TEMPORAL PRECISION OF SENSORY RESPONSES

Berry and Meister, 1998

Today:
(1) how can we measure temporal precision?
(2) what mechanisms enable/limit precision?
WHY SHOULD YOU CARE?

A. 0.1 pA average rod current

B. Ganglion cell spikes

C.

1. Important characteristic of the neural code
2. Precision can dramatically exceed apparent limits set by sensory inputs
WHAT'S THE PROBLEM?

difference between two responses includes dropped spikes, spontaneous spikes and temporally jittered spikes - which spikes should be compared?
SPIKE-TRIGGERED AVERAGE AND SPIKE JITTER
Aldworth et al., 2005

jitter spikes until relation between stimulus and spikes degraded
identify bursts that:
1. are preceded by period of silence
2. have spikes in large fraction of trials

measure variance of first spike time in bursts

problem:
only quantify precision of small fraction of spikes
USING VICTOR DISTANCE METRIC TO QUANTIFY PRECISION OF ALL SPIKES

Victor and Purpura, 1997

| Spike Train 1 |   |   |   |   |   |   |   |
| Spike Train 2 |   |   |   |   |   |   |   |

- Map spike train 1 onto spike train 2 by (1) deleting spikes, (2) adding spikes, and (3) sliding spikes
- Distance associated with each operation

5 ms
USING VICTOR DISTANCE METRIC TO QUANTIFY PRECISION OF ALL SPIKES

Victor and Purpura, 1997

Spike Train 1
Spike Train 2

5 ms

distance = $c\Delta t$

two paths equal when

$\Delta t = \frac{2}{c}$

distance = 2
USING VICTOR DISTANCE METRIC TO QUANTIFY PRECISION OF (NEARLY) ALL SPIKES

Victor and Purpura, 1997

Spike Train 1

Spike Train 2

5 ms

distance = cΔt

two paths equal when

Δt = 2/c

distance = 2

count

cumulative probability

0 1

0 1

Δt (ms)

Δt (ms)
Victor distance metric quantifies precision of majority of spikes in model-independent fashion
SUMMARY (TAKE 1)

- Signals traversing rod bipolar pathway evoke temporally precise responses in mouse ganglion cells

- Temporal precision limited by noise in synaptic inputs rather than noise intrinsic to ganglion cell (i.e. in dendritic processing or spike generation)

• Phototransduction:
  - Single photons reliably transduced
  - Reproducible responses to each absorbed photon

• Synaptic transmission:
  - Reliable transmission of single photon responses

• Neural coding:
  - Absorption of a few photons produces change in optic nerve activity
HOW ARE EXCITATORY AND INHIBITORY CONDUCTANCES COMBINED TO CONTROL SPIKING?

spike responses and excitatory and inhibitory currents

excitatory and inhibitory conductances

Cell Attached

Whole Cell

10 mV

-70 mV

2 nA

200 ms

20 nS

200 ms

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DYNAMIC (CONDUCTANCE) CLAMP

mimicking a real conductance with injected current fails to account for voltage dependence - dynamic clamp is an alternative

![Diagram of a conductance clamp]

(1) measure voltage
(2) compute current

\[ I = g_{exc}(V - V_{exc}) + g_{inh}(V - V_{inh}) \]

(3) inject current

![Graphs showing excitatory and inhibitory currents](#)
modulated light stimulus

dark (with spontaneous synaptic inputs)

record on cell
(all noise sources intact)

conductance clamp stimulus
(spontaneous inputs, spike generation)

precision similar ± modulated light stimulus

light response

\( g_{\text{exc}} + g_{\text{inh}} \)

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SPIKE GENERATION CONTRIBUTES LITTLE NOISE

modulated light stimulus

record on cell
(all noise sources intact)

dark (with spontaneous synaptic inputs)

conductive clamp stimulus
(spontaneous inputs, spike generation)

synaptic inputs blocked

conductive clamp stimulus
(spike generation)

light response
$g_{exc} + g_{inh}$ control
$g_{exc} + g_{inh}$ synaptic inputs blocked

modulated light stimulus

50 mV
50 ms

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SYNAPTIC INPUTS ACCOUNT FOR NOISE IN SPIKE OUTPUT

- Synaptic inputs blocked
  - Same $g_{\text{exc}}$, $g_{\text{inh}}$ (spike generation)
  - Different $g_{\text{exc}}$, $g_{\text{inh}}$ (spike generation, conductance waveforms)

![Graph showing cumulative probability over time](image)

- Cumulative probability
- Time $\Delta t$ (ms)
- Light response

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• Signals traversing rod bipolar pathway evoke temporally precise responses in mouse ganglion cells

• Temporal precision limited by noise in synaptic inputs rather than noise intrinsic to ganglion cell (i.e. in dendritic processing or spike generation)

• Different ganglion cell types achieve precision using distinct strategies to integrate excitatory and inhibitory inputs
3 ALPHA CELL TYPES IN MOUSE RETINA

Pang et al., 2003

10 Rh*/rod/sec

Cell Attached

ON

OFF Transient

OFF Sustained

50 pA

200 ms

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RELATIVE AMPLITUDES OF EXCITATION AND INHIBITION DIFFER AMONG ALPHA CELLS

ON

OFF T

OFF S

Peak Conductance (nS)

500 ms

20 nS

G_{exc}

G_{inh}

ON

OFF T

OFF S

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KINETICS OF EXCITATION AND INHIBITION DIFFER AMONG ALPHA CELLS

ON
OFF T
OFF S

200 ms

correlation between $G_{exc}$ and $G_{inh}$

msec

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WHAT DO DIFFERENCES IN SYNAPTIC INPUTS MEAN FOR SPIKE GENERATION?

$g_{\text{exc}}$  

$g_{\text{inh}}$  

$g_{\text{exc}} + g_{\text{inh}}$  

Cumulative Probability

$\Delta t$ (ms)
WHAT DO DIFFERENCES IN SYNAPTIC INPUTS MEAN FOR SPIKE GENERATION?

ON

firing dominated by excitatory input

OFF T

excitation and inhibition work in push-pull manner

OFF S
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