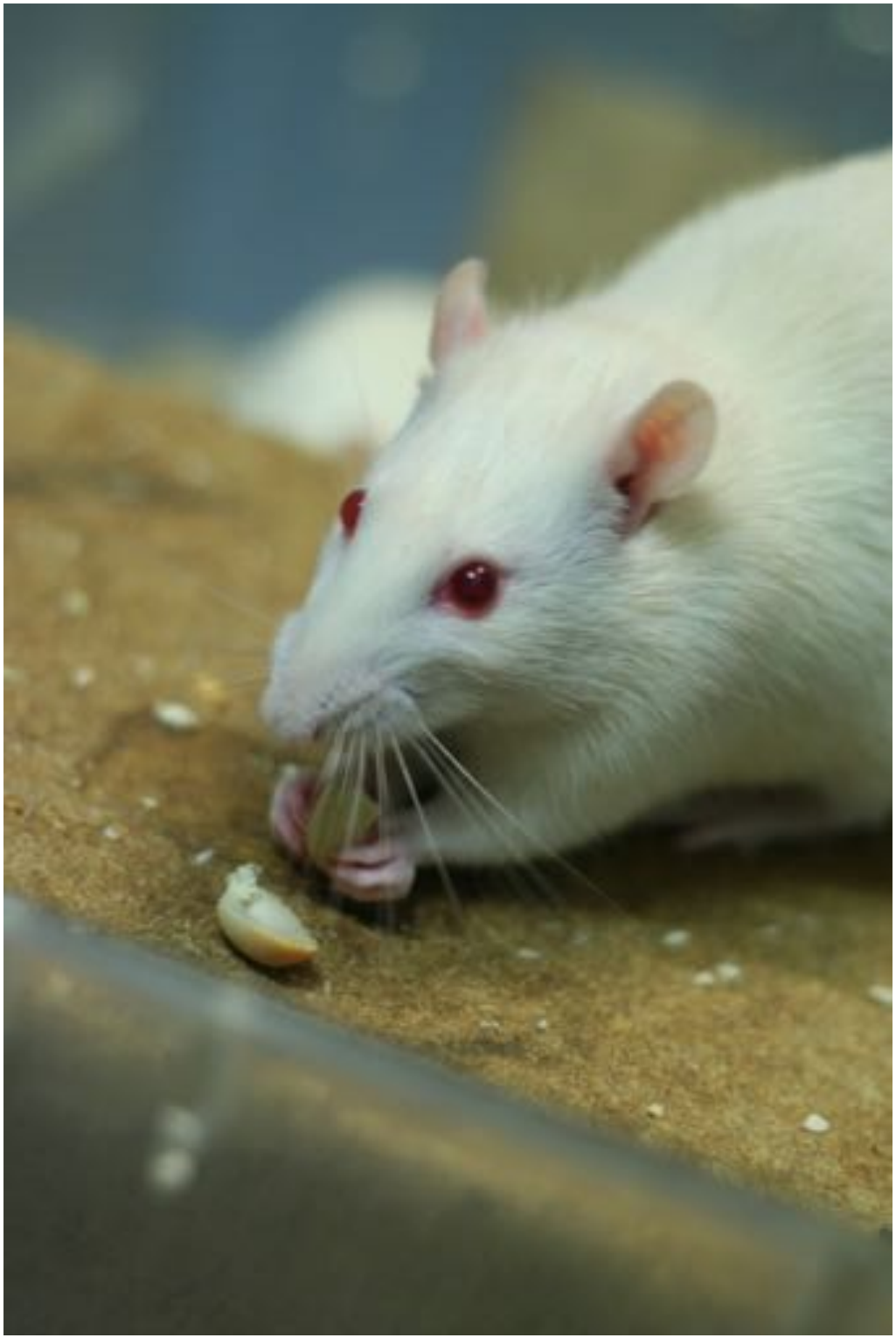
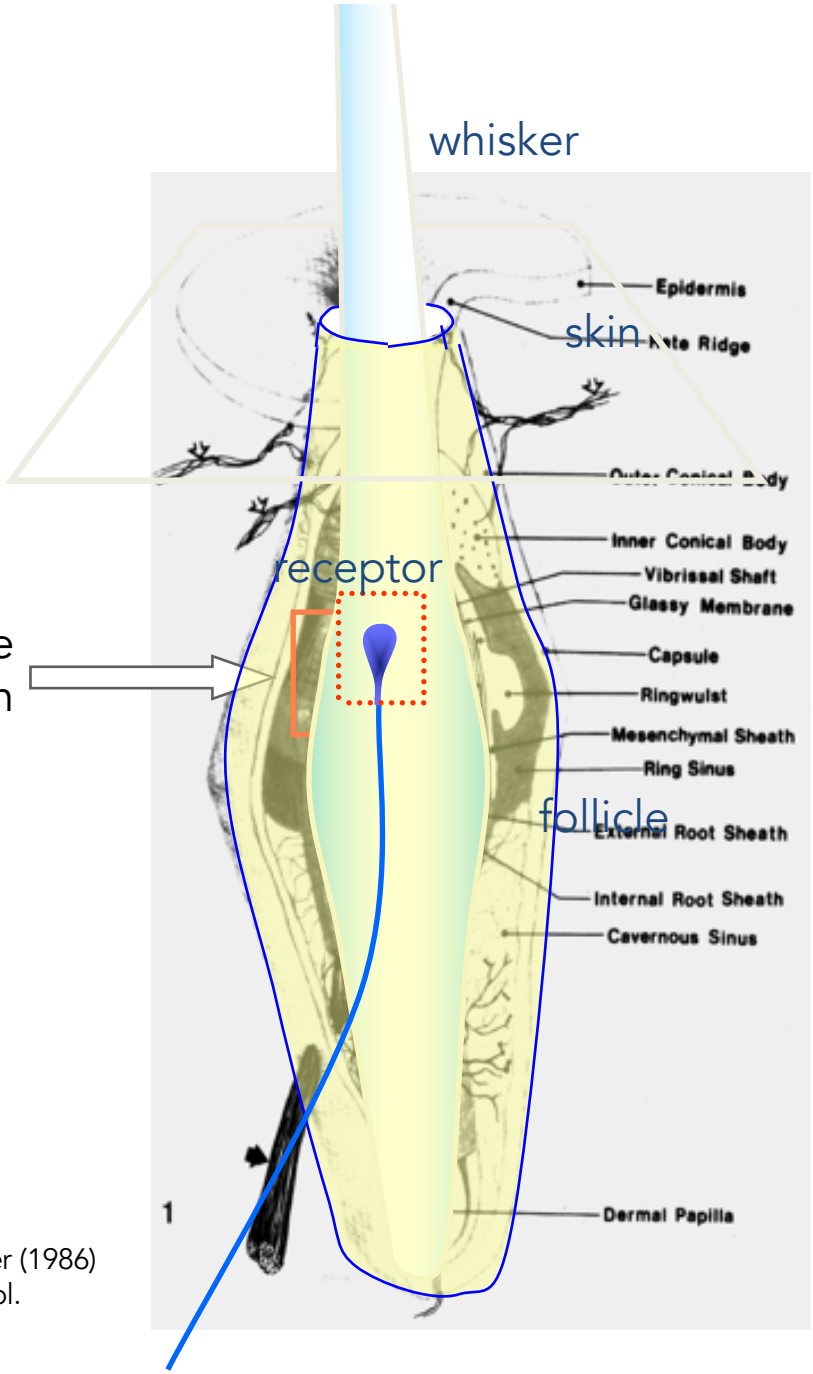
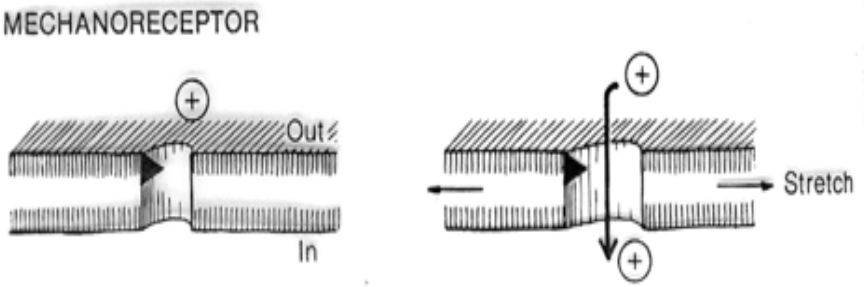
Perceptual Uncertainty

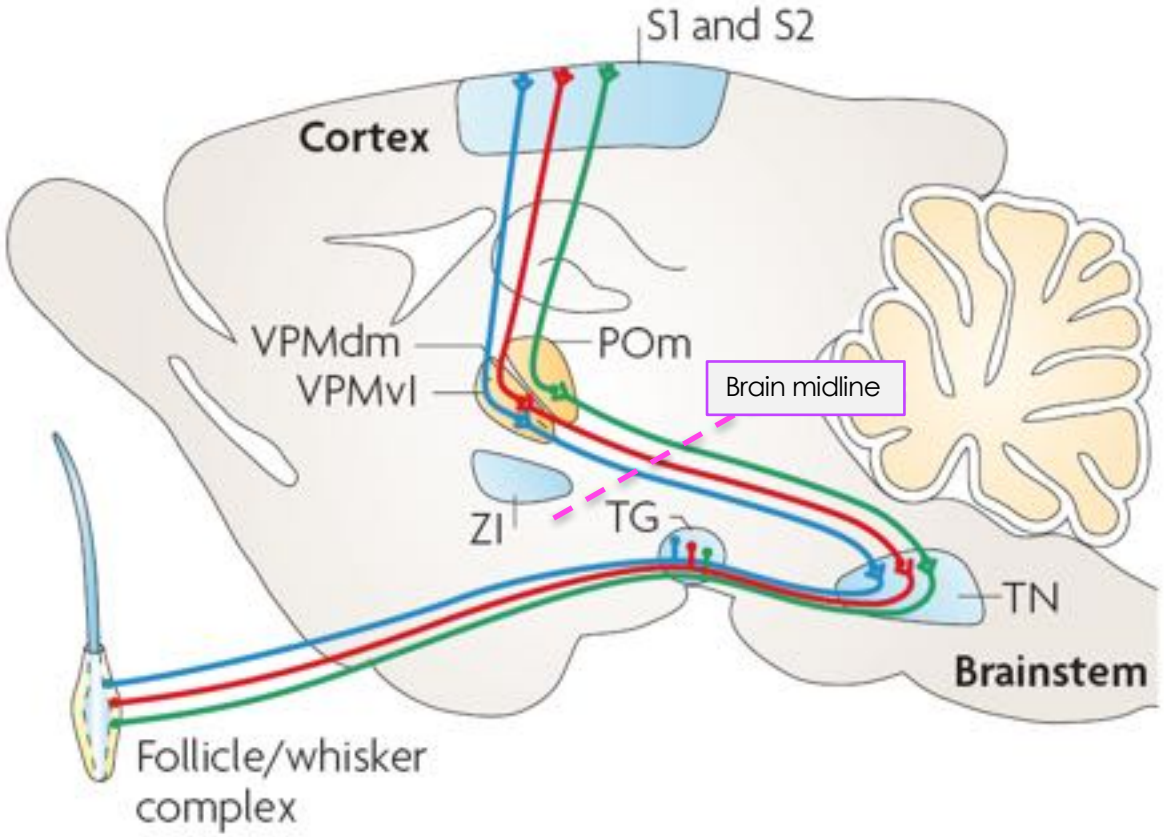
- What is it?
- Can instances of perceptual uncertainty help us understand something?
- How can the brain overcome uncertainty?
- What sorts of confusion occur when the brain simply *cannot* overcome uncertainty?

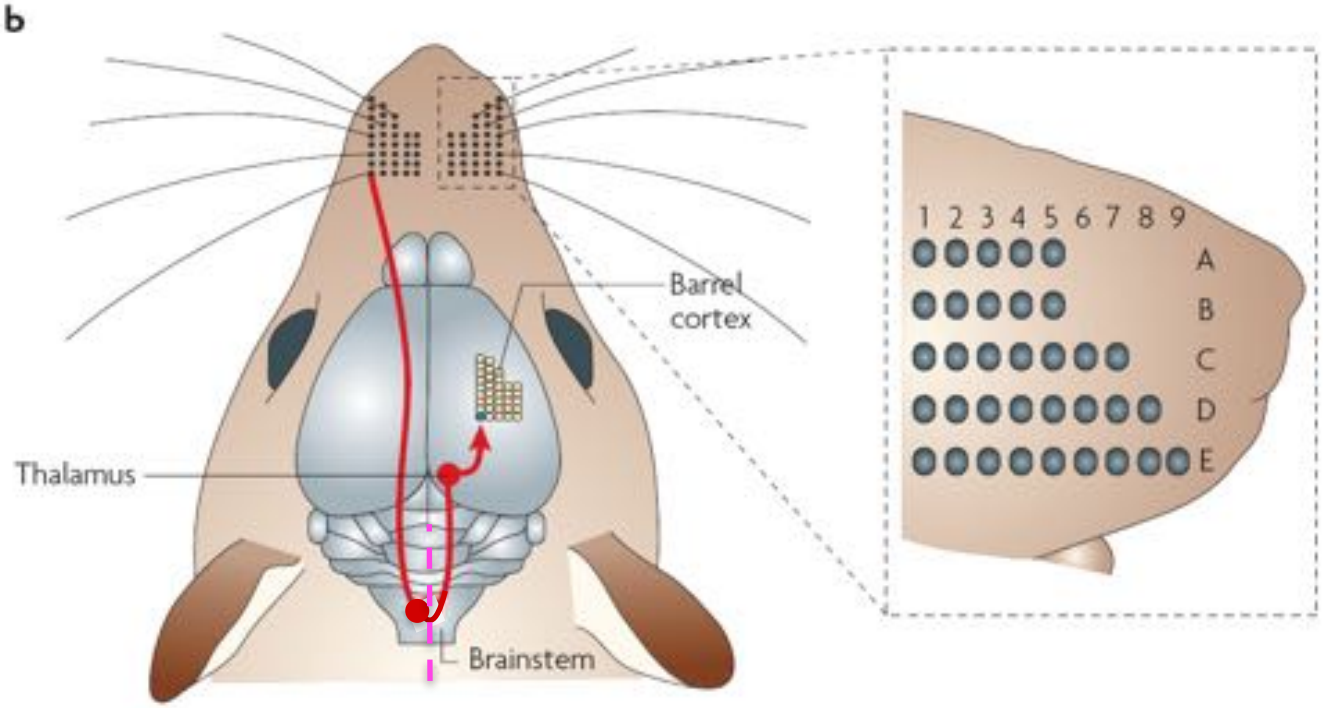


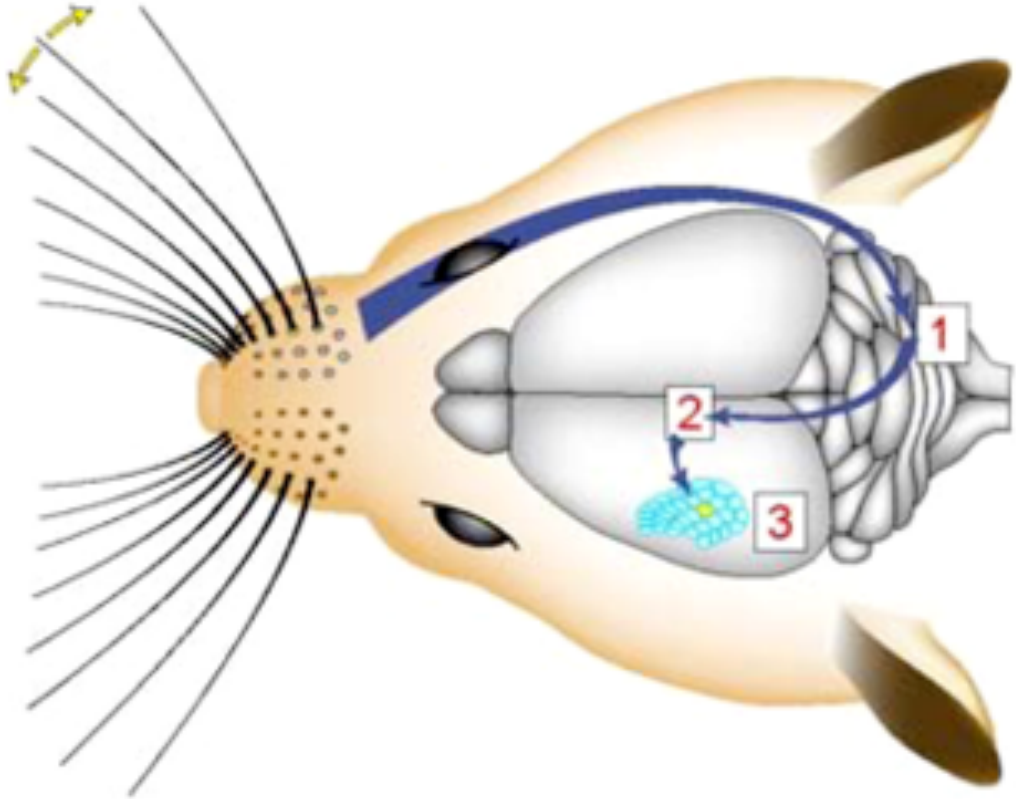


Rice and Munger (1986)
J. Comp. Neurol.

