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The neurofeedback method – how to train the brain

***Abstract**. This text discusses neurofeedback training, explains the concept of such training as well as the issues and problems involved. It points out the areas and medical problems where this method is useful. Finally, the text attempts to present the neurofeedback from technical, construction and user perspectives.*

***Streszczenie**. Artykuł ten oparty jest na zagadnieniu treningu neurofeedback. Stara się przybliżyć, na czym polega koncepcja takiego treningu, z jakimi zagadnieniami jest związany. Wskazuje dziedziny i problemy, w których taka metoda terapii jest przydatna. Stara się przedstawić zagadnienia związane z neurofeedbackiem zarówno od strony konstrukcyjnej, technicznej jak i użytkowej.* ***Metoda treningu typu neurofeedback**.*

Keywords: biofeedback, neurofeedback, eeg
Słowa kluczowe: biofeedback, neurofeedback, eeg

doi:10.12915/pe.2014.04.61

Introduction

Neurofeedback is one of the most effective among all the treatments categorized as biofeedback. Biofeedback, or biological feedback, uses information about physiological changes in a patient to provoke (and through repeated training consolidate) desired reactions in the said patient. The most often measured physiological parameters defining the modality of the treatment include: galvanic skin response (GSR), temperature, breathing, heart rate, electromyography (EMG). In neurofeedback the feedback information include certain characteristics of nervous system activities (EEG). EEG frequency distribution is especially important, since specific ranges of component frequencies of the signal (called rhythms) refer to commonly known and medically described brain activities (Alpha, Beta, etc.). Depending on the situation and mood certain bands may be expressed stronger than other and vice versa - changes in brain activity influence person's psychophysical state. The Neurofeedback Method exploits the fact, that with effort of will and methodical training certain bands can gain advantage over other and thus influence the patient's mood and his skill of conscious expression of learned state. Thus with appropriate biofeedback training we want to change the EEG frequency characteristic. The results of EEG spectral analysis of the treated person are presented as symbolic graphical parameters. Observation of the changes in brain activity allows the patient to try to re-model brain activity according to directives adopted in the beginning of the treatment. This re-modelling is the goal of the training.

Currently to achieve this effect we use electrodes attached to patient's head and plugged into biological amplifiers (also called EEG head boxes). The signal is recorded and digitalized (in the described solution by sigma-delta converters) and then sent to the computer for further analysis. Apart from preliminary filtration, decimation and other actions allowing to obtain a signal with suitable parameters, the main analysis consists of the previously mentioned frequency analysis based on fast Fourier transform (FFT), which gives us a number of the EEG signal's component parameters which have specific frequencies. Medically interesting EEG spectrum can be found between 0.5÷1Hz to several dozens of HZ and is divided into bands reflecting particular brain activities. The coach decides where electrodes are to be attached (and thus the trained part of the brain) as well as the rhythm trained and amplitude level of the corresponding wave which the patient aims to achieve during the training. On the patient's screen a visualisation is shown. It aims to effectively show the training patient the current state of the brain activities in relation to the goal set by the coach. By effective visualization I mean how clear and intuitive it is as well as the speed it reacts to registered changes of EEG.

Neurofeedback treatment is commonly used in many areas of medicine and in connection with numerous neurological problems. The most common applications include treatments of children and young adults: ADHD treatment, ADD, cognitive disorders [1] and speech disorders (dysarthria, stuttering, apraxia of speech). Neurofeedback also augments treatments of problems like dyscalculia, dyslexia, dysgraphia. Moreover, it is used when treating more serious neurological problems like Tourette syndrome, autism [2] and epilepsy [3]. Another area where neurofeedback is commonly used is sport. It helps sportspeople to train concentration and the ability to ignore distracting external stimuli – a key skill in today sports.

