LINEAR AND NONLINEAR EEG MEASURES IN THE CONTEXT OF BRAIN TRAINING

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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. Our study was designed to explore changes in complexity measures, power spectra, correlations and subjective feelings.**
The poster will illustrate the changes of the following measures: linear correlation, mutual information content, approximate entropy, correlation dimension, spectral edge frequency, relative power of alpha band and results of subjective assessment.

Keywords: **EEG, brain training, mind machines, correlation dimension, Fourier spectra**

Introduction

One of popular mind machines was used to entrain brain waves by a sound and light stimuli of certain frequencies (from 1 Hz to 20 Hz). The aim of the present study is to investigate possible effects of the device exploring changes both in traditional linear and novel non-linear measures.

The use of non-linear techniques was inspired by the fact, that to a certain extent EEG resembles chaotic behavior. Apparent periodicities and also many irregularities are seen in various parts of the signal. The irregularity is probably due to the noise but may be also due to the complex deterministic dynamics. Therefore, besides conventional approach we tried to treat EEG by methods, which were originally developed for complex non-linear (especially chaotic) signals, despite the fact that brain was not proved to be following chaotic behaviour.

Materials and Methods

Group of 6 healthy adult volunteers (2 females and 4 males) aged from 23 to 39 years was involved in the training with mind machine. All subjects were right-handed. 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 at Cz and ground at Fpz.

A total of 3200 electroencephalograms were analysed. The sampling rate was 500 Hz; the length of each series is 3 minutes (i.e. 90000 samples). Series with artefacts and obvious sleep occurrence were excluded.

The next measures were computed: linear correlation, mutual information content, approximate entropy, correlation dimension, spectral edge frequency, and relative power of alpha band.

Volunteer's subjective perception of training process was also monitored.

Results and discussion

At first we focused on the complexity of EEG signal. For that purpose we estimated the *entropy* and the *correlation dimension* [1]. 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 synchronisation of left and right hemisphere and rise of alpha frequencies (8-12 Hz).

To investigate the cooperation between hemispheres, we estimated *linear correlation* and *mutual information*

content of signals from left and right hemispheres. 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. Even thought, we did not detect an increase of hemispheres synchronisation. Actually a slight decrease of synchronisation in frontal parts of brain was observed in the course of training.

To uncover the rise of alpha frequencies, we estimated the *relative power of alpha band* in a signal and the so-called *spectral edge frequency* (the frequency below which one finds 95% of the EEG power). During first trainings we have observed a slight increase of alpha band in frontal area. Then return to initial values came. Unexpectedly in occipital parts of brain a slight decrease of alpha band was identifiable. At the same time the spectral edge frequency decreased in occipital parts of brain as well. These two results indicate that the contribution of frequencies below 8 Hz (the sign of deeper relaxation) might increase in occipital region. But we must stress that trends of change are only moderate and these results cannot be taken as strong evidence of successful relaxation training. The figure 1 shows the evolution of relative power of alpha band in right occipital region of brain.

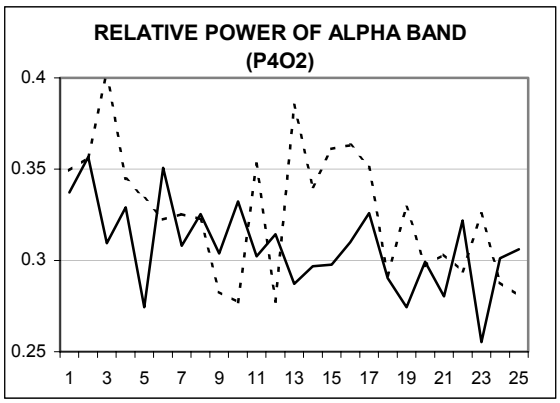

Fig. 1. Relative power of alpha band in EEG signal recorded from right occipital region of brain. Dashed line - before trainings, continuous line - after trainings.

Conclusions

Subjective assessment can help to set objective changes into the frame of subject's experience. Only 2 of 6 volunteers were optimistic about the impact of a mind machine. One of them had neutral opinion, and three people 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.

We have combined wider range of different measures to classify EEG signal during the brain training process.

Spectral measures identify changes in the frequency domain while coherence measures occurrence of certain synchronization in the functioning of the hemispheres.

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.

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