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ОСОБЕННОСТИ ЭЛЕКТРОЭНЦЕФАЛОГРАММЫ У ЛЕВШЕЙ ПРИ ВООБРАЖЕНИИ И ВЫПОЛНЕНИИ ДВИЖЕНИЙ НОГАМИ

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Актуальность исследования обусловлена недостатком знаний об особенностях программирования и реализации движений у лиц с разными профилями моторного доминирования. Эти знания важны для понимания нейрофизиологических механизмов двигательных функций и создания нейрокомпьютерных интерфейсов. ***Цель работы*** − анализ паттернов электроэнцефалограммы (ЭЭГ) у левшей при воображении и выполнении движений правой и левой ногами. ***Материалы и методы.*** Обследованы студенты-левши, которые с учетом значений коэффициентов моторной асимметрии были разделены на две группы − с низкой (n=14) и высокой (n=7) степенью правополушарного доминирования (НСПД и ВСПД). ЭЭГ у испытуемых регистрировали на нейровизоре «NVX 36 digital DC EEG» в стандартных отведениях в покое и при последовательном воображении и осуществлении движений правой и левой ногой. Анализировали спектральные карты ЭЭГ, по которым определяли типы ЭЭГ, а также оценивали амплитуду сенсомоторного альфа-ритма. ***Результаты.*** Анализ карт спектральной мощности показал, что в покое большинство левшей с НСПД имели I тип ЭЭГ, меньшинство − III тип, тогда как у всех левшей с ВСПД отмечался I тип ЭЭГ. При воображении и осуществлении движений ногами в первой группе увеличивалось количество лиц с III типом ЭЭГ, а у представителей второй группы тип ЭЭГ не менялся. Двигательные задачи вызывали депрессию мю-ритма в центральных и фронтальных отведениях, но с разной выраженностью у левшей с НСПД и ВСПД. Более заметная десинхронизация центрального мю-ритма наблюдалась у левшей с ВСПД, тогда как амплитуда фронтального альфа-ритма, наоборот, сильнее снижалась у левшей с НСПД. ***Заключение.*** Полученные данные свидетельствуют о зависимости паттерна ЭЭГ у левшей при воображении и выполнении двигательных актов ведущей и неведущей ногой от степени доминирования правого полушария головного мозга и могут найти клиническое применение.

Ключевые слова*: электроэнцефалограмма (ЭЭГ), альфа-ритм, мю-ритм, воображение движений, выполнение движений, левши.*

PECULIARITIES OF ELECTROENCEPHALOGRAM OF LEFT-HANDED INDIVIDUALS IN IMAGINATION AND REALIZATION OF FEET MOVEMENTS

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Background. Relevance of the study arises from a lack of knowledge about peculiarities of programming and realization of movements in individuals with different profiles of motor dominance. This knowledge is important for understanding the neurophysiological mechanisms of motor functions and for creating neurocomputer interfaces. ***Aim.*** The analysis of electroencephalo-

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gram (EEG) patterns in lefties during imaginary and real motor acts by right and left legs. ***Materials and Methods.*** The left-handed students were examined. They were divided into two groups on the basis of coefficients of motor asymmetry – with low (n=14) and high (n=7) degree of right-hemisphere dominance (LDRD and HDRD). EEG was recorded on neurovisor «NVX 36 digital DC EEG» in standard leads at rest and in successive imagination and fulfillment of movements by the right and left legs. Types of EEG were determined and the amplitude of the sensorimotor alpha-rhythm (mu-rhythm) was evaluated on the basis of analysis of spectral patterns of EEG. ***Results.*** It was shown that the majority of left-handed individuals with LDRD had type I EEG, and the minority had type III, whereas all left-handed individuals with HDRD had type I EEG. In imagination and realization of leg movements in the first group the quantity of individuals with EEG of type III increased, while in the second group the type of EEG did not change. Motor tasks were associated with depression of alpha-rhythm in central and frontal areas, but with different extent of evidence in lefties with LDRD and HDRD. More pronounced desynchronization of the central mu-rhythm was observed in left-handed individuals with HDRD, while the amplitude of the frontal alpha-rhythm, on the contrary, was more decreased in left-handed individuals with LDRD. ***Conclusions.*** The obtained data show dependence of EEG pattern in left-handed people during imagination and realization of motor acts by the leading and non-leading leg on the degree of the right hemisphere dominance that may find clinical application.

