Sci. Bull. (2015) 60(22):1969–1971
DOI 10.1007/s11434-015-0945-2

www.scibull.com
www.springer.com/scp

News & Views

An introduction and guidance for neurodynamics

Jun Ma · Jian Xu

Published online: 16 November 2015

Diseases associated with nervous system have brought much pain and anxiety for patients. As a result, clinical diagnosis such as big data analysis based on functional magnetic resonance imaging (fMRI) [1], computational neurodynamics, and cognitive neurodynamics have been paid much attention. It is believed that potential mechanism for abnormality [2] in nervous system could be discerned by detecting dynamic behavior of central nervous system and discovering general theories of cognitive functions in terms of theoretical biophysics. The brain is a high-dimensional nonlinear system and its collective electrical activities are dependent on signal propagation among one hundred billion neurons and also a variety of gliocytes. Cognitive neurodynamics is considered capable of information processing in the nervous system. Theoretical models have been set up at different levels ranging from microcosmic, mesoscopic, up to macroscopic scale, so that the generation of cognition and potential mechanisms underlying neural information processing could be discerned. Indeed, the deterministic neuronal models could be available for bifurcation analysis, synchronization transition between neurons and networks, networks of networks, and information encoding. Furthermore, some reliable neuronal circuits could be implemented for signal detection as sensors. Some biological experiments and also theoretical neuronal models have shown that single neuron exhibits rich dynamical behaviors such as periodic spiking, periodic bursting, chaotic spiking, and chaotic bursting [3]. In fact, the electrical activities in neuron are very complex, for example, one or more bifurcation parameters are carefully adjusted to produce multiple modes of electrical activities while other suggested the present neuronal model should be improved to include more bifurcation parameters and variables. It is believed that when neuronal systems function abnormally, neurons could fire abnormal spikes. Hence, various control schemes have been presented to recover normal neuronal functions. The delay in the neural system is derived from the finite speed of action potentials propagating along s neuron axons, but it is also associated with finite response period to external forcing or internal signal processing. As a result, the inevitable time delay plays an important role in regulating the electrical activities of neurons and self-organization in networks as well [4, 5]. Neurons are basic structures and functional units of the nervous system, and dynamic changes of neuronal discharge rhythm are critical to understanding functions of the nervous system [6, 7]. For example, experimental results from branching and chaoticity of neural discharge induced by potassium are typical examples and provide additional parameters such as calcium current as well [3]. These findings are important to understand potassium-induced dynamics.

Synaptic connections also play an important role in transmitting information among neurons. Synapses are generally divided into electric and chemical synapses to display that they are electrically or chemically activated. It is also base of these Synapses action. It is found that there is a special type of synapse among certain intermediate neurons and it reconnects to cell bodies or axons through certain bypass circuits and forms self-synaptic structures as autapse. In oscillator model based on the electrical activity of neurons [8], the regulation of self-synaptic structures on

J. Ma
Department of Physics, Lanzhou University of Technology,
Lanzhou 730050, China

J. Xu (✉)
School of Aerospace Engineering and Applied Mechanics,
Tongji University, Shanghai 200092, China
e-mail: xujian@tongji.edu.cn

neural electrical activities can be described by applying a time-lag current on the membrane. From neural dynamics perspective, this type of self-synaptic structures is excitatory or inhibitory, and the autaptic connection accounts for the self-adaptation in biological function. Particularly, local distribution of self-synaptic structures can regulate collective behaviors of networks by generating stable pacemaker as target waves or defects blocking the wave propagation and spatial distribution.

Multistability is an important feature of the nervous system. For certain dynamical system with given parameters, it is considered that this system has multistable phenomenon [9] when the final developed state is dependent on the selection of initial values. Multistability provides certain convenience for functional diversity of the nervous system, and the changes of initial values can alter final states of the system [10]. The application of stability theory could provide sufficient conditions for multi-resting states of the neuronal networks, and coexistence of multi-periodic states could be generated by applying appropriate peripheral external stimulation [11].

The frontal cortex is composed of multiple types of neurons, roughly divided into excitatory pyramidal cells and inhibitory interneurons. Their morphology, neurotransmitter and electrophysiological feature may be variant [12]. Some electrophysiological features and electrophysiological experiments have displayed that pyramidal cells and interneurons [13] have different functions in coding information [14]. It is seen that the coding of both the pyramidal cells and the interneurons reward information in a complimentary manner in cortex. For example, Pan et al. [15] claimed that the preferential reward information can be encoded in wide-wave neurons by increasing discharge rate, while decreasing discharging rate is associated with non-preferential reward information.

