О биоэлектрической буферной системе головного мозга

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About bioelectric buffer system of the brain

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Реферат

Цель. Разработка объективного количественного критерия электроэнцефалограммы для оценки функционального состояния головного мозга человека.

Материалы и методы. Проведен анализ фоновых электроэнцефалограмм в 6 группах обследованных пациентов с разными диагнозами (всего 41 пациент). Группу контроля составили 7 человек в возрасте от 20 до 56 лет (средний возраст 35 лет). Запись электроэнцефалограмм проводили при помощи 16-канального электроэнцефалографа «NeuroCom standart» (ХАИ – Медика, Украина) в соответствии с международной системой записи «10–20». Анализировали количество значимых межполушарных асимметрий по мощности сигналов отдельных ритмов и по мощности суммарного биоэлектрического сигнала в билатерально-синхронных точках головы в каждой из групп. Эпоха анализа – 1 мин.

Результаты. Установлено, что наименьшей значимой разницей по мощности биоэлектрического сигнала в билатерально-синхронных точках головы можно считать разницу в 1,4 раза. Количество значимых межполушарных асимметрий у человека может варьировать в большом диапазоне – от 9 до 25. Не все значимые межполушарные асимметрии по мощности сигналов отдельных ритмов сохраняются при анализе значимых межполушарных асимметрий по мощности суммарного биоэлектрического сигнала. Межполушарные асимметрии по мощности суммарного биоэлектрического сигнала в билатерально-синхронных точках головы могут иметь более важное информационное значение, чем межполушарные асимметрии по мощности сигналов отдельных ритмов.

Выводы. Количество значимых межполушарных асимметрий по мощности сигналов отдельных ритмов у здоровых людей может варьировать от 16 до 18. Уменьшение количества межполушарных асимметрий по суммарной мощности биоэлектрического сигнала по сравнению с количеством межполушарных асимметрий по мощности сигналов отдельных ритмов более чем в 4 раза говорит о наличии биоэлектрической буферной системы головного мозга.

Ключевые слова: электроэнцефалограмма; значимые межполушарные асимметрии; биоэлектрическая буферная система головного мозга.

Abstract

Objective. Elaboration of objective quantitative criterion of electroencephalogram for estimation of the brain functional state in man.

Materials and methods. The background electroencephalograms analysis was conducted in 6 groups of the examined patients with various diagnosis (41 patients at all). Control group consisted of 7 patients, ageing 20 – 56 yrs (average age 35 yrs). Recording of EEG was conducted, using 16-channel electroencephalograph «NeuroCom standart» (KhAI – Medika, Ukraine) in accordance to international system of recording «10–20». There were analyzed a quantity of meaningful interhemispheric asymmetries in accordance to power of summarized bioelectric signal in bilateral-synchronous points of the head in every group. The analysis time have constituted 1 min.

Results. There was established, that the least meaningful difference in accordance to the bioelectrical signal power in bilateral-synchronous points of head may be considered in 1.4 times. Quantity of meaningful interhemispheric asymmetries in man may vary in large diapason – from 9 to 25. Not all meaningful interhemispheric asymmetries in accordance to power of signals of separate rhythms are preserved while doing analysis of meaningful interhemispheric asymmetries in accordance to power of a summarized bioelectrical signal. Interhemispheric asymmetries in accordance to power of the summarized bioelectric signal in bilateral-synchronous points of the head may have more important informative meaning, than interhemispheric asymmetry in accordance to the signals power of separate rhythms.

Conclusion. Quantity of meaningful interhemispheric asymmetries in accordance to power of signals of separate rhythms in healthy persons may vary from 16 to 18. The interhemispheric asymmetries quantity reduction in accordance to power of the summarized bioelectric signal, comparing with quantity of interhemispheric asymmetries in accordance to power of signals of separate rhythms more than in 4 times, witnesses presence of the brain bioelectrical buffer system.

Keywords: electroencephalogram; meaningful interhemispheric asymmetries; bioelectrical buffer system of the brain.

Introduction

Inter hemispheric asymmetry (IHA) is one of the fundamental characteristics of the functioning of the human brain [1–9]. The presence of functional asymmetries is reflected in the bioelectric activity of the brain recorded on the scalp surface. One of the main tasks of modern electrophysiology of the

central nervous system (CNS) is the development of diagnostic criteria for the analysis of bioelectric EEG signals and their use to assess the functional state of brain [10–17].

