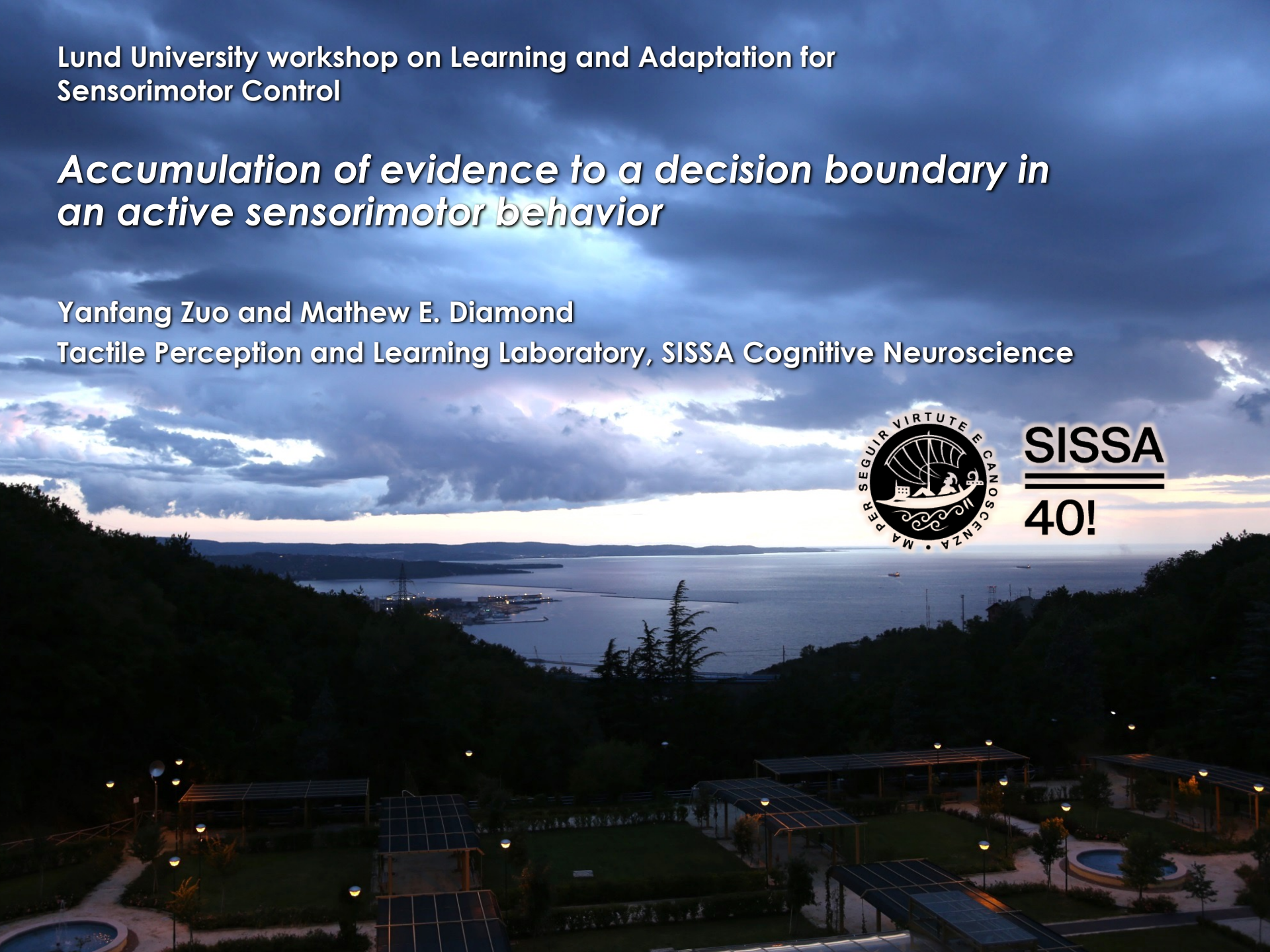
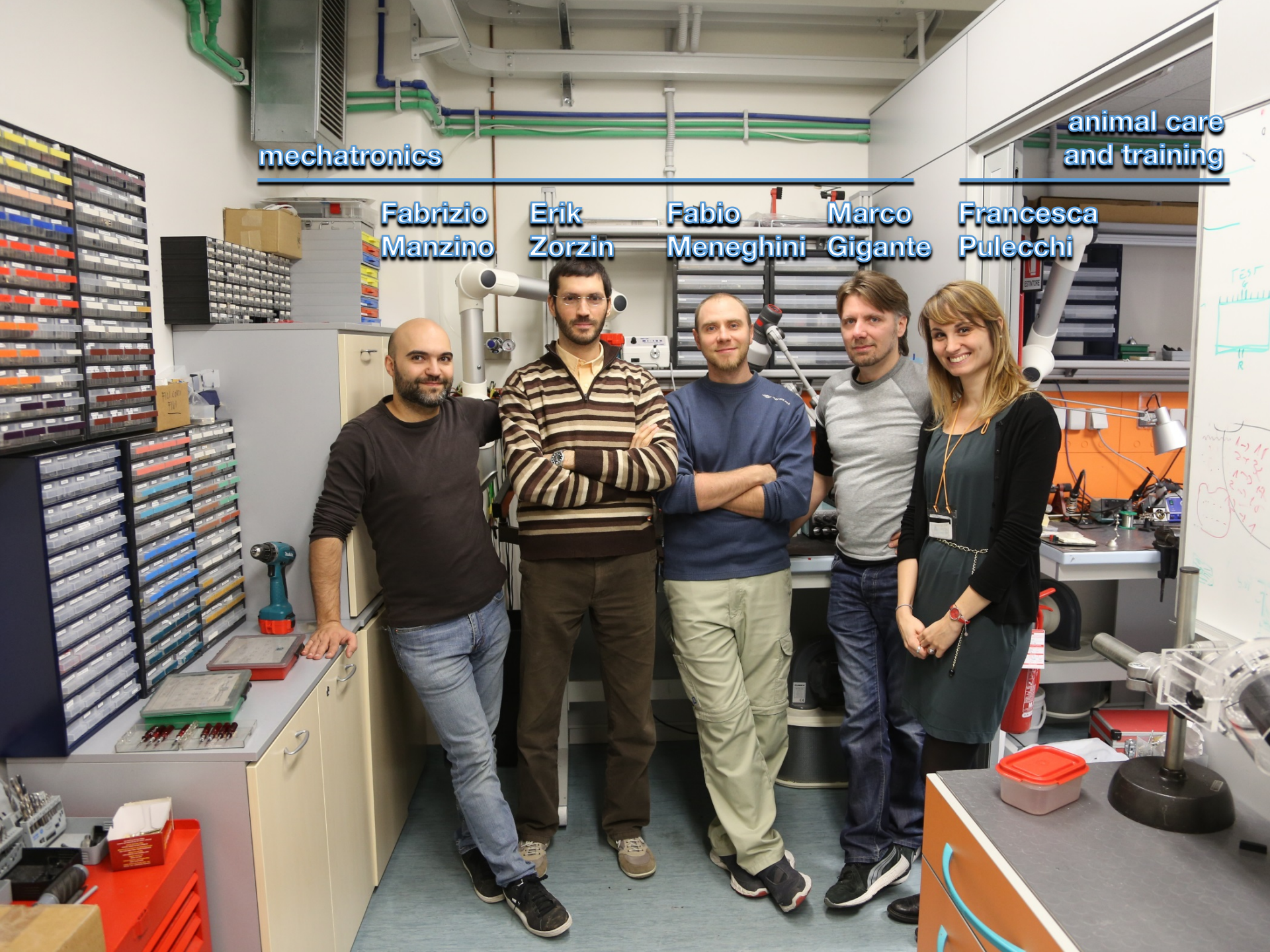
Lund University workshop on Learning and Adaptation for Sensorimotor Control

Accumulation of evidence to a decision boundary in an active sensorimotor behavior

Yanfang Zuo and Mathew E. Diamond

Tactile Perception and Learning Laboratory, SISSA Cognitive Neuroscience



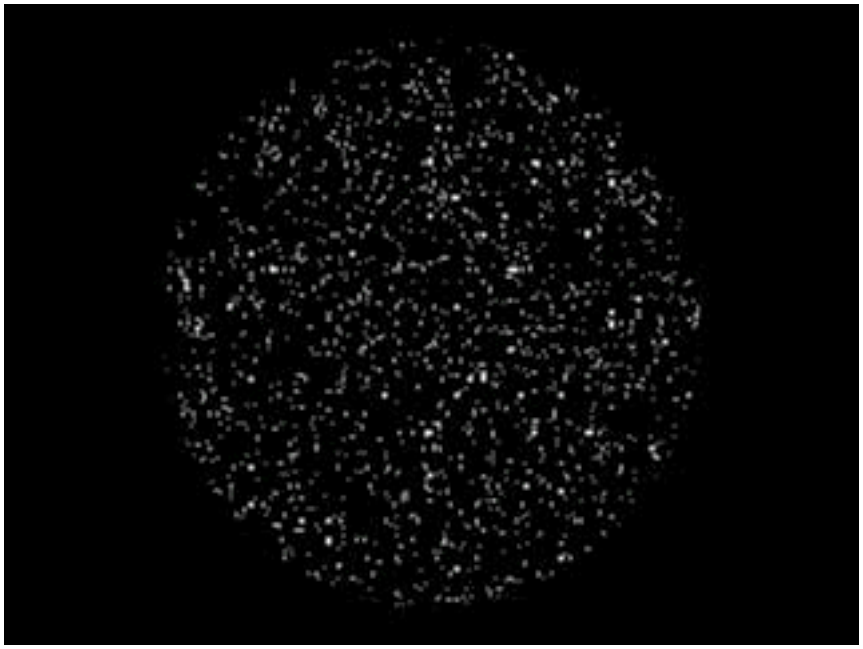

mechatronics
animal care
and training
Fabrizio
Manzino
Erik
Zorzin
Fabio
Meneghini
Marco
Gigante
Francesca
Pulecchi

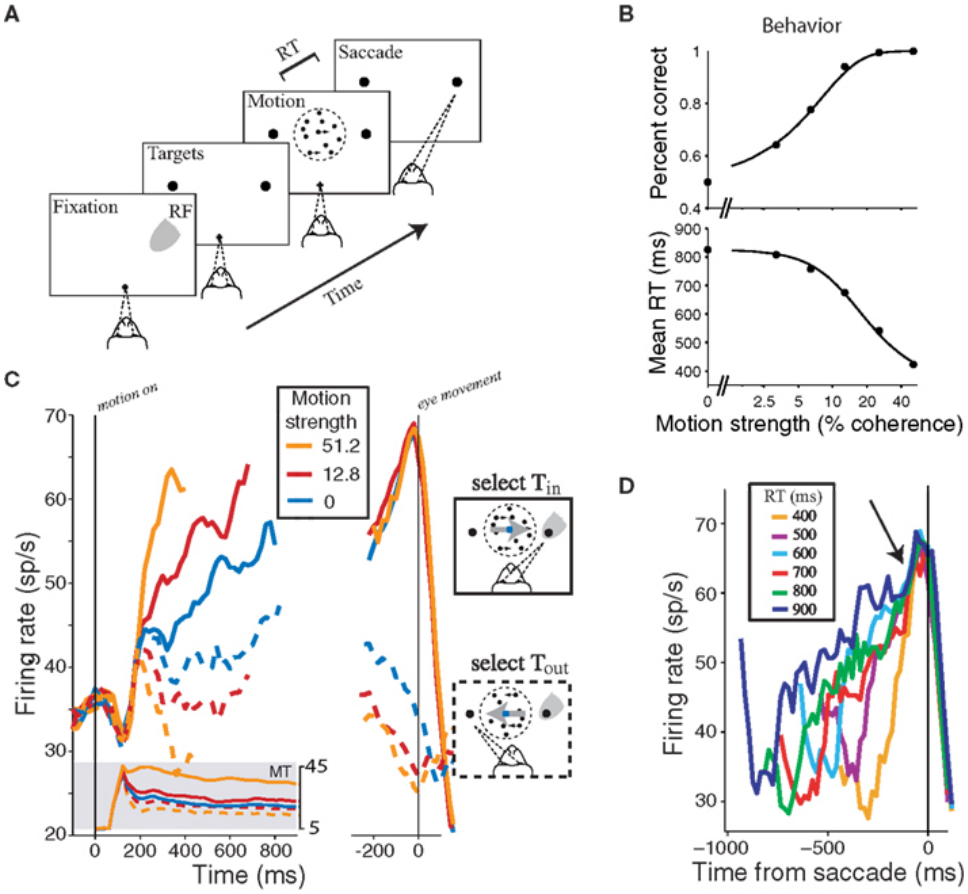
Yanfang Zuo

SISSA → Institute of Neuroscience
Chinese Academy of Sciences
Shanghai

all results shown today from Zuo & Diamond
"*Accumulation of evidence to a decision boundary in an active sensorimotor behavior*"
under review

Sensory-perceptual decision making

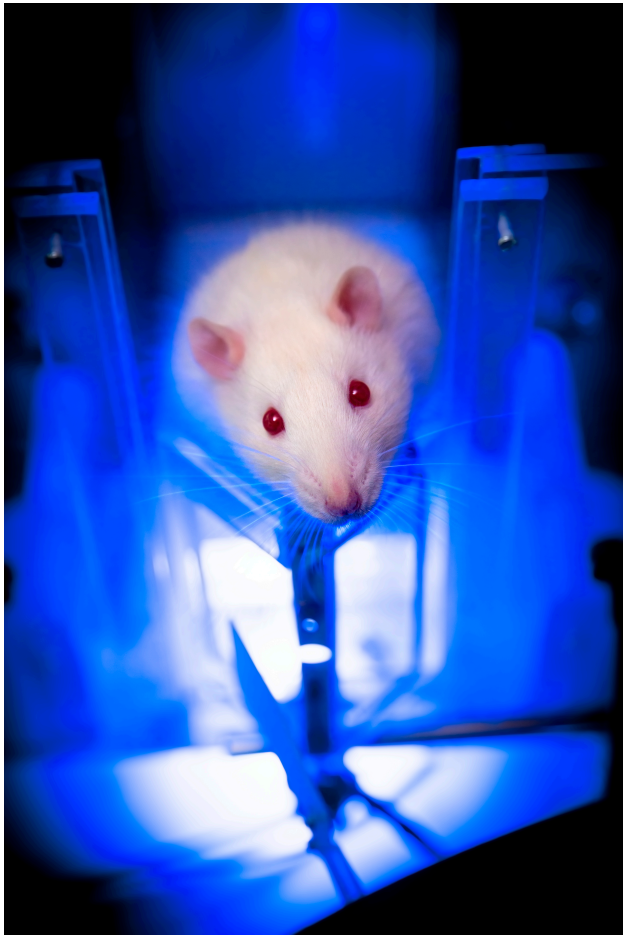




Gold and Shadlen (2007)

