Neurofeedback as an aid in the treatment and rehabilitation of selected neurological disorders

Neurofeedback – metoda wspomagająca w leczeniu i rehabilitacji wybranych zaburzeń neurologicznych

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STRESZCZENIE

Neurofeedback (NFB) jest odmianą terapii biofeedback, w której wykorzystywana jest analiza sygnałów EEG. W tej technice uczenia pacjentowi przekazywane są informacje zwrotne o tym, jak działa jego mózg. Celem terapii NFB jest redukcja zaburzeń psychicznych i neurologicznych, poprawa zdrowia i wydajności pacjenta. Metoda ta zakłada, że czynność bioelektryczna mózgu odzwierciedla poziom aktywacji i wzbudzenia procesów psychicznych pacjenta i może być trenowana. NFB jest stosowany na całym świecie od ponad 40 lat. Celem tego artykułu jest przedstawienie istoty terapii NFB, przegląd aktualnych doniesień naukowych dotyczących skuteczności, potencjalnych skutków ubocznych, jak również omówienie wymogów prawnych. Autorzy przedstawiają powszechnie stosowane procedury diagnostyki i późniejszego leczenia. Jednostki chorobowe, w których NFB ma zastosowanie to m.in. zespół deficytów uwagi z nadpobudliwością (ADHD), padaczka, stany lękowe, depresja, autyzm i zespół Aspergera, migrena i bóle głowy typu napięciowego oraz urazy czaszkowo-mózgowe.
Słowa kluczowe: biofeedback, neurofeedback, neuroterapia, rehabilitacja, QEEG, zastosowanie, skuteczność

ABSTRACT

Neurofeedback (NFB) is a form of a biofeedback in which the analysis of EEG signals is used. It is also called Brain-Computer Interface (BCI) training. This learning technique provides feedback to the patient about how the brain works in order to reduce neurological and psychic symptoms, improve patients' health and performance. This method assumes that the electrical activity of the brain reflects the mental state of the patient and can be trained. Neurofeedback has been used worldwide for over 40 years. The goal of this paper is to present the essence of this therapy and a condensed review of current reports regarding efficacy, potential adverse effects, as well as legal requirements for practitioners. The authors outline the commonly used assessment procedures and subsequent course of treatment. Disorders that respond to neurofeedback include attention-deficit/hyperactivity disorder (ADHD), epilepsy, anxiety, depression, autism and Asperger's syndrome, migraine and tension type headache and traumatic brain injury (TBI).
Key words: biofeedback, neurofeedback, neurotherapy, rehabilitation, QEEG, application, efficacy

INTRODUCTION

Biofeedback (BFB) is a learning process. It involves providing an individual with objective measurements concerning his or her physiological processes so that they can be brought under self-regulatory control. These physiological measurements include peripheral skin temperature, skin conduction (also called electrodermal response or EDR), muscle tension (electromyogram or EMG), respiration, heart rate, and heart rate variability (HRV). With sufficient commitment and active exercise, the patient can be taught to consciously control physiological processes in order to optimize his or her bodily functions. In addition, the patient can learn to maximize the brain's efficiency as well as to eliminate or alleviate the symptoms of some disorders using EEG biofeedback, also called neurofeedback [1, 2].

Neurofeedback (NFB) or brain-computer interface (BCI) training is essentially a form of biofeedback which employs the analysis of EEG signals [3]. EEG is a non-invasive method for monitoring bioelectrical activity of the brain. It was originally developed to analyze mental processes. Later it turned out to have a broad clinical application, especially in the diagnosis of epilepsy. Starting in the 1960s, the EEG visual patterns were quantified (QEEG) and correlated with functions and disorders of the central nervous system. This methodology has become one of the key diagnostic tools in neurophysiology [4]. The Federal Drug Administration (FDA) in the United States has recently recognized this diagnostic potential by approving an instrument that uses EEG measurements and theta/beta ratios for use in the diagnosis of attention-deficit/hyperactivity disorder (ADHD) [5].

By monitoring bioelectrical activity of neurons using EEG measurements we are able to provide the patient with feedback regarding the brain's functioning in order to improve it [2]. Neurotherapy based on this method assumes that the brain's electrical activity reflects the patient's mental states and that it can be trained. As mental states change, so do the amplitudes of different brain wave frequencies. The information about brain wave activity of interest is displayed in real-time on a computer screen. While observing it, the patient tries to influence the brain waves in order to complete specific exercises and achieve the set goal, thus developing the ability of self-regulation of various mental states, including attention and mood [1, 3].

