



A Hyperbolic Model of Neuronal Spiking Patterns in Parkinson's Disease

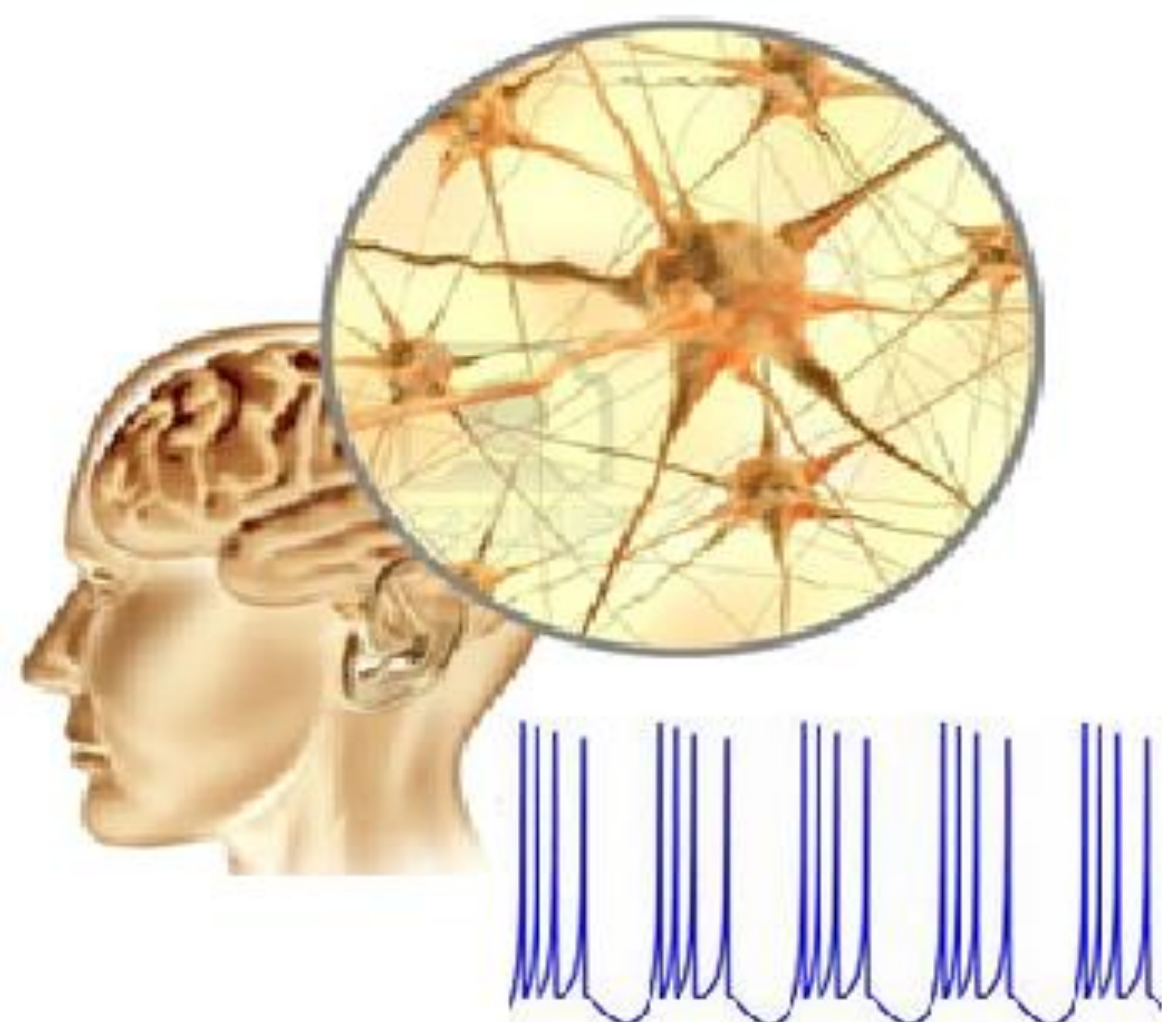
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Abstract

To investigate how different types of neurons in brain can produce well known spiking patterns, a new computationally efficient model is proposed in this poster. The model can demonstrate various neuronal behavior observed in vivo such as abnormal pattern of subthalamic nucleus (STN) in Parkinson's disease. The irregular and arrhythmic behavior of STN firing pattern under normal conditions can easily be transformed to those caused by Parkinson's disease through simple parameter modifications. This model can explicitly show the change of neuronal activity patterns in Parkinson's disease, which may eventually lead to effective bio-chip designs that can be used to assist in the control, treatment, and ultimately, the cure of the disease.