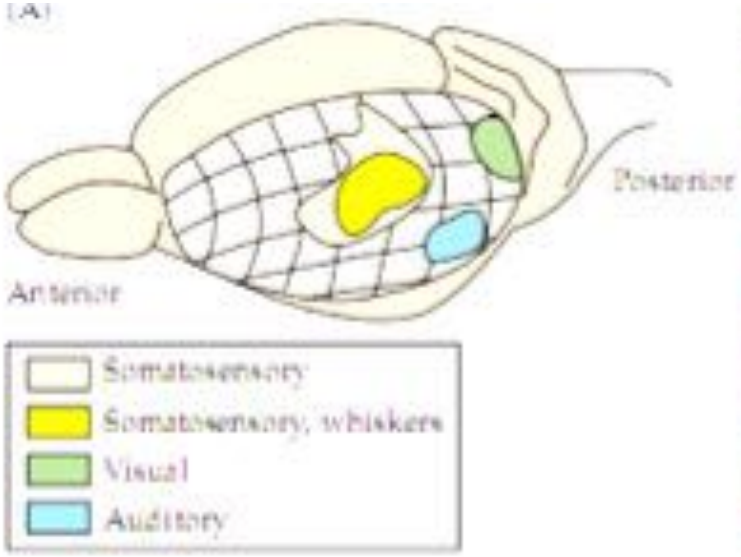



S1 and S2
Cortex
VPMdm
VPMvl
POm
Brain midline
ZI
TG
TN
Brainstem
Follicle/whisker
complex

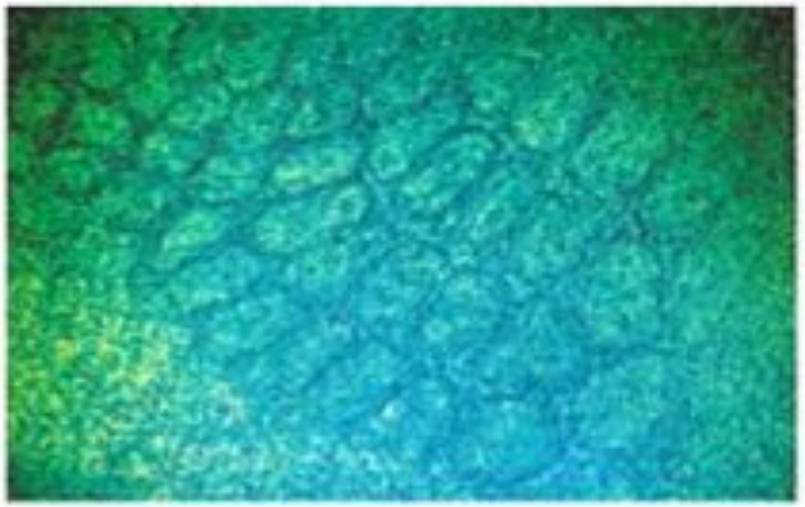

b
Barrel cortex
Thalamus
Brainstem
1 2 3 4 5 6 7 8 9
A
B
C
D
E


1
2
3

(A)


Posterior
Anterior
Somatosensory
Somatosensory, whiskers
Visual
Auditory

(B)



(C)

A1
A2
A3
A4
α
B1
B2
B3
B4
β
C1
C2
C3
C4
C5
γ
D1
D2
D3
D4
D5
D6
δ
E1
E2
E3
E4
E5
E6
D6
D5
D4
D3
D2
D1

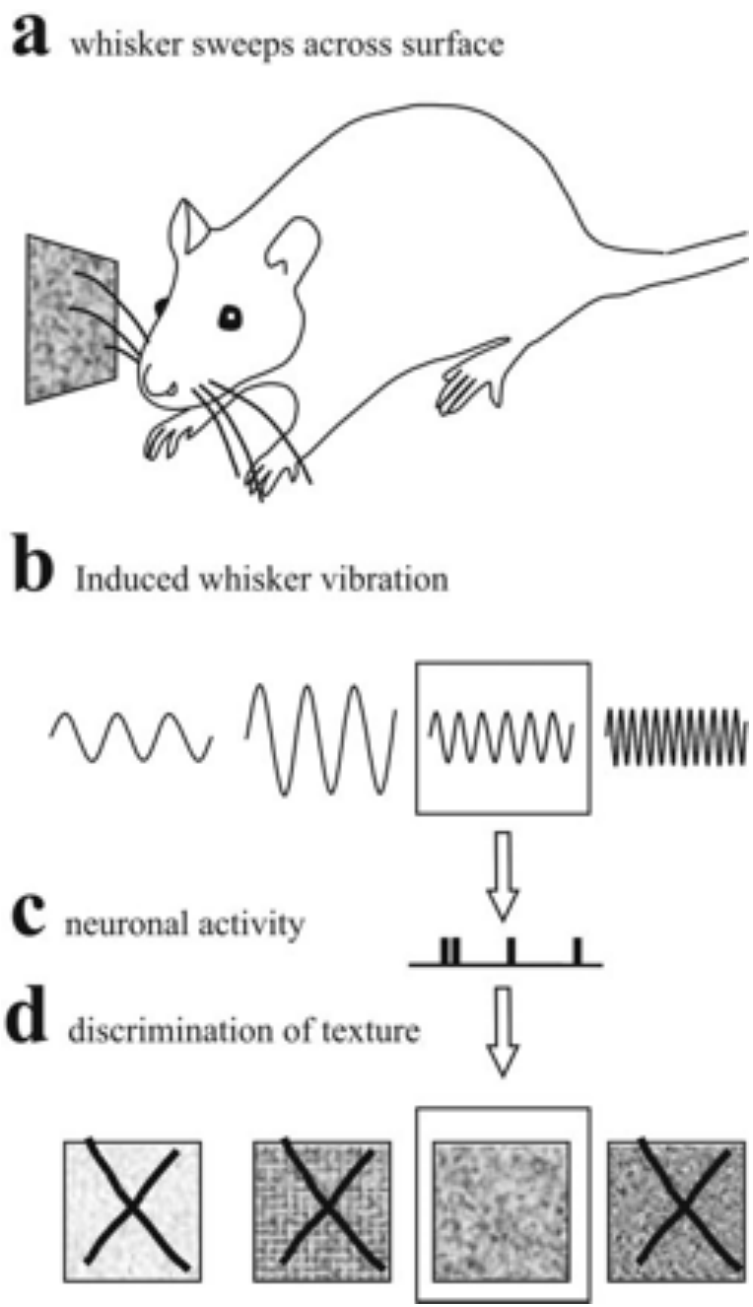
Texture discrimination acuity with the whiskers is equivalent to humans with the fingertip.

How is this achieved?

There was a great quest for the answer, 2003-07.

Neuronal basis for perception of whisker vibrations

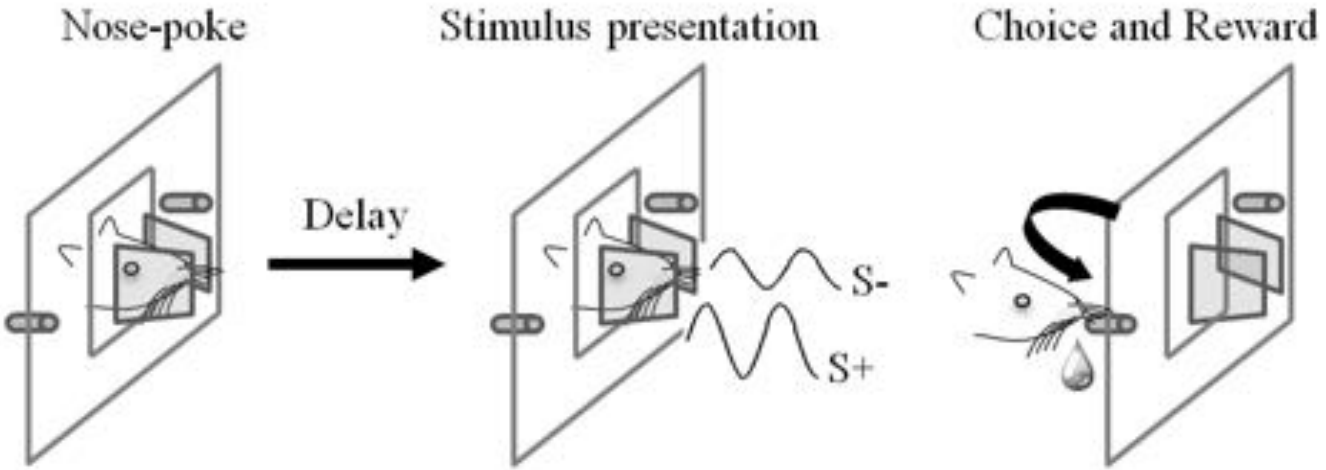
Ehsan Arabzadeh

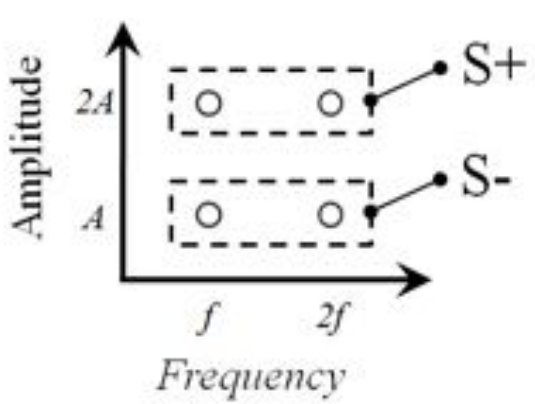


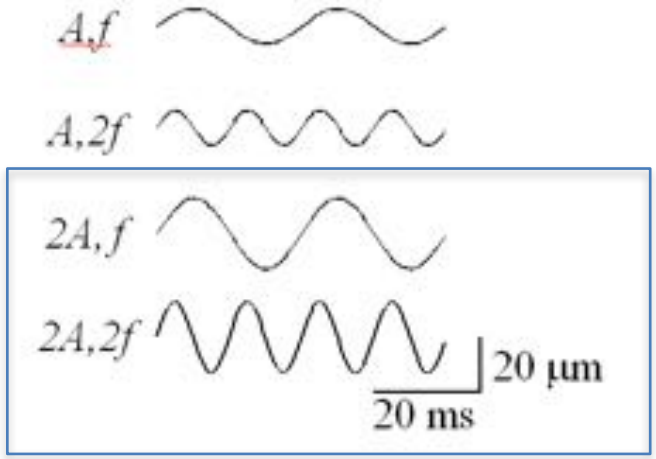
Schematic model for texture discrimination: the kinematic "signature" of whisker vibrations is encoded by neurons. In this scheme, vibrations take the simplest possible form, sinusoidal waveforms.

But what features of a vibration can a rat really feel?