Keywords: *electroencephalogram (EEG), alpha-rhythm, mu-rhythm, imagination of movements, realization of movements, left-handed individuals.*

Specificity of behavior and of physiological functions of a human is determined by numerous factors including individual typological peculiarities of an organism, the most important being the functional asymmetry of hemispheres. Domination of the right or left hemisphere determines the type of thinking activity, emotional status and lateralization of sensory and motor functions [1,2]. An important instrument of studying hemispheric asymmetry is the method of electroencephalography (EEG) used to identify differences between right-handed and left-handed individuals in labor, studying and sporting activity, and also for predicting the course of diseases of the nervous system [3]. Of special importance in the problem of asymmetry is analysis of central mechanisms of construction of motor programs and realization of movements by individuals with different profiles of motor domination [4]. At present intensive study of EEG patterns of not only real, but also of imaginary movements in humans is going on which is important for a deeper understanding of neurophysiological mechanisms of motor functions and for creation of neurocomputer interfaces [5,6]. A significant part of research is dedicated to the role of cerebral cortex in organization of movements of hands mainly in right-handed individuals, whereas much less attention is given to EEG-correlates of motor activity in left-handed ones [3,7]. As to dynamics of rhythms of EEG in movements of legs, information about it is scarce [8], and this aspect is practically not investigated in individuals with different lateralization of motor functions.

Aim of work was analysis of EEG patterns in left-handed individuals in imagination and performance of movements with right and left legs.

Materials and Methods

The study was conducted on a mixed group of healthy left-handed students (n=21) from 18 to 23 years of age. Test subjects gave written informed consent for participation in the experiment, all stages of which were performed with observance of the rules of bioethics, the Protocol of research work was approved by Bioethics Commission of Samara National Research University (Protocol №3 of 10 Feb 2017).

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Individual profile of motor domination was determined by the coefficient of motor asymmetry (coefficient of predomination of the right leg and hand) [7], and taking account its values, two groups of left-handed individuals were formed. The first group (n=14) included individuals with a low degree of right hemisphere dominance (LDRD) with asymmetry coefficients from -16% to -55%, and the second group (n=7) included those with a high degree of right hemisphere dominance (HDRD) and asymmetry coefficients from -56% to -70%.

EEG was recorded on neurovisor «NVX 36 digital DC EEG» in unipolar standard leads with orientation of electrodes according to the international scheme «10-20». A reference (combined ear) electrode was fixed on the right ear lobe. During record of EEG the participants were seated in a comfortable armchair with closed eyes in the room isolated from noise and light. EEG was taken in the initial condition (quiet wake), in imagination of a static muscle effort (pressure on the floor) at first with the right, then with the left foot, and in a real performance of this movement successively with the right and left foot. Duration of the imaginary and real muscle efforts was 12 sec. After that spectral patterns of EEG were analyzed and the type of EEG was determined according to methods [9], and intrahemispherical and interhemispherical differences in the amplitude of alpha rhythm (murhythm) in the central (C3, C4) and frontal (F3, F4) leads were evaluated.

Statistical processing of results was carried out in the program Sigma Plot 12.5 (Jandel Scientific, USA). Distribution of data was checked for normality using Normality Test (Shapiro-Wilk). Reliability of variations in the amplitude of alpha rhythm in performing motor tasks in each group was evaluated using t-test, differences between the groups were evaluated using Mann-Whitney Rank Sum Test. Statistically significant were differences at $p<0.05$.

Results and Discussion

At the first step of research a qualitative analysis of EEG patterns was conducted on the basis of spectral patterns of the tested left-handed individuals. It was found that imaginary and real movements of legs in the form of a static muscular effort in individuals with a different extent of dominance of the right hemisphere lead to controversial alterations in EEG activity. This is confirmed by peculiarities of topographic representation of different rhythms in spectral patterns and the corresponding dynamics of EEG types in the tested individuals at rest and in performing motor tasks. Thus, at rest, the majority (71.4%) of left-handers with LDRD had type I EEG, and the rest (28.6%) had type III EEG. According to the conventional classification, type I EEG is characterized by domination of a regular alpha rhythm with well expressed zonal differences, and type III EEG is characterized by a diffused disorganization of rhythms with reduction in the share of alpha waves, enhancement of spectral power of beta rhythm and appearance of low-frequency waves [9]. In the process of imagination of movements with the right and left legs, four individuals of the first group with the initial type I EEG changed to type III. In the process of a real muscular effort, independent of its lateralization, in three individuals type I EEG changed to type III, and in one individual, vice versa, type III changed to type I. Finally, in movement with both dominant and non-dominant leg type I EEG was noted in 57.1%, and type III – in 42.9% of students with LDRD. In the left-handed individuals with HDRD only type I EEG was recorded at rest and remained the same both in imagination and in performance of the movements. That is, spatial redistribution of spectral power of EEG in imagination and performance of movements with legs is more characteristic of left-handers with LDRD. Differences in power spectrum of EEG rhythms in left-handed individuals with LDRD and HDRD before and during performance of one of motor tasks are shown in Figure 1.

