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The use of EEG Biofeedback/Neurofeedback in psychiatric rehabilitation

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Summary

The aim of the systematic review was to evaluate the use of EEG Biofeedback/Neurofeedback in patients treated for mental disorders. The review covered publications analyzing influences and effects of therapy in patients receiving psychiatric treatment based on EEG Biofeedback/Neurofeedback. Selection of publications was made by searching PubMed and Scopus databases. 328 records concerning applications of the presented method were identified in total, including 84 records for patients diagnosed with mental disorders. The analysis of studies indicates that EEG Biofeedback/Neurofeedback is used for treatment of neurological, somatic and mental disorders. Its psychiatric applications for clinically diagnosed disorders include treatment of depression, anorexia, dyslexia, dysgraphia, ADD, ADHD, schizophrenia, abuse of substances, neuroses, PTSD, and Alzheimer's disease. Research results imply that the neuromodulating effect of the therapy positively influences cognitive processes, mood, and anxiety levels. Positive effects of EEG Biofeedback confirm usefulness of this method as a main or auxiliary method in treatment of people with mental disorders. On the basis of conducted studies, it is worthwhile to consider inclusion of this method into the comprehensive neurorehabilitation activities.

Key words: EEG Biofeedback, neuromodulation, psychiatric rehabilitation

Introduction

Recently, a significant increase in interest in providing rehabilitation services to patients with mental disorders is observed. Community support and outpatient care are developing robustly, and innovative neurorehabilitation methods and professional diagnostics are introduced. Availability of a range of therapeutic methods offers numerous treatment possibilities to patients with mental disorders, and multidirectional initiatives support the development of professional care.

Currently, a standard rehabilitation model is based on psychiatric rehabilitation units and day care units providing various forms of rehabilitation activities. Those activities are based on determining patient's deficits and implementation of rehabili-

tation regimens. Their main aim is to prevent or alleviate disease consequences, and preventing it from passing into the chronic stage [1–6].

Each rehabilitation activity (early, delayed) involves medical and resocialization aspects. Early rehabilitation aims at preventing disease progressing to chronic stage, as well as at eliminating permanent incapacity to work and social exclusion [2]. Delayed rehabilitation aims at defect compensation, and focuses mainly on a training and restoring of the lost functions, as well as at stimulating social and professional activities. In professional regimens, they are also included in the community support, which is supposed to subordinate those activities to the community requirements, and focuses on so-called re-adaptation, that is, professional and social reorientation [1–4]. Similar criteria are adopted by the American R4 system which refers to rehabilitation, reintegration, rehabituation and resiliency. This system uses various forms of exerting influence, including EEG Biofeedback, whose position is increasingly stronger amongst services offered all over the world [7].

The analysis of the studies implies that neurofeedback (NF) efficacy is high not only for somatic or neurological disorders, but also for mental ones. Relevant mental disorders include depression, anorexia, schizophrenia, neuroses, substance abuse, ADD, ADHD, PTSD and Alzheimer's disease [7]. The beneficial effect of the therapy depends on a correctly performed QEEG, adequately selected training protocol and a specified number of sessions [7–9].

Considering problems with social functioning of mentally ill people and positive results of the NF therapy it seems justified to incorporate this method into the psychiatric rehabilitation system.

Aim

This paper aims at presenting the Neurofeedback/NF therapy, rules for its performance, its effect on improving brain functions, and possibilities to apply it in patients diagnosed with mental disorders.

Method

Publications analyzing an influence and effects of therapy in patients receiving psychiatric treatment based on EEG Biofeedback/NF were reviewed using PubMed and Scopus browsers. On a basis of available literature, the study was divided into subsections concerning: 1) synaptic enhancement and neuromodulation; 2) description of EEG Biofeedback/NF therapy; 3) principles underlying EEG Biofeedback/NF effect; 4) the use of EEG Biofeedback/NF in psychiatry.

Synaptic enhancement and neuromodulation

A neuron is a basic component forming the nervous system. It consists of a cell body, and long (axons) and short (dendrites) projections. Information is transmitted to the cell body via dendrites, and from the cell body to other cells and effector organs

via axons. The cells are connected with chemical and electrical synapses. Depending on a type of neurotransmitter, chemical synapses are classified as excitatory and inhibitory ones [10–12].

