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NON-LINEAR ANALYSIS OF INSTRUMENTAL TURKISH TRADITIONAL MUSIC MODES VIA HUMAN'S EEGS

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Abstract: *In this paper, we examined methods for analysing EEG (electroencephalogram) signals by listening some instrumental Turkish Traditional Music Modes. Investigations of the mutual interaction between EEG and music were employed via nonlinear signal analysis. For this aim, we calculated Correlation Dimension (CD) and Lyapunov Exponents (LE) of EEG signals taken from three subjects. Further, surrogate analysis and high order spectral analysis were implemented. Thus, we tried to obtain the experimental results from the beginnings works about psychological and physiological treatment by suitable musical modes.*

Keywords: *Nonlinear chaos, EEG, musical therapy, high order spectrum.*

1. INTRODUCTION

Listening the music plays an important role among the higher brain functions [1]. However, limited number of studies based on EEGs has more dedicated to this question. There is no consensus about the contribution of distinct areas of the human's brain to the processing of the music. In the human's brain, the complex behaviour of the neural network at various levels strongly emphasizes the nonlinear nature of interactions in human's brain. Music and sound processing rely on widely distributed cortical neural networks involving superior temporal and dorsolateral frontal lobes, and also parietal brain regions [2]. Listening the music however is much more than processing acoustic patterns; music can be powerful tool to elicit emotions. We have little known about the neurobiological basis of this process. The brain system consists of dozens of functional subsystems and their cooperative process enables high level recognition such a music listening. Meanwhile in recent years the progress of the musicotherapy is remarkable. Also, the importance of the musicotherapy has been more closely evaluated [3]. Linear methods that have been used in the field of biomedical signal processing, can not always be powerful enough to analyse signal coming from very complex nonlinear living systems such as human's brain. Recent developments in the theory of nonlinear dynamics have highlighted some methods for analysis of the time series representing signal measured from linear segments.

In this study, we have investigated of the nonlinear mathematical analysis under

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listening to some Turkish traditional music's modes by using chaotic parameters such as Correlation dimension and Lyapunov exponents. Also, we have used high order spectral moment such as skewness to discriminate the EEG signal of interest from Gaussian distributed effects. In order to establish the interaction between music and human's brain, EEG signals taking from three male subjects are evaluated respect to mentioned chaotic parameters. By this way, it is aimed to help doctors for therapy.

2. METHODS

The first attempt for description of nonlinear systems is to reconstruct its state-space portrait. The time sequence taking from the system of interest by experimental fashion will be projection of true state-space of the system. One possible way of doing this can be Takens method of delays [4]. This technique explains how to construct an attractor of dynamic systems in k-dimensional state-space from only one dimensional time sequence. But, it is often necessary to extract some useful parameters such as Correlation dimension, Lyapunov exponent, the Pointwise dimension, and Kolmogorov entropy.

A. Correlation Dimension

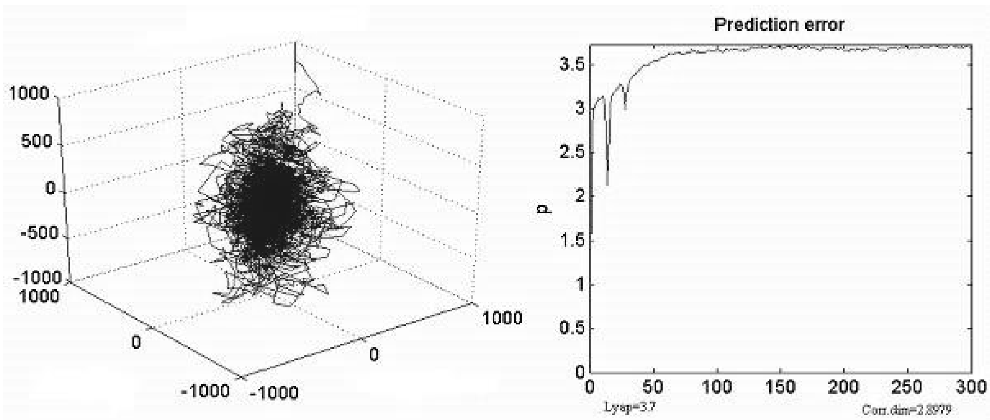
The correlation dimension is given based on pairs of points in the phase-space set that are separated by a distance of less than r. CD is computed as follows [5]

$$CD = \lim_{r \to 0} \frac{\log C(r)}{\log r} \quad (1)$$

where the correlation integral $C(r)$ is;

$$C(r) = \frac{1}{N^2} \sum_{i=1}^{N} \sum_{\substack{j=1 \\ i \neq j}}^{N} \theta\left(r - \left|X_i - X_j\right|\right) \quad (2)$$

where $x(i)$ and $x(j)$ are the points of trajectory in the phase space. N is the number of data points, r is radius around each reference point, $x(i)$ and Q is the Heavyside function which excludes values outside of radius r. CDs correspond to the properties of the dynamical process investigated. Those properties could be regular deterministic, chaotic, and stochastic behaviour.