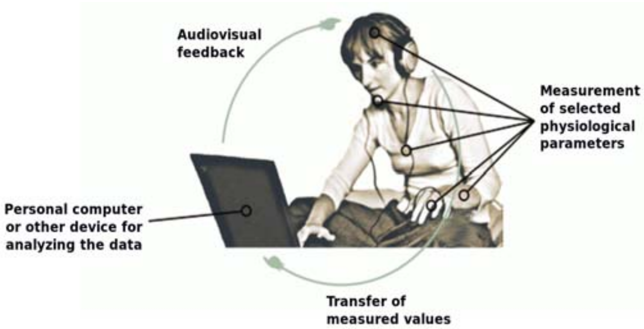

Fig.1. Biofeedback loop [5]

Measurements

The EEG signal is the main feedback carrier in neurofeedback training. Training repeatability and comparability of results forces us to use certain measurement points located on the head. A network of such points is defined by the international "10-20" system. It is a method describing placement of electrodes on the skin of the head in the context of EEG [4]. Among the locations described in "10-20" system, neurofeedback most often uses electrodes C3, C4 and Cz. These are located in the so-called electrodes central belt of the central cortex, which is a safe place to train. It has a lot of connections to thalamus, which is a relay center of the brain. C3, C4 and Cz are the sites suitable for most general types of trainings while other locations are chosen for more specific ones. The main rule of most trainings is to promote Beta waves/activities in the left hemisphere and SMR in the left and diminish Theta and Beta2 waves. The measurement system was presented in Fig. 2. The EEG signal is extremely difficult to record and analyze. The first problem is its low amplitude. Usually it oscillates between 1÷100 μV - i.e. lower than natural electromagnetic interference.

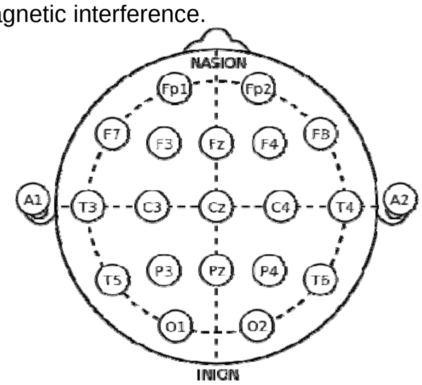

Fig. 2. The measurement system "10-20" [5]

Thus the signal is prone to be influenced by artefacts. There are many sources of them. One of the most important s poor fixation of electrodes, which results in increased impedance in the connection between the electrode and skin. The impedance, together with the input impedance of amplifiers creates a voltage divider which lowers the signal's amplitude in relation to interference. Moreover, high impedance lowers resistance to environmental electromagnetic interference. The situation can be made even worse by sweat on patient's skin or other physiological factors. Another source of artefacts can be found in blinking and eyeball movement, which creates a several milivolt difference in potentials between retina and cornea - significantly bigger than voltage of typical brain activity. Blinking involves the Bell effect i.e. turning the eyeballs up. and – like in the eyeball side movement - a sudden rise in potential is noticed. Next very strong source of artefacts include electromyography and electrocardiography, which is the strongest generator of electrical signal in the human body.

A different problem, but not less serious, is random and sometimes difficult to avoid placing the reference electrode over a secondary artery, which results in signal ECG propagating to all channels. Everything that causes appearance of DC offset in the measurement system like head movements can show in the results as unnaturally high Delta band values. Thus it is practical to verify its level in the beginning of the measurement and using high pass filters to eliminate it.

Another group of factors influencing the treatment include technical artifacts. Like thermal interference, interference caused by converters and amplifiers and interference caused by electrochemical forces.

All these factors make the analysis of the complex EEG signal even more difficult. Due to its inter-individual variation and temporal changeability it is a pseudo stochastic and non-stationary signal, which makes it difficult to compare results to each other and to the model defined by neurofeedback. This causes a number of problems. Due to the necessity of separating specific frequency bands and setting their power and amplitudes it undergoes the FFT analysis, or more precisely, DFT (due to digitalization). Frequency bands found in neurofeedback include Delta 0.5–4 Hz, Theta 4–7 Hz, Alpha 8–12 Hz, SMR 12–15 Hz, Beta 15–22 Hz, Beta2 22–32 Hz [6].

