



[PERCEPTUAL] DECISION MAKING

Rony Paz



Challenges for studying decision making

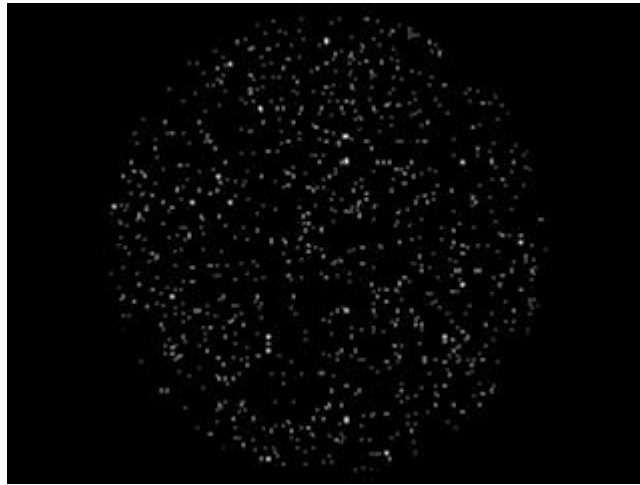
A commitment to a categorical action based on information associated with [valuable] outcomes

- Number of options ($h_1, h_2 \dots$)
- Evidence (e) [Sensory information]
- Noise
- How to combine evidence (e)
- When to commit ($p(h_1|e) \dots$)
- Priors on the state of the world ($p(h_1), p(h_2) \dots$)
- Value of action
- Confidence / certainty

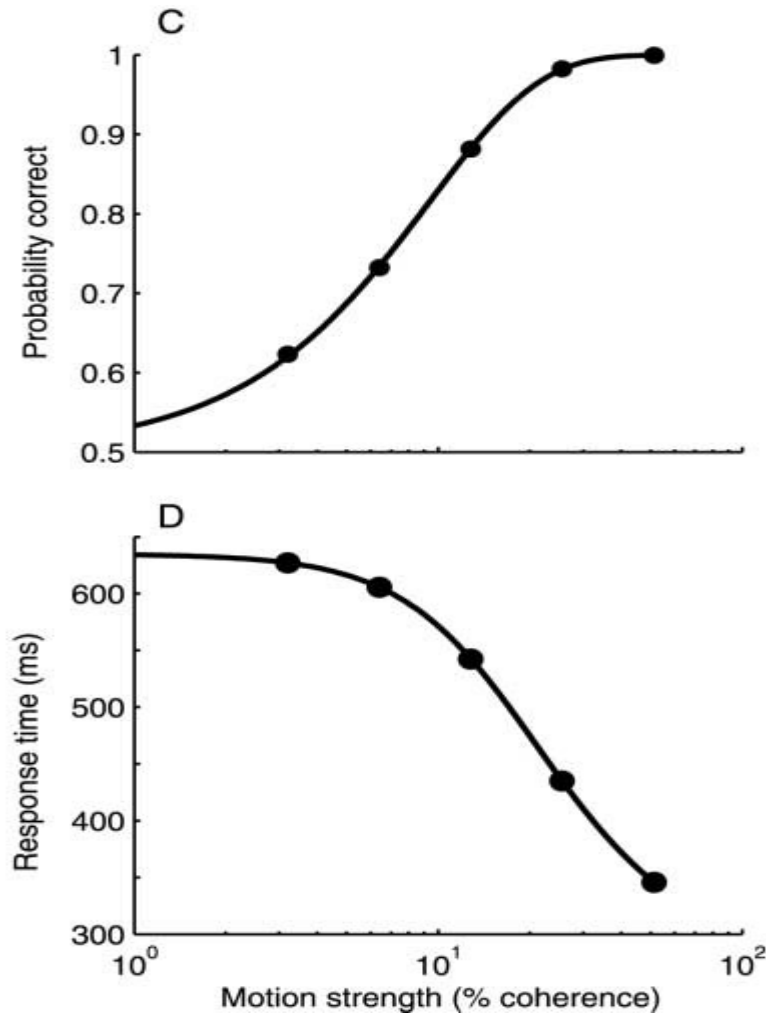
Newsome's random dot task – in
search for the neural basis of
subjective experience (of motion)



1. Random dot task can be made difficult

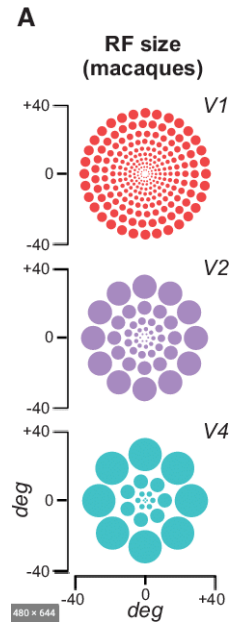
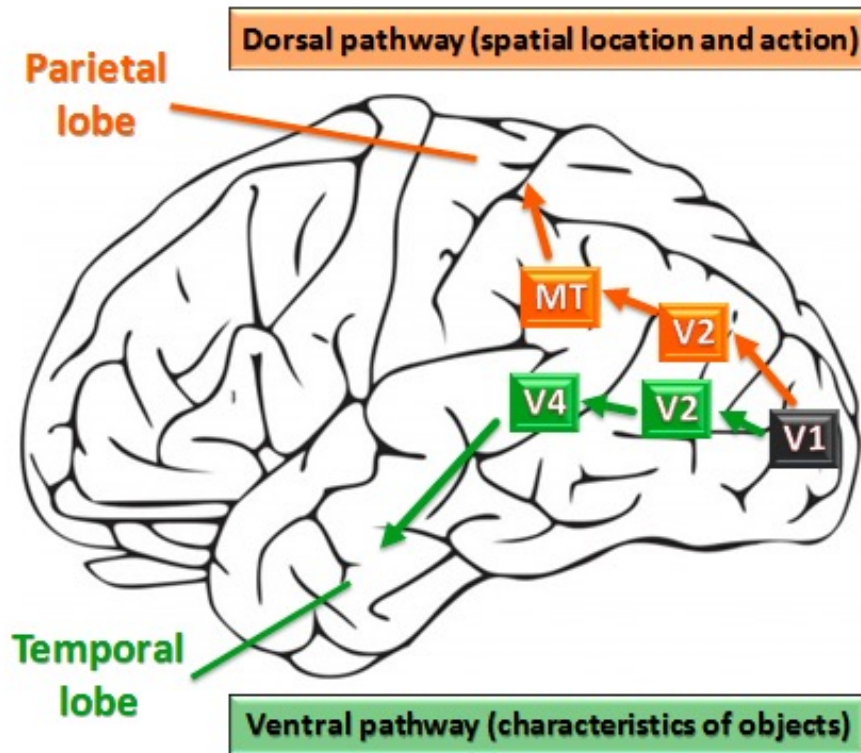


Performance



Sensory evidence

Area MT: motion sensitive neurons



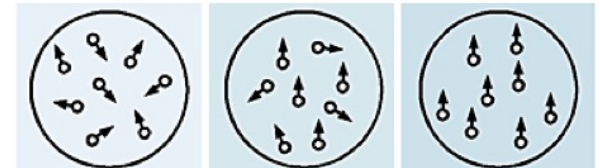
Motion coherence and MT neurons

Motion stimulus

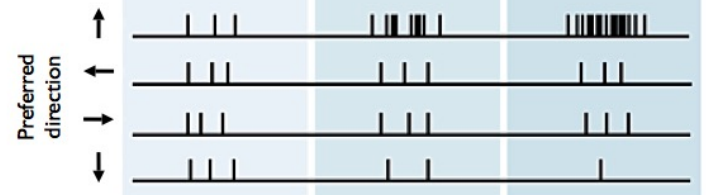
no coherence

50% coherence

100% coherence



Responses of MT neurons

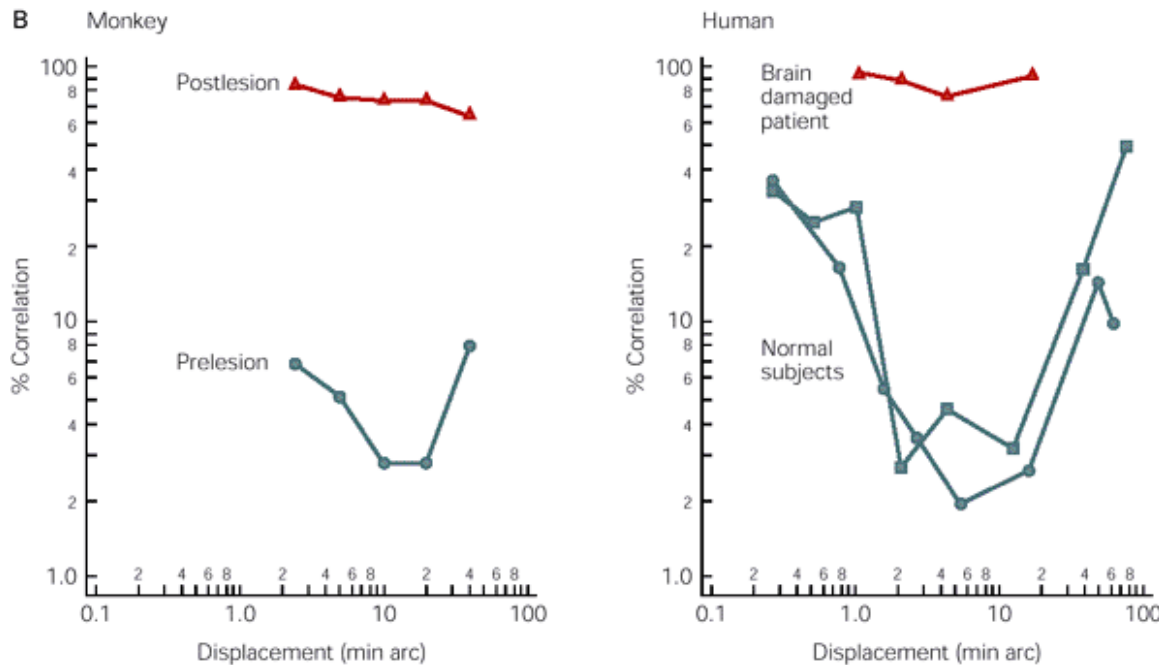
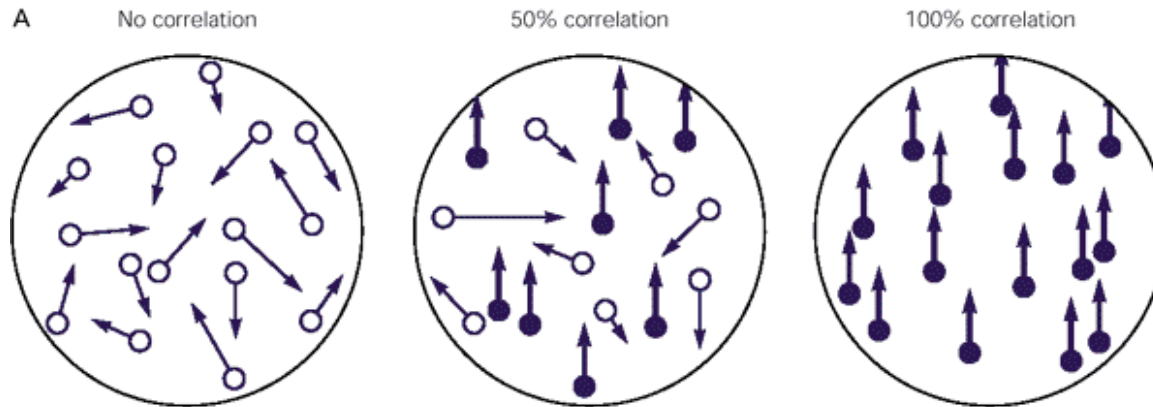


Is it MT (v5) that supplies the evidence?