*how do sensorimotor systems **generate and control** the incoming sensory stream to support a perceptual choice?*

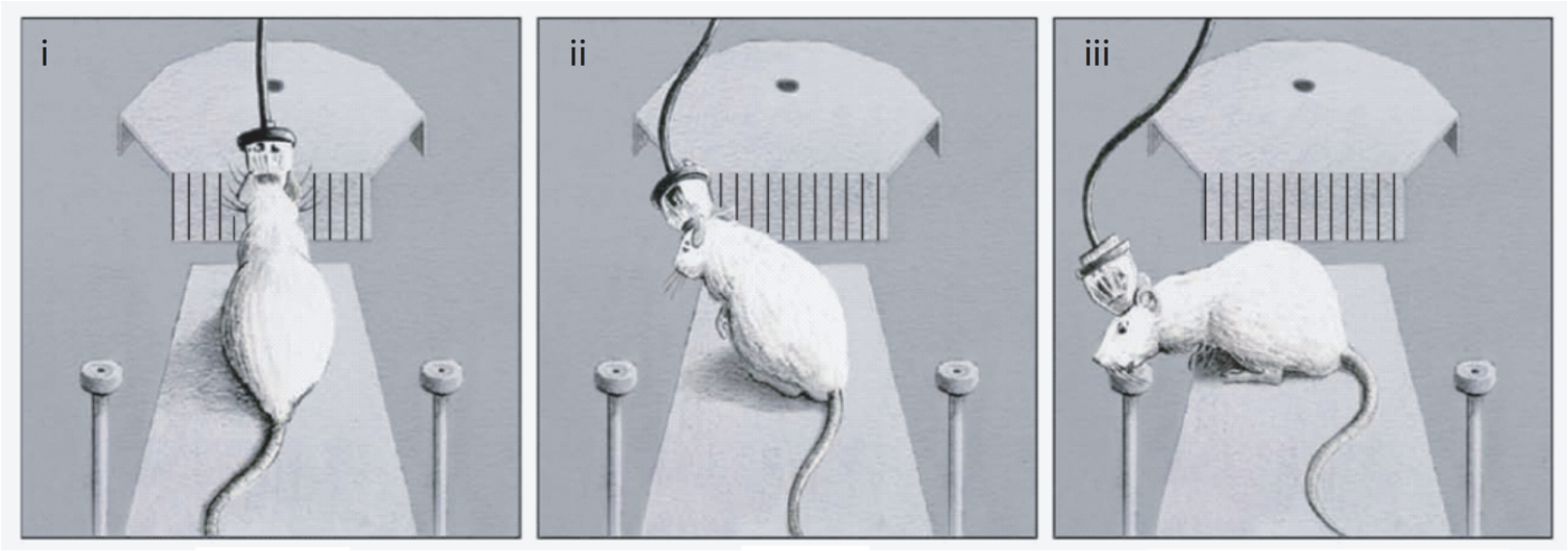
superb tactile capacities

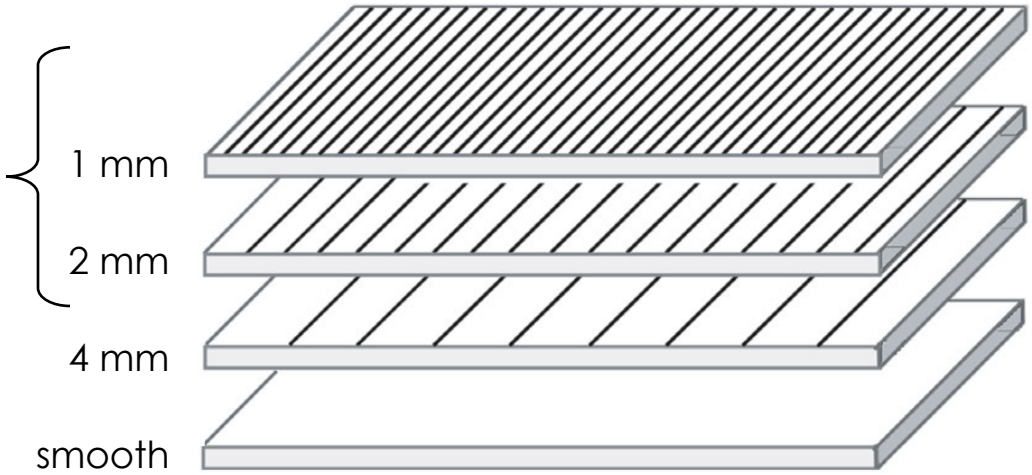


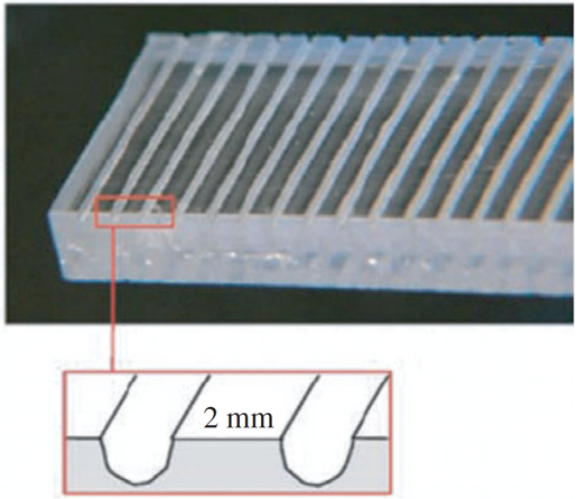
- *object localization*
- *size discrimination*
- *shape discrimination*
- *vibration amplitude estimation*
- *roughness and texture discrimination*

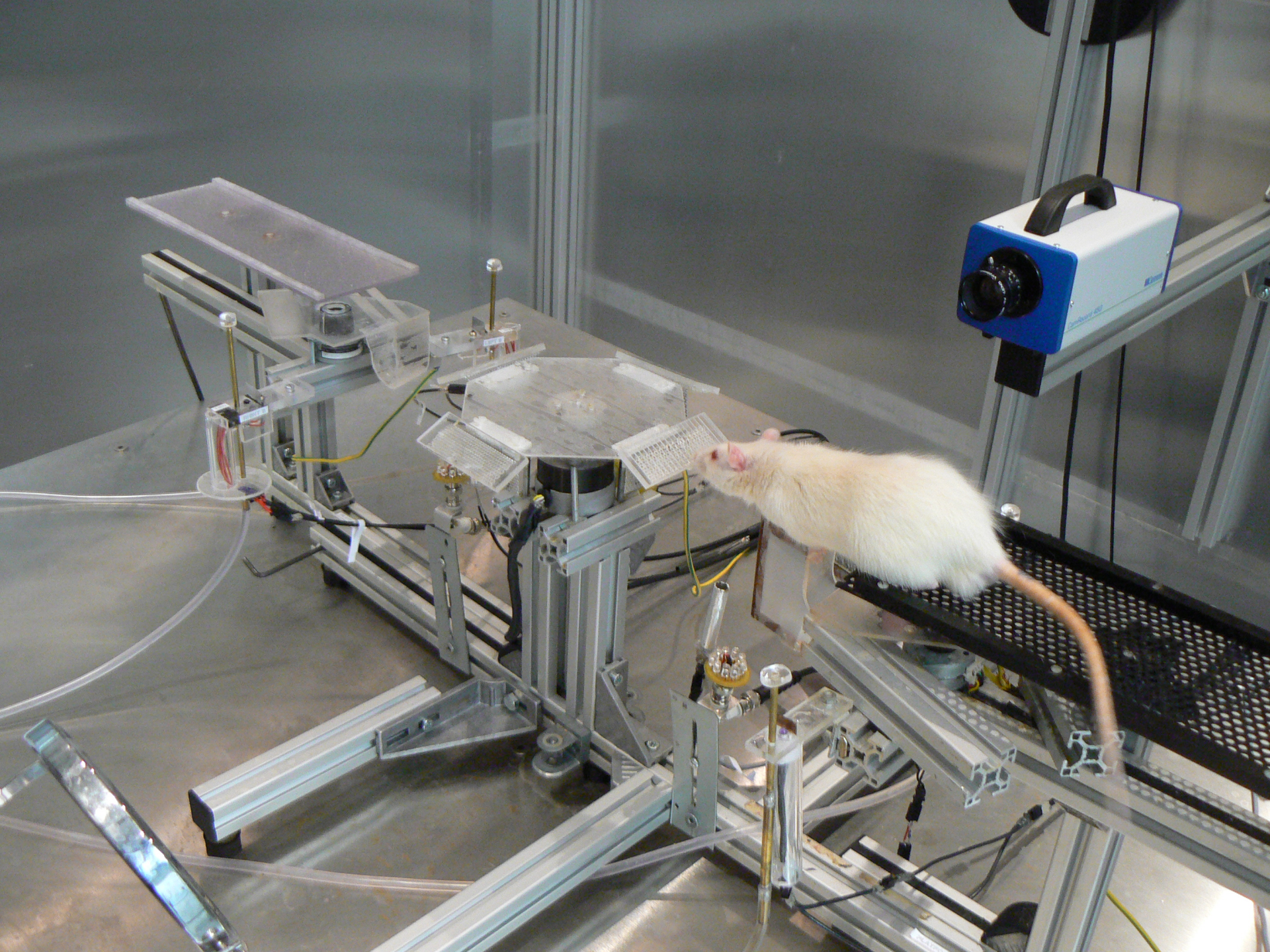
active generation of sensory signals through sensorimotor system

i. generate texture percept through active whisker motion identify texture
ii. withdraw
iii. make choice, collect reward

