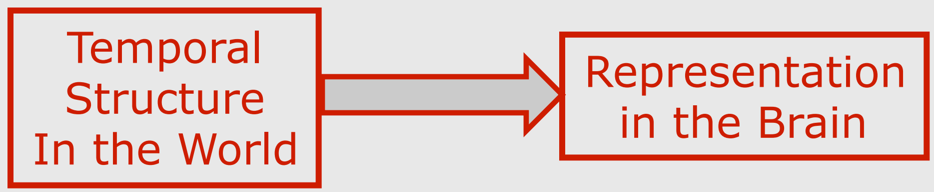
Precise Spike Timing and Reliability in Neural Encoding of Low-Level Sensory Stimuli and Sequences

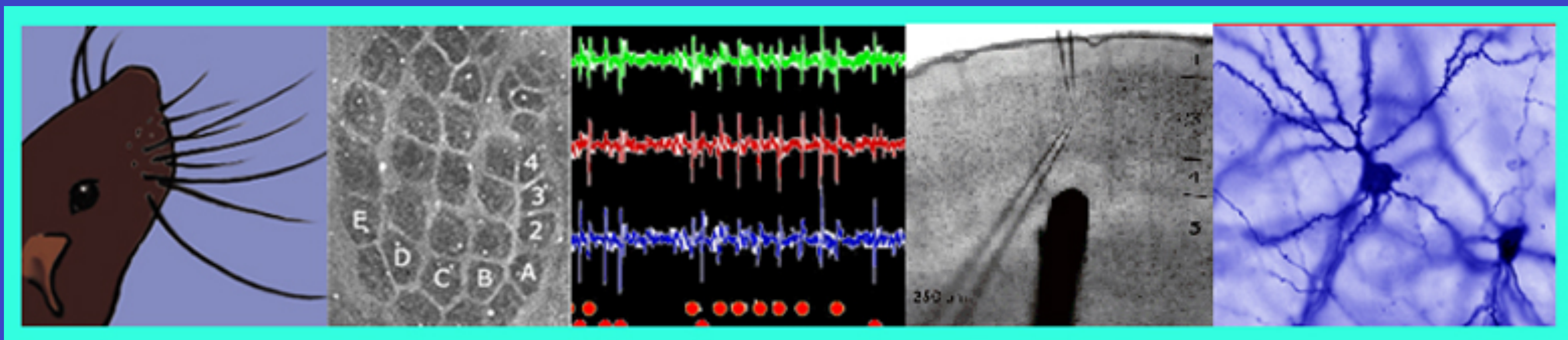


Project 1.1.2

Feldman and Harris Labs

PART ONE

Temporally Precise Coding in the Rodent Whisker System

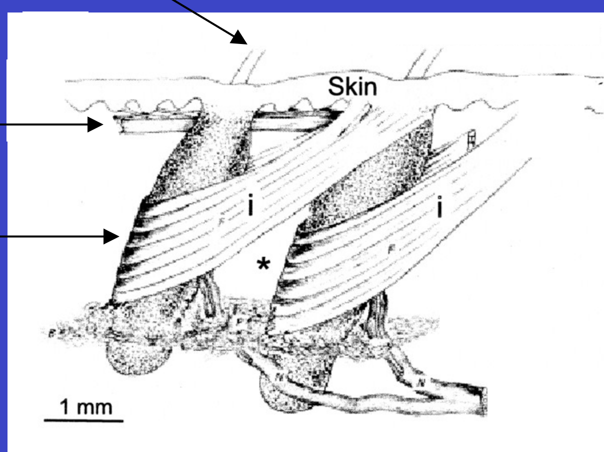


Dan Feldman, Jason Wolfe, Shantanu Jadhav
Toshio Miyashita, Sharri Zamore, Joe Goldbeck

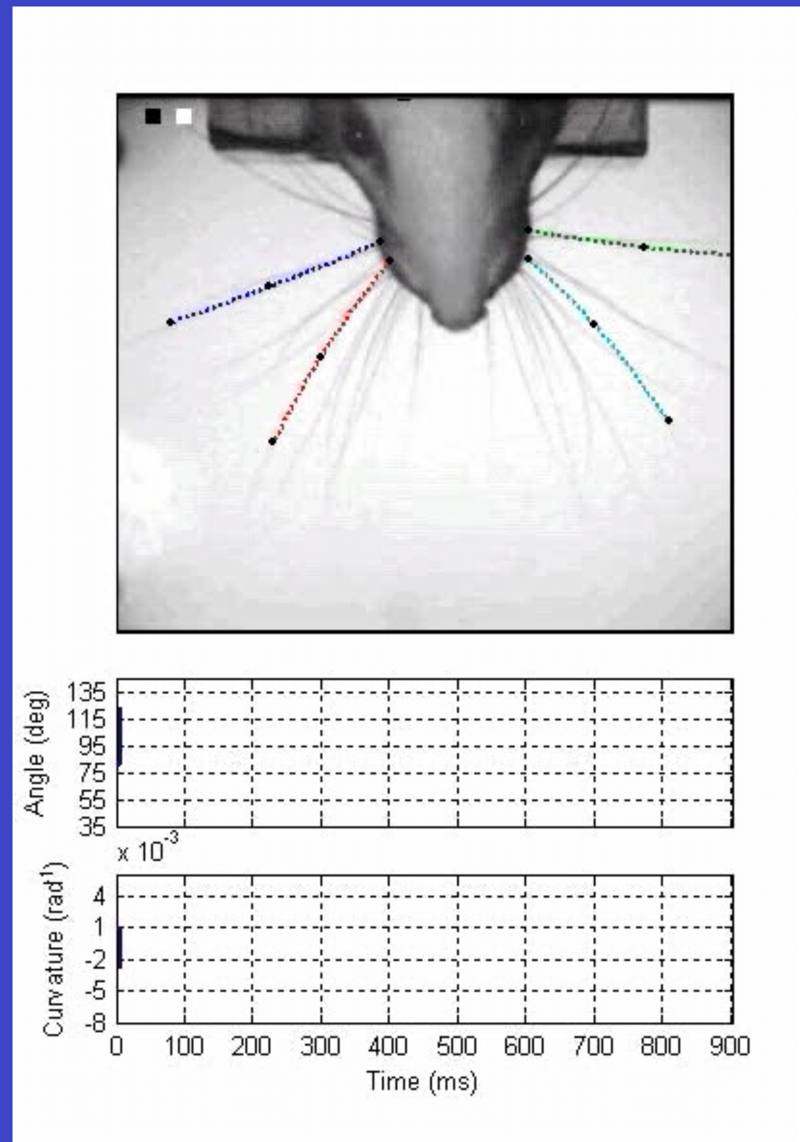
SMN Network

Dept. of Molecular & Cell Biology
Helen Wills Neuroscience Institute
UC Berkeley

Active whisker sensation



Berg et al., 2003



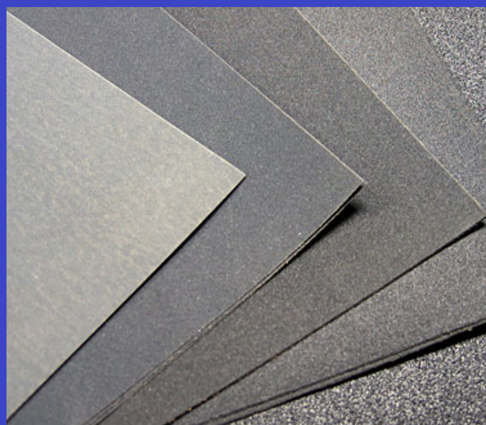
slowed
~10x

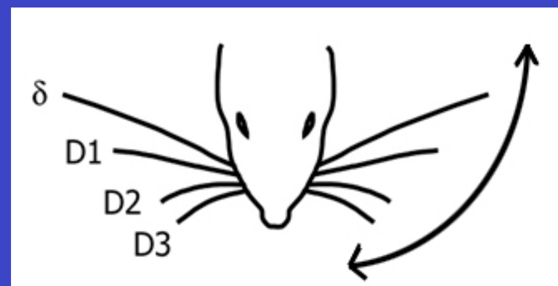
Knutsen .. Ahissar,
J. Neurophysiol., 2005

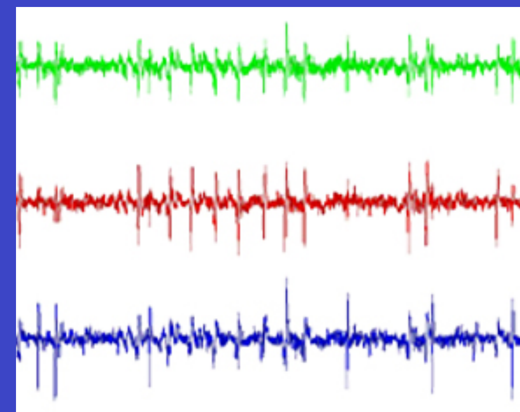
Active whisker sensation

Takeshi Morita

Coding of surface properties during active whisker sensation







Surface ⟶ Whisker kinetics ⟶ Neural response in S1 cortex

Physical Transformation

Discretization into a time series of transient elements

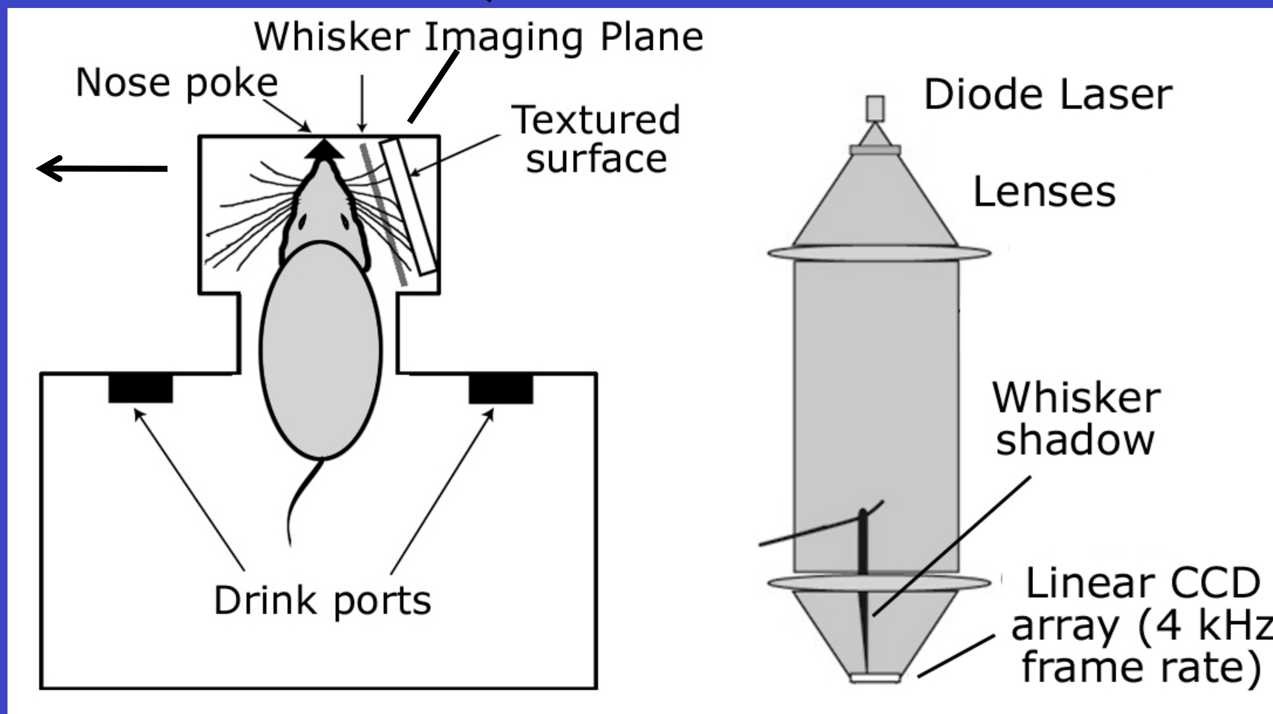
Neural Transformation

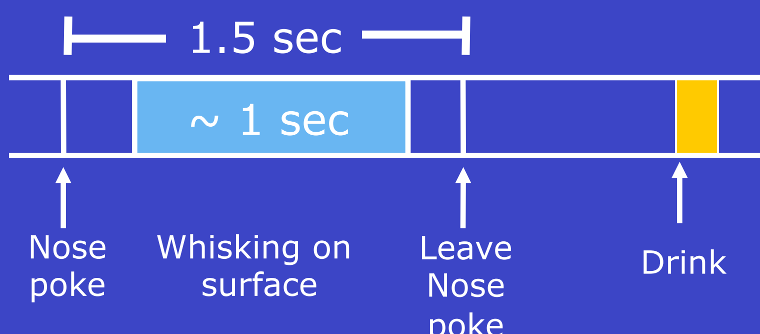
Representation of each element by temporally precise, correlated firing

