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BRAIN-COMPUTER INTERFACE TECHNOLOGIES AND NEUROFEEDBACK

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Abstract
The issues of using neurofeedback for various diseases and disorders of the functional state of the brain in children and adults are considered. In addition, the presentation of one's bioelectric potentials of the brain allows one to learn to control physiological functions controlled by a person unconsciously. Biofeedback (BFB) sessions based on EEG parameters influence fundamental rhythmic mechanisms by changing the neuro-modulatory influences of the brain stem, the plasticity of neural networks, and the formation of new neural ensembles. By changing the level and degree of EEG activity, this training normalizes activation mechanisms, thereby improving cortical stability. As a result of learning to control central regulatory mechanisms, EEG feedback sessions lead to the stabilization of the functioning of the nervous system as a whole. This plays a big role in increasing the functional abilities of the brain in both children and adults. The most effective use of this method is for epilepsy, various types of addictive disorders, sleep disorders in adults, and attention deficit hyperactivity disorder in children; it has also been successfully introduced into the training process of athletes. However, despite numerous studies, questions regarding the effective use of neurofeedback remain unresolved. In particular, researchers have not developed a consensus on the number, duration, and frequency of neurofeedback sessions. It is also important to study the problems of motivation and take into account the cognitive capabilities of the subjects in understanding tasks during the EEGBS training. The study of the dynamics of the spectral characteristics of the main rhythms during the EEG training course, and the assessment of the self-regulation strategy after completion of the biofeedback course based on EEG parameters will serve as the basis for the development of methodological recommendations for the development of skills for effective self-regulation of mental functions.
Keywords: Brain-computer interface; Neurofeedback; EEG; electroencephalogram

Introduction

Brain-computer interface is a computer information management system, that records brain signals, analyzes and transforms them into commands coming to output devices to perform

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desired actions. According to the definition, BCI is a system measuring brain activity and transforming it into an artificial output signal, which substitutes, recovers, triggers, supports, informs, or improves a natural output signal, and in such a way, changes the current interactions of the brain with external and internal environments [1].

The year 1973 is considered to be the origin of BCI technology when the term "brain-computer interface" was suggested, and there was set a plan of experimental studies on human brain-computer interaction [2]. However, there is every reason to believe that the trend is based on a bioelectric control technique, which was formed in the 50–60-ies of the last century, and is developing rapidly nowadays. It presupposes the use of bioelectric potentials generated by human tissues or organs for automatic control of various external devices [3]. A perfect example of the trend is a pioneer work by N.P. Bekhtereva demonstrates a rhythmical photic stimulation automatically controlled by the patient's brain electric signals to increase the abundance of EEG alpha activity and is the most effective type of functional load than common photo-stimulation types [4]. Subsequently, different variants of this approach were used abroad for treatment purposes and were called "EEG-driven photic stimulation" or "alpha power dependent light stimulation" [5–6].

The major goal of BCI technology is in the substitution or recovery of useful functions for individuals unable to perform them due to neuromuscular disorders, such as amyotrophic sclerosis, cerebral palsy, stroke, or spinal injury [7].

Brain-computer interface is one of the most promising technologies in the sphere of treatment of neurological conditions and injuries. It enables to establish the communication between intact brain areas and auxiliary devices, which makes it possible to compensate for motor and sensory functions. For example, patients paralyzed due to spinal fracture, can restore their mobility using BCI, which connects neuronal structures of the motor cortex with robotic arms, exoskeletons, or neuromorphic electro-generators [8]. Moreover, sensory BCI can serve to recover the sensitivity of paralyzed body parts by transmitting somatosensory sensations of touch, temperature, pain, and vibrations in these patients [9]. There are some achievements in BCI development including those made in Russia [10].

In addition to neurostimulators aimed, mainly, at motor function recovery, BCI with an auxiliary function holds a prominent place in rehabilitation medicine. BCI makes it possible for patients, by acts of will, to type on a monitor screen, press virtual on-off buttons available for their self-maintenance, user-devices of hospital beds, etc. The complex of such BCI systems assisting a patient can be called neuro-communicators, since they, in their own way, help a human without any muscular movements to choose certain symbols to type a text or a command on a computer screen [11].