Introduction

What happens that actually leads to different types of neuronal spiking, is the existence of various ionic currents. Definition of a practical model that can address real brain problems through a wide variety of disorders, is to consider biological features of a cell along with less complex mathematical equations. In Parkinson's disease, depletion of dopamine modifies synaptic transition, causing abnormal firing patterns in STN. In this work, the bursting pattern of STN in Parkinson's disease will be studied through a mathematical relationship, capable of modeling this kind of abnormality.



Proposed Model

In order to study normal spiking patterns of neurons in brain most works had implemented biologically inspired Nobel prize winning Hodgkin Huxley model [1]. Here we present a new mathematical model based on Izhikevich cortical neurons model [2], which is more compatible with abnormal spiking patterns, specifically due to Parkinson's disease.

$$\frac{dv}{dt} = \alpha \cosh\left(\frac{v-v_{rest}}{\beta}\right) - \epsilon - H + I \quad \frac{dH}{dt} = \tau_H(n_H v - H)$$

Where α is insulation of cell membrane around a neuron, I is stimulus current and v is membrane potential with resting state v_{rest} . β is an adjustable parameter to control the sharpness of spikes and ϵ is related to general gate voltage of inward calcium. Finally rates of spikes can be customized through τ_H & n_H .

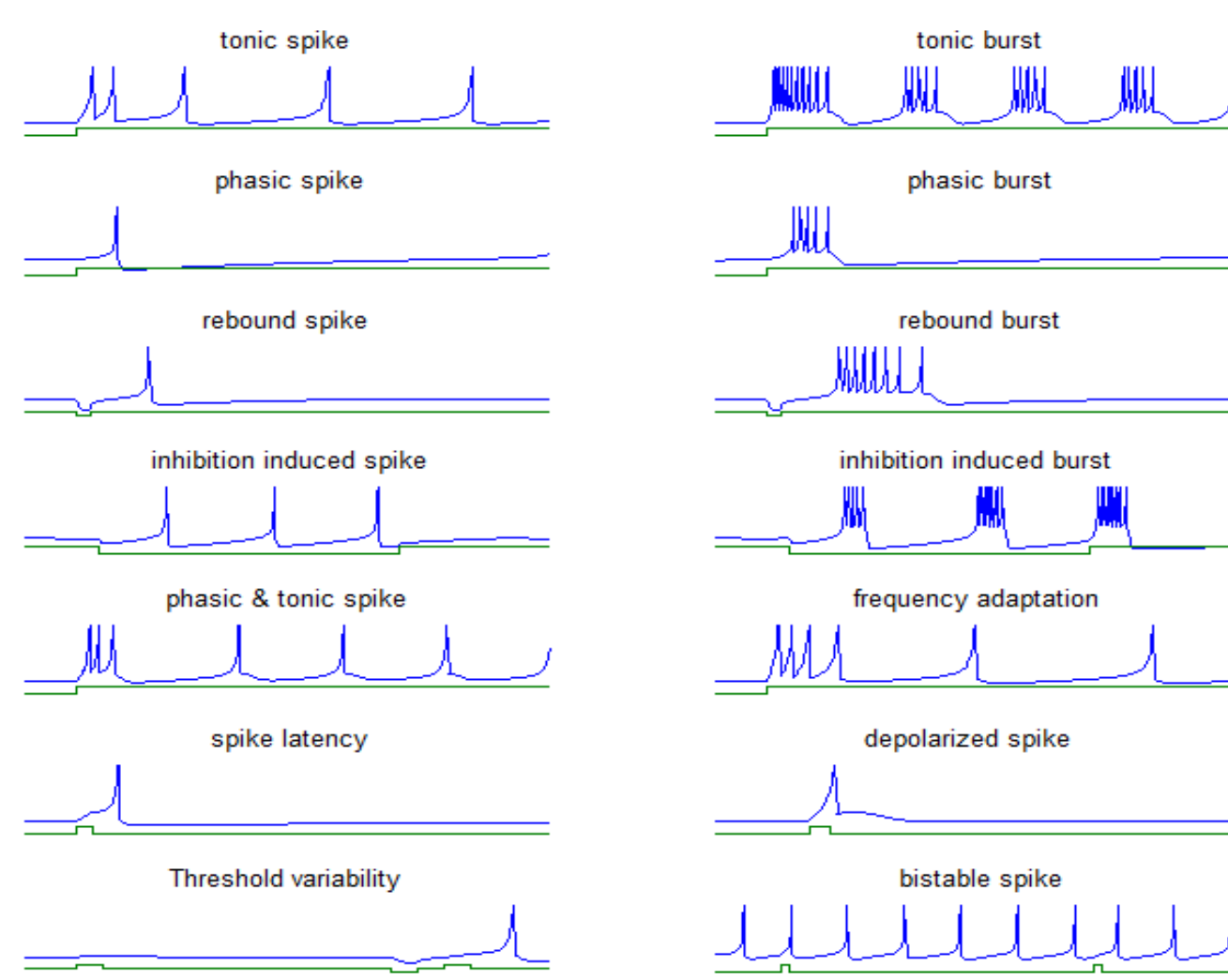


Figure 1: Different spiking patterns generated by our via MATLAB model. Green lines are the input currents to our model and blue plots are the output firing patterns.

For Parkinson's Disease we should investigate STN neurons. STN neurons can change their firing patterns from single spike mode to bursting patterns. This transition between two modes is observed via our mathematical model using MATLAB.

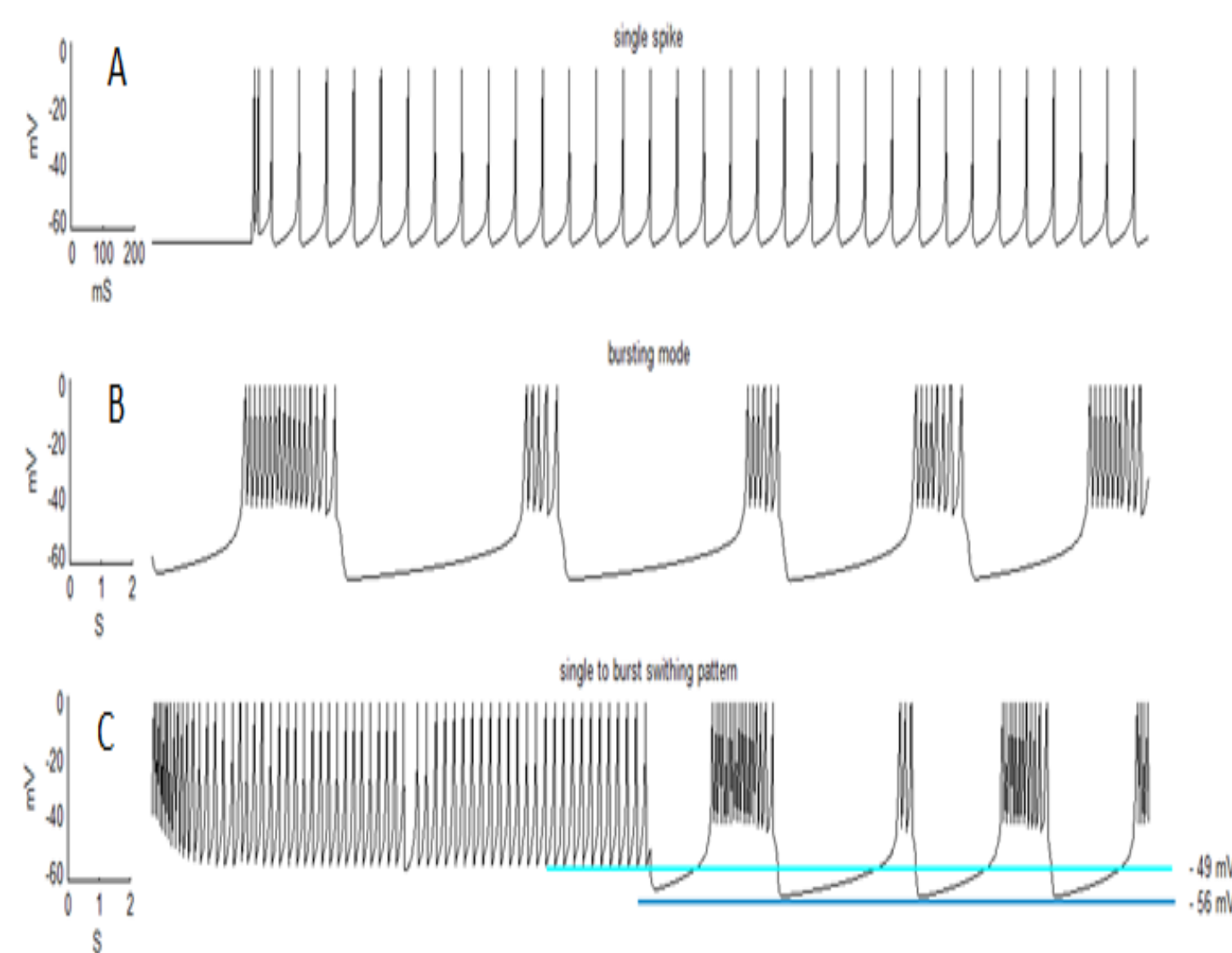


Figure 2: Single, burst and switching mode of STN neurons spiking generated by our model. The amplitude and frequency of these spikes are within the range of recorded firing responses [3].