Performance depends on signals carried by direction-selective cortical neurons.

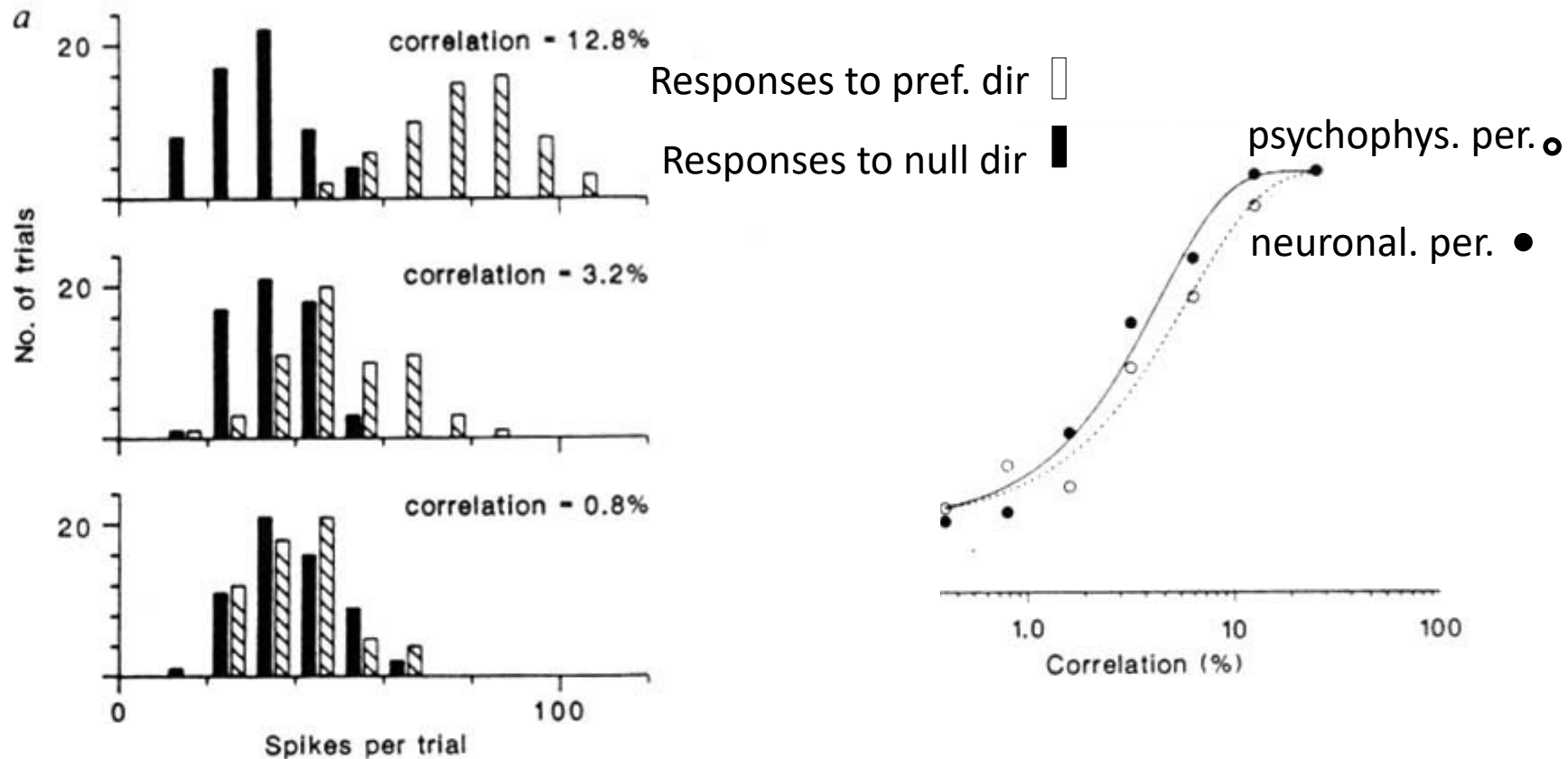
1. Is performance impaired following chemical lesions of MT?
2. Are cortical neurons sufficiently sensitive to the motion signal in to account for psychophysical performance?
3. Can we influence perceptual judgments with electrical micro-stimulation?

Impaired following chemical lesions



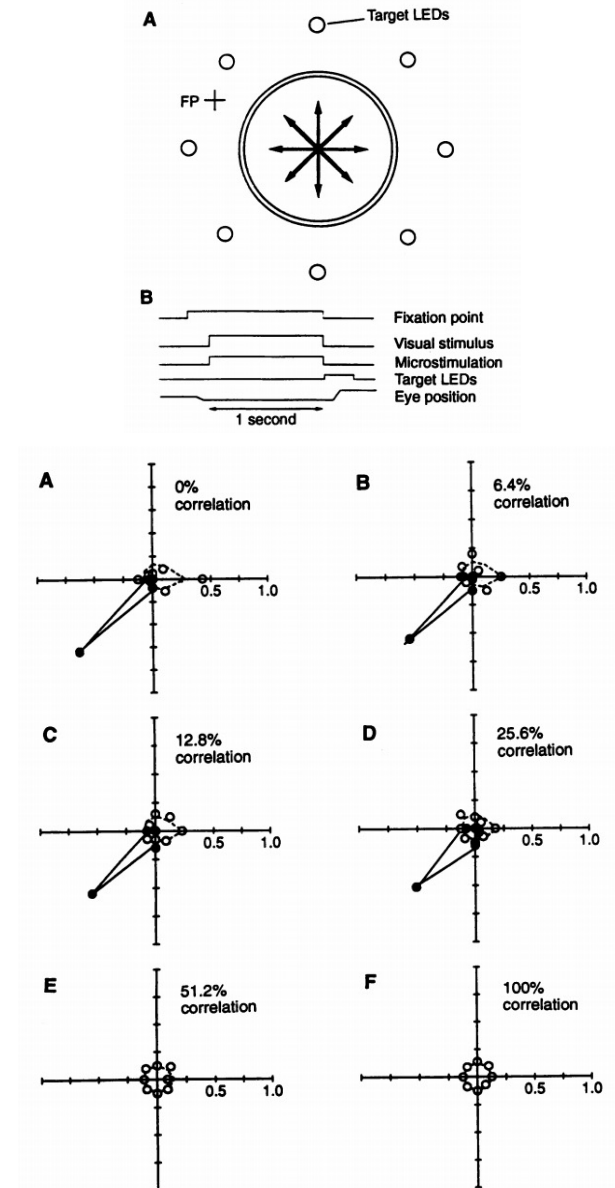
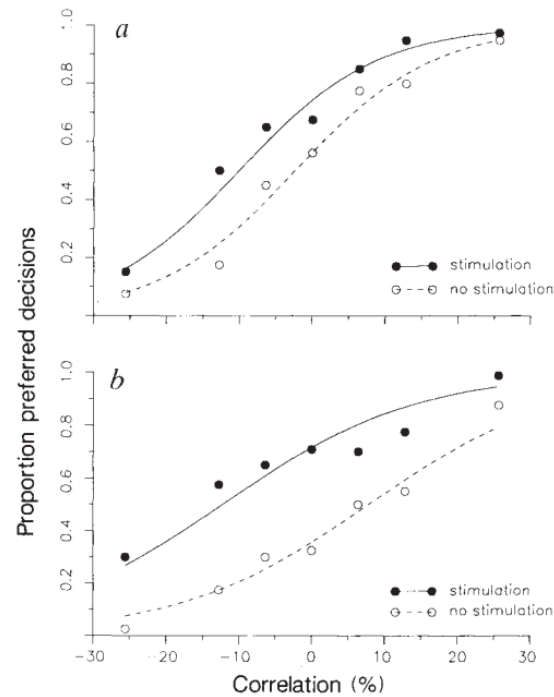
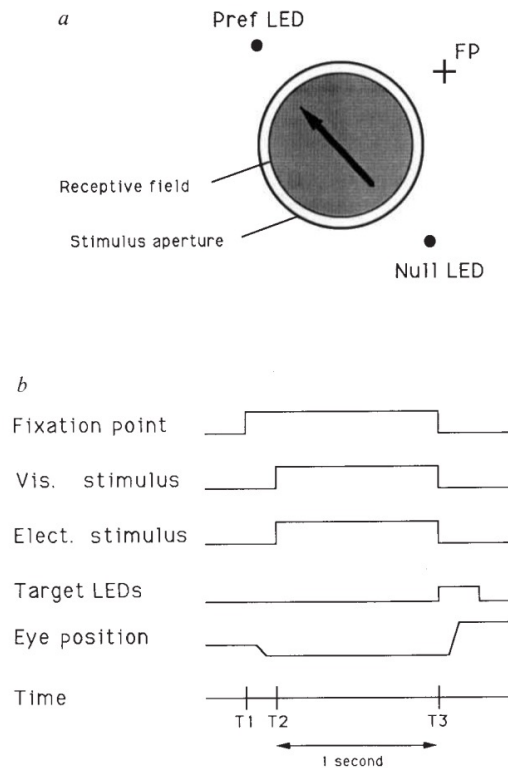
Newsome >1980s...
Shadlen > 1990s

MT neurons' sensitivity and psychophysical performance



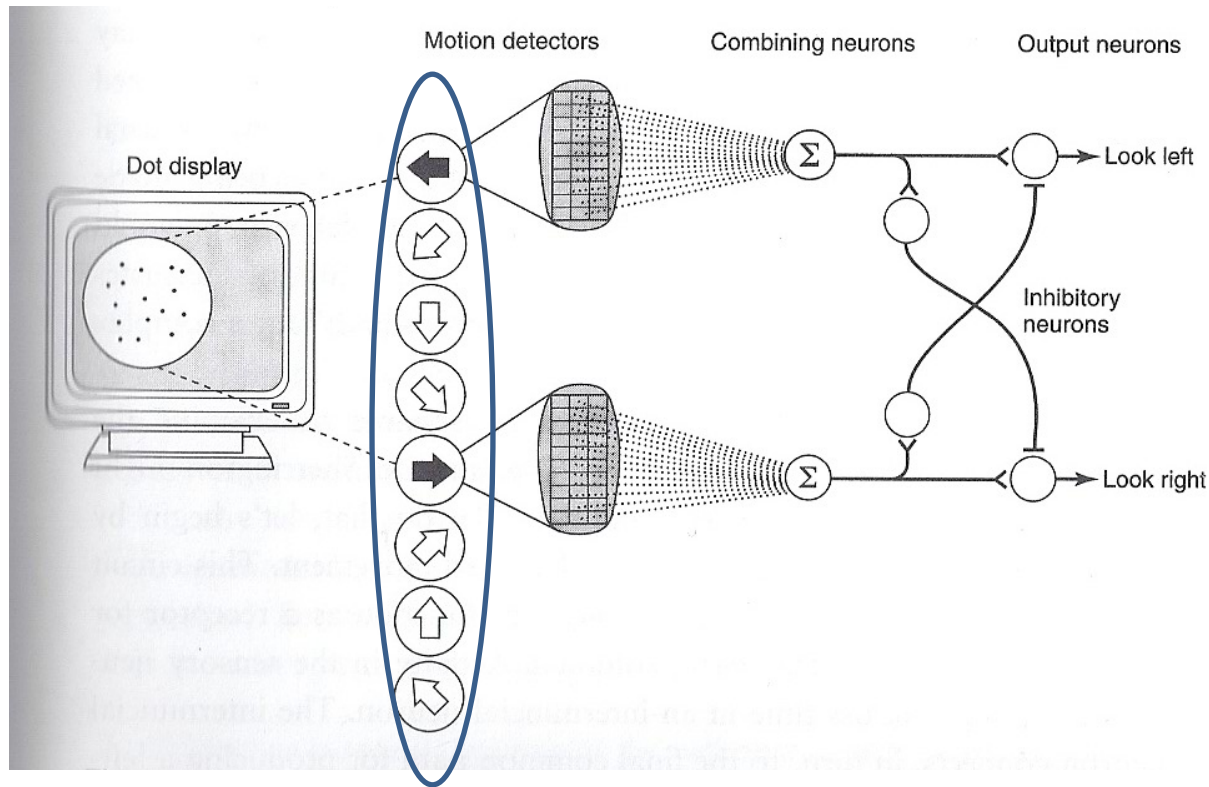
Newsome, Britten and Movshon, 1989

MT microstimulation induces bias



(Salzman and Newsome 1990, 1994.)

