Journal of Theoretical Biology 382 (2015) 279–283

Contents lists available at ScienceDirect

Journal of Theoretical Biology

journal homepage: www.elsevier.com/locate/yjtbi

Dense neuron system interacting with the gravitational potential

R.A. Thuraisingham *

Honorary Research Fellow, Rehabilitation Studies Unit, Northern Clinical School, University of Sydney, NSW 2065, Australia

HIGHLIGHTS

- The role of gravitational interaction between neurons is studied theoretically.
- The study examines gravitational interactions alone under zero gravity.
- Density changes show effects from thermal motion and gravitational interactions.
- Gravitational interactions give rise to a collective low oscillation frequency.
- Provides a mechanism to understand organized behavior in microgravity.

ARTICLE INFO

Article history:
Received 16 February 2015
Received in revised form
2 June 2015
Accepted 3 July 2015
Available online 15 July 2015

Keywords:
Interacting neurons
Gravitation potential
Collective behavior

ABSTRACT

A theoretical model is developed to study the role of the gravitational potential between neurons in the brain under conditions of zero gravity. The model includes firing and non-firing neurons in a neural network where the source of interaction is the gravitational potential. The importance of this study is its ability to examine the role of the weak gravitational potential alone without the inclusion of other interactions between neurons. The results of the study show density fluctuations contain components from thermal effects and gravitational interactions. It also shows collective oscillatory behavior amongst neurons from gravitational interactions. The study provides a simple alternate mechanism to understand organized behavior of neurons in the brain under conditions of zero gravity.

1. Introduction

Since most of the tasks in the brain are performed by neuronal assemblies it is of interest to understand whether gravitational interactions between them can result in organized behavior. This is studied theoretically by focusing on the role of the gravitational interaction between neurons under zero gravity. The study is carried out theoretically by examining the effect of gravitational interaction on a dense neuron system consisting of activated and non-activated neurons. Does the weak but ubiquitous gravitational potential between neurons result in organized behavior of neurons under zero gravity? This question is examined by selecting the gravitational potential as the only source of interaction between the neurons. The ability to study specifically the effect of the gravitational potential alone between neurons is one of the key aspects of this paper. Such a study is not feasible experimentally due to the difficulties in excluding the effects of other strong interactions present between neurons. It does not mean that there are no complex interactions between neurons which can give rise to organized behavior. What is examined here is to study in a non-contaminated manner the effect of the gravitational interaction on a dense system of neurons. Such a study of the specific effect of the gravitational potential on a dense system of neurons has not been carried out before and hence its importance and interest.

When neurons are in the presence of the earth's gravitational field mechanisms have been put forward to understand how neurons connect themselves to form assemblies. The theory of Hebb (Hebb, 1949; http://en.wikipedia.org/wiki/Hebbian_theory) is one of them. According to this theory simultaneous repeated activity of a group of neurons results in association, where activity in one facilitates the activity in the other. For example if one cell repeatedly assists in firing another, the axon of the first cell either develops synaptic knobs or enlargement if they already exists, in contact with the soma of the second cell (Hebb, 1949,p. 63). It describes a mechanism for synaptic plasticity (Hughes, 1958), where synaptic plasticity is the ability of synapses to strengthen or weaken over time depending on the increase or decrease in their activity. Another approach that has provided evidence of

* Correspondence to: 1A, Russell street, Eastwood, NSW 2122, Australia. Tel.: +61 2 98743022 *E-mail address:* ranjit@optusnet.com.au .
E-mail address: ranjit@optusnet.com.au

http://dx.doi.org/10.1016/j.jtbi.2015.07.004
0022-5193/

dynamical neuronal interactions and of collective neuronal behavior are experiments that involves simultaneous recording of multiple spike trains (Gerstein, 2010). The recorded data are analyzed using a technique referred to as gravity clustering (Gerstein and Aertsen, 1985; Gerstein et al., 1985) where the simultaneously recorded N multiple spike trains are represented as N charged neurons moving in N dimensional space. The charges in the neurons are transient and are produced by action potentials on the neurons being fired. An appropriate force law results giving rise to particle trajectories. Clusters of neurons will result when the neurons are fired near synchronously. Under zero gravity will gravitational interaction amongst neurons be an alternate mechanism for organized behavior of neurons?

The model that is examined looks at the motion of neurons in a neural network interacting with each other with the gravitational potential under conditions of zero gravity. Due to the complexity in dealing with the simultaneous interaction of each neuron with all other neurons, the motions of the neurons are analyzed in terms of density fluctuations. The neurons are described in terms of the Fourier components of the neuron density at each point in space. These Fourier components describe the density fluctuations of the neurons in the brain. The network of neurons is taken here as consisting of activated (firing) and non- activated (non-firing) neurons where the interaction potential between the neurons is the gravitational potential. The approach adopted in the method of analysis has similarities to the approach used in the study of a dense electron gas (Pines and Bohm, 1952). However there are differences: The potential used in the study of electrons is the much stronger Coulomb potential; in the study of the electron gas there is only one type of particle, namely the electron while here there are two types, the activated and the non-activated neuron.

