学 位 論 文 の 要 旨

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学　位　論　文　名　　Novel Class of Neural Stochastic Resonance and Error-free Information Transfer

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論 文 内 容 の 要 旨

INTRODUCTION

Stochastic resonance (SR), the enhancement of information transfer through systems exhibiting non-linearity by the addition of an optimal level of noise to the system in the presence of a small signal, is ubiquitous in non-living and living systems. In conventional neural SR, too much noise increases random firings which degrade the system's ability, leading to a characteristic ``bell-shaped" curve for the information transfer. In our study, we introduced a novel class of neural SR, where the decline of the bell-shaped curve for large input noise arises without any increase in noise-induced random firings. Due to this feature, the neuron can efficiently transfer information of weak input signals without erroneous firings, even when exposed to a noisy environment. As a first experimental realization we explored the tactile blink reflex in humans: the ability of air-puff stimulations to an eyelid (input) to induce blinks (output) was optimized by adding auditory white noise, although the noise alone was not capable of increasing the baseline blink probability. Next, we studied numerically and analytically an integrate-and-fire (IF) model with short-term synaptic depression (STSD) which nicely accounts for the observed experimental results. We thus suggest this novel class of neural SR constitutes a new mechanism in which neurons in the brain make constructive use of external and/or internal noise.

MATERIALS AND METHODS

The experiment was performed on 46 healthy men (age 18 to 40 years). Tactile stimuli (signals) were applied by air puffs at about 10 mm distance from the lateral canthus. The tactile blink reflexes were detected by an electromyogram (EMG) of the orbicularis oculi muscle, while auditory Gaussian white noise (frequency range: 10–20 kHz) was administered through headphones. The threshold of the tactile blink reflex was determined by using a modified up-and-down method. We set the intensity of the tactile stimulation to be 5% below the threshold. After setting the intensity level, we started sessions to examine response probabilities of the tactile blink reflex at each of the following levels of white auditory noise intensity: 35 dB (sound pressure level: SPL), 55 dB, 65 dB, 70 dB and 85 dB. A search window for the tactile blink reflex was set at 20 – 100 msec after the onset of the tactile stimulation. If the EMG activity exceeded three standard deviations of background activity, which was taken from the corresponding *control (no stimulation) trials, we considered a blink response to have occurred. The baseline* blink probability per unit (a unit consists of an 80 msec detection window) was taken from the EMG data before each tactile stimulation.

RESULTS AND DISCUSSION

No significant ($p > 0.05$) difference in the baseline blink probability was detected between sessions. However, Ryan's multiple comparisons revealed that the tactile blink probability at 70 dB was significantly ($p < 0.05$) higher than those at the other noise levels except for the the tactile blink probability at 65 dB, suggestive of a SR-type optimization of the tactile blink reflex at this intermediate noise intensity. Both auditory and tactile inputs are known to be integrated in a well-identified region in the brainstem, called the caudal pontine reticular nucleus (PnC), to cause the blink reflex to emerge. 85 dB auditory noise is considered large enough to elicit an auditory startle reflex. Thus, the membrane potential of PnC neurons can reach the threshold by 85 dB auditory noise alone, and the increase in spike firings should be observed irrespective of the input signals, leading to a corresponding increase in α. This feature, however, is not observed. A synapse which connects to the PnC neuron is known to have adaptive properties, where repeated stimulations of the afferent fiber cause a significant decay of the excitatory postsynaptic potential. The mechanism at work is proposed to be STSD. Indeed, we demonstrate that our experimental findings are well described by taking such STSD into account. We set up an IF model with STSD, describing the dynamics of the postsynaptic membrane potential. We performed the numerical simulation of IF model by using the fourth-order Runge-Kutta method. Simulation results fit well with experimental results. We also performed an analytical explanation. Our experimental and analytical results imply that even with the erroneous firing of the neuron being zero, a neuron with STSD can still display SR-type behavior. Consequently, the neuron with STSD can act as an error-free detector for weak signals.

CONCLUSION

We explored experimentally and theoretically a novel class of neural SR in the auditory noise-optimized human tactile blink reflex. An IF model with STSD nicely accounts for the experimental finding. The novelty of this class of SR lies in the fact that the drop-off of the input-output cross-correlation at large auditory noise intensity arises without an increase in noise-induced random firings. This very feature is in distinct contrast to conventional SR where the corresponding escape rates monotonically increase with increasing noise intensity. This novel feature enables a neuron to act as an error-free detector for weak signals. Within our experimental framework, this means that humans can react to weak tactile signals by making use of auditory noise but without being disturbed by too much auditory noise. We conclude that this class of neural SR provides yet another important mechanism by which neurons in the brain operate in noisy internal/external environments.