How might far different network topologies impact the development of epilepsy? – A modeling approach.

Manuel Garcia-Russo[1], Natasha Astudillo[1], and David Quesada[1,*]

[1] School of Science, Technology, and Engineering Management, St. Thomas University, Miami Gardens, FL 33054, USA; E-Mail: dquesada@stu.edu;

* Author to whom correspondence should be addressed; E-Mail: dquesada@stu.edu; Tel.: +1-305-474-6910; Fax: +1-305-628-6706.

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Abstract: Interest in neurological disorders has grown exponentially over the last decade with rapidly developing technologies and more refined diagnostics. Epilepsy is the neurological disorders with well-localized sources of seizures. The understanding of conditions that lead to different types of epileptic seizures of different types, as well as the extent of the damage caused by these seizures is limited. Insight into these issues is especially critical in surgical procedures in cases of epilepsy that are currently non-treatable with medication. In this communication, two models of neuron dynamics (the Kuramoto model and the FitzHugh-Nagumo model) were analyzed. While the FitzHugh-Nagumo network model addresses an ensemble of neurons interacting each other and identifies their synchronic behavior, the Kuramoto model is used to investigate the synchrony between different cortical areas that belong to different brain zones from where EEGs are measured. In both cases, the influence of the connectivity matrix on the dynamical response is studied. Conditions favorable for epileptic seizure were assessed in terms of topological measures of the network. Centrality and clustering values were observed to be the most significant.

Keywords: *Neuronal networks, Fitzhugh Nagumo model, Kuramoto model, network topology, centrality, adjacency matrix, functional and anatomical networks.*

Introduction

Epilepsy is the 4th most common neurological problem in the USA, followed by migraine, strokes and Alzheimer disease. The average incidence of this condition each year in the USA is estimated at 48 incidents for every 100,000 people. Young children and older adults are the groups with the highest rates. In addition, the prevalence of this condition is estimated at 2.2 million people or 7.1 for every 1000 people in the USA [1]. Epilepsy is a medical condition characterized by seizures or disruptions of the electrical communication between neurons. Some epileptic seizures can be controlled with medications while others require surgical interventions. In these cases, surgeons must decide how much of the brain to remove or disconnect. Since our understanding of the inner workings of the brain is still at its infancy, there are many cases in which surgical procedures do not resolve episodic seizures.

This communication is aimed at assessing the relevance of the topology of the neuronal networks and how it impacts the synchronization between many neurons. Based on accumulated experience Refs. [2 – 5], it is hypothesized that some specific changes in neuronal networks are conducive to the appearance of seizures, for example, a lack of synchrony, with an escalating noise spread over extensive areas of the brain, can result in a frustrated dynamic state of neuron bundles. The goal is to translate results into the clinic to improve decision-making and accuracy during surgical procedures.

Model and Results

The brain is considered as one of the most challenging complex systems to be understood. Thus, models presented below are in agreement with methodologies used in complex systems. For instance, we are interested in the interplay between anatomical and functional complex networks. Two models of interest are solved for the sake of simplicity for model-designed networks: the Fitzhugh-Nagumo model which accounts for the dynamics of connected neurons, and the Kuramoto model, which accounts for synchronization between different patches of cortical areas where neuronal networks are sparse (see Table 1).

Fitzhugh – Nagumo model (microscopic picture)	**Kuramoto model (mesoscopic picture)**
$$\frac{dv_i}{dt} = v_i - \frac{v_i^3}{3} - w_i + I_{inter} + I_{ext}$$ $$\varepsilon\frac{dw_i}{dt} = v_i + a - bw_i$$ $$I_{inter} = \sum_{j=1}^{N} G_{ij}a_{ij}(I_j - I_i)$$	$$\frac{d\theta_i}{dt} = \omega_i + \sum_{j=1}^{N} \sigma_{ij}a_{ij}\sin(\theta_j - \theta_i)$$

Table 1: Equations defining both models to be explored in this communication. In the case of the Fitzhugh Nagumo model, v represents the action potential of the neuron in the node (i), while w is the complement function. In the case of the Kuramoto model, θ is the phase of the (i) oscillator.

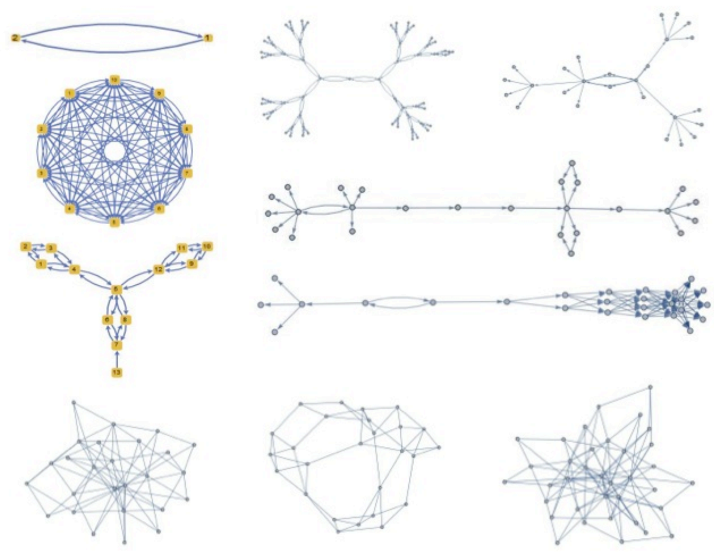

Fig. 1: Network configurations used in this communication. They are representative of local clusters of neurons. The maximum number of nodes was 128, and nodes were connected either through regular graphs or scale-invariant, or random graph.

Examples of neuronal models analyzed within this communication are summarized in Fig. 1. For each of the networks, the adjacency matrix **A** = || a_{ij} || is computed and the weights for connections were randomly generated. Weights were contained in the matrices **G** and **σ** for each of the models. In each case, topological measure as the vertex distribution, centrality, clustering coefficient, network's shortest distance, and synchronization parameters were computed.

Conclusions

Network topology influences the ability of bundle of nodes to reach the state of synchronization. A fair indicator is the clustering coefficient. The state of synchronization may suffer from a phenomenon similar to the Braess paradox observed in road networks. Networks of neurons with bridges are important because they might turn off the overall connectivity between different areas of the brain and therefore influence the appearance of seizures. A comparison with real epileptic brain networks obtained from EEG inverse signal processing, is planned for the future.

Conflicts of Interest

The authors declare no conflict of interest.

References and Notes

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