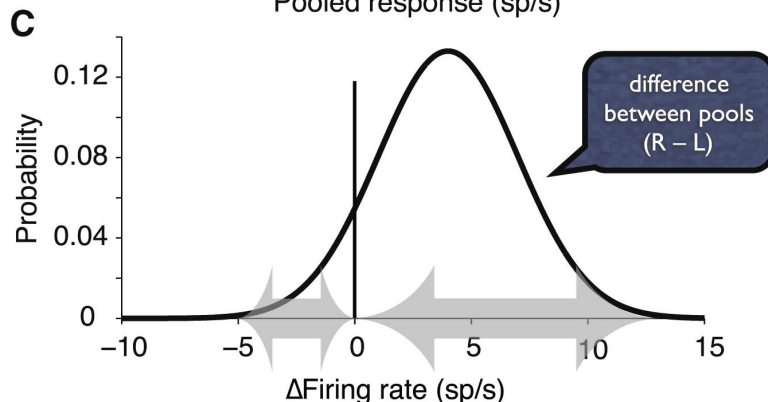
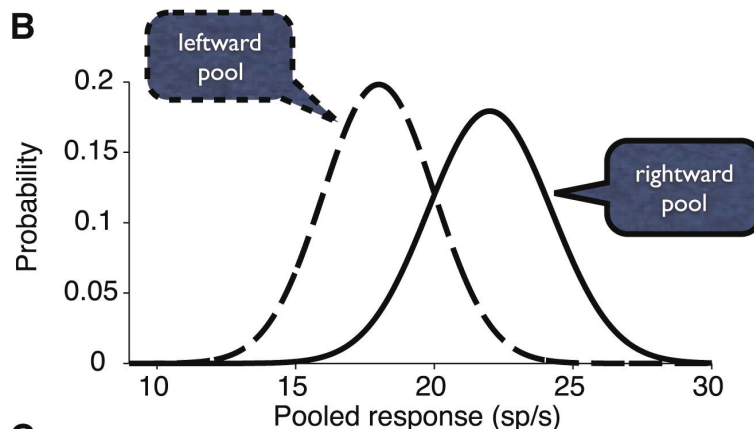
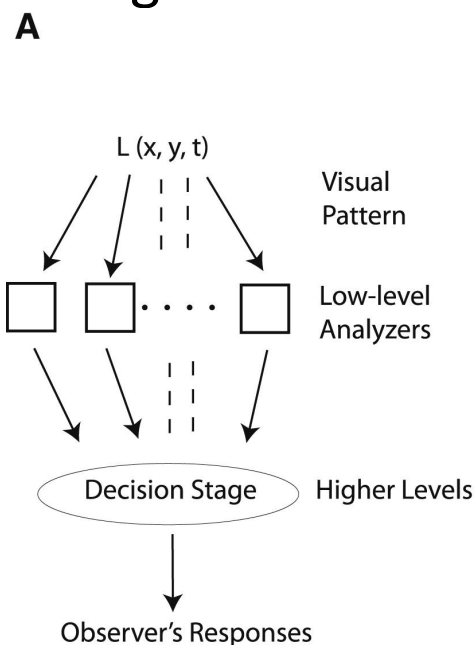
How can this decision happen?



Shadlen et al., 1996

Signal detection theory (SDT)

- Observation of noisy evidence => categorical choice



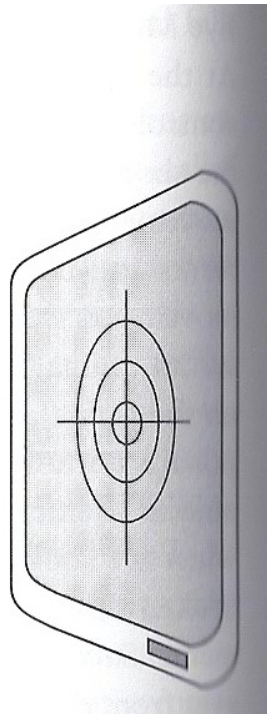
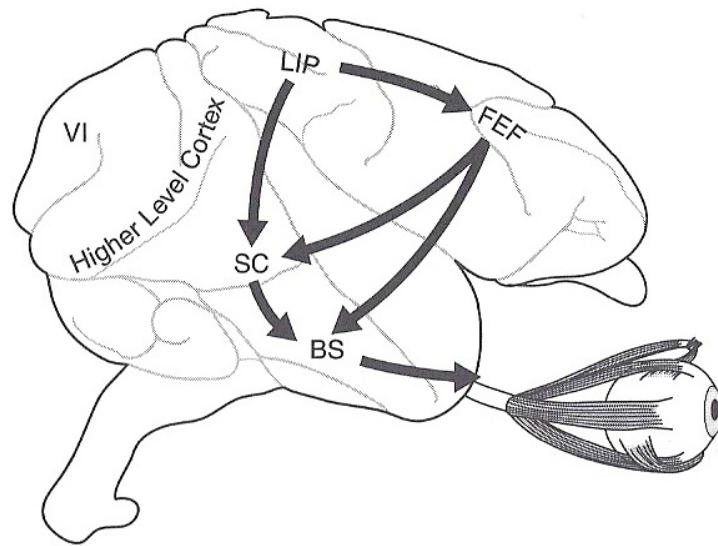
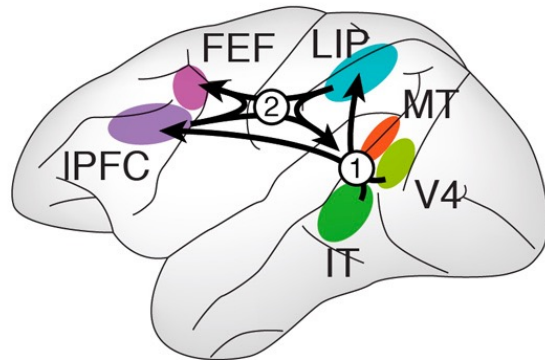
$$\frac{p(e|h1)}{p(e|h2)} > \beta$$

Green & swets 1966

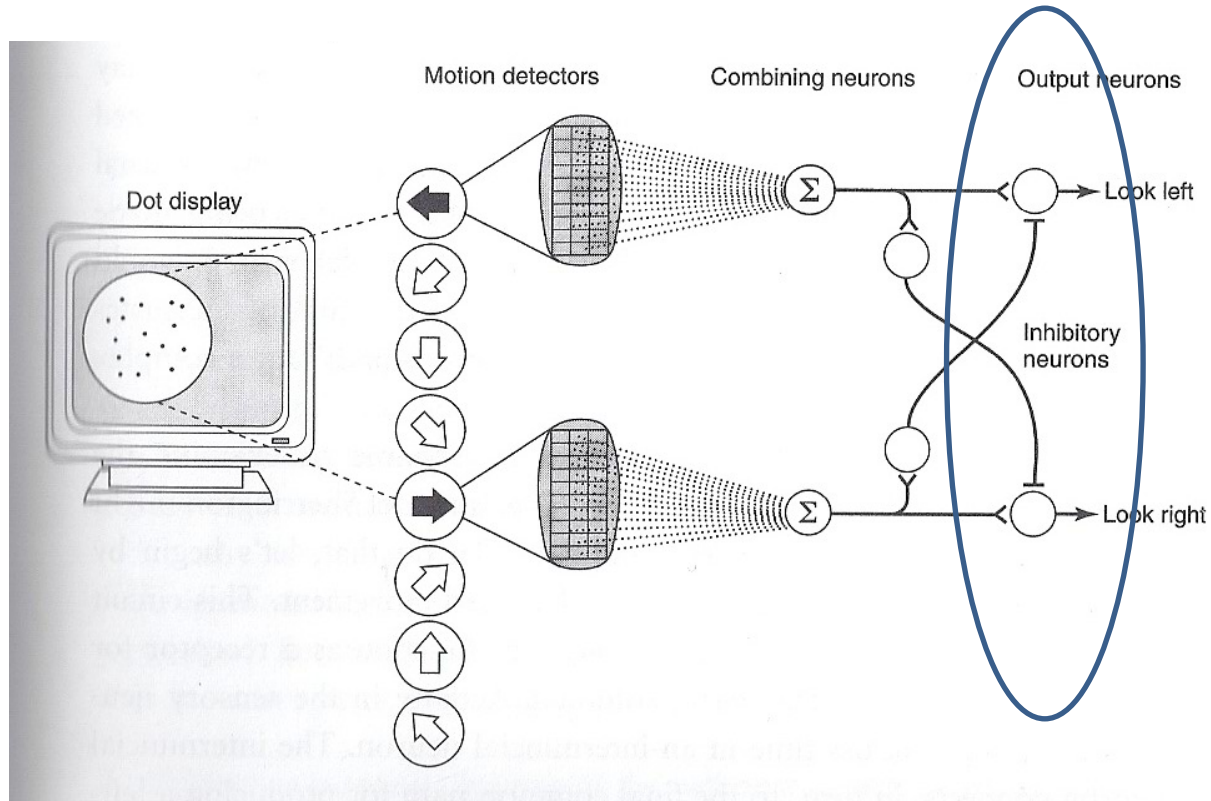
What about time and accumulating evidence?