HISTORY

The basic characteristics of the electroencephalogram (EEG) were outlined by a German psychiatrist, Hans Berger [6]. In 1929 he published his research and described the main types of brain waves and assigned the name of the first letter of the Greek alphabet to the higher amplitude synchronous waves (alpha) and the second letter to the faster, desynchronized, lower amplitude activity (beta) [7]. In 1934 two British scientists, E. Adrian and B. Matthews, confirmed his findings which are still relevant today [8].

The origins of BFB date back to the 1950s and 1960s. At the time, John Basmajian and Neal Miller published their studies on instrumental conditioning of the autonomic nervous system. Instrumental conditioning, also called operant conditioning, is based on the observation that rewarded behavior is more likely to occur again. In psychology, Edward Thorndike in 1905 called it *'The Law of Effect'* but the principles involved have always been practiced by parents and by animals trainers. With respect to the development of EEG Biofeedback, Joe Kamiya was one of the pioneers. In experiments conducted in the 1950s he demonstrated that patients were capable of recognizing when their brain produced alpha waves. Beginning in the late 1960s M.B. Sterman et al. conducted animal studies (on both monkeys and cats), which showed that instrumental conditioning had an influence on brain wave changes [9]. Moreover, they identified a spindling, low frequency beta rhythm (12–15 Hz) that he termed sensorimotor rhythm (SMR) because it was only observed over the sensorimotor cortex and it related to inhibition of sensory input and motor output. Training a patient to increase this SMR activity was shown to reduce the frequency of epileptic seizures [10]. In the 1970s M. Shouse and J. Lubar made the first attempt to use NFB in treating children with ADHD [11].

The first publications in Poland regarding the use of NFB appeared in the early 2000s in several medical circles, including the Department of Pediatrics Neurology and Rehabilitation at the University Children's Clinical Hospital in Białystok [12–14].

LEARNING THEORIES AND EEG BIOFEEDBACK

Two basic learning models are employed in neurotherapy:

1. Classical conditioning (Pavlovian conditioning), based on associating a stimulus with an autonomic response.
2. Instrumental conditioning (operant conditioning), dealing with voluntary responses that remain under conscious control.

Classical conditioning was first described by a Russian physiologist, Ivan Pavlov [15]. He studied conditioned responses in dogs. Having noticed that dogs salivated at the sight of food, he made them associate receiving food with the ring of a bell. He was soon able to elicit the dogs' salivation at the sound of the bell. The unconditioned stimulus (the food) was replaced with the conditioned stimulus (the bell sound), which evoked the same response, i.e. salivation.

Instrumental conditioning is based on Edward Thorndike's law of effect, as mentioned above. According to his findings, rewarded particular behaviors increase the probability of their recurrence in the future.

In EEG biofeedback the reward for achieving the behavior of a desired mental state, corresponding to specific brain wave patterns, is feedback to the patient that is both visual and auditory. The visual feedback is given on a computer monitor in the form of bar-graphs, calculations, animations, and games. Using the provided data, the patient tries to find the correct physiological state to fulfill the task (i.e., change their brain wave pattern to a more desirable one) and receive the reward. After multiple repetitions of a given exercise the patient achieves the set goal with more ease [1]. Moreover, with enough practice, the changes in brainwave patterns appear to last even after training has been discontinued [16].

PRELIMINARY DIAGNOSIS AND TRAINING GUIDELINES

Regarding our experience, prior to NFB therapy, a thorough medical history should be taken from the patient. Next, a diagnosis should be determined on the basis of a comprehensive examination. This information gathering may include pediatric, neurological, logopedic, rehabilitational as well as psychological examinations. This comprehensive history and examination will allow to make decisions regarding including NFB as part of a patient's treatment. Neurofeedback is not a stand-alone therapy but is usually combined with other forms of treatment appropriate for the patient. After gaining a detailed insight into the case, neurophysiological diagnostic tests are recommended. This testing includes: an electroencehalogram (EEG) followed by a qualitative and quantitative analysis after artifacts have been removed [17]. The EEG assessment usually comprises both single channel (at Cz) and 19 channel recordings. It is always done both with eyes closed and eyes open and may also be done in other mental states which include reading and mathematics. The test results will determine whether the patient is a good candidate for training. It will also enable the practitioner to discuss with the patient this form of treatment's potential efficacy and to set realistic goals for the therapy.

