EEG in the Context of Audiovisual Stimulation

M. Teplan, A. Krakovská, S. Štolc

Institute of Measurement Science, Slovak Academy of Sciences, Dúbravská cesta 9, 841 04 Bratislava, Slovakia

michal.teplan@savba.sk

Abstract

Audiovisual stimulation of the brain and EEG biofeedback has been studied for their possible applications to variety of conditions. One of the most fundamental principles of biofeedback is the necessity of accurate monitoring and feedback of the physiological processes of interest in order to control it. Here we present application of nonlinear measures and their comparison with spectral measures in detection of different brain states. A group of volunteers was involved in audiovisual stimulation training. EEG was recorded during their attempt for general resting. Following measures were tested: linear correlation, averaged mutual information, spectral edge frequency, relative power of alpha, beta, delta and theta band, spectral entropy, correlation dimension, and results of subjective assessment. Results from this study showed their changes in the course of the training. Nonlinear measures employed deserve further attention.

Materials and Methods

A group of 6 healthy adult volunteers (2 females and 4 males) aged from 23 to 39 years was involved in the audiovisual stimulation training. Commercially available mind machine was used to entrain subjects' brain waves by a sound and light stimuli from 18 Hz down to 2 Hz (Fig.1). Overall training consisted of 25 single 20 minutes program sessions during 2 months. Subjects were lying in a darkened electrically shielded room. Before and after each training session subjects were instructed to keep their eyes closed and relax. EEG signal was recorded from eight channels: F3, F4, C3, C4, P3, P4, O3 and O4 according to International 10-20 system. The reference electrode was placed at Cz and ground electrode at Fpz. The length of each series was 3 minutes (i.e. 90000 samples).

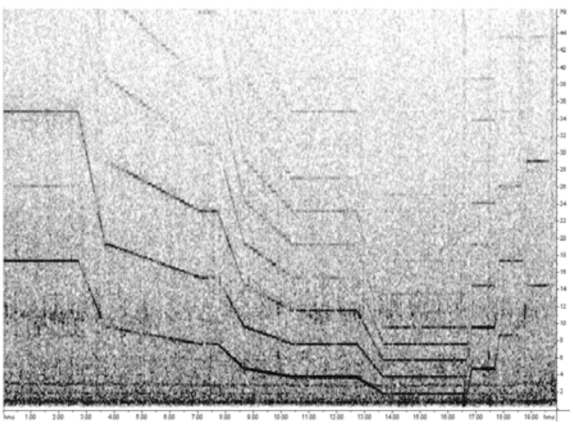

Fig. 1. Entrainment of the EEG dominant frequency during audiovisual stimulation. 20 minute program entrained subject's brain waves from 18 Hz down to 2 Hz and back to 15 Hz.

We used EEG recording device with following parameters: Sampling frequency 500 Hz, overall amplifying gain 402, resolution of the A/D converter 16 bits, resolution of the input signal 0.46uV per unit. Analog high pass filter at 0.07Hz (-3dB) and low pass filter at 234 Hz (-3dB). Digital high pass FIR filter with cut-off at 0.75 Hz with width 3000 data points and Blackman window.
Standard cap system with Ag-AgCl electrodes was employed. In order to prevent signal distortions impedances at each electrode contact with the scalp were in most of the accepted cases bellow 5 K Ohms, and balanced within 1 K Ohm of each other. Volunteer's subjective perception of training process was also monitored: before and after each session subjects filled in the form in order to identify their physical, mental and emotional state and their experiences with audiovisual stimulation. A total of 3200 electroencephalograms were analyzed. Series contaminated by that with either patient-related or technical artefact sequences and obvious sleep occurrence were excluded by eye inspection and according to the subjects' assessment. In our control group there were 2 volunteers who absolved the same measurement procedure but instead of audiovisual stimulation they listened to relaxation music.

