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Permutation Entropy of Brain Electrical Activity During Routine EEG Tests in Healthy Subjects

Anton Popov, Oleksii Kanaykin

Abstract - **The study of permutation entropy (PE) characteristics of electroencephalogram (EEG) is conducted in this paper. EEG of a set of age and gender matched healthy subjects who undergo a standard routine clinical EEG tests is recorded, and PE of orders 3-5 is calculated and studied. The dependences of EEG PE on the time lag for different orders are revealed. PE of different orders and time lags showed that the tendency of PE change from test to test holds for different orders, but the absolute values of PE decrease with order decrease. Typical increase of PE with lag increase was revealed as well, suggesting the corresponding increase of chaoticity of brain activity for all clinical tests.**

Keywords - **brain, EEG, entropy, permutation entropy, healthy subjects, clinical tests, routine tests.**

I. INTRODUCTION

Among many nonlinear techniques of biosignal analysis, permutation entropy (PE) is one of the most widespread due to its ability to recover pattern dynamics in time series. This characteristic is widely used in the research on brain electrical activity based on electroencephalogram (EEG). EEG is multichannel time signal of potentials differences between point on the scalp and reference electrode, often placed on the ear. This signal is proven to reflect highly complex nature of processes occurring in the brain, hence the nonlinear dynamics approaches to study brain activity is essential [1-4]. The target is primarily the epilepsy research.

Epilepsy is one of common and widespread neurologic disorders worldwide, which is often characterized by unpredictable repeated seizures caused by abnormal excessive activity of synchronized neuronal groups in one or several locations of the brain. Clinical manifestations of epilepsy are abrupt and unforeseen motor phenomena, loss of consciousness, psychic and sensory symptoms etc., causing the low everyday life quality of patients. The most widespread way to analyze brain functioning in healthy and epileptic conditions is to develop the automatic systems to monitor or predict the epileptic seizures or the presence and development of epileptic focus in the brain. The essence of such analysis is the comparison of EEG parameters for healthy and diseased states. To make possible the disease diagnostics, the reference data from healthy patients is needed.

There are a lot of publicly available databases, e.g. PhysioBank [5] which is the most comprehensive, or others mentioned in the paper [6]. But none of them contains EEG data from healthy patients, thus cannot be used to obtain reference parameters of EEG, so there is the need for creating such database.

During routine EEG recording in clinics, a patient undergoes the series of standardized tests aimed to study the functioning of the brain in rest and under certain influences. Relative changes in characteristics of brain activity from test to test gives important information for diagnostics. This information can be used in the study of physiologic state of healthy subjects to detect deviations from the normal conditions, e.g. in human functional state analysis and prognosis, adaptivity of human body to stresses, sympathic/parasympathic system balance estimation, treatment and rehabilitation success analysis, subject stratification, screening tests in human population etc. Knowledge of typical parameters of brain activity, in particular nonlinear ones, can be used as the reference for making the diagnostic conclusions during treatment of diseases as well.

In this paper the newly available EEG database containing brain electrical activity of healthy subjects is used to obtain EEG parameters. Entropy characteristics of EEG of healthy subjects are studied for different combinations of permutation entropy parameters. The behavior of PE measure across the standard EEG trial is evaluated for the set of matched healthy subjects, the new data allowing to study the changes in brain activity during the course of several tests is obtained.

II. PERMUTATION ENTROPY BASICS

The measure of Permutation Entropy was introduced in [2]. It evaluates numerically the relative frequencies of patterns occurrence in discrete signal. PE analysis approach benefits from the fact that PE does not depend on the signal absolute values and uses only the symbol sequence.

Permutation entropy of order m $(m \geq 2)$ of the signal $x(n)$ is given by:

$$PermEn_x(m,l) = -\sum_{j=1}^{m!} p(\pi_j) \log p(\pi_j) .$$

This value is the measure of the amount of information contained in comparing m consecutive

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signal samples over time interval. The relative frequency of permutation π_j is defined as:

$$p(\pi_j) = \frac{q(j)}{N-(m-1)l},$$

where $q(j)$ is the number of occurrence of permutation π_j, N – is the signal length, and l is the time lag. There are general considerations regarding the meaning of tile lag and PE order [3]:

- order m may be connected to the diversity of patterns to be found in the signal. Selecting large order means finding more diverse patterns in the signal, i.e. more variations of combinations of consecutive samples;
- lag l is responsible for the time span between signal samples in each pattern of order m. For selected order, the lag l corresponds to the duration of each pattern.

