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Information Processing During Transient Responses in the Crayfish Visual System

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# Information Processing During Transient Responses in the Crayfish Visual System

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**Abstract**

We analyzed sustaining fiber responses in the crayfish visual system to light pulses using information processing techniques. The light pulse stimuli elicited a transient and a steady-state component in the EPSP input and in the firing rate of the spike train output. The overall information transfer of the system was very low ( $10^{-3}$), with a sharp increase during the transient portion of the response followed by a steady decrease. The change in the information transfer rate is related to the difference in communication rates possible in spike trains with varying rates. This analysis corroborates the observed light reflex behavior.

## Summary

Sensory neurons generally encode some aspects of the information present in a stimulus and suppress others. Understanding and characterizing a sensorineural system's information processing capabilities in the presence of different stimuli is critical to progress in determining the coding structures underlying neural communication. Recently, a new theory of information processing has been presented that draws from classical information theory and statistical signal processing to provide a framework for quantifying the information processing characteristics of a general system [1].

This analysis framework is based on the concept of presenting a system with two different stimulus conditions and observing both the inputs and the corresponding responses. We use an information-theoretic distance measure (such as the Kullback-Leibler distance) to quantify the difference between the inputs as well as between the responses. A fundamental result from information theory states that the distance between the output responses will always be less than or equal to the distance between the input responses. In other words, no amount of processing can increase the information content of a signal. We term the ratio of the output to input distances the "information transfer ratio"; it is a single quantitative measure of the information processing capabilities of the system for the stimulus condition under consideration. The information transfer ratio will always be a number between zero and one, with a value of one representing perfect information transfer of the stimulus change (regardless of the code used) and a value of zero representing total information loss.

The sustaining fibers of the crayfish visual pathway are spiking neurons receiving analog EPSP inputs from pre-synaptic, non-spiking retinal neurons. This information processing analysis was applied previously to sustaining fiber recordings when the stimuli consisted of light contrast changes, and the information transfer ratio was found to be on the order of $10^{-3}$ [2].

We used simple histogram estimators of the spike responses to quantify the probability law for the sustaining fiber output. The statistical characteristics of the analog EPSP inputs are relatively difficult to characterize because of non-stationarities. We have developed a new, more sophisticated model for the EPSPs that incorporates neuron conductance changes into the analysis of the recorded membrane noise. The biophysical properties of the neuron at rest correspond to a simple RC-circuit (lowpass filter) model for behavior of the neuron to injected current. It is also known that EPSP variations are a result of changes in the total membrane conductance [3]. Depolarizations indicate an accompanying increase in the overall membrane conductance. With respect to the RC-circuit model for the membrane, this conductance increase contributes to both a decreased overall membrane noise power and a change in the spectral properties of the membrane noise. Using time-varying linear system theory, these changes can be directly related to the measured EPSP, and the non-stationary correlation structure of the membrane noise can be efficiently calculated. Based on this model, the distance between inputs can be more accurately calculated.

Several recordings were made from a crayfish sustaining fiber when the stimulus was a square wave pulse of light with intensity varying from trial to trial. At the stimulus onset, the input EPSP exhibits a transient pulse of high potential for approximately 100 ms followed by a decrease to a plateau which is maintained for the duration of the stimulus. Both the size of the transient pulse and the value of the steady-state potential are related to the intensity of the stimulus. The output spike trains also exhibit a transient burst of high firing rate, followed by an adaptive response that reduces the firing rate to a steady-state value maintained for the stimulus duration.

Using the analysis techniques briefly outlined above, preliminary results indicate that the information transfer ratio ranges from $1.1 \times 10^{-3}$ to $8.7 \times 10^{-3}$. These results are comparable to what was found previously when a similar analysis was performed on the sustaining fibers using light contrast as the change in the stimuli [2]. Preliminary calculations using the spatial frequency of light gratings as the changing stimuli also indicate similar results. The low value for the information transfer ratio indicates a large amount of information present about the stimulus change in the input signals is not being conveyed by the spike trains.

Plotting the information transfer ratio as a function of time revealed a sharp increase immediately after the stimulus onset followed by a slow decrease to a steady-state value. The sharp jump indicates that the system is transferring the information more efficiently during that part of the response. When examining the input signal distances, we found a sharp increase in the distance near the stimulus onset followed by a steady monotonic increase over the stimulus duration. However, the distance between the output responses frequently exhibits a sharp peak during the transient part of the response immediately followed again by very low values.

This behavior can be explained by considering the rate at which the two signals can be used to convey information. In the analog input signals, information can be communicated as fast as the highest frequencies present in those signals. Theoretically, even a sampled version of the analog signal could communicate information with each sample. However, a single spike train can only communicate information with each action potential, and is therefore limited by its firing rate. With the stimuli used in this analysis, the high firing rates during the transient part of the response allow the sustaining fiber to communicate most efficiently. When the adaptive mechanism takes over and the rates are reduced in the steady-state response, the sustaining fibers are no longer able to maintain that maximum communication rate. In any case, even the maximum rates achievable by the sustaining fibers are still far too low to convey the vast amount of information contained in the analog input signals about the stimulus, as illustrated by the low value of the information transfer ratio.

When also observing the elicited light reflex of the crayfish to the stimulus, the behavior is complete within 100–150 ms after the transient part of the spike response. Accounting for the latency of the motorneurons and the muscle contractions, we concluded that all of the information from the stimulus being conveyed by the reflex behavior is communicated through the sustaining fiber during the first 100 ms after the stimulus onset. This corresponds to the transient part of the spike response, and corroborates our analysis of the information processing capabilities of the earlier stages of the visual system.

# References


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