A new look at stochastic resonance enhancement of mammalian auditory information processing

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Abstract

Among the communities of medicine and physiology, it has been long recognized most biological systems can be described as deterministic systems with some added noise [5]. Stochastic resonance (SR) in biological systems was originally referred to a situation where a *noise at an intermediate level* is added to a signal to improve the detection of the signal.

It is also known to the community of neuroscience that the intrinsic noise in a mammalian auditory system may be utilized to enhance information processing. Such phenomena are also termed as SR. The traditional methodology in modeling and analysis of SR in mammalian auditory systems focuses on biophysical aspects of the systems. In the early of 1990s Moss and his colleagues studied how the addition of the energies carried respectively by the intrinsic noise and a subthreshold signal in a mammalian auditory system may result in a detectable signal, which was called Type E SR (where 'E' is for energy). However, in the early of 2000s it was found in experiments that some SR cannot be explained as Type E; that is, the energy addition was not sufficient to produce a detectable signal, while SR was observed. This was called Type I SR (where 'I' is for information). To explain Type I SR had been an open problem. We refer the reader to [3], [8], [9], [10] for a background of SR in biological sensory information processing. Recently, Hong et al [7] proposed a wavelet-based mathematical model that can explain Type E and I SR in the same model.

All models mentioned in the previous paragraph did not include a mathematical formulation of the term *noise at an intermediate level*. Hong [6] proposed such a mathematical formulation which was named weak noise. The biological validity of weak noise is based upon the experiments in [4]. With the concept of weak noise, we take a new look at SR in mammalian auditory systems. The two obtained results are as follows.

(i) Similar to [7], weak noise may lift a subthreshold signal beyond the threshold when the noise is added to the signal. However, with weak noise the mechanism for lifting subthreshold signal is much simpler.

(ii) Weak noise may be used to facilitate signal propagation. To the best of our knowledge, such a result has never reported before. The weakness of noise is essentially characterized by a parameter λ

$\in (0, \frac{1}{2})$. For any value that λ may take, the following holds. Suppose a signal takes N time units to propagate. If the probability for the signal to propagate ensured by the signaling pathways is at least $\varepsilon_1(N, \lambda)$, then utilizing the weak noise, the probability for a correct response to the signal to occur is at least $(1 - \varepsilon_2(N, \lambda))$ where $\lim_{N\to\infty} \varepsilon_1(N, \lambda) = 0$, and at the same time $\lim_{N\to\infty}(1 - \varepsilon_2(N, \lambda)) = 1$ at convergence rates sub-exponentially fast in terms of N, respectively. Mathematical expressions for $\varepsilon_1(N, \lambda)$ and $\varepsilon_2(N, \lambda)$ will be given in an explicit way.

The result (ii) is a concrete realization of an emerging notion in today's systems biology: biological systems are designed to function well under the uncertain behavior of their components. See [1], [2]. This result in theory demonstrates that utilizing the weak noise, robust signal propagation may be achieved through unreliable signaling pathways in mammalian auditory systems.

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