The use of EEG biofeedback to improve memory, concentration, attention and reduce emotional tension

Zastosowanie EEG biofeedback w celu poprawy pamięci, koncentracji, uwagi i zmniejszenia napięcia emocjonalnego

Joanna Biakowska 1 (ABDEF), Dorota Mroczkowska 1 (ABDF), Martyna Wickland-Bialkowska 2 (BEF)

1 Department of Public Health, Faculty of Health Sciences, Collegium Medicum, University of Warmia and Mazury in Olsztyn, Clinical University Hospital in Olsztyn, Poland
2 Voivodeship Specialist Children’s Hospital in Olsztyn, Poland

Key words
EEG biofeedback, neurorehabilitation, computer software in rehabilitation

Summary
Biofeedback is a method of giving patients computerised feedback signals about changes in the physiological state of their body. This allows them to learn how to consciously modify functions not controlled consciously. This method allows active and conscious involvement of the patient in controlling their own physiological processes. The therapy aims to regulate the frequency of human brain waves. The human brain produces different ranges of waves that are characteristic of different types of human activity, a mechanism used in this method. The use of this method in routine rehabilitation with a specifically designed computer programme provides physicians, physiotherapists, neuropsychologists and speech therapists with a new tool for treatment, opportunities for improvement in treatment, and helps them better plan and develop treatment strategies using Evidence-Based Medicine. The aim of the work is to discuss how EEG Biofeedback software can be applied in neurorehabilitation and to discuss the use of EEG Biofeedback software in order to improve memory, concentration, attention, reduce emotional tension, increase resistance to stress, improve self-control, self-esteem and relaxation.

Słowa kluczowe
biologiczne sprzężenie zwrotne, neurorehabilitacja, EEG Biofeedback

Streszczenie
Biologiczne sprzężenie zwrotne (biofeedback) jest metodą polegającą na podawaniu pacjentowi sygnałów zwrotnych o zmianach stanu fiziologicznego jego organizmu przez system komputerowy, dzięki czemu może on uczyć się modyfikować funkcje, które nie są kontrolowane świadomie. Metoda ta pozwala na aktywne zaangażowanie pacjenta w kontrolowanie własnych procesów fiziologicznych. Terapia EEG-biofeedback ma na celu regulację częstotliwości i amplitudy fal mózgowych. Jest to możliwe dzięki wytwarzaniu przez mózg różnych fal, które są charakterystyczne dla określonych typów aktywności. Podczas zmiany aktywności mózgu pacjenta w ustawionym przez terapeuta przedziale, komputer „nagradza” osobę ściślezącą punktami sygnalizowanymi dźwiękiem. Pozwala to choremu nauczyć się reakcji własnego mózgu i modyfikować jego pracę. Trenująca osoba może świadomie modyfikować rodzaj fal mózgowych i dzięki temu osiągać optymalny stan równowagi fiziologicznej. Wsparcie rutynowej rehabilitacji poprzez zastosowanie specjalnego programu komputerowego daje lekarzom, fizjoterapeutom, neuropsychologom oraz neurologom nowe narzędzie i możliwości usprawniania oraz ułatwia organizację i planowanie leczenia w oparciu o Evidence-Based Medicine. Celem pracy jest omówienie zastosowania w neurorehabilitacji oprogramowania informatycznego EEG Biofeedback w celu poprawy pamięci, koncentracji, uwagi, zmniejszenia napięcia emocjonalnego, zwiększenia odporności na stres, poprawy samokontroli, samooceny i relaksacji.
INTRODUCTION

EEG Biofeedback (EEG-BFB) is recognised in Poland by the Polish Society of Clinical Neurophysiology as one of the five disciplines of clinical neurophysiology in addition to electromyography, electroencephalography, autonomic system studies and evoked potentials. It belongs to forms of neuromodulation, which means “change in neuronal functioning”\(^1,2\). EEG-BFB technology has been shown to promote recovery due to the neuroplasticity-related properties of the brain\(^1,4\). The EEG-BFB method, which is one of the methods of applied psychophysiology, assumes that specific brain wave patterns correlate with mental disorders or syndromes. Irregularities in the area of appropriate mental functions are characterised by a specific image of brain waves, appropriate for a given disorder\(^1,3,7,8\). The improvement of behavioural functioning is possible by changing the percentage of specific brain waves and their amplitudes. These changes occur as a result of enhancing the desired frequencies and inhibiting those undesirable. Jiang et al. indicate that EEG-BFB therapy increases patient’s self-esteem, improves mood and motivation, and slows down biological aging process\(^6\).