Shadlen & Kiani, 2013

Command and Saccade production

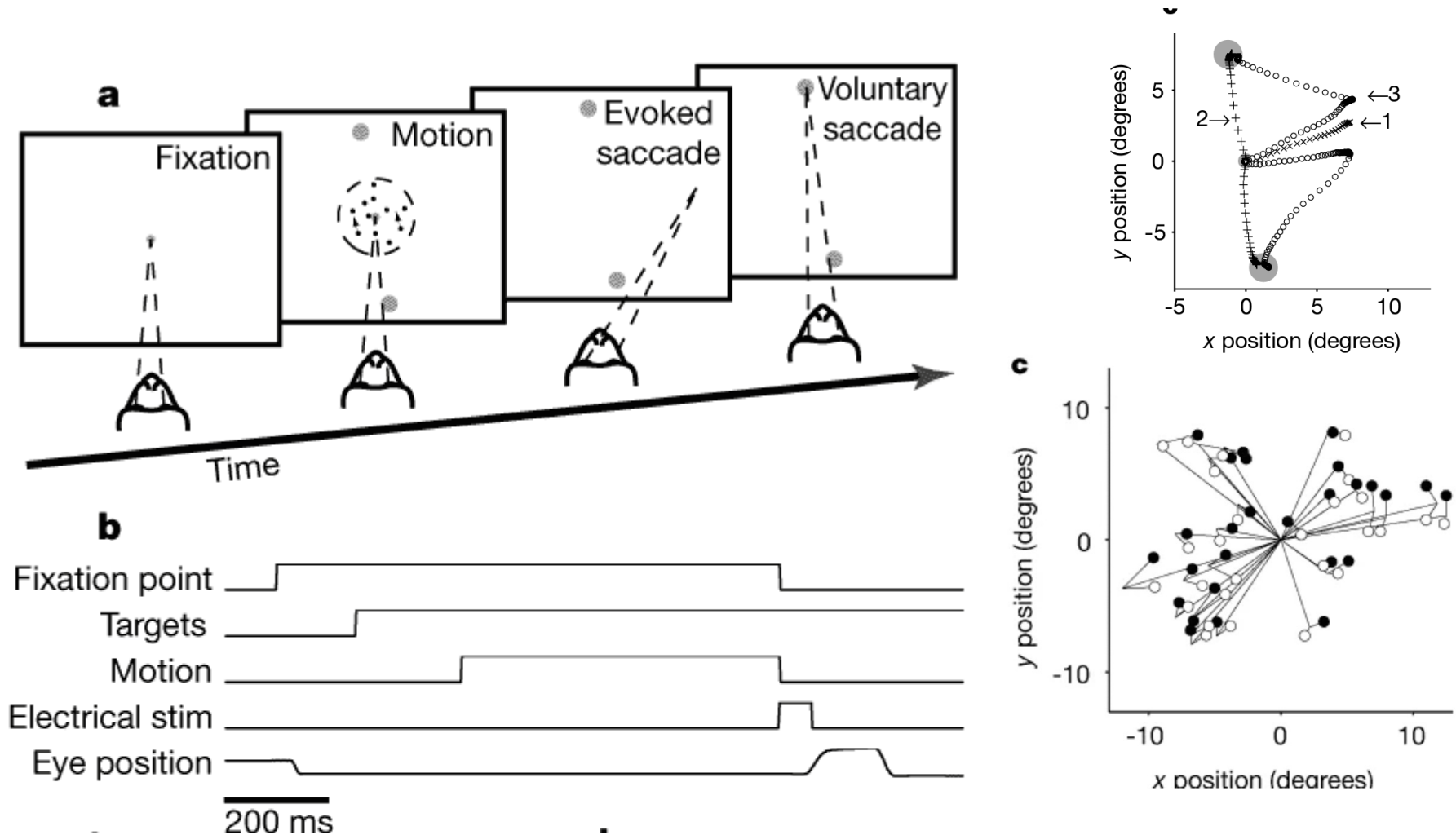


Executing the decision?

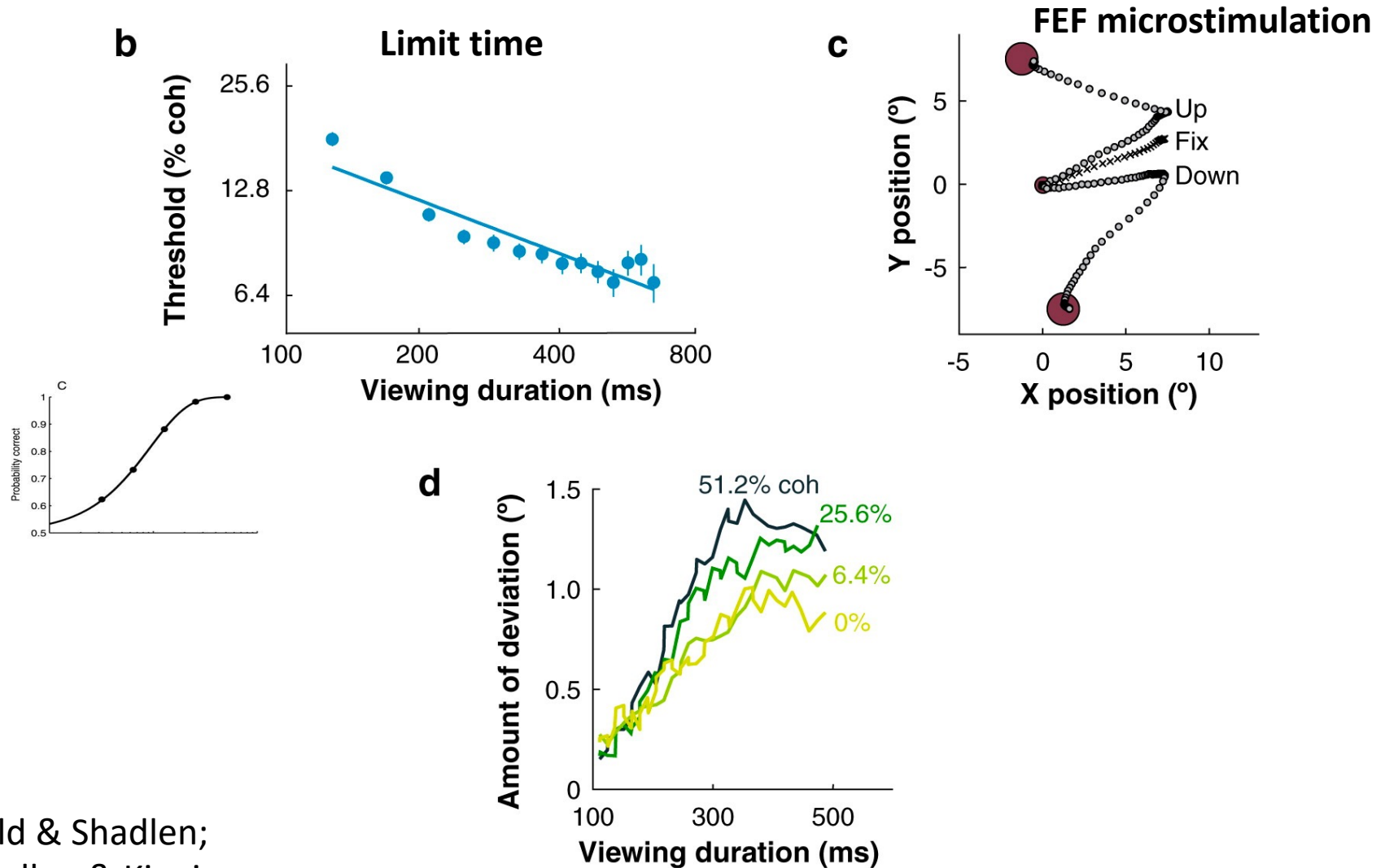


Shadlen et al., 1996

Decision processes revealed by microstimulation in FEF

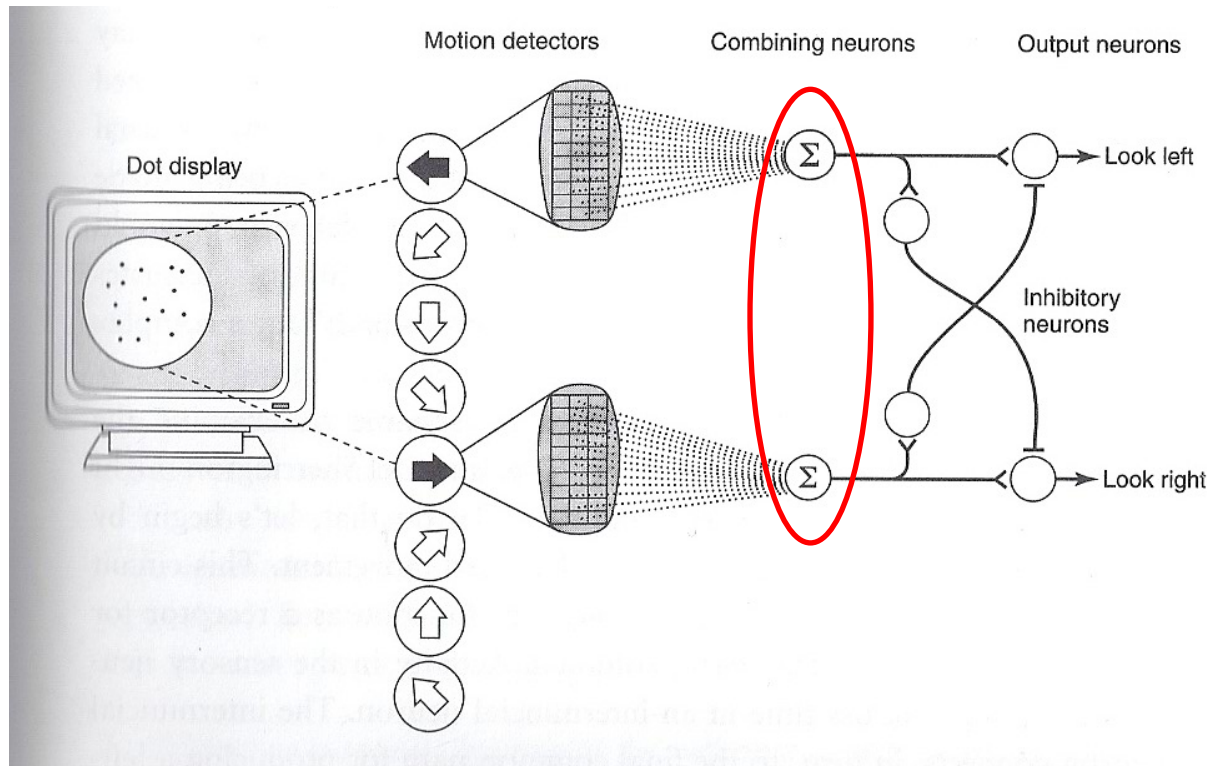


Evoked saccades biased by perception



Gold & Shadlen;
Shadlen & Kiani,

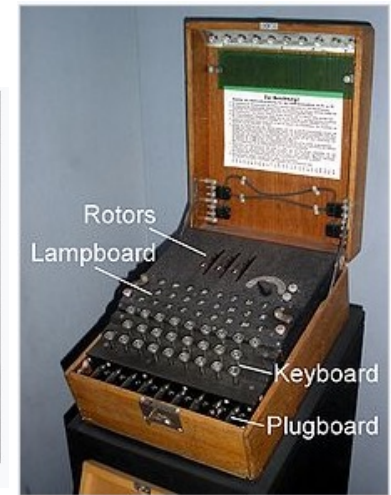
Accumulating evidence?