Coding of surface properties during active whisker sensation

Image
whisker vibrations

Record
S1 spikes

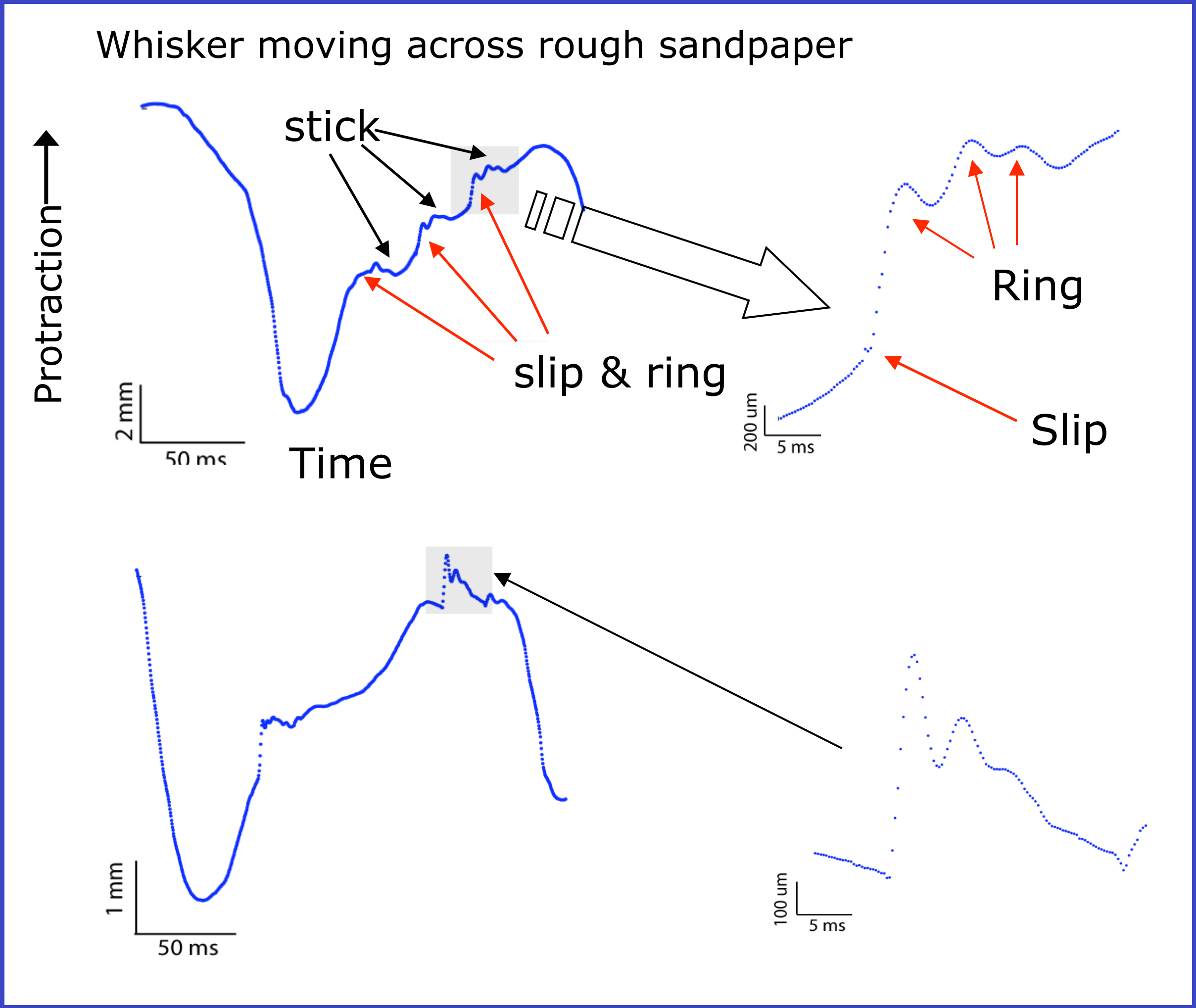


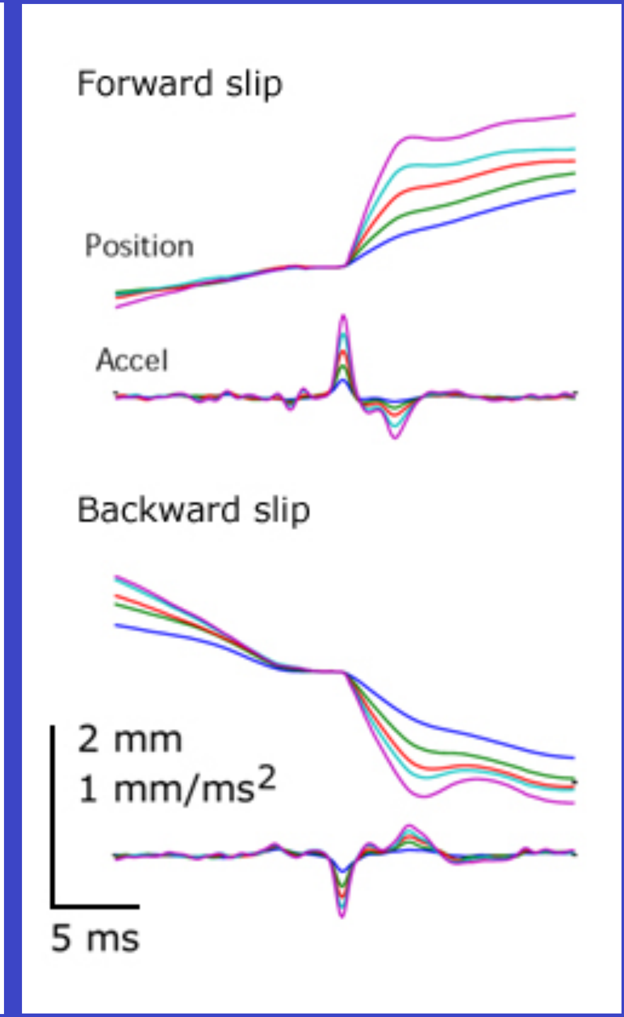


Jason Wolfe
Shantanu Jadhav

Coding of surface properties during active whisker sensation

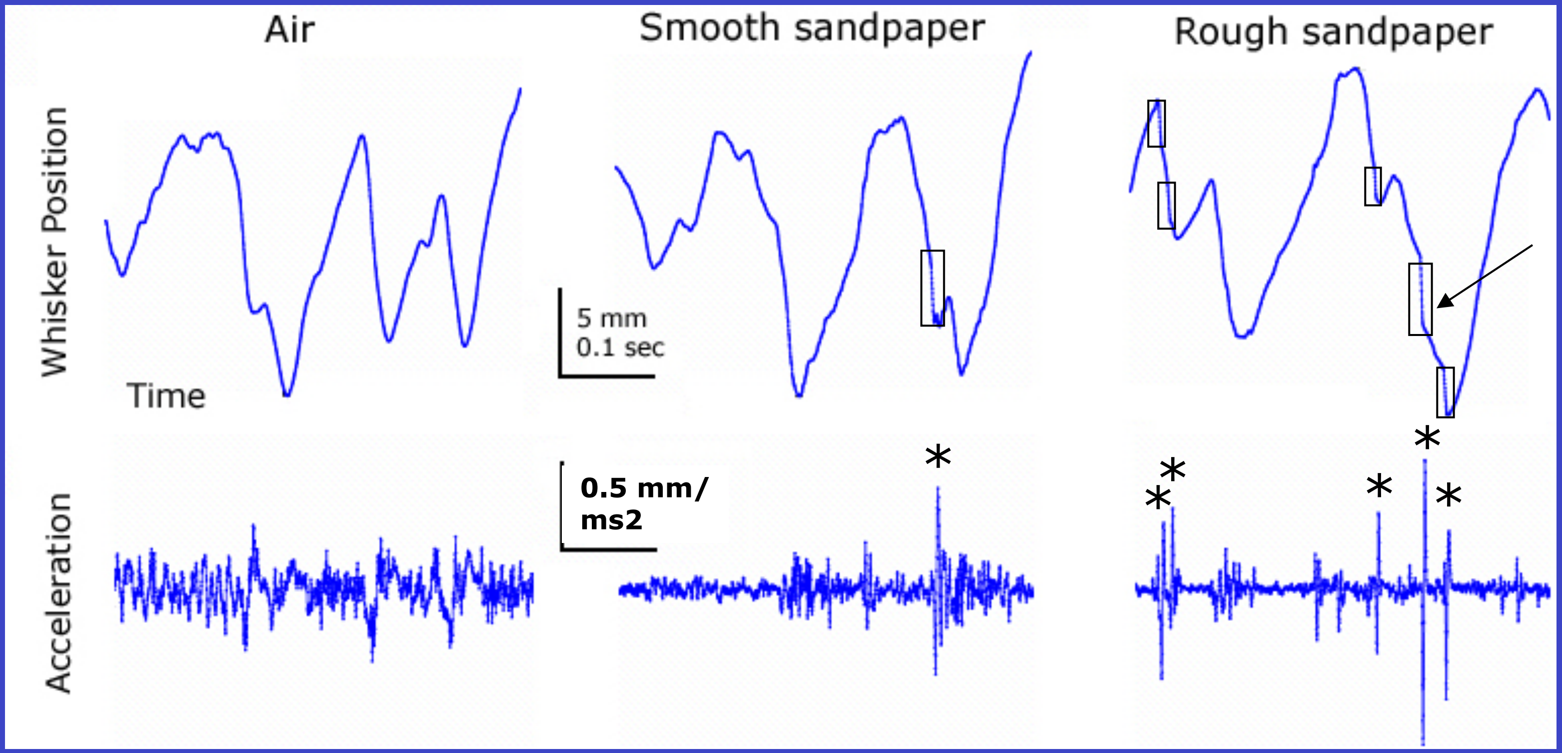
Whisker slips are temporally discrete features of active whisker input



