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Criteria for the Synchronization between Neural Networks used in Diagnostics of Functional States of Athletes Bodies

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Abstract

Background: It was the goal of this research to identify individual parameters of criteria for synchronization processes that occurred in various functional body states in athletes who played acyclic sports requiring strong capability for mobilizing body resource.

Materials and methods: 15 athletes have been examined, using Electroencephalography (EEG); 17 subjects of the same age, who practice psychophysical self-regulation relaxation and 19 controls.

Results: Regular synchronization periods have been found on EEG in all the subjectsin more than 50% of the deflections, with a synchronization pattern similar to that of a neural network visually detectible. The synchronization periodicity ranged between 5 and 70 sec, varied between subjects belonging to specific groups and depended on their state (functional test results). The Athlete Group had the highest periodicity, while the Control Group had the lowest one. It is worth noting that accelerated synchronization was detected as subject were doing cognitive test (mental subtraction), with numbers of deflections involved being increased. Alpha-wave generalization that periodically occurred in the wake of a synchronization pattern at the same frequency was observed in all of the subjects when both open-eye and closed-eye EEGs were being recorded. Thesaid generalization was most commonly found in the athletes: synchronization being predominant in the fronto-centro-temporal deflections; the shortest generalization pattern period, prolonged alpha-wave generalization aftera pattern, both of the brain hemispheres being equally involved, etc. We have been first to demonstrate that most of the criteria found in the relaxation groups are parametrically similar to those found in the athletes.

Conclusion: We recommend using our research findings for functional diagnostics and performance prognostication in, e.g., sports. E.g., better resource mobilization found in the Athlete Group by EEG came hand in hand with improved performance in various activities.

Keywords: Electroencephalography • Functional state • Neural network • Brain currents synchronization • Resourcemobilization • Athletes

Introduction

Body functional state assessment is of utmost importance in academic environment, clinics, sports, military training and training other specialists, bioelectric brain activity parameters being the principal criterion for the assessment. As of now, sufficient amounts of findings have been obtained, proving that neuronal activity synchronization is among the principal mechanisms for neuronal synchronization, with the synchronization in question being primarily of rhythmic nature [1,2]. The phase structuring of EEG alpha-wave activity or sync period intermittence – desynchronization – as it is knows to researches, is a sign that respective neural ensembles build up and then become destroyed. According to present-day data on morphofunctional brain organization, large-scale distributed neural networks – ensembles of interacting macroscopic brain structures specific to certain activities – are the structures that control research activities and purposeful behaviors [3]. Those ensembles are dynamical formations, which means that they buildup when preparing to an activity and become destroyed as the activity is finished. The modulation of the force of functional bounds between the future ensemble areas is the principal formative mechanism of the ensembles [4]. Neural bounds specific to an individual are formed as the personality evolves and the brain matures [5]. Research findings of neural network parameters synchronization in alpha-wave are essential to understanding resource mobilization mechanisms to achieve optimal functional state.

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It is known that functional rhythm underlies life cycles, including adaptive processes, in all living beings. The verynature of rhythms is caused both internal mechanisms and environmental impact [6]. Biological currents and life processes caused by them are regulated by various oscillatory brain systems [7,8]. Here, the pivotal role is played by the pineal gland – hypothalamussystem and the key role – by the thalamus [9]. In particular, the very nature of brain rhythms islinked to individual parameters of body self-regulatory mechanisms and plasticity levels of neurodynamical processes [10]. The dynamical organization of distributed neural networks that form in the process of activities is determined not only by goals and the nature of the very activities, but by more rigid species- related (phylogenic modulation) and age-related (ontogenetic modulation) parameters of links between various brain structures [11] – the morphofunctional basis under distributed neural networks.

Plasticity of neurodynamic processes is linked to interactions between cortical areas when in alpha-wave. While performing individual operations, extensive local aggregates of neural cells called neural ensembles form within natural neural networks [12]. Individual parameters of neurodynamic processes plasticity [13] manifest themselves as variations intrinsic to the very nature of rhythms and as synchronizations between bioelectric processes on EEGs from subject to subject. Those facts are backed by research findings of alpha- and beta-wave synchronizations between various cortical areas when functional body state changes [14] which are indicative of a significant role of alpha-waves in cortical synchronization processes [15] and neuroplasticity.

