COMPUTATIONAL INSIGHT IN THE VISUAL GANGLION DYNAMICS*

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The role of the lamina visual ganglion in the phototransduction of the compound eye was studied. Experimental and computational investigation on the dynamics of the visual system of *Drosophila melanogaster* was carried out by means of electroretinographic signal ERG recording under various intermittent light frequencies. ERG signal dynamics was found significantly changed to the variation of the illumination frequency. The asymmetrical amplification of the ERG hyperpolarization component to the enhancing of the illumination frequency was revealed. The role of the neural cells of the first optic ganglion in the transduction of high frequency stimuli was discussed on the basis of the correlation dimension calculated using adequate mathematical algorithm.

Key words: *Drosophila melanogaster*, periodic stimulation, visual cell, complexity analysis, chaotic trends.

1. INTRODUCTION

Characterized by an intermediate grade of complexity, the organization of the dipteran (flies) visual system is somewhat parallel to that of the vertebrate visual analyzer while its set of neurons is more limited and easier to identify. Why studying the eye of *Drosophila melanogaster*? Because *D. melanogaster* has numerous mutants (many with visual system peculiarities); the photoreceptor cells are not tightly compacted as in the vertebrate retina being easier to investigate; there are numerous types of K^+ ion channels in the photoreceptors membranes, their study being of high interest for all types of excitable cells. The ERG signal is given by the superposition of the corneal projections of the depolarization signals from the peripheral (R1-R6) and central (R7-R8) photoreceptors (that are leading to the generation of the ERG component named "receptor potential") as well as the hyperpolarization signals from the lamina ganglion cells (giving the ERG component named "lamina-on-transient"). After

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the light absorption in the rhodopsine molecules, the membrane selective permeability for different ions (Na^+, K^+, Ca^{2+}, Cl^-, …) is modified by means of complex and not very well known mechanisms, and an action potential is generated [1]. In the photoreceptor cells, the action potential induced by the light consists into a membrane depolarization while in the first optic ganglion, lamina, bioelectrogenesis phenomena lead to a membrane hyperpolarization.

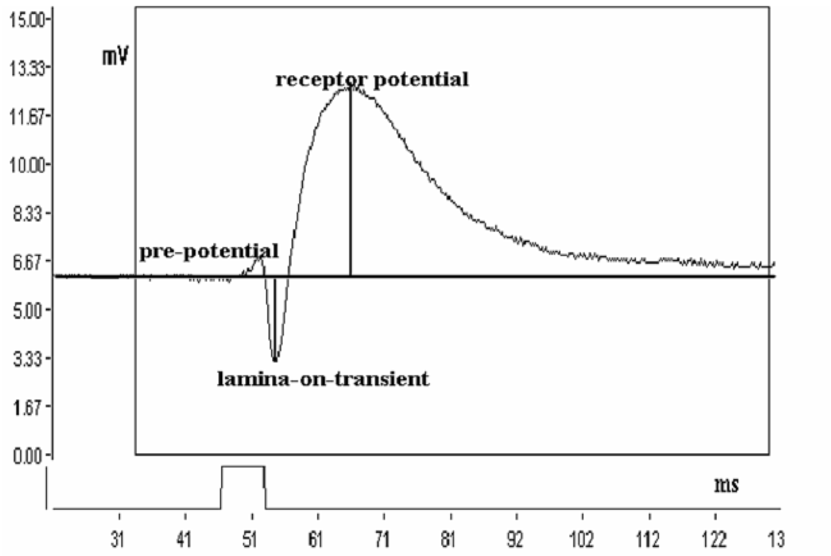

Fig. 1 – The ERG response to periodic light stimuli application (about 10 Hz) in white light of relatively high intensity; typical for the compound eye (original recording).

Regarding the medical applications, one need to know that recordings of electrical activity of the main vital organs represent important physiological investigation tools for medical researchers, but also for biophysicists. Electro-encephalograms, electrocardiograms, [2–3] electromyograms [4] and electro-retinograms are more or less present in day-to-day medical diagnostics. In parallel with the experimental studies the theoretical ones were developed. Application of chaos theory to the study of the electroencephalographic signals [5] has generated the highest and earliest interest in both medicine and physics (for instance the emphasis of distinct degrees of complexity in normal and epileptic subjects).

Among the most recent reports regarding the non-linearity of the electro-cardiographic signal we mention:

– the evidence of changes in heart rate variability during induction of general anesthesia [6–7];

– the study of heart rate variability in different generations [8];

– the discrimination of healthy patients from those with cardiac pathology based on wavelet analysis of heartbeat intervals [9].

Very few data [10–11] referred to the non-linearity of the electroretinographic signal. In the next some quantitative approaches of the ERG signal provided by the compound eye are presented.