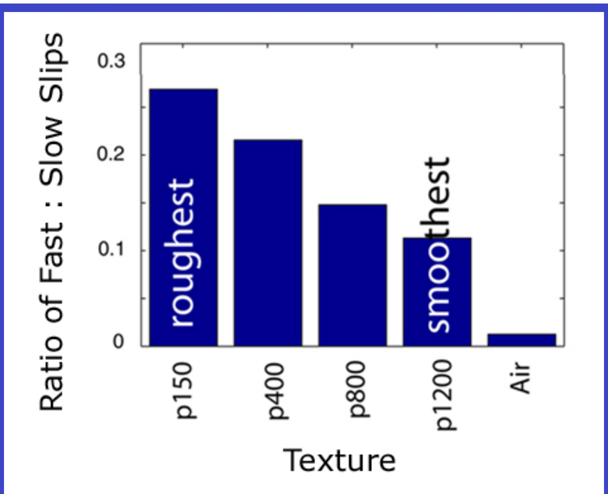


Wolfe et al., *PLoS Biology* 2008

Slips are a candidate cue for surface features



Slips

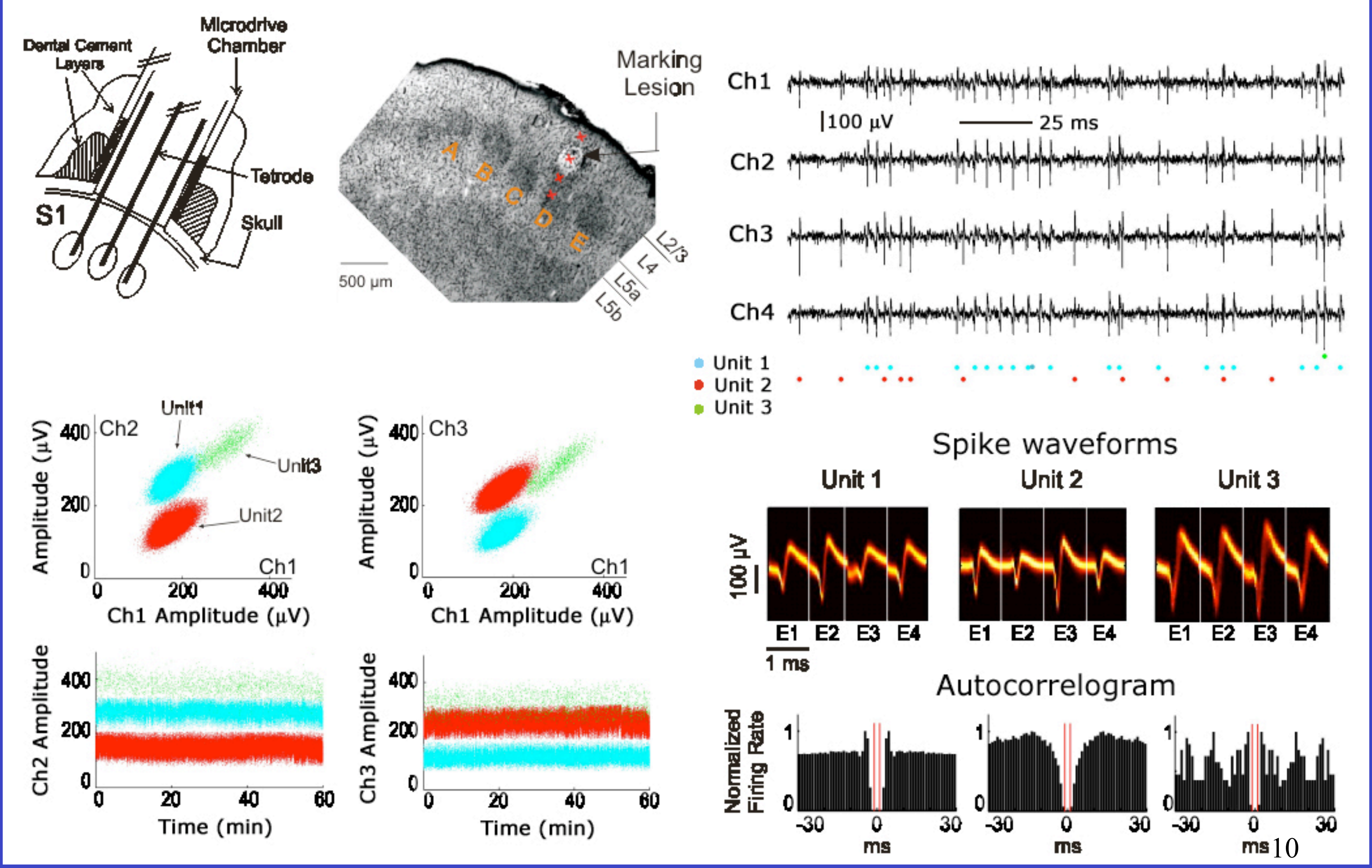


Wolfe et al.,
PLoS Biology 2008

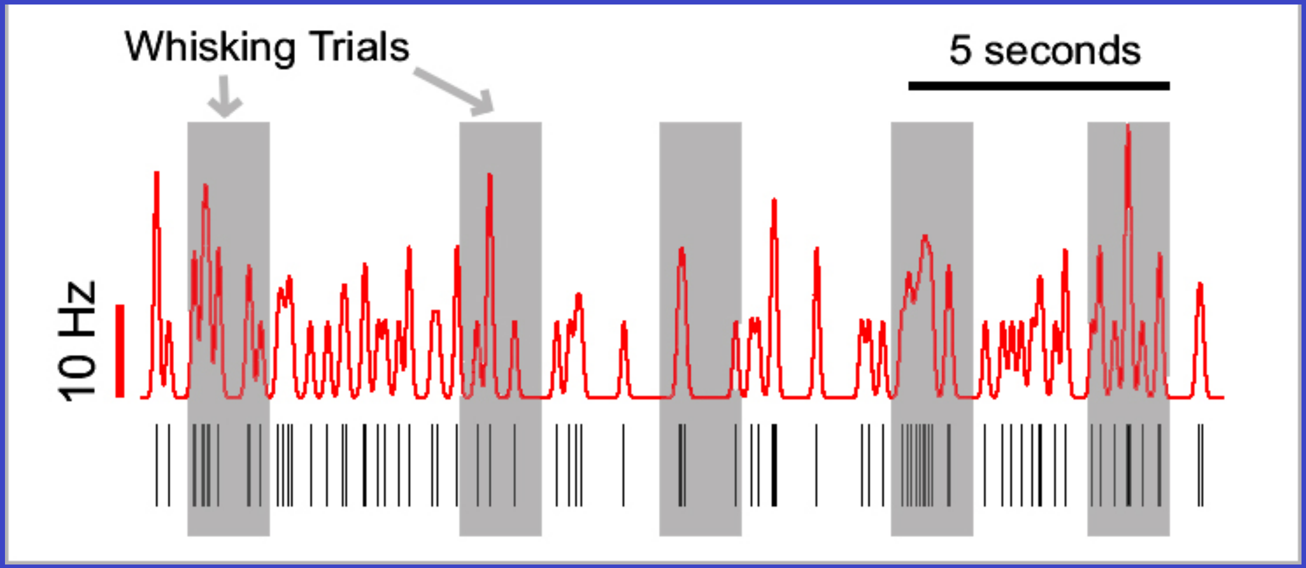
S1 coding of slips and surfaces

Chronic tetrode recording

n = 90 neurons, L4 and L5, 3 rats



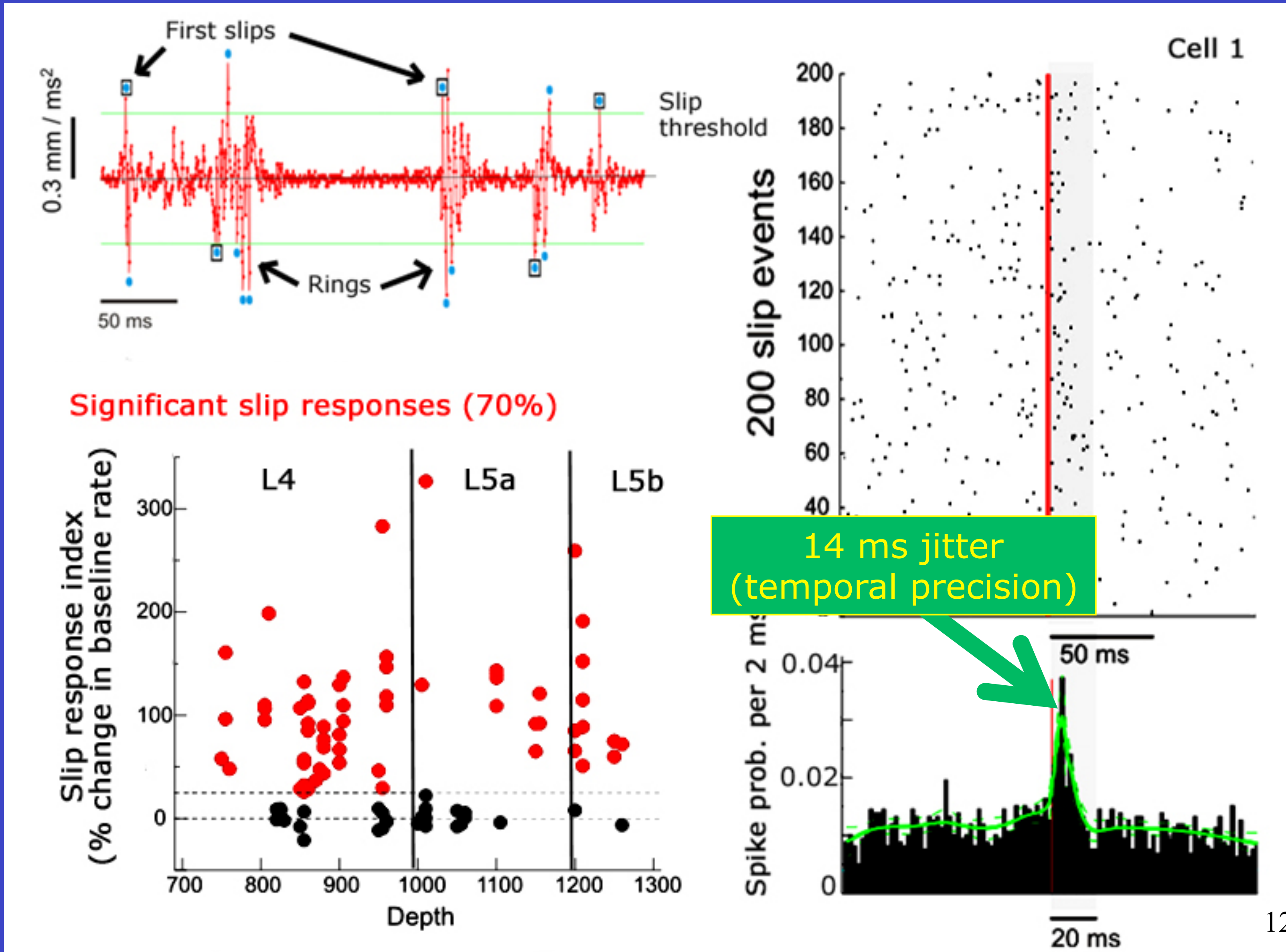
S1 spike trains in awake, behaving rats



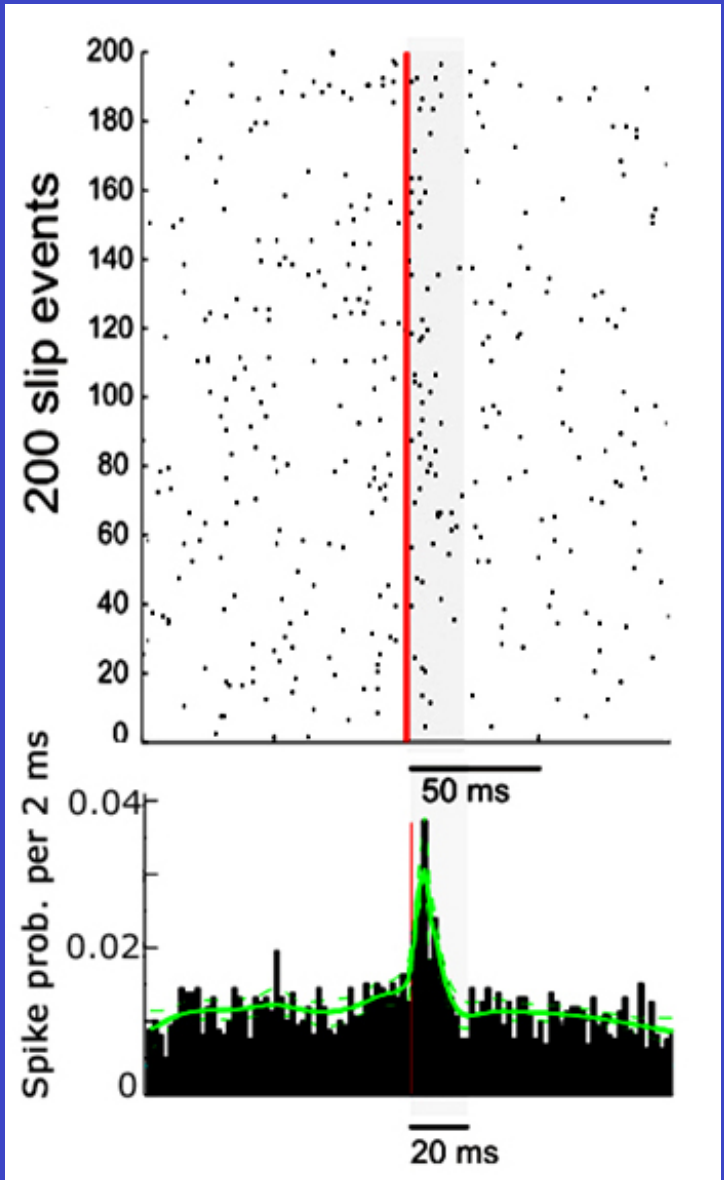
Background spiking consists primarily of single spikes, not bursts, at median 6 Hz.

