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Shuffled data in the investigation of complex dynamics of the neuromotor saccadic system

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***Abstract*—Saccadic temporal data series were examined for evidence of chaotic behavioral trend. To do this, we analyzed the saccadic data series recorded from healthy voluntary subject in special experimental design. Some computational tests based on chaos theory, as phase-space portrait reconstruction and estimation of its correlation dimension and Lyapunov exponent, were applied on saccadic raw data series, in comparison to the shuffled data of the same signal leading to evidence of chaotic dynamics in both cases. Comparison with theoretic chaotic data, quasi-periodic signal and pure random series was also discussed considering corresponding raw and shuffled data.**

Keywords—saccades, random visual stimuli, surrogate data method, chaotic behavior.

I. INTRODUCTION

Modeling the neuro-motor control and analyzing the eye movement temporal series by using nonlinear dynamics techniques gained a real interest in the last years [1], [2], [3] since these studies can help in characterizing and comparing the pathological signals with the normal ones, as an alternate approach in clinical diagnosis. Computational algorithms based on correlation dimension and Lyapunov exponent were used to evidence the difference between physiologic and pathologic in the case electrocardiographic (ECG) signal, for arrhythmia characterization [4]. The differences between normal heart rhythm and arrhythmia showed by statistical analysis were significant, so this can be used as a tool in ECG arrhythmia detection.

The method of surrogate data associated to the analysis of biomedical signal extracted from human body investigation was reported, among others by Small et al [5], Theiler et al. [6] and Theiler & Rapp [7] with focus on the brain activity analysis through electroencephalography. It seems that the identification of chaotic dynamical trend in a temporal series could be better sustained using this procedure since it is known how difficult is to distinguish between purely random signals and chaotic ones. We have reported previously chaotic behavioral trend in the neuromotor cortex activity responsible for rapid voluntary eye movements recorded in different experimental conditions [8, 9] based on the interpretation of various computational tests derived from chaos theory. However the problem remained an open question so that in the next paragraphs the study is completed with the results we obtained using surrogate data.

II. MATERIAL AND METHODS

We recorded the saccadic eye movements from healthy voluntary subject, as part of a larger experiment (with a total of twelve subjects) developed in Laboratory of Sensorimotor Research, at National Eye Institute, USA.

We studied voluntary saccades executed in response to two visual stimuli (not sensorial or auditory) presented to the subject after a well established protocol – two red spots projected from lasers on a translucent screen placed in front of the eyes, a fixed laser spot acting as the central fixation point for the subject eye, while a second one was moved at the left and at the right of the fixation point, acting as visual target.

First, the subject had to look at the central fixation point, and as soon as a target appears, to execute a saccade in that direction. There were two types of ten stimuli sequences: the sequences in which the amplitude, the duration and the frequency had constant values chosen from the arrays given below (predictable sequences) and sequences in which the amplitude, duration and frequency varied randomly (random sequences). The two sequence types were randomly interleaved totalizing a recording duration of about 25 min. The possible stimulus amplitudes were 4, 6, 8, 10, and 12 degrees, the possible durations of the stimulus were 1000, 1050, 1100, 1150 and 1200 ms while the possible durations between offset of the fixation point and onset of the target were 500, 350, 200, 150, 100, 50, and 0 ms. Using a real-time data acquisition and control system (REX, version 8.0) the desired parameters were set to perform the recording sessions for each subject. We have chosen a random sequence of

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