2. MATERIALS AND METHODS

ERG recordings were carried out on 3–8 days old *D. melanogaster* flies raised on standard cornmeal-agar medium at room temperature as presented in [11]. The white-eyed mutant *white* was chosen for investigation due to the higher ERG amplitudes. The light intensity was of about 10^{-4} mW/cm^2 (measured with a Tektronix photometer); the illumination frequency ranged between 5 and 100 Hz.

The soft package Chaos Data Analyzer [12] (commercially available) was used to calculate the correlation dimension of the data series corresponding to extreme values of the illumination frequency. The basic idea of the correlation dimension algorithm is to construct a function *C(r)* representing the probability that two arbitrary points on the system trajectory shaped in the state space are closer together than r (the radius of a hypothetical hypersphere drawn to cover the attractor) [13]. This is usually done by calculating the distance between every pair of *N* data points and sorting them into bins of width *dr* proportional to *r*. The correlation dimension is given by:

$$C_D = \lim_{dr \to 0} \frac{d\left(\log C(r)\right)}{d\left(\log r\right)} \tag{1}$$

where one must consider *r* tending to 0, and *N* tending to infinity. For simple systems, with totally predictable dynamics the correlation dimension is an integer while for more complex systems this number is a fraction. For high unpredictable systems the correlation dimension is higher than 5 suggesting strong noise overlapped onto the studied signal.

3. RESULTS AND DISCUSSIONS

In Fig. 2 the ERG signal recorded in intermittent beam of white light with a frequency of about 10 Hz is presented. The structure of the signal is totally concordant with the literature data [14].

For small illumination frequencies the amplitudes of the ERG depolarization components (receptor potential) are equal among them and the amplitudes of the hyperpolarization components (lamina-on-transient) are equal among them

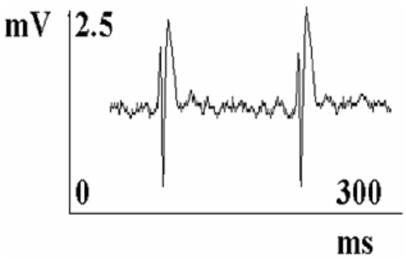

Fig. 2 – The ERG signal recorded in white light with the frequency of 10 Hz in *D. melanogaster* compound eye. Two consecutive ERG responses (for two consecutive light stimuli) are presented.

too. For higher illumination frequencies the ERG amplitudes – both depolarization and hyperpolarization components diminish gradually. But after certain critical frequency threshold the amplitudes of lamina-on-transient components are alternatively large and small.

In Fig. 3 the ERG recording for high illumination frequency is given.

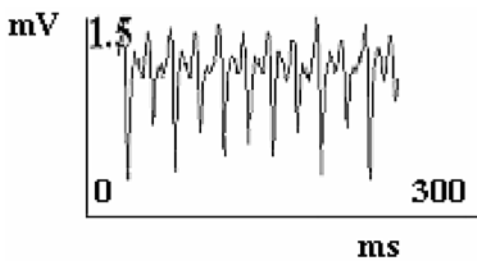

Fig. 3 – The ERG signal recorded in white light with the frequency of 95 Hz in *D. melanogaster* compound eye. Twelve consecutive ERG responses are presented.

While the receptor potential amplitudes are approximately equal to each other the lamina-on-transient amplitudes are alternatively large and small. The application of *t*-test (pair type, two tailed) revealed statistically significant difference between the average values corresponding to the two frequencies.

The phenomenon has been observed previously [15] being suggested a resonant interaction between the lamina large monopolar cells. We computed the correlation dimension in order to get a quantitative indicator of this experimental issue.

For both frequencies the correlation dimension are non-integer numbers suggesting the high complexity degree of the visual system dynamics – as revealed by ERG temporal data series (Table 1). The eye capacity of following the stimuli frequency is not unlimited – in the case of the fly compound eye the distinct ERG responses appear only until about 100 Hz. For all recorded data

Table 1

The correlation dimension values for ten *D. melanogaster* individuals grown and analyzed in the same conditions

10Hz	2.561	2.303	2.107	2.402	2.298	2.341	2.412	2.634	2.174	2.652
95Hz	3.834	3.782	4.109	3.672	4.39	3.5671	4.231	3.561	3.381	3.801

