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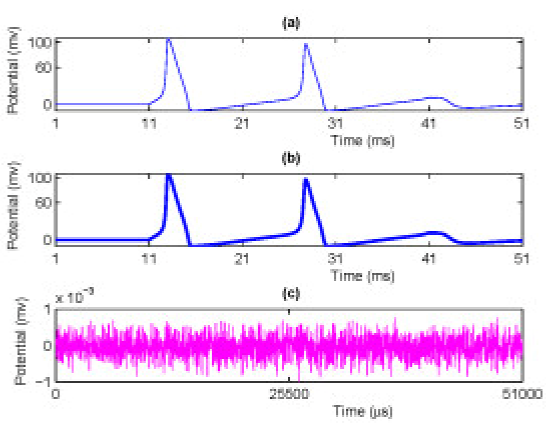
A force behind signal propagation in the brain

Cognitive functions require signal propagation in the brain, i.e., signals propagating via spike trains (at a timescale of milliseconds) in a brain structural network where the nodes and links are individual neurons and synapses, respectively. During a given single trial of signal propagation, the expected values of membrane potential of each individual neuron are uniquely determined by the underlying synaptic connection. And, by the principle of causality for dynamic systems, success of signal propagation requires membrane potentials of every individual neuron to be close to their expected values over the time.



In an article published in Journal of Theoretical Biology, January 2016, we presented a stochastic analysis in a general setting: Two factors—that have been overlooked in the study of signal propagation in the brain—are functionally important. One factor is rapid random fluctuations (RRF) in membrane potentials of individual neurons due to the following: The irregular openings and closings of ionic channels in neurons underlie all neural activities; and the rate constants of these openings and closings are up to 1 microsecond. The other factor is a synaptic delay *K* about 1 millisecond at the very beginning of any single trial of signal propagation.

Our result showed that RRF with synaptic delay *K* cause a force behind signal propagation in the brain. To illustrate this, let us, for instance, consider the first milliseconds during a given single trial of signal propagation. Here the synaptic delay *K* counts 1 millisecond. In panel (a) of the figure below, a curve represents the expected values of membrane potential of a neuron with label over milliseconds after the synaptic delay *K*. Suppose that over milliseconds, in every 1 microsecond, the value of membrane potential of neuron is within mV of its expected value with a probability that may take any value in . This implies that the underlying synaptic connection guides signals to propagate (the probability) but may not guarantee the success (the probability may be anywhere in). Such a probability needs to be applied for times, since there are microseconds over milliseconds. Thus the success of signal propagation seems hopelessly remote. But, as our analysis showed, with a probability , the following event occurs. In every 1 microsecond over milliseconds, the values of membrane potential of neuron are within mV of their expected values, which is depicted in panel (b).

This event is by an “alter-and-concentrate effect” of RRF in neuron with the synaptic delay *K* depicted in panel (c): Over milliseconds, in every 1 microsecond, RRF alter the value of membrane potential of neuron , but with the synaptic delay *K* the altered value is controlled to be concentrated within mV of the expected value.

In 1948 the Dutch physicist Hendrik Casimir discovered quantum random fluctuations may cause forces. In 2008 it was found random fluctuations of a classical nature may also cause forces. The alter-and-concentrate effect—an analogue of Casmir force—brings a new insight into signal propagation in the brain: A brain structural network is a flexible framework that guides signals to propagate but may not guarantee the success; under such a framework, RRF with a synaptic delay almost surely force signals to successfully propagate. We have conducted wet lab experiments. The data confirmed the presence of RRF and its effect on the brain function. This suggests that based on measuring and analyzing of RRF, methods may be developed to diagnose abnormality of subjects—whose brain structural networks appear to be normal—in neuronal processing that underlies cognition.

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Publication

A stochastic mechanism for signal propagation in the brain: Force of rapid random fluctuations in membrane potentials of individual neurons.
Hong D, Man S, Martin JV.
J Theor Biol. 2016 Jan 21

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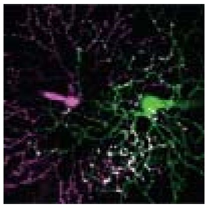

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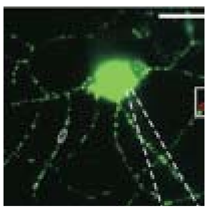

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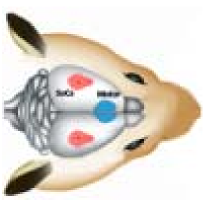

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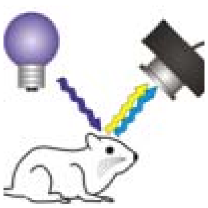

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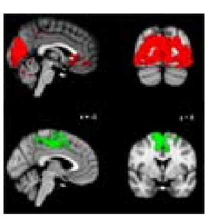

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brain, Casimir force, neuron, signal propagation

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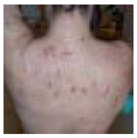

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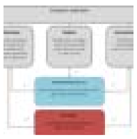

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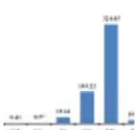

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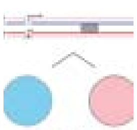

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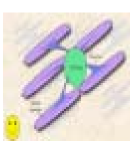

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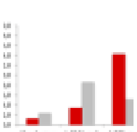

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