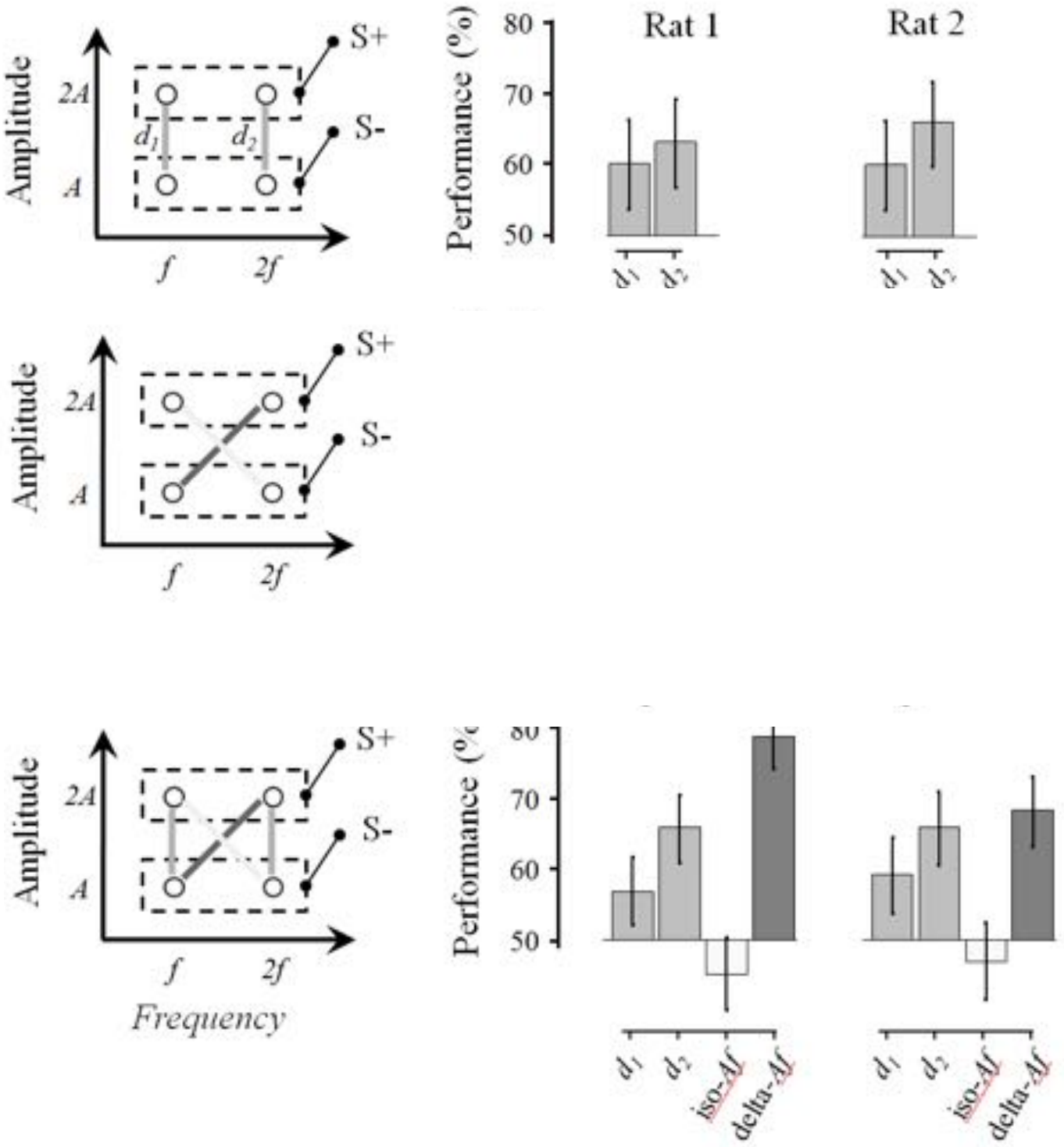
Adibi, Diamond, Arabzadeh

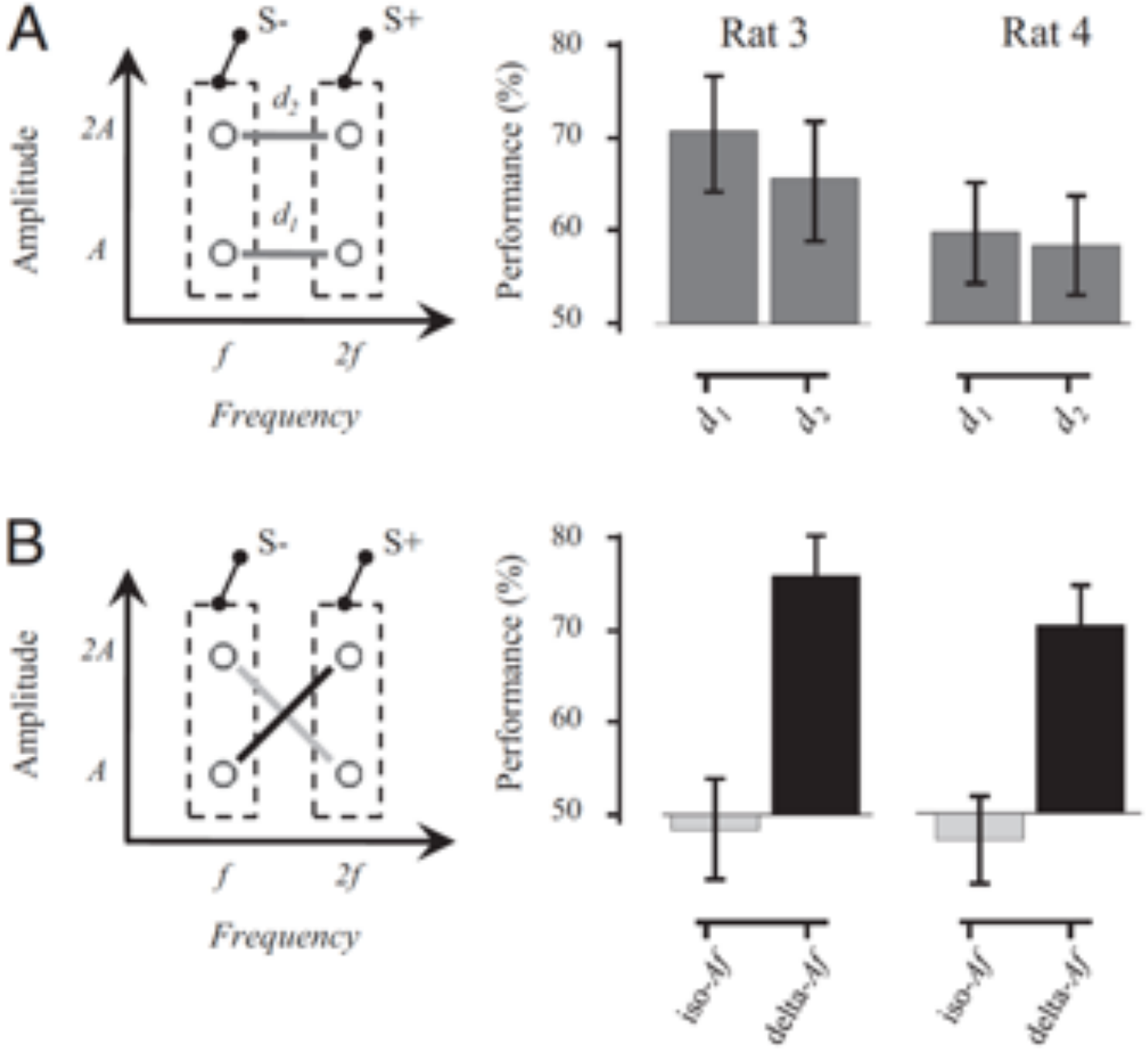

Nose-poke
Stimulus presentation
Choice and Reward
Delay
S-
S+


Amplitude
2A
A
f
2f
Frequency
S+
S-


A,f
A,2f
2A,f
2A,2f
20 µm
20 ms

S+


Amplitude
2A
A
f
2f
S+
S-
d_1
d_2
Performance (%)
80
70
60
50
Rat 1
Rat 2
Amplitude
2A
A
f
2f
S+
S-
Amplitude
2A
A
f
2f
Frequency
S+
S-
Performance (%
80
70
60
50
d_1
d_2
iso-Δf
delta-Δf
d_1
d_2
iso-Δf
delta-Δf


A
S-
S+
2A
A
Amplitude
d_2
d_1
f
2f
Frequency
Performance (%)
80
70
60
50
Rat 3
Rat 4
d_1
d_2
B
iso-Δf
delta-Δf

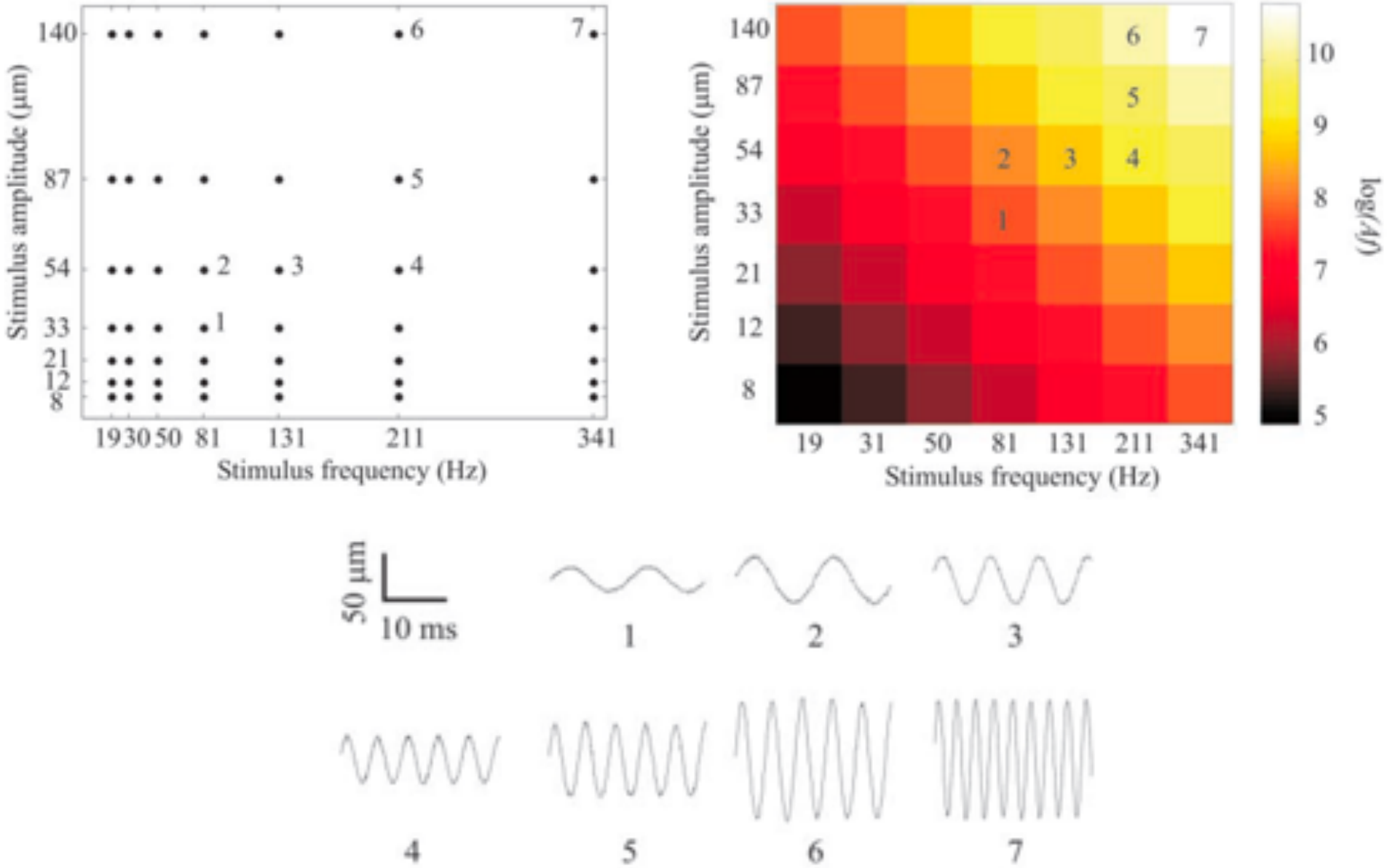
What we have, then, is perceptual uncertainty.

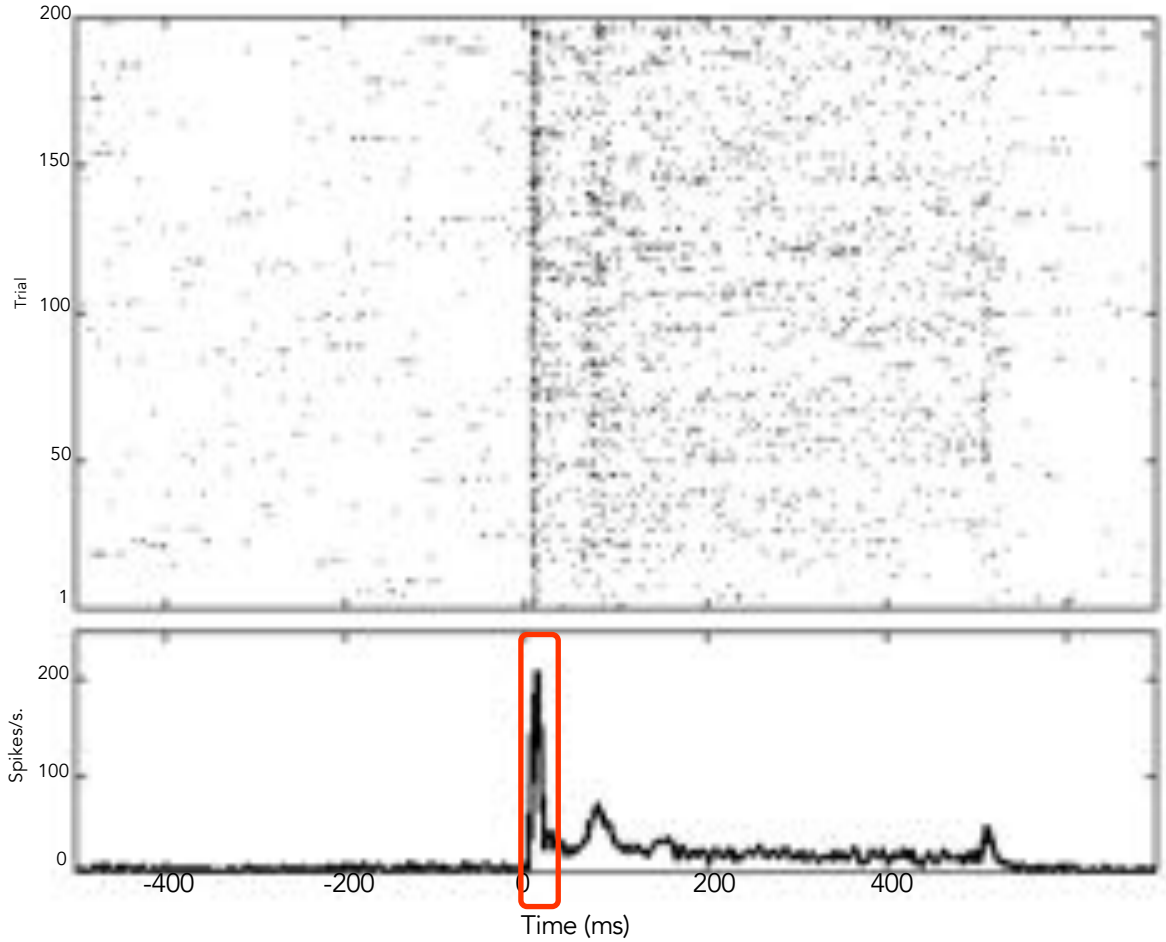
Rats can discriminate between two vibrations provided they differ in Af.

If they do NOT differ in Af, they cannot be distinguished.

This tells us something to look for in neuronal coding. Two stimuli can be distinguished only if they produce in the brain two different representations. The prediction, from the uncertainty expressed by behavior, is that neurons can encode A and f, but cannot encode differences in vibrations 1 and 2 if A1f1 = A2f2.

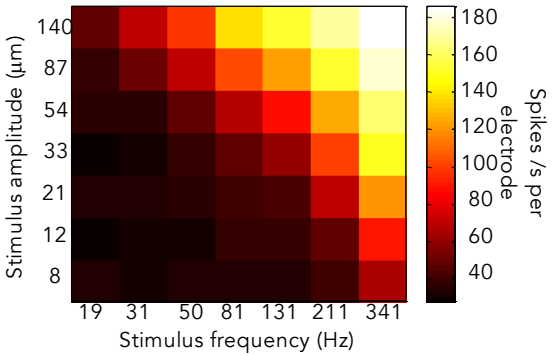
stimulus set for measuring cortical encoding of vibration



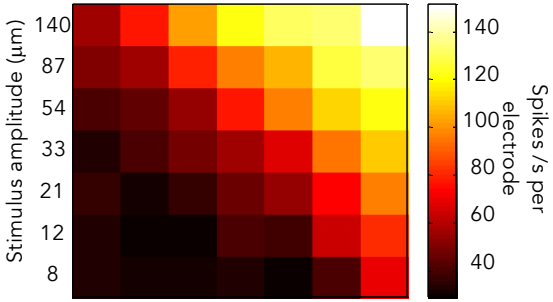


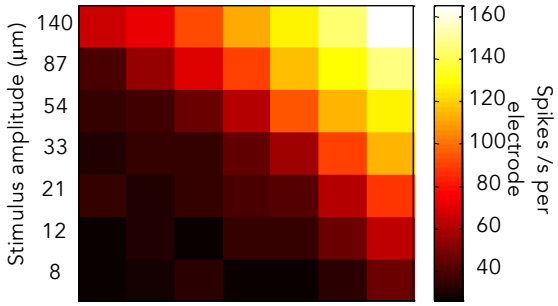
Onset response

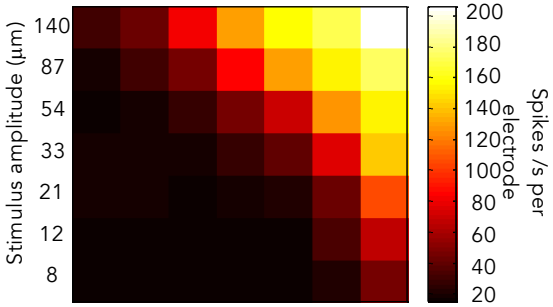
Peak 5-ms spike density

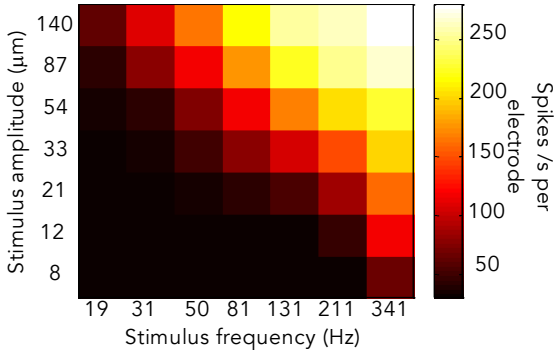


barrel cortex encoding of vibration velocity at stimulus onset



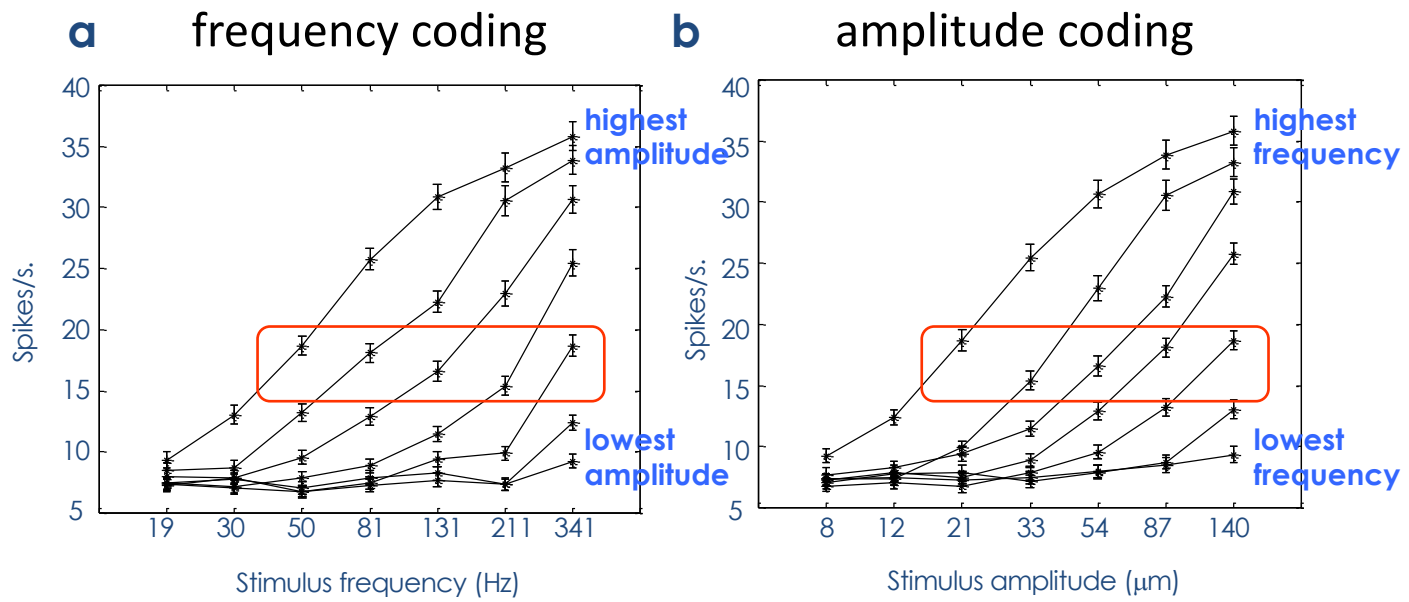






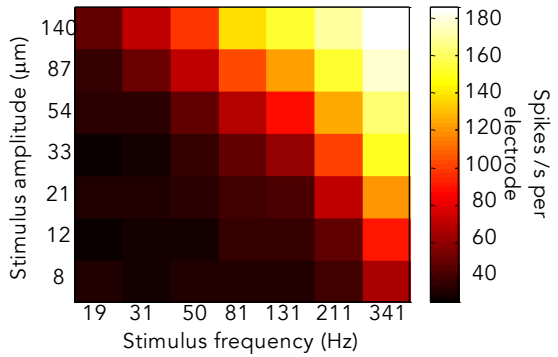
Coding of vibration frequency *f* and amplitude *A* …

