LINEAR AND NONLINEAR EEG MEASURES IN THE CONTEXT OF BRAIN TRAINING

M. Teplan, A. Krakovská, S. Štolc

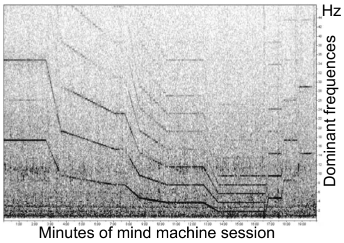
michal.teplan@savba.sk

Institute of Measurement Science, Slovak Academy of Sciences, Dúbravská cesta 9,
842 19 Bratislava, Slovak Republic

Abstract

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. The purpose of this study was to determine certain effects of popular mind machines. They are supposed to induce relaxation and changed states of mind, which are not exactly defined. We recorded EEG during mind maschine training and counted the changes of the following measures: linear correlation, mutual information content, spectral edge frequency, relative power of alpha, beta, delta and theta band, spectral entropy; correlation dimension, and results of subjective assessment.

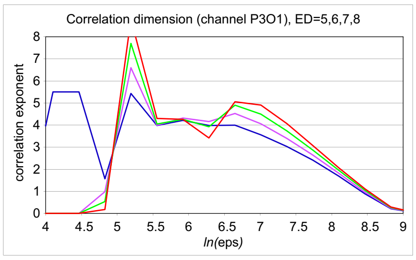
Experiment description



A group of 6 healthy adult volunteers was involved in the training with mind machine. The machine was used to entrain subjects' brain waves by a sound and light stimuli from 18 Hz down to 2 Hz. Overall training consisted of 25 single 20 minutes trainings during 2 months. Subjects were lying in a darkened electrically shielded room. They were instructed to keep their eyes closed and relax. Before and after each training the 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 at Fpz. The sampling rate was 500 Hz; the length of each series was 3 minutes (i.e. 90000 samples). Series with artefacts and obvious sleep occurrence were excluded.

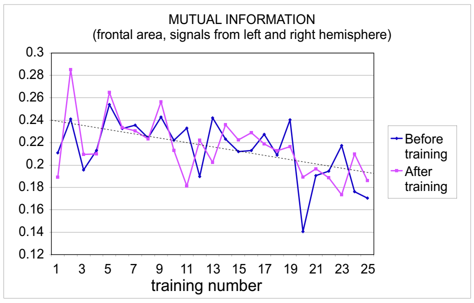
Results and discussion

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 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.

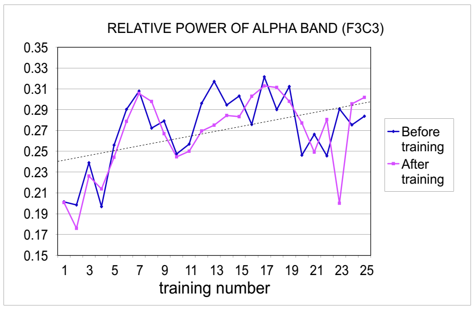


In neurophysiology the mostly cited indicators of relaxation are rise of alpha frequencies (8-12 Hz) and synchronisation of left and right hemisphere.

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). 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. 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). The overall rise of alpha frequencies in both left and right frontal areas was observed, according to linear regression by the factor of 24-30 %. As frontal areas reffer 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. This effect was not supported by our control group where two persons listened to relaxation music instead of mindmaschine, and 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.



Only 2 of 6 volunteers were optimistic about the impact of a mind machine. Nevertheless the subjective rate of the relaxation depth increased by 45 % during the training process.

Conclusions

The rise of alpha frequencies in frontal areas may indicate the possibility of positive relaxation training effects of mind maschines. On the other hand we did not detect any increase of hemispheres synchronisation as another feature of relaxation.

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