The high dynamics and precision of acquired data is a crucial assumption in spectral signal analysis, recorded during biofeedback training. The feedback must be a fast feedback, with possibly low inertia and simultaneously as clear and easy to understand as possible. In other words each change in the amplitude of the brain waves being trained has to be noticed as soon as possible and presented to the trainee and the coach. The ideal feedback inertia is estimated around 300 ms, which equals event related potential P300.

These assumptions force a number of requirements and limits on the methodology of applied spectral analysis. We should also take into the account that the EEG signal being analysed is a stochastic signal. Power spectral density of the stochastic signal is given as a Fourier transformation of the autocorrelation function $R_xxx(n)$ of the input signal $x(n)$:

(1) $$X(m)=\sum_{n=0}^{N-1} w(n)R_{xx}(n)e^{-2\pi i\frac{nm}{N}}$$

where $w(n)$ is window function to eliminate aliasing.

As Fourier transformation (DFT) states, if all the components of the input signal do not fall into the analysed fragment of the total number of their phases, their power to some extent manifests in all the frequencies of the received power spectral density. This phenomenon, called aliasing is to some extent limited by using the window $w(n)$. It should be noted that there are many shapes of windows and each influences results in a different way.

However, using a DFT window will not completely eliminate aliasing. This becomes a real nuisance in the case of the aliasing-related values derived from high power components. In the case of the EEG signal it involves slow waves of frequency below 1 Hz. The signals generated as a result of head, body and eyeball movements or sweating are low-frequency interferences (below 2 Hz) and fall within the range of slow and delta waves.

Their amplitude might be so high, that the leakage coming from them is able to completely distort the desired image of the spectrum. Thus it is absolutely necessary to use a high pass filter with correctly chosen cut off frequency. Naturally the coach must not forget that the treatment adequately lowers the number of the trainable rhythms.

While discussing filters one more quality of Fourier power spectral density computation for real signal should be mentioned – its symmetry:

(2) $$X(m)=X(N-m), m=1,2,\dots N-1$$

It means that the value in point m is a sum of the components with frequencies $m * f_r$ i $(N - m) * f_r$, where f_r is DFT resolution. Since the power values (and the amplitudes estimated on their basis) of specific brainwaves have to be mapped as precisely as possible and not only their relations are interesting, but also the absolute values, the neurofeedback method requires using a low pass filter, which will clear the input signal from the components which in the spectrum would correspond with

(3) $$m>\frac{1}{2}N$$

Let us go back to the dynamics of acquiring results. To fulfil the criteria explained above, spectral analysis has to be completed very often - several to about 20 times per second. Moreover, the analysed signal cannot be too long, so the result does not carry information too distant in time from the moment when the trainee receives the feedback. Thus automatically we should question all the estimation methods of power spectral density based on averaging series of time epoch (for example Bartlett's method or popular Welch's). The so called modified periogram, or DFT square module of signal multiply by window $w(n)$ seems effective enough. Smooth periodogram through the autocorrelation function also smooth by window $w(n)$ (for example with

Blackman-Tukey method) is even better. There is still a problem with a correct and precise normalization of acquired results so their values would have an absolute meaning, since only then the results can be related to published norms [7]. Any additional operation, like windowing or autocorellation introduces additional interference in the absolute values of the results and makes their recovery significantly more difficult.

research of appropriate estimation of amplitude of a chosen rhythm should concentrate on acquiring a credible model for comparison. Due to the stochastic quality of the EEG signal the analysis of artificial signals might be misleading due to their deterministic quality. Hopefully a relation with medical circles can be established and an attempt made to separate concrete, specific neurophysiological states, which would allow to create a database of signals.