STUDY AIM AND METHODOLOGY

The aim of the work was to present the operating principles and possibilities of using EEG-BFT in memory, concentration and attention disorders as well as increased emotional tension. The study was based on a narrative review of literature on the subject and the authors’ own experience of working at the University Clinical Hospital.

The following research questions were posed:
1. In what disease entities is EEG-BFB used?
2. What is the operating principle, course of therapy and EEG-BFB training protocol?

RESULTS

The use of EEG-BFB after stroke, head and brain injuries, in the treatment of cerebral palsy, migraines, chronic headaches, in asthma, bedwetting, diabetes, cardiovascular diseases, attention deficit hyperactivity disorder – ADHD, in autism, dyslexia, dysgraphy, dyslexia, dyscalculia, concentration, attention, memory and sleep disorders, in Alzheimer’s and Parkinson’s disease, Tourette’s syndrome, anorexia, bulimia, neurosis, anxiety, depression, mood disorders, schizophrenia and addiction treatment\(^10,11\), as well as the possibility of using this method in healthy people, has been described in the literature\(^13\).

The way EEG Biofeedback works

The use of EEG-BFB together with methodological and clinical recommendations has been presented in many review articles\(^5,8,10-15\). EEG Biofeedback uses the biological link between the patient’s mental state and neurophysiological brain function. The application of this method in patient therapy is possible thanks to computer technology, the function of which is to perform qualitative and quantitative assessment of EEG recordings. The wave amplitude is processed by a computer programme via quantitative electroencephalogram analysis technology. EEG recording depends on many factors such as age, maturity level of the central nervous system (CNS) or psychomotor state of the subject. It is assumed that synchronous rhythms generated in different areas of the brain, and above all, the temporal and spatial correlations between them, are a reflection of mental processes related to perception, memory and attention\(^16\). Sensorimotor rhythm (SMR) activity at a frequency of 12-15 Hz correlates with the processing of sensory information received by the senses. SMR is associated with a state of mental serenity, alertness and concentration. A 15-20 Hz beta rhythm correlates with mental activity, promoting logical thinking and verbal communication. Theta rhythm with a frequency of 4-8 Hz correlates with drowsiness, internal orientation, lack of concentration regarding external stimuli. It is associated with extracting information from the memory and the ability to control responses to specific stimuli. In adults, the dominance of this rhythm is associated with attention deficit disorder. A beta2 rhythm of 20-35 Hz correlates with anxiety, nervousness, and irritation\(^17\).

EEG biofeedback training protocol

The EEG-BFB therapy plan contains information on which regions of the brain the therapist will affect and what rhythms of the brain will be inhibited and which will be strengthened\(^18\). The decision to choose a rehabilitation plan depends on the result of neurophysiological and psychological assessment of the type and severity of the patient’s dysfunction. This decision is made after neuropsychological diagnosis and so-called brain mapping, which provides information about the quantitative EEG pattern. The use of various EEG-BFB protocols and research methods\(^10,11\) is described in the subject-based literature. Kober et al. use therapeutic protocols that seek to reduce excessive slow waves and enhance brain bioelectrical activity within the 10-12 Hz range. In addition, protocols that compare the effects of enhancing brain bioelectrical activity from the 10-12 Hz and 12-15 Hz ranges are used\(^14\), or protocols enhancing brain bioelectrical activity within the 12-15 Hz range\(^1\). The most commonly applied treatment protocols mainly focus on strengthening the alpha or beta rhythm, or inhibiting theta and beta2\(^10,19\). Many variables influence the selection of the best training protocol. In addition to the patient’s physical and mental state, it is important how s/he reacts.
to therapy. Gender, education and socioeconomic status are not without significance. Moreover, the patient may have individual goals that s/he would like to achieve as a result of therapy. The most common determinant of the effectiveness of therapy are the results of patients’ functioning before and after EEG-BFB therapy, performed using neuropsychological tests.