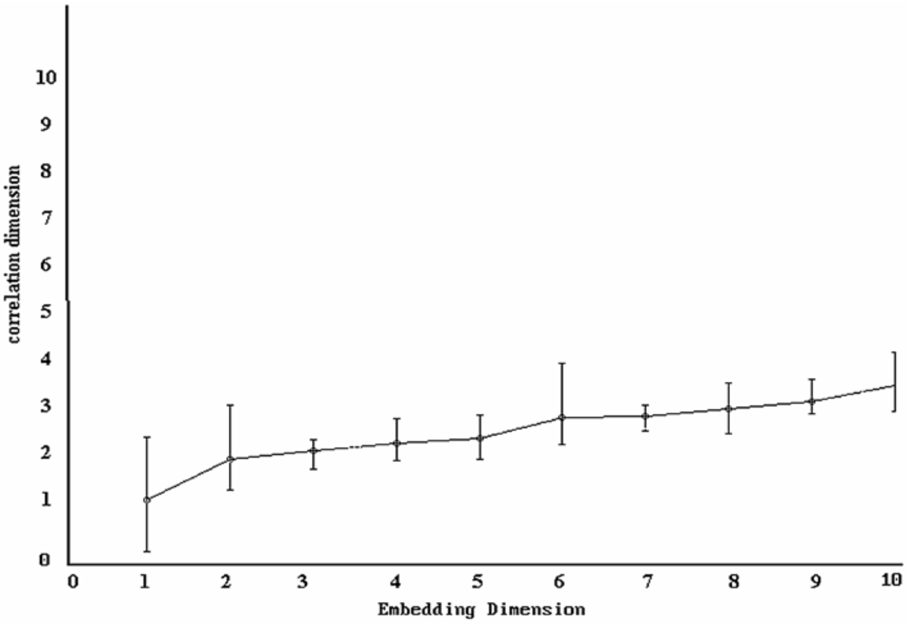

Fig. 4 – The saturation tendency of the correlation dimension *versus* the embedding dimension; 10Hz illumination frequency.

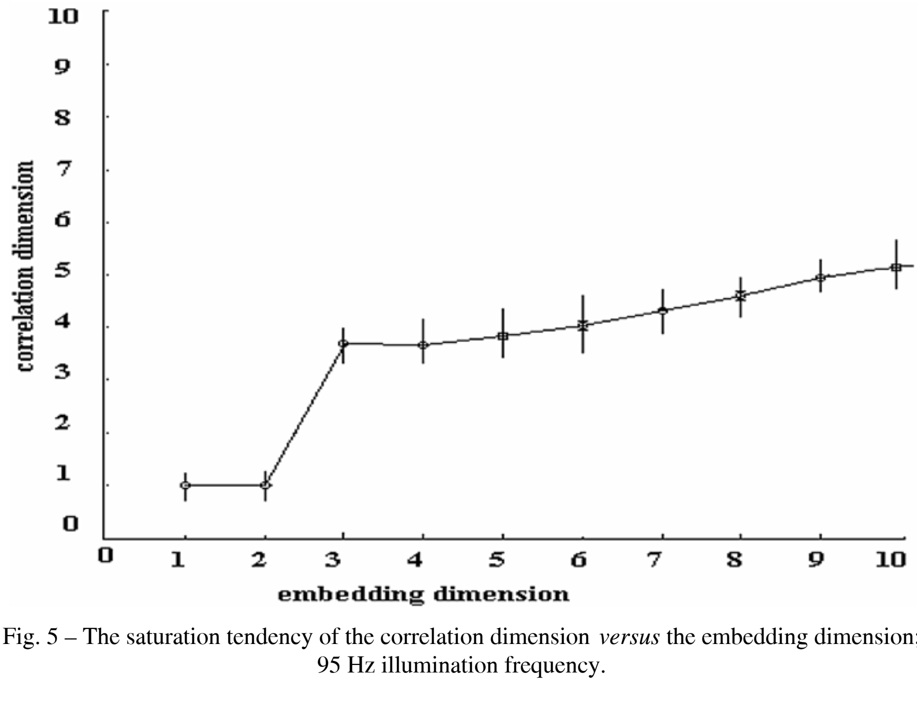

Fig. 5 – The saturation tendency of the correlation dimension *versus* the embedding dimension; 95 Hz illumination frequency.

series we obtained similar dependency of the correlation dimension versus the embedding dimension (Fig. 4). The embedding dimension is corresponding to the observation scale in the data series, being a useful theoretical tool in identifying the fractals – objects presenting geometrical feature invariance to the observation scale. We may mention at this point that the correlation dimension might be taken as a measure of the fractal dimension According to literature, the saturation tendency – as that revealed in Figs. 4–5 – is related to the dominance of the chaotic trend in the system dynamics [16]. So, using the correlation dimension as computational tool one might say that the visual system dynamics under intermittent illumination has a distinct chaotic trend – in the sense of deterministic chaos. The increased correlation dimension to the increase of the illumination frequency from 2.38 (average value for 10 Hz) to 3.83 (average value for 95 Hz) – with statistical significance related to the threshold of 0.0001 – is an indication on the increasing complexity degree of the visual system dynamics to the increasing of the illumination frequency. Further computational investigation is planed using mathematical algorithms able to provide deeper insight in the biological systems.

4. CONCLUSIONS

The electroretinographic signal was recorded in different illumination conditions by changing gradually the frequency of light stimuli. The phenomenon of variable lamina on transient amplitude was evidenced for the highest illumination frequencies – of about 95 Hz. The correlation dimension calculated for the temporal data series showed non-integer values and saturation tendency for high values of the embedding dimension. The deterministic chaos trend in the visual system has been revealed by computational means suggesting that the main implication is that of the neural cells from the lamina first optic ganglionaris.

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