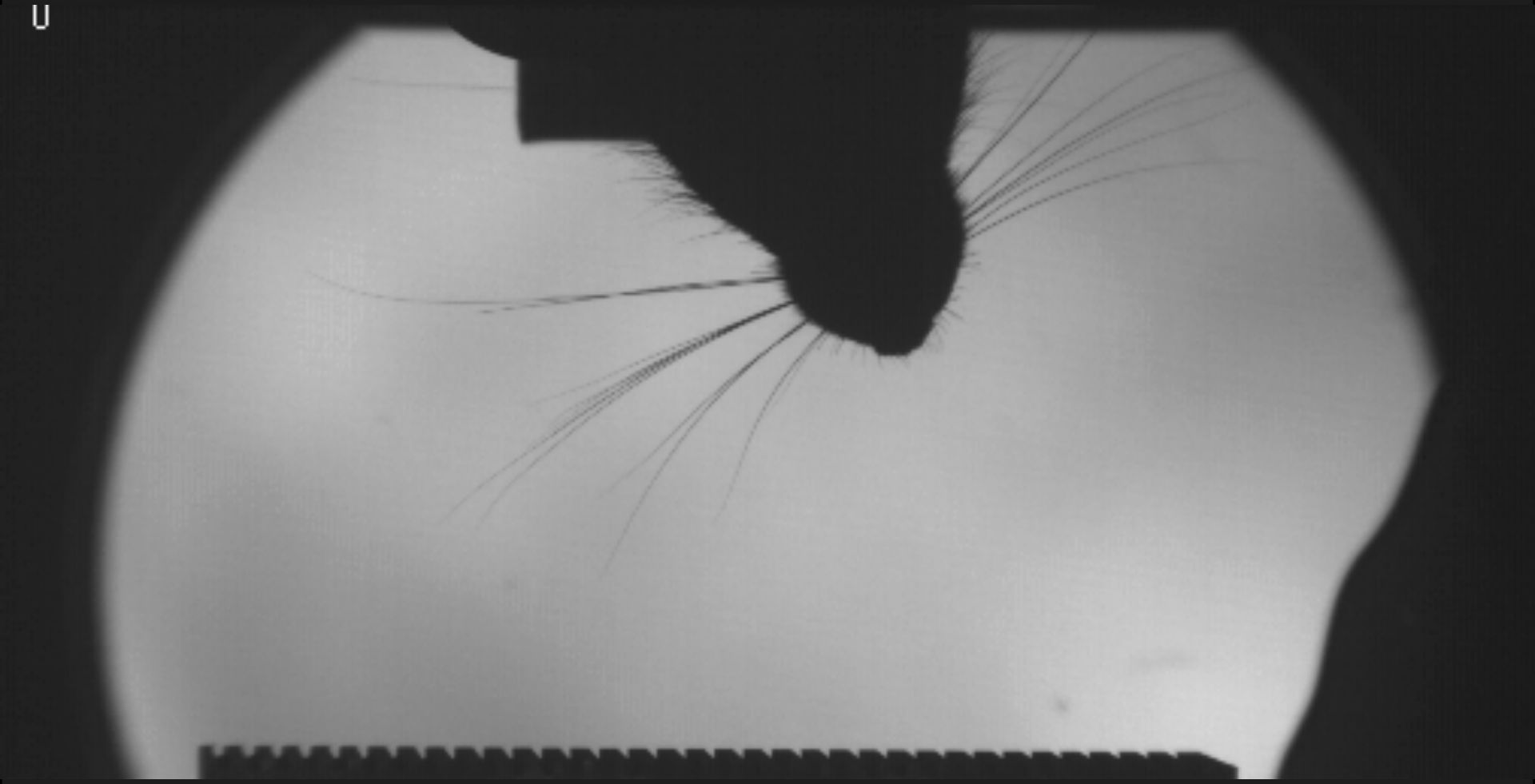



1 mm
2 mm
4 mm
smooth


2 mm

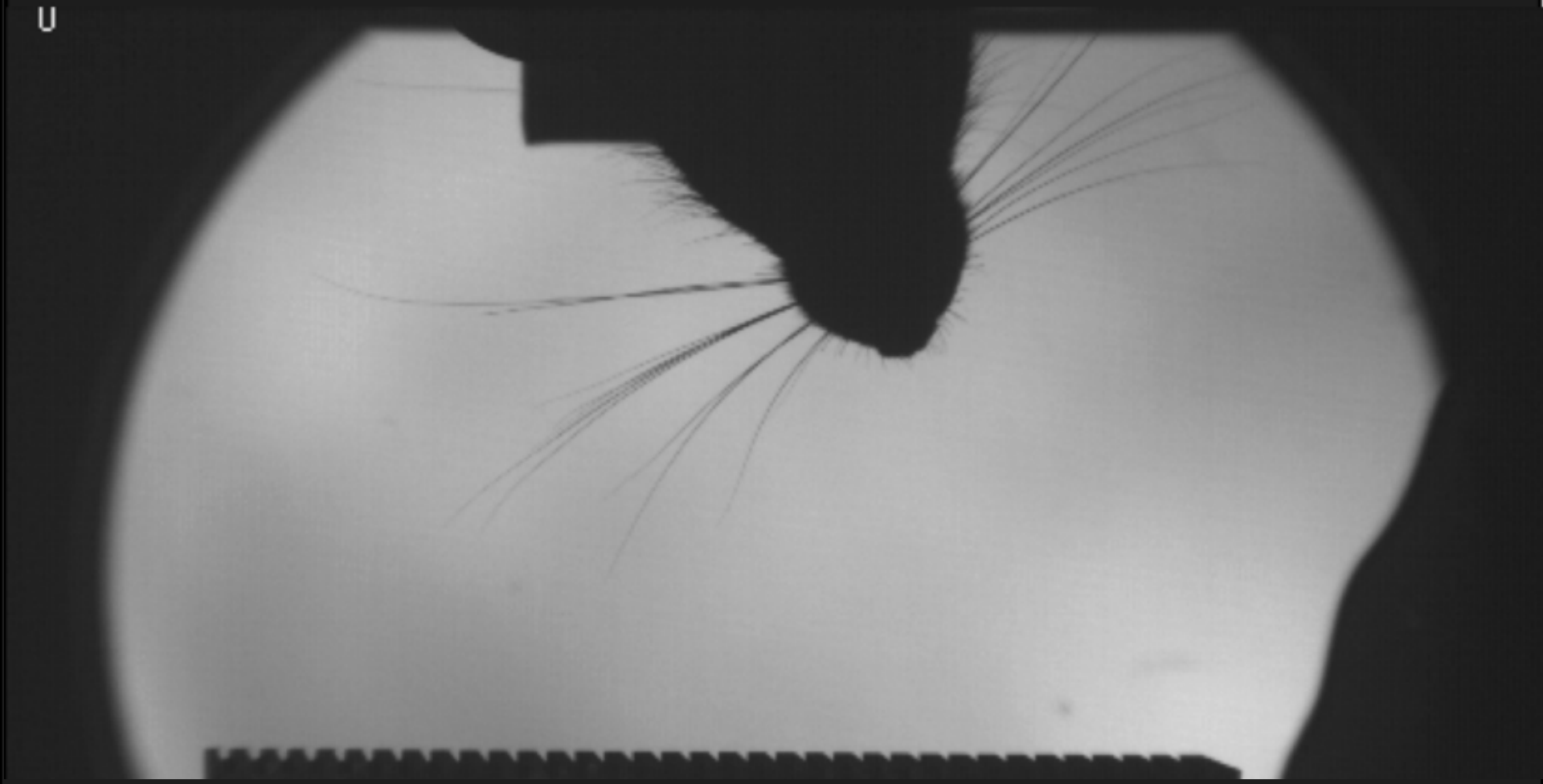


U

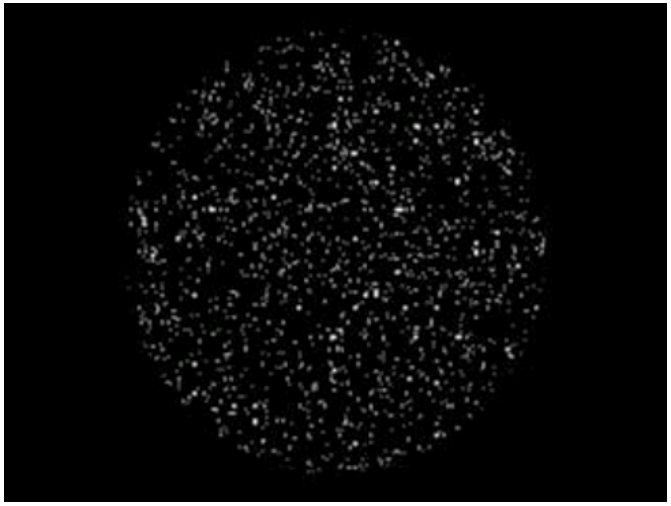


multiple whisks on this trial...

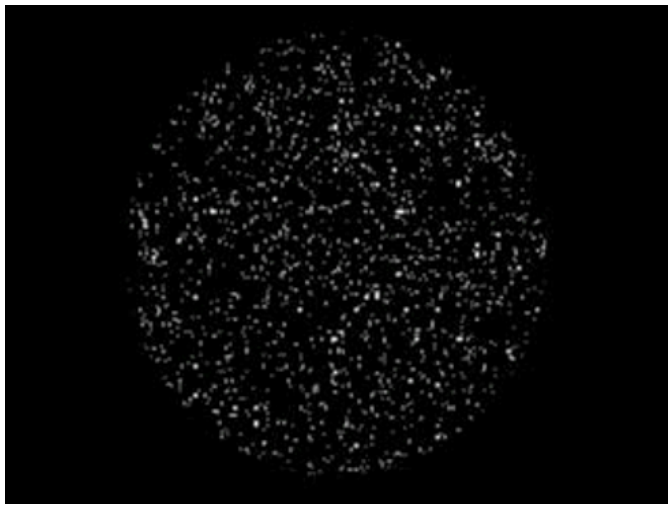
why?

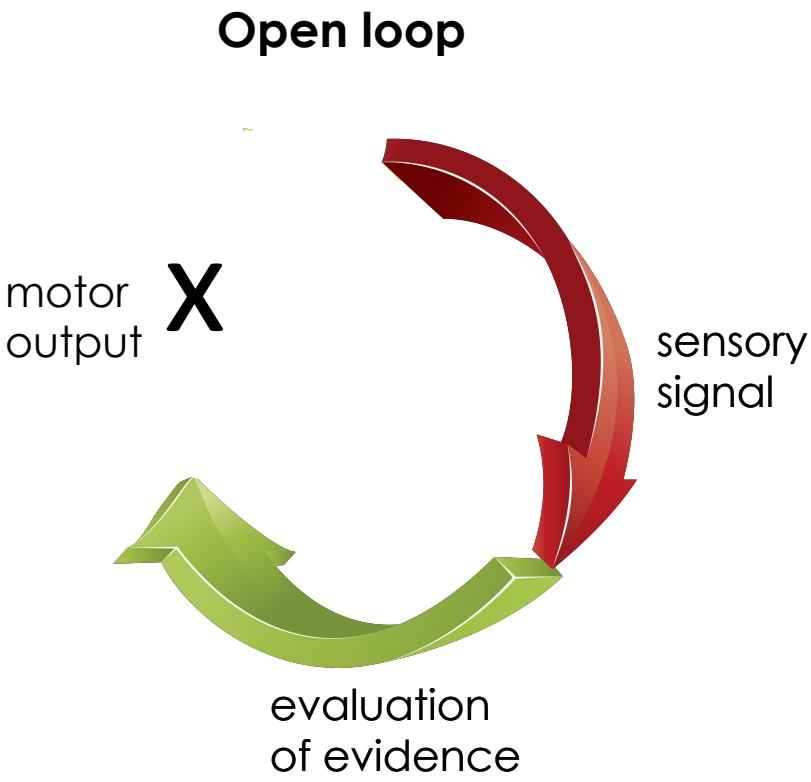


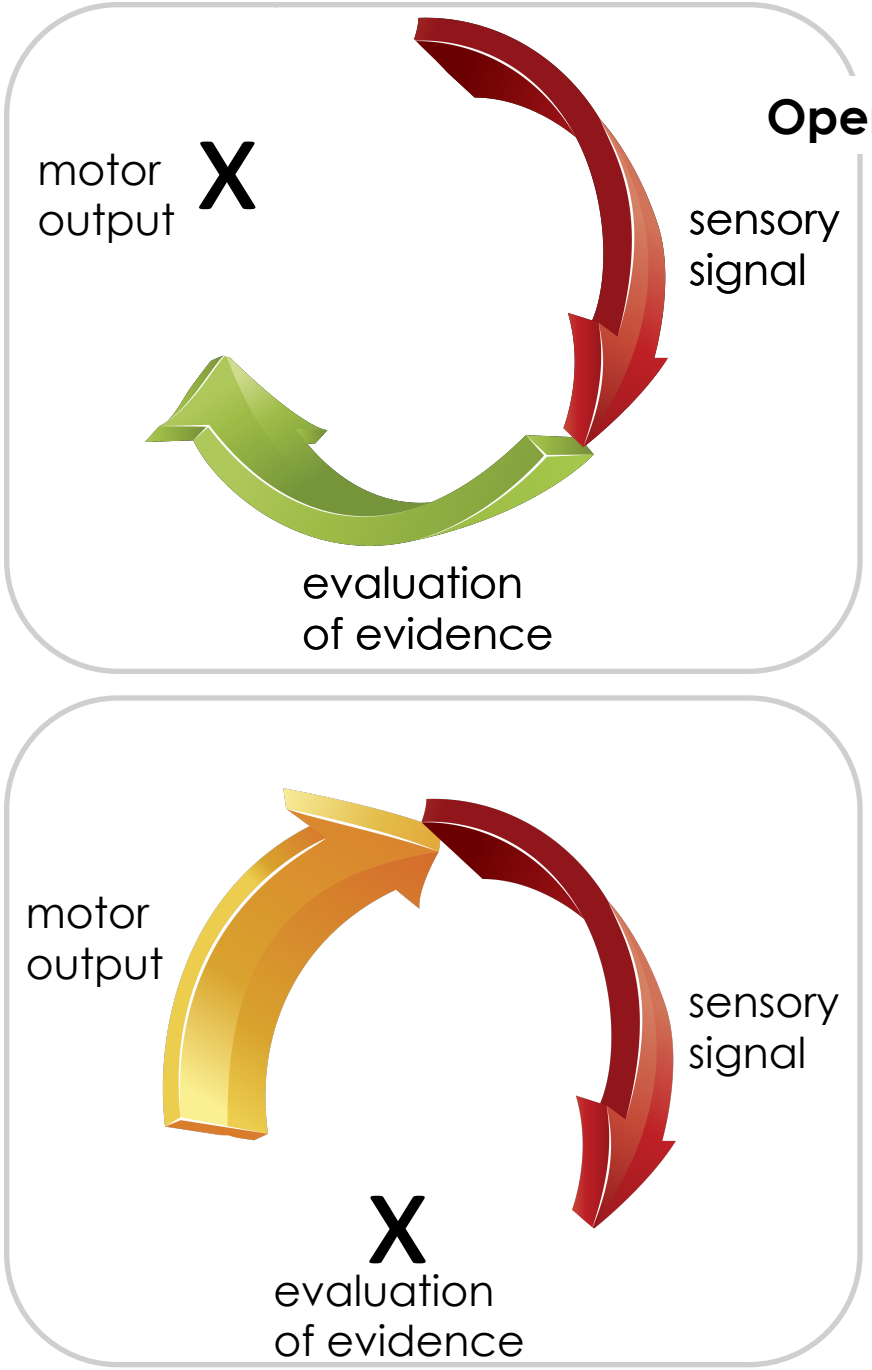
Sensory decision making and open/closed loops



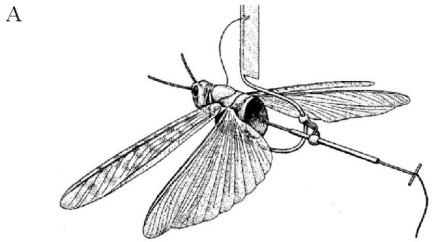
Sensory decision making and open/closed loops

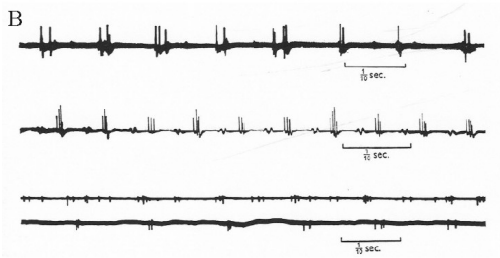


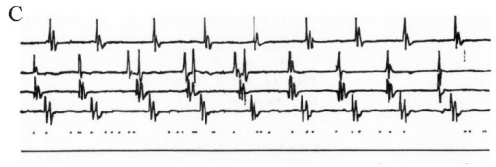



Open loops
motor output
X
sensory signal
evaluation of evidence
motor output
sensory signal
X
evaluation of evidence
Closed loop
motor output
sensory signal
evaluation of evidence

Open loop

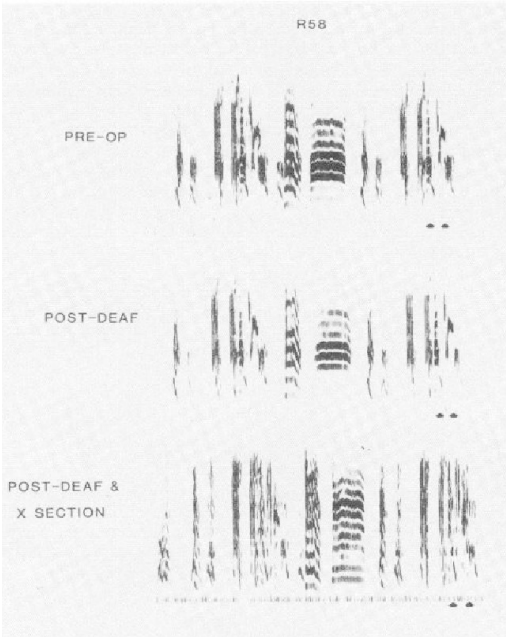






locust wing flaps in absence of sensory feedback from wings

(D. Wilson)