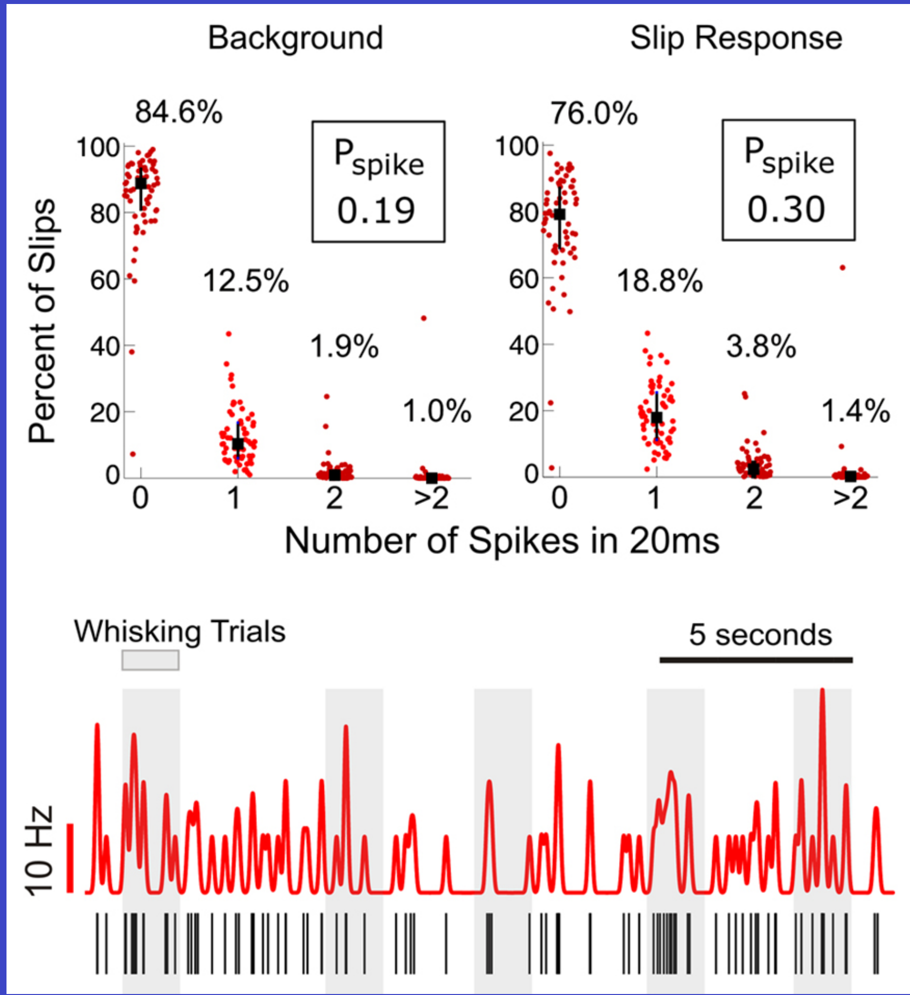
Shantanu Jadhav

Whisker slips drive sparse, temporally precise spikes



Whisker slips drive sparse, temporally precise spikes





Slip responses are usually 1-2 spikes.

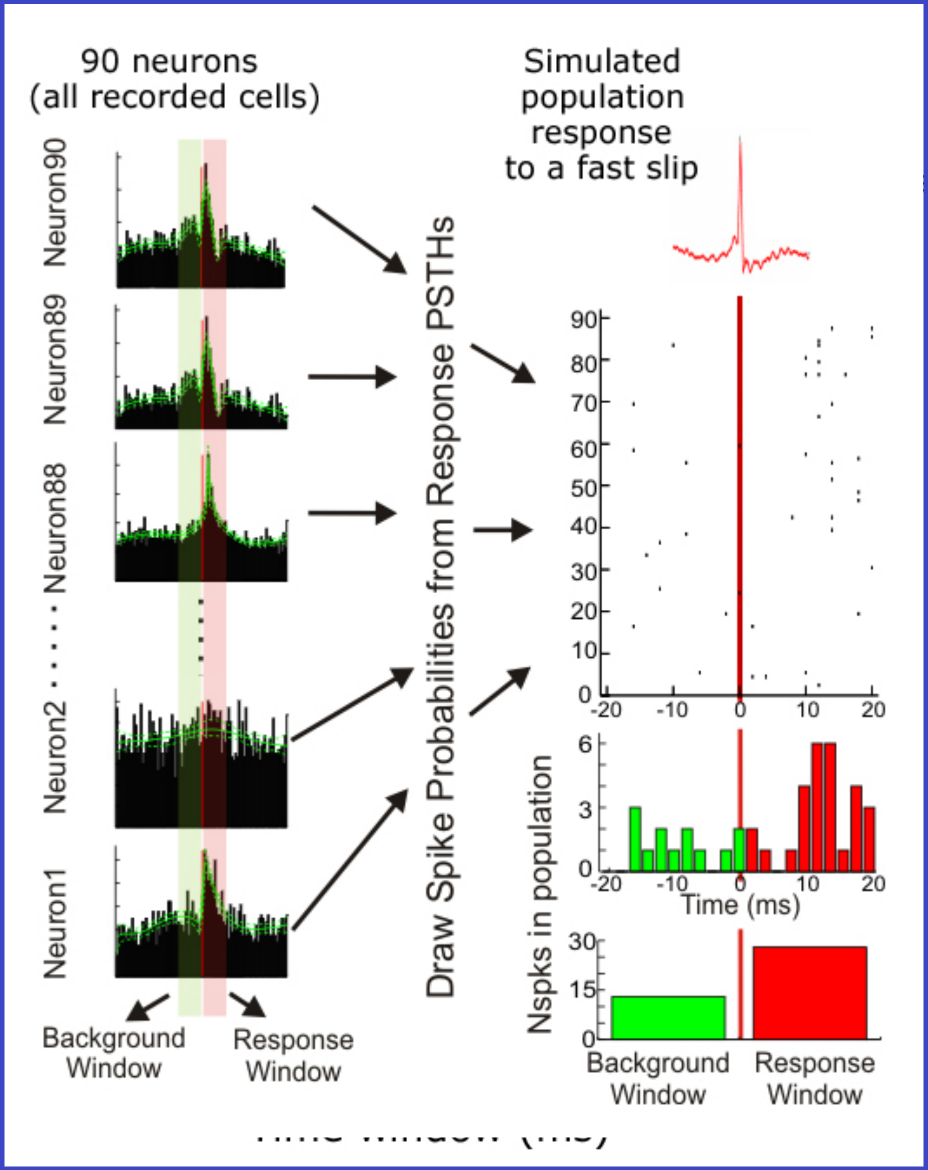
Net P(spike) over background = 0.11

Transient firing correlations robustly encode slips

ROC analysis shows that slips are accurately encoded by synchronous firing (20 ms scale) in small neuronal populations (100 neurons, 97% accuracy)

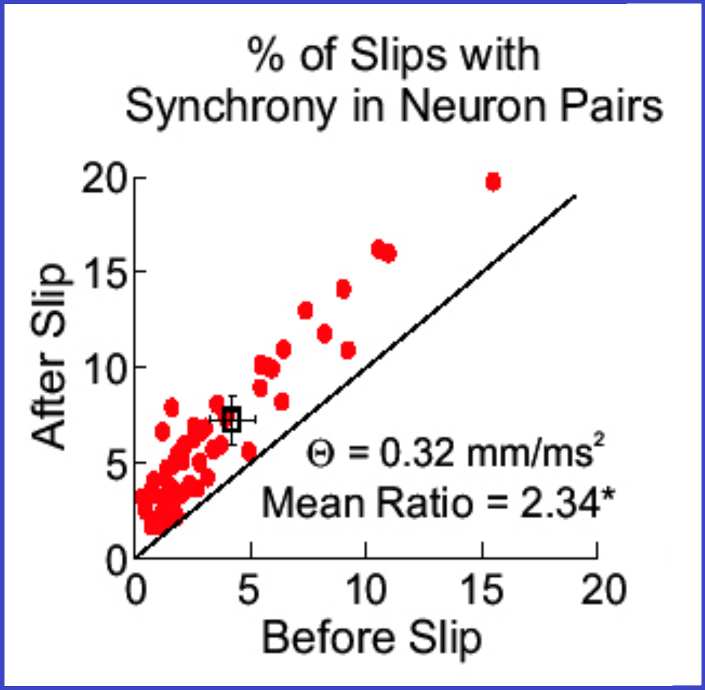
Thus, precise timing of responses enables decoding of the sparse population signal.

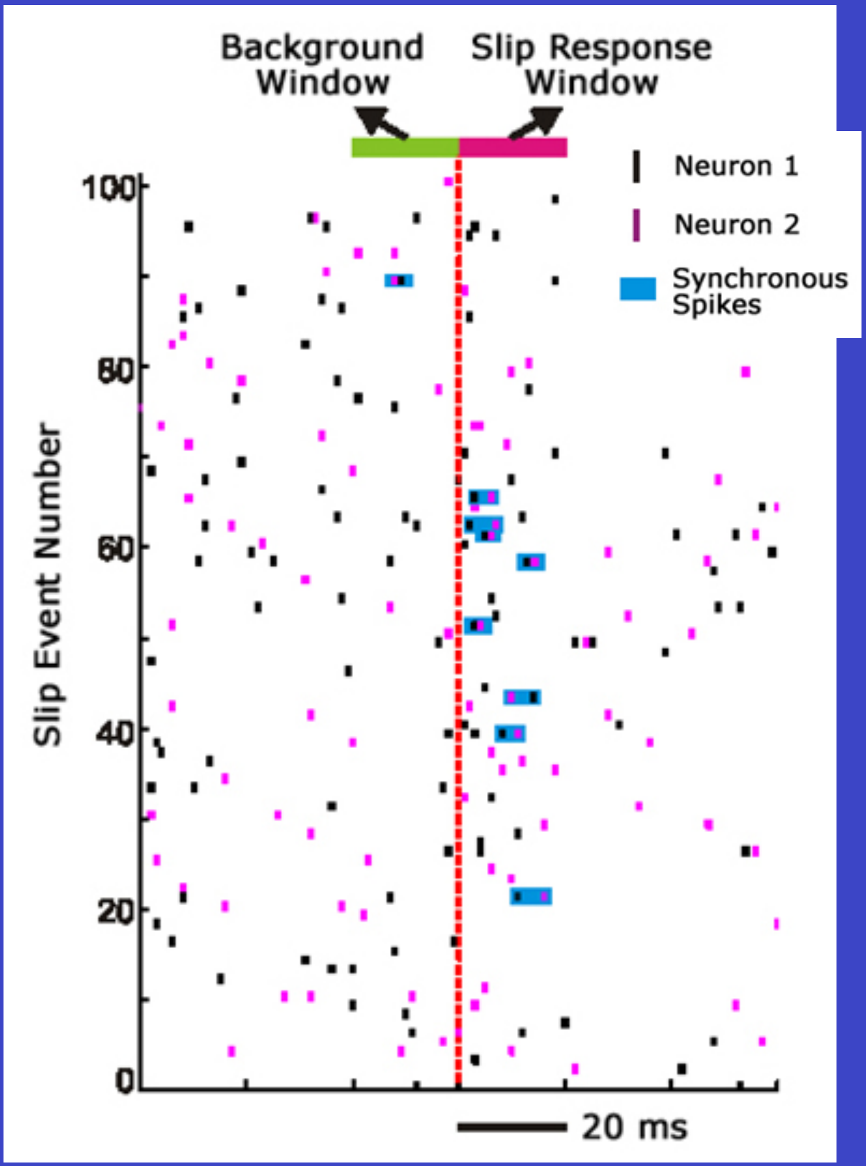
This constitutes a transient synchrony code for slips.