The resource mobilization ability is of great prognostic importance to assessing goal achievement. There exist separate studies of synchronizations occurring in the cortex as an individual does various activities [16,17]. However, the very nature of neural process rhythms and brain current synchronization in age individuals who vary in age and psychophysical state and are capable of instant resource mobilization and consequently, high performance, needs further study. High-profile athletes are an adequate model for theassessment of those processes. It was the aim of this research to identify individual parameters of synchronization criteria in athletes who play acyclic sports and when in various functional states.

Methodology

The Observation Group was made up of 15 subjects – high-profile male athletes (wrestlers, kickboxers); Group 2 was made up of 17 physically unfit subjects of the same age who practiced self-regulation (psychophysical relaxation sessions, PPRS); and the Control Group was made up of 19 subjects of the same age and sex who playedno sport (Group 3). Explained at introductory sessions by an instructor, the PPRS [18] was in doingpsychophysical concentration while achieving a state of relaxation exercises, to be practiced 10 to 15 min daily. We have examined a total of 51 subjects; their average age being 26 ± 4. The researches has been conducted on voluntary informed consent, subject to the Directive of the Declaration ofHelsinki and the minutes approved by the Ethical Committee of the Russian Academy of Sciences.

Electrophysiological method

Synchronization processes were studied by electrophysiological method. Multichannel recording from 16 cup electrodes connected to ear electrodes and placed according to 10-20 system was done by a Neuron Spectra unit manufactured by Neurosoft, Russia. A number of functional tests were performed, namely, taking background EEG records, 30-minute-long Eyes Opening (EO) and Eyes Closing (EC) tests, cognitive test where a subject was to subtract 5 and 2 intermittently within 100 sec, as well as Psychophysical Relaxation Session (PPRS) that involved self-visualization against country landscapes. The EEG sampling rate was 250 Hz. Computer-assisted encephalography included spectral, periodometric, coherent and correlation analysis done by means of the software from the manufacturer company.

The EEG record was automatically being scanned for artifacts that were removed by regression procedure. Areas with amplitudes exceeding 180 µV within a window of 650 µsec were marked as a bad channel, while areas with amplitudes exceeding 140 µV were considered as motion artifacts and those exceeding 60 µV – as visual and muscle artifacts. The EEG data were selected from epochs that corresponded to their respective tests.

At least 2.5 sec-long 20 artifact-free epochs were used to process the EEG records, which provided additional protection against impact from eye and muscle artifacts on EEG spectral records, the frequency step being 0.25 Hz. The artifacts were removed by regression procedure. Spectral analysis was conducted at the EEG frequency ranges: range between 4 and Hz; α range between 8 and 13 Hz; low-frequency β range or $\beta 1$ (13 to 20 Hz); and high-frequency β range or $\beta 2$ (20 to 35 Hz) by using Neuron Spectra. NET software by Neurosoft, Ivanovo, Russia. Spectral power and activity index were found for each of the above frequency ranges.

A spectrogram (Fourier transformation, modulus squared) was found for each EEG epoch. The Fourier transformation was expansion of signals into harmonic series without any information losses. Each of the harmonics was comprised of the three parameters: the amplitude, the initial phase and the frequency. Spectral analysis found that the amplitudes and the phases of the harmonics depended on the frequency [19].

Statistical analysis

Statistical data processing was done by standard IBM SPSS Statistics 22 software suite. As we did statistical processing, the representative samples allowed for applying parametrical analysis to finding confidence intervals by using a 95% confidence probability and the t Student's criterion at $p \leq 0.05$. Non-parametric method for findingthe Spearman's rank correlation coefficient was also used.

Results

Spectral analysis of EEG alpha-wave activity found that EEG areas called analysis epochs could be identified, where synchronization on the same predominant alpha-wave rhythm could be observed in the subjects. The EEG analysis found regular synchronization periods in more than 50% of the deflections (8 to 10 out of 16) in all of thesubjects. Thus, a certain synchronization pattern and its individual differences were discovered within the deflection groups of the cerebral hemispheres.

Thus, a repetitive synchronization that occurred within a limited locality and a variable set of synchronization deflections was discovered in a smaller number of deflections (not exceeding 30%). In EEGs recorded for an hour or longer, synchronization was discovered in 45% deflections of 38 subjects at the same alpha-wave frequency (Table 1). The shape of an EEG of such synchronization is similar to that of a neural network and is periodically rediscovered in all of the subjects. It is the synchronization area regularly occurring in certain deflections that corresponds to the "synchronization pattern". Please refer to table 1 below for a synchronization area found in G-v, age 33, provided by way of illustration (Table 1).

