

Quantitative Measure of Population Adaptation of Retinal Ganglion Cells' Light Response

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Abstract—Adaptation helps retinal ganglion cells encode varying visual signals. However, an index for population adaptation is still lacking. In present study, we applied entropy theory to characterize the process of adaptation for a group of ganglion cells under the stimulus of both full-field white light and pseudo-random checker-board. We noticed that entropy rate shared the same trend with meaning firing rate of the group of cells, and there were some difference of the relationship between entropy rate and firing rate under different visual stimulus, which may caused by the difference of concerted encoding among ganglion cells under different stimulations.

Keywords—population adaptation; firing rate; entropy; concerted encoding

I. INTRODUCTION

In vertebrates, retina is the first stage where visual information processing starts. The neuronal signals are sent to the central visual system via the action potentials generated by the retinal ganglion cells. Correlated activity among retinal ganglion cells plays an essential role when encoding visual stimulus [1]. On the other hand, the retinal ganglion cell's activity is characterized by adaptation in response to sustained stimulation [2]. While single neuron's adaptation can be clearly demonstrated using classical peri-stimulus time histogram (PSTH) [2], a proper index for describing the adaptation of population activity is still lacking. In the present paper, we applied the entropy theory to inspect population adaptation of the retina ganglion cells, and find that the entropy rate can be used to characterize the process of population adaptation.

II. METHODS

A. Multi-Unit Recordings and Visual Stimulation

Detailed extracellular-recording procedure was previously reported [3, 4]. Spikes from ganglion cells were recorded by

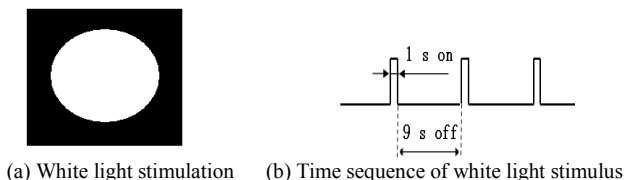


Figure 1. White light stimulus.

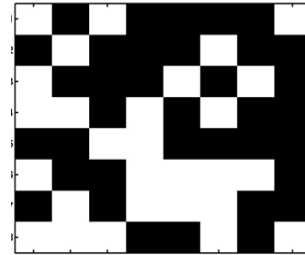


Figure 2. An example frame of pseudo-random binary checker-board flickering

MEA electrodes (8×8) using a commercial multiplexed data acquisition system with a sampling rate of 20 kHz. The recording system was purchased from MCS GmbH, Germany.

The stimulation protocols were: (1) Full-field white light flashes (1-s light-ON duration vs 9-s light-OFF intervals) (Fig. 1); (2) pseudo-random binary checker-board flickering with frames refreshed every 30 ms (Fig. 2) [5].

B. Calculation of Entropy Rate

Entropy theory was successfully applied to study the information transmission by spikes of a single cell [6]. In the present work, it is applied to investigate the spatial pattern changes of the population neurons during adaptation.

Spike trains recorded from different ganglions cells are divided into time bins of 10 ms. If there are spikes in the bin, then it labeled as "1", if there is no spikes, the bin is marked as "0"; these label are 'letters', and several letters constitute a word (Fig. 3). The entropy rate is calculated as follows:

$$H_t = (-1) \frac{1}{n} \sum_{r_i} P_t(r_i) \log P_t(r_i) \quad (1)$$

Where r_i is the i -th word constructed by the letters, n is the number of ganglion cells of the population under investigation, $P_t(r_i)$ is the probability that r_i appears at time t . For the example given in Fig. 3, the probability of word "11111" is $1/2^5$, while the probability of word "10101" is 0. An intuition can be derived from the calculation of entropy – when all ganglion cells in the group fired following the same "word" during a certain period, $H_t = 0$, however, if the "words" are

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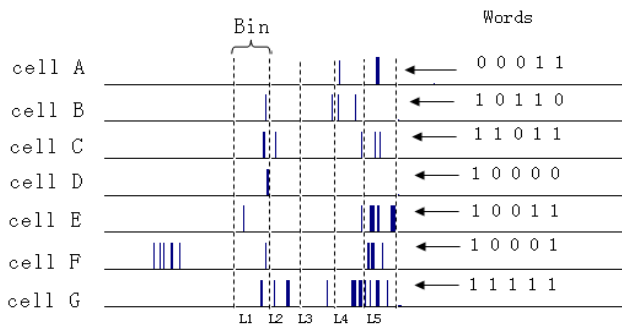


Figure 3. "Letters" and "words" for different cells' firing sequences

totally different, as the case presented in Fig. 3, H_t attains the maximal value. Therefore, the value of H_t can be applied to demonstrate the dynamic synchronization degree within a group of cells.

III. RESULTS

Mean firing rate and entropy rate calculated from a group of retinal ganglion cells in response to both full-field white

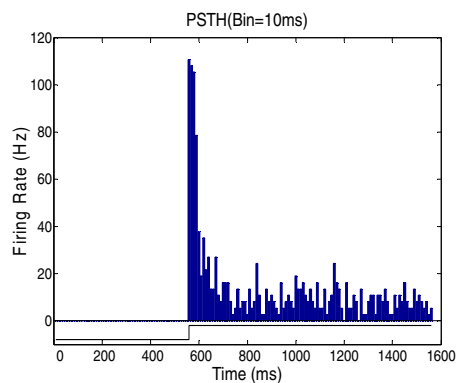
light illumination and checker-board flickering are displayed in Fig. 4.

From Fig. 4, it's easy to see that both firing rate and entropy rate are high when initially exposed to either full-field white light illumination or checker-board flickering and are followed by a slow decline during the process of adaptation.