B. Lyapunov Exponent

The most striking feature of chaos is the unpredictability of the future despite a deterministic time evolution. This unpredictability is a consequence of the inherent instability of the solutions, reflected by what is called sensitive dependence on initial conditions [6]. Lyapunov exponents quantify the average growth of infinitesimally small errors in initial points. Chaotic and stochastic processes are characterized by positive LEs, which mean that neighbouring points of trajectories in the phase space diverge [5].

$$LE = \frac{1}{N\Delta k}\sum_{k=1}^{N}\log_2 \frac{L(k+\Delta k)}{L(k)} \quad (3)$$

where $L(k+\Delta k)$ is distance between the developed points in the phase space. $L(k)$ represents distance between starting point and the nearest Euclidian neighbour and Δk is prediction time interval. LE in negative, zero, positive finite and infinite will be for stable fixed point, stable limit cycle, chaos, and noise, respectively. The Lyapunov exponents carry the units of an inverse time and give a typical time scale for the divergence of nearby trajectories. Thus, the Lyapunov exponents are average local divergences rates over the whole data [6]. Figure 1 shows a strange attractor and prediction error plot of the EEG signal for subject 2 without listening to music.

When we establish algorithms to estimate the Lyapunov exponent and Correlation dimension from a time series, it is assumed that the data quality and the quantity had to be sufficient to observe clear scaling regions. Although these include some very interesting signals, many other data set for which classical, linear time series methods seem inappropriate do not fall into this class. In the case of some doubt interpretation of estimated dimensions, what we need is a proper test which enables us to distinguish the states of the system with a specified level of significance. These tests concentrating on the two important cases that we either want to distinguish nonlinearity in general from Gaussian linear stochastic processes.

3. Experimental Studies and Results

A. Musical Recordings

In the first step, we chose some kinds of Turkish traditional music recordings played by different musical instruments. These recordings belong to selected numerical modes such as *Hüzzam, Hüseyni, Mahur, Nihavent, Saba, Segah, Karcığar, Rast.* In these experiments, the Turkish traditional music instruments used, can be classified as follows; *Kanun, Keman, Ney, Kemençe, Yaylı Tambur, Klarnet.* Musical recordings have been taken at two different sampling rates, mono/stereo format and two-word length as shown in Table 1. The nonlinear analyses were implemented on second group of recordings (e.g. f_s=8000 Hz, 8bit, Mono) to obtain short calculation time.

B. Participants

In order to investigate interaction between musical recordings and human's EEG, we chose three healthy male subjects. Both subjects were undergraduate students aged 25, 23, and 24 years old, respectively. The mental condition of the subjects during the experiments should be identical and subjects must pay attention to music. However, Turkish traditional music experience of the subjects was different levels as follows; high level for subject-1, moderate level for subject-3, and low level for subject-2.

C. EEG Recordings

The EEG data of three subjects were recorded under relaxing condition; relaxing with eyes closed for 20 seconds and music listening; listening to music for 20 seconds with eyes closed. EEGs were recorded with 16 electrodes positioned according to the International 10/20 Electrode System at Ege University Medical School, Dept. of Neurosurgery. Nihon Kohen EEG instrument were used with following settings; sensitivity 7 μV, sampling frequency 100 Hz, band pass filter 0.3-3.5 Hz.

Table 1. Musical recordings used in the experiments

Recordings		PCM, f_s=44100 Hz, 16 bit, Streo (kb)	PCM, f_s=8000 Hz, 8 bit, Mono (kb)
Instrument	**Mode**		
Ney	*Saba*	17.761	806
Ney	*Karcığar*	28.604	1.298
Ney	*Segah*	20.070	911
Ney	*Rast*	13.464	612
Ney	*Hüseyni*	11.229	510
Ney	*Segah*	19.452	883
Keman	*Hüzzam*	17.951	815
Keman	*Nihavent*	41.104	1.865
Keman	*Segah*	44.719	2.029
Keman	*Mahur*	15.849	720
Kemençe	*Hüzzam*	22.960	1.042
Kemence	*Hüseyni*	21.377	970
Kanun	*Saba*	29.553	1.341

D. Signal Analysis

In the fist step, for EEG recordings, we computed Auto-mutual information function, Embedding dimension, and Correlation dimension by Takens estimator [4]. To calculate Lyapunov exponents, we have used the prediction error function. In order to test, EEGs data belongs to nonlinear dynamical system or Gaussian stochastic system, the higher order statistical moment, skewness, was estimated.

