9,28±0,23	8,91±0,23	9,40±0,24	8,92±0,23
P3	9,29±0,17	9,59±0,23	8,87±0,23	9,07±0,25	9,46±0,23
P4	9,04±0,15	9,25±0,21	8,74±0,22	9,47±0,26	8,71±0,18
O1	9,19±0,15	9,35±0,21	8,96±0,21	8,83±0,21*	9,47±0,20
O2	9,04±0,14	9,12±0,20	8,93±1,26	9,07±0,22	9,02±0,19

* p=0,031 — reliability of differences with the indicators of the group “age ≥40 years”.

* p=0,031 — достоверность различий с показателями группы «возраст ≥40 лет».

Table 2

Comparative characterization of the percentage representation of alpha rhythm in occipital leads (M±m)

Таблица 2

Сравнительная характеристика процентного представительства альфа-ритма в затылочных отведениях (M±m)

Контингент исследуемых / Contingent of the studied	Процентное представительство альфа-ритма, % / Percentage representation of alpha rhythm, %	
	отведение O1 / lead O1	отведение O2 / lead O2
Все наблюдения / All cases of observation, n=106	13,59±1,24	13,90±1,19
Женщины / Women, n=62	14,23±1,66	14,13±1,60
Мужчины / Men, n=44	12,69±1,88	13,57±1,81
Возраст <40 лет / Age <40 years, n=46	14,94±2,16	15,99±1,96
Возраст ≥40 лет / Age ≥40 years, n=60	12,55±1,44	12,29±1,46

Note: O1 — left occipital lead; O2 — right occipital lead.

Примечание: O1 — левое затылочное отведение; O2 — правое затылочное отведение.