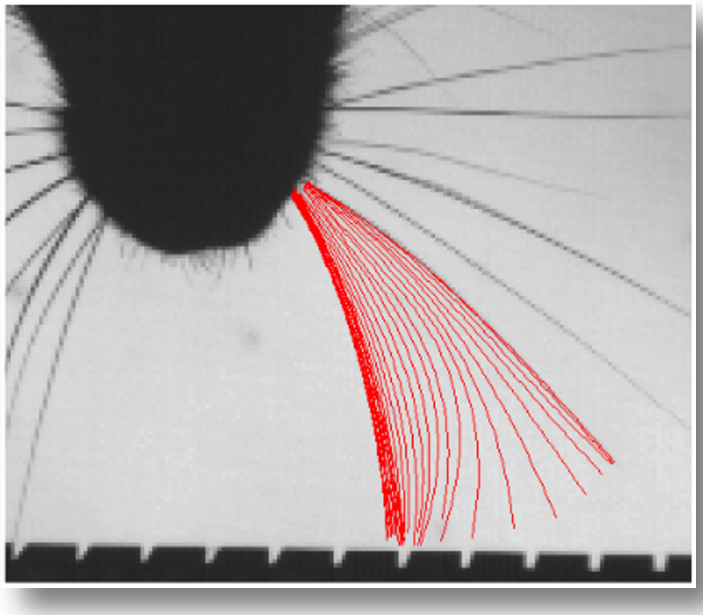


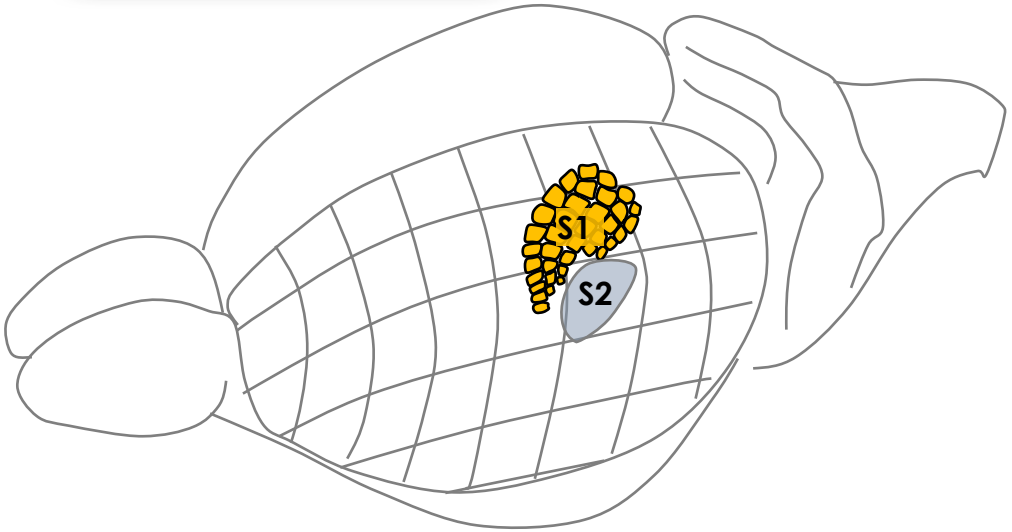
deaf zebra finch singing

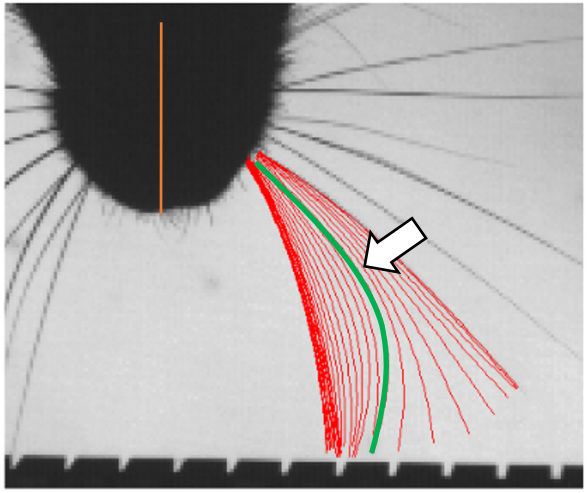
(M. Konishi)

So… rat feels texture by open or closed loop?

we need to identify what is the sensory evidence

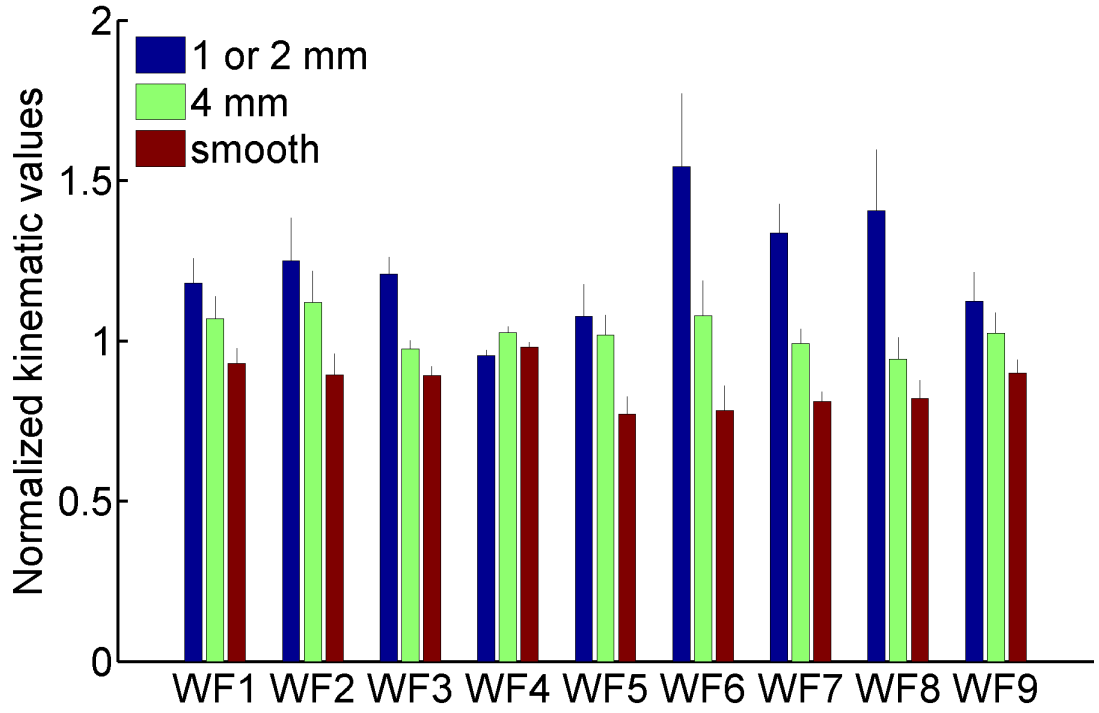


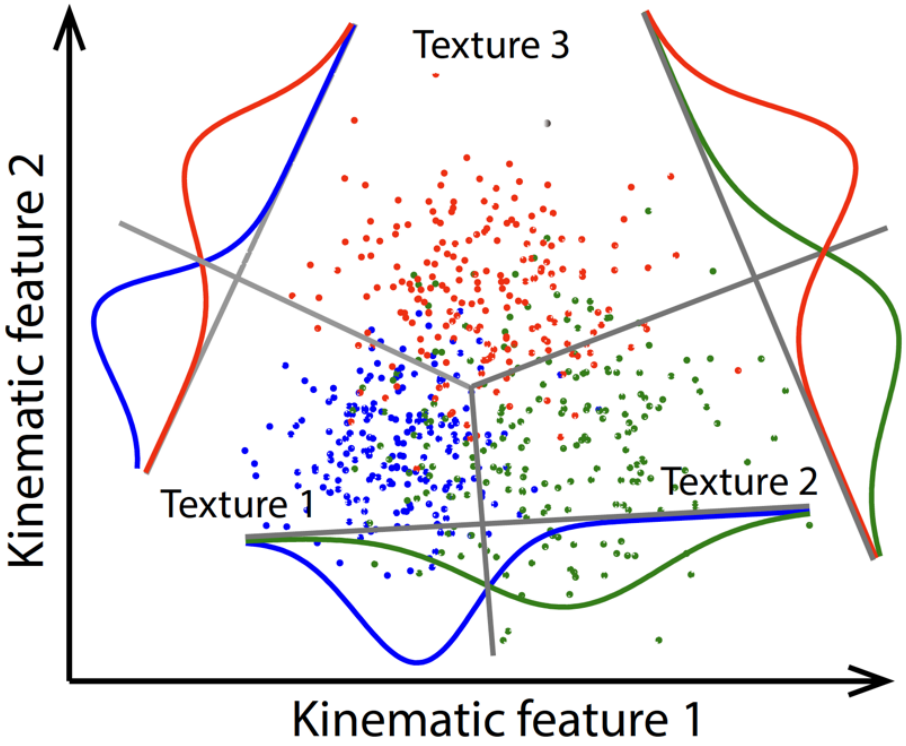




kinematic signatures of textures

the whisker features (WFs) distinguish the various textures



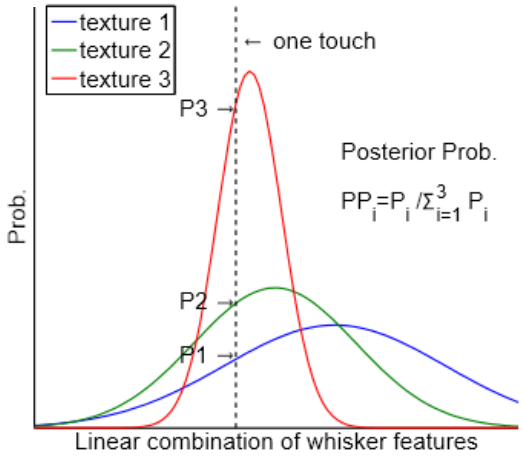


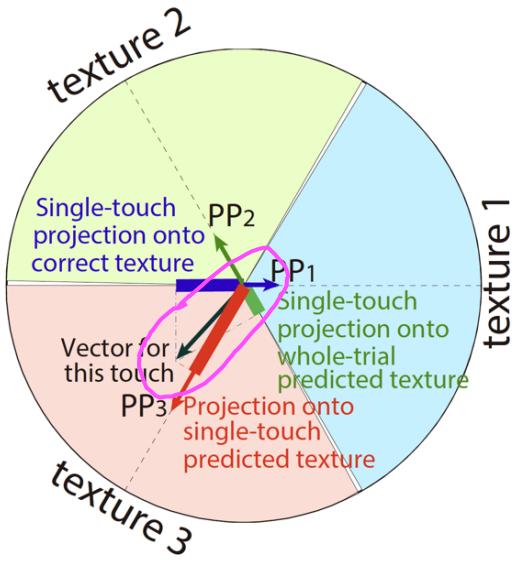
We exploit kinematic signatures of textures to DECODE (make prediction) of texture based on kinematic features of single touch.

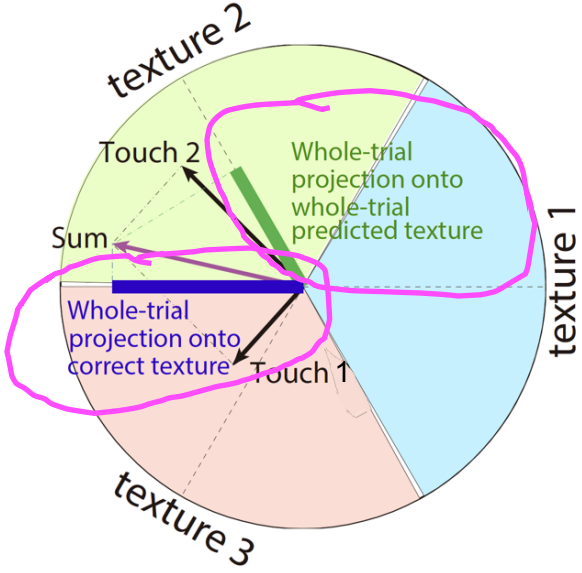
Bayesian multivariate linear discriminant analysis finds optimal linear combination of 9 features.

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

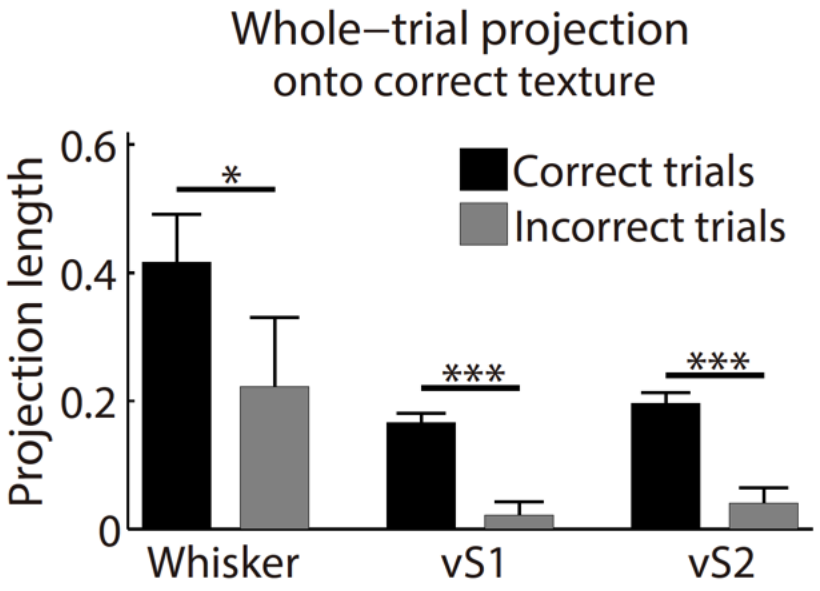
based on the probability density function for each texture, calculate posterior probability that any observed combination of 9 kinematic features per touch corresponds to each candidate texture.