Neurofeedback

Neurofeedback technology is a computer information management system, that enables the modification of brain biopotentials with an active participation of a patient himself. To accomplish this, a current amplitude of a certain EEG rhythm using various computer means is reflected in parameters of light and/or audio feedback signals shown to a patient to teach him a conscious brain control of the intensity of his own rhythmic EEG components to achieve desirable curative effects. If a human in real-time can hear or see an adequate reflection of his biopotentials, then he has an opportunity to learn to change them in the direction required. At first, the achieved effects are short-term, but in the course of training in most people, this skill is reinforced. Thus, NFB offers auxiliary facilities for non-drug rehabilitation of various brain pathologies [12].

In general, the NFB system consists of five elements or processing steps: brain signal reception, signal preliminary processing, distinguishing key features, feedback signal generation, and adaptive training. After EEG recording, the data are preliminarily processed (e.g., artifact detection, removal, and correction), with generation and selection of features, and feedback signal computation and notation. The last step closes the feedback circuit, where a participant attempts to learn to use a feedback signal to change the brain activity according to instructions. All the necessary steps are taken on a real-time basis. The distinguished features, as a rule, reflect quantitatively the activity level of a certain brain area or network, and a feedback signal transmits the information on the corresponding changes in the brain condition. Participants are trained to find and adapt the strategies to change intentionally the state of their brains under the preliminary instructions.

An initial stage of establishing NFB technology was a series of research carried out by Kamiya in the 60-ies of the last century, which demonstrated the human capability to change voluntarily the intensity of spectral components of his own EEG [12]. Subsequently, this fact served as the basis for the development of a number of clinical NFB applications to treat many diseases through direct rearrangement of electric processes in the brain.

The mechanisms of therapeutic action of NFB are still unclarified, though many studies are devoted to their understanding [13]. According to one concept, potential mechanisms of NFB are rearrangements of neural networks including the increase in their global interconnection and neuroplasticity [14]. Other researchers consider NFB to perform the adjustment of brain electric activity vibrations set up for such a homeostatic level, which provides an optimal balance between neural network flexibility and stability.

By the present time, there has been positive clinical experience of NFB application for a wide range of diseases. Among them, there is attention deficit-hyperactivity disorder, learning disability stroke, traumatic brain injury, uncontrolled epilepsy, substance abuse [15], depression, autism, migraine, eating disorders [16–17], pain syndromes, and other pathologic conditions. It should be noted that regardless of the origin of symptoms, NFB training holds out auxiliary facilities for rehabilitation through direct re-education of electric processes in the brain.

In literature one can encounter the data on curative effects of NFB application in psychiatric disorders, such as eating disorders, schizophrenia, and psychoses, to treat the function of executive control in Tourette syndrome, as well as for recovery and improvement of functions in high-performance sport [18].

It is worth mentioning that there are conflicting opinions on NFB efficiency in the treatment of various pathological conditions and disorders. Some authors consider NFB to be certainly an effective and specific cure for epilepsy, attention deficit-hyperactivity disorder, and anxiety disorders, probably effective — in the treatment of brain injuries, drug addiction, and insomnia, and insufficiently effective — in depressive disorders, autism, and posttraumatic stress disorders [19]. Other authors when studying the reports in the literature have concluded that NFB is effective in autistic spectrum disorders, drug intervention, and brain injury consequences. There is one more group of authors, who think NFB to be a potentially clinical

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tool in severe neuropsychiatric disorders: schizophrenia, depression, Parkinson's disease, etc. [20].

Problems and prospects of brain-computer interface and neurofeedback technologies

Despite international recognition of the topic's significance and specialized scientific journals, there are still a number of problems in BCI and NFB studies requiring solutions.

For BCI technology optimization, two major tasks should be completed. Firstly, there should be selected the most dynamic biometric signals with the following distinguishing from them reliable markers of human mental efforts. The second task is to develop greatly individualized schedules of the procedure to form a command mental effort, which should result in clear and stable changes in the recorded electrographic or metabolic indices [11].

Progress is needed in the development of invasive and noninvasive BCI, as well as in the development of techniques of precisely targeted stimulation of brain or sensory channels with high spatial and temporal resolution to substitute the lost sensory inputs (e.g., touch sensation prosthesis in amputees), an immediate correction of dysfunctional networks (e.g., detection and mitigation of neuronal activity disturbance) and a long-term recovery of healthy functional networks through the use of brain plasticity neural mechanisms [21]. As a result, a new trend in medicine will advance — neuro-prosthetics, or interdisciplinary research areas including neuroscience, computer science, physiology, and biomedical engineering to substitute or recover motor, sensory, or cognitive functions that could be damaged due to an injury or a disease.