The article is devoted to the study of IHA according to the signal power of individual rhythms of the right and left hemispheres of the brain, as well as to the study of IHA according

to the total signal power at bilaterally synchronous points of the head in people with different functional states.

The IHA was studied according to the power of bioelectric signals in bilaterally synchronous points of the head with a difference of 1.4 times or more. This figure was not chosen by chance. Analysis of the difference in the power values of bioelectric signals in bilaterally synchronous points of the head (8 points) for all rhythms (4 rhythms) in 7 patients (224 values) showed that the largest number of IHA has a value of 1.1 (occurs in 36 cases), 1, 2 (in 32 cases) and 1.3 (in 32 cases). Such IHA values as 1.4, 1.5, 1.6, etc. occurred twice less often – in 18, 14 and 14 cases, respectively. This suggests that such IHA values as 1.1, 1.2 and 1.3 are natural, background characteristics of the bioelectric activity of the brain, and IHA values of 1.4 and more can be regarded as functional asymmetries. Thus, the 1.4-fold difference in the power of the bioelectric signal at bilaterally synchronous points of the head can be considered the minimum significant indicator of IHA, which must be taken into account when comparing the power of the EEG rhythms signals.

The aim of the study was to develop an objective quantitative EEG criterion for assessing the functional state of the human brain.

Materials and methods

The background EEG analysis of 41 people was carried out, which constituted 6 groups of subjects. 7 people were examined with the diagnosis "brain concussion" (BC), 7 people with the diagnosis "syncopal", 7 people were in intensive care in a coma, 8 people were a group of patients with amputation of limb segments (ALS), 5 people with a diagnosis of atherosclerosis obliterating of the lower limbs vessels (AOLLV). The control group consisted of 7 people aged 20 to 56 years (average age 35 years). EEG recording was performed using a 16-channel electroencephalograph "Neuro Com standard" (KHAI-Medica, Ukraine) in accordance with the international recording system "10–20". During the study, the subjects were in a dark screened room in a sitting position with their eyes closed. We determined the signal powers of individual rhythms, the values of the sum of the signal powers of fast (beta + alpha) and slow (theta + delta) rhythms, as well as the values of the total signal powers (beta + alpha + theta + delta) at bilaterally synchronous points of the brain. The number of significant inter hemispheric asymmetries in individual rhythms, the number of significant inter hemispheric asymmetries in terms of the total signal power in bilaterally synchronous points of the head, as well as the number of existing inter hemispheric asymmetries in each of the examined groups were analyzed. The analysis epoch is 1 minute.

Results

As a result of the study, it was found that the number of significant IHA in humans can vary in a wide range – from 9 to 25. In the control group, significant IHA in terms of signal strength of individual rhythms were found in the amount from 16 to 18. In the group of patients with BC, significant IHA was

found in an amount from 11 to 16, in the group of patients with ALS – from 10 to 21, in the group of patients with AOLLV – from 9 to 22, and in the group of patients in coma – from 9 to 25. Thus, the average numbers of significant IHA the subjects of different groups have approximately the same: from 14 to 17. But the ranges of observed significant IHA in different groups of subjects are different. Thus, the smallest range of significant IHA in terms of signal power of individual rhythms, equal to 2, was observed in the group of healthy people – from 16 to 18 IHA. The largest range of significant IHA, equal to 16, was observed in the group of patients in a coma – from 9 to 25 IHA. Such, almost the same number (16..18) of significant IHA in terms of the signal power of individual rhythms and a small range (2), in all subjects of the control group, can be one of the important criteria for assessing the normal functional state of the brain (FSB). At the same time, a low (9) or, on the contrary, a large (25) number of significant IHA in terms of the power of signals of individual rhythms, which occurs in the group of patients in coma, indicates a significant instability of FSB in these categories of subjects, manifested in both a significant decrease and a significant increase in the central nervous system functional lability.