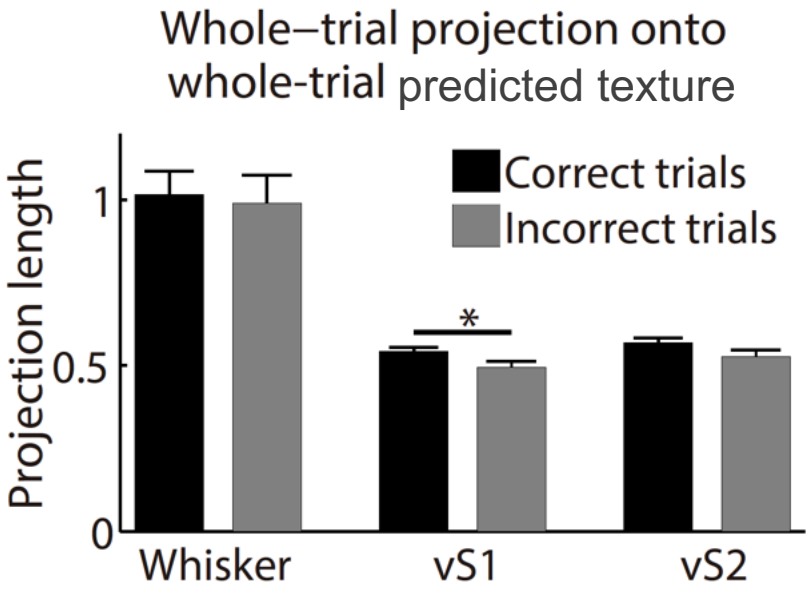




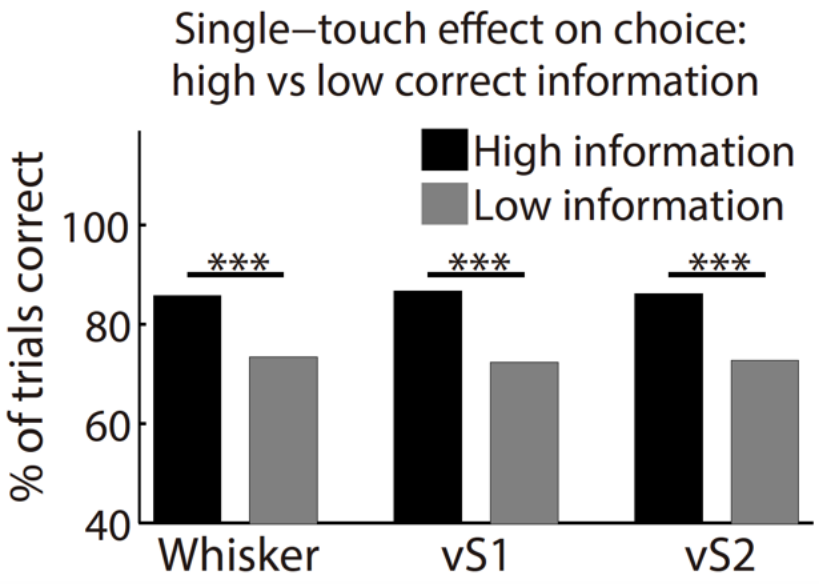
whisker kinematics and neuronal firing provide correct signal on correct trials



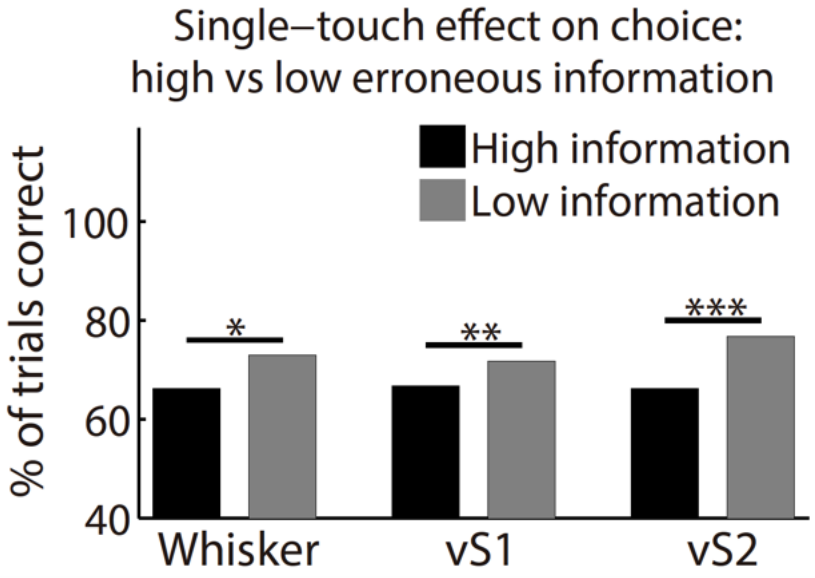
whisker kinematics and neuronal firing provide equally strong signal, whether choice correct or incorrect



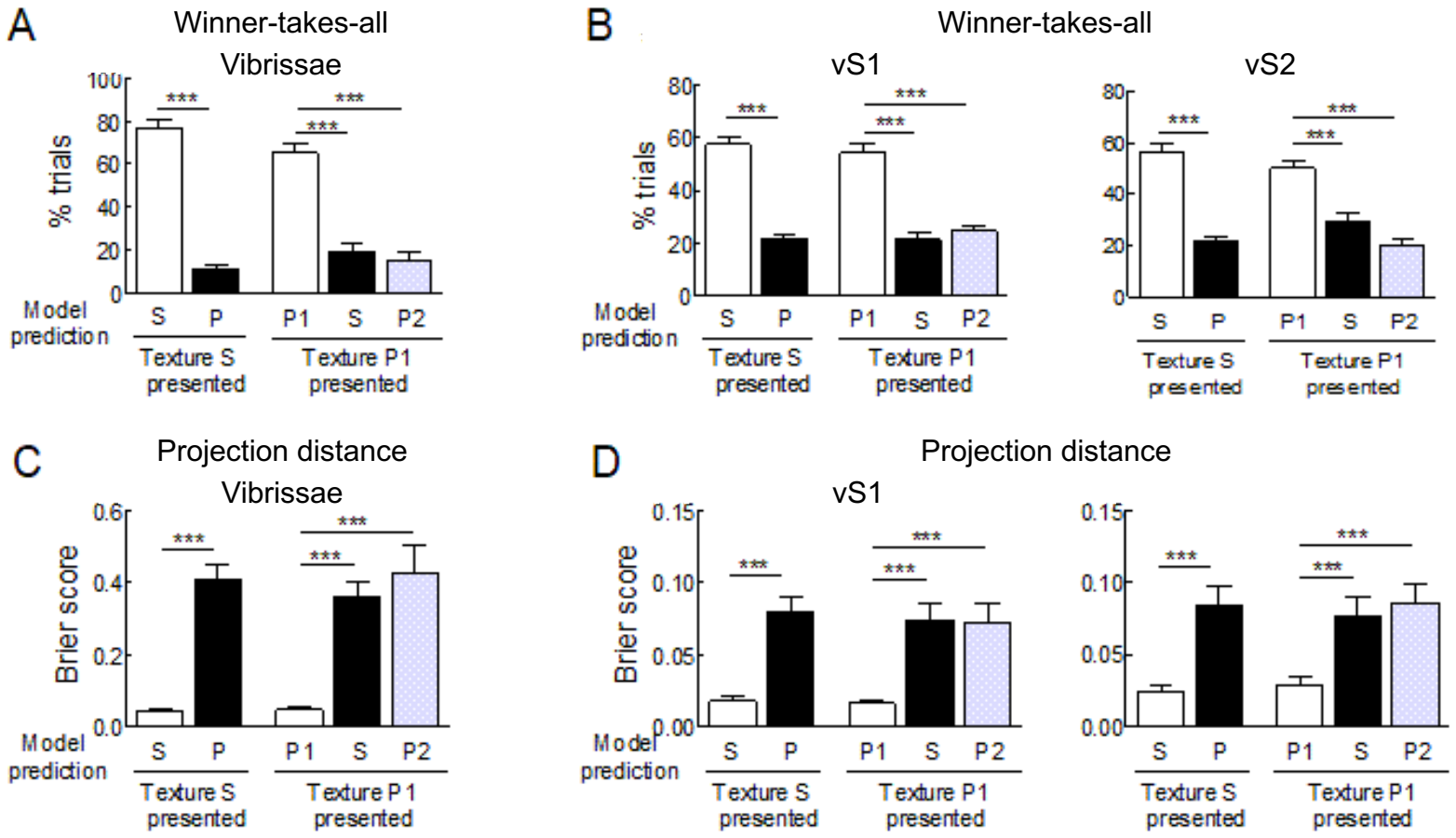
a strong, correct signal on *single touch* leads to correct choice



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



the whole-rat's choice follows from vibrissal and neuronal evidence



- 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.

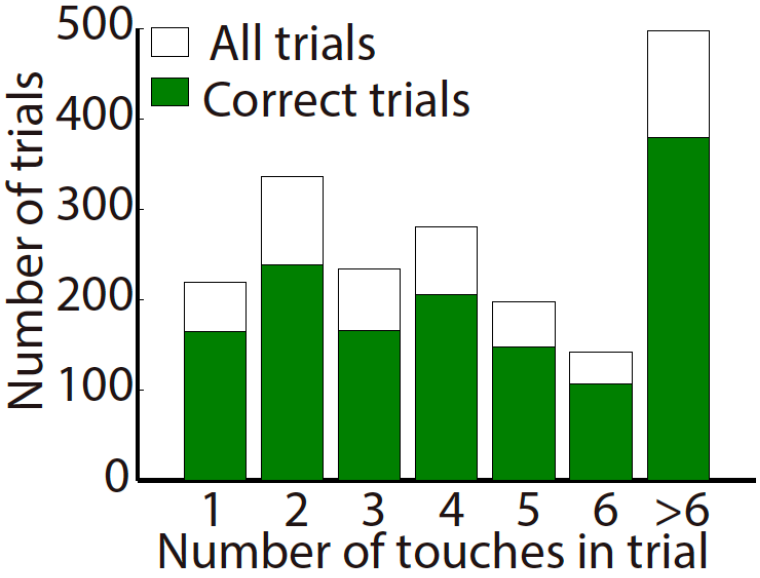
- How does the rat decide whether to initiate another contact or else to turn toward a reward spout? Two hypotheses:
  - **Motor Program (open loop)**
  - **Evidence Accumulation (closed loop)**

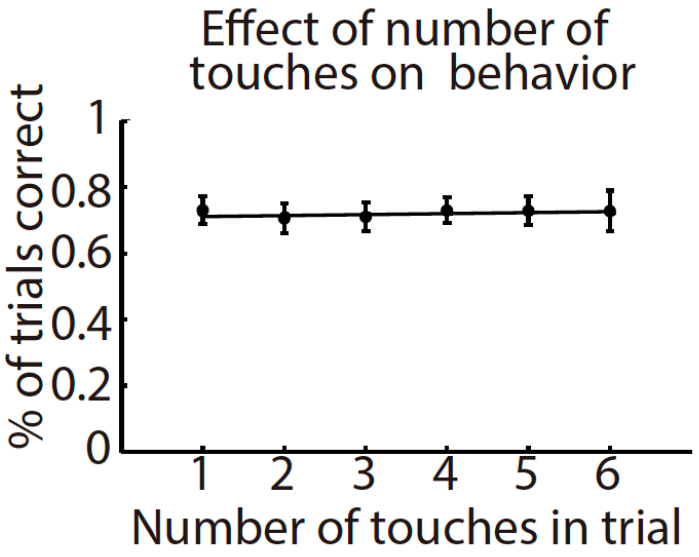
Motor program hypothesis

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





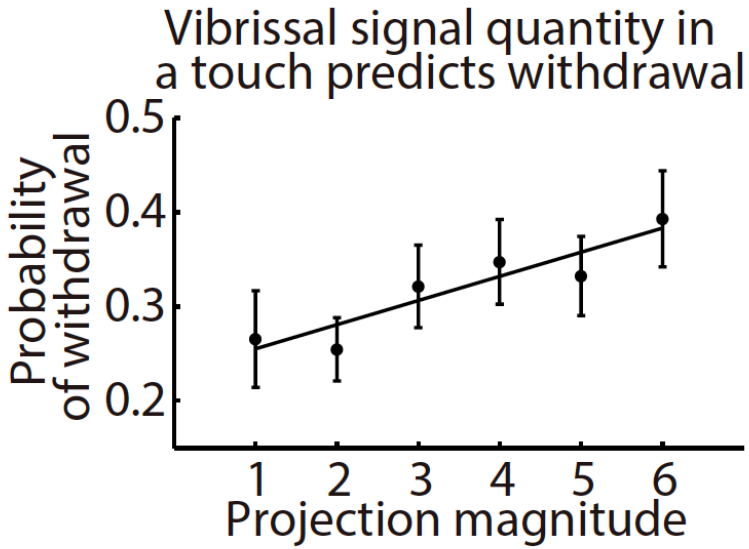
Motor program hypothesis

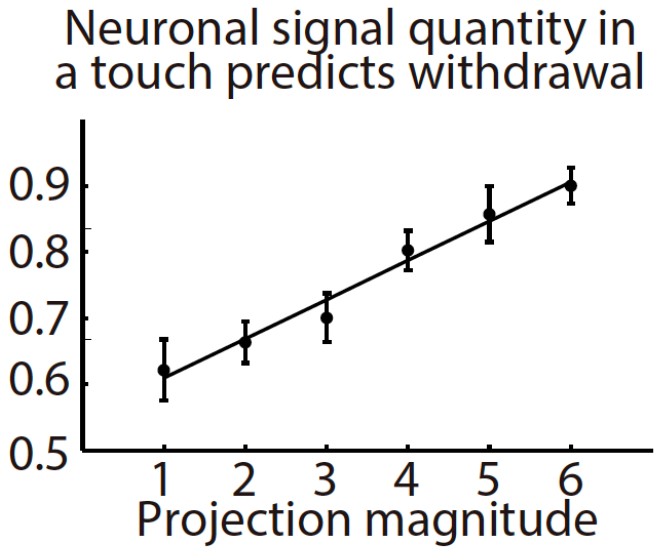
probability of decision independent of single-touch signal

Evidence accumulation hypothesis

contact providing no evidence can never cause threshold crossing.

probability of decision positively correlated with quantity of signal.