**EEG biofeedback course of therapy**

Before starting therapy, a computer diagnostic examination of the brain wave recording is performed, thanks to which the therapy is adapted to the individual needs of each patient. During diagnostics and therapy, electrodes are placed on the patient’s head in accordance with the “10-20” standard, approved by the International Federation of Electroencephalography and Clinical Neurology (Figure 1).

During each exercise, two cup-electrodes are adhered to the scalp with a special paste and two ear electrodes (clips attached to the earlobe flakes). During therapy, the patient observes a videogame. Graphic charts are displayed on the monitor, in which elements responsible for changing parameters resulting from the test protocol are highlighted (Figure 2). The therapist selects the stimulation board depending on the purpose of the training. During EEG-NFB (Electroencephalographic neurofeedback) therapy, information about the amplitude and frequency of the generated rhythms appears on the therapist’s monitor. The patient’s task is to open the sashes of the window (strengthening the promoted rhythm of SMR and beta). The patient opens the curtains by halting the theta rhythm, while a better view outside the window (without fog) is achieved by inhibiting the beta2 rhythm. The patient receives a “reward” in the form of points and a sound signal when his/her brain produces a rhythm with the desired frequency and amplitude. In this way, s/he obtains the ability to consciously control the bioelectrical activity of the brain. With repeated EEG-BFB sessions, the desired behaviours lead to a permanent changes in brain function. The number of therapeutic sessions is individually adjusted to the patient’s clinical condition. The results of EEG-BFB training sessions are available in the form of a report (tables with values of rhythm amplitudes, percentages and coefficients). After completing EEG-NFB therapy, the therapist has the opportunity to analyse its effects in the form of a so-called patient learning curve.

In the opinions of some authors, the use of EEG biofeedback is disputable, therefore, it would be advisable to conduct clinical trials involving a broader group of patients. In the case of EEG biofeedback, the difficulty is to design tests with a double-blind trial to exclude or confirm the placebo effect. Long-term, randomised, double-blind, non-controlled trials could ultimately settle doubts about the introduction of new therapeutic methods into standard care. Unfortunately, long-term studies using placebos are often not possible because they may contradict medical ethics.

**CONCLUSIONS**

Supporting therapy with the use of special computer programmes provides new tools and possibilities for rehabilitation and facilitates the organisation as well as planning of treatment strategies based on Evidence-Based Medicine. IT applications allow to diversify tedious and long-term therapy, increasing the patient’s motivation to practice. The essence of the EEG-BFB...
method is based on the plasticity of the nervous system, thanks to which, even after deep brain damage, it is possible to recover lost mental, motor, sensory and vegetative functions. In response to damage, the brain initiates spontaneous repair processes. Complex rehabilitation of patients started early, leads to the recovery of lost functions by developing compensatory mechanisms. The course of this process is faster if systemic stimulation is additionally delivered externally, as is the case of the EEG-BFB method. The process of structural and functional changes within the neural networks is initiated. These changes are an important mechanism of the learning process. EEG-BFB therapy improves the pattern of brain bio-electrical activity, which is related to successive clinical improvement in the sphere of speech and memory disorders. Plasticity changes in the brain depend on the frequency of stimuli repetitions and the duration of intervals between them. Rehabilitative exercises, based on EEG-BFB mechanisms, strengthen brain plasticity by reinforcing the flow of information in existing synaptic connections and influencing the creation of new ones. Neurplasticity processes have been shown to be age-dependent. Many authors have described the effect of weakening neurogenesis as a result of aging of the body. In recent studies using EEG-BFB, it is shown that the age of patients should be taken into account when selecting a rehabilitation plan. According to the criteria of the Association for Applied Psychophysiology and Biofeedback and the International Society for Neuronal Regulation of 2002, five levels of effectiveness of EEG-BFB therapy are distinguished. Compared to pharmacological and placebo treatment, EEG-BFB therapy has statistically higher effectiveness in anxiety, ADHD and migraine disorders as well as stress urinary incontinence in women. The effectiveness of EEG-BFB therapy in patients after stroke, especially in improving concentration, they argue that, on the one hand, it has a positive effect on memory functions, while on the other, it leads to the normalisation of bioelectrical activity of the patient’s brain with pathological brain activation patterns. Reichert et al. demonstrate improved functioning in the area of non-verbal and verbal learning tasks. They claim that enhancing the SMR rhythm amplitude can be successfully used in stroke patients and seniors. Researchers also point to the prolonged effects of EEG-BFB therapy in the form of reducing anxiety, increasing levels of motivation, learning ability, improving intellectual function and quality of sleep. In a study by Kob et al., 70% of patients undergoing EEG-BFB therapy achieved significant improvement in short- and long-term memory, regardless of the protocol used. Patients in whom the SMR protocol was applied exhibited greater improvement regarding short-term, visual-spatial memory, while in the group of patients with the beta-enhancing protocol, working memory was mainly improved. The enhancement of cognitive function in both groups was greater than the improvement in cognitive function in the group where only traditional rehabilitation methods were used. The question of the duration of EEG biofeedback therapy is a debatable issue. Some researchers say that these changes are permanent, while others indicate that the effects of training sessions last up to 6 months after the completion of therapy. In a study by Ko et al. (2002), 70% of patients undergoing EEG-BFB therapy achieved significant improvement in short- and long-term memory, while in the group where only traditional rehabilitation methods were used, the effects of training sessions lasted up to 6 months after the completion of therapy.