Spiking Pattern in Parkinson's Disease

With few parameter modification our model was able to generate Dopamine deficiency patterns of STN neurons which happened in Parkinson's Disease.

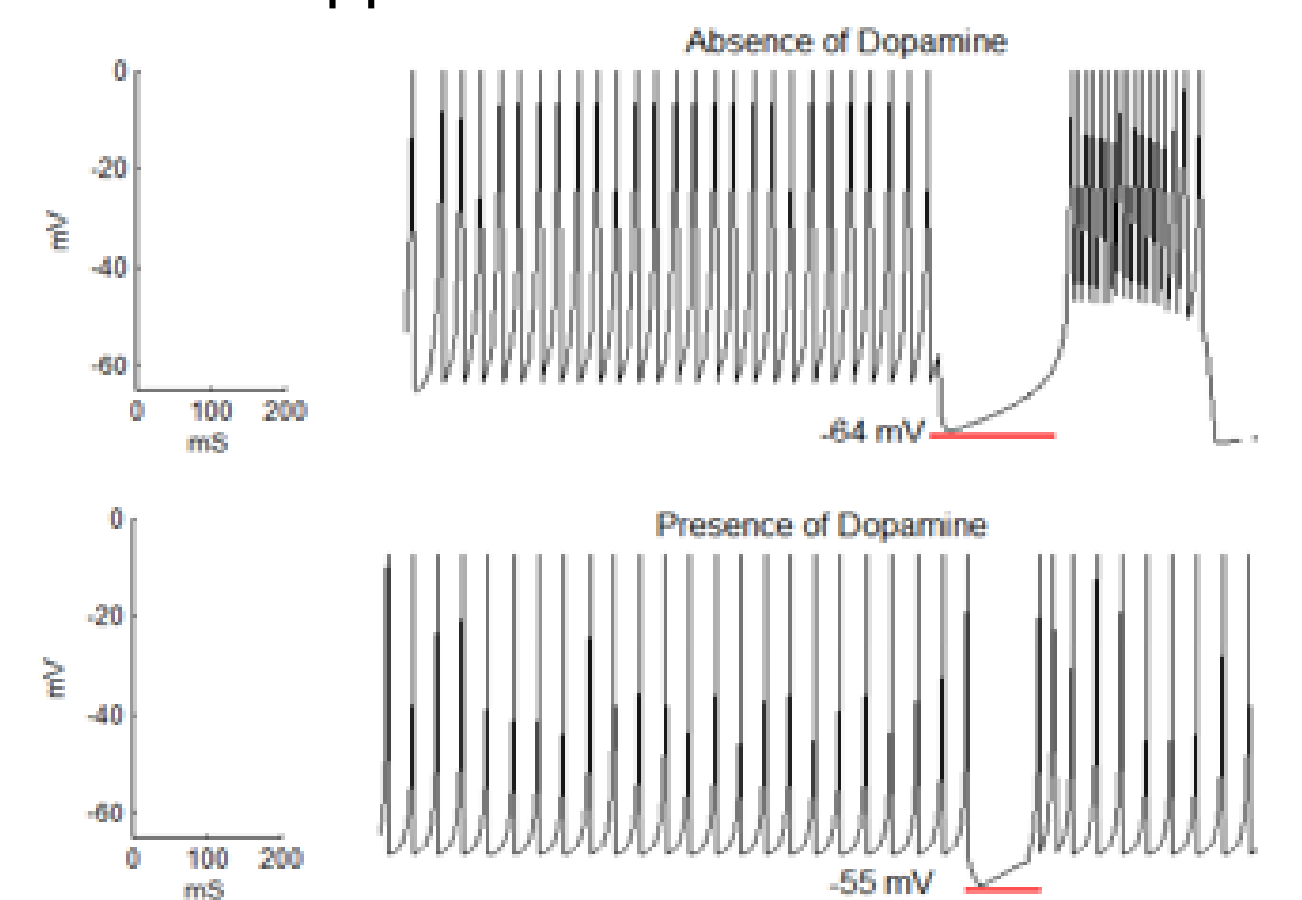


Figure 3: Result of our model generated by MATLAB in absence (UP) and presence (Down) of dopamine in STN neuronal firing.