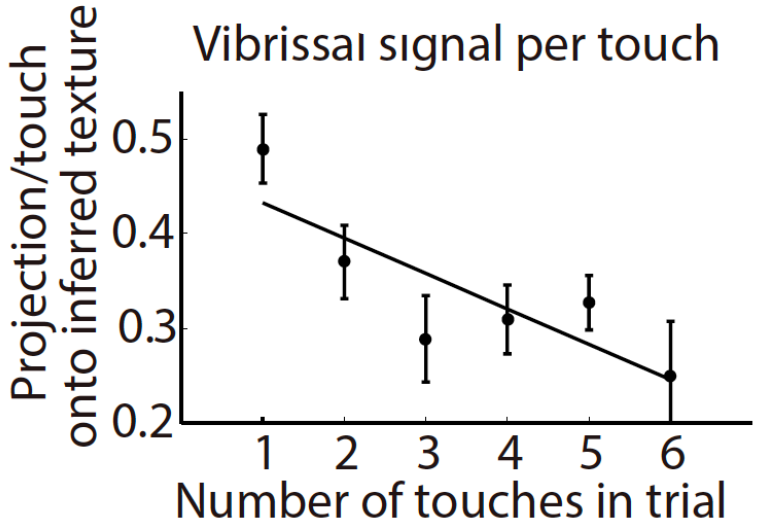


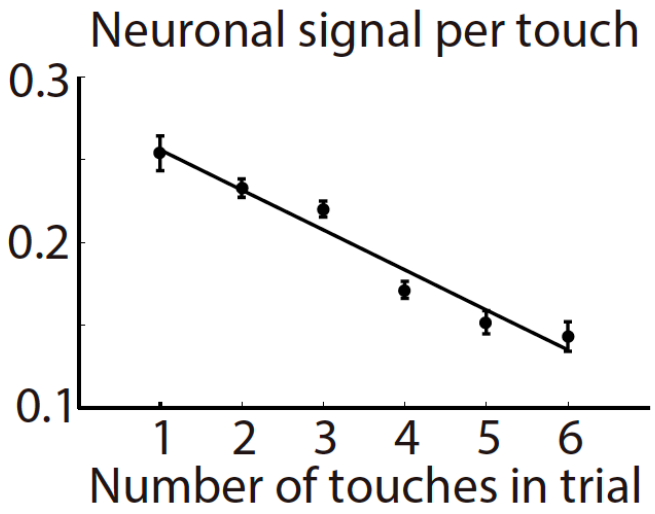
Motor program hypothesis

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



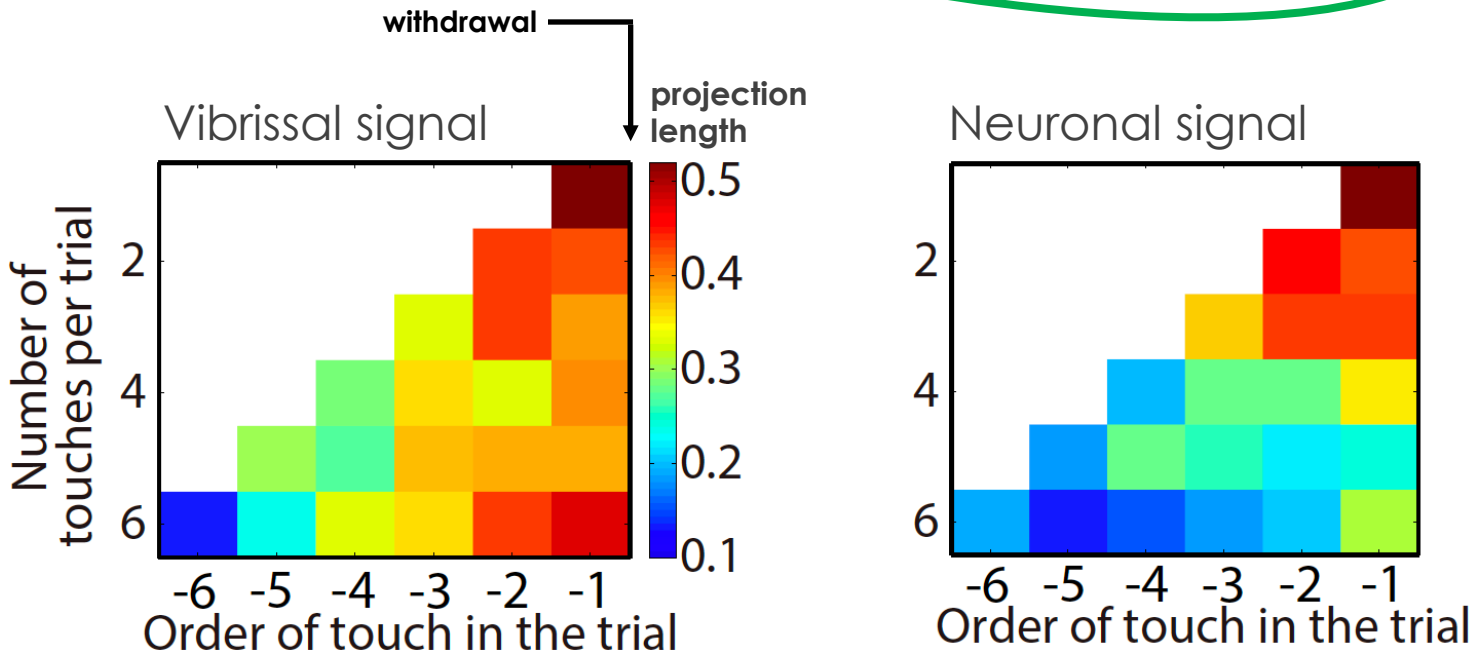


Motor program hypothesis

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.*

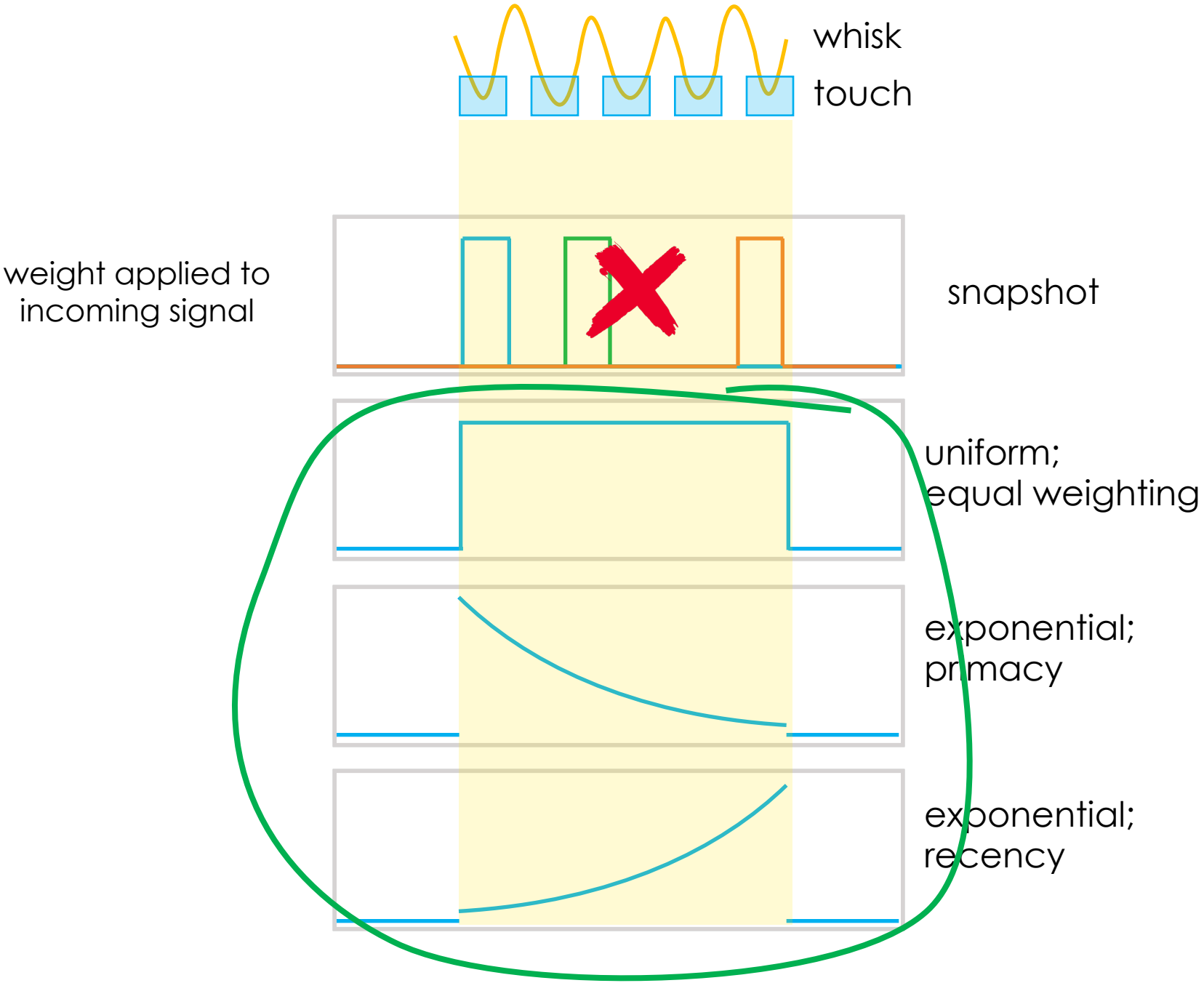
Also, the final touch (same as the first touch on 1-touch trials) tends to carry the greatest signal.

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

- 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)**

But by what integration algorithm is evidence getting accumulated?

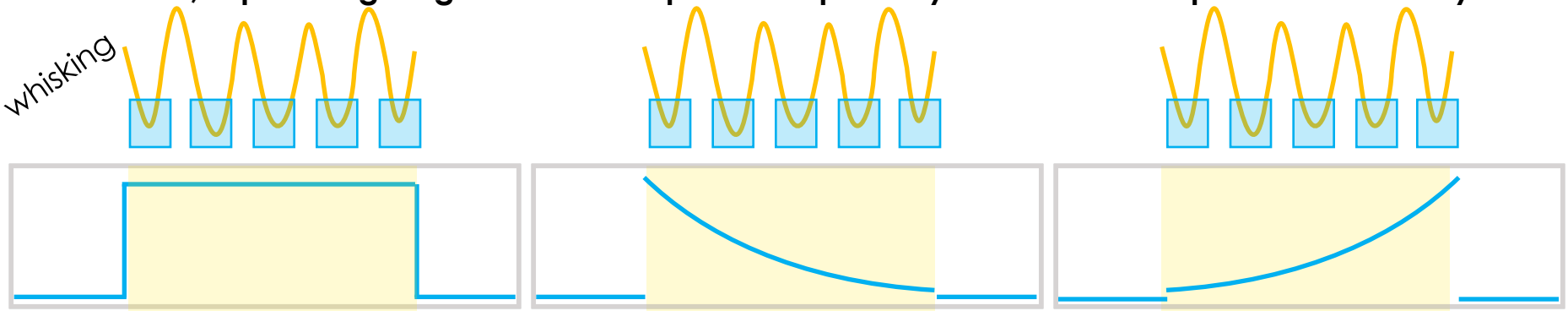

whisk
touch
weight applied to incoming signal
snapshot
uniform; equal weighting
exponential; primacy
exponential; recency