… and the resulting uncertainty

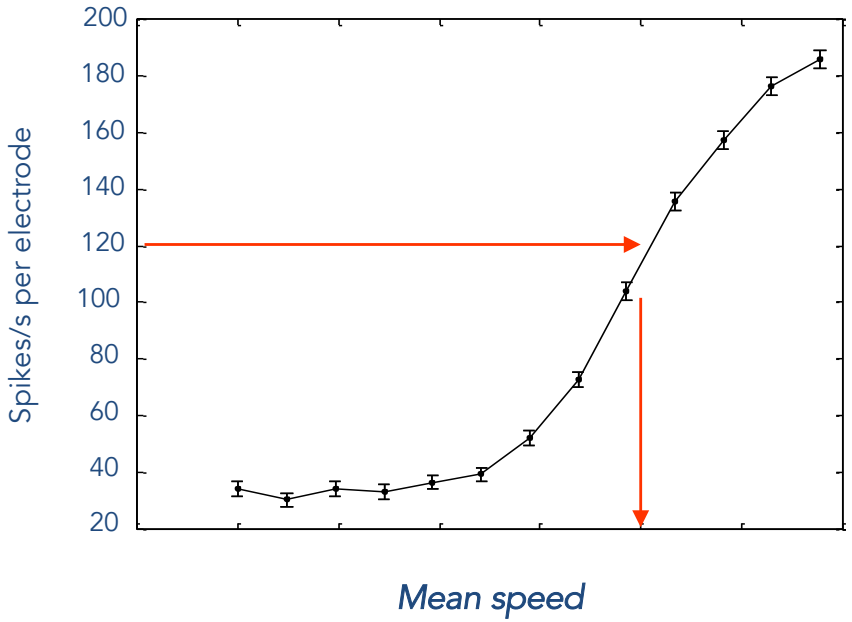


For a sinusoidal function characterized by amplitude A and frequency f, mean speed (abs velocity) across an integer number of cycles is proportional to the product Af.

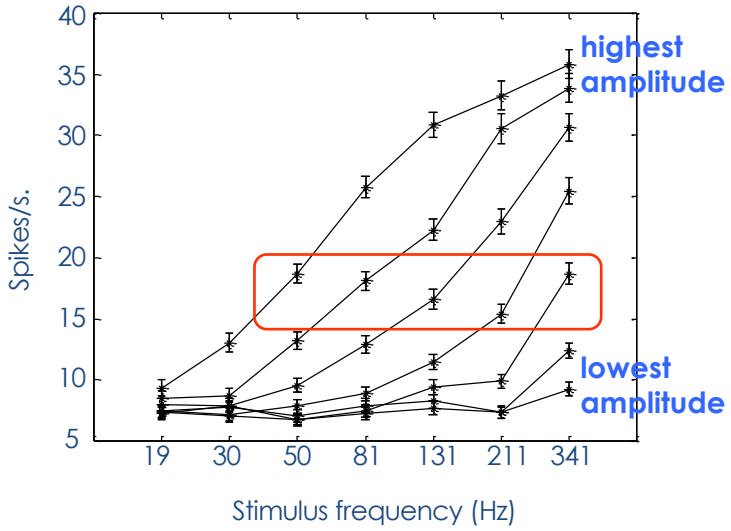
Barrel cortex firing proportional to Af

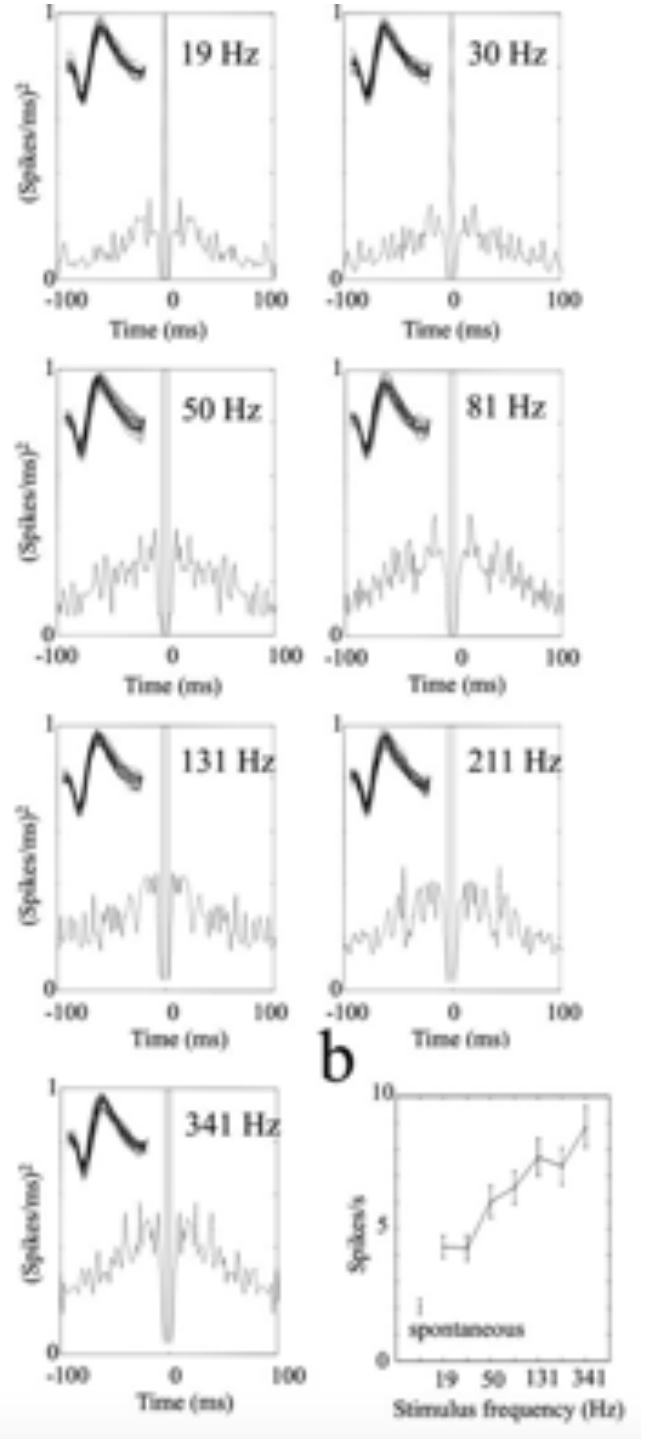


decoding barrel cortex activity to mean whisker speed

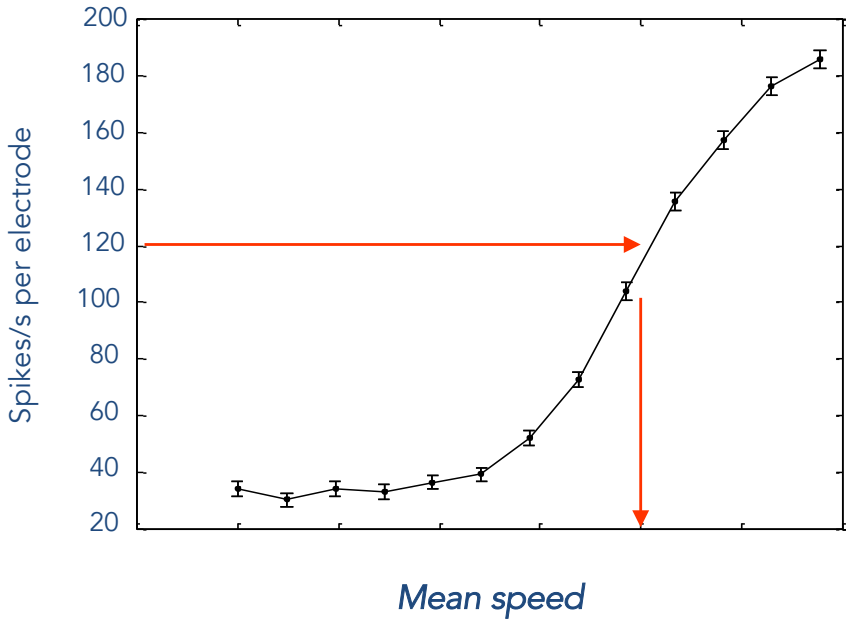


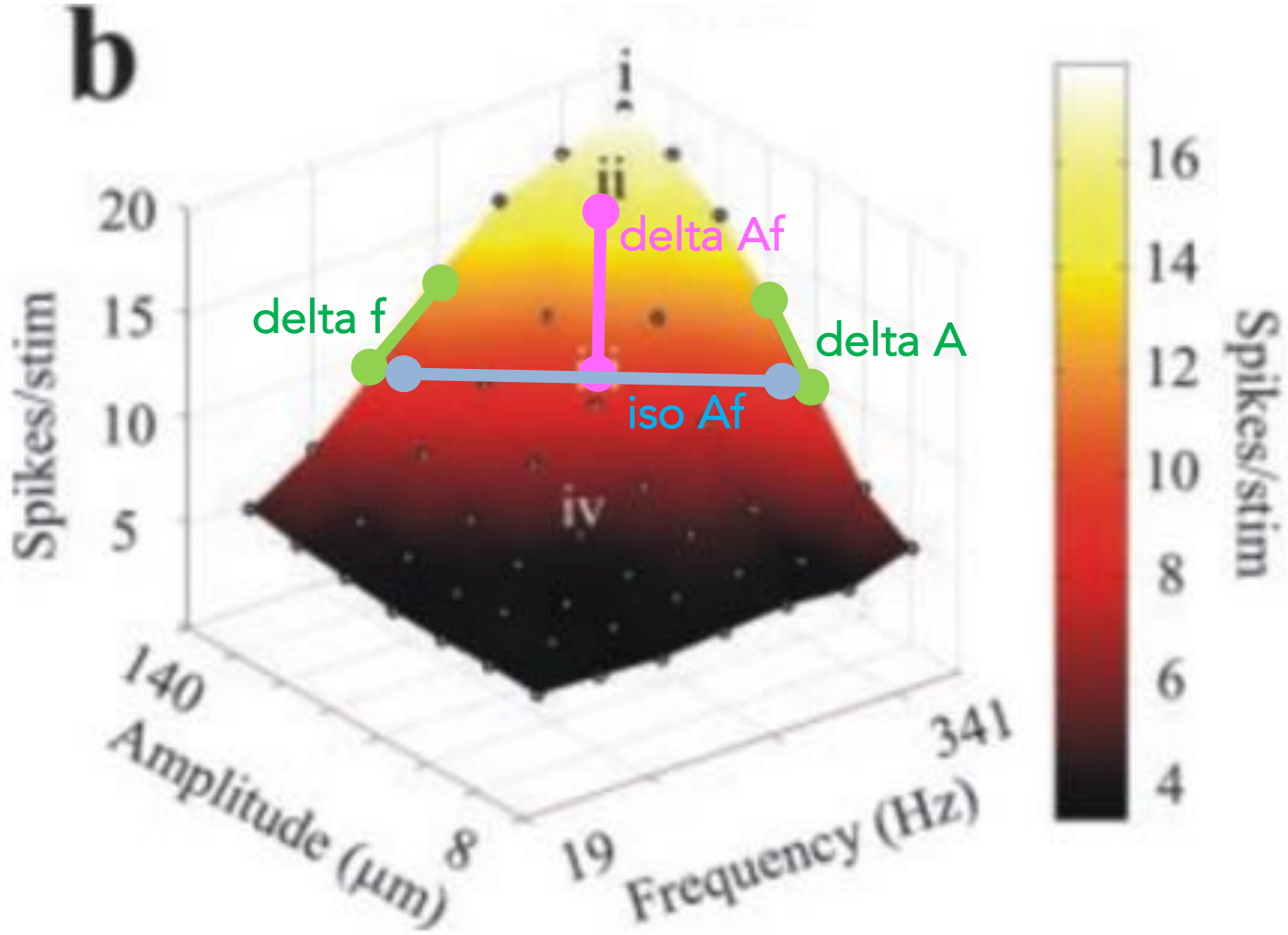
No sign of temporal code





decoding barrel cortex activity to mean (across cycles) whisker speed




b
i
ii
iv
delta Af
delta f
delta A
iso Af
20
15
10
5
Spikes/stim
140
8
Amplitude (µm)
19
341
Frequency (Hz)
16
14
12
10
8
6
4
Spikes/stim

Perceptual Uncertainty

- What is it?
- Can instances of perceptual uncertainty help us understand something?
- How can the brain overcome uncertainty?
- What sorts of confusion occur when the brain simply *cannot* overcome uncertainty?

Texture discrimination acuity with the whiskers is equivalent to humans with the fingertip.

How is this achieved?

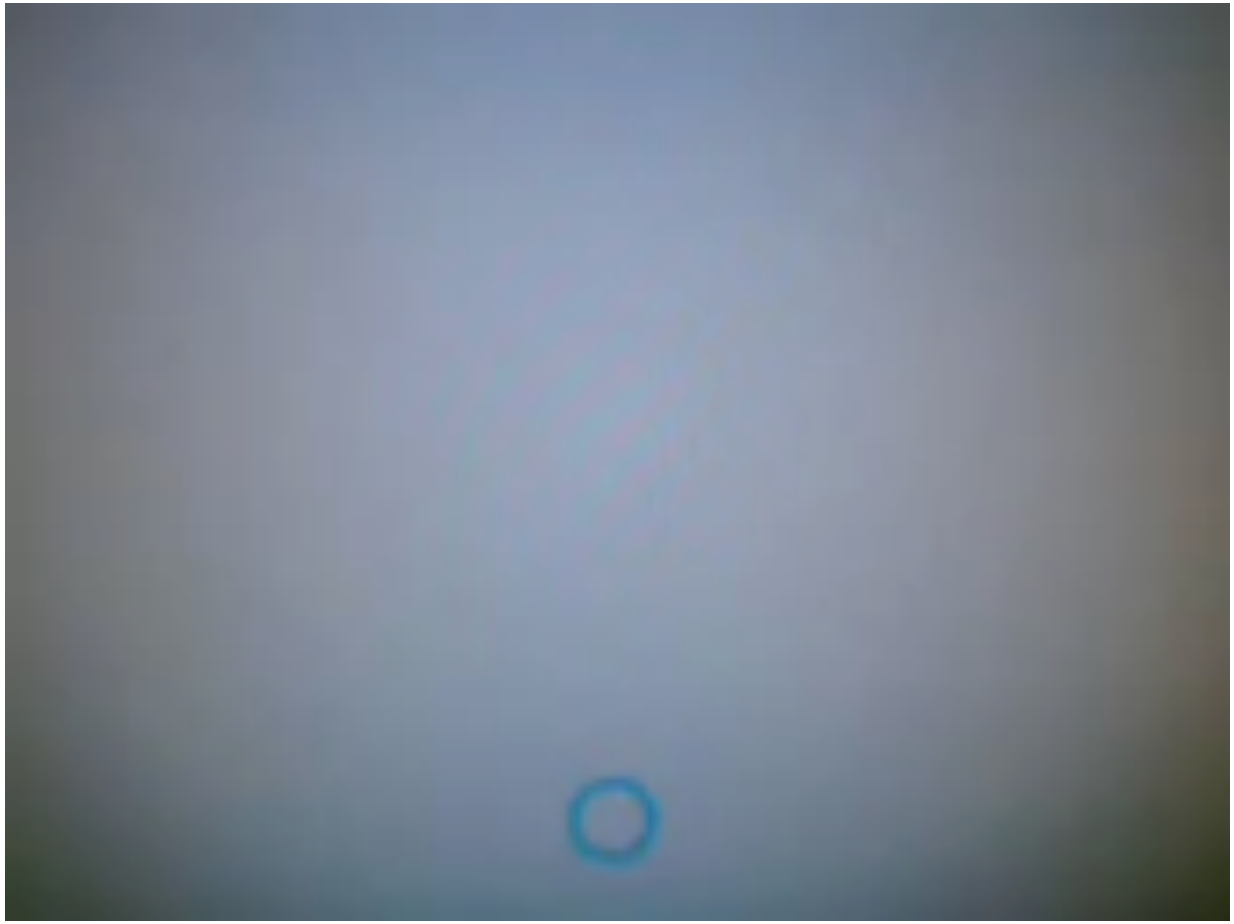
There was a great quest for the answer, 2003-07.