There are many pending questions and problems in NFB. Some authors emphasize an insignificant number of strictly controlled studies and minimal samples used in the investigations devoted to different NFB variants despite the positive findings [19]. Other researchers analyzing the studies on NFB indicate such problems as no adequate selection of an experiment design, inadequate use of controlled conditions and control groups of test subjects, and the lack of concepts of learning mechanisms participating in brain self-regulation. Clinical prospects of NFB are thought to depend directly on the solution of the above-mentioned and other methodological problems, as well as the wider use of modern live brain imaging technologies (e.g., functional magnetic resonance tomography in a real-time mode, or near-infrared spectroscopy). The utilization of the technologies using stricter research protocols will throw light on in-deep NFB mechanisms which contribute to the development of more effective clinical applications of neuro-interfaces [22].

Two advanced tendencies can be distinguished in current studies on BCI and NFB. One of them is related to the use of individually revealed specific EEG components instead of overmuch wide-band, predetermined traditional EEG rhythms. According to some works, such an approach leads to a significant improvement in treatment procedure efficiency. The second tendency consists of the combination of neuro-interface technologies with other ones: transcranial magnetic stimulation or audio-visual stimulation [23] which also improves efficiency.

Musical neuro-interface

One of the major problems in NFB technology is that of optimal organization of feedback signals as a key factor determining the success of biocontrol. However, the most promising approach to the organization of NFB procedures is a combined exploration focused on the interaction between the human brain, body, and behavior. The technology of musical NFB developed by the authors is just the technology combining the utmost individuality of

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biocontrol and the benefit of unconscious perception of the stimuli typical for musical therapy [24].

The approach is based on the use of musical or music-like stimuli, which are organized in strict accordance with the current values of the patient`s brain biopotentials. The characteristic feature of the technique is musical feedback from narrow-frequency EEG oscillators typical and relevant for an individual and revealed in a real-time mode based on a specifically developed dynamic approach [25].

Music is known to be able, on its own, to trigger strong emotions, change mood, and help in the treatment of psychiatric and neurologic disorders. Music has an effect on the human brain, basic body functions, and behavior suppressing stress, correcting the state of consciousness, and serving as a universal therapeutic remedy. Music has particular efficacy if presented according to the individual brain characteristics of a patient. In our situation, musical impact is organized in strict accordance with narrow-frequency EEG oscillators functionally significant for a patient, owing to which treatment procedures assume peculiar healing properties [26].

The key advantage of the musical NFB technology is the possibility of its application to correct unfavorable functional states under conditions, which do not require conscious efforts of test subjects. It is of particular concern in treatment procedures with children and patients with specific psychiatric conditions or those with drug therapy contraindicated. Therefore, musical NFB technology was successfully tested to correct psycho-emotional disorders in pregnancy and when watching out for labor, as well as to eliminate stress-induced disorders. Currently, there have been carried out the studies aimed at eliminating the signs of attention deficit hyperactivity disorder in children employing the present technology [27].

Conclusion

The carried out review of the literature shows that, currently, neuro-interface technologies are coming into use in medicine to substitute or recover useful functions in people incapable of performing these functions due to neuromuscular disorders or injuries, as well as to treat a wide range of diseases and disorders without medications.

Brain-computer interface technology helps compensate motor and sensory functions, contributes to the recovery of sensitivity of damaged body areas, and makes it possible to perform out-patient monitoring to detect and prevent potentially dangerous conditions (e.g., epileptic seizures). It will provide the recovery of some lost functions in paralyzed patients. Due to brain-computer interface technology paralyzed patients can, by acts of will, type on a monitor screen and press virtual on-off buttons available for their self-service devices. Ultimately, by a multi-type cooperation of neurologists, psychologists, physicians, engineers, and mathematicians the mentioned capabilities of brain-computer interface technology will be completed by accelerated education programs and targeted memory regeneration that will enable to extend significantly the sphere of its clinical application for both diagnostics of diseases and screening of risk groups, and also for effective correction of various pathological conditions.

Neurofeedback technology was initially focused on clinical applications, and by now it has been successfully tested in the treatment and correction of a large number of diseases and disorders ranging from attention deficit-hyperactivity disorder and autism to drug addiction and immunodeficiency. Despite a number of unsolved problems, by now neurofeedback technology appears to be, at least, a very useful supplement for the existing treatment facilities. Looking forward, due to the development of more perfect research protocols, the use of modern technologies of human brain imaging, and optimal organization of feedback signals (e.g., in the form of music), interface technologies can hold key positions in clinical practice.

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