uniform; equal weighting

exponential primacy

exponential recency

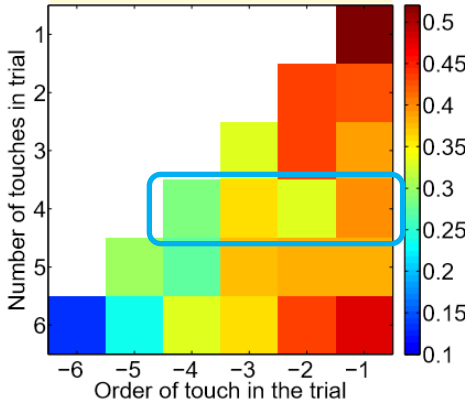
whisking

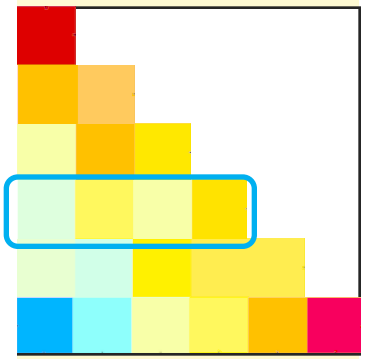


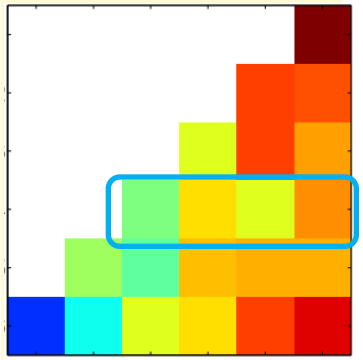
x

x

x







Σ touches

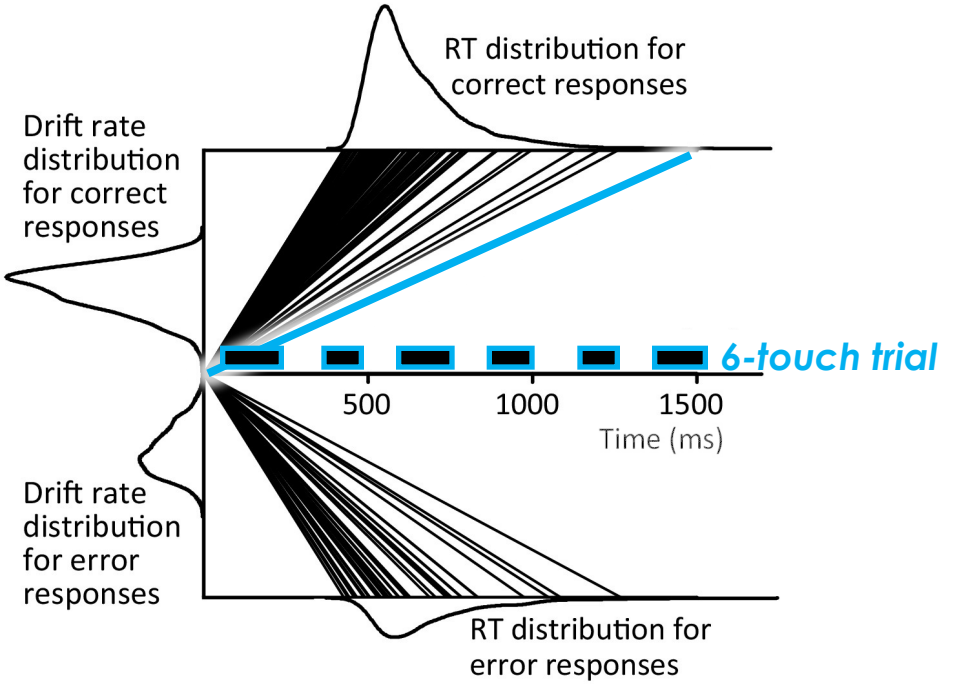
Σ touches

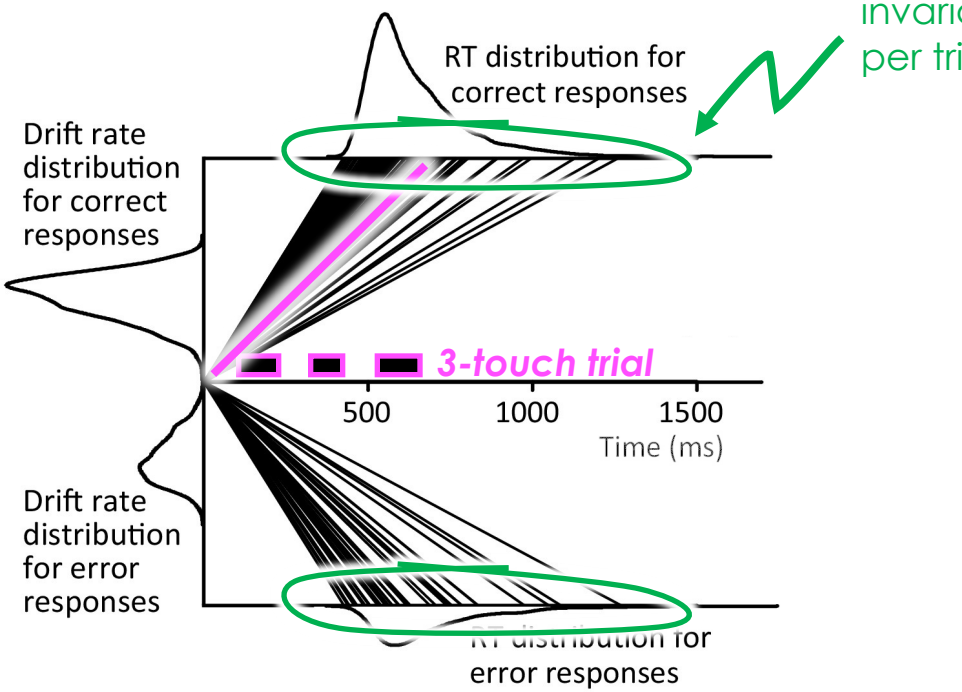
Σ touches

total texture signal/trial

total texture signal/trial

total texture signal/trial

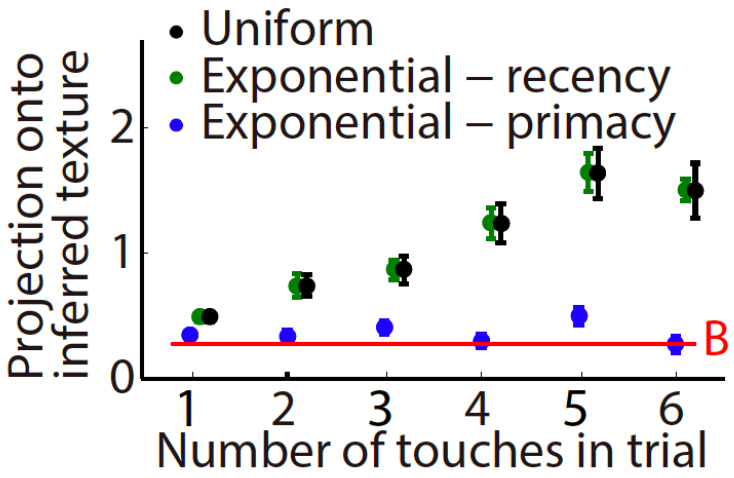




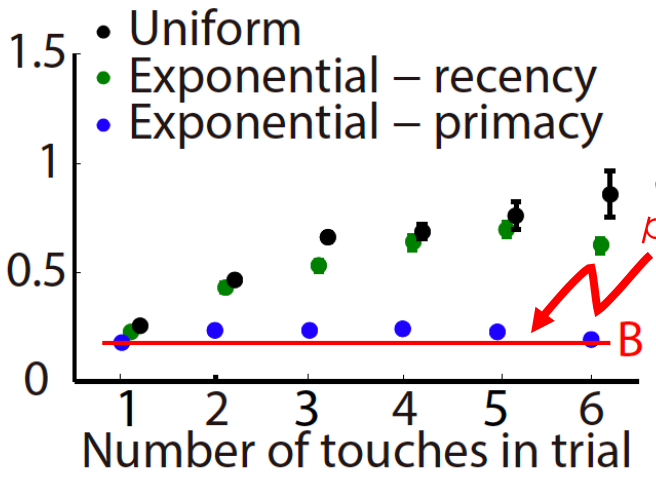
invariant quantity of evidence per trial at time of withdrawal

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

Vibrissal signal

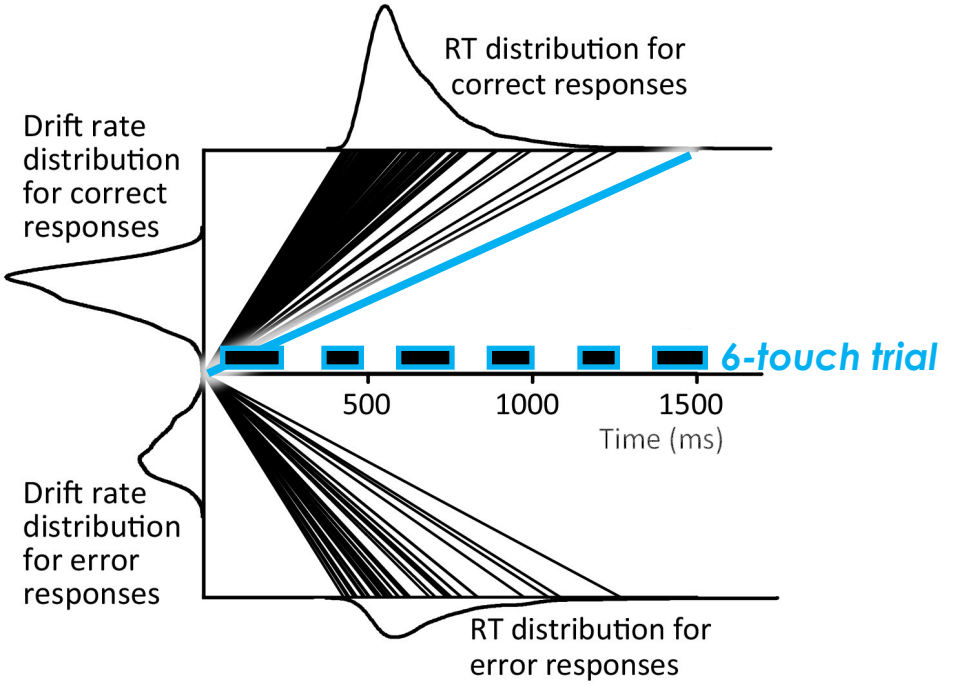


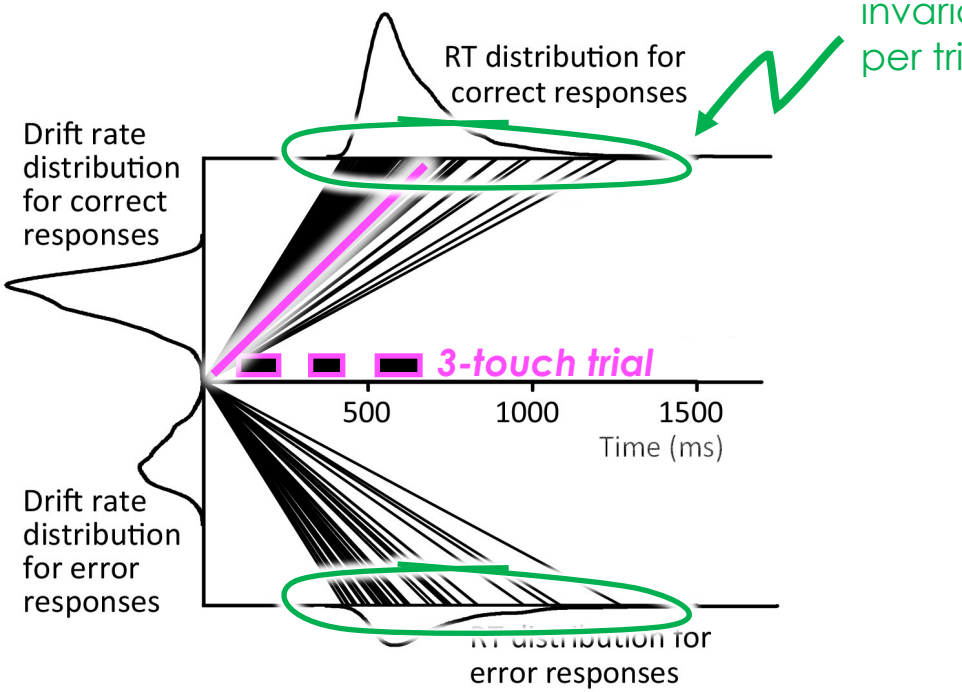
Neuronal signal



decision boundary (B) visible only by exponential primacy

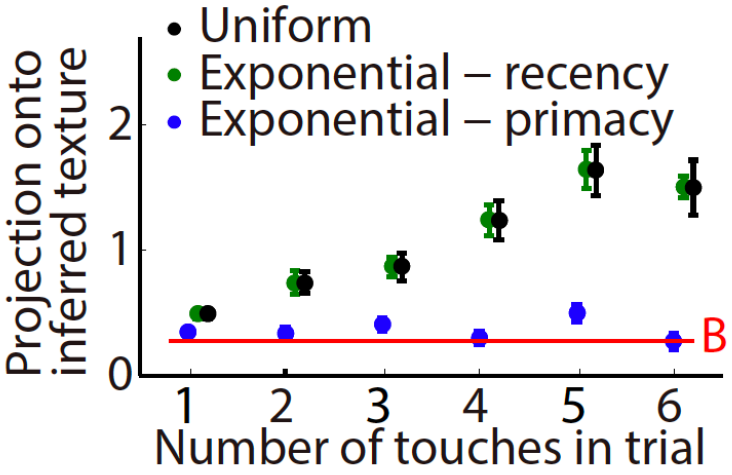
Ratcliff R, Smith PL, Brown SD, McKoon G. (2016)
Diffusion Decision Model: Current Issues and History.
Trends Cogn Sci.

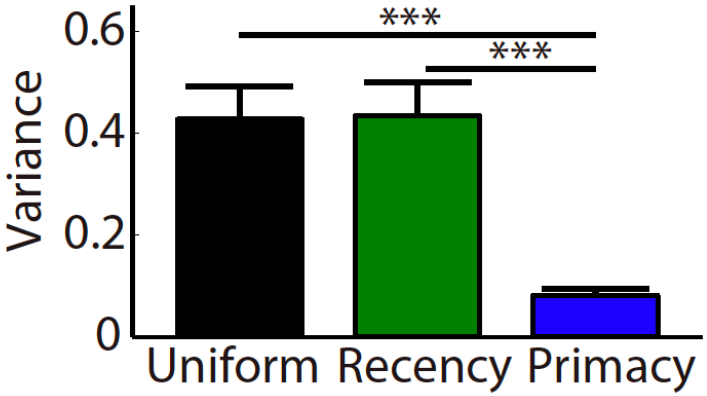




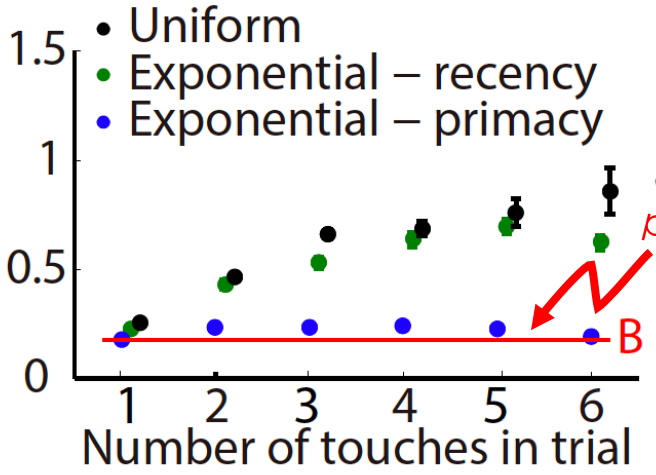
invariant quantity of evidence per trial at time of withdrawal