Transient firing correlations robustly encode slips

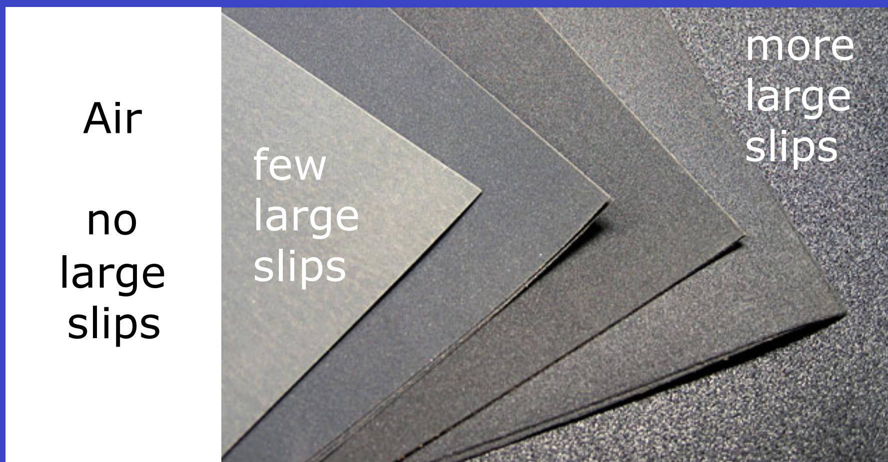
Confirming this idea,
slips transiently increase firing correlation for neuron pairs in vivo.

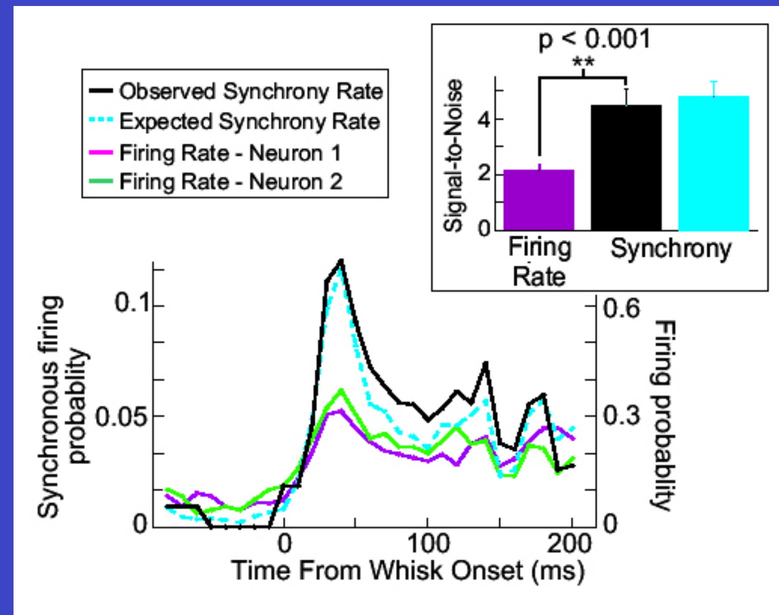




Utility of a synchrony code for slips: coding of surface properties

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

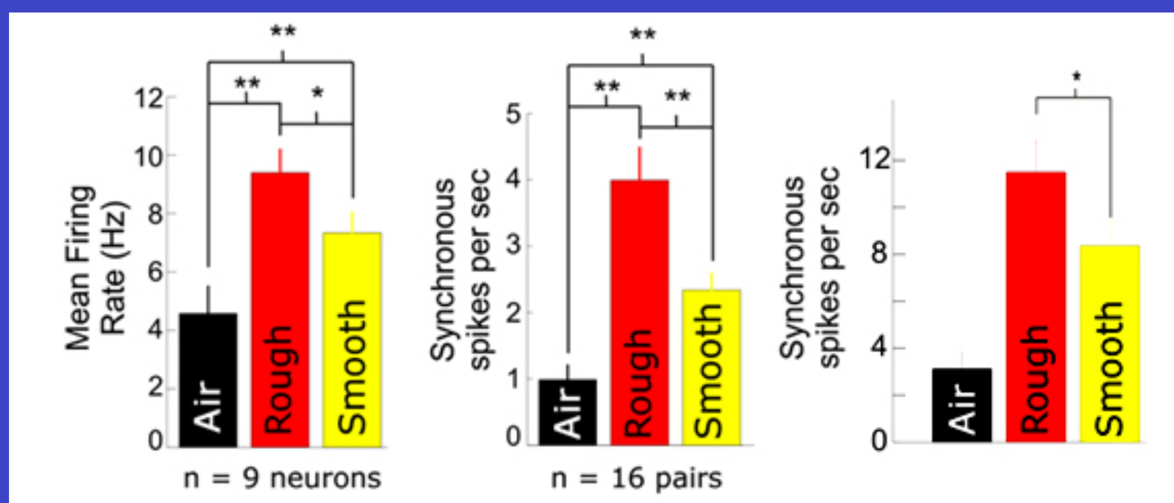




Firing rate

Firing correlations (20 ms window)

Firing correlations (100 ms window)



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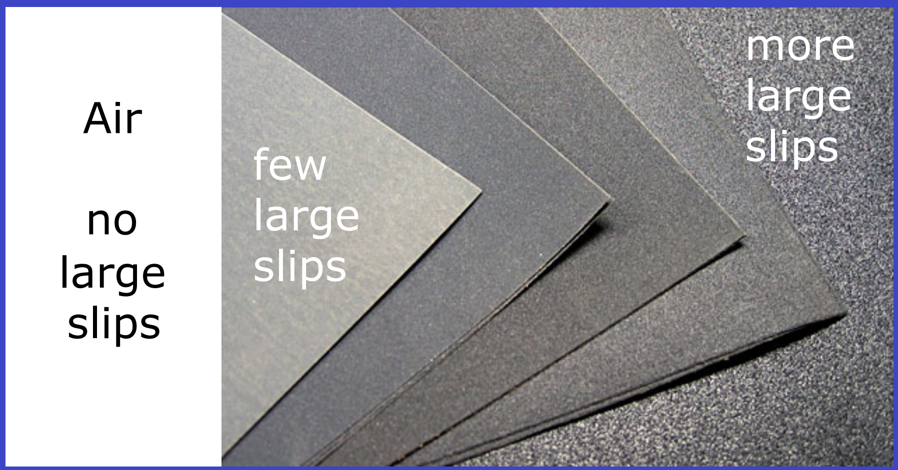
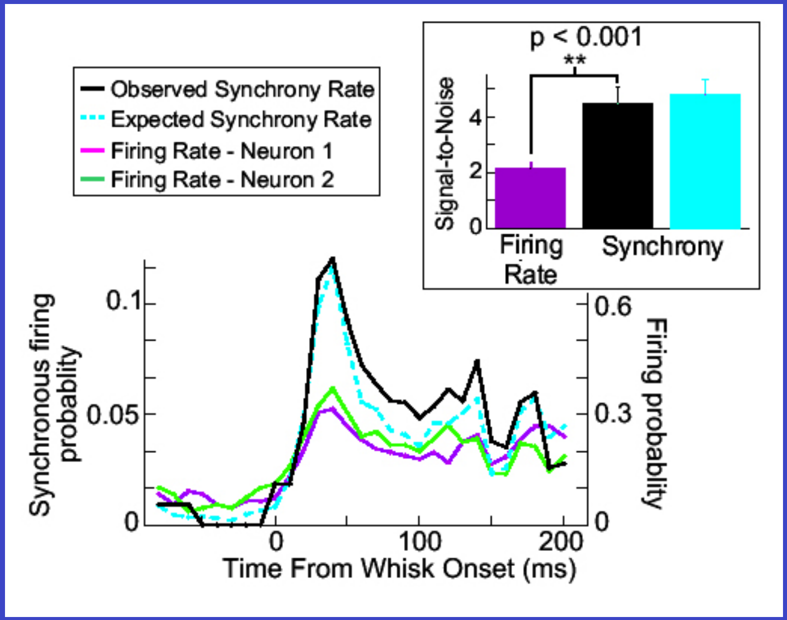


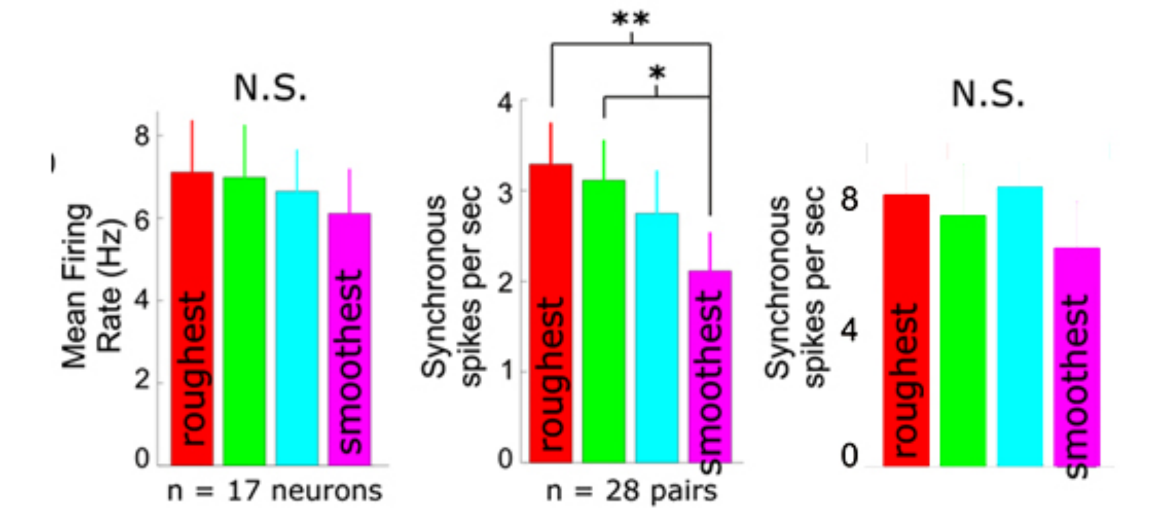


Four similar sandpapers (P150, 400, 800, 1200)

Firing rate

Firing correlations (20 ms window)

Firing correlations (100 ms window)



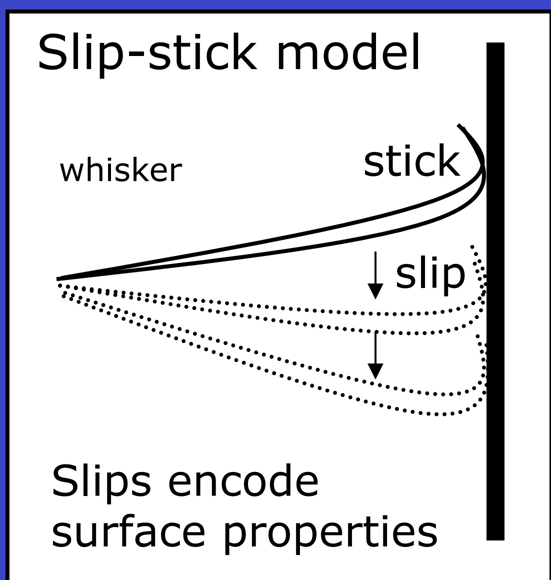
Summary: Time in Tactile Whisker Sensation