Complexity of the system can be estimated with the correlation dimension (CD). For that purpose correlation sum can be counted [1] as

$$C(r) = \frac{2}{N(N-1)} \sum_{i}^{N} \sum_{j>i}^{N} \theta(r - \|\mathbf{v}_i - \mathbf{v}_j\|) \qquad (1)$$

In (1) N denotes number of data points, $\mathbf{v}_i$ embedded vectors comprising subsequent data points of a time series, θ denotes Heaviside function, ||.|| represents maximum norm in a phase space of embedded vectors, and the parameter r is the diameter of the phase space partition. Then (CD) can be estimated from d (ln C(r))/d (ln r).

Averaged mutual information between two time series is a kind of nonlinear "correlation" and can be counted as

$$AMI = \sum_{a_m, b_n} P_{AB}(a_m, b_n) log_2 \left[\frac{P_{AB}(a_m, b_n)}{P_A(a_m) P_B(b_n)} \right] \qquad (2)$$

where $P_A(a_m)$ denotes the normalized histogram of the distribution of observed values am in the first time series and $P_{AB}(a_m,b_n)$ is the joint distribution of both series [2].

Results and discussion

We used the *correlation dimension* [1] and the *entropy* [2] for estimation of the complexity of EEG signal. Claims of low-dimensional dynamics in brain behaviour have to be taken with very much scepticism. Most estimates of low dimension from complex experimental data seam to be artefacts (most often artefacts of too small data set). We expected a failure of the attempt to determine a low dimension as well, but a significant indication of correlation dimension about 4 was found in some cases (Fig.2) what implies possibility of quite successful modelling of relaxed state of mind by 5-8 ordinary (probably non-linear) differential equations. This remains to be explained but what we take for granted is, that the low value of dimension is not an artefact of small data set size (we used 90000 samples), it is neither an effect of low pass filtering (our measuring device fully covered frequency band from 1 to 100 Hz) and it is not a consequence of some simplification of dimension estimation method (the original estimator without any modifications was applied). There was observed no significant change of entropy and correlation dimension during the training process.

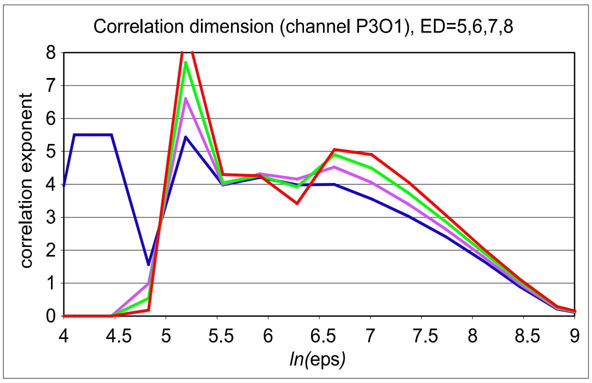

Fig. 2. Correlation dimension, occipital area

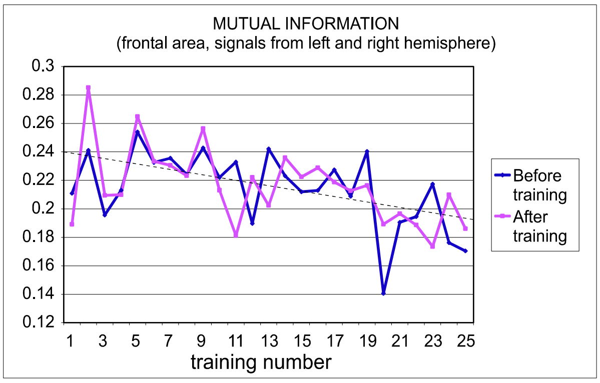

Fig. 3. Mutual information from frontal area

In neurophysiology the mostly cited indicators of sensorimotorical and mental relaxation are rise of alpha frequencies (8-12 Hz) and synchronisation of left and right hemisphere.

To investigate the cooperation between hemispheres, we estimated *linear correlation* and *mutual information content* of signals from left and right hemisphere (usually coherency measure is used). Any significant change of the value of linear correlation was not observed. The second measure - mutual information content is a more interesting characteristic, as it is able to detect a presence of non-linear correlations as well. We did not detect an increase of hemispheres synchronisation by these measures. Actually a slight decrease of synchronisation in frontal parts of the brain was observed in the course of training (Fig.3). Mutual information content appeared to be more sensitive than linear correlation.