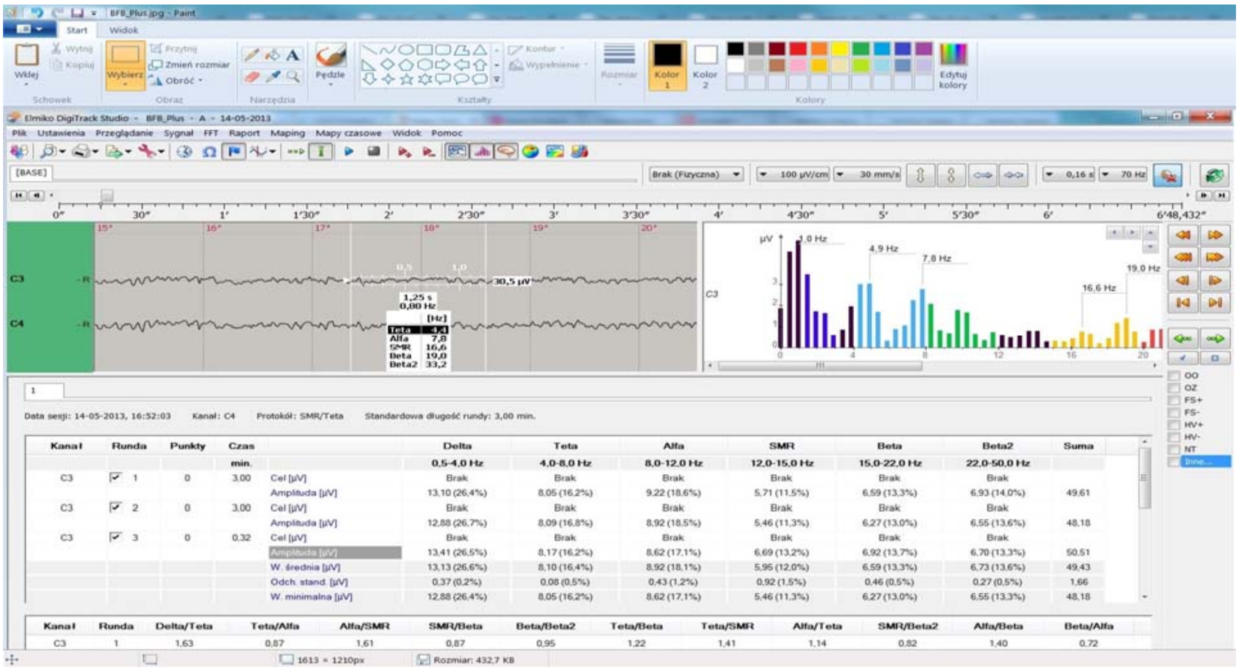

Fig. 3. The screen of the therapist with the results available after training.

Currently we are conducting research on the influence of using different DFT windows in the above mentioned methods and on the influence of using various spectral analysis algorithms on accuracy of acquired results. However, to find referential pattern turns out to be quite a serious problem. We observe quite distinct differences at various approaches, but it is very difficult to evaluate them, since we lack alternative evaluation methods. So far we have to continue using the solutions resulting from mathematical theory.

The Fig. 3 shows the screen of the therapist with the results available after training. In addition to the panels showing the EEG recorded from all electrodes (top left) and the frequency distribution of the selected fragment of EEG (top right) the screen shows the result of quantitative analysis or QEEG (Quantitative Electroencephalography). It shows numerically parameterized EEG recorded during the training.

Summary

The text attempts to present the concept of the neurofeedback treatment. Starting with the general feedback mechanism in biofeedback treatment (of which neurofeedback is a special case), through EEG data acquisition and collected data analysis, the text outlines where such treatment is useful in a number of dysfunctions and illnesses as well as where it improves the quality of life of the healthy. The issues of interference and artefacts strongly influencing the signal during neurofeedback, locations of training points on the head and the treatment itself are all discussed, as well as the division into rhythms and typical qualities of the EEG signal and the problems intrinsic to its nature.

Our work and experience clearly show that neurofeedback is an excellent way to train the brain. Further

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