Precise Spike Timing and Reliability
in Neural Encoding of
Low-Level Sensory Stimuli and Sequences

Project 1.1.2

Feldman and Harris Labs
PART ONE

Temporally Precise Coding in the Rodent Whisker System

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SMN Network

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Active whisker sensation

Berg et al., 2003

Knutsen .. Ahissar, J. Neurophysiol., 2005

slowed ~10x
Active whisker sensation

Takeshi Morita
Coding of surface properties during active whisker sensation

Physical Transformation

Surface \longrightarrow Whisker kinetics \longrightarrow Neural response in S1 cortex

Representation of each element by temporally precise, correlated firing

Discretization into a time series of transient elements
Coding of surface properties during active whisker sensation

Record S1 spikes

Image whisker vibrations

Whisker Imaging Plane

Nose poke

Textured surface

Drink ports

1.5 sec

~ 1 sec

1.5 sec

Nose poke
Whisking on surface
Leave Nose poke
Drink

Diode Laser
Lenses
Whisker shadow
Linear CCD array (4 kHz frame rate)

Jason Wolfe
Shantanu Jadhav
Coding of surface properties during active whisker sensation
Whisker slips are temporally discrete features of active whisker input.

Wolfe et al., *PLoS Biology* 2008
Slips are a candidate cue for surface features

Wolfe et al., PLoS Biology 2008
S1 coding of slips and surfaces

Chronic tetrode recording

$n = 90$ neurons, L4 and L5, 3 rats
S1 spike trains in awake, behaving rats

Background spiking consists primarily of single spikes, not bursts, at median 6 Hz.
Whisker slips drive sparse, temporally precise spikes

14 ms jitter (temporal precision)
Whisker slips drive sparse, temporally precise spikes.

Slip responses are usually 1-2 spikes.

Net $P(spike)$ over background = 0.11
ROC analysis shows that slips are accurately encoded by synchronous firing (20 ms scale) in small neuronal populations (100 neurons, 97% accuracy)

Thus, precise timing of responses enables decoding of the sparse population signal.

This constitutes a transient synchrony code for slips.
Confirming this idea, slips transiently increase firing correlation for neuron pairs in vivo.

Transient firing correlations robustly encode slips.
Utility of a synchrony code for slips: coding of surface properties

**Slip-driven firing synchrony** provides a useful code for surface roughness.

- Air: no large slips
- Few large slips

![Graph depicting firing rates and correlations](image)

- Mean firing rate for different conditions
- Synchronous spikes per sec

![Bar charts](image)

- Firing rate: Air, Rough, Smooth
- Firing correlations (20 ms window): Air, Rough, Smooth
- Firing correlations (100 ms window): Air, Rough, Smooth

*Note: Additional details and statistical significance marked with asterisks.*
Utility of a synchrony code for slips: coding of surface properties

**Slip-driven firing synchrony** provides a useful code for surface roughness

<table>
<thead>
<tr>
<th>Air</th>
<th>more large slips</th>
</tr>
</thead>
<tbody>
<tr>
<td>no large slips</td>
<td>few large slips</td>
</tr>
</tbody>
</table>

Four similar sandpapers (P150, 400, 800, 1200)

Firing rate

Firing correlations (20 ms window)

Firing correlations (100 ms window)
Summary: Time in Tactile Whisker Sensation

Summary
Friction transforms continuous surface whisking into a series of discrete slip-stick events, which are fundamental encoded elements of tactile sensation.

Slips are represented by sparse, low-probability, precisely timed spikes.

Temporal precision allows efficient decoding of sparse activity by synchronous firing of S1 neurons. This strategy has benefits for representing dense temporal input streams.
Summary: Time in Tactile Whisker Sensation

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Friction transforms continuous surface whisking into a series of discrete slip-stick events, which are fundamental encoded elements of tactile sensation.

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Ongoing and future questions
Do specific sequences of whisker stimuli carry behavioral meaning?

Can tactile sequences be learned?

How are tactile sequences represented in the brain?
PART TWO

State dependence of sensory-evoked responses in neocortex

Sensory input → Neural response → Internal dynamics

Behavioral and attentional state

Ken Harris Lab
IMSN Network
Rutgers University
Activated and Inactivated Brain States in Cerebral Cortex

**Activated state:** High-frequency, low-amplitude LFP and EEG
Alert wakefulness and REM sleep

**Inactivated state:** Low-frequency, higher-amplitude rhythm
Inattentive wakefulness, slow-wave sleep

Poulet & Petersen, Nature 2008
Accuracy of rapid sensory encoding depends on brain state

Record A1 responses to click pairs in anesthetized rats.
Response variability is especially evident during click sequences

1\textsuperscript{st} click: variable response

2\textsuperscript{nd} click: (50 ms later) very variable
Response variability is especially evident during click sequences.

1st click: variable response

2nd click: (50 ms later) very variable
Prediction of the stimulus from spiking is more accurate in the activated state.
Reliability in response to ongoing noise stimuli

- Inactivated state: High trial-to-trial variability
- Activated state: Low trial-to-trial variability, Sharper time-locking, Amplitude-modulated noise stimulus
Conclusions and Challenges:

Spike timing carries important information about low-level sensory features.

Local internal dynamics influence timing and reliability of spikes.

Do S1 and A1 have similar coding strategies? How does this influence encoding and perception of patterns and sequences?
**Progress**

1.1.1 Cross-modal comparison of learning simple sensory patterns and sequences

SMN, IMS

Are there common time scales, neural representations, and computational strategies for learning sequences across modalities? (Feldman: rodent whiskers, Chiba: rodent vision, Harris: rodent hearing; de Sa, Sereno: human cross-modal)

Train rats to distinguish temporal patterns of whisker impulses.

1 vs. 2 discrimination

Interval discrimination
Slips contribute to modest firing rate elevation on surfaces.

Mean 2.2-fold increase in firing rate on surfaces.
People

Lab Members
Shantanu Jadhav
David House
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Joe Goldbeck
Sharri Zamore

Collaborators
Beat Lutz (Munich)
Daniel Shulz (CNRS)
Ken Mackie (UW)

David Kleinfeld (UCSD)

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