Many features (Figure 4) can be extracted from these patterns with the ability to explain biological phenomenon happening in Brain neurons.

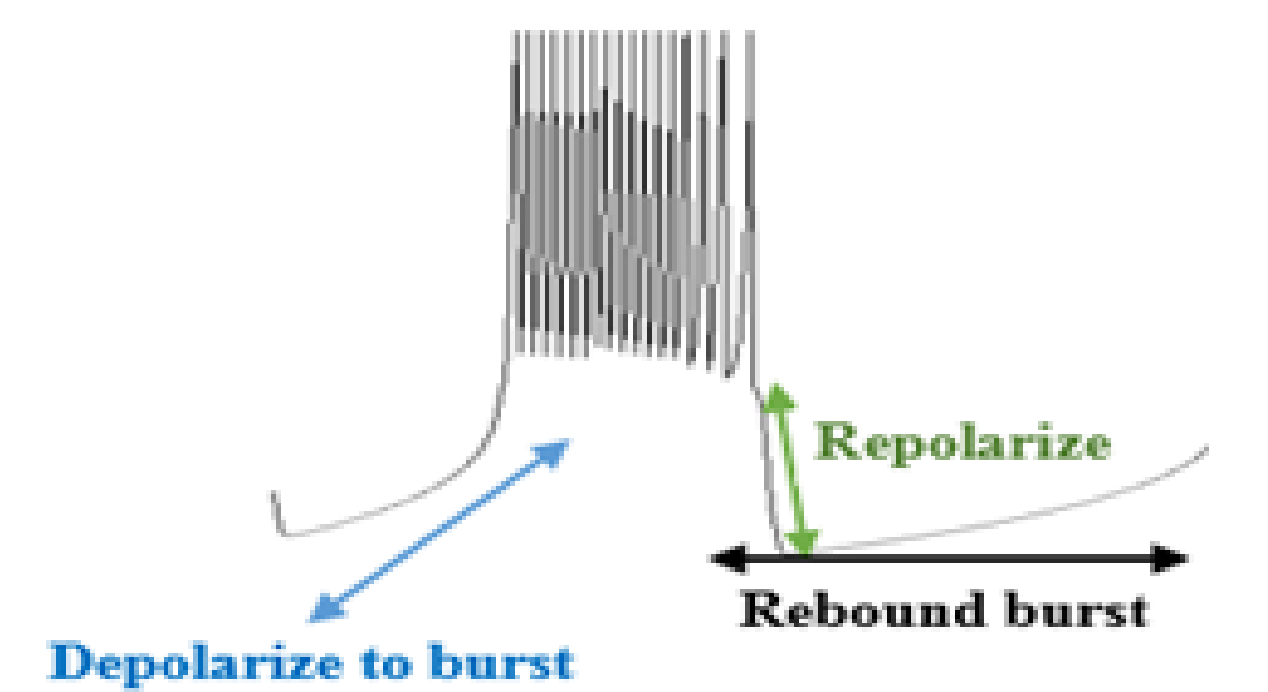


Figure 4: Each area in this spike is corresponded to a chemical reaction in a STN neuron

Discussion

This work presented a mathematical model to generate various neuronal spiking patterns. The key advantage of this model is the fact that it has low computational complexity, and can produce various neuronal firing patterns by only adjusting very few parameters. Due to impact of STN neurons on Parkinson's disease we can adjust our model to reflect this single to burst switching patterns. There would be a significant application for treating Parkinson's disease through stimulating STN cells with models like this, well correlated to physiological phenomena in STN cells, implemented and integrated on a Biochip.

References

- [1] Hodgkin, A. L., & Huxley, A. F. (1954). A quantitative description of membrane excitation in nerve. *J. Physiol*, 117, 500-544.
- [2] Izhikevich, E. M. (2003). Simple model of spiking neurons. *IEEE Trans. Neural Networks*, 14, 1569-1572.
- [3] Beurrier, C., Congar, P., Bioulac, B., & Hammond, C. (1999). Subthalamic nucleus neurons switch from single-spike activity to burst-firing mode. *The Journal of neuroscience*, 19(2), 599-609.