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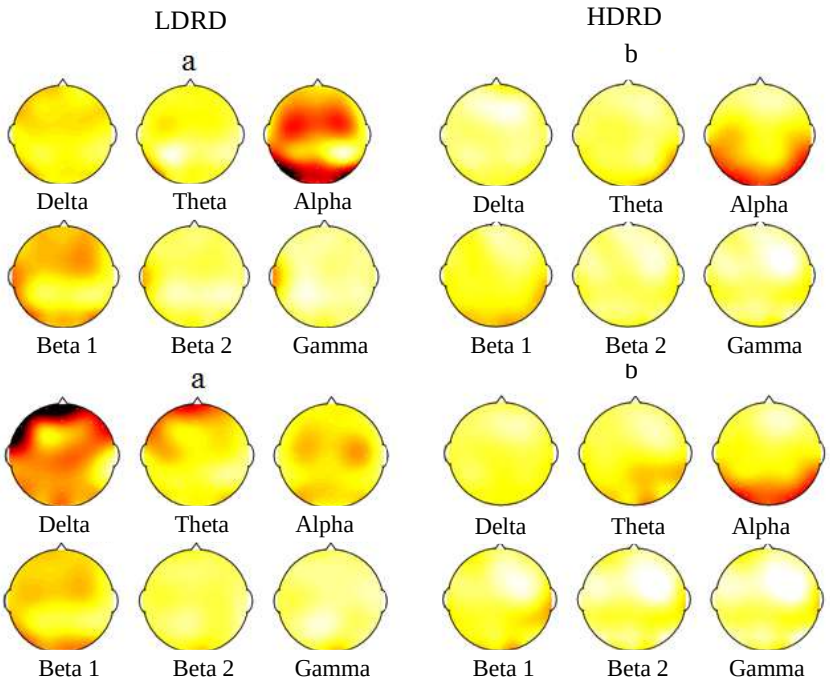

Fig. 1. Examples of spectral patterns of EEG typical of left-handed individuals with LDRD and HDRD at rest (a) and in tension of muscles of the left leg (b)

The results of analysis of spectral patterns permit to suggest that the type of EEG in left-handers is determined by the extent of functional interhemispherical asymmetry. Here, of interest is existence among left-handers with LDRD of individuals having type III EEG not only in imagination and performance of motor acts, but also at rest. Theta and delta rhythms characteristic of this type of EEG are considered to be the basic rhythms of limbic origin conditioned by cortico-hippocampal connections and by activation of the system of behavioral inhibition [10]. Predomination of slow-wave rhythms in the frontal lobes of test subjects may be regarded as a correlate of emotional tension and alarm [10,11] with the probably higher level in left-handers with LDRD. It is interesting that the general picture of the brain activity in spectral patterns of both groups of left handed individuals showed little dependence on lateralization of imaginary and real movements of legs. This fact agrees with the results of research works conducted on right-handed individuals, the majority of which showed practically the same EEG pattern in imagination of movements by fingers of the left and right hands [5].

The existence of peculiarities of rhythmic activity of the brain in two groups of left-handed individuals in imagination and performance of movements by legs is confirmed by analysis of the amplitude of EEG rhythms (second stage of study). Taking into account literature data about the character and localization of changes in EEG in performing motor tasks [8], we evaluated the amplitude of the central (C3 and C4 leads) and frontal (F3 and F4 leads) alpha rhythm which is considered as a sensorimotor murhythm [6,12]. In the course of analysis some differences were detected in the dynamics of alpha rhythms in left-handed individuals with LDRD and HDRD.