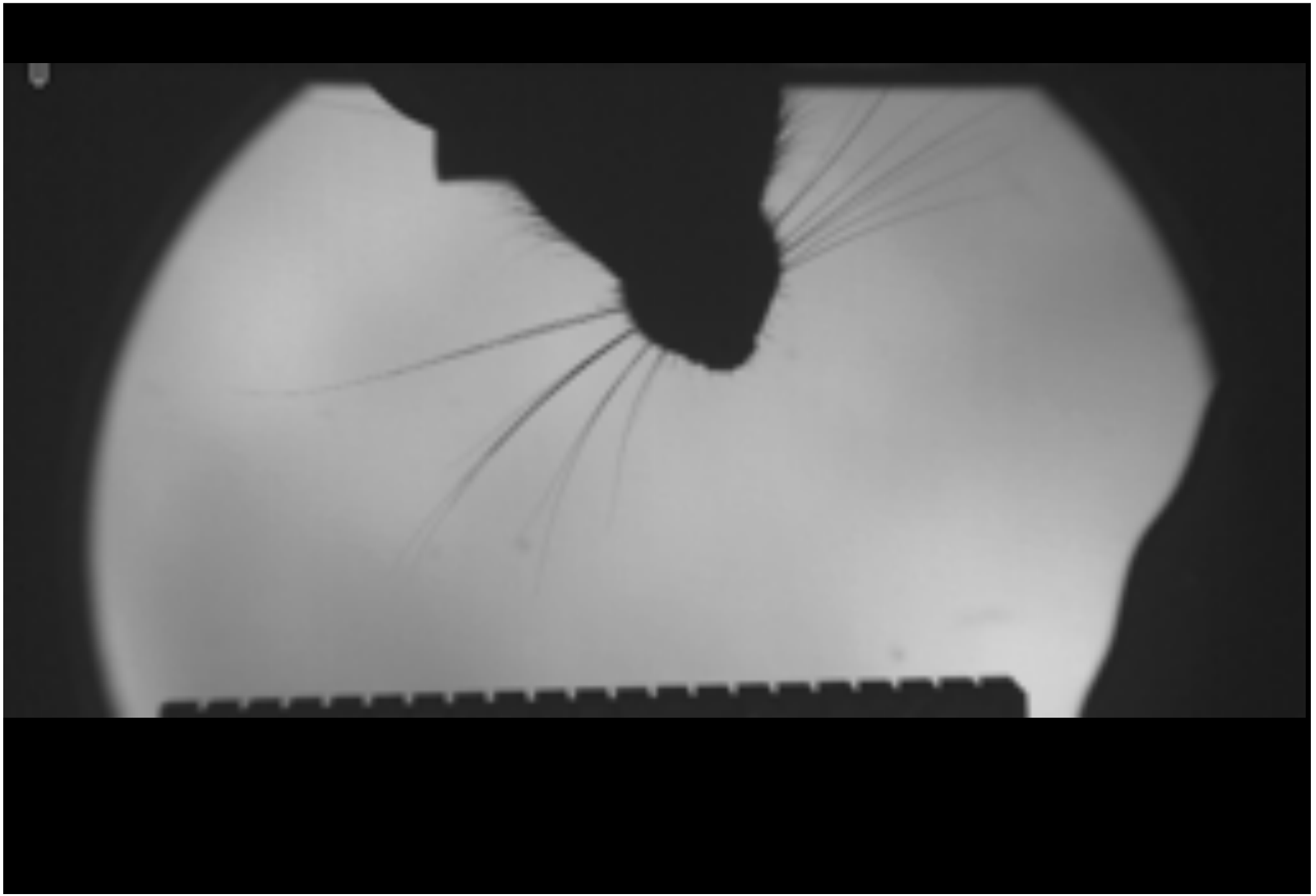
Yanfang Zuo

SISSA → Institute of Neuroscience
Chinese Academy of Sciences
Shanghai

- Zuo, Y., & Diamond, M. E. (2019). Rats Generate Vibrissal Sensory Evidence until Boundary Crossing Triggers a Decision. *Current Biology, 29*(9), 1415-1424.e1415.
- Zuo, Y., & Diamond, M. E. (2019). Texture Identification by Bounded Integration of Sensory Cortical Signals. *Current Biology, 29*(9), 1425-1435.e1425.

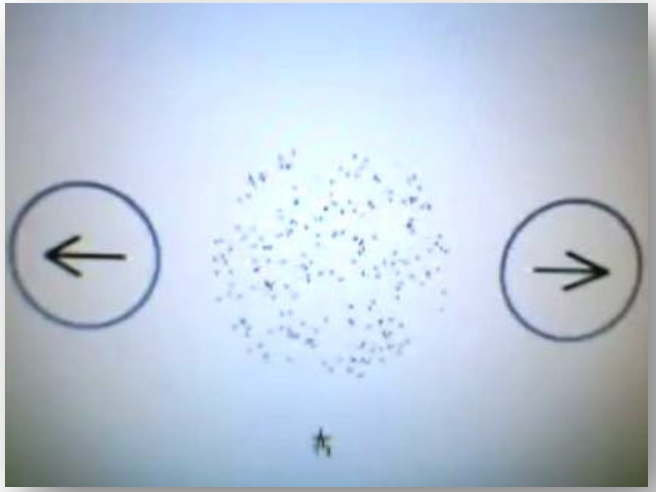
Bounded integration –
Leading model for perceptual decision making with uncertain evidence… but model built from primate visual system.

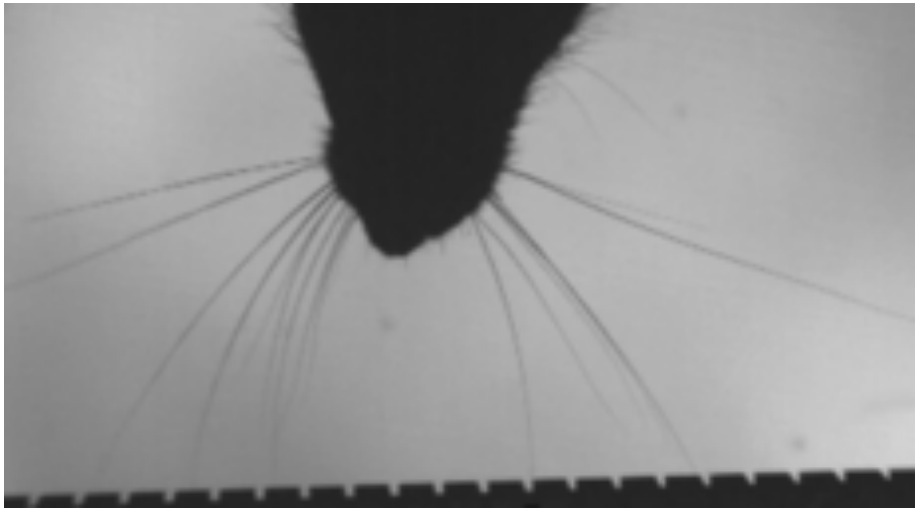


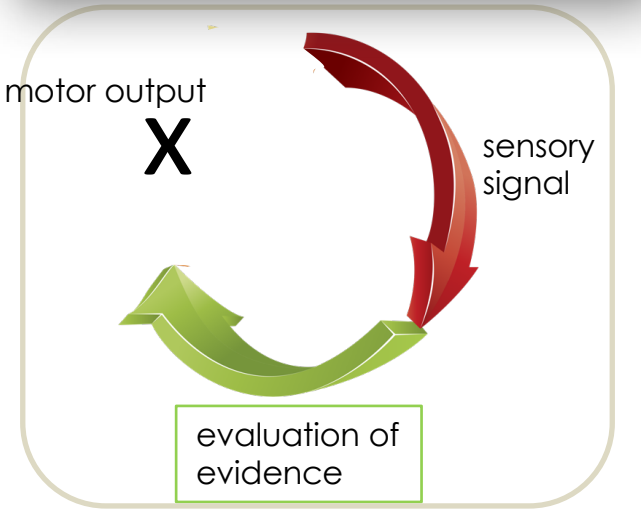


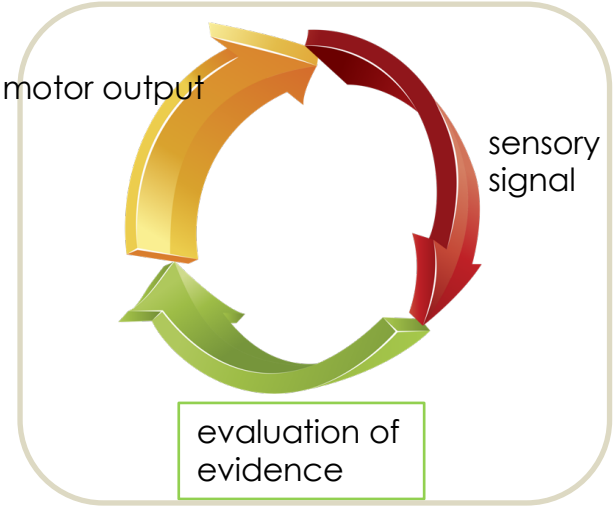
- They typically execute 1–6 touches before withdrawing.

- How does the rat decide whether to initiate another contact or else to turn toward a reward spout? Two hypotheses:
  - **Motor Program (open loop)**
  - **Evidence Accumulation (closed loop)**