Thus, periodical synchronization on the recurrent list of 50% or more defections is found in all of the subjects. Theinterval between those "synchronization patterns" was 20 to 40 seconds when in background mode for all of the subject groups.

A "synchronization pattern" with the prefrontal cortex involved was also identified in subjects doing "Mental subtraction" oral cognitive test (Table 2). This pattern could be also observed in the subjects who succeeded incompleting the task over a shorter period of time. Here, faster neural network synchronization was discovered in successful subjects, with the very synchronization period being

Table 1. Synchronization pattern of a background record taken at a frequency 9.8 Hz.

Deflection	A max	S max	A med	S med	A full	S full	F dominant	F med	Index
Fp1A1	1,5	2,3	0,89	0,91	12	12	9	9,4	20
Fp2A2	1,6	2,4	0,79	0,81	11	11	9	10,2	18
F3A1	2,0	4,1	0,91	1,1	12	15	9,8	9,8	13
F4A2	1,7	2,7	0,78	0,91	10	12	9,8	9,8	16
C3A1	2,1	4,4	1,0	1,3	14	18	9,8	9,4	25
C4A2	2,0	3,9	0,9	1,2	12	17	9,8	9,8	26
P3A1	2,5	6,2	1,1	1,6	15	22	9,8	9,4	17
P4A2	1,9	3,6	1,	1,4	13	20	9,8	9,8	21
O1A1	2,0	4,1	1,3	2,0	18	27	10,9	10,9	25
O2A2	2,9	8,6	1,4	2,6	20	35	10,2	10,2	10
F7A1	1,8	3,1	0,8	0,84	11	11	9,8	9,8	20
F8A2	1,5	2,3	0,7	0,77	9,8	10	10,9	10,2	10
T3A1	1,7	2,8	0,81	0,88	11	12	9,8	9,8	24
T4A2	1,6	2,7	0,75	0,82	10	11	9,8	9,8	14
T5A1	1,6	2,4	0,85	0,83	11	11	10,9	10,9	19
T6A2	1,3	1,7	0,71	0,65	9,9	9,1	9	10,2	24

Conventional notations: A–Spectral amplitude, µV/sec; S–Spectral power, µV2; F: frequency, Hz; Rhythm Index–%. Spectrum and frequencies (Alpha) 36 sec, Epoch 3.

5 to 10 sec shorter, which could be indicative of improved resource mobilization, coming in the shape of faster rate and cortical links between respective brains areas involved in solving the test.

EEG analysis found that pattern borders (up to 25% of the deflections) could shift either to the left or to the right cortical hemisphere, while the pattern typical of a specific subject remained unchanged (e.g. fronto-centro- temporal) in all of the groups. Thus, the dynamical nature of changes in the sync pattern borders could be observed. Any changes in the sync pattern intervals are similar to that found when in background state. Dominant alpha- wave frequencies were individual-specific and depended on a specific test being done. This cyclic nature of periodic synchronization of deflections groups was discovered in alpha-, theta- and even beta-range waves, thoughit was both cyclic and stable in EEG alpha-wave range only.

Having analyzed EEGs of all the subjects, we discovered four synchronization pattern types (Figure 1). Type Onepattern was synchronization between fronto-centro-temporal deflections of the cerebral cortex – the “frontal type”.Type Two pattern was periodical interaction between fronto-centro-occipital deflections at the same alpha-wave –the “fronto-occipital type”. Type Three pattern occurs whenever regular synchronization between centro-temporo-occipital deflections occurs – the “occipital type”. Type Four pattern is synchronization between centro-temporaldeflections with frontal or occipital deflections periodically joining in – the “parietal type” (Figure 1).

In each of the above pattern types, synchronization with the somatosensory area of the cerebral cortex involved could be observed; some researchers believe that the area in question is the projection area of the conductivepathways in the thalamic nuclei. The analysis of the EEG records found that Type One synchronization between the fronto-centro-temporal deflections of the cerebral cortex was the most common among all of the subjects, 28 subjects out of 51 or 54% of all the subject groups studied. Type Two pattern or the synchronization between fronto-centro-occipital deflections was found in 11 subjects (21%). Synchronizations between the centro-temporo-occipital deflections were the least common (7 subjects, 14% of all of the subjects).