Each cell activity is associated with a change in its action potential accompanied by a release of a transmitter substance. The intensity of signals transmitted between cells, and different types of connections (axodendritic, axosomatic, axoaxonic) result in signal modifications [8, 10–13].

Each change in the action potential in the membrane and the sprouting process result in biochemical and anatomical changes leading to synaptogenesis (neuromodulation). Strong and regular stimulations generate enhancements and contribute to formation of new connections (so-called long-term potentiation – LTP). Additionally, weak stimulations do not initiate long-term enhancement in the long-term memory, while subthreshold values may even weaken it [13–14].

In the neuromodulation process, an important role is played by two basic systems generating brain waves: the thalamocortical system where stimuli are processed and selected, and the septo-hippocampal system with the frontal lobes and the thalamus, where attention, concentration and memory are controlled [15]. Both systems are interdependent and form a so-called feedback loop (stimulating or inhibiting). Their function is reflected in the cortical activity. A correct cooperation of the systems depends on homoeostasis and normal neurophysiological control. The internal homoeostasis is disrupted by adverse stimuli. Stress can be an example of such factor, as its adverse influence on structures and functions of connections "destabilizes loops" and, in consequence, causes changes in generation of brain waves [15–16].

Therefore, when dysregulation represents the main problem, then an alternate corrective measure is to restore regulation. Using autoregulatory training techniques Neurofeedback increases this stability, restores internal cohesiveness, and through regular influences it stimulates formation of new neural circuits [12, 15–17].

Description of EEG Biofeedback/NF therapy

EGG Biofeedback/Neurofeedback (NF) is a non-invasive technique for modelling of the human brain function, based on a graphic record of generated electrical waves and using feedback [18–21]. A record of wave rhythm proves that the brain performs a specific activity. That activity, spontaneous or provoked, results from the cortical function. It is recorded by an EEG apparatus with special software and the Fourier transform algorithm for spectral recording [21–22].

A change in the electrical potential is expressed graphically by wave frequencies and amplitudes. It reflects neural discharges generated at specific intervals, recorded in units (Hz) determining a number of cycles per second. Those cycles are called the brain rhythm or the action current [9, 13–15, 23].

The image of brain waves reflects the current patient condition, which is modified depending on their psychophysical status. Agitation causes an increase in wave frequency, while relaxation and calmness result in its decrease. Disruptions in the number of generated waves result in their mixing. Desynchronization results in the incorrect

brain rhythm, and in inability to reach minimum and maximum stimulation between hemispheres, and in consequence, disrupts their interactions [13].

Each hemisphere encodes in a different way; the left one is responsible for logical thinking and verbal processes, while the right one is responsible for holistic and intuitive thinking. Normal interhemispheric synchronization proves presence of two waves, in two cortical regions, achieving a similar intensity at the similar time [13–15].

In NF, the following brain wave ranges are distinguished: delta (0.5–4 Hz), theta (4–8 Hz), alpha (8–12 Hz), beta (>12 Hz), SMR (12–15 Hz), beta1 (15–18 Hz), beta2 (18 Hz), and gamma (40 Hz and above) [15]. All waves are generated simultaneously, and have specific amplitudes and frequencies. Normal ranges prove that generated waves are synchronized and the brain functions normally, while too low or too high ranges imply anomalies [9]. The wave ranges are evaluated by comparing amplitude values between the left and the right hemispheres, and between anterior and posterior parts of the brain. The verified results are used to specify rules for the training (to establish a threshold). The stimulation threshold is established at 30% below the mean amplitude value when low amplitude ranges are to be enhanced, and at 30% above the mean amplitude value when high amplitude ranges are to be reduced [15]. This way, the desired (positive) waves are promoted and undesirable (negative) waves are suppressed. It should be remembered that in disorders involving both hemispheres, the training is started in the left hemisphere along the central belt to the front, and from the central belt backwards, without enhancing alpha in the left frontal region, delta, theta, beta2 and those waves with amplitudes exceeding the upper normal range. Enhancement of positive waves and reduction of negative ones is the essence of the EEG Biofeedback therapy. Its understanding is based on knowledge of individual waves, their effect on the body and correct use during the training. Characteristics of individual waves are presented below [15, 23].