EEG AND QEEG DIAGNOSTICS

EEG recordings can be analyzed qualitatively in the time domain or quantitatively in the frequency domain. In qualitative analysis, commonly used in neurology and sleep studies, characteristics of EEG recordings are described in a general manner [18]. Visual inspection determines if there are abnormal wave forms (such as epileptic discharges) or patterns unusual for age and state (such as alpha intrusions during sleep) [4]. The assessment of the recordings is subjective and may vary depending on the electroencephalographer's experience and specialty. By contrast, in quantitative EEG (QEEG), broadly applied in psychological studies and neurological treatment, the signal's parameters and characteristics are subject to mathematical and statistical analysis [19]. In neurotherapy, qualitative analysis is helpful and it is supplemented by its quantitative counterpart. They both complement each other, providing a comprehensive view of the patient's clinical state [2, 17].

Preliminary QEEG tests prior to NFB training may be based on recordings from one to four sites. However, in cases of complex disorders such as depression or concussion (TBI), a quantitative electroencephalogram (QEEG) is carried out with at least 19 channels using the international 10–20 electrode placement sites [20]. The 19 channel assessment is frequently called a "full-cap" assessment because the electrodes are imbedded in a stretchable cap to ensure standard distances between electrodes.

The EEG signal is recorded in a resting position, with eyes open (EO) and closed (EC) and for various states of brain activity while performing tasks, such as reading, counting, listening etc. Before quantitative analysis can be performed, the recordings should be reviewed in order to remove artifacts [21]. These may be caused, for example, by the movement of electrodes or wires, blinking, eye or tongue movement, muscle contractions, cardiovascular activity or interference from electrical devices [22]. One should also take into account other factors influencing the brain's bioelectrical activity, such as medications, nicotine, caffeine, alcohol or drugs.

The QEEG results should be compared with data from the control group or the normative database [23], both of which constitute an objective source of information regarding the expected functioning of the brain in a given age group and in a given state of brain activity [24]. Thus, the therapist determines whether bioelectrical activity of the patient's brain deviates from the norm, and if so, to what extent and in what respect. A sequence of papers by various authors emphasizes the need for individualization in NFB [25–28]. QEEG analysis prior to NFB therapy provides reliable, non-invasive, objective, culture-free and relatively low cost evaluation of brain functioning, permitting individualization of treatment and added liability protection [27, 29].

BRAIN WAVES AND TRAINING

Model wave patterns for particular states of brain stimulation at a given age are used in order to evaluate physiological parameters of EEG recordings as well as their abnormalities. Basic types of waves present in EEG recordings include delta, theta, alpha, SMR, beta-1, beta-2 and gamma waves (Tab. I). Individual frequency bands are thought to represent different mental states [1, 4]. Note that different authors will use different frequency ranges for the Greek letter designations, so it is always best to define the frequency range and not just use a name like "beta-1".

Tab. I. Characteristics of individual frequency bands [1]

Frequency band (Hz)	Wave type	Characteristics
0.5–4	Delta	Dominant in infants up to the age of 6 months, they reflect decreased activity of pyramidal cells. They are also recorded during deep sleep and in cases of brain damage (e.g. tumors) and learning disabilities.
4–8	Theta	Dominant in children between the ages of 6 months and 6–7 years, also present in the hypnagogic state just before falling asleep, when creative thoughts may occur. Increased presence in frontal lobes is found in association with lack of concentration and difficulty focusing attention.
8–12	Alpha	Dominant in recordings from parieto-occiptal sites in adults, eyes closed (EC). Characteristic of a state of rest or "standby mode".
13–15	SMR	Sensorimotor Rhythm. Recorded in the central area of the cerebral cortex (C3, Cz and C4), indicative of relaxation and calmness, motorically still but mentally alert.
13–21	Beta-1	Dominant in states of alertness when recorded in frontal sites. Indicates concentration, increased mental activity and problem solving.
21–32	Beta-2	Indicative of a "busy-brain", which can be due to emotional arousal, anxiety and rumination.
> 30	Gamma	Frequencies over 30 Hz are not usually trained using neurofeedback as they are low amplitude and prone to EMG artifact. The 40 Hz response has been called a binding rhythm and may be associated with learning.