Open-eye EEG background record (BR) data analysis suggests that the brain asymmetry value tends to a decrease from the Control Group (15–25%) to the Athlete Group (15–20%) and down to the PPRS Group (10–15%). No such difference between groups is found when doing closed-eye test, with the brain asymmetry value decreased to 10–15% in all of the groups. The cyclic nature of synchronization processes was the most pronounced in the athletes, with rather an equal involvement of both brain hemispheres in the process when in all of the states studied. The periodicity of pattern occurrence when BR EEG was being recorded varied from group to group: when recording with the Eyes Open (EO), the least period of sync pattern formation in alpha-wave was observed in the athletes and it took the pattern 10 ± 5 sec on average to form in the PPRS Group it took 15 ± 5 sec and 20 ± 5 sec in the Control Group.

When taking records with Eyes Closed (EC), the pattern periodicity decreased in the Athlete Group and the PPRSGroup compared to the EO BR and was 10 ± 5 sec, while in the Control Group it was 15 ± 5 sec. The differences between the groups were not confidential, with alpha-wave generalization detectible in all of the subject groups, occurring periodically after the sync pattern and at the same frequency. Moreover, in the athletes, the generalization was detected 2 to 3 times a minute and lasted 5 to 15 sec; in eth PPRS Group subjects, it was 20 to30% longer, while on the Control group, the generalization was observed once in a minute and lasted 5 to 8 seconds.

EO and EC BR EEG analysis discovered changes on the alpha-wave sync pattern frequency (Figure 2). In the Athlete Group and the PPRS Group, the change in question was a wave-shaped (cyclic) switch from a low- frequency spectrum (7.5–8.9 Hz) to a medium-frequency band (9–10.9 Hz) and occurred 2 to 4 times a minute, while in the Control Group, changes in the alpha-wave sync pattern frequency showed no rhythmic nature and occurred once or less than once in a minute (Figure 2).

The data suggesting that synchronization patterns in athlete groups are of similar nature to those found in groups practicing PPSR are of interest. Sync pattern is detected in the fronot-centro-temporal deflections in 80% of those

Table 2. Synchronization pattern in the “Mental subtraction” test at a frequency 9.8 Hz.

Deflection	A max	S max	A med	S med	A full	S full	F dominant	F med	Index
Fp1A1	1,7	3,0	0,83	0,88	11	12	9,8	9,8	11
Fp2A2	1,2	1,5	0,6	0,43	8,3	6,0	9,8	9,8	11
F3A1	1,9	3,4	0,86	0,92	12	12	9,8	9,8	4
F4A2	1,1	1,3	0,68	0,51	9,5	7,1	9,8	10,2	5
C3A1	1,7	3,1	0,94	1,1	13	14	9,8	10,2	19
C4A2	1,4	1,9	0,68	0,54	9,5	7,5	9,8	9,8	13
P3A1	1,7	2,9	0,97	1,1	13	15	11,7	10,5	10
P4A2	1,4	1,9	0,68	0,59	9,5	8,2	9,8	9,8	10
O1A1	2,5	6,1	1,2	1,8	16	25	11,7	11,3	31
O2A2	1,6	2,6	0,78	0,76	10	10	11,7	10,9	3
F7A1	1,4	2,0	0,79	0,76	11	10	9,8	10,2	15
F8A2	1,2	1,5	0,53	0,36	7,4	5,1	9,8	9,8	10
T3A1	1,4	2,0	0,81	0,77	11	10	11,3	11,3	18
T4A2	1,2	1,5	0,45	0,27	6,2	3,8	9,8	9,8	7
T5A1	1,9	3,7	0,92	1,0	12	14	11,3	11,3	24
T6A2	1,3	1,6	0,46	0,3	6,4	4,2	9,8	9,8	9

Conventional notations: A–Spectral amplitude, µV/sec; S–Spectral power, µV2; F –frequency, Hz; Rhythm Index–%. 632 sec, Epoch 11.