The alpha rhythm, recorded mainly in the occipital region, is the main, basic rhythm. It appears during concentration, thinking, when eyes are closed, and before falling asleep. It oscillates between the low and the high frequency. The low frequency (8–10 Hz) is responsible for maintaining a balance and inner awareness, while the high frequency (10–13 Hz) supports concentration and increases creativity. The alpha activity is usually more or less symmetrical, with a higher amplitude in the non-dominant hemisphere. The research conducted by Kamiya in 1978 proved that the increase in alpha wave amplitudes reduces anxiety levels and increases mental capacities. The similar results are reported by Trousselard, Yuan and Scheinost et al. [24–27].

The theta waves are mainly located in the hippocampus, where its electrical activity is generated. This rhythm is responsible for memory and associations. It is present during sleep and located symmetrically. Its absence indicates structural brain damages, while its excessive presence in the frontal lobe implies problems with concentration and attention (ADD, ADHD, depression, epilepsy) [7].

Delta waves are synchronized and the slowest. They appear during deep sleep, when body regenerates, and growth hormone (GH), DHEA steroid hormone and melatonin controlling the so-called biological clock are released into the bloodstream. When

these waves are recorded while a person is awake, presence of pathological changes is implied. The lower their amplitude, the more severe the damage. In children, elderly people and youth, presence of delta waves is not an anomaly [15, 23].

Beta waves are rhythmical, and present mainly in the central part of the frontal lobe. They reflect reception of stimuli from the external environment [10, 11, 15]. Their increased amplitude is observed when certain medicines are used (barbiturates, tricyclic antidepressants), while it is reduced by motor stimuli. A significant difference in those waves amplitudes in hemispheres indicates an asymmetry implying a disease. An increase is observed after craniotomy, in diagnostics of abnormal masses, while their decrease is visible after stroke or subdural fluid accumulation [13, 28]. The beta waves range in NF is classified into low, medium and high [15].

Low beta waves are described as a sensorimotor rhythm (SMR) or a sensorimotor wave. In 1971 Sterman proved that by enhancing SMR waves it is possible to reduce epilepsy symptoms and restore body's ability to maintain homoeostasis. Low SMR is observed in people with attention deficit (ADD) and hyperactivity (ADHD). Use of the NF therapy based on protocols increasing low beta rhythm can correct above-mentioned deficits [29–30].

Beta1 is responsible for logical thinking, concentration, memory, and an emotional status. It is the most commonly used wave in EEG Biofeedback trainings.

Beta2 is characteristic for people who are anxious or nervous, therefore, sessions within this range should be conducted with care.

Gamma waves, discovered relatively recently, are of the highest frequency, present throughout the brain, and possibly accompanying strong emotions and association processes [14, 31].

Abnormal records (sharp records or peaks) can be observed for the described waves, which must always be consulted with a specialist [10, 11, 23].

Principles underlying EEG Biofeedback/NF effect

The Neurofeedback training is based on inducing the beta1 state in the dominant hemisphere, and the SMR state in the non-dominant hemisphere, with simultaneous suppression of theta and beta2. Those influences facilitate restoration of a balance between the hemispheres and maintaining of the internal homoeostasis.

Main protocols used in the NF training are SMR/theta, SMR/delta, beta1/delta, and beta1/theta trainings [30, 32]. In this case, SMR and beta1 waves are stimulated, while the theta and delta waves are suppressed. A different protocol is used in the relaxation training; here sessions focus on alpha/theta trainings to put a patient into a relaxed state [15].

In EEG Biofeedback we focus on stimulation of alpha, SMR and beta1 waves and on suppression of slow delta, theta and beta2 waves. ADHD and ADD are exceptions where alpha waves are suppressed [29, 33, 34].

We promote and suppress waves using stimulating games containing specially adapted control components contributing to a specified direction of changes. This regulation is described on a basis of brain waves frequency ranges and amplitudes,

depending on the patient's age and diagnosis determined by a person providing the training during an initial examination – so-called quantitative EEG, i.e., QEEG (with open and closed eyes) [18].