Neurofeedback and instrumental conditioning enable one to develop the ability to influence brain wave patterns. This, in turn, may lead to a specific behavioral change, and that is the principle that underlies effective neurotherapy: when you change brain waves you change behavior. In practice, particular frequency bands are often used (e.g. 3–7 Hz, 12–15 Hz, 13–17 Hz, 20–24 Hz), individually fine-tuned with respect to QEEG analysis as well as the patient's symptoms and needs [14].

During neurofeedback training usually 1 or 2 active electrodes recording EEG signals are placed on the patient's scalp. The remaining ones, i.e. the reference and the ground electrodes, most often are attached to earlobes but, alternatively, they may be placed over the right and left mastoid bones. Next, impedance, the resistance to the flow of an alternating current, must be checked. Its values should be lower than 5kΩ and the difference between electrode pairs should not exceed 1kΩ [30]. Higher impedance may increase artifacts, decrease real power of EEG signal and consequently distort the results of NFB training or preliminary analysis [22].

A single NFB training session usually lasts 20 to 45 minutes. It begins with a one- to three-minute baseline recording, on whose basis the training thresholds are set. Then, with consecutive training tasks or game like displays, the patient receives auditory and visual feedback when generating the desired brain wave pattern [30]. The feedback display may contain graphs, charts, numbers, animations, movies, and games [1, 31]. The duration of a full training cycle depends on the goal of training and on specific disorders, ailments and practical considerations, like the patient's availability. Training most frequently comprises several dozen sessions (over 40), with first possible changes noticeable after 20–25 visits. In complex cases of ADHD, learning disorders, Asperger's, autism, concussion, or affect disorders, the total number of sessions may increase to 50-100 training sessions or more [2].

Typical NFB training can be complemented by practicing metacognitive strategies and intellectual tasks, such as reading, counting and concentration exercises. According to classical conditioning principles, a newly learned brain wave pattern, accompanied by a new behavior, will be used while performing intellectual tasks. Audio feedback during exercises, such as reading or solving a mathematical problem, indicates that the desired state of concentration is maintained. If the sound stops, the patient should focus again on the training screen [1, 31].

BIOFEEDBACK APPLICATIONS

The list of disease entities which can be treated with BFB and NFB is a vast one and includes, among others, such disorders as ADHD, epilepsy, learning disabilities, autism, Asperger's syndrome, depression, alcohol and substance abuse, obsessive compulsive disorder (OCD), mood disorders, general anxiety disorder, tension headaches and migraines, closed head injuries, Tourette's syndrome, Parkinson's disease, dystonia, chronic fatigue syndrome and fibromyalgia [30, 32, 33]. The clinical effects of NFB in the treatment of epilepsy and ADHD can be regarded as clinically meaningful [34, 35]. For other disorders there are promising clinical outcomes using NFB but not yet enough randomized or controlled studies to establish efficacy, hence the need for ongoing research. Main factors limiting studies with BF and NFB include lack of large samples, double blinding and testing of blind validity and sham inertness. Many authors underline that the primary and essential area for improving research involves peer-reviewed and published, double-blind sham-NFB controlled trials, with large samples and follow-up [36–39].

In 2001 an expert group consisting of members of the International Society for Neurofeedback and Research (ISNR) and the Association of Applied Psychophysiology and Biofeedback (AAPB) developed a five-scale efficacy ratings for BFB based treatment of various disorders (Tab. II) [40, 41]. The rating criteria were based on the number of scientific studies, the number of cases and randomization. The overall summary is continuously updated with data from new research studies [32, 42].

Additionally, NFB can be applied in order to optimize one's mental capabilities, to improve cognitive flexibility and to learn to achieve states of alertness, relaxation and focused attention. These aspects of neurotherapy can be beneficial to students, managers, athletes, and even musicians [43–47].

According to the AAPB and ISNR, five levels of efficacy were distinguished:

Tab. II. AAPB's 2008 efficacy ratings for biofeedback based treatment of selected disorders [32, 48]

Level of efficacy	Description	Disorder	NFB	BFB
5	Efficacious and specific	urinary incontinence in females		+
4	Efficacious (based on randomized studies)	ADHD	+	
		anxiety	+	+
		headache in adults	+	+
		epilepsy	+	
		hypertension		+
		temporomandibular disorders		+
		urinary incontinence in males		+