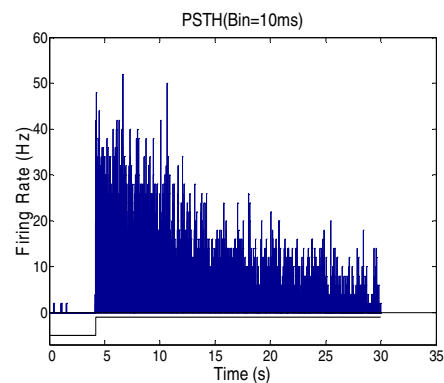
In order to see more clearly the relationship between entropy rate and firing rate during adaptation, BARS (Bayesian Auto-Regressive Splines) method [7, 8] is applied to generate smooth curves to describe the time-dependent changes of firing rate and entropy rate, as plotted in Fig. 5.

It is clearly shown by Fig. 5 that the entropy rate shares the same trend with firing rate, they almost attain maximum at the same time, and decrease synchronously.

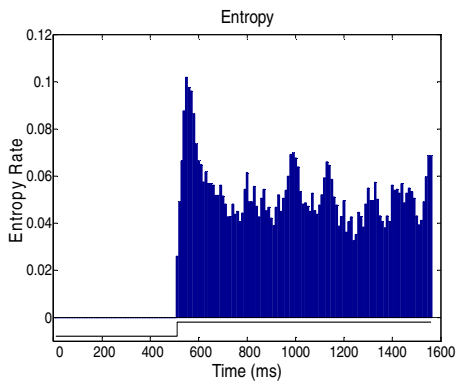
However, there are some evident differences between Fig. 5 (a) and Fig. 5 (b) During full-field white illumination, the firing rate dropped quickly and dramatically, while entropy rate was less decreased. However, during checker-board flickering, the result is totally different, firing rate and entropy rate decrease at nearly the same speed.



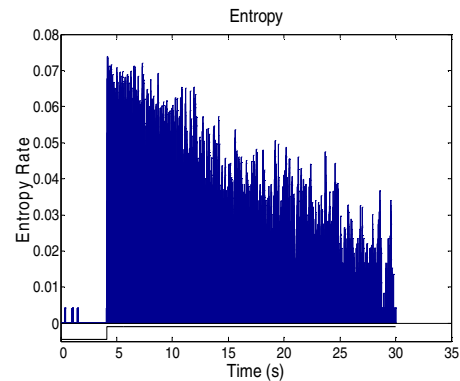
(a) Firing rate with white light stimulus



(b) Firing rate with checker-board stimulus



(c) Entropy with white light stimulus



(d) Entropy with checker-board stimulus

Figure 4. Firing rate and entropy rate of a group of cells.

(a) Firing rate in response to full-field white light stimulus, (b) Entropy rate changes during full-field white light stimulus, (c) Firing rate in response to checker-board flickering, (d) Entropy rate changes during checker-board flickering. The lines at the bottom of each plot indicate the stimulus.

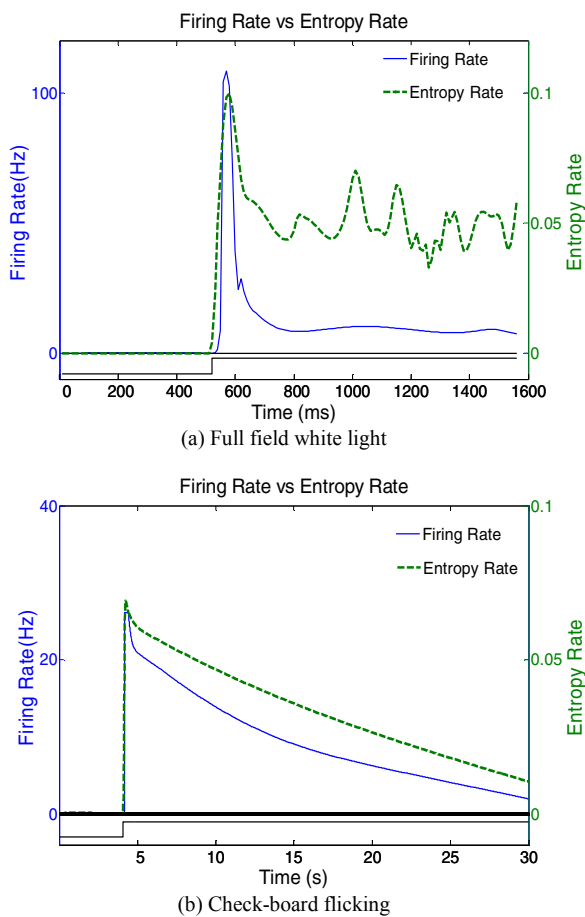


Figure 5. Time-dependent changes of firing rate and entropy rate. The line at the bottom of each plot indicates the stimulus

IV. DISCUSSION

These results suggest that when the retinal ganglion cells are exposed to visual stimulus with spatial correlation (such as full-field white light), the neuronal activities are still somewhat concerted while their firing rates are decreased. On the other hand, when exposed to checker-board flickering (which is both time-varying and spatial-varying), fewer ganglion cells are

concerted compared to that of white light stimulus. When there are a few ganglion cells concerted, or the strength of correlation is not high, the entropy rate depends heavily on the firing rate. So as displayed in Fig. 5 (b), firing rate shares the same trend with entropy rate.

By way of above analysis, it is clear that entropy rate, as an index, can be applied to characterize the process of adaptation of population activity; more important, it can be also applied to the analysis of degree of synchronization before and after adaptation.

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