Vibrissal signal

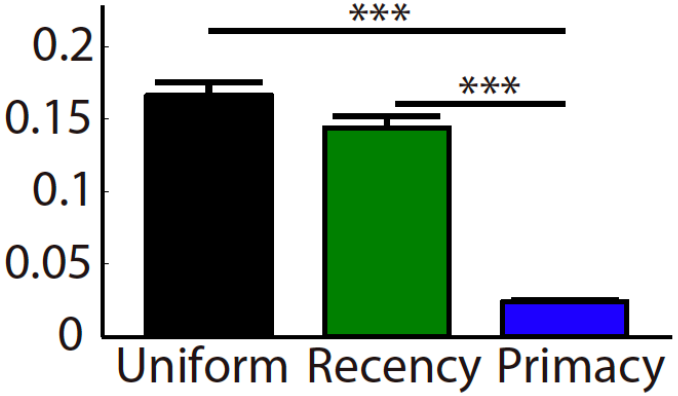




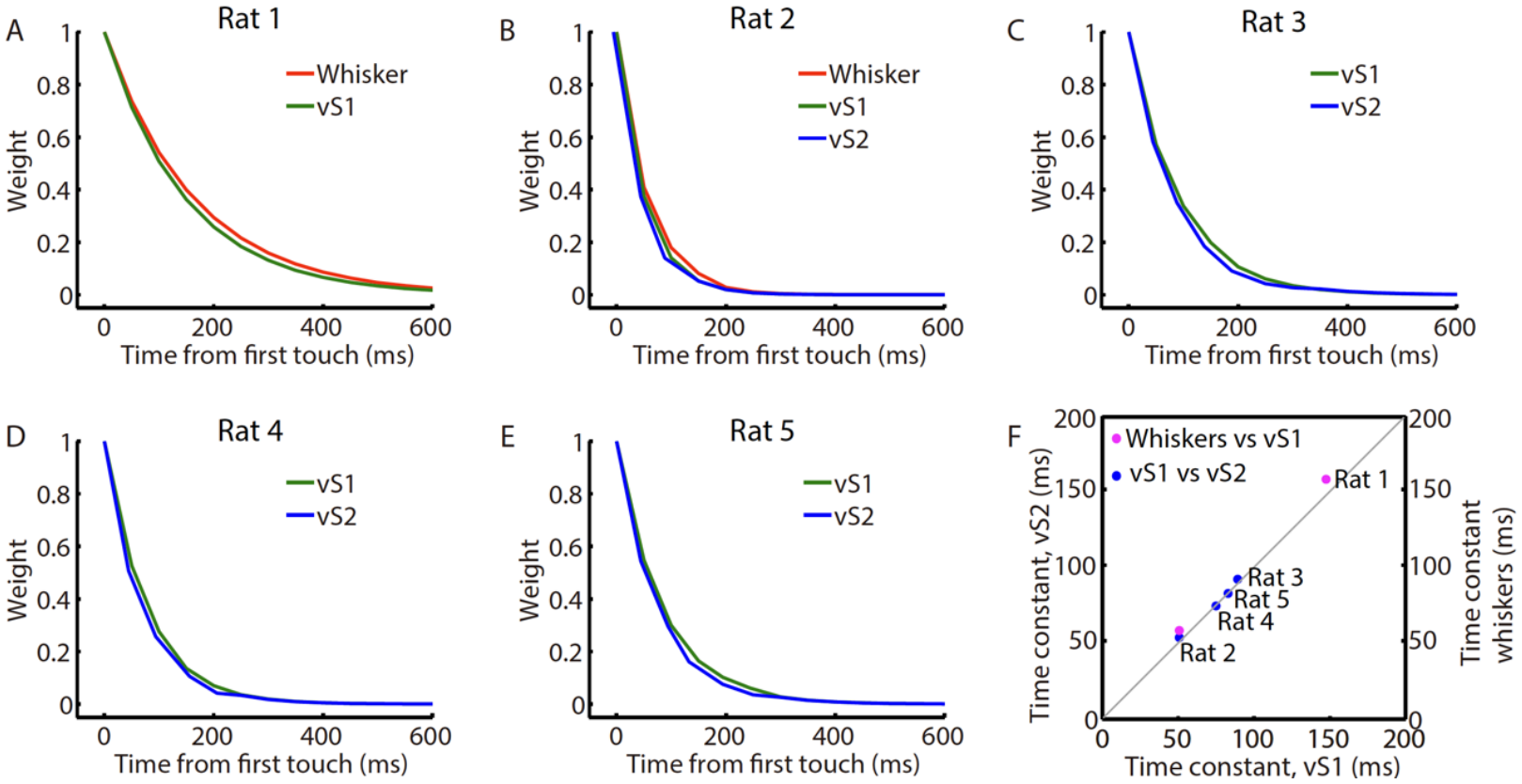
Neuronal signal



decision boundary (B) visible only by exponential primacy



Within individual rat, vibrissal and cortical time constants are perfectly matched.
This tells us that vS1 and vS2 do not accumulate vibrissal signals, they distribute them. Signals are integrated downstream.



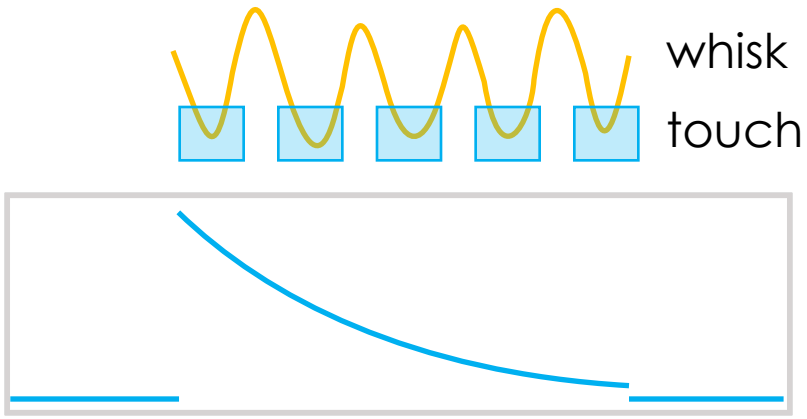
This experiment extends the major model for making choices with complex sensory data – evidence accumulation to boundary – in 3 directions:

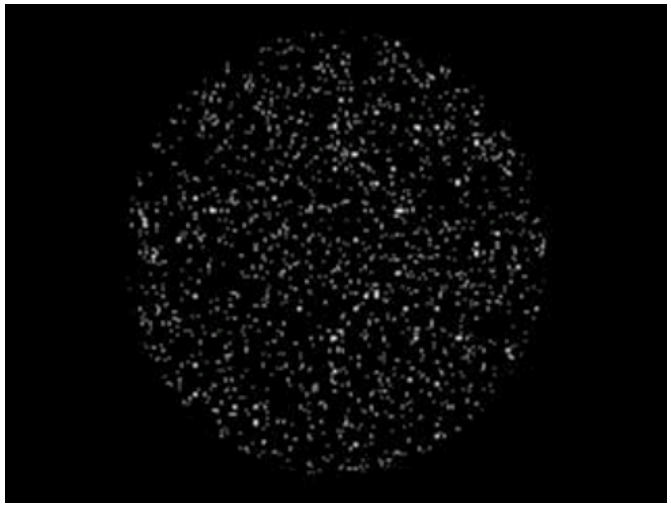
- in new modality – touch
- in new mode of sensing – active generative sensing
- in non primate

REFLECTIONS

Strong weighting of initial evidence – "primacy" – has also been noted in detecting visual dot motion direction in primates (Kiani et al., 2008). Likely in olfaction as well.

Given the radically different states of the sensorimotor system when it is generating stimuli as opposed to receiving stimuli, the equivalence of the temporal integration profile suggests primacy is a general principle.

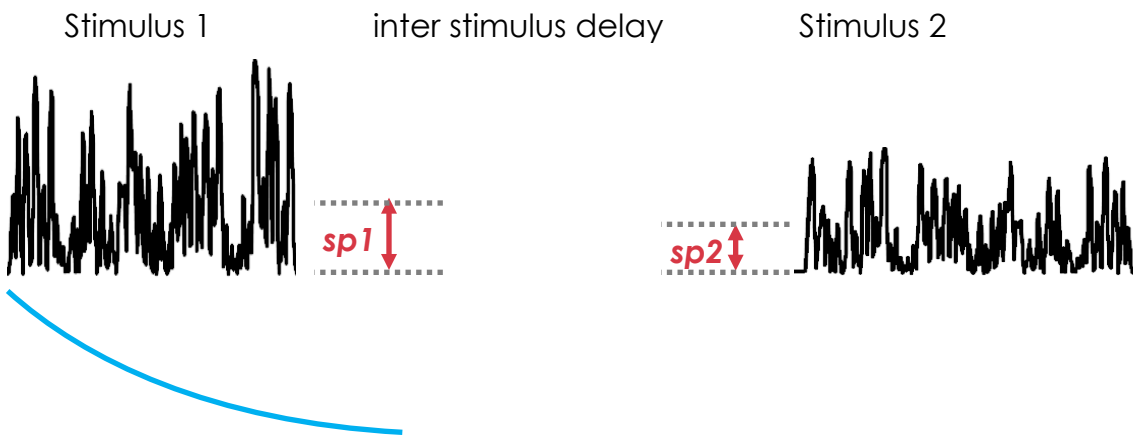




REFLECTIONS

When rats receive a stochastic whisker vibration and must judge its amplitude, they "weigh" the evidence (stream of sensed amplitudes) by exponentially weighted primacy

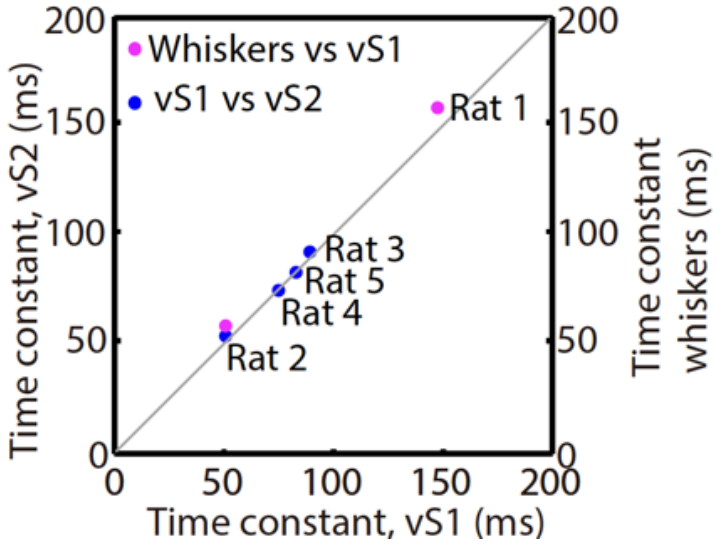
Also humans with the finger tip!



The integration time course uncovered in the current study shares the weighting function, $e^{-t/\tau}$, with vibration perception; even the range of values of the time constant across subjects is similar, from about 50-150 ms.

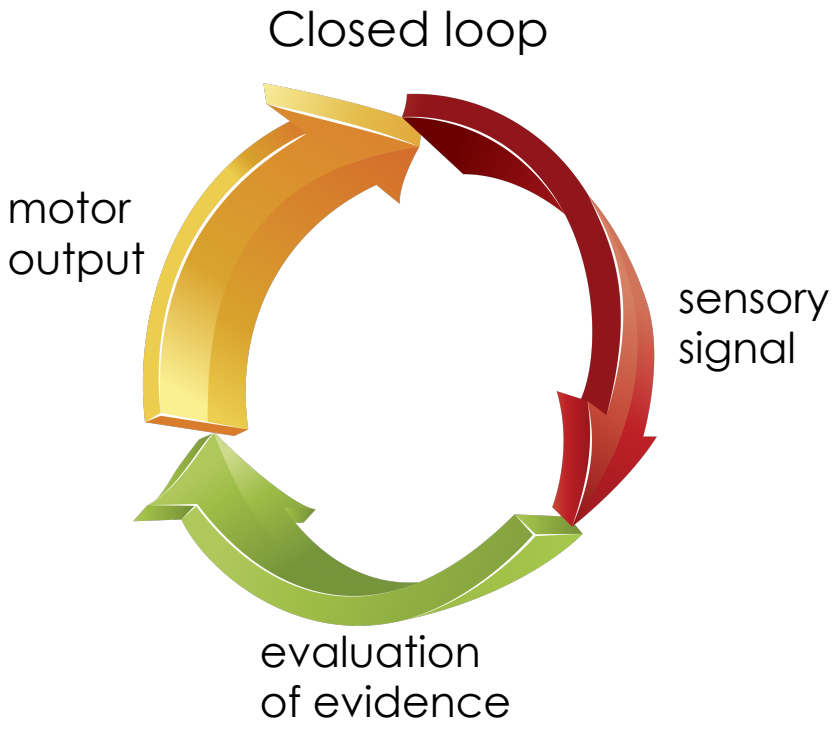
REFLECTIONS

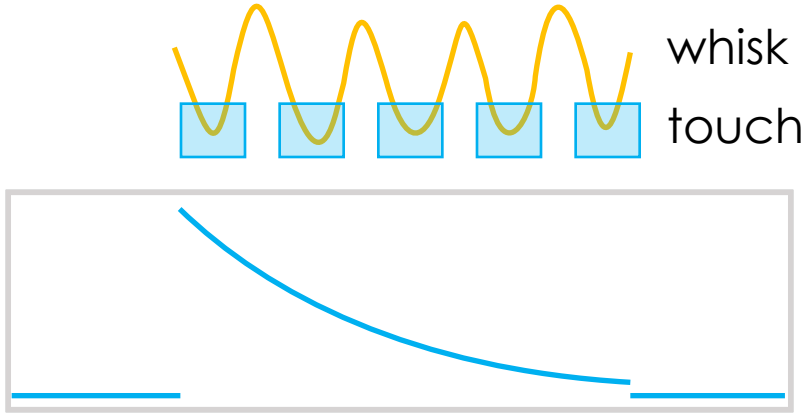
speed/accuracy tradeoff

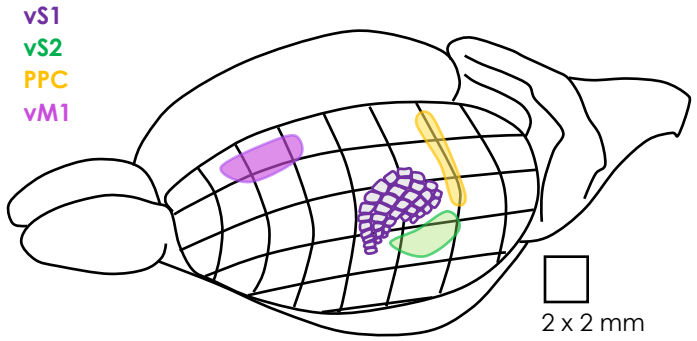


REFLECTIONS

In the texture perception experiment, the feedback loop is very fast, order of 50 ms.







REFLECTIONS

The rats know what they know.

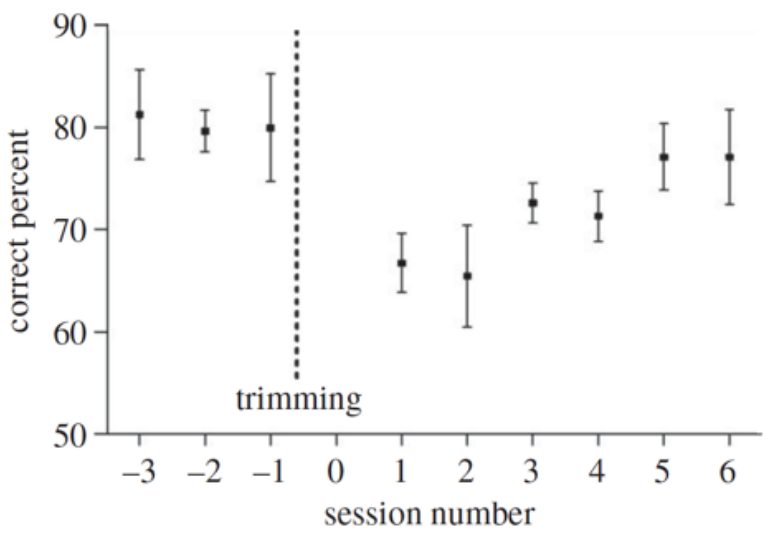
PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B

Phil. Trans. R. Soc. B (2011) **366**, 3058–3069
doi:10.1098/rstb.2011.0161

Research

Whisking and whisker kinematics during a texture classification task

Yanfang Zuo, Igor Perkon and Mathew E. Diamond*



thanks for your attention