In the following the PE characteristics are studied for the group of age matched healthy subjects, which can be used in the two main ways: to study the nonlinear activity of healthy subjects undergoing standard EEG tests, and to use this results further for the reference in studying the brain activity in various diseases.

III. PERMUTATION ENTROPY DURING CLINICAL TESTS

Eight young healthy adult males (age 22 ± 1.1) were subject to the standard EEG routine clinical test, conducted in the Dept. of Functional Diagnostics of the Institute of Neurosurgery of Ukraine (Kyiv, Ukraine) using the BRAINTEST EEG recorder (DX-Systems, Kharkiv, Ukraine, http://www.dx-sys.com.ua/). 10/20 electrode placement system with physical reference (connected ears) was used. EEG was sampled at 1 kHz.

Permutation entropy was calculated for the orders from 3 to 5 and for the time lags from 1 to 45 msec according to the experiment setup described in [3-4]. PE was studied separately for different tests during each trial.

In Figures 1-3 the following labels are used for the following trials' names:

1 – "Background activity, before trial";
2 – "Eyes open-eyes closed test";
3 – "Photophonostimulation, Frequency 3 Hz";
4 – "Photophonostimulation, Frequency 10 Hz";
5 – "Photophonostimulation, Frequency 20 Hz";
6 – "Hyperventilation";
7 – "Background activity, after trial".

Figures 1-2 show the boxplots of PE for the different orders. It can be seen that the values of PE characteristics are very close from test to test, suggesting the idea that healthy and intact brain does not react significantly to the tests, at least in terms of permutation entropy characteristics. Mean PE value is approximately 0.83 for order 3 and 0.7 for order 5. Since PE order corresponds to the variety of different patterns that can be found in the signal, this result suggests that in EEG there are no complex patterns of permuted EEG values.

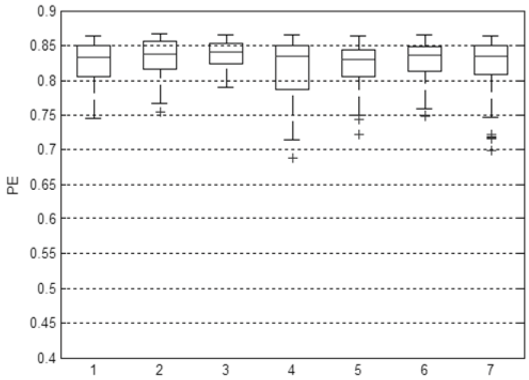

Fig.1. EEG PE for different tests for order 3

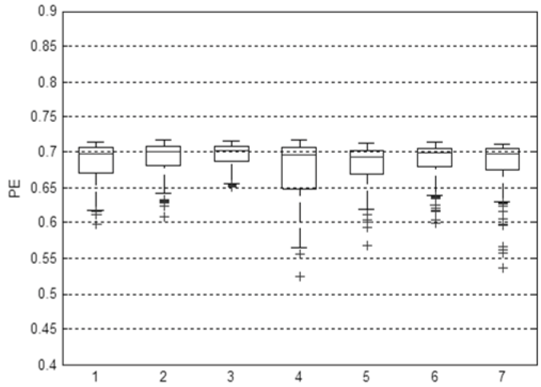

Fig.2. EEG PE for different tests for order 5

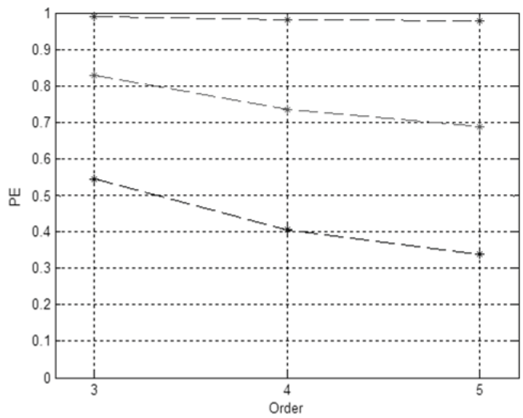

Fig.3. EEG PE order dependence for different time lags: 1 (blue), 5 (green), 45 (red)