The paper is structured as follows: Section 2.1 in the methods section provides a brief description of the neural network model and Section 2.2 details the theoretical analysis; Section 3 gives the numerical results; Section 4 is the discussion and Section 5 is the conclusion.

2. Method

2.1. Neural network model

The basic unit of the brain is considered to be the neuron. The input to a neuron can be direct from the senses and also from other neurons connected via synapses. The output from the neuron is via the axons to other neurons. The brain is thus considered as complex interconnected network of nodes, where the nodes are neurons. Further each neuron is considered as a two state device, which means that there are two possible states for the neuron. One state is where it is not fired up while the other is when it is fired. When the inputs from the synapses exceed a certain threshold, then the neuron fires, that is it sends an electric pulse down its axon. In this study the Hopfield neural network (Hopfield, 1982; www.scholarpedia.org/article/Hopfield_network), is used as a model to understand the brain. The values these two states of each neuron (s_p) are taken here as $+1$ and -1, the bipolar representation. The value -1 is when the neuron is not fired while $+1$ is when the inputs exceed the threshold energy θ_p and fires an electric pulse. The model also assumes that every pair of neuron in the network is connected, with an interaction energy $w_{pj}s_p s_j$ where $w_{pj}=w_{jp}$ that is symmetric and $w_{pp}=0$. For a neuron whose state is s_p the interaction energy with all others neurons can be written as:

$$\phi = s_p \sum_{j_1} w_{pj_1} - s_p \sum_{j_2} w_{pj_2} \tag{1}$$

where the first sum is over all the neurons which are activated; and the second sum is over all the neurons which are not activated.

2.2. Theoretical analysis

Let us assume at this stage that w_{pj} is a function that depends on the distance of separation between neurons p and j, that is

$$w_{pj} = f(|x_p - x_j|) \tag{2}$$

At this stage the exact functional form is not specified. Let us consider the equation of motion of the pth neuron, where the interaction energy with all other neurons is ϕ.The equation of motion of the pth neuron is given by,

$$\ddot{\vec{x}}_p = (-1/m)(\partial\phi/\partial x_p) \tag{3}$$

Where m is the mass of the neuron and $\ddot{\vec{x}}_p$ denotes the second differential of the coordinate $\vec{x}_p$ with respect to time. Let us expand the term containing the interaction term in Eq. (2) as a Fourier series in box of unit volume with periodic boundary conditions as follows:

$$f(|\vec{x}_p - \vec{x}_j|) = \sum_k f_k e^{i\vec{k}.(\vec{x}_p - \vec{x}_j)} \tag{4}$$

where

$$f_k = \int d(\vec{x}_p - \vec{x}_j) f(|\vec{x}_p - \vec{x}_j|) e^{-i\vec{k}.(\vec{x}_p - \vec{x}_j)} \tag{5}$$

The letter i in Eq. (5) is the imaginary number $\sqrt{-1}$, and $\vec{k}$ is the wavevector. Eq. (3) can then be written as,

$$\ddot{\vec{x}}_p = z_1 - z_2 \tag{6}$$

where,

$$z_1 = (-is_p/m) \sum_{j_1,k} f_k \vec{k} e^{i\vec{k}(\vec{x}_p - \vec{x}_{j1})} \tag{7}$$

$$z_2 = (-is_p/m) \sum_{j_2,k} f_k \vec{k} e^{i\vec{k}(\vec{x}_p - \vec{x}_{j_2})} \tag{8}$$

In Eqs. (7) and (8), $k=0$ is excluded, since the mean interaction energy amongst all neurons is zero when $k=0$. The solution of Eq. (6) is difficult and we follow here the approach of Pines and Bohm (Pines and Bohm, 1952).

Assume the neurons are point particles and the neuron density in a box of unit volume is given by,

$$\rho(\vec{x}) = \sum_p \delta(\vec{x} - \vec{x}_p) \tag{9}$$

Again it is more convenient to work with the Fourier components ρ_k of the density. These are given by,

$$\rho_k = \int d\vec{x} \rho(\vec{x}) e^{-i\vec{k}.\vec{x}} = \sum_p e^{-i\vec{k}.\vec{x}_p} \tag{10}$$

Thus,

$$\rho(\vec{x}) = \sum_{k,p} e^{i\vec{k}.(\vec{x} - x_p)} \tag{11}$$

In Eq. (10), ρ_0 represents the mean density and ρ_k with $k \neq 0$ describe the fluctuations about this mean density. Let

$$\rho_k^1 = \sum_{p=1}^{j_1} e^{-i\vec{k}.\vec{x}_p};\ \rho_k^2 = \sum_{p=1}^{j_2} e^{-i\vec{k}.\vec{x}_p} \tag{12}$$