To uncover the spectral changes, we estimated the *relative power of alpha, beta, delta and theta band* of a signal and the so-called *spectral edge frequency* (the frequency below which one finds 95% of the EEG power). Frequency spectrum was divided in 3 bands: delta + theta (0.5- 8 Hz), alpha (8- 12 Hz), and beta band (12- 25 Hz). The overall rise of alpha frequencies in both left and right frontal areas was observed (Fig.4), according to linear regression by the factor of 24-30 %. As frontal areas refer to higher nervous activities, this fact may support increase of mental relaxation of subjects during the course of training period. Some other unwanted effects may be involved, e.g. adaptation to the training, regardless of the mindmaschine use. Our control group did not support this effect; their alpha power did not rise at all. Still the number of subjects in our control group and also in the test group is too small for statistically more valuable results. Delta and theta frequencies increased in occipital areas and this was supported by decrease of spectral edge frequency in back parts of the brain. In frontal and central regions spectral edge frequency did not display any significant changes.

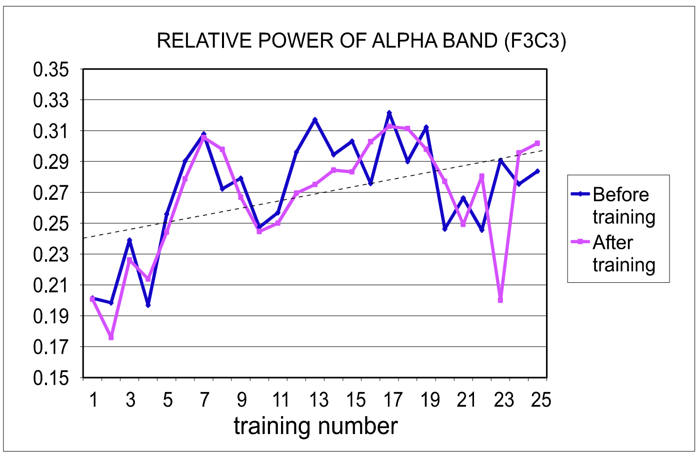

Fig. 4. Relative power of alpha band from frontal area F3C3.

Only 2 of 6 volunteers were optimistic about the impact of a mind machine. One of them had neutral opinion, and three persons did not expect any progress in relaxation ability in the future. Nevertheless the subjective rate of the relaxation depth increased by 45% during the training process. On the other side spontaneous relaxation skill was perceived as unchanged.

Conclusions

The rise of alpha frequencies in frontal areas may indicate the possibility of positive relaxation training effects of audiovisual stimulation. On the other hand we did not detect any increase of hemispheres synchronisation as another feature of relaxation.
We have combined wider range of different measures to classify EEG signal during the brain training process.

Non-linear measures (mutual information content, correlation dimension, some types of entropy) adjust the qualitative description of EEG concentrating on the dynamics of the brain processes. We want to call attention to these powerful tools originally developed for chaotic and complex non-linear systems. They are more sensitive to non-linear aspects of physiological processes than traditional methods.

References

[1] P. Grassberger, I. Procaccia, "Measuring the strangeness of strange attractors", Physica, vol. 9D, pp. 189-208, 1983.

[2] H.D.I. Abarbanel, "Analysis of Observed Chaotic Data", Springer-Verlag New York, 1996.

[3] A. Galka, "Topics in Nonlinear Time Series Analysis. With Implications for EEG Analysis", World Scientific, 2000.

[4] S.-H. Jin, et al., "Nonlinear dynamics of the EEG separated by independent component analysis after sound and light stimulation", Biological Cybernetics, vol. 86, pp. 395-401, 2002.

[5] T. Kobayashi & co., Human Sleep EEG Analysis Using the Correlation Dimension, Clinical EEG, vol. 32, 2001.