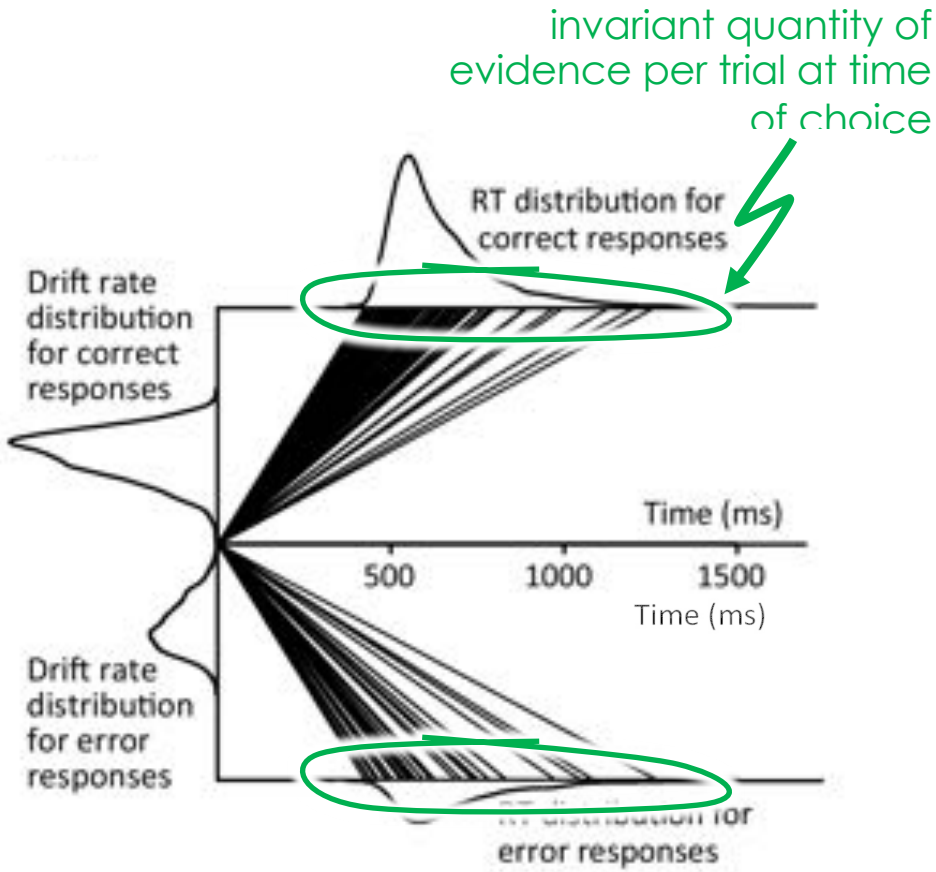




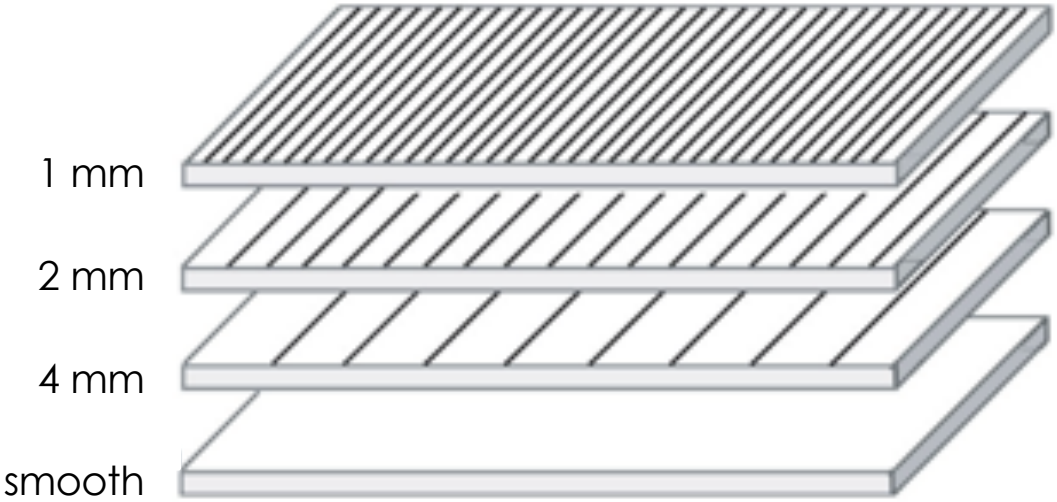


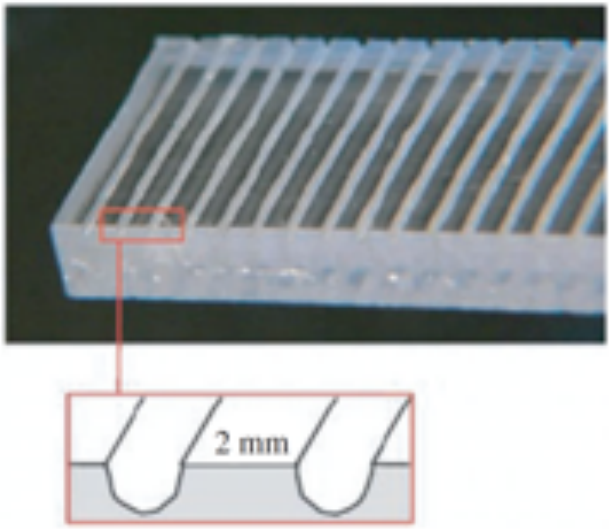
Open loop

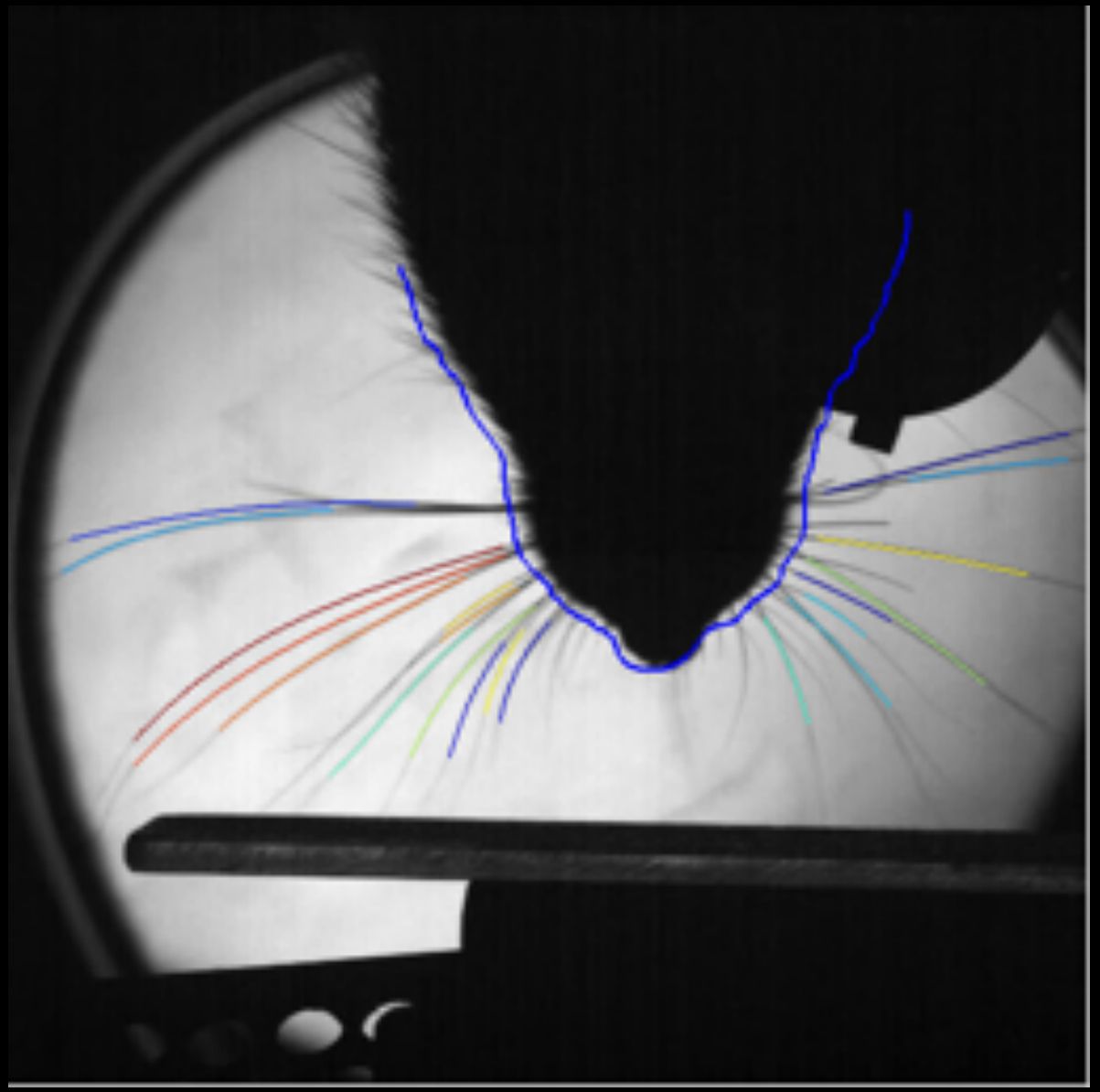
Closed loop:
100 ms per cycle

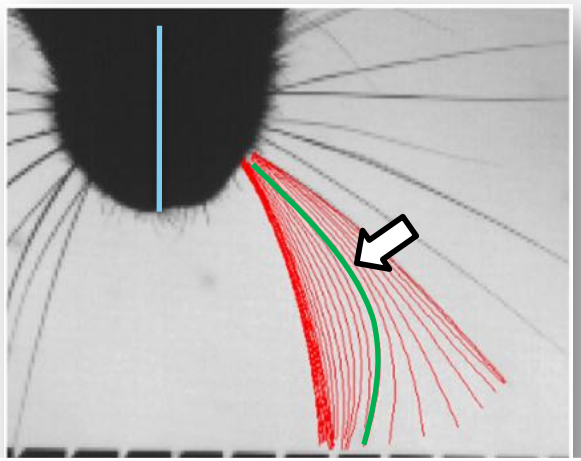


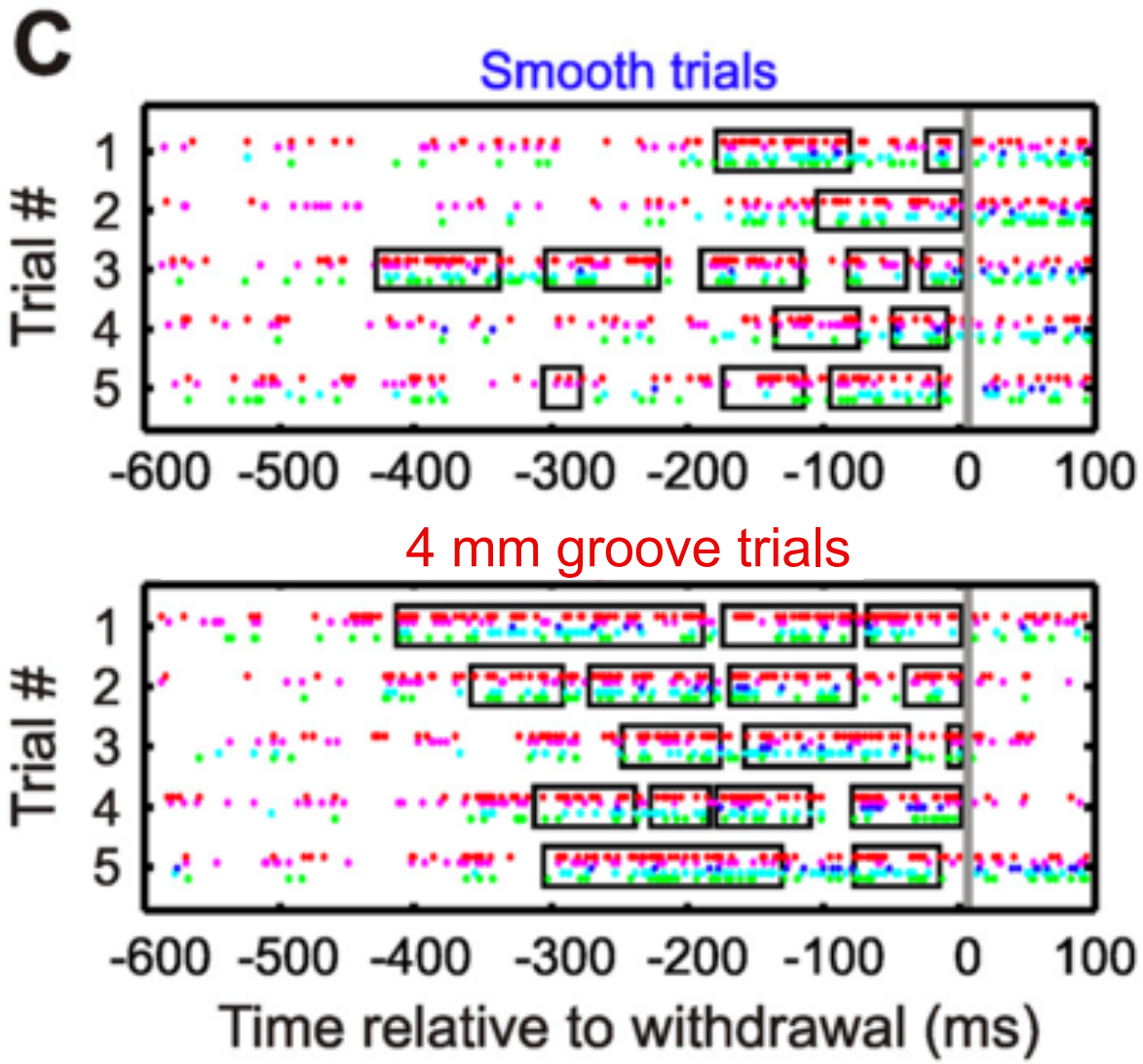
Ratcliff R, Smith PL, Brown SD, McKoon G. (2016)
Diffusion Decision Model: Current Issues and History.
Trends Cogn Sci.

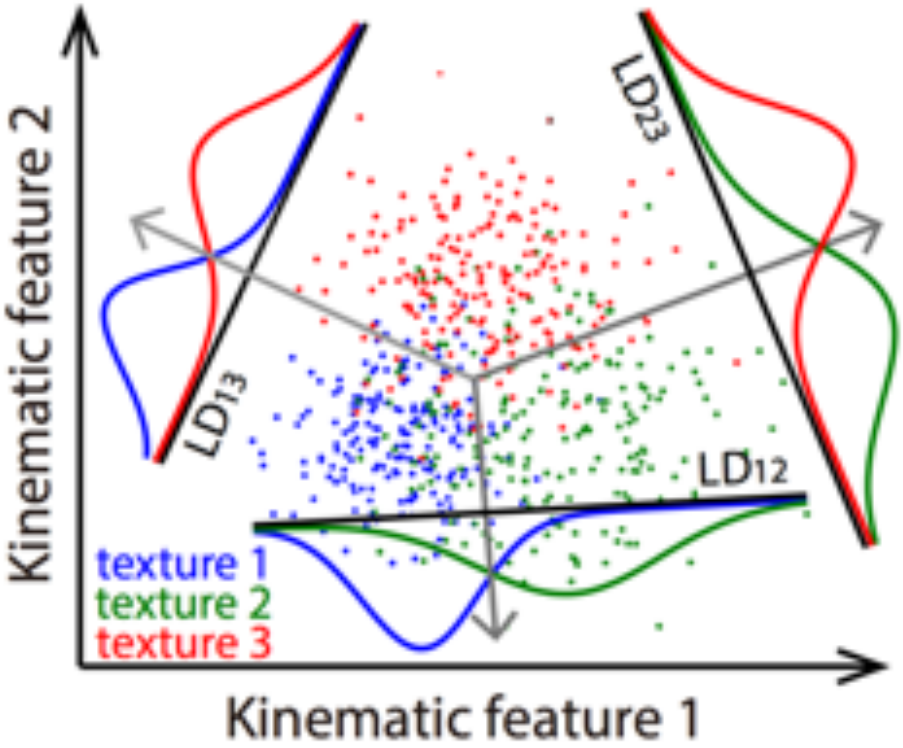

1 mm
2 mm
4 mm
smooth


2 mm






C
Smooth trials
Trial #
1
2
3
4
5
-600
-500
-400
-300
-200
-100
0
100
4 mm groove trials
Trial #
1
2
3
4
5
-600
-500
-400
-300
-200
-100
0
100
Time relative to withdrawal (ms)

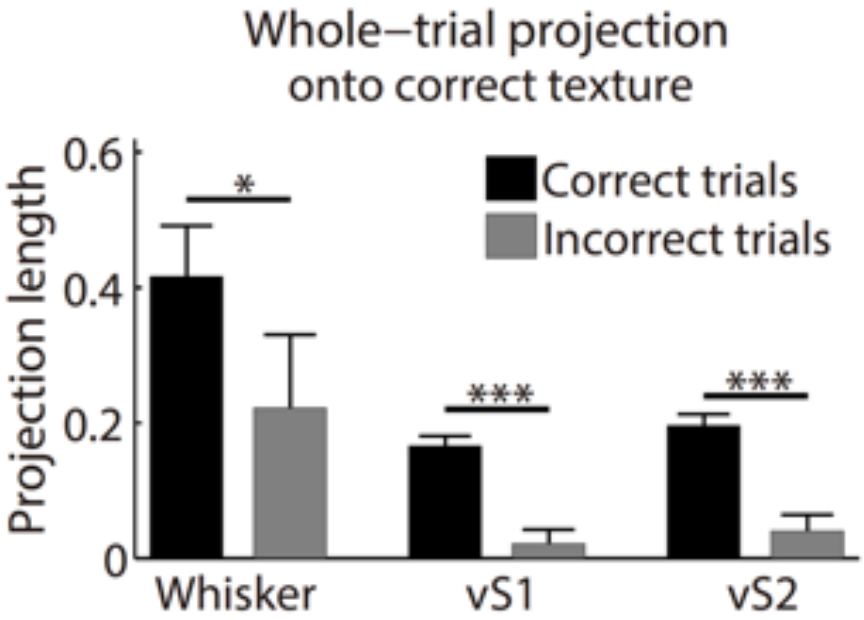


We exploit kinematic signatures of textures to DECODE (make prediction) of texture based on kinematic features of single touch.

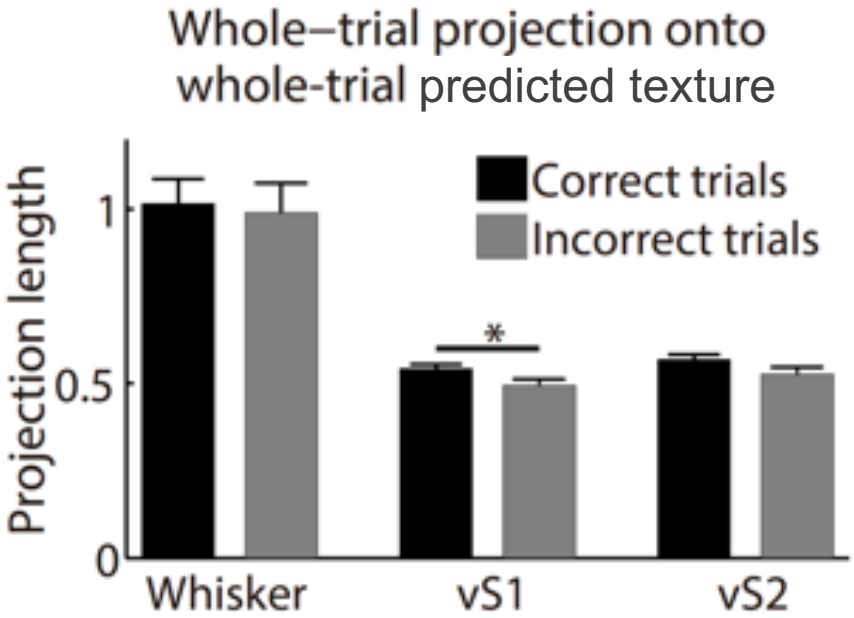
Bayesian multivariate linear discriminant analysis finds optimal linear combination of 9 features.

Similar analysis to decode texture from neuronal firing in primary (vS1) and secondary (vS2) vibrissal somatosensory cortex.

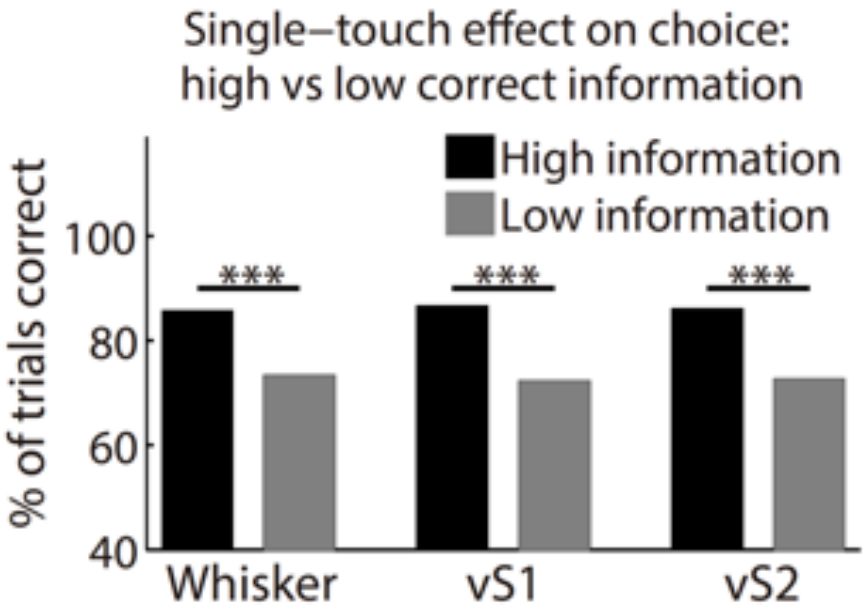
whisker kinematics and neuronal firing provide correct signal on correct trials



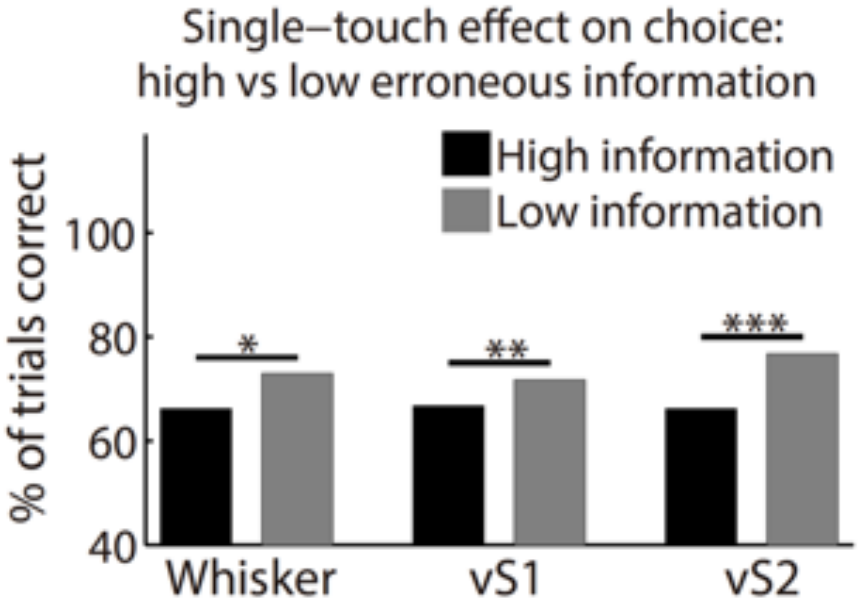
whisker kinematics and neuronal firing provide equally strong signal, whether choice correct or incorrect



a strong, correct signal on *single touch* leads to correct choice



a strong, incorrect signal on *single touch* leads to incorrect choice



- Rats' choices follow from the texture signals carried by whisker kinematics and neuronal firing (*that is, we identified the right form of evidence*).