Quantitative EEG requires a precise analysis as it represents a baseline for trainings. All artifacts (blinking, looking around, muscle flexing) must be removed, as they cause abnormal records and incorrect analysis resulting in an incorrectly specified training protocol. Verification is based on standard relationships: D>T>A>SMR>Beta1>Beta2 and EEG standards for EEG Biofeedback according to Sterman or Tyle [15, 18].

Games for specific parameters (two or three) are selected using specified promoted and suppressed rhythms on a basis of performed quantitative EEG. The first controlling parameter in the protocol is always the promoted rhythm, and it is associated with the first regulated component on the board. The suppressed rhythms concern the successive stage or the two remaining stages. Achieving the desired therapy effect depends on the correctly defined protocol and an appropriately selected number of trainings and the number of rounds per session [35].

The latest research indicates that positive results are obtained for sleep disorders (5–7 sessions), ADHD (40–60 sessions), and brain dysfunctions (40–80 sessions) [18, 34, 35].

Use of EEG Biofeedback/Neurofeedback in psychiatry

Neurofeedbakc/NF is a popular therapy combined with other methods or applied alone. It is used for treatment of: ADHD, depression, anxiety, dysgraphia, dyslexia, aggression, autism, head injuries, epilepsy, sleep disorders, anorexia nervosa, neurosis, schizophrenia, MS, and Parkinson's disease [18, 19, 36–40]. This is confirmed by numerous reports, justifying consideration of this form of therapy as an auxiliary therapy in the psychiatric rehabilitation model.

Many authors emphasize that patients with mental disorders are characterized by significant deficits in activity of specific brain regions, resulting in problems in daily life. Structural and functional anomalies mainly involve the frontal and prefrontal cortex, the cingulate gyrus, the temporal lobes, and medial and limbic structures [41–42]. The most important are those associated with frontal and prefrontal regions, as they are responsible for working memory, processing of information, abstract thinking, planning, and executive functions. The above-mentioned disorders result in problems with solving of daily problems, leading, in consequence, to deteriorated general social functioning of those people [43]. Rybakowski [41] additionally emphasizes that cognitive deficits, attention and memory are influenced by an abnormal movement of eyeballs found in ca. ¾ schizophrenia patients. Similar conclusions are also mentioned by Rosse et al. [44].

The anomalies can be minimized by influences introduced both in a hospital and outside a hospital. They include numerous interventions: physical exercises, social skills trainings, communication trainings, interpersonal trainings, artistic and integrating influences, and teaching the patients how to actively participate in the pharmacotherapy.

Their obvious benefit is an optimal support, but it appears they focus on secondary symptoms. Patients' behaviors and cognitive mechanisms remain the same, and the "tunnel approach" focuses mainly on the current situation [1–6, 45].

New technologies, including NF, facilitate other, more modern type of rehabilitation, with a holistic approach, thus focusing not only on aims, needs and problems, but also on autoregulatory mechanisms as patient's own resources. Currently, comprehensive studies justify this form of a behavioral therapy as an effective one, possible to be applied. This study does not aim at discussing its wide range of applications, but papers confirming positive effect of the therapy, particularly in patients with mental disorders, should be considered.

The review of available publications showed that the conducted studies support a statement that the NF therapy is highly effective. This is emphasized by many authors, including Trousselard and Scheinost et al., who are of the opinion that regulation of brain waves reduces fear, anxiety and stress levels, that is, those symptoms which are commonly observed in patients with mental disorders [24, 26, 46]. Similar conclusions are presented by Larsen who states that use of Neurofeedback/NF is a desired direction in therapy of patients reacting negatively to pharmacotherapy and psychotherapy. The author is of the opinion that NF represents an alternative to those approaches, with a positive prognosis for rehabilitation [46].

Considering these positive reports, it should be emphasized, however, that provided neurorehabilitation services do not always bring expected results to patients. When selecting those services, patient's abilities must always be considered, with forms of influence specified to achieve the expected results. As Stoeckel et al. said, correctly selected neurotherapeutic methods are a precondition for improving cognitive function and general functioning and to induce a process to modify the brain function [47, p. 253]. Koush et al. emphasize that "brain training" can be understood as a positively acquired behavioral feedback improving psychical function and developing brain functional network through visual exercises [20].