Level of efficacy	Description	Disorder	NFB	BFB
3	Probably efficacious (based on multiple non-randomized studies)	alcoholism , substance abuse	+	
		chronic pain		+
		fecal elimination disorders		+
		headache in children	+	+
		insomnia	+	+
		arthritis		+
		traumatic brain injury	+	
2	Possibly efficacious (based on at least one non-randomized study with well defined results)	asthma		+
		cerebral palsy		+
		irritable bowel syndrome		+
		Reynaud's disease		+
		stroke	+	+
		tinnitus	+	
		depression	+	
		fibromyalgia	+	+
		Post-Traumatic Stress Disorder	+	
1	Not yet empirically supported	Autism	+	
		eating disorders		+
		multiple sclerosis (except for urinary incontinence disorders)		+
		spinal cord injuries		+

LIMITATIONS AND ADVERSE EFFECTS

Hammond and Kirk (2007) list a numerous uncontrolled case reports, showing the potential adverse effects which can occur from inappropriate NFB training, ie. „increased anxiety and agitation, panic attacks and, manic-like behavior, headaches, nausea, fatigue, sleep disturbance, anger and irritability, crying and emotional lability, incontinence, enuresis, an increase in depression, and decline in cognitive functioning, increase in somatic symptoms, vocal tics, seizures, and loss of previous symptomatics improvements" [29]. One of the reasons they mention is that the trainings are conducted on a fixed frequency bands (alpha, beta, theta, etc.) instead of individually adjusted to the problematic EEG activity. Another is that the therapy is carried out by not well educated and inexperienced practitioners.

ADHD

ADHD (Attention-Deficit/Hyperactivity Disorder) is a disorder characterized by inattention, hyperactivity and impulsivity [49]. Affecting 3–10% of school children, it is the most commonly diagnosed psychiatric disorder in this age group. If unmanaged, ADHD may lead to serious mood and behavior disturbances, as well as difficulties in concentrating and learning, which leads to underachievement in school. The treatment usually involves stimulant medications (amphetamine derivatives, among others), which, although effective, have numerous adverse effects. Stimulants, though effective for the short-term management of behavior, have not been shown to improve learning and do not have lasting effects. The effectiveness of cognitive-behavioral therapy as well as family therapy is limited [50, 51].

Monastra et al. (2002) found, through QEEG analysis, that 85–90% of ADHD patients demonstrated excess theta activity, decreased alpha and beta activity, and increased theta/alpha and theta/beta ratios, especially at frontal and central sites [49]. It is believed that high theta activity correlates with attention deficit, whereas low SMR is correlated with hyperactivity and impulsiveness. A significantly smaller number of patients showed the prevalence of beta waves, low alpha activity, and decreased theta/beta ratios. Patients with increased beta activity do not respond well to psychostimulants whereas about 70–75% of those with excess theta will show reduced symptoms, especially with respect to hyperactivity [52, 53]. Both groups can benefit from individualized NFB training.

In 1998, the results obtained at the ADD Centre in Toronto, Canada using neurofeedback on a group of 111 subjects with ADHD were published. The 98 children and 13 adults underwent 40 sessions. The goal of these sessions was to decrease slow wave activity (mainly 4–7 Hz) and increase fast wave activity (15–18 Hz) for most patients and 13–15 Hz for patients with hyperactivity and impulsiveness). Metacognitive strategies were taught during at least one segment of each session. The therapy succeeded in producing significantly lower theta/beta ratios. As a result, the percentage of children taking methylphenidate dwindled from 30% before the training to 6% after the training. An improvement in focusing and sustaining attention was observed with significant improvements on the objective Test of Variables in Attention (TOVA). The Weschler Intelligence Scale (IQ) scores rose with an average increase of 12 points [31].

In 2002, Monastra et al. (2002) conducted a study (with a control group) on 100 patients with ADHD aged 6 to 19. They were split into two groups. Each of the 49 children in the first group underwent a year-long therapy, which included methylphenidate, school consults and parenting classes. The other group received the same therapy, but additionally attended neurofeedback sessions. The results were evaluated in the course of using the medication and a week after the patients stopped taking it. While both groups demonstrated significant clinical improvement, only those patients who received EEG training retained the beneficial effects of the treatment after they stopped taking medication. Also, their QEEG showed decreased slow wave activity. The above study indicates that the effectiveness of psychostimulant medication is short-lived, whereas neurotherapy with NFB based on learning mechanisms brings lasting improvement [54].

