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Complexity measures and self-similarity on spreading depression waves

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HIGHLIGHTS

- Some authors conjecture that there is self-similarity in spread depression phenomenon.
- SDL complexity measure was applied to experimental data related to chicken retina spread depression.
- Two concomitants of spread depression waves were measured in different spatial scales.
- SDL measures presented remarkable differences for the different spatial scales.

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ABSTRACT

Self-similarity has been considered to be present in most of the spatial pattern formation phenomena occurring in natural contexts. In the case of the spreading depression (SD), there are conjectures about the presence of self-similarity in the circular wave formations. Shiner–Davison–Landsberg (SDL) complexity measure framework has been used in several contexts, in order to understand and classify systems and behaviors that are supposed to be complex. Here, by using SDL measure over data collected on SD experiments, self-similarity conjecture is tested. The data came from chicken retina spreading depression experience by measuring two concomitant signals: the extra-cellular potential and the intrinsic optical signal, that were collected in two different spatial scales. The SDL complexity was calculated for the data and two main results appeared: all the studied substances present similar SDL dynamical behavior and, considering the same substance, optical signals present different SDL values for different spatial scales. Consequently, it is not possible to conclude that SD phenomenon presents self-similarity.

1. Introduction

The spreading depression (SD) phenomenon that consists in the depression of the neurons electrical activity can be described by a sequence of local events triggering a global behavior that is propagated as a wave along the gray matter [1,2]. Extra-cellular potential variations appear due to the ionic flux associated to the wave propagation and there are some conjectures about the self-organizing criticality character of SD, expressed through its scale invariance [3].

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This question has been studied by the membrane physiology group from the Institute of Zoo-physiology, Hohenheim University in Germany by using a chicken retina model which wave is a good model for the SD observed by Leão [1,4,5].

Recently, the Hohenheim group performed several experiments with chicken retina SD experimental sets measuring concomitant electric and optical signals during the wave propagation and the authors here were authorized to try different approaches to study the data, trying to improve the analyzing methods.

The idea is that, besides the ion movements through the membrane that characterize the electrophysiology of the phenomena, there are optical signal variations according to light dispersion and propagation [5]. These signals were registered and, by using concepts from biological complexity measures [6,7], they are studied trying to find out any theoretical explanations about SD.

Since Shannon's work on Information Theory [8], there are a lot of efforts trying to unify the concepts of informational and thermodynamical entropies [9] and relating them with complexity and organization concepts in life sciences [10].

As the spreading depression phenomena was firstly reported seven decades ago [1,2] and, since then, it is being studied profoundly by using electrical and optical techniques [4,5,11], it is reasonable to suppose that the experimental technics and theoretical models are well developed, in spite of the lack of a complete integrated mathematical-physics model for the SD wave propagation.

The purpose here is to add a small contribution to the understanding of the phenomena, applying Shiner–Davison–Landsberg (SDL) complexity measure [12] to the electrical and optical signals obtained when the effects of several substances (ritalin, amphetamine, caffeine and cocaine) on SD wave propagation were measured.

In the next section the materials and experimental methods are described, followed by a brief theoretical explanation about complexity. Then, the results are explained and discussed emphasizing the temporal evolution of the SDL measure. Some theoretical conjectures are presented in the conclusion section.

2. Experimental methodology and materials

The experiments were conducted at Zoo-physiology Institute, Hohenheim, in Germany, following the local ethical regulation.

The analyzed SD waves were isolated and circular in presence of different substances with a total number of twenty-nine experiments. Considering all experiments, five were obtained in presence of ritalin, seven with amphetamine, nine with caffeine and eight with cocaine.

SDL complexity calculations, described in the next section, were performed over the electrical and optical registration. Optical profiles were obtained in two different spatial scales: macro (IOS) and micro (GOS). The electrical potential was measured in the internal plexiform layer (IPL) [13].

These concomitant signals associated to SD waves were used to analyze how order and disorder are balanced, in order to generate complexity.

2.1. Preparation of the eye-cup

For the experiments, chicken at the age from 5 to 21 days were used. After decapitation the eyes are removed out of the eye socket. Eyes are sectioned close to the equator and vitreous body is removed with a tweezers.

The posterior eye-cups are immersed in Ringer solution. The eye-cups are then glued each in a Petri dish and put in the set up where they are perfused with Ringer solution. Before the measurements started the retinas are allowed to recover for 30 min.

2.2. Ringer solution

The solution used to perfuse the isolated retinas has the following composition: 100 mM NaCl; 6 mM KCl; 1 mM $MgSO_4$; 1 mM $CaCl_2.2H_2O$; 30 mM $NaHCO_3$; TRIS 10 mM and 30 mM glucose. The pH was fixed at 7.4.

2.3. Retinal setup

The setup is enclosed in a Faraday cage in which a camera and a photomultiplier are aimed at central retina region through a microscope.

Electrical recordings were performed with extracellular glass micro-electrodes (tip diameter around 10 m, filled with potassium solution) inserted in the retina by using a micromanipulator and optical control.

The positioning was aimed to the inner plexiform layer. The electrical potential of the tissue relative to the bathing solution was measured with a high impedance amplifier connected to a Ag/AgCl-electrode in the glass micro-pipette versus another Ag/AgCl coil wire electrode immersed in the bath (reference electrode).

The retina is maintained under perfusion at 1 ml/min rate and at 30° C temperature.