Sequential analysis (SA): accumulate evidence over time to decide

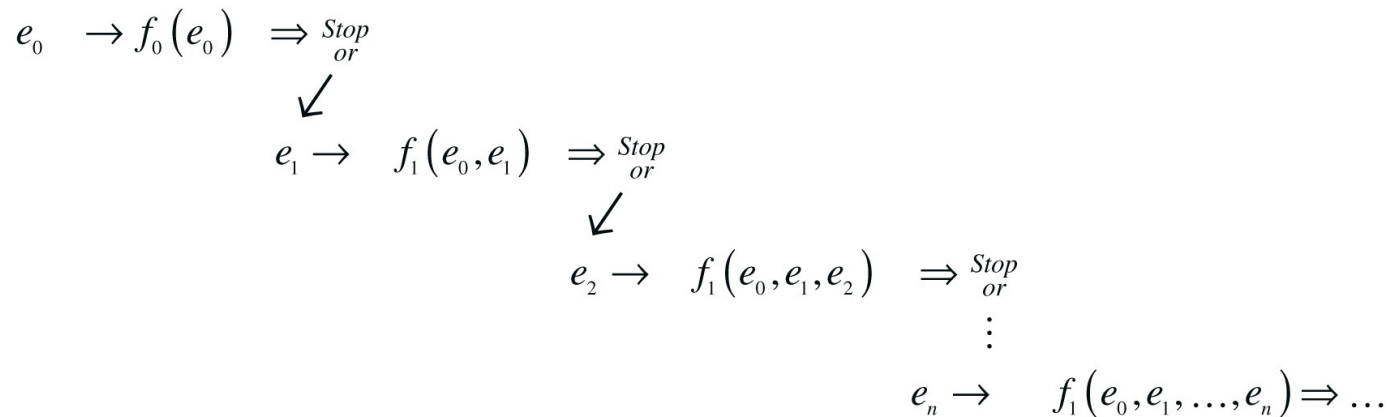
General framework:

1. Generate alternative hypotheses
2. Define the evidence for each hypothesis
3. Update this evidence with new information
4. Form a decision rule for sufficient evidence
5. Perform judgment



The Enigma:
**Are two messages
encoded by the same
machine?**

a Sequential analysis framework



1. Generate alternative hypotheses (machine 1 or 2? Left or right movement?)

2. Define the evidence for each hypothesis

Compute Log likelihood ratio

3. Update evidence with new information

➔ Evidence can be accumulated (Log is additive)

$$\begin{aligned}
 \log LR_{12} &\equiv \log \frac{P(e_1, e_2, \dots, e_n | h_1)}{P(e_1, e_2, \dots, e_n | h_2)} \\
 &= \sum_{i=1}^n \log \frac{P(e_i | h_1)}{P(e_i | h_2)}.
 \end{aligned}$$

4. Form a decision rule

A threshold can be defined to any given accuracy

SPRT (sequential prob. Ratio test)

- Two coins are identical except that one is fair and the other is a trick coin, weighted so that heads appears on 60% of tosses, on average.
We can base our decision on a series of any amount of tosses.
- In **SPRT** each observation (toss) e_i is converted to a weight of evidence, the logLR in favor of the trick coin hypothesis. There are only two possible values of evidence, heads or tails, which give rise to weights (w_i):

$$w_i = \begin{cases} \log \frac{P(e_i = \text{heads} | h_1 : \text{trick coin})}{P(e_i = \text{heads} | h_2 : \text{fair coin})} \\ \quad = \log \frac{0.6}{0.5} = 0.182 & \text{if heads} \\ \log \frac{P(e_i = \text{tails} | h_1 : \text{trick coin})}{P(e_i = \text{tails} | h_2 : \text{fair coin})} \\ \quad = \log \frac{0.4}{0.5} = -0.223 & \text{if tails} \end{cases}$$

- The decision variable (DV) is the running sum (accumulation) of the weights.

$$y_n = \sum_{i=1}^n w_i$$

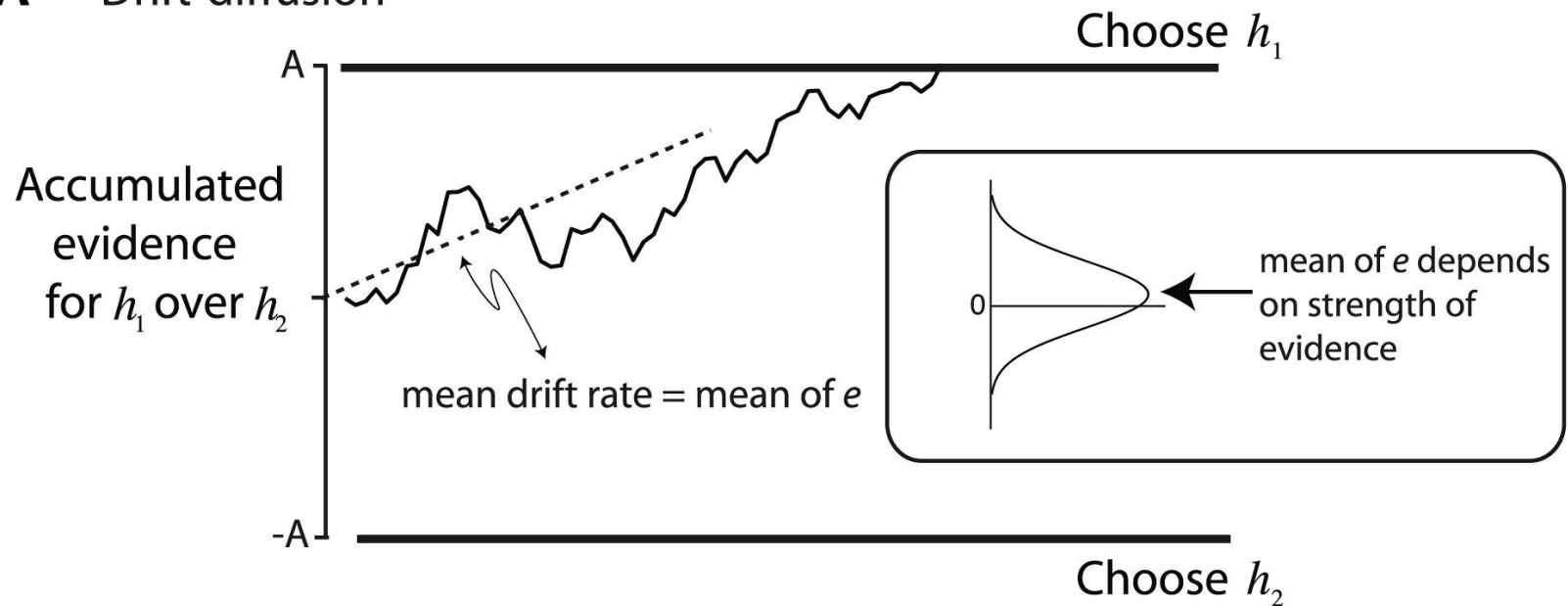
- We apply the following rules:

$$\begin{aligned} &\text{if } y_n \geq \log \frac{1 - \alpha}{\beta} \text{ answer "trick"} \\ &\text{if } y_n \leq \log \frac{\alpha}{1 - \beta} \text{ answer "fair"} \\ &\text{if } \log \frac{\beta}{1 - \beta} < y_n < \log \frac{1 - \alpha}{\alpha} \text{ get more evidence} \end{aligned}$$

- where α is the probability that a fair coin will be misidentified [i.e., a type I error: $P(H_1 | h_2)$] and β is the probability that a trick coin will be misidentified [a type II error: $P(H_2 | h_1)$].
For example, if $\alpha = \beta = 0.05$, then the process stops when $|y_n| \geq \log(19)$. The criteria can be viewed as bounds on a random walk. To achieve a lower rate of errors, the bounds must be moved further from zero, thus requiring more samples of evidence, on average, to stop the process.

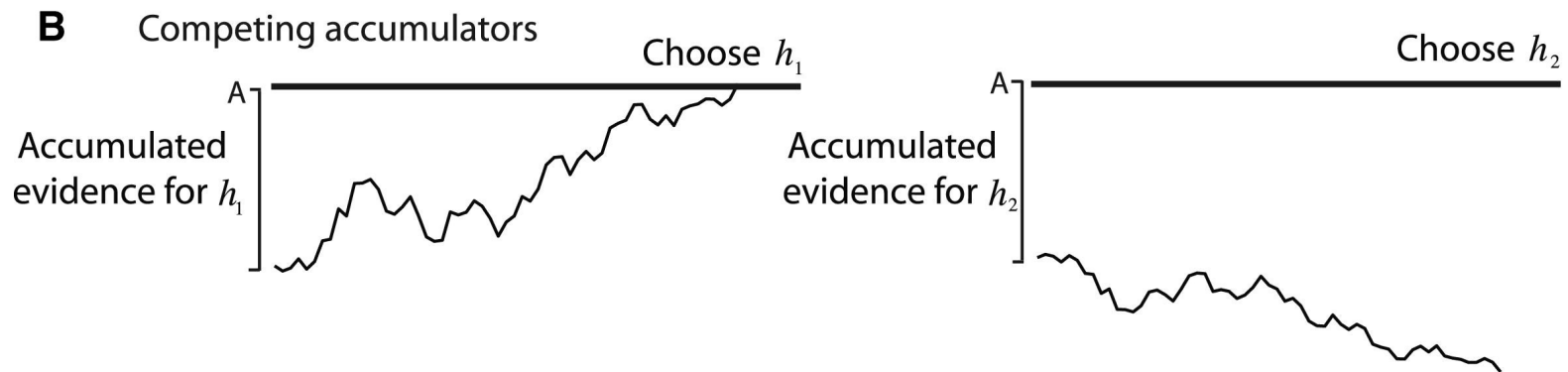
Drift-diffusion models

A Drift-diffusion

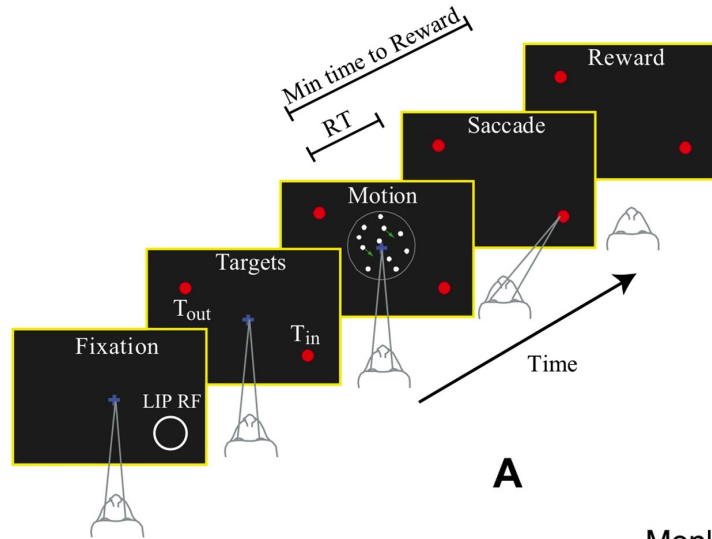


N options ...