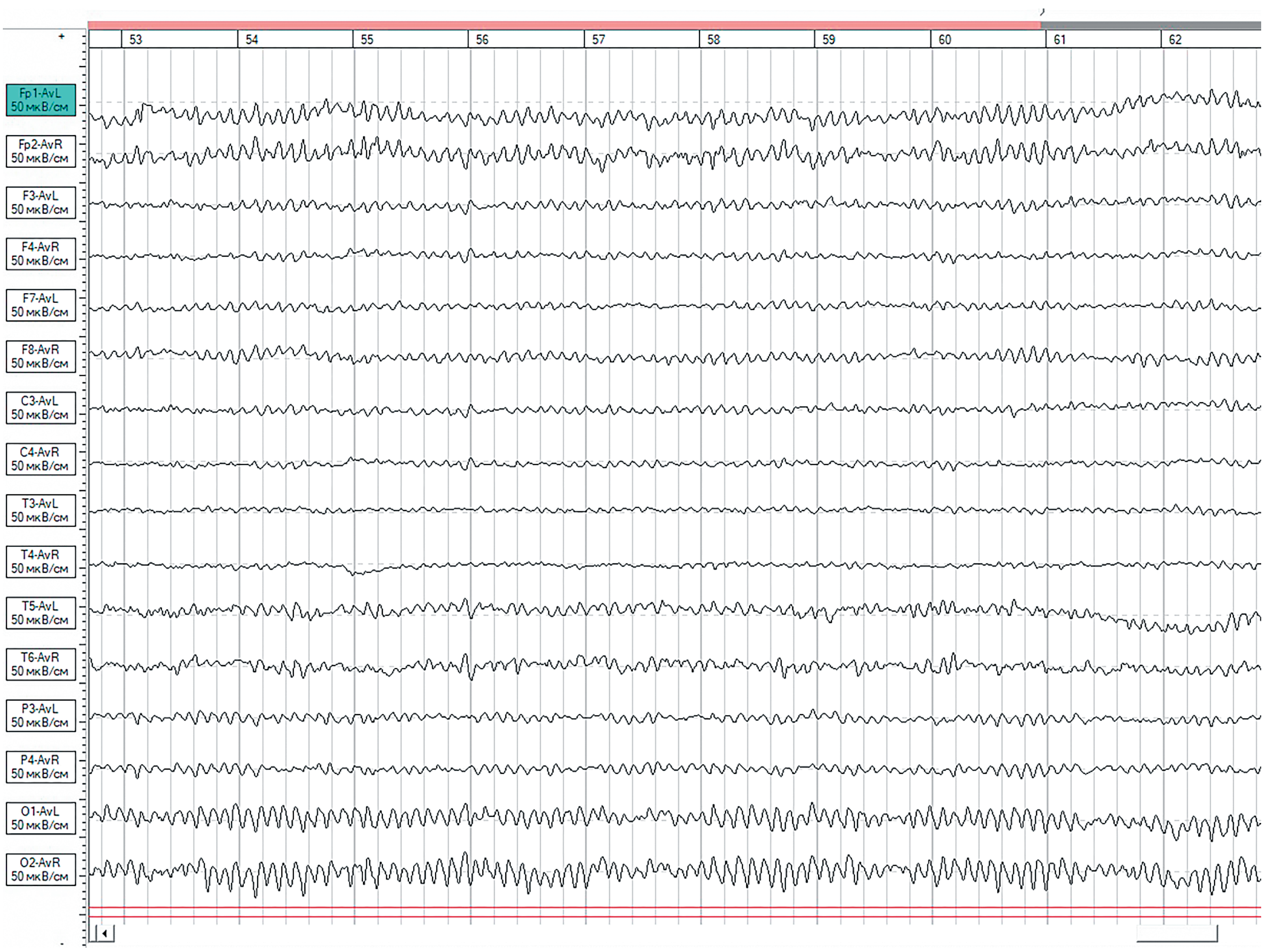

Fig. 2. EEG of a 50-year-old subject, average oscillation frequency 9.4 Hz with diffuse distribution and moderate occipital predominance

Рис. 2. ЭЭГ испытуемой, 50 лет, средняя частота колебаний 9,4 Гц с диффузным распределением и умеренным затылочным преобладанием

potential ability of functioning neural networks to perform cognitive activities [29, 32, 33]. At a high frequency of total electrical oscillations of neural networks, there is a faster alternation of excitation and inhibition phases, which is reflected in a faster speed of sensory information processing [34]. We suggest that the decrease in the frequency of brain electrical activity in the alpha range that we have established indicates a tendency toward a decrease in the speed of information processing by neural networks. It is believed that this phenomenon will lead to an increase in errors in professional activities [31].

A decrease in the alpha rhythm frequency in the left occipital lead in people under 40 years of age (8.83±0.21 Hz) indicates a possible change in the processing of visual signals. Since this trend is significantly more common among young people, who use gadgets to a greater extent, it can be assumed that they have impaired visual perception analysis. Further research is needed to clarify the relationship between changes in alpha rhythm frequency in occipital leads and the recognition of complex visual signals in gadget-dependent individuals.

Alpha band oscillations have so far been dominant in occipital leads during quiet wakefulness [35–39]. Our study revealed a decrease in alpha band representation to 13–15%. Until now, alpha waves have been detected on EEG during quiet wakefulness for up to 50–90% of the recording time. Suppression and blockade of the alpha rhythm (desynchronization reaction) were observed during any nonspecific activation: during sound or light signals or when the subject's attention was heightened. Therefore, as a rule, researchers associated the presence of alpha rhythm with inhibitory processes in the brain and, conversely, the replacement of the alpha band with the beta-1 and beta-2 bands with the activation of neural networks and the predominance of excitation processes. At the same time, inhibition is an active process of information processing that helps to increase the signal-to-noise ratio by suppressing the activity of those neurons that are not involved in signal processing and analysis, thereby helping to ensure optimal excitation of working neurons [40]. Thus, with the decrease in alpha rhythm representation that we obtained, we can expect disturbances in concentration, memory, and retrieval of information from memory — processes in which inhibition is necessary to suppress so-called noise.

The power of alpha oscillations is significantly higher in people capable of effective self-control and lower in subjects with impulsive behavior [6], therefore, a decrease in the power of the alpha band in the population may lead to insufficient control of behavioral and emotional reactions. Further research is needed to confirm these hypotheses.

CONCLUSION

1. In adults who are practically healthy residents of St. Petersburg, there is a decrease in the average frequency of the alpha range of the EEG in all leads of both hemispheres.

2. A decrease in the frequency of the alpha rhythm was recorded in all age groups. The most active decrease was found in people under 40 years of age in the left occipital lead. A reliable positive weak correlation between alpha band frequency and age was established.

3. A decrease in the representation of the alpha band of the EEG in the occipital leads to 14–15% was established. The loss of alpha rhythm dominance indicates an imbalance between excitation and inhibition processes in neural networks.

4. The reduction in alpha rhythm frequency and loss of its dominance indicates a change in the inhibitory activity of the brain and the associated impairment of sensory signal processing.

ADDITIONAL INFORMATION

Author contribution. Thereby, all authors made a substantial contribution to the conception of the study, acquisition, analysis, interpretation of data for the work, drafting and revising the article, final approval of the version to be published and agree to be accountable for all aspects of the study.

Competing interests. The authors declare that they have no competing interests.

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Consent for publication. Written consent was obtained from the patient for publication of relevant medical information within the manuscript.

ДОПОЛНИТЕЛЬНАЯ ИНФОРМАЦИЯ

Вклад авторов. Все авторы внесли существенный вклад в разработку концепции, проведение исследования и подготовку статьи, прочли и одобрили финальную версию перед публикацией.

Конфликт интересов. Авторы декларируют отсутствие явных и потенциальных конфликтов интересов, связанных с публикацией настоящей статьи.

Источник финансирования. Авторы заявляют об отсутствии внешнего финансирования при проведении исследования.

Информированное согласие на публикацию. Авторы получили письменное согласие пациентов на публикацию медицинских данных.

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