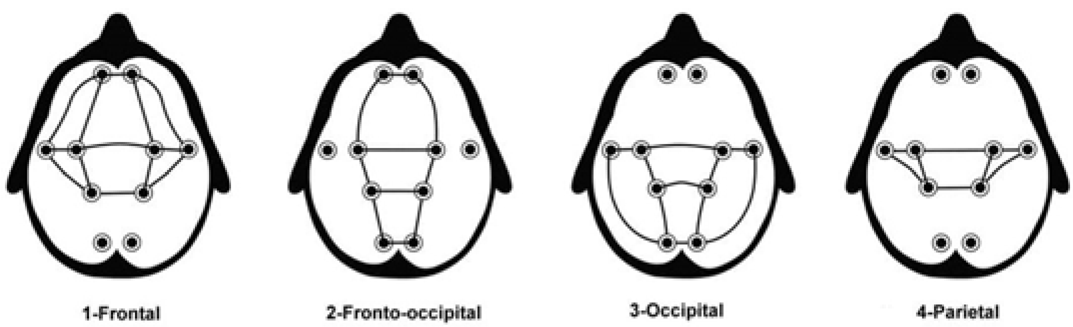

Figure 1. EEG deflection layouts depending on synchronization pattern types.

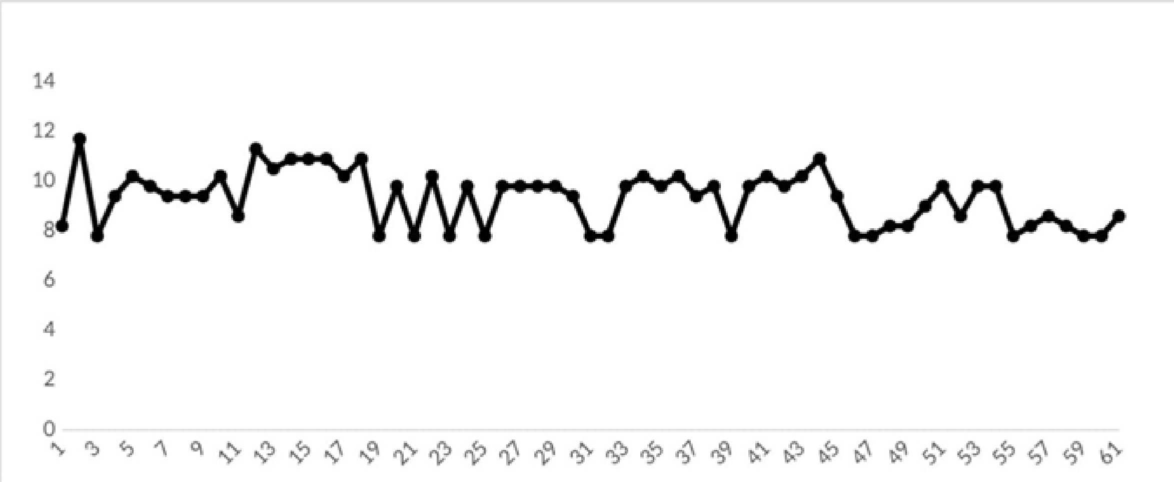

Figure 2. Changes in alpha-wave frequency when synchronization patterns form within an hour when a EEG is being record. Notations: X axis is EEG analysis epochs, Y axis is an alpha-wave frequency, Hz.

Table 3. Asymmetric synchronization pattern of a background record (subjectYe-v, age 24, control group).

Deflection	F Dominant	F Med	Index
Fp1A1	9,4	9,8	14
F3A1	9,4	9,4	11
C3A1	9,4	9,4	18
P3A1	9,8	9,8	31
O1A1	9,4	9,8	18
Fp2A2	9,4	11,3	11
F4A2	9,4	9,8	22
C4A2	9,4	9,8	28
P4A2	9,8	9,8	38
O2A2	10,5	10,5	24

Conventional notations: A–Spectral amplitude, µV/sec; S–Spectral power, µV2; F–frequency, Hz; Rhythm Index–%.

subjects and in fronto-centro-occipital deflections and in centro-temporo-occipital deflections in 20% of those subjects.

Almost all synchronization pattern types, except for the "parietal", can be found in the Control Group, with the "fronto-occipital type" of fronto-centro-occipital deflections being predominant in this Group and found in 5 out of 12 subjects. EEG analysis suggests that the alpha-wave index in the frontal and the temporal deflections of theanterior sync pattern type is on average 50% higher than the alpha-wave index in the same-type transversal deflections (Table 3). In contrast to the Athlete Group, pattern border shift towards either the left or the right hemisphere is detected in 1/3 of the controls.