Race model

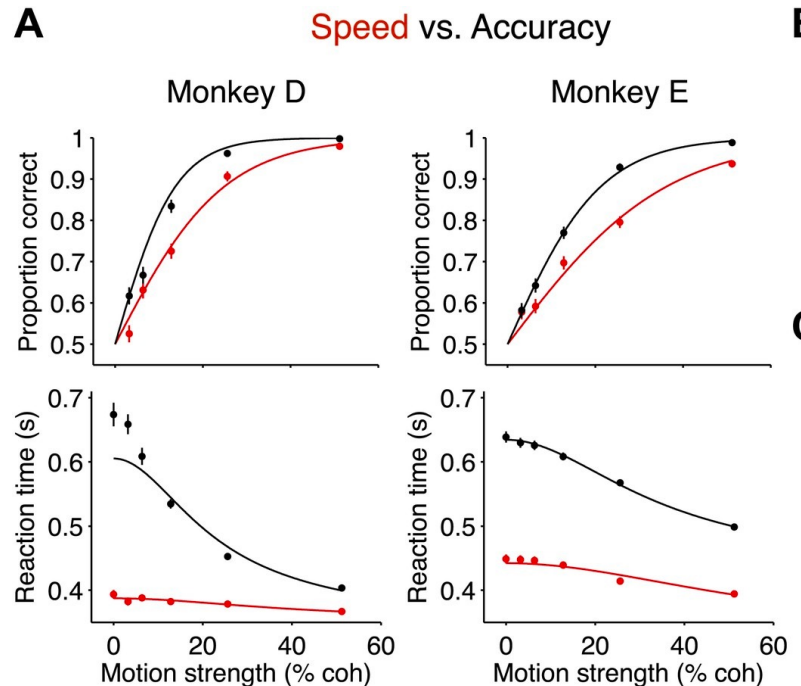


Speed-accuracy tradeoff

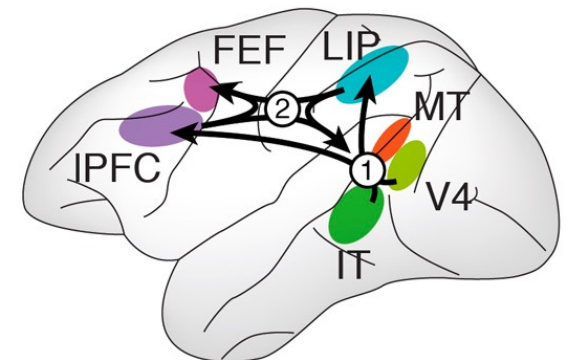
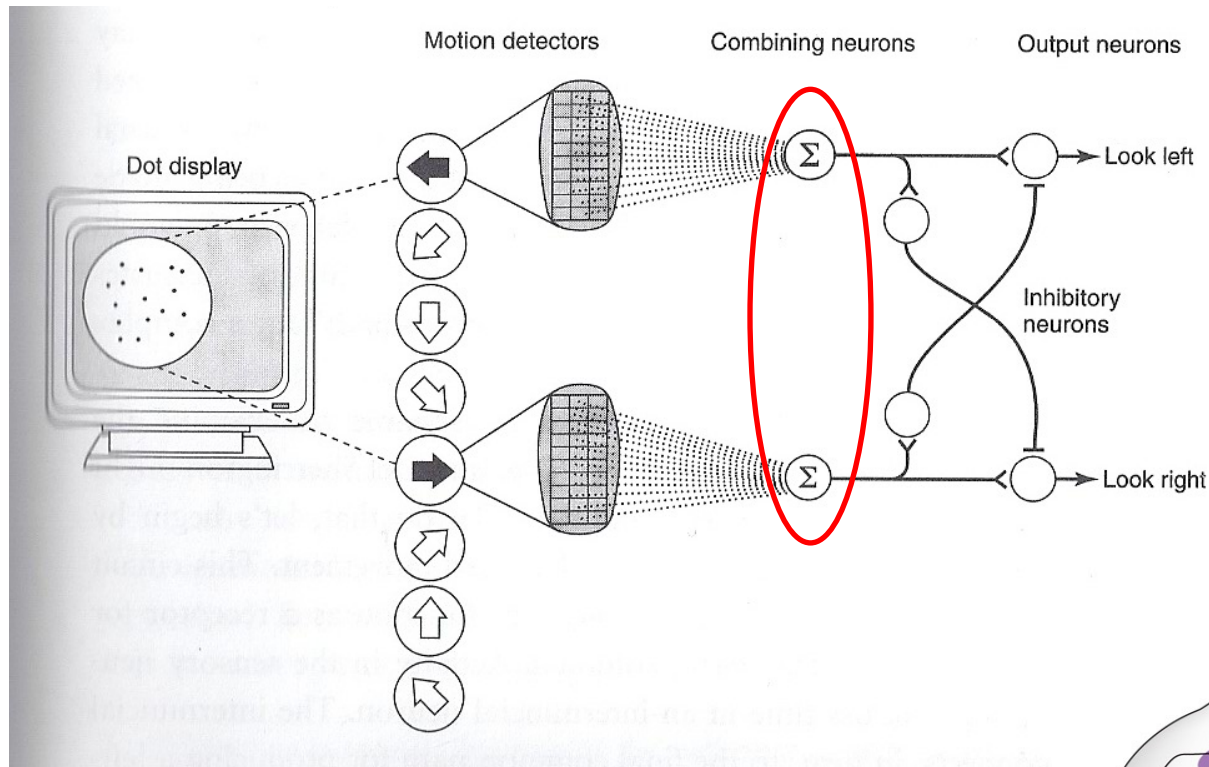


To encourage **speed**, reward the monkey immediately after each correct response, since monkeys are naturally inclined to make fast responses (at the expense of accuracy).

To encourage **accuracy**, reward was delayed so that fast responses involved additional wait until delivery of reward

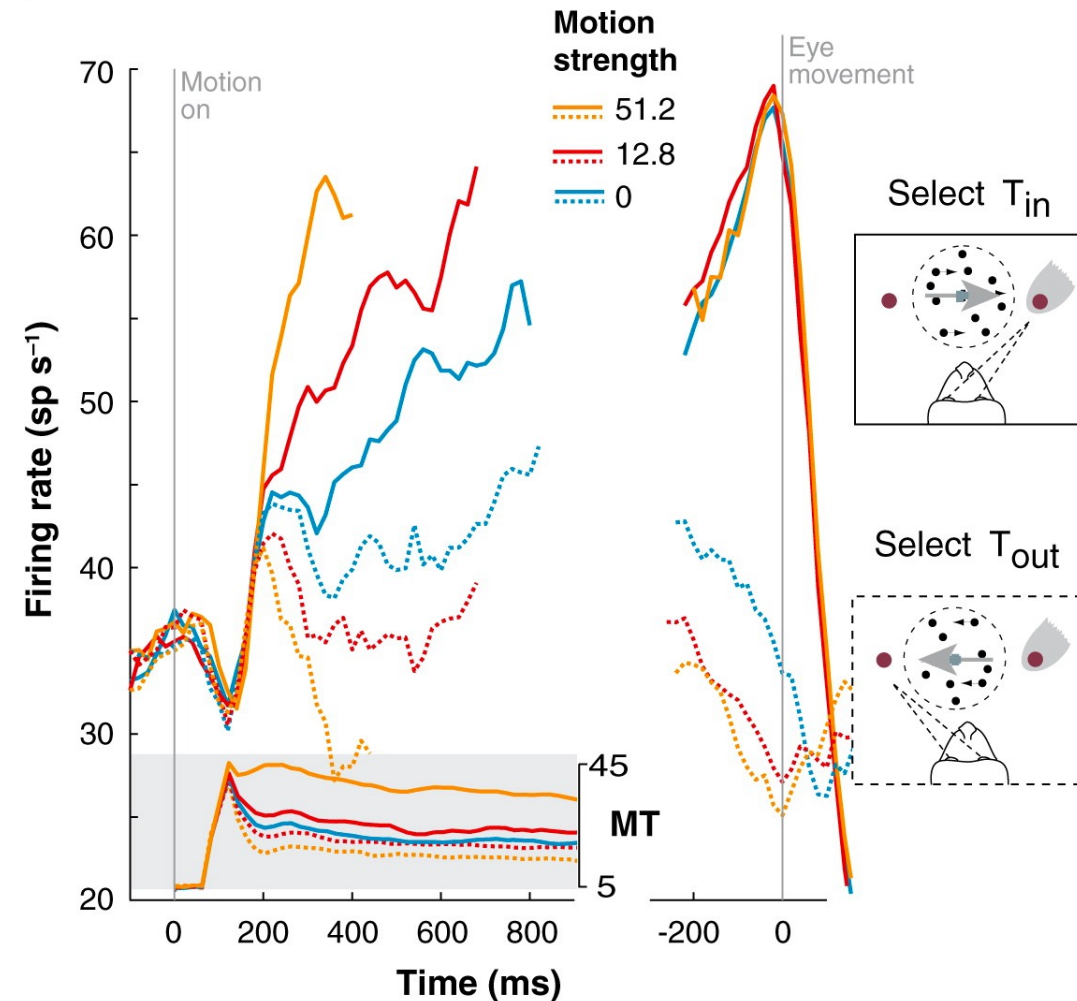


Accumulating evidence?

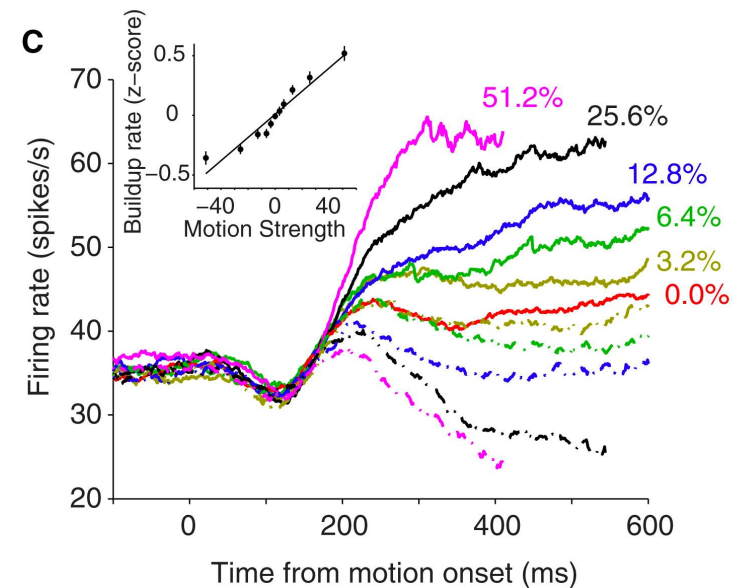


LIP neurons in reaction time task

c

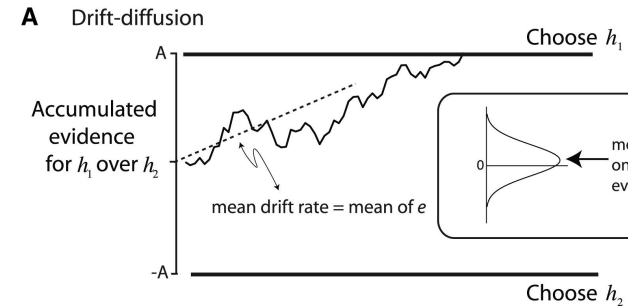
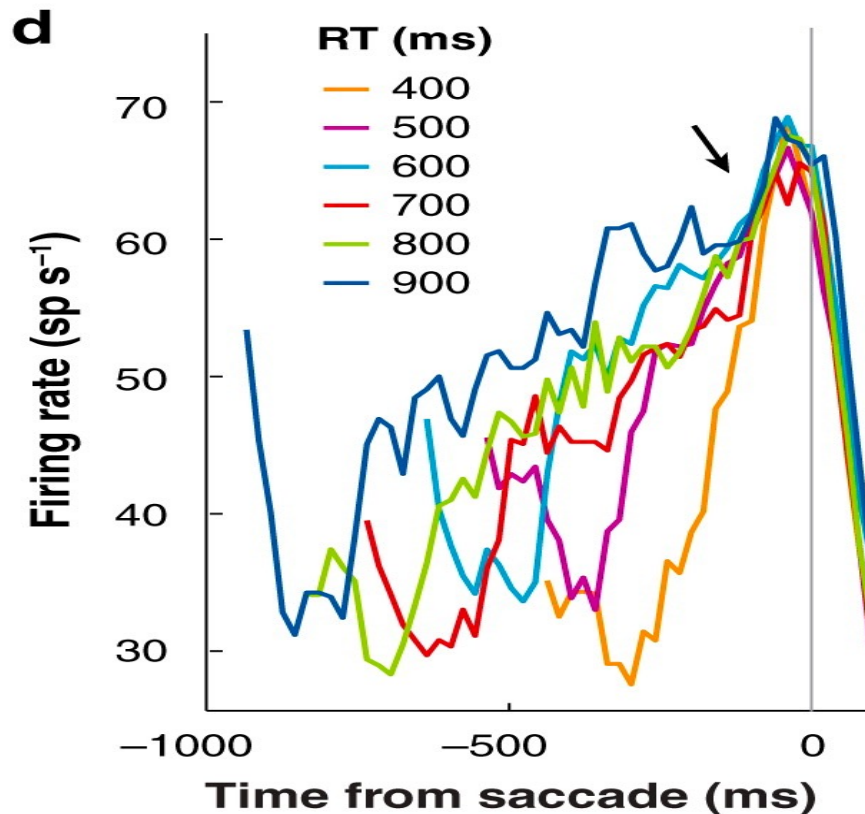