- They typically execute 1–6 touches before withdrawing.

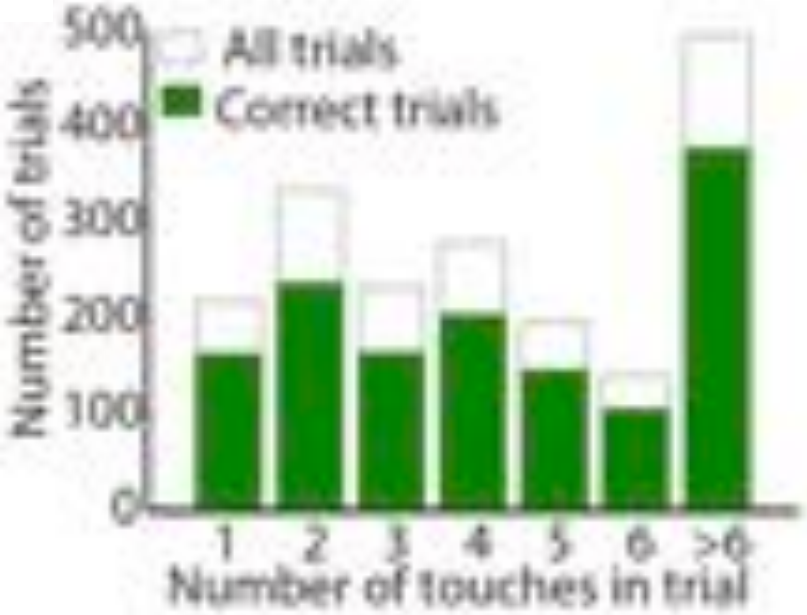
- How does the rat decide whether to initiate another contact or else to turn toward a reward spout? Two hypotheses:
  - **Motor Program (open loop)**
  - **Evidence Accumulation (closed loop)**

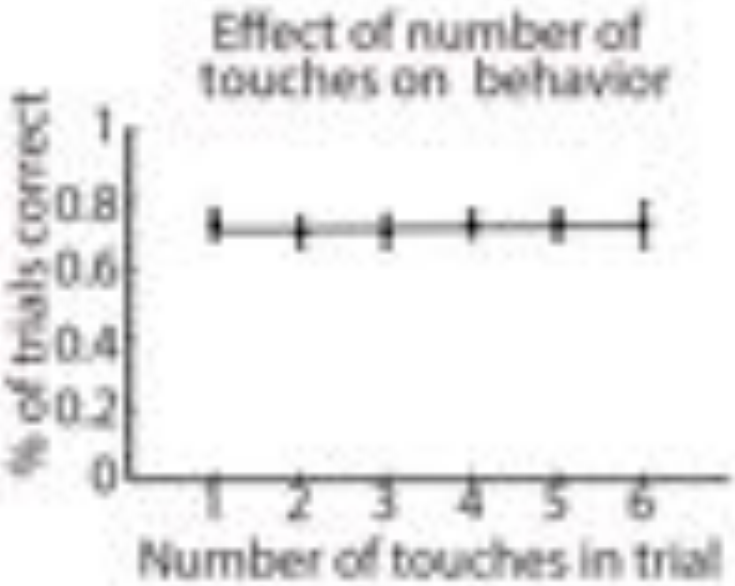
Motor program hypothesis

greater number of contacts means greater quantity of kinematic signal available thus better performance

Evidence accumulation hypothesis

performance independent of the number of contacts per trial





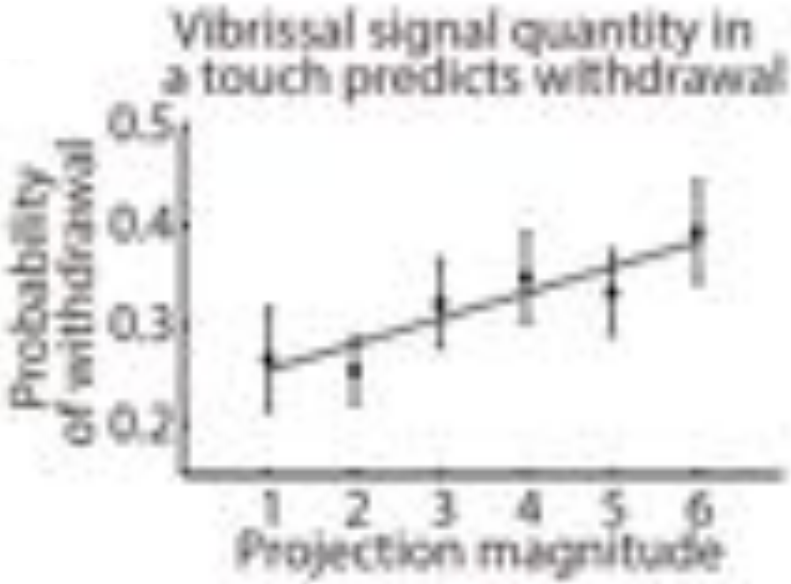
Motor program hypothesis

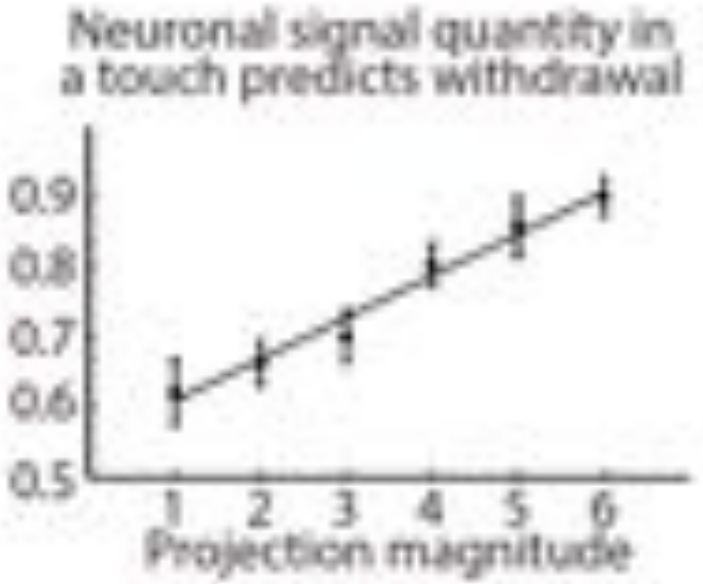
probability of decision independent of single-touch signal

Evidence accumulation hypothesis

contact providing no evidence can never cause threshold crossing.

probability of decision positively correlated with quantity of signal.



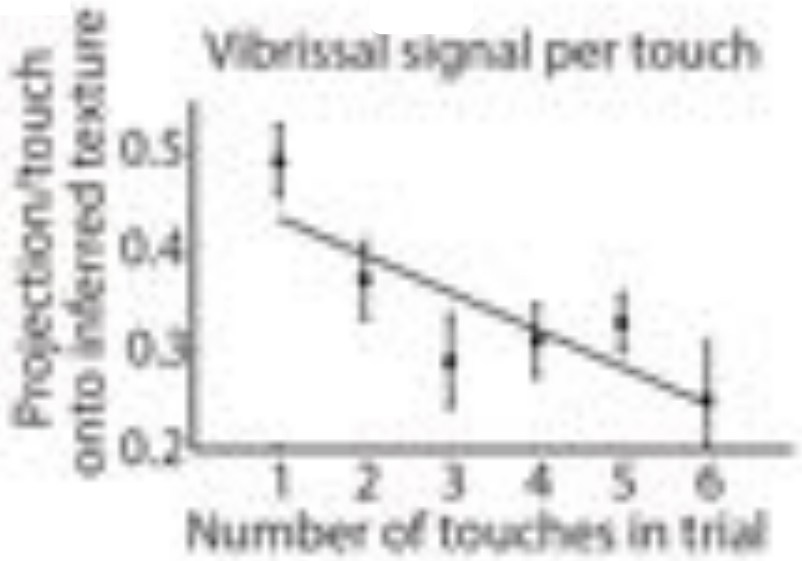


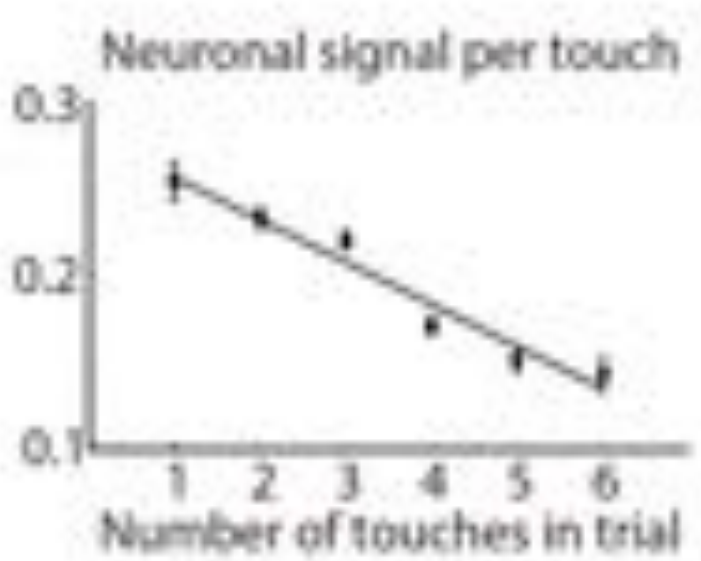
Motor program hypothesis

quantity of signal per touch independent of the number of touches executed in that trial

Evidence accumulation hypothesis

when individual touches provide little evidence, the rat requires more touches: inverse relationship



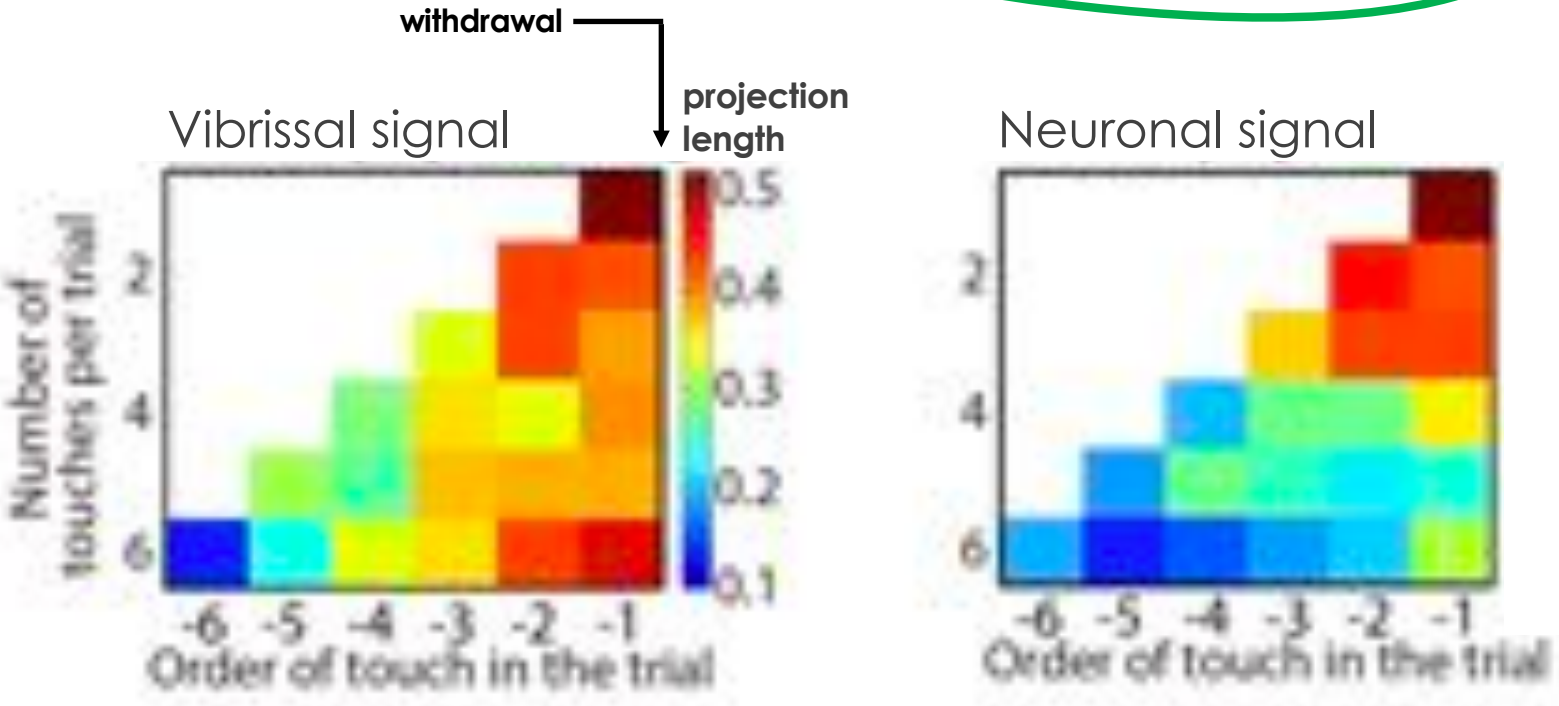


Motor program hypothesis

no serial order effect in the quantity of signal across multiple contacts

Evidence accumulation hypothesis

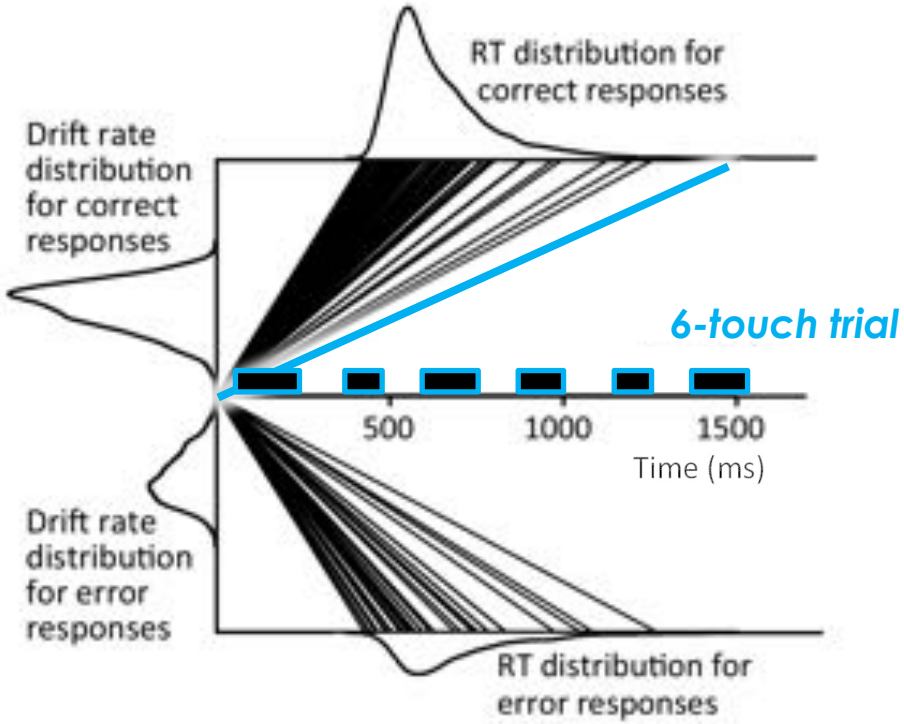
quantity of signal non-random across touches