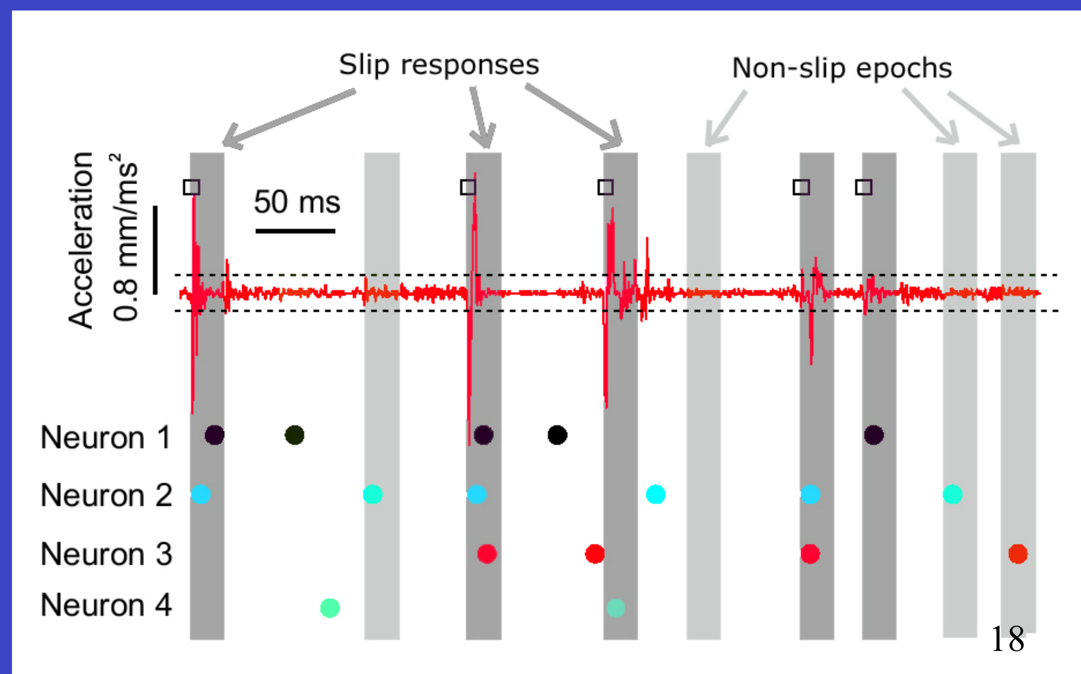
Summary

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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Ongoing and future questions

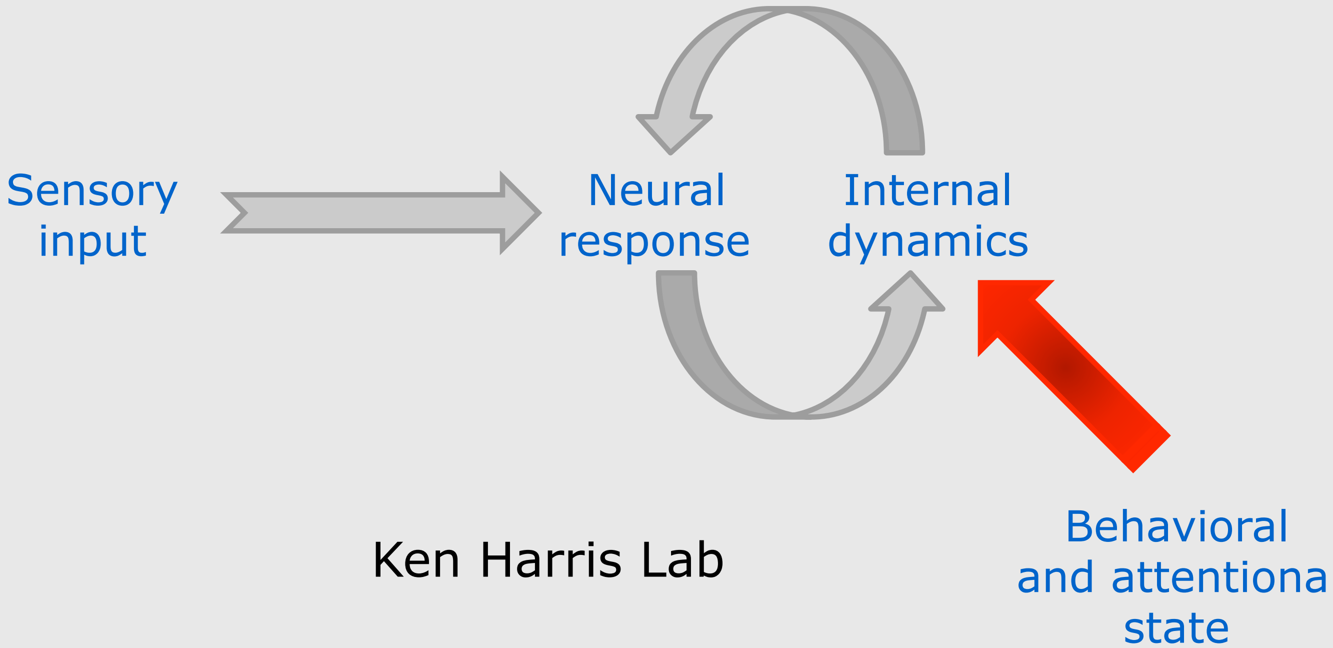
Do specific sequences of whisker stimuli carry behavioral meaning?

Can tactile sequences be learned?

How are tactile sequences represented in the brain?

PART TWO

State dependence of sensory-evoked responses in neocortex



Ken Harris Lab

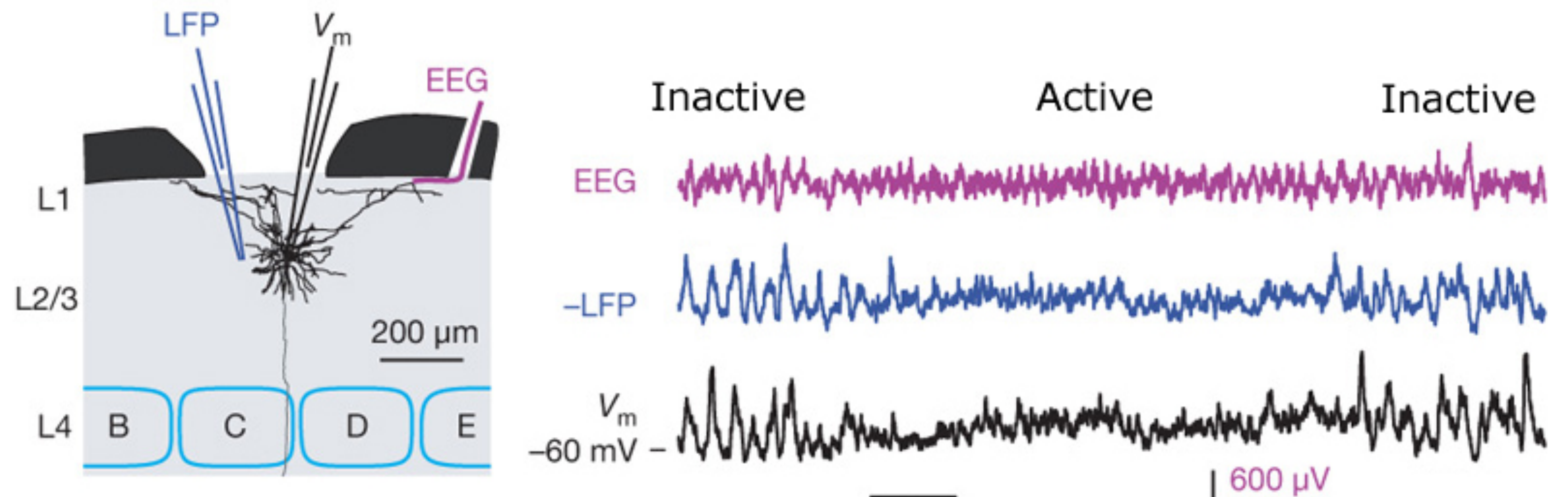
IMSN Network

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

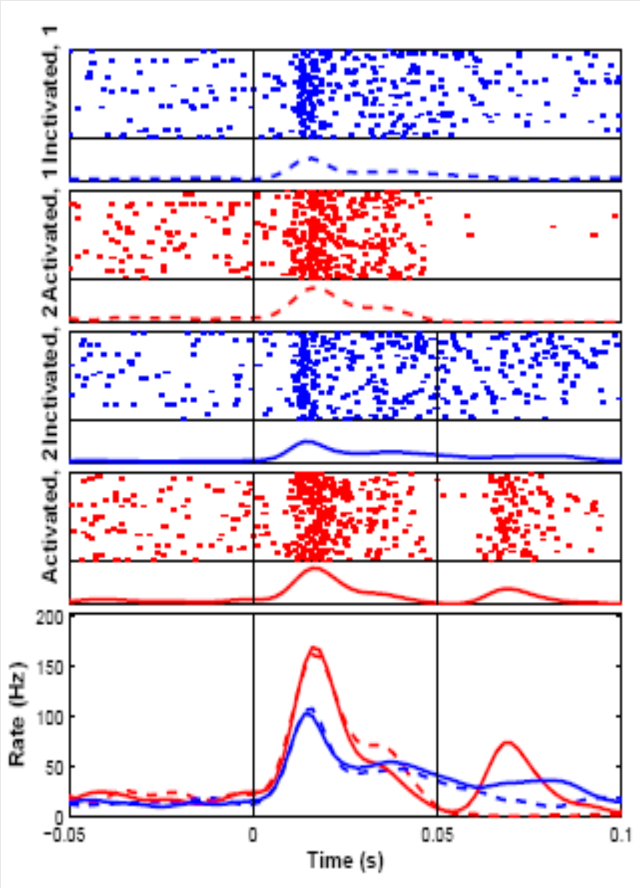
Record A1 responses to click pairs in anesthetized rats.