All of the above characteristics relate to the analysis of significant IHA by the power of signals of individual rhythms. Analysis of significant IHA by the total power (alpha + beta + theta + delta) of the generated signal at bilaterally synchronous points of the head showed that the number of significant IHA occurs not four times less (each total analyzed signal corresponds to the four main EEG rhythms), but even less or more. In other words, if on the background EEG of the subject there are 16 significant IHA in terms of the signal power of individual rhythms, and in the total signal power 4 significant IHA is preserved, then we can say that the significant IHA in terms of the signal power of individual rhythms is not compensated by anything. But if the results of the study show that out of 16 significant IHA by the power of signals of individual rhythms, when analyzing significant IHA by the total signal power at bilaterally synchronous points of the head, not 4, but 3 or 2 IHA are observed, this means that at some points of the head the power bioelectric signals of individual rhythms have balanced each other. This phenomenon can be called the brain bioelectric buffer system (BBBS). Thus, if the number of significant IHA according to the power of signals of individual rhythms is divided by the number of significant IHA according to the total power of bioelectric signals, we get a ratio equal, for example, 15: 3 or 5: 1. This means that for such a person, BBBS is 5: 1. That is, five significant IHA for separate rhythms when assessing the total signal power at bilaterally synchronous points of the head give one significant IHA. And, as noted above, if the ratio of 4: 1 indicates that the inter hemispheric asymmetries in the power of individual rhythms are not compensated by anything, then with a ratio of 5: 1 one of every 5 inter hemispheric asymmetries of the brain is fully compensated.

It can be concluded that the greater the ratio of the number of significant IHA for individual rhythm to the number

Table 1. Power values of the main EEG rhythms, their sums and indicators of inter hemispheric asymmetry for these values in the examined E

Points	β , μV^2	IHA	γ , μV^2	IHA	θ , μV^2	IHA	δ , μV^2	IHA	$\beta+\gamma$, μV^2	IHA	$\theta+\delta$, μV^2	IHA	$\beta+\gamma+\theta+\delta$, μV^2	IHA	β/γ
Fp1	51		126		97		358		177		456		632		0.41
Fp2	36	1.4	124	1.01	59	1.7	177	2	160	1.1	235	1.9	395	1.6	0.29
F3	29		66		44		133		95		177		272		0.43
F4	25	1.2	73	1.1	23	1.9	53	2.5	98	1.1	77	2.3	175	1.6	0.34
F7	54		234		80		153		288		233		521		0.23
F8	43	1.3	169	1.4	63	1.3	146	1.1	212	1.4	209	1.1	421	1.2	0.25
T3	72		428		82		134		500		216		716		0.17
T4	80	1.1	703	1.6	79	1.1	146	1.1	783	1.6	225	1.0	1007	1.4	0.11
C3	57		378		39		56		436		95		530		0.15
C4	45	1.3	247	1.5	30	1.3	46	1.2	292	1.5	76	1.2	368	1.4	0.18
T5	169		1818		101		178		1987		279		2266		0.09
T6	173	1.2	2120	1.2	105	1	188	1.1	2293	1.2	292	1.1	2585	1.1	0.08
P3	146		1952		79		151		2098		230		2328		0.07
P4	116	1.3	1702	1.2	76	1.1	201	1.3	1818	1.2	277	1.2	2096	1.1	0.07
O1	198		2954		121		181		3152		302		3454		0.07
O2	239	1.2	3748	1.3	112	1.1	214	1.2	3986	1.3	326	1.1	4312	1.2	0.06

Table2. Power values of the main EEG rhythms, IHA indices by the power of signals of individual rhythms, by the total power of the signal and the coefficient of activation of the cortex in bilaterally synchronous points of the head in subject E

Points	β , μV^2	IHA	γ , μV^2	θ , μV^2	IHA	δ , μV^2	$\beta+\gamma$, μV^2	IHA	$\theta+\delta$, μV^2	$\beta+\gamma+\theta+\delta$, μV^2	IHA	β/γ	IHA
Fp1	51	—	126	97	—	358	177	—	456	632	—	0.41	—
Fp2	36	—	124	59	—	177	160	—	235	395	1.6	0.29	1.4
F3	29	—	66	44	—	133	95	—	177	272	—	0.43	—
F4	25	X	73	23	—	53	98	X	77	175	1.6	0.34	1.3
F7	54	—	234	80	—	153	288	—	233	521	—	0.23	—
F8	43	—	169	63	—	146	212	—	209	421	1.2	0.25	1.1
T3	72	—	428	82	—	134	500	—	216	716	—	0.17	—
T4	80	X	703	79	X	146	783	—	225	1007	1.4	0.11	1.5
C3	57	—	378	39	—	56	436	—	95	530	—	0.15	—
C4	45	—	247	30	—	46	292	—	76	368	1.4	0.18	1.2
T5	169	—	1818	101	—	178	1987	—	279	2266	—	0.09	—
T6	173	—	2120	105	—	188	2293	—	292	2585	1.1	0.08	1.1
P3	146	—	1952	79	—	151	2098	—	230	2328	—	0.07	—
P4	116	—	1702	76	X	201	1818	X	277	2096	1.1	0.07	1.0
O1	198	—	2954	121	—	181	3152	—	302	3454	—	0.07	—
O2	239	—	3748	112	X	214	3986	—	326	4312	1.2	0.06	1.2
Note.	The hyphens in the IHA columns indicate the parallel direction of the decrease in inter hemispheric asymmetry, the X marks indicate the cross direction of the decrease in the hemispheric asymmetry.												

of significant IHA for the total signal power is, the better expressed BBBS is.