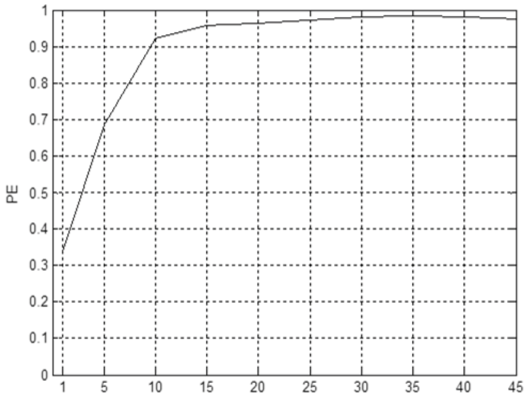

Fig.4. PE of order 5 for different time lags for the "background activity, before trial" test

On the other hand, the decreasing of PE with the order increase can be further used as a classification or pattern recognition characteristic. The rate of such decrease might be used for this purpose.

In Figure 3 the example of order dependence of PE for different time lags is presented for hyperventilation test. The same behavior is revealed to be typical for other functional tests for the group under evaluation. It can be seen that for different time lag the behavior of the line is different: for small time lag there is obvious decrease of PE with order increase, suggesting the sensitivity of nonlinear parameters for the complexity of pattern. In the same time with the increase of time lag the dependence from the order vanishes, showing stable value for lag 45. Moreover, the PE value for large lag tends to 1, which means that the patterns are picked from the random signal. This can suggest the use of PE increase rate as new derivative nonlinear characteristic of EEG, showing the lost of predictability, or attaining of randomness by the EEG.

Previous results can be connected to the dependence presented in Fig. 4, which shows the increase of PE for increasing of time lags for order 5, which is typical for other orders and tests. It can be seen that after some time lag (approximately 15 in the considered case), the PE approaches to 1, that means that EEG under analysis shows random behavior. The slope of the curve, as well as the value of time lag from which the saturation starts, can be used as the characteristic of processes in the brain.

III. Conclusion

In this paper the new database containing EEG signals of matched healthy subjects was used to obtain the entropy characteristics of brain electrical activity. The new results on the EEG permutation entropy for healthy subjects during standard routine clinical EEG tests were studied.

The main result is that it is that there are observable changes in the entropy characteristics for different PE orders and time lags, suggesting that this measure react to the EEG behavior.

After experiments it is revealed that PE of different orders and time lags showed that the tendency of PE change from test to test holds for different orders, but the absolute values of PE decrease with order decrease. Typical increase of PE with lag increase was revealed as well, suggesting the corresponding increase of chaoticity of brain activity for all clinical tests.

Based on the analysis of obtained dependencies, several promising characteristics of EEG are proposed and discussed, such as rates of PE decrease with order, and time instant of PE saturation, which might be studied further to evaluate their usefulness in clinics.

References

[1] M. Zanin, L. Zunino, O.A. Rosso , and D. Papo, "Permutation entropy and its main biomedical and econophysics applications: a review," *Entropy*, 14, pp. 1553-1577, 2012.

[2] C. Bandt, and B. Pompe, "Permutation Entropy: a natural complexity measure for time series," *Physical Review Letters*, vol. 88, no. 17, pp. 174102-1 - 174102-4, 2002.

[3] A. Popov, O. Avilov, and O. Kanaykin, "Saturation of electroencephalogram permutation entropy for large time lags," *XXXIII IEEE International conference "Electronics and nanotechnology"*, pp. 251-254, April 16-19, 2013.

[4] Anton Popov, Oleksii Avilov and Oleksii Kanaykin, "Permutation entropy of EEG signals for different sampling rate and time lag combinations," *Signal Processing Symposium SPS-2013* (Jachranka, Poland), June 4-7, 2013.

[5] A. L. Goldberger, L. A. N. Amaral, L. Glass, J. M. Hausdorff, P. C. Ivanov, R. G. Mark, J. E. Mietus, G. B. Moody, C.-K. Peng, and H. E. Stanley, "PhysioBank, PhysioToolkit, and PhysioNet : Components of a New Research Resource for Complex Physiologic Signals," *Circulation*, vol. 101, no. 23, pp. e215–e220, Jun. 2000.

[6] D. M. Alschuler, C. E. Tenke, G. E. Bruder, and J. Kayser, "Identifying electrode bridging from electrical distance distributions: A survey of publicly-available EEG data using a new method," *Clin. Neurophysiol.*, Oct. 2013.