SUPRATHRESHOLD STOCHASTIC RESONANCE IN PHYSIOLOGICAL SYSTEMS

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ABSTRACT

Recent computer simulations of level-crossing detectors [2] and leaky integrate-and-fire nerve models [1] have shown that if many threshold devices are stimulated with independent noise sources in addition to a common information-bearing signal then the transmitted information can be enhanced by the noise even if the information-bearing signal is suprathreshold. This new form of stochastic resonance based on an information-theoretic measure has been termed suprathreshold stochastic resonance (SSR). A key feature of SSR is that the maximum information transmitted by an array of threshold devices is greater for suprathreshold signals than for subthreshold signals. It contrasts conventional stochastic resonance where the effect of noise is quantified by the signal-to-noise ratio (SNR) of the combined outputs; noise always leads to a decrease in the SNR if the signal is suprathreshold, i.e stochastic resonance (in these terms) does not occur.

Despite the potential of SSR to enhance neural coding, there have been no studies of SSR in real physiological systems. We have therefore investigated the effect of noise on the transmission of information by sciatic nerve fibres from the toad *Xenopus laevis*. The sciatic nerve is a useful model for studying stochastic resonance effects because the fibres are not spontaneously active in the absence of a stimulus, which implies a low level of internal noise. This makes it possible to study the effects of low levels of external noise.

The sciatic nerve was completely dissected and placed on a pair of platinum electrodes, which were used to electrically stimulate the whole nerve. The stimulus, which was identical for each presentation, was a Gaussian signal that was exponentially correlated with a correlation time 1.6 ms and lasted 1 s. For each presentation, a different realization of background noise was added at pseudo-random levels from -50 dB to 30 dB relative to a base noise level that caused approximately 2 spikes/second. The response of a single sciatic nerve fibre to each stimulus presentation was recorded using a microelectrode. For each fibre studied, the stimulus was presented at one of four levels: 6 dB below threshold, or 3, 6, or 12 dB above threshold. Twenty stimulus presentations were made at each noise level and the responses were taken to be equivalent to those that would have been obtained by simultaneously recording the responses of twenty identical ("virtual") fibres to a single stimulus. For each noise level, we measured the transinformation between the input signal and the optimal reconstruction of the input signal calculated from the spike times using the Wiener-Kolmogorov method [3]. The calculation was repeated with either 1, 2, 4, 8, 16 or 20 virtual fibres used to form the reconstructed signal.

The results were remarkably similar to those from the leaky integrate-and-fire model [1]. For subthreshold stimuli, the transinformation was optimized by a non-zero noise level and further increases in noise level caused the transinformation to decrease. This effect was observed even with a single virtual fibre. With more virtual fibres, however, the optimal transinformation was higher. For suprathreshold signals, the transinformation could only be enhanced if responses from more than one virtual fibre were used to reconstruct the input signal. With a single virtual fibre, noise always decreased the transinformation. With multiple virtual fibres, the optimal transmission was higher with suprathreshold signals than for subthreshold signal.

These results clearly demonstrate suprathreshold stochastic resonance in a real physiological system. We conclude that the effect is robust and may therefore be exploited by sensory systems. The effect may also be exploited by cochlear implants, which are used to partially restore the speech comprehension of many profoundly deaf people by artificial electrical stimulation of the cochlear nerve [1].

Keywords: stochastic resonance, information theory, cochlear implant.

References

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