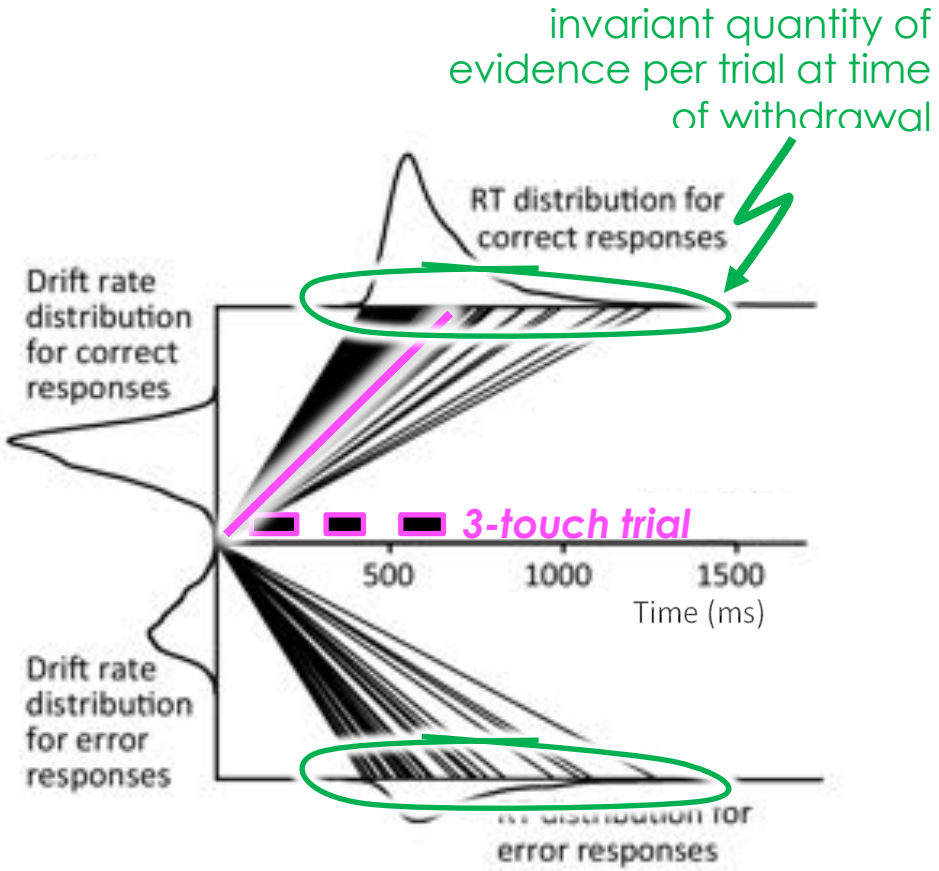


*Signal **not** independent across touches: multi-touch trials (4, 5, 6 touches) tended to begin with low-signal touches.*

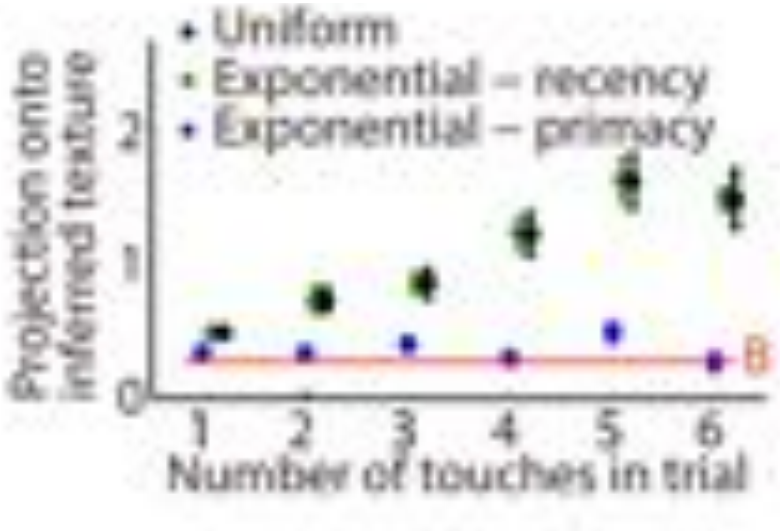
Also, the final touch (same as the first touch on 1-touch trials) tends to carry the greatest signal.

Ratcliff R, Smith PL, Brown SD, McKoon G. (2016)
Diffusion Decision Model: Current Issues and History.
Trends Cogn Sci.

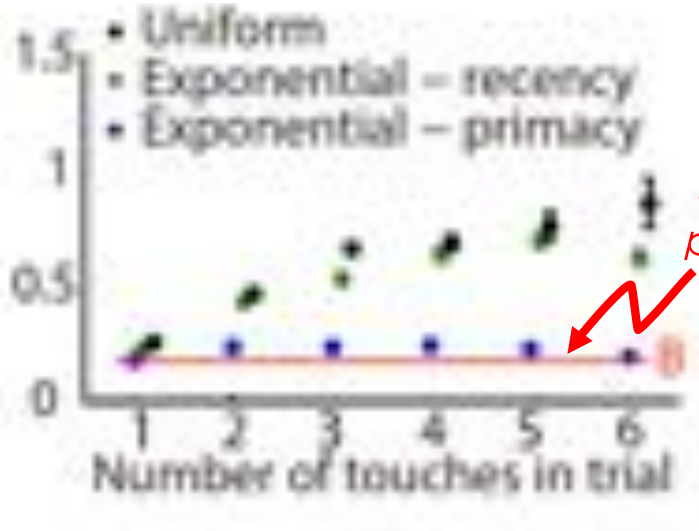




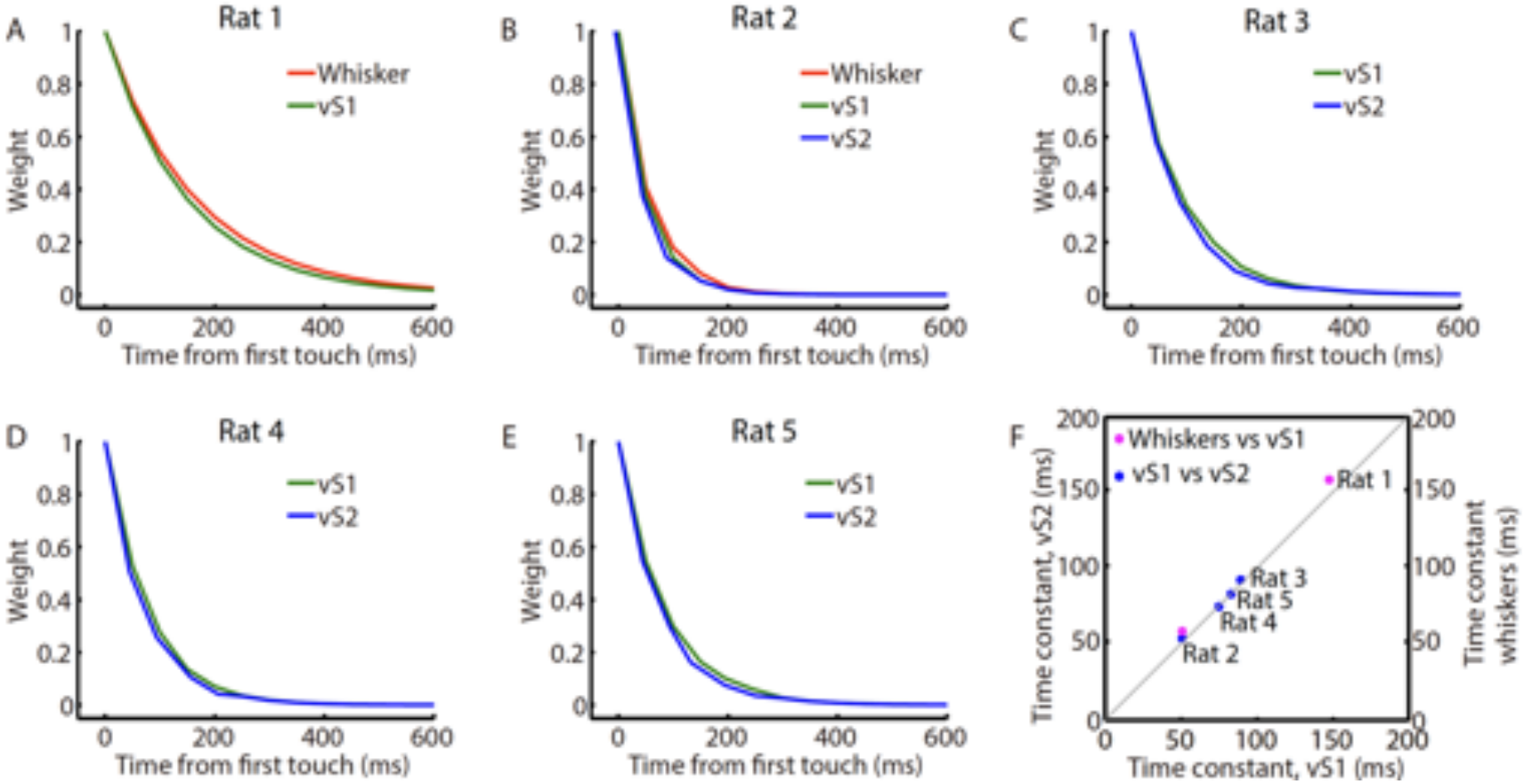
Vibrissal signal

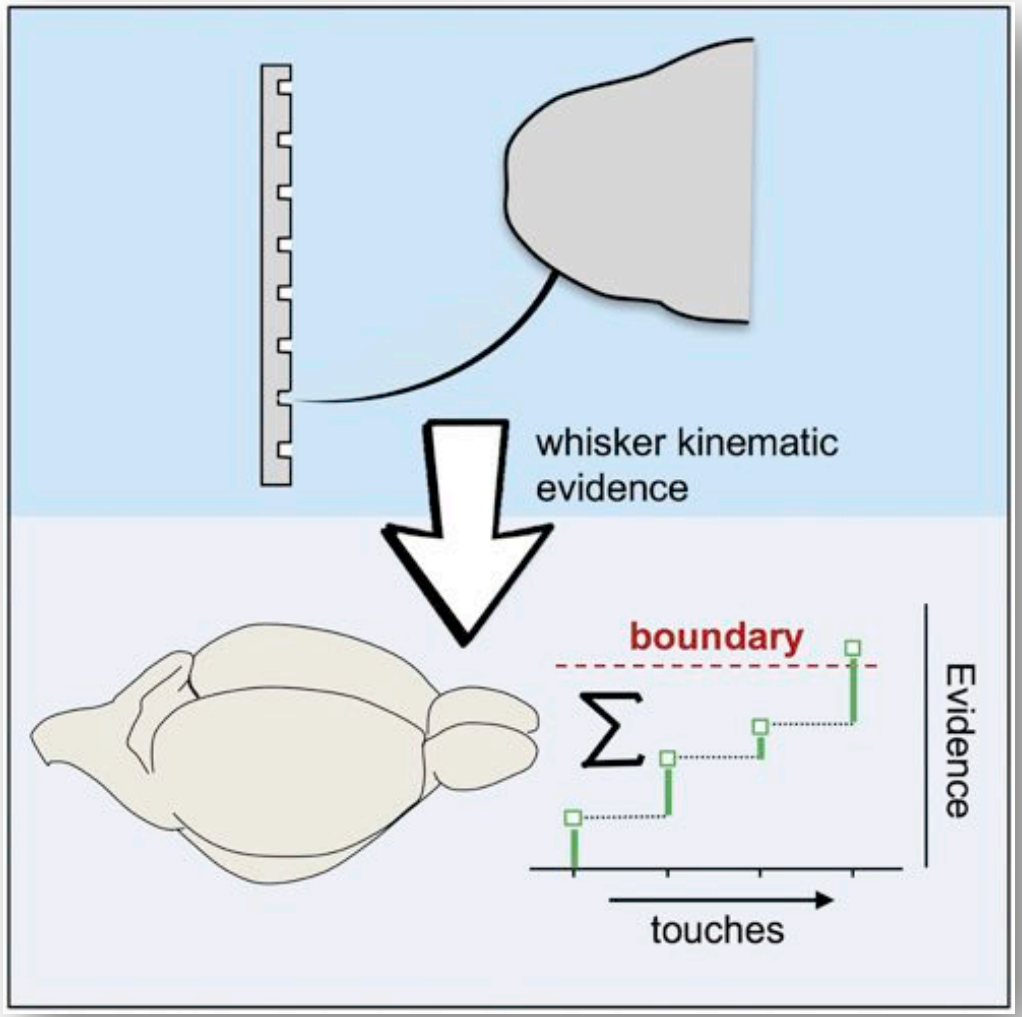


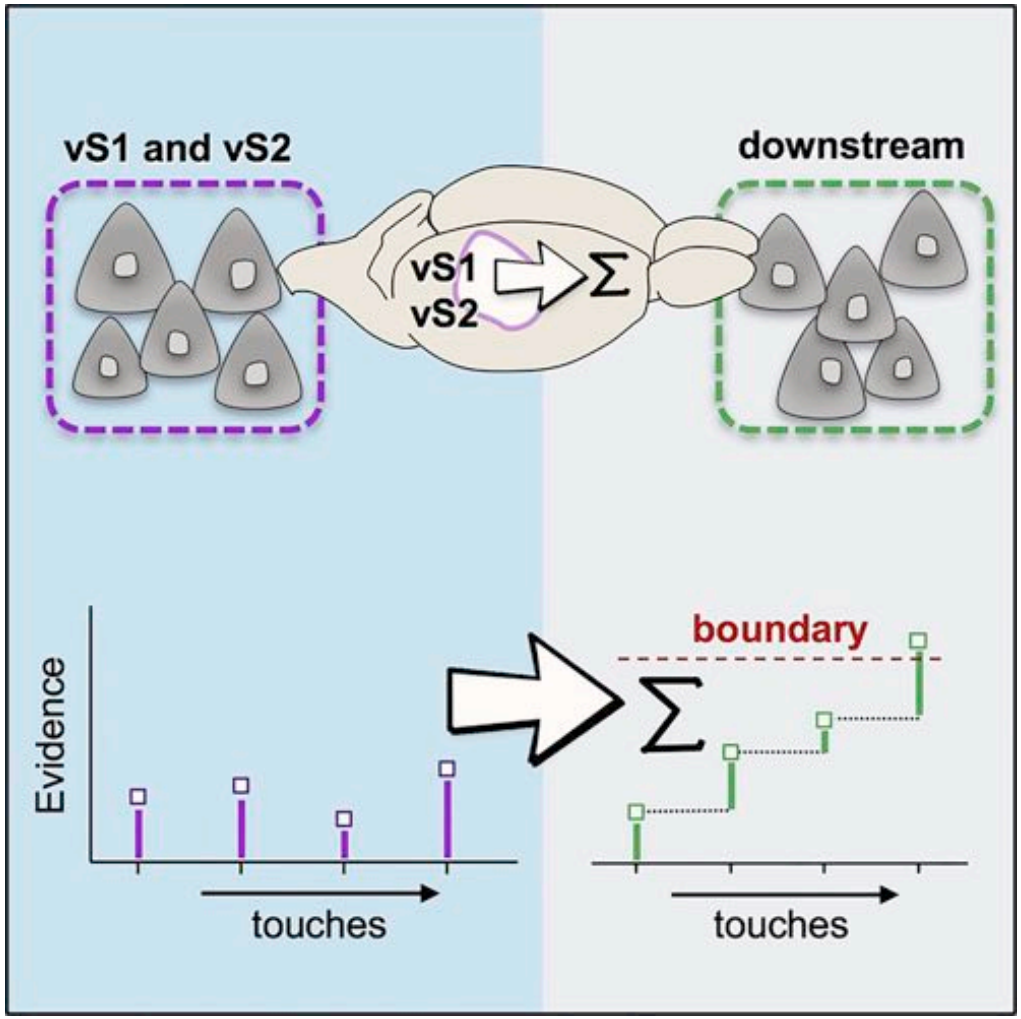
Neuronal signal



decision boundary (B) visible only by exponential primacy


A
Rat 1
Whisker
vS1
Weight
Time from first touch (ms)
B
Rat 2
Whisker
vS1
vS2
Weight
Time from first touch (ms)
C
Rat 3
vS1
vS2
Weight
Time from first touch (ms)
D
Rat 4
vS1
vS2
Weight
Time from first touch (ms)
E
Rat 5
vS1
vS2
Weight
Time from first touch (ms)
F
Whiskers vs vS1
vS1 vS2
Rat 1
Rat 3
Rat 5
Rat 4
Rat 2
Time constant, vS2 (ms)
Time constant, vS1 (ms)
Time constant whiskers (ms)


whisker kinematic
evidence
boundary
Σ
Evidence
touches


vS1 and vS2
downstream
vS1
vS2
Σ
Evidence
touches
boundary
Σ
touches