Birbaumer and Mathiak compare NF self-regulation to the learning process and the operant conditioning initiated by Thorndike – not always conscious, but based on enhancing and rewarding specific behaviors [48, 49]. The authors report that the process involves the dopaminergic system, which plays a significant role in encoding of the reward pathway (substantia nigra-SN/ventral tegmental area-VTA). Similar opinion is presented by Sulzer et al. who additionally emphasized a particular ability for SN/VTA self-regulation. He based his conclusions on positive correlation with skin responses (GSR) and emotional stimulation. According to Sulzer et al., this correlation proves a positive effect of the Neurofeedback therapy and a hypothetical possibility for "control over secretion of endogenous dopamine" [50, p. 822].

Rota et al. report interesting conclusions based on research, as they report that a NF-based training to activate the frontal region of the right inferior gyrus has a positive effect on speech modulation and processing [51]. The authors are of the opinion that while following the conducted trainings, a significant improvement is observed in ordering of Brodmann area (BA45), and this is confirmed in the fMRI scan. A similar influence was observed by Ruiz et al. [52]. They notice their significant importance in

correct perception of emotions in people diagnosed with schizophrenia, while Naimijoo et al. emphasize the effect on executive functions [32].

Neurofeedback-based cortical and subcortical modulation in a group of Parkinson's patients is confirmed by research conducted by Subramanian et al. [53]. The authors are of the opinion that the trainings resulted in improvement in motor functions. The authors observed a 37% increase in the motor function in the hypothalamus and globus pallidus region in patients undergoing NF versus a group not subjected to such influences. The data obtained by Subramanian et al. is confirmed by analyses of research based on the Unified Parkinson's Disease Rating Scale, an analysis of clinical symptoms and by follow-up fMRI.

Numerous reports emphasize a significant effect of NF on treatment of depression. Research by Yuan et al. [25] implies that NF interventions have an effect on the amygdala function and increase its activity. The authors compare a group of 27 people diagnosed with depression and undergoing trainings versus a group of healthy people. The results indicate that in people with depression EEG Biofeedback interventions improve connections between temporal cortical regions and the hippocampus and the amygdala, and the active NF training improves emotional control and reduces the disease symptoms severity. These results are also confirmed by Choi et al. who note that in people diagnosed with depression, strengthening of alpha waves activity improves their emotional, behavioral and cognitive functioning [54]. The authors emphasize that an increase in those waves in the right frontal region leads to alleviation of symptoms, positively influences emotions, and improves cognitive function. Similar conclusions are presented by Gruzelier, who emphasizes a positive effect of the alpha and theta waves on reduction in anxiety levels in the PTSD and depression [55].

Interesting reports focusing on NF application in elderly people have also been published. Angelakis and Becerraze et al. report a relationship between NF operant conditioning and the brain activity in this group of patients. The authors note that an increase in the alpha rhythm positively influences cognitive functions in the subjects, and in the future this may represent an interesting technique for their modulation and use [56, 57]. Similar results are also emphasized by Wang, who additionally confirms an improvement in functioning of the working memory in these people [58].

Summing up this review, it can be said that in the future Neurofeedback/NF may form an important therapeutic component in the comprehensive psychiatric rehabilitation. Regular application of trainings may help people with mental disorders to restore their cognitive and general social abilities [59].

Conclusions

1. Neurofeedback/NF as an innovative method of brain wave activity regulation which can be used in psychiatric rehabilitation.
2. There is a relationship between EEG Biofeedback interventions and modulation of the psychophysiological condition.
3. NF-based operant conditioning causes changes in morphology and activity of dendrites associated with brain neuroplasticity.

4. The increased number of generated action potentials results in formation of new chemical synaptic connections.
5. Neurostimulation as a model of psychiatric rehabilitation increases patient's individual abilities and improves their social functioning.
6. Comprehensive psychiatric rehabilitation involves: pharmacotherapy, psychological support as well as environmental and neurostimulating/regulatory influences.

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