References

1. Schwartz M.S., Schwartz N.M. Definitions of biofeedback and applied psychophysiology. In: Schwartz M.S., Andrasik F. (eds): Biofeedback: a practitioner’s guide, 3rd ed. Guilford, New York 2003: 29-39.
2. Russell-Chapin L.A., Chapin J.T. Neurotherapy and Neurofeedback: Brain-Based Treatment for Psychological and Behavioral Problems. Routledge, New York 2013: 23-29.
3. van Dokkum L.E.H., Ward T., Laffont I. Brain computer interfaces for neurorehabilitation – its current status as a rehabilitation strategy post-stroke. Ann Phys Rehabil Med 2015; 58(1):3-8.
4. Liu Z.X., Gillner D., Tannock R., Woltering S. EEG alpha power during maintenance of in formation in working memory in adults with ADHD and its plasticity due to working memory training: A randomized controlled trial. Clin Neurophysiol 2016; 127: 1307-1320.
5. Pichiorri F., Mrachacz-Kersting N., Molinari M., Kleih S., Kübler A., Mattia D. Brain-computer interface based motor and cognitive rehabilitation after stroke – state of the art, opportunity, and barriers: summary of the BCI Meeting 2016 in Aislomar Brain-Computer Interfaces 2016; 4:1-2, 53-59.
6. Remsk A., Young B., Vermilyea R., Kiekkober L., Abrams J., Evans F., Etkin S., et al. A review of the progression and future implications of brain-computer interface therapies for restoration of distal upper extremity motor function after stroke. Expert Rev Med Devices 2016; 13: 445-454.
7. Droppo P., Haltzczuk I., Rejdak K. Monitorowana czynność bioelektryczna mózgu u pacjentów w stanie zaburzonej przytomności leczonych na oddziałach intensywnego nadzoru neurologicznego (ICU). X Zjazd Polskiego Towarzystwa Neurofizjologii Klinicznej, “Nowoczesna elektrofizjologia w praktyce klinicznej”, Kraków 2015. [Available from: https://szkolenia.mp.pl/szkolenia/bigsite.html?congress_id=10714&page_id=127030].
8. Renton T., Tibbles A., Topolovec-Vranic J. Neurofeedback as a form of cognitive rehabilitation therapy following stroke: A systematic review. PLoS One 2017; 12(5): e0177290.
9. Jiang Y., Abiri R., Zhao X. Tuning Up the Old Perception in Stroke: A Randomized Control Trial. J Phys Ther Sci 2015; 27: 673-676.
10. They claim that enhancing concentration...
enhances efficacy of motor imagery-based training in poststroke victims: a pilot study. Stroke 2013; 44(4): 1091-1096.
22. Sun L., Yin D., Zhu Y., Fan M., Zang L., Wu Y., et al. Cortical reorganization after motor imagery training in chronic stroke patients with severe motor impairment: a longitudinal fMRI study. Neuroradiology 2013; 55(7): 913-925.
23. Oweiss K.G., Badreldin I.S. Neuroplasticity subserving the operation of brain-machine interfaces. Neurobiol Dis 2015; 83: 161-171.
24. Hattori N., Swan M., Stobbe G.A., Uno Moto J.M., Minoshima S., Djang D., et al. Differential SPECT activation patterns associated with PASAT performance may indicate frontocerebellar functional dissociation in chronic mild traumatic brain injury. J Nucl Med 2009; 50: 1054-1061.