E. Numerical Results

For the aim of comparison between the states of three subjects under listening to different musical modes recordings for different musical instruments, we calculated nonlinear parameters. Table 2 shows Correlation dimension (CD), Lyapunov exponents (LE), and Surrogate Lyapunov exponents (SLE) which were estimated for randomly reordered EEG segments. In all experiments, length of EEG segments was 20 seconds.

As shown in Table 2, all Correlation dimensions and Lyapunov exponents are positive and finite numbers. Thus, we can say that corresponding EEG signals are moderate dimensional chaotic signals. For the aim of comparison, the Lyapunov exponents are taken as reference parameters. Without listening to music, LE values are relatively low levels while listening to musical record for mode *Saba* by played *Ney* instrument LE values rather high levels for all subjects (LE: 4,84 and SLE: 4,80 for subject 1, LE: 4,45 and SLE: 4,4 for subject 2, LE: 4,6 and SLE: 4,7 for subject 3). Generally, we can say that LE and SLE are changing respect to musical modes.

In Table 3, we give higher order spectral parameter averaged skewness for some kinds of musical recordings. Since all averaged skewness values are greater than zero, we can accept that EEG's segments are non-Gaussian distributed.

Table 2. Estimated nonlinear parameters of EEGs

Musical Recordings		Subject 1			Subject 2			Subject 3		
Instrument	**Mode**	**CD**	**LE**	**SLE**	**CD**	**LE**	**SLE**	**CD**	**LE**	**SLE**
*	*	2.9052	3.95	3.9	2.8979	3.7	3.7	2.8945	4	4
Kemençe	*Hüzzam*	2.8510	4.4	4.4	2.8968	4.15	4.1	2.9505	4.5	4.5
Kemençe	*Hüseyni*	2.7649	4.4	4.4	2.8645	4.1	4.05	2.9477	4.5	4.45
Keman	*Hüzzam*	2.9145	4.45	4.45	2.9947	4.1	4.1	2.9471	4.5	4.4
Keman	*Mahur*	2.9879	4.4	4.3	2.8955	4	4	2.9163	4.6	4.6
Keman	*Nihavent*	2.9331	4.6	4.6	2.8590	4.15	4.1	2.9825	4.5	4.45
Keman	*Segah*	2.9531	4.5	4.5	2.7719	4.05	4	2.9526	4.5	4.5
Ney	*Hüseyni*	3.0001	4.25	4.25	2.8345	3.9	3.9	2.9760	4.4	4.35
Ney	*Karcığar*	2.5573	4.8	4.8	2.6809	4	3.95	1.9864	5.1	5
Ney	*Saba*	2.9204	**4.84**	4.8	2.4594	**4.45**	4.4	2.9721	**4.6**	4.7
Ney	*Segah1*	2.9972	4.5	4.5	2.8070	4.02	4	2.9675	4.6	4.55
Ney	*Segah2*	2.9986	4.6	4.6	2.8070	4.05	4	2.9112	4.2	4.2
Ney	*Rast*	2.9271	4.4	4.4	2.9932	3.85	3.8	2.8550	4.7	4.7
Yaylı	*Tambur*	2.8901	4.5	4.5	2.6331	4.05	4	2.8768	4.6	4.55

(*): Without listening to music

Table 3. Estimated averaged skewness values

Musical Recordings		Averaged Skewness
Instrument	**Mode**	
Kanun	*Saba*	3.0525
Kemençe	*Hüzzam*	3.6269
Kemençe	*Hüseyni*	3.2118
Keman	*Hüzzam*	2.6750
Keman	*Mahur*	2.6738
Keman	*Nihavent*	3.7807
Keman	*Segah*	3.4021
Ney	*Hüseyni*	2.7044
Ney	*Karcığar*	2.6254
Ney	*Saba*	**2.4305**
Ney	*Segah*	3.5196
Ney	*Rast*	2.9124

In Figure 2, the strange attractor and prediction error plots are given which are belonging to subject 2 for instrument *Ney* and mode *Saba*.