Thus, at rest in left-handers with LDRD, murhythm of low amplitude was recorded (26.10±1.61 μV and 25.97±1.86 μV, respectively). As to left-handers with HDRD, the amplitude of murhythm in C3 and C4 leads at rest was higher ($p<0.05$) and made 47.98±8.01 μV and 35.04±3.01 μV, respectively. Certain differences in alpha rhythm in

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participants with LDRD and HDRD were exhibited even in F3 and F4 leads, however, in contrast to C3 and C4 leads, the amplitude of frontal murhythm at rest was higher ($p<0.05$) in left-handers with LDRD. In particular, in these students in F3 and F4 murhythm was recorded with the amplitude 58.67±7.30 μV and 57.97±12.67 μV, while in the individuals with HDRD the amplitude was 36.37±3.18 μV and 32.62±2.53 μV, respectively. The differences in the initial amplitude of the central and frontal murhythms in two groups of left-handers permit to suggest different levels of the background activity of the respective areas of cortex in the examined individuals. It follows from the obtained data that in the condition of a quiet wake the level of excitation in a somatosensory zone is higher in left-handed individuals with LDRD, and, conversely, the activity of sensorimotor cortex prevails in left-handed individuals with HDRD. The cause of these differences may be peculiarities of the functional condition of the brain determined by organization of central connections, formation of interhemispherical interrelations, expressiveness of motor asymmetry. For example, it is known than dextocerebral individuals differ from sinistocerebral ones by the type of intra- and intercortical relations and have more diffuse representation of some functions in the right and left hemispheres [7].

Differences between students with LDRD and HDRD manifested themselves in alterations in the amplitude of alpha rhythm in response to imaginary and real movements. In particular, in central leads of left-handed individuals with LDRD in fulfillment of motor tests no significant alterations of murhythm were observed, except reduction in its amplitude by 23.2% ($p<0.05$) in the right hemisphere (C4) in imagination of tension of the non-dominating (right) leg. In individuals with HDRD in imaginary and real movements alterations in EEG appeared with higher regularity and were more expressed. In particular, the amplitude of murhythm in them decreased in imagination of a muscle effort by the dominating (left) leg by 37.0% ($p<0.05$) in C3 and by 31.7% ($p<0.01$) in C4. A similar picture was observed in case of a real tension of the left leg when the amplitude in C3 and C4 decreased by 30.9% and 24.5%, respectively ($p<0.05$). In fulfillment of tasks with participation of the non-dominant (right) leg murhythm in left-handers with HDRD reliably decreased only in response to a real action and only in lead C4 (by 29.8%; $p<0.05$). Here, it is worth to note the absence of statistically significant interhemispherical differences in the amplitude of murhythm in symmetrical central leads in fulfillment of motor actions by participants of both groups.

The observed reduction in murhythm in central leads in imagination and fulfillment of actions with legs indicates the effect of desynchronization of EEG and enhancement of functional activity of the neuronal network of somatosensory area responsible for processing of proprioceptive information [13]. The obtained data suggest that in left-handers with HDRD in imagination and fulfillment of movements of legs the somatosensory area is activated more frequently and more strongly than in left-handers with LDRD. Evident desynchronization of murhythm in motor tests of left-handers with HDRD may be probably attributed to better development in them of connections of the cortex with reticular and relay thalamic nuclei that, in the opinion of researchers [14], participate in generation and grouping in EEG rhythms. Some authors believe that a strong suppression of murhythm in central leads is an electrophysiological parameter of kinesthetic imagination of movements [6,8] which is probably better expressed in left-handers with HDRD than in those with LDRD.

Alterations in the amplitude of frontal alpha rhythm in fulfillment of motor tasks also depended on the extent of domination of the right hemisphere (Fig. 2). In left-handers with LDRD a statistically significant depression of murhythm was noted in F3 lead in fulfillment of two tasks (imagination of tension of the right leg and real tension of left

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leg) and in F4 in fulfillment of all the four motor tasks. In individuals with HDRD reactions of murhythms in frontal leads were more rare, namely, in lead F3 in imagination of tension of the left and real tension of the right leg, and in F4 – in imagination of tension of the right and left legs. A characteristic feature was that alterations in the amplitude of murhythm of the right and left hemispheres, like in symmetrical central leads, did not show a statistically significant difference. Of special attention was the fact that in imagination and fulfillment of movements with legs, desynchronization of alpha rhythm in leads F3 and F4 was more expressed in left-handed individuals with LDRD in all motor tasks (Fig. 2). On the one hand, this may reflect a more active involvement of sensorimotor cortical zones into realization of motor tasks in this group of individuals, which agrees with the literature data about activation of the frontal lobe in imagination of complicated and prolonged actions [5]. On the other hand, expressed desynchronization of frontal alpha rhythm in combination with increase in the spectral power of delta- and theta-activity, characteristic of a significant amount of left-handers with LDRD, permits to suggest that processes of imagination and fulfillment of lateralized movements in partial left-handers are accompanied by a notable tension of mental functions.