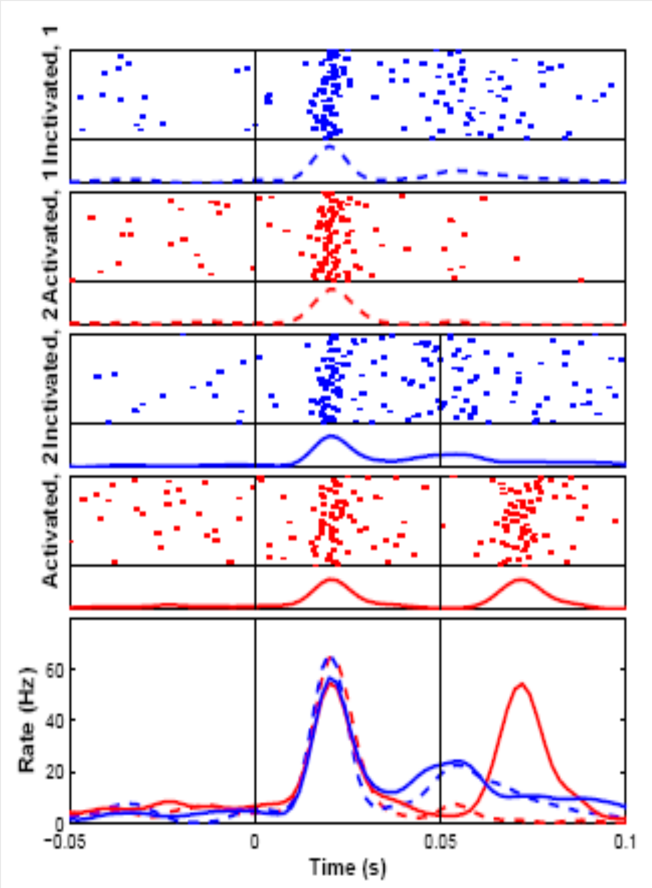
inactivated

activated

inactivated

activated

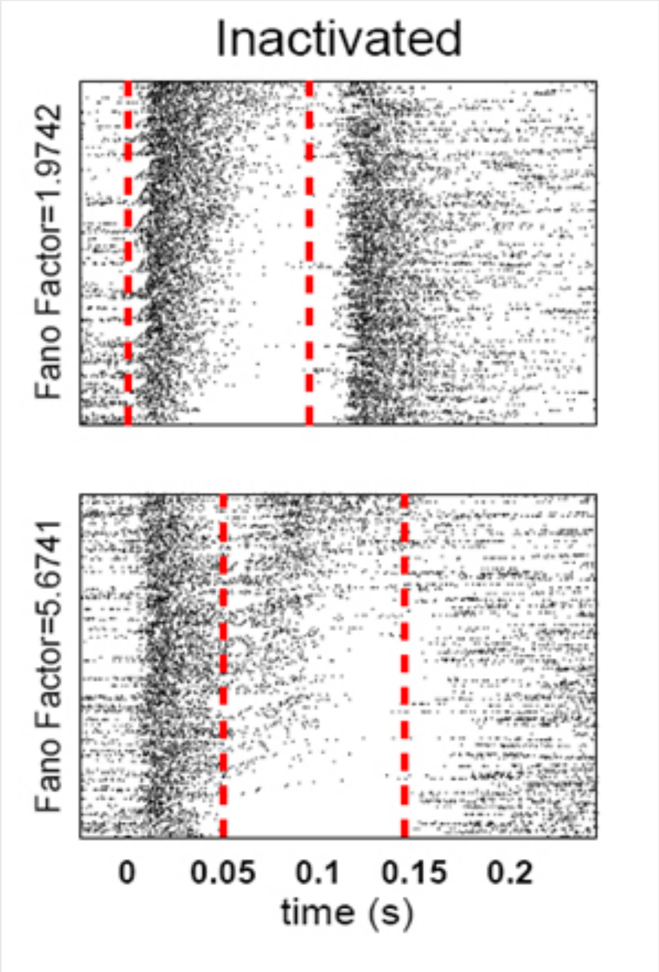




Response variability is especially evident during click sequences

1st click:
variable
response

2nd click:
(50 ms later)
very variable



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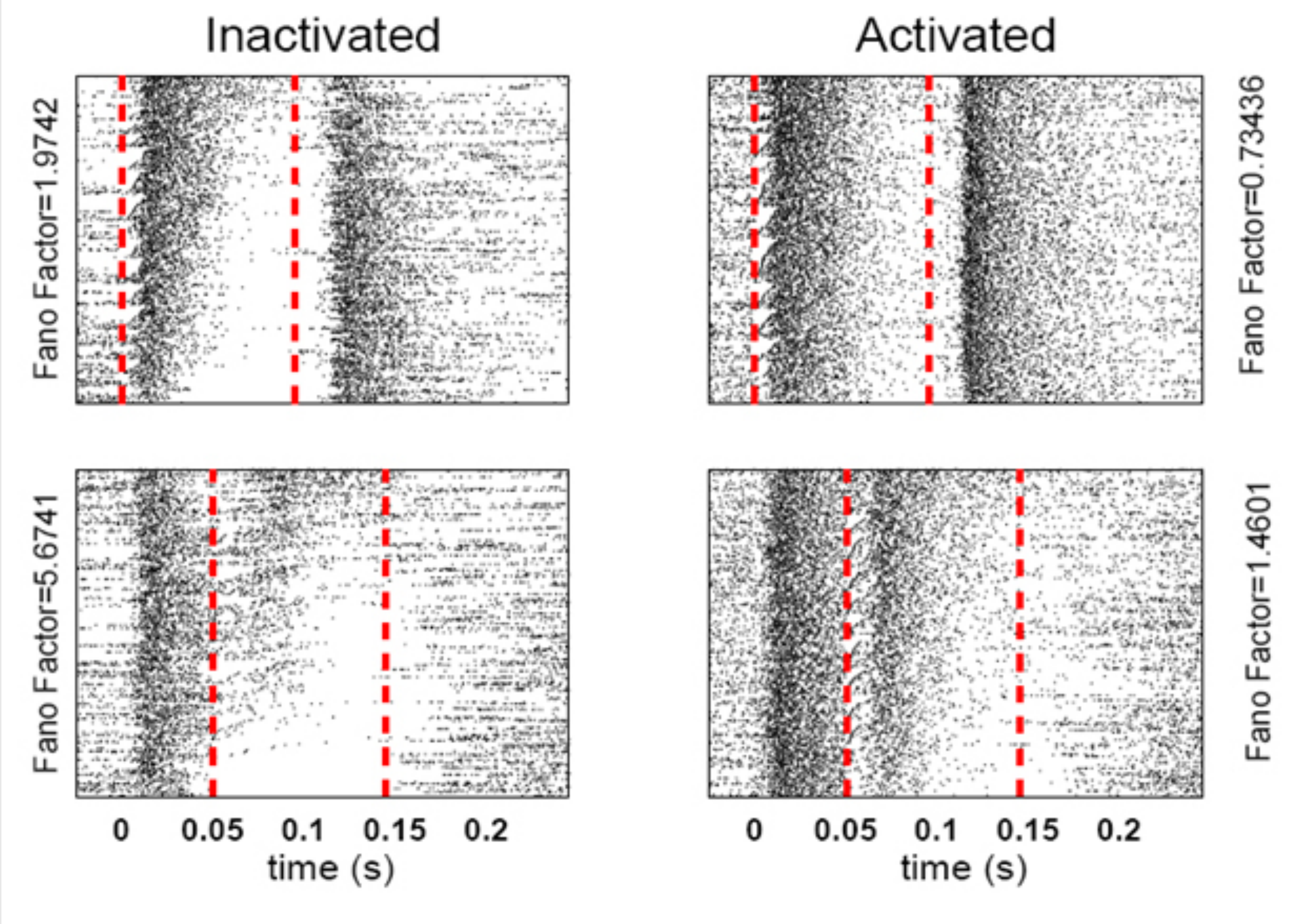
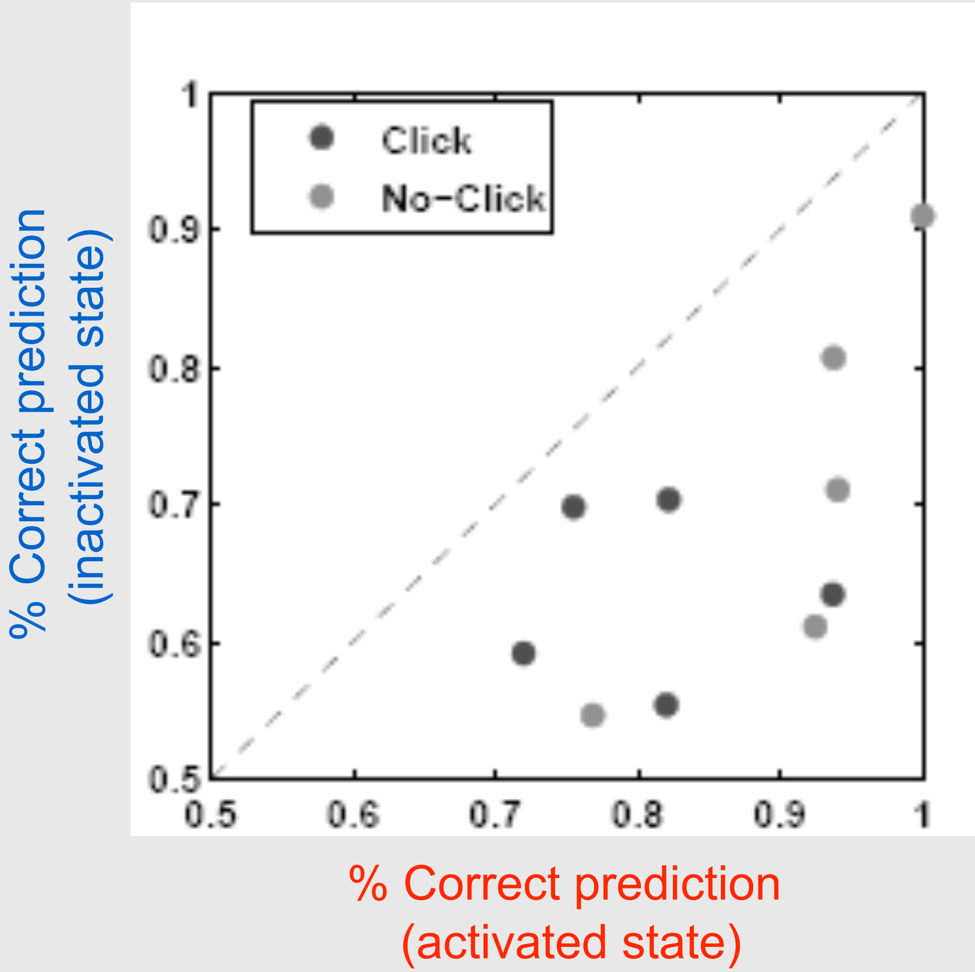
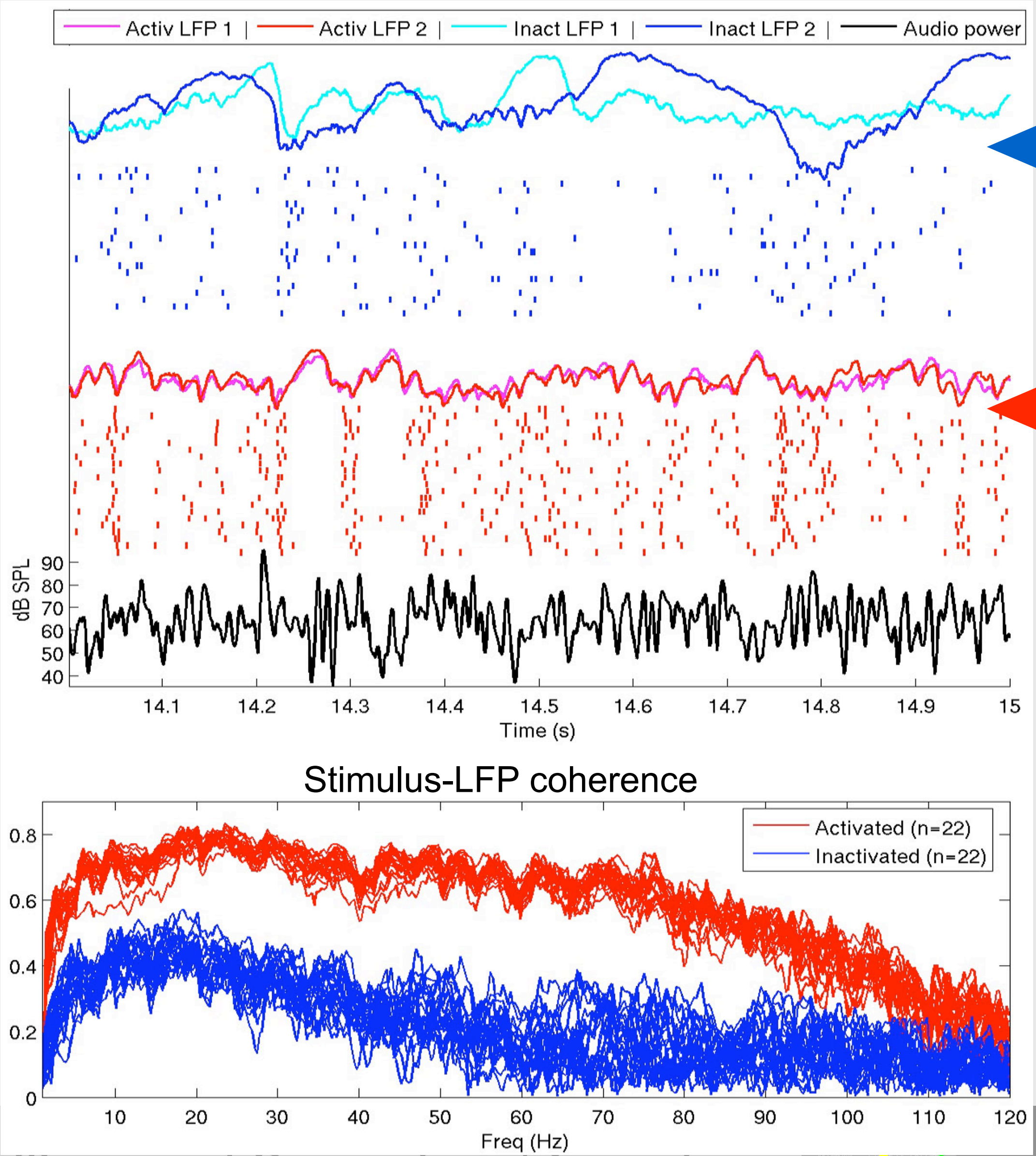