Discussion

Let us present a table of the power values of the signals of the main EEG rhythms; their sums, as well as indicators of inter hemispheric asymmetries in terms of the power of signals of individual rhythms and in terms of the total power of bioelectric signals in bilaterally synchronous points of the head (Table 1).

Let us consider the changes in the IHA indices, starting with the values of the asymmetry in terms of the signal power of

individual rhythms, then the values of the IHA in the sum of the signal power of fast and slow rhythms, and finish with the analysis of the IHA according to the total power of the bioelectric signal in the frontal regions F1 and F2 in the examined E.

As seen from the table 1, in the examined E. female patient IHA by the signal power of the beta rhythm in the frontal regions (F1 and F2) was equal to 1.4, by the signal power of the alpha rhythm – 1.0, by the theta rhythm – 1.7 and by the delta rhythm – 2.0.

After summing up the power values of fast (beta + alpha) and slow (theta + delta) rhythms signals, it can be seen that already at this stage, the IHA between the bilaterally synchro-

nous points of the head became less. In terms of the power of signals of fast rhythms (alpha + beta), the IHA became equal to 1.1, and in terms of the power of signals of slow rhythms (theta + delta) – 1.9. And the last IHA value in terms of the total signal power between these parts of the brain became equal to 1.6. Thus, it can be seen that as the powers of the rhythms combine, the IHA value decreases.

The analysis showed that in these parts of the brain, the decrease in IHA is carried out in a parallel direction, that is, the asymmetry gradually decreases from an individual rhythm to the sum of rhythms.

When analyzing the IHA in the examined E. in departments F3 and F4 (Table 2), it can be seen that here a decrease in IHA occurs not only in the parallel, but also in the cross direction.

That is, if the power of the signal of the alpha rhythm is greater on the right at a given point of the head, then in the left hemisphere it is more beta signal strength. When summing up the signal powers the alpha and beta rhythms at these points of the IHA head become less.

The studies carried out indicate that the decrease in MPA from the signal power of a separate rhythm to the total signal power at the investigated point of the head both in parallel and in the cross direction is the result of the work of the bioelectric buffer system of the brain.

The expediency of such an analysis of the generation of bioelectric signals is obvious. When assessing the presence of significant IHA by the power of signals of individual rhythms, we can talk about the functional necessity of the brain to generate at the moment in the left hemisphere, for example, the power of the signal of the alpha rhythm is greater than in the right. But if we consider the presence of significant IHA in terms of the total bioelectric signal power at bilaterally synchronous points of the head, then the preservation of these asymmetries, so to speak, at the “exit”, can be considered not only as a functional necessity, but also possibly of nervous tissue pathology especially if this asymmetry is of great importance.

Conclusions

1. The smallest significant difference in the power of the bioelectric signal in bilaterally synchronous points of the head can be considered the difference in the signal by 1.4 times.

2. The number of significant inter hemispheric asymmetries in terms of the signal strength of individual rhythms in healthy people can be from 16 to 18.

3. In people with a pathological condition (in a coma), the number of significant inter hemispheric asymmetries in terms of the signal power of individual rhythms can be from 9 to 25.

4. IHA in terms of the power of the total bioelectric signal at bilaterally synchronous points of the head is of more important informational value than IHA in terms of the power of signals of individual rhythms.

5. A decrease in the number of IHA by the total power of the bioelectric signal compared to the number of IHA by the power of signals of individual rhythms by more than 4 times, indicates the presence of a bioelectric buffer system of the brain confirmation.

Funding information. Information about This study is a fragment of a planned research work. State budget financing

Conflict of interest. The authors declare that they have no conflicts of interest.

Authors contributions. Makarchuk N.E. – development of the concept and design of research, editing the article; LV Berezovchuk – collection and processing of materials, analysis of the data obtained, writing and formatting of text for printing.