c

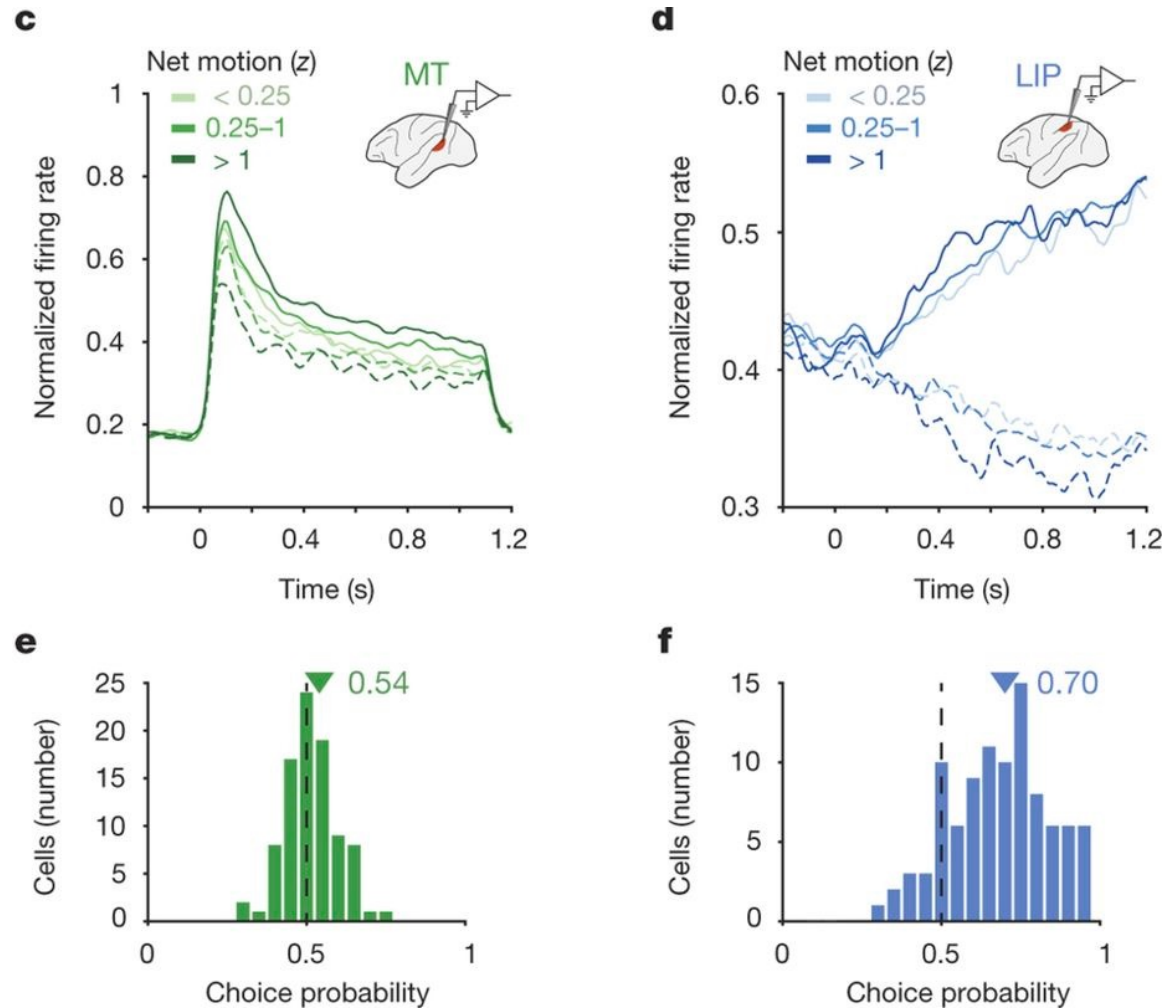


Shadlen M + many influential students

LIP neurons reach threshold

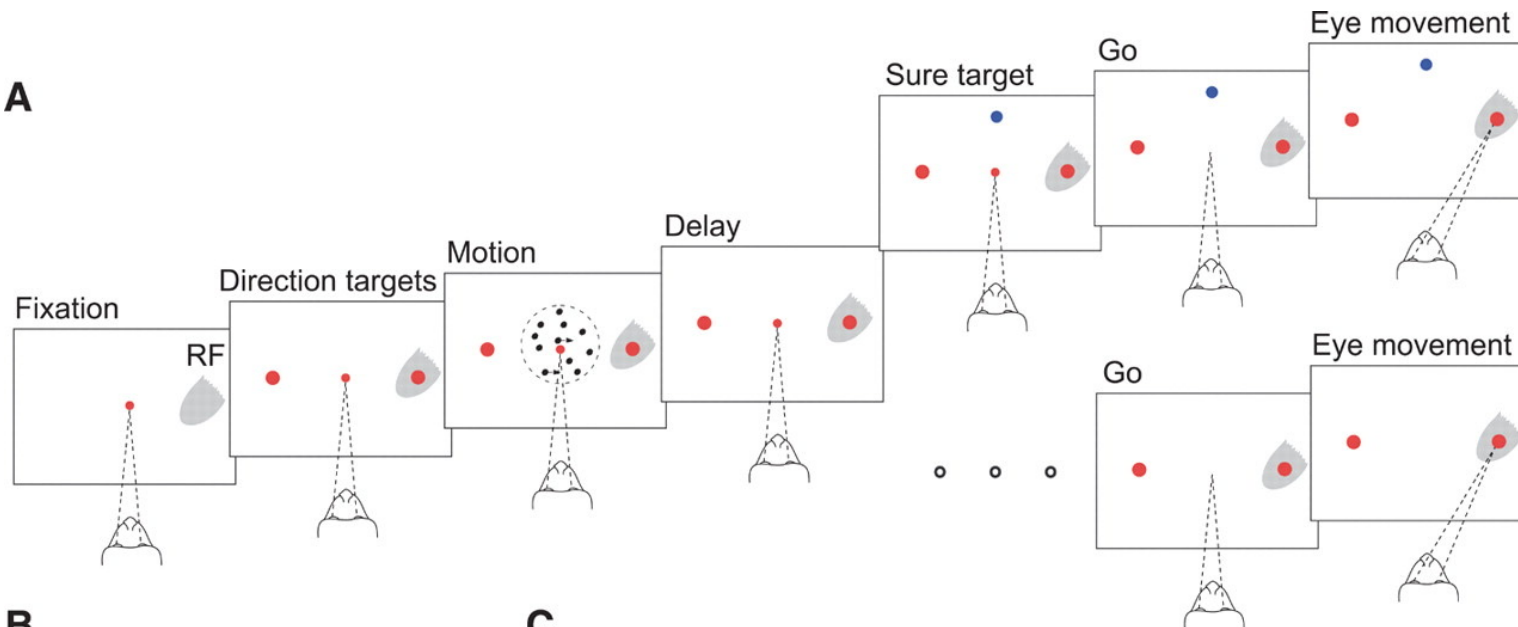


Choice-Neural correlations

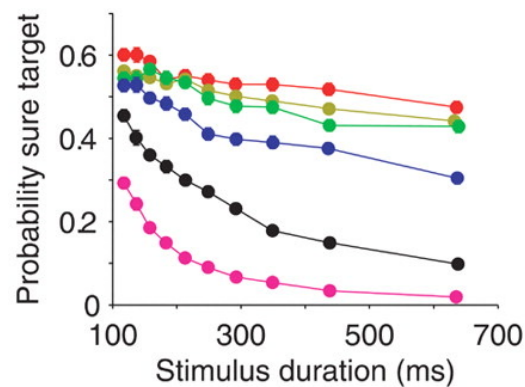


Post-decision wagering indicates certainty

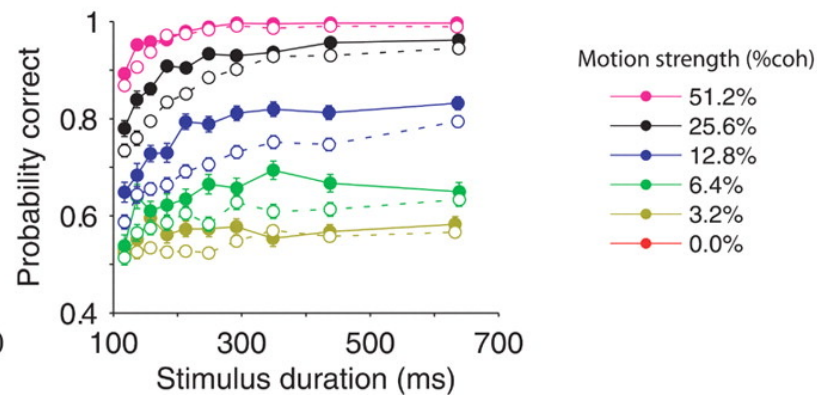
A



B



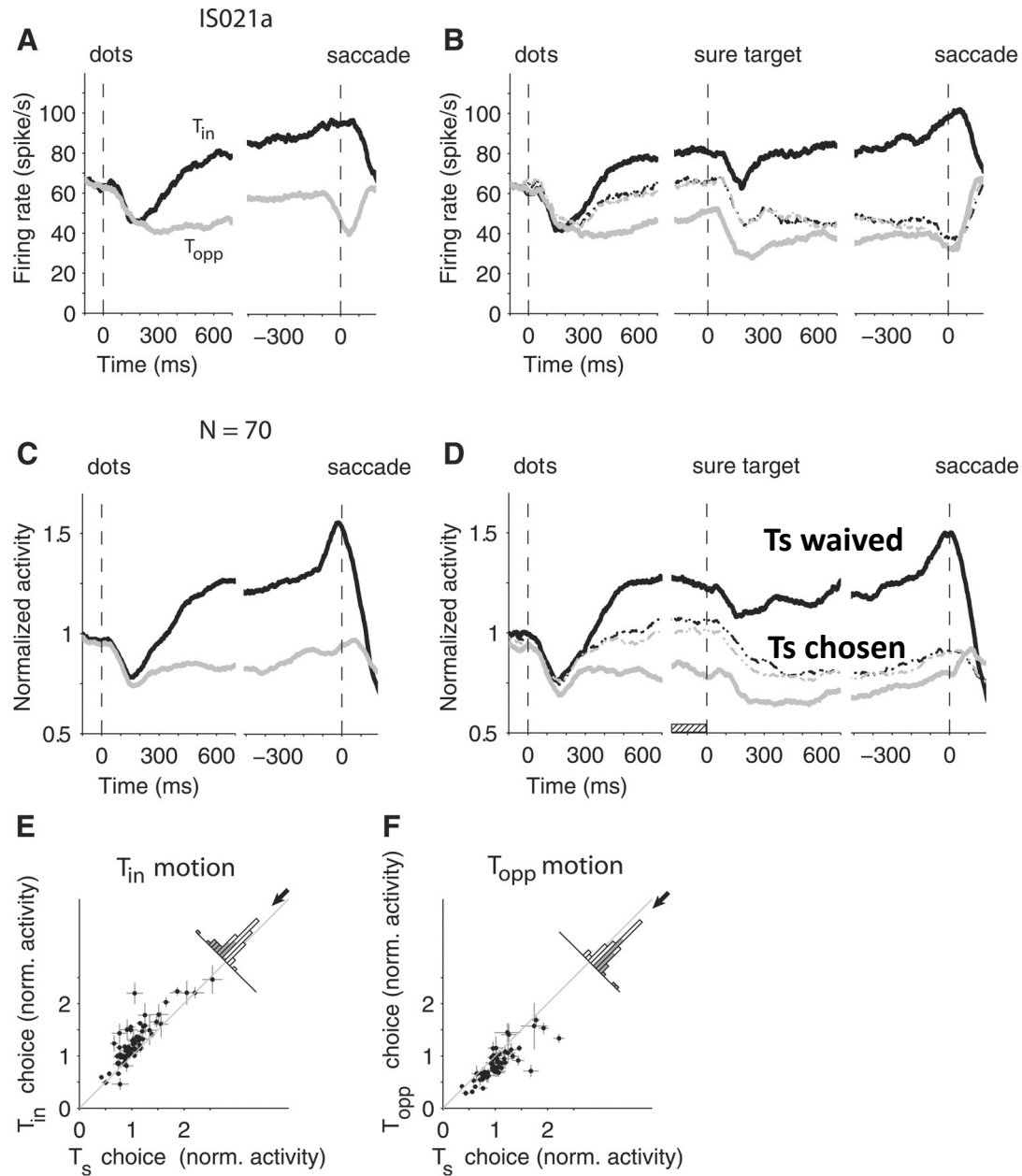
C