The meta-analysis investigating the effect of NFB in children conducted by Arns at al. (2009) included 15 studies, from which 6 were with randomization and 3 compared with stimulant medication, with a total of 1194 subjects. Final conclusion were that "NFB treatment for ADHD can be considered "Efficacious and Specific" (Level 5 according to AAPB and ISNR guidelines) with a large effect size for inattention and impulsivity and a medium effect size for hyperactivity" [34]. This result was undermined by Lofthouse at al. (2012), who applying the American Psychiatric Association guidelines concluded that NF efficacy for pediatric ADHD is only "probably efficacious" [39]. Authors suggested that more research with randomization, double-blind with testing the validity of the blinded, sham-NF-controlled trials with testing the inertness of sham-NFB and large samples are needed. It would improve the importance of further research and reduce methodological misstatements.

In 2012 the summary report prepared by the American Academy of Pediatrics, biofeedback was recommended as being among the most effective interventions (Level 1 – Best support) in treating ADHD [55].

EPILEPSY

Epilepsy invariably constitutes a serious diagnostic and therapeutic challenge. Antiepileptic medications still have numerous adverse effects, and what is more, 20–30% of the patients are resistant to pharmacotherapy [56]. EEG biofeedback is therefore a valid complementary treatment that can substantially improve their prognosis [48, 57]. Antiepileptic effects of SMR training were demonstrated by M.B. Sterman, who in the late 1960s studied the convulsive response to hydrazine [58]. This toxic substance present in rocket fuel was feared to cause seizures in people working on the manned space flights for NASA. After receiving a grant to study the convulsant effects of hydrazine, Sterman used 50 cats of which 10 previously had a six-week training aimed at increasing SMR activity. All cats were administered a 9 mg/kg dose of hydrazine. Seizures in the control group occurred approximately 60 minutes after the injection. They were preceded by vomiting, increased respiratory rate, excessive salivation and hyperactivity. In cats with SMR training the seizures did not occur at all or were preceded by a longer prodromal period (80–220 min) However, premonitory symptoms were present in both groups, which showed that SMR training, while increasing the seizure threshold, did not change the toxic properties of hydrazine [9, 59, 60]. There was thus a serendipitous finding that training to increase SMR activity in the mammalian brain made it resistant to seizures. Subsequent work with monkeys and humans confirmed the finding.

One of the EEG biofeedback methods applied in treating epileptic seizures is based on inhibiting slow wave activity in seizure onset areas and enhancing SMR activity over the sensory-motor strip. According to Sterman, a rise in SMR wave production from the ventrobasal nuclei of the thalamus causes a decrease in the frequency of the red nucleus discharge, located in the midbrain and connected by nerve fibres to muscle spindles [61]. Inhibiting the red nucleus activity decreases muscle tone. Additionally, enhancing SMR activity, by increasing the excitation threshold of pyramidal cells that produce EEG activity, diminishes both the frequency and intensity of epileptic seizures as well as shortens their duration [62, 63].

In 2000, M.B. Sterman's review of the studies from 1972–1996 on a total of 174 epileptic patients confirmed the effectiveness of SMR training. As many as 142 patients (82%) demonstrated clinical improvement with at least a 50% reduction in the number of seizures [64]. One of the studies reviewed, conducted by Lubar and his colleagues, used an ABA design. During the first phase of rewarding an increase in SMR production their seizure rates decreased, and during the second stage when a reduction of SMR was rewarded, seizures increased. In the third phase, after training the correct parameters as at the beginning, seizures decreased again. Their results stated that uncontrolled epilepsy could be treated with NFB or made worse if the wrong kind of NFB was conducted. Though an unethical research design for human studies, now that efficacy for SMR training has been established, this ABA design study stands as a powerful reminder that training success is specific to training the amplitude of a specific frequency band in the right direction for a specific disorder.

Another example of that basic principle is that previously cited research shows that you decrease theta amplitudes for successful treatment of children with ADHD [22] but increase theta amplitudes to improve aspects of performance (especially the emotional interpretation of the music) in skilled musicians [46, 65]. Obviously, these two groups would have different pre-training EEG profiles; since highly trained musicians have no problem with sustained attention, they would not show the excess theta characteristic of people with ADHD. A separate meta-analysis by G. Tan et al. in 2009 encompassed 10 studies conducted between 197–2005 that met his criteria for analysis. Across the studies, there was a total of 87 patients with drug-resistant epilepsy. With EEG biofeedback, the reduction in seizure frequency of > 50% was observed in 74% of the subjects [48].