References

1. Bragina NN, Dobrokhotova TA. Human functional asymmetries. Moscow: Medicine; 1988. 284 p. [In Russian]. ISBN 5–225–00102–5.
2. Zhavoronkova LA. Features of the interhemispheric asymmetry of the EEG of right-handers and left-handers as a reflection of the interaction of the cortex and regulatory systems of the brain. In: Bogolepov NN, Fokin VF, editors. Functional interhemispheric asymmetry. Reader. Moscow: Scientific world; 2004. 728 s. [In Russian]. ISBN 5–89176–257–9.
3. Ignatova JP, Makarova II, Zenina OJ, Aksenova AV. Current aspects of functional hemispheric asymmetry studying (literature review). Human Ecology. 2016;(9):30–9. [In Russian]. doi: 10.33396/1728–0869–2016–9–30–39.
4. Knyazeva MG, Farber DA. Formation of interhemispheric interaction in ontogenesis. Electrophysiological analysis. Human physiology. 1991;17(1):5–13. [In Russian]. ISSN: 0131–1646.
5. Leutin VP, Nikolaeva EI. Psychophysiological mechanisms of adaptation and functional asymmetry of the brain. Novosibirsk: Science, SO; 1988 192 p. [In Russian].
6. Leutin VP Functional asymmetry of the brain and adaptation. In: Functional interhemispheric asymmetry: a reader. Moscow: Scientific world; 2004. 481–522. [In Russian]. ISBN: 5–89176–257–9.
7. Fokin VF, Bogolepova IN, Gutnik B, Kobrin VI, Shulgovsky VV. Moscow: Scientific world; 2009. 836 p. [In Russian]. ISBN: 978–5–91522–065–1.
8. Simonov PV. Functional asymmetry of emotions. Reports of the Russian Academy of Sciences. 1994; 338(5):689–695. [In Russian].
9. Yakovenko AI. Interhemispheric asymmetry of the spatial orientation of human cortical potentials in the perception of emotional and indifferent images. Zh Vyssh Nerv Deiat I P Pavlova. 1989;30(6): 221–7. [In Russian].
10. Zenkov LR. Clinical electroencephalography (with elements of epileptology). Moscow: MEDpress–inform; 2002. 368 p. [In Russian]. ISBN 5–901712–21–8.
11. Leutin VP, Nikolaeva EI, Fomina EV. Brain asymmetry and human adaptation. Asymmetry. 2007;1(1): 71–3. [In Russian].
12. Palmiero M, Piccardi L. Frontal EEG Asymmetry of Mood: A Mini-Review. Front Behav Neurosci. 2017;11:224. doi: 10.3389/fnbeh.2017.00224. PMID: 29209180; PMCID: PMC5701669.
13. Park DH, Shin CJ. Asymmetrical Electroencephalographic Change of Human Brain During Sleep Onset Period. Psychiatry Investig. 2017;14(6):839–843. doi: 10.4306/pi.2017.14.6.839. Epub 2017 Nov 7. PMID: 29209389; PMCID: PMC5714727.
14. Moshirian Farahi SM, Asghari Ebrahimabad MJ, Gorji A, Bigdeli I, Moshirian Farahi SMM. Neuroticism and Frontal EEG Asymmetry Correlated With Dynamic Facial Emotional Processing in Adolescents. Front Psychol. 2019;10:175. doi: 10.3389/fpsyg.2019.00175. PMID: 30800085; PMCID: PMC6375848.
15. Sikka P, Revonsuo A, Noreika V, Valli K. EEG Frontal Alpha Asymmetry and Dream Affect: Alpha Oscillations over the Right Frontal Cortex during REM Sleep and Presleep Wakefulness Predict Anger in REM Sleep Dreams. J Neurosci. 2019;39(24):4775–4784. doi: 10.1523/JNEUROSCI.2884–18.2019. Epub 2019 Apr 15. PMID: 30988168; PMCID: PMC6561691.

16. Petrantonakis PC, Hadjileontiadis LJ. A novel emotion elicitation index using frontal brain asymmetry for enhanced EEG-based emotion recognition. *IEEE Trans Inf Technol Biomed.* 2011;15(5):737–46. doi: 10.1109/TITB.2011.2157933. Epub 2011 May 27. PMID: 21622077.
17. Zhao G, Zhang Y, Ge Y, Zheng Y, Sun X, Zhang K. Asymmetric hemisphere activation in tenderness: evidence from EEG signals. *Sci Rep.* 2018;8(1):8029. doi: 10.1038/s41598-018-26133-w. PMID: 29795119; PMCID: PMC5966511.

Надійшла 17.04.20