Choosing more sure-option with less evidence and lower Coherence

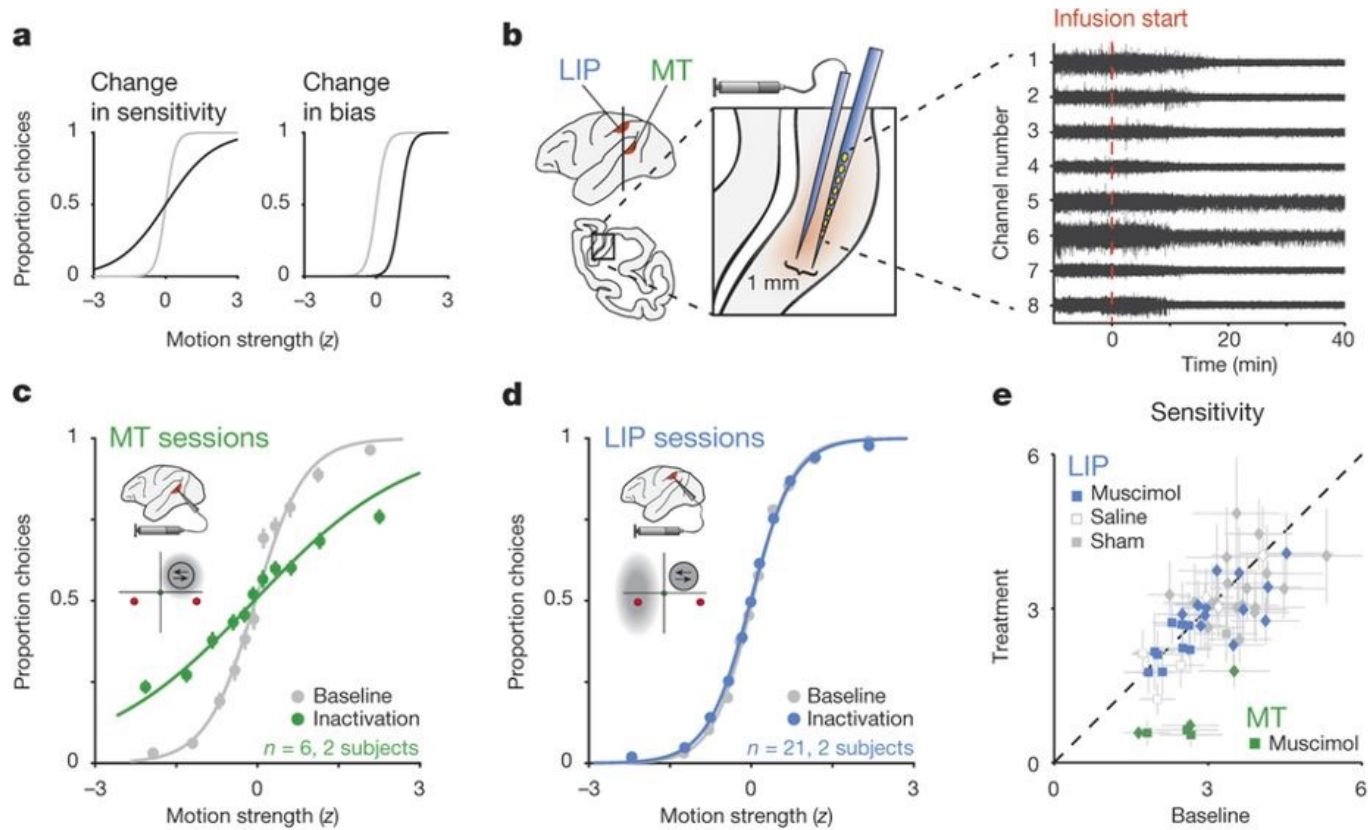
Ts waived > no Ts

LIP activity predicts choices and the post-decision wager.

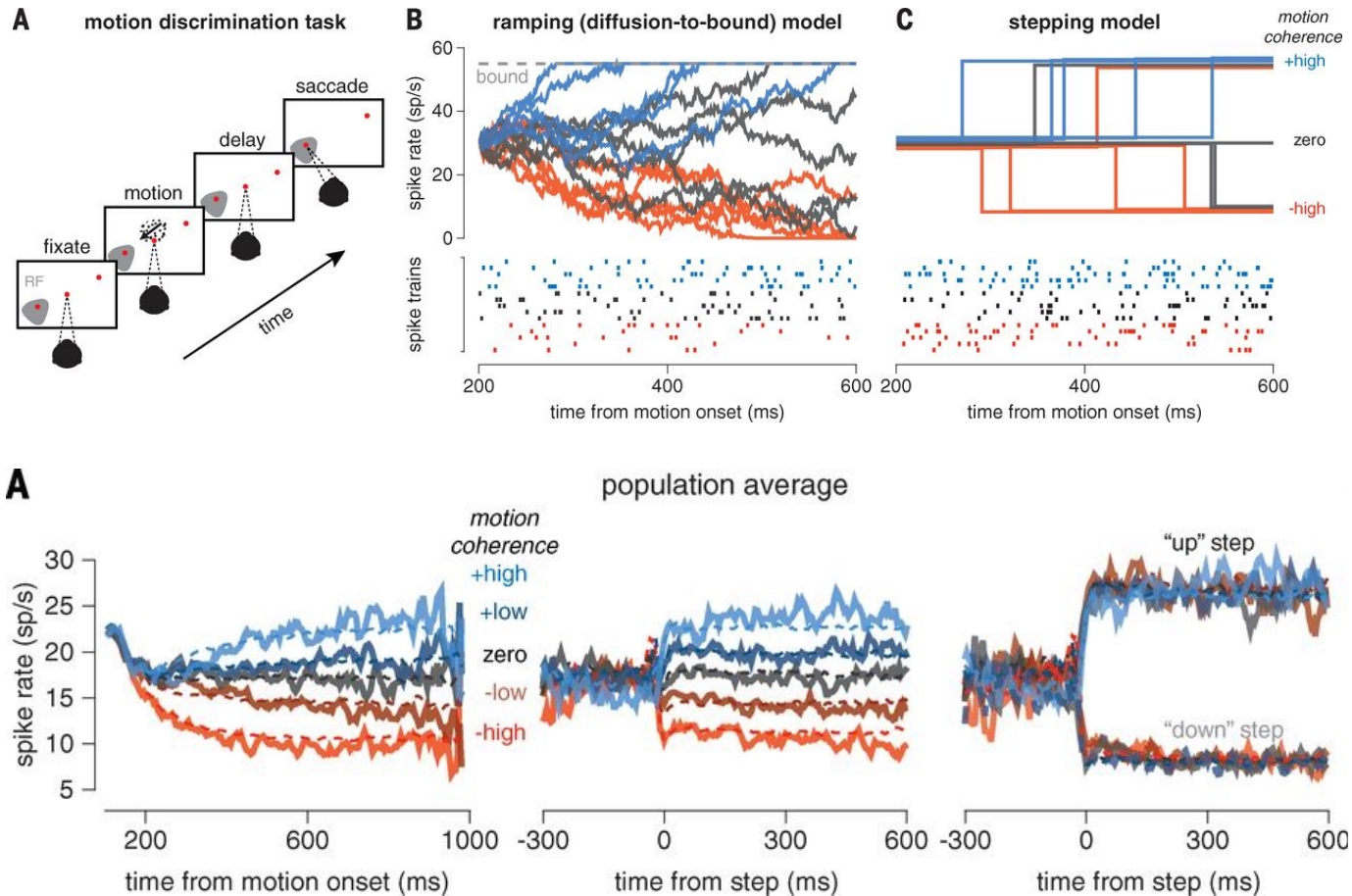


Recent emerging debates

LIP as the decision variable?

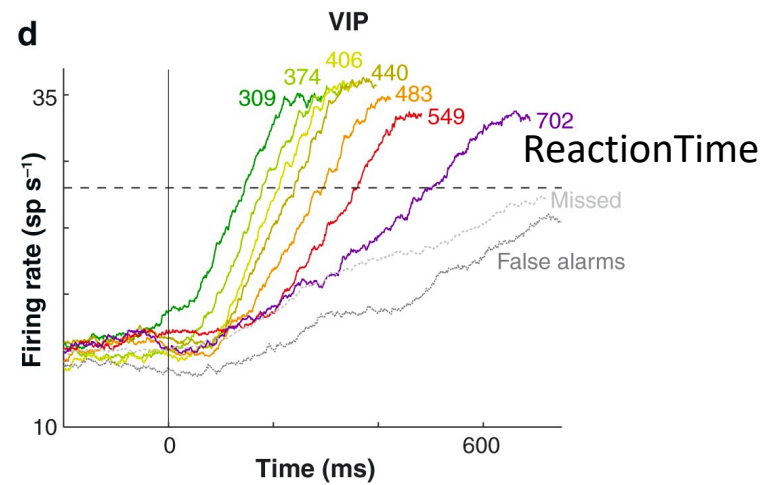
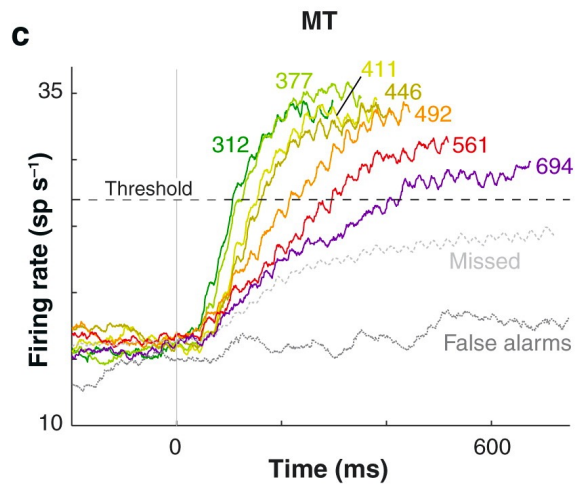
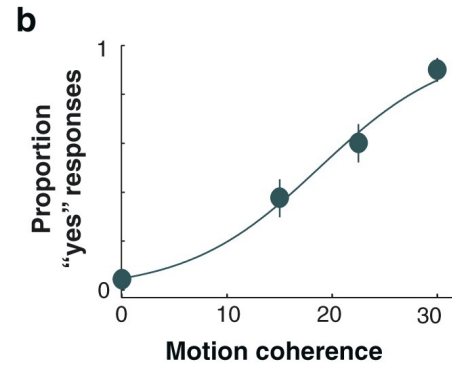