Prediction of the stimulus from spiking is
more accurate in the activated state



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

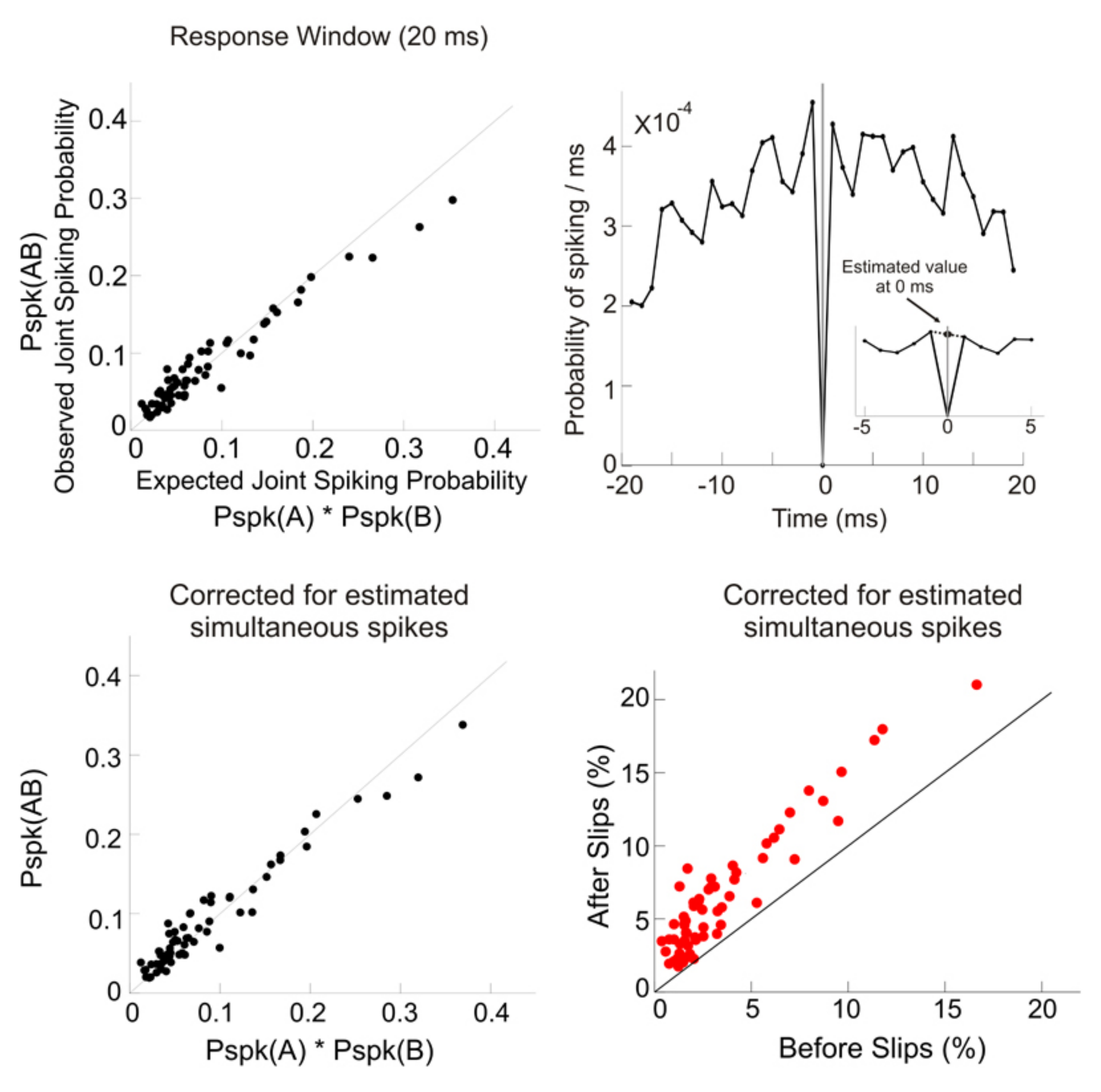
Interim Summary

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?



Response Window (20 ms)
Pspk(AB)
Observed Joint Spiking Probability
Expected Joint Spiking Probability
Pspk(A) * Pspk(B)
X10^-4
Probability of spiking / ms
Estimated value at 0 ms
Time (ms)
Corrected for estimated simultaneous spikes
Pspk(AB)
Pspk(A) * Pspk(B)
Corrected for estimated simultaneous spikes
After Slips (%)
Before Slips (%)

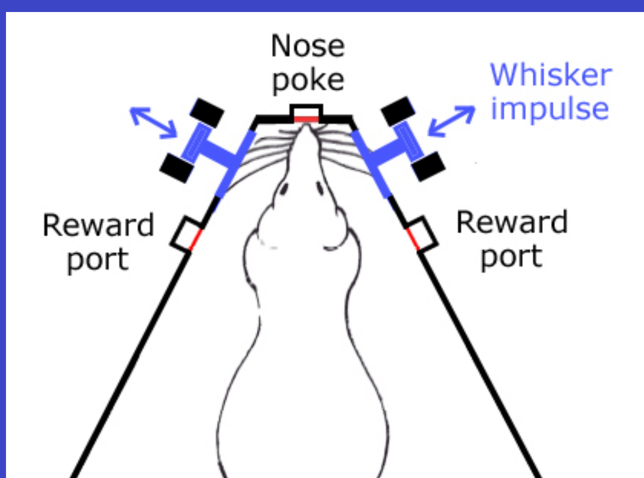
Progress

SMN, IMS

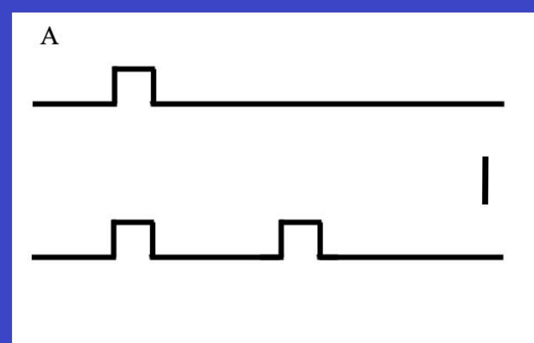
1.1.1 Cross-modal comparison of learning simple sensory patterns and sequences

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)

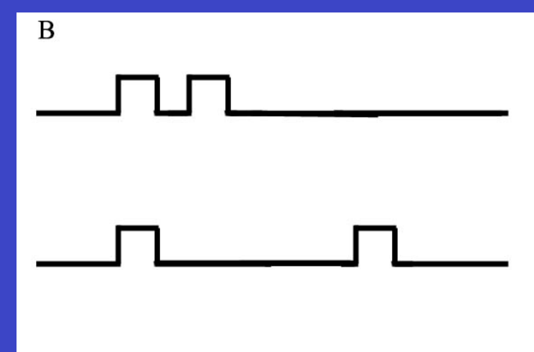
Train rats to distinguish temporal patterns of whisker impulses.



1 vs.2 discrimination

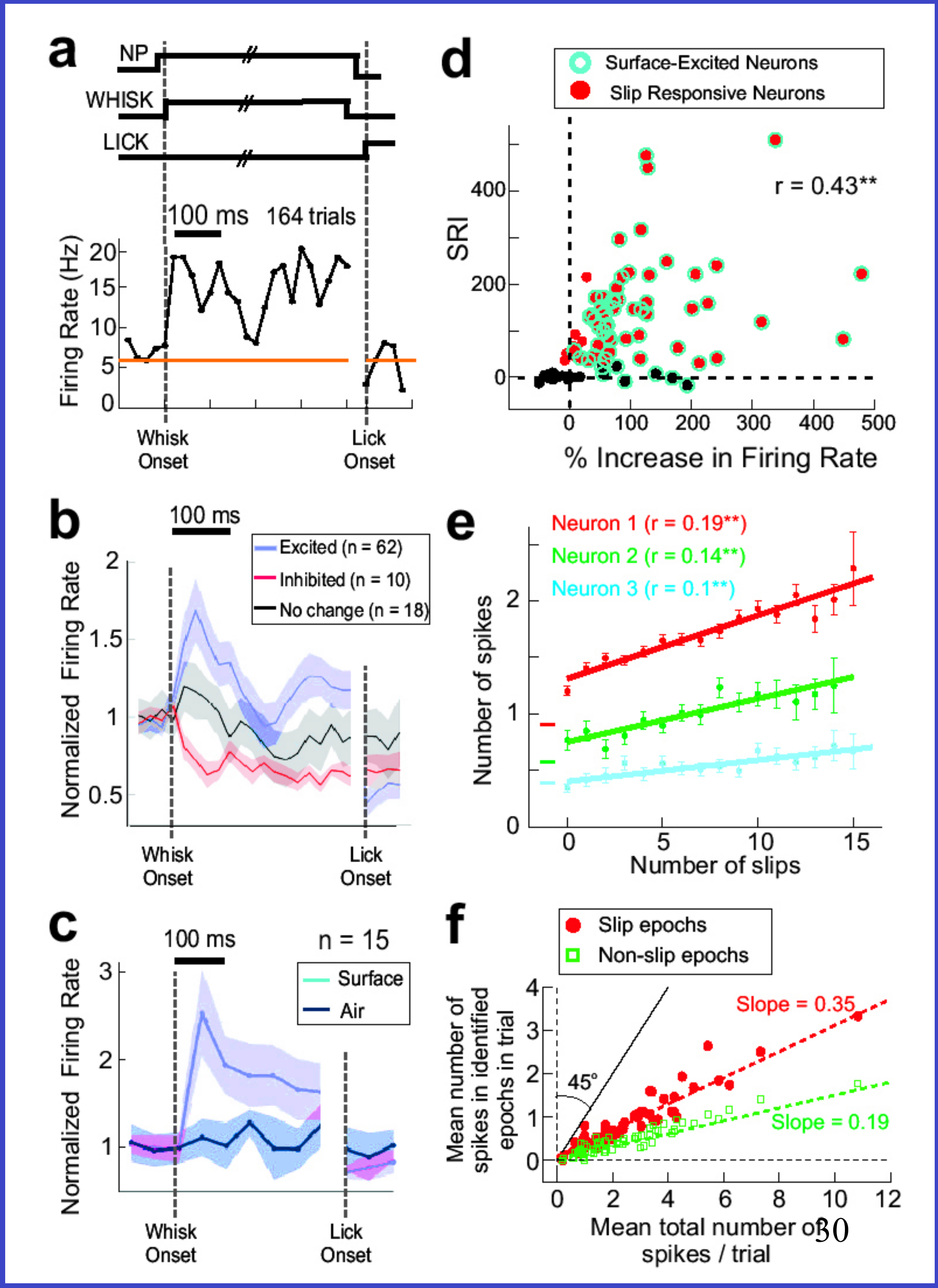


Interval discrimination



Slips contribute to modest firing rate elevation on surfaces

Mean 2.2-fold increase in firing rate on surfaces



People

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Daniel Shulz (CNRS)
Ken Mackie (UW)

David Kleinfeld (UCSD)

Support

NINDS
NSF CAREER Award
NSF Temporal Dynamics of Learning Center