AUTISM AND ASPERGER'S SYNDROME

Autism is a pervasive developmental disorder characterized by impaired social interaction and communication, and by restricted stereotypical behavior patterns [66]. It is often defined as a spectrum condition, which means that its symptoms can be manifested in various forms and with different intensity. Its etiology is multifactorial, i.e. both genetic and environmental [67]. Although exact causes have not yet been determined, contemporary studies link autism to biological and neurological malfunction of the brain [68, 69].

Early diagnosis and treatment are essential in ensuring an autistic child's optimal development. Traditional methods of treating autism include pharmacology as well as behavioral techniques, such as speech therapy, sensory therapy, music therapy and hippotherapy (therapeutic horseback riding) [70, 71]. Despite a large number of therapeutic methods commonly used with autistic children, no therapy at present produces satisfactory results. However, in recent years neurofeedback as a neurophysiological treatment has been gaining significance [72].

B. Jarusiewicz conducted a study into the effects of EEG biofeedback on autistic patients [73]. The results for 12 children (11 boys, 1 girl), aged 4–13, were compared with a control group of 20 children. Patients attended an average of 36 training sessions (from 20 up to 69). The treatment produced a 26-percent reduction in ATEC symptom scores (The Autism Treatment Evaluation Checklist). An improvement was also reported in parent interviews.

Another study was conducted by R. Coben et al. on a group of 37 autistic children with a control group of 12 children [74]. The training protocols were chosen individually, based on QEEG. The results showed significant improvement in patients who received NFB training, compared with the control group. According to ATEC scoring, ASD symptoms decreased by 40% and EEG coherence decreased in 76% of the subjects.

Holtman at al. reviewed case reports and controlled trials prior to 2011, investigating the effectiveness of NFB as a treatment of the core symptoms of ASD. They concluded that existing evidence does not support NFB as a treatment recommended for ASD core symptoms, mostly showing an improvement in comorbid ADHD symptoms [72]. Kouijzer at al. evaluated the effects of NFB in children and adolescents with ASD in a pretest-posttest control group design study. 38 patients were randomly divided to NFB, skin conductance biofeedback and waiting list group, participated in 40 individual sessions provided twice a week. QEEG analysis indicated that 54% of the participants reduced their slow activity in EEG and improved cognitively. Outcomes suggested that NFB can be used to regulate EEG activity in scope of improvment in cognitive flexibility but does not result in significant reduction in symptoms of ASD [75].

Unlike other autism spectrum disorders, Asperger's syndrome does not impair the development of speech and cognitive functions [76]. Among other EEG differences, patients with Asperger's syndrome demonstrate low activity in the right hemisphere areas responsible for emotion processing. Clinical manifestations of abnormal activity in the right temporal-parietal junction include sensory aprosodia, i.e. the inability to comprehend emotion in speech and gestures, and interpret nuance and innuendo. This may be accompanied by abnormal activity in the right frontal lobe associated with motor aprosodia, i.e. the inability to convey emotion in speech through rhythm, pitch and tone of voice. No effective pharmacological therapy for Asperger's syndrome is known, though many drugs, ranging from stimulants to antidepressants and antipsychotics, are frequently prescribed to try to reduce symptoms. Psychotropic drugs do not reduce the basic difficulties in social interaction and communication [77] and some, such as stimulants, may increase anxiety. Neurofeedback, combined with heart rate variability, skin temperature and muscle tension biofeedback, can be an effective component of therapy [33, 78].

In 2009, L. Thompson and M. Thompson published the results of a study on 150 patients with Asperger's syndrome and 8 patients with a diagnosis of low functioning autism [79]. Based on the qualitative analysis of the 19-channel EEG recordings, 83% of the Asperger's patients demonstrated lower activity in the right posterior temporal area, compared with the homologous area in the left hemisphere (P8 > P7) for slow wave activity), with increased alpha activity at 8–9 Hz. In 86% of the cases, Fz and Cz sites registered excess slow theta waves and a higher theta/beta ratio, compared with normative databases. After 40 sessions of training the outcomes were positive, with reduced symptom severity measured by continuous performance tests and parent questionnaires and a 10 point gain in IQ scores using the Wechsler Intelligence Scales.

MIGRAINES AND TENSION TYPE HEADACHES

BFB training has also found its application in migraine and tension-type headache therapy. Common techniques include heart rate variability, skin temperature, and muscle tension training, all of which complement pharmacological and behavioral therapy [80, 81].