Thus, spectrum frequency analysis of the EEGs identified a regular synchronization at a specific dominantfrequency of alpha-wave activity in 50% of deflections. It is worth noting that the synchronization in question occurs between a certain set of deflections (8–10 out of 16) and is visually shaped like a pattern of synchronizationbetween a groups of deflections in the cerebral cortex. The sync periodicity ranged between 5 and 70 sec and depended on both a subject's being member of a specific group and their state (the functional test results), with the pattern periodicity being highest in the Athlete Group and lowest in the Control Group. Based on synchronization variations within alpha-wave range, we identified four pattern types. The synchronization pattern between fronto-centro-temporal deflections of the cerebral cortex was the most common and was mostly found in the athletes and those practicing PPRS. The "frontal" and the "fronto-occipital" types were most common sync types among the controls.

EEGs recorded with eyes open and closed, alpha-wave generalization that occurred periodically in the wake of the sync pattern at the same frequency was found in all of the subjects, being most commonly discovered in athletes' EEGs.

Our findings allow concluding that the synchronization process parameters that are predominant in the athletes having improved resource mobilization ability are as follows

Synchronization pattern being predominant in the fronto-centro-temporal deflections.

The shortest synchronization pattern formation period.

Wave-shaped changes from low-frequency to medium-frequency band of alpha-waves when inbackground state with eyes open.

Long alpha-wave generalization coming in the wake of a synchronization pattern.

Least shift of pattern borders towards the left or the right hemisphere.

Both of the brain hemispheres being equally involved in the synchronization process.

It is noteworthy that most of the parameters found in the subjects practicing relaxation are similar to thosefound in the athletes in terms of their values.

Discussion

Our research findings suggest that functional cycles are part of the human body when it is physiologicallyat rest or when in a state of adaptive compensatory rearrangements. The findings presented in this Article imply that there exist individual and possibly, genetically fixed mechanisms for the central organization of adaptive processes.

There exist scientific researches suggesting that a "functional core" organizing bioelectric brain activity within certain frequency ranges is formed by oscillations at the alpha-wave activity frequency [20,21]. It is possibly due to the "functional core" that regular synchronization patterns arefound within the alpha-wave range.

It is noteworthy that any pattern type synchronization occurs within the deflections of the somatosensorycerebral cortex that is the brain's projection of the conductive pathways from the thalamic nuclei. Alpha-wave synchronization is attributed to pronounce activity in the trunco-thalamo-cortical system that, depending on a frequency and tasks to be accomplished, may exert either an excitatory or an inhibitive influence on the cerebral cortex. An extent to which alpha-wave activity occurs within all brain areas reflects the internal activity balance of the synchronizing influences from the thalamus and desynchronizing influences (primarily, from reticular and truncal structures) on the cerebral cortex [22,23].

Periodic occurrence of alpha-wave generalization in the wake of synchronization at a frequency similar to that of the very pattern, that is, the occurrence of synchronization at the same frequency within more than 90%of the deflections may indicate that low-frequency wave activity occurs in the reticular formation. We know from research by Giuseppe Moruzzi that the reticular formation safeguards generalized activation of extensive cortical areas, while working at low frequencies, which contributes to onset of a state of rest. Present-day data [12] suggest that whenever excitation occurs, it is closely followed by inhibition that limits an excitation period, thus creating a time window of integration, which occurs within nearing cortical neural networks.The mechanism in question may be functioning within local neural networks in the same way as it works at a distance. Synchronization between neurons is much higher when there is an ordered time structure of their activity(excitation-inhibition cycles) that it is when there occurs spontaneous neural activity.

Thus, our research confirms that functional states linked to a subject's resource mobilizing ability are organized centrally. E.g. In the Athlete Group, regular synchronization of more than one-half EEG deflections primarily predominant within fronto-central cortical areas contributes to higher self-regulation levels and improved performance in various activities.

Conclusion

Our findings provide more efficacious ways to improving functional abilities of the central nervous system. E.g. relaxation sessions practiced regularly can be a way to enhancing body resource mobilization.

Our research data can be applied to in functional diagnostics as prognostic criteria for various specialized trainings, or, most importantly, in a clinical environment. It is common knowledge that prognosis and body resource mobilization are pivotal for therapy courses. This prospect needs further comprehensive studies.

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Author Contribution

TVP[1] organized and prepared the manuscript, prepared tables; YuIK.[2] conducted research and statistical processingof the results; OGK[3] took part in the physiological analysis of the results and the selection of literature.

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None.

Conflict of Interest

The authors certify that there is no conflict of interest with any financial organization regarding the materialdiscussed in the manuscript.

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