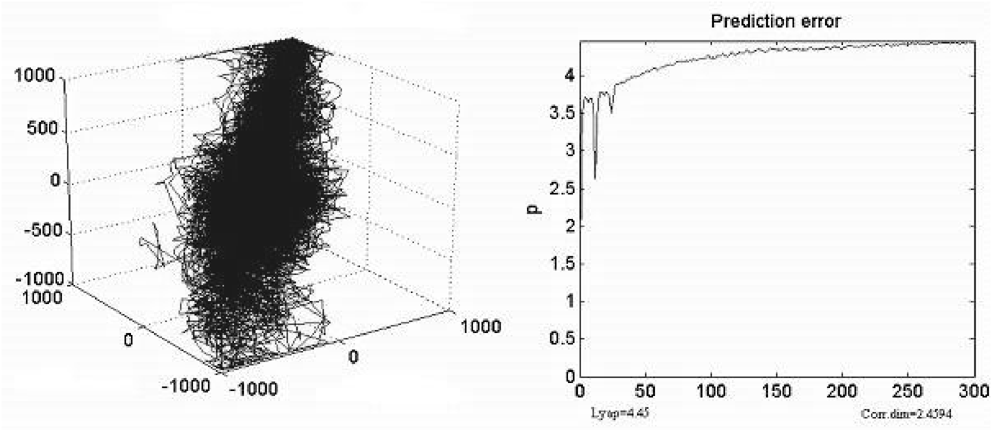


Fig. 2. The strange attractor and prediction error which are belonging to Subject-2 for instrument *Ney* and mode *Saba*.

4. CONCLUSIONS

The present paper demonstrates that a measure based on nonlinear time series analysis can distinguish significant effects of cognitive task, in particular listening to Turkish traditional music modes upon the EEGs. The aim of the present study is to gain further insights into brain mechanism during processing of emotions induced by listening to complex auditory stimulation such as musical effect. The brain activation data (e.g. EEGs) presented here demonstrates that positive value attributions to music are accompanied by characteristic differences in cortical brain activation patterns. In this context, it should be mentioned that the relationship between music preference underlying subjective emotional states is not completely straightforward. However, we can say that the estimated chaotic parameters could effectively denote relationship between musical structures and emotional states. Given results in here is an important step in understanding the organisation of emotional behaviour during listening to Turkish traditional music modes. The main goal of this study is to provide the experimental results obtain from the beginning work about the possibility of medical treatment by Turkish traditional music. In the future, the other nonlinear parameters can be used at further studies for different sex (i.e. female) and aged subject groups.

REFERENCES

[1] Bhattacharya, J., Petshe, H., Pereda, E., Interdependencies in the spontaneous EEG while listening to music, *International Journal of Psychophysiology*, 42: 287-301, 2001.

[2] Altenmüller, E., Schürmann, K., Lim, V.K., Parlitz, D., Hits to the left, flops to the right: different emotions during listening to music are reflected in cortical lateralization patterns, Pergamon, *Neuropsycholigia*, 40: 2242-2256, 2002.

[3] Kawamura, K., *New supporting system for musicotherapy using computer processing*, 18th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 1996.

[4] Fojt, O., Holcik, J., Applying non-linear dynamics to ECG signal processing, *IEEE Eng. in Med. and Biology Magazine*, 96-101, 1998.

[5] Hoyer, D., Schmidt, K., Bauer, R., Zwiener, U., Köhler, M., Lüthke, B., Eiselt, M., Non-linear analysis of heart-rate and respiratory dynamics, *IEEE Eng.*

in Med. and Biology Magazine, 31-39, 1997.

[6] Kantz, H., Schreiber, T., Non-linear time series analysis, Cambridge University Press, 2000.

[7] Web Sites: http://www.gweep.net/~rocko/sufficiency/node27.html http://arttech.about.com/library/bl_chaos_music.htm http://www.math.pitt.edu/~gartside/math0450/chaos/studentReports/HeatherElko.html http://members.aol.com/dspondike/fractal.htm http://members.aol.com/dspondike/mnr/linknav.html#navfractal http://members.aol.com/dspondike/mnr/mnrfractal.html#linkfractal http://hometown.aol.com/strohbeen/fml.html http://www.pjbmusic2.freeserve.co.uk/ http://www.elucida.com/TranslatingSpace.htm

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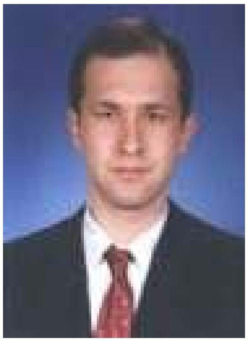

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