In 2010, D. Stokes and M. Lappin published the results of a study on 37 migraine patients (aged 9–79), who underwent a therapy consisting of EEG biofeedback, hemoencephalography (HEG biofeedback) and skin temperature biofeedback [82]. All patients had been experiencing at least one migraine attack a month and had been taking at least one anti-migraine medicine. The results, evaluated 14 months after the treatment, which consisted of an average of 20 sessiogbbgns, showed at least a 50-percent reduction in migraine frequency in 70% of the patients.

In J. Walker's study with a control group, a total of 71 patients (aged 17–62) with recurrent migraine headaches were examined [28]. Their QEEG showed an excess of beta activity (21–30 Hz) in 1–4 cortical areas. Forty six patients received neurotherapy, reducing amplitudes of 21–30 Hz activity and increasing the amplitude of 10 Hz waves. The remaining 25 patients in the control group continued their pharmacological treatment. In the EEG training group 54% of the patients experienced cessation of their migraines, and a further 39% showed a reduction in migraine frequency of more than 50%. In the control group only 8% of the subjects experienced a decrease in migraine frequency of greater than 50% and a reduction of less than 50% was observed in 20% of the subjects. As many as 68% of the patients in the control group reported no change in headache frequency.

One can state that combining NFB and BFB training positively influences the effectiveness of migraine headache treatment, increases the patients' chances for normal everyday functioning and improves their overall quality of life [28].

Traumatic brain injury and post-concussion syndrome

The most frequent causes of head trauma are traffic injuries, falls from height, swan dives, combat sports, violence and workplace accidents. One aftereffect of head injuries is the post-traumatic syndrome. The symptoms include headaches, dizziness, disturbance in memory and attention, changes in personality, and increased nervousness [83, 84]. Numerous studies have confirmed the efficacy of NFB in reducing these problems and improving the patients' clinical state [85]. Training protocols and parameters are determined on the basis of QEEG comparison with normative databases [86, 87]. The relevant publications indicate different numbers of training sessions, ranging from 20 to 167, depending on the type of trauma and the training protocol utilized [88–90].

In the Department of Pediatric Neurology and Rehabilitation of the University Children's Clinical Hospital in Białystok, NFB therapy was used on a 23-year-old student who, as a result of a traffic accident, had sustained a craniocerebral injury with concussion and a brain and brainstem contusion [91]. The patient was comatose for several days. His neurological examination showed symptoms of left faciobrachial paresis and significant memory loss. One of the forms of therapy was EEG biofeedback consisting of 40 individualized training sessions. The treatment measurably improved his memory and concentration.

LEGAL REQUIREMENTS

In 2011 the Biofeedback Section of the Polish Society of Clinical Neurophysiology (PTNK) was founded [92]. This led to drawing up the criteria for obtaining EEG Biofeedback therapist and specialist licenses. A doctor applying for the license is required to complete the training, which duration depends on the applicant's specialty (medicine, psychology, etc.) and on the license for which he or she is applying. Gaining expertise and developing new skills in the field of biofeedback is made possible thanks to courses and annual conferences held by international organizations, such as the Biofeedback Foundation of Europe (BFE), the Biofeedback Certification International Alliance (BCIA), the Association of Applied Psychophysiology and Biofeedback (AAPB), the International Society for Neurofeedback and Research (ISNR) and the Polish Society of Clinical Neurophysiology [40, 41, 92-94]. BCIA is the most recognized international standard in biofeedback certification. Online training is also available and is becoming increasingly popular.

Neurotherapy should be practiced by qualified and licensed clinicians. Training sessions conducted by inexperienced and unknowledgeable persons may prove not only ineffective, but also harmful. Improperly done therapy can lead to adverse effects and exacerbation of symptoms. The ability to operate the instrument is important but not sufficient to provide proper rehabilitation treatment [2, 17].

CONCLUSIONS

The Neurofeedback method combines elements of psycho- and neurotherapy. The training is a safe, physiological aid to treatment and rehabilitation. NFB enables one to influence the brain's bioelectrical activity, thus enhancing neurorehabilitation of various neurological, psychiatric and psychological disorders stemming from dysregulation of central nervous system mechanisms. These techniques can also be employed to enhance performance in athletes and other high performing individuals. Still, in the case of many disease entities, further research is necessary to verify the method's efficacy including studies with large samples, follow-up, blinding and sham control trials.

Owing to the fact that NFB trainings entails modifying a person's behaviour and central nervous system functioning, all procedures should be overseen by a specialist who is qualified to make the diagnosis of the person's disability and track their improvements.

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