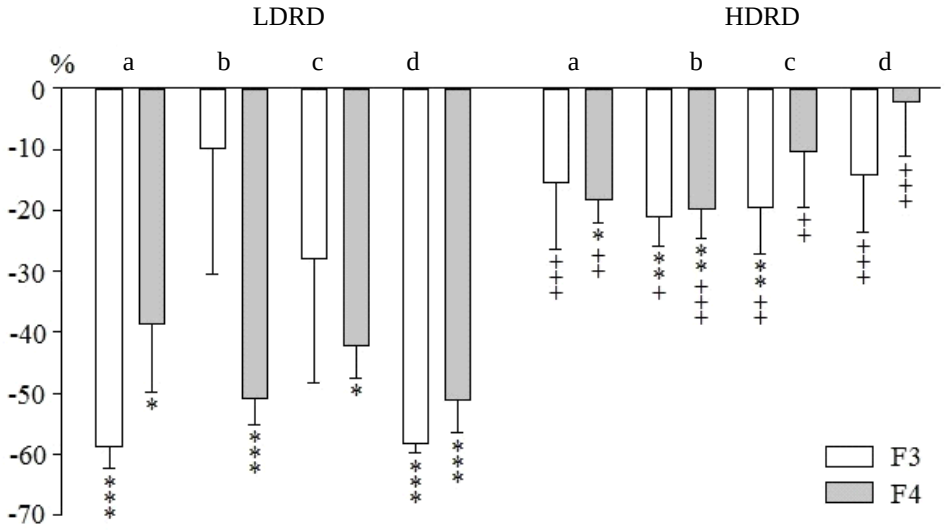

Fig. 2. Alteration (in % relative to rest) of the amplitude of murhythm in F3 and F4 leads in left-handed individuals with LDRD and HDRD in motor tasks (a – imagination of action with the right leg, b – imagination of action with the left leg, c – real action with the right leg, d – real action with the left leg).

Note: *(p<0.05); **(p<0.01); ***(p<0.001) – statistically significant differences from resting condition; +(p<0,05); ++(p<0.01); +++(p<0.001) – statistically significant differences between groups

In evaluation of the observed changes in EEG it should be noted that some studies revealed interhemispherical differences in the sensorimotor murhythm. For example, frequency and amplitude asymmetry of murhythm was found in the central parietal and central frontal areas in movements of wrists of the right and left hands in right-handed and left-handed individuals [3]. In imaginary movements of wrists in right-handers, interhemispherical asymmetry of murhythm was shown in the central cortical zones (C3-C4) in the form of predomination of its power in the left hemisphere, while in F3 and F4 leads no reliable interhemispheric asymmetry of topographic distribu-

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tion of murhythm was noted [12]. Interhemispheric asymmetry found in the examined left-handers in imagination and performance of actions with legs, was not statistically significant ($p>0.05$) both in the central and in the frontal leads with one possible explanation being specific cerebral organization in the individuals with left-sided motility. Thus, characteristic neuroanatomical and functional peculiarities of the brain of left-handers are its lesser asymmetry in comparison with right-handers [1], predomination of synchronous interactions of complementary types between hemispheres as well as between cortical and subcortical structures [7]. Besides, there exists an opinion that explains the absence of lateralization in alterations in EEG patterns by complexity and prolongation of tasks that require a wide activation of cortical zones in symmetrical hemispheres [15].

Conclusion

Thus, electroencephalography patterns in left-handers at rest and in imagination and fulfillment of movements by legs depend on the extent of domination of the right hemisphere which is the factor that determines topographic distribution of power spectrum of electroencephalography rhythms and specific electroencephalography type, and also influences the amplitude of sensorimotor murhythm. Differences in the amplitude of murhythm in the central and frontal leads in imaginary and real movement of legs in left-handers with low and high extent of the right hemisphere domination may reflect different extent of involvement of somatosensory and sensorimotor cortical areas into the mechanisms of programming and realization of motor actions in such individuals. The obtained data contribute to understanding of neurophysiological mechanisms of regulation of voluntary movements in left-handers and may be used in practical purposes.

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