25. Billard JM. Ageing, hippocampal synaptic activity and magnesium. Magnes Res 2006; 19(3): 199-215.
26. Castellano J.M., Mosher K.I., Abbey R.J., McBride A.A., James M.L., Berdnik D., et al. Human umbilical cord plasma proteins revitalize hippocampal function in aged mice. Nature. 2017; 544(7651): 488-492.
27. Zieliński K. Procesy warunkowania. [In:] Gór-ńska T., Grabowska A., Zagrodzka J. (eds.). Mózg a zachowanie. PWN. Warszawa 2006: 375-395.
28. Shindo K., Kawasaki K., Ushiba J., Ota N., Ito M., Ota T., et al. Effects of neurofeedback training with an electroencephalogram-based brain-computer interface for hand paralysis in patients with chronic stroke: a preliminary case series study. J Rehabil Med 2011; 43(10): 951-957.
29. Cincotti F., Fichiori F., Aricò P., Aloise F., Leotta F., de Vico Fallani F., et al. EEG-based Brain-Computer Interface to support post-stroke motor rehabilitation of the upper limb. Conf Proc IEEE Eng Med Biol Soc 2012; 4112-4115.
30. Constanas A., Pin-barre C., Temporado J.J., Decherchi P., Laurin J. Influence of Aerobic Training and Combinations of Interventions on Cognition and Neuroplasticity after Stroke. Front Aging Neurosci 2016; 8:164-165.
31. Opie G.M., Vosnakis E., Ridding M.C., Ziemann U., Semmler J.G. Priming theta burst stimulation enhances motor cortex plasticity in young but not old adults. Brain Stimul 2017; 10(2): 298-304.
32. Zich C., Debener S., Thöne A.K., Chen L.C., Kranczioch C. Simultaneous EEG-fNIRS reveals how age and feedback affect motor imagery signatures. Neurobiol Aging 2017; 49: 183-197.
33. Yucha C.B., Montgomery D. Evidence-based practice in biofeedback and neurofeedback. Faculty Publications 2008: 4-5.
34. Cannon K.B., Sheryn L., Lyke R.R. Neurofeedback efficacy in the treatment of a 43-year-old female stroke victim: a case study. J. Neurother 2010; 14(2): 107-121.
35. Mroczyńska D., Białkowska J., Rakowska A. Neurofeedback as supportive therapy after stroke. Case report. Post Psychiatr Neurol 2014; 23(4): 190-201.
36. Szubert-Czarnocka MM. Biofeedback jako metoda komplementarna w leczeniu zaburzeń lękowych. Neuropsychiatria 2014; 6(3): 141-147.
37. Lubar J.F. Discourse on the Development of EEG Diagnostics and Biofeedback for Attention-Deficit/Hyperactivity Disorders. Biofeedback Self Regul 1991; 16(3): 201-225.
38. Mesel V., Servera M., Garcia-Banda G., Car- do E., Moreno I. Reprint of “Neurofeedback and standard pharmacological intervention in ADHD: a randomized controlled trial with six-month follow-up”. Biol Psychol 2014; 95: 116-125.
39. Steiner N.J., Frenette E.C., Rene K.M., Bren- nan R.T., Perrin E.C. In-school neurofeed- back training for ADHD: sustained improve- ments from a randomized control trial. Pedi- atrics 2014; 133(3): 483-492.

Address for correspondence
Joanna Białkowska
ul. Warszawska 30, 10-082 Olsztyn, Poland
Phone: +48 504-053-403
e-mail: bialkowska.j@gmail.com