The functional hyperemia is observed when nerve activities occur in certain functional areas of the brain. Therefore, local blood glucose level is increased so that the need of energy for generating action potential and metabolism could be satisfied greatly. Brain energy supplies are critical for maintenance of intracellular and extracellular ion concentration gradient, neurotransmitter circulation, information detection, and processing among cells. The brain energy is greatly dependent on the level glucose so that normal nerve activities could be kept. As a result, insufficient supply of brain energy could be induced by hypoglycemia/ischemia that decreases in brain function.

The topic about neural coding and decoding in neuroscience is the most challenging problem. Indeed, the nerve system develops its self-adaption that the neural activities in the brain must consume the minimal energy to keep normal activities during the process of signal transmission. The brain's information-processing capacity is much dependent on the amount of energy supplied by blood flow in active brain areas. The technology of functional magnetic resonance imaging is available to discern the brain activity [1], but the activity of blood flow cannot be described exactly. It is believed that neural information can be expressed by energy [13] that the energy can be used to unify the neural models of various levels. Unfortunately, the investigation about energy consumption in the nervous system has been carried on experiments instead of quantitative theoretical analysis due to the brain complexity. Interestingly, most of neuronal models are described by a variety of oscillators and we argued that dimensionless Hamilton energy function based on Helmholtz's theorem could be effective to detect the mode transition in electrical activities. The emergence of the cognitive function is determined by the multi-level coupling and coordination between different functional regions in brain because the neural structure of the brain has multi-level distribution. It is argued that the coupled oscillation of the neural network has a unique correlation with the network energy oscillation. Namely, the pattern formation and the selection of the spatial distribution for the membrane potentials in neuronal network can interpret the information encoding on energy supply due to the unique consensus between various distribution patterns of neural energy and the oscillation mode of the network.

References

1. Wu X, Xu LL, Yao L (2014) Big data analysis of the human brain's functional interactions based on fMRI. Chin Sci Bull 59:5059–5065
2. Qi Y, Li Q, Tian MQ et al (2014) The neural mechanisms of vital loss emotions. Chin Sci Bull 59:1856–1863
3. Gu HG, Chen SG (2014) Potassium-induced bifurcations and chaos of firing patterns observed from biological experiment on a neural pacemaker. Sci China Technol Sci 57:864–871
4. Wang HX, Wang QY, Zheng YH (2014) Bifurcation analysis for Hindmarsh-Rose neuronal model with time-delayed feedback control and application to chaos control. Sci China Technol Sci 57:872–878
5. Wang QY, Chen GR, Matjaž P (2011) Synchronous bursts on scale-free neuronal networks with attractive and repulsive coupling. PLoS ONE 6:e15851
6. Yamada Y, Kashimori Y (2013) Neural mechanism of dynamic responses of neurons in inferior temporal cortex in face perception. Cogn Neurodyn 7:23–38
7. Yang ZQ, Hao LJ (2014) Dynamics of different compound bursting in two phantom bursting mechanism models. Sci China Technol Sci 57:885–892
8. Herrmann CS, Klaus A (2014) Autapse turns neuron into oscillator. Int J Bifurcat Chaos 14:623–633

9. Pisarchik AN, Feudel U (2014) Control of multistability. Phys Rep 540:167–218
10. Schwartz JL, Grimault N, Hupé JM et al (2012) Multistability in perception: sensory modalities, an overview. Philos Trans R Soc B 367:896–905
11. Huang Z, Song Q, Feng C (2010) Multistability in networks with self-excitation and high-order synaptic connectivity. IEEE Trans Circuits Syst 57:2144–2155
12. Wonders CP, Anderson SA (2006) The origin and specification of cortical interneurons. Nat Rev Neurosci 7:687–696
13. Kvitsiani D, Ranade S, Hangya B et al (2013) Distinct behavioral and network correlates of two interneuron types in prefrontal cortex. Nature 498:363–366
14. Zheng HW, Wang RB, Qiao LK et al (2014) The molecular dynamics of neural metabolism during the action potential. Sci China Technol Sci 57:857–863
15. Pan XC, Fan HW, Wang RB et al (2014) Contributions of distinct prefrontal neuron classes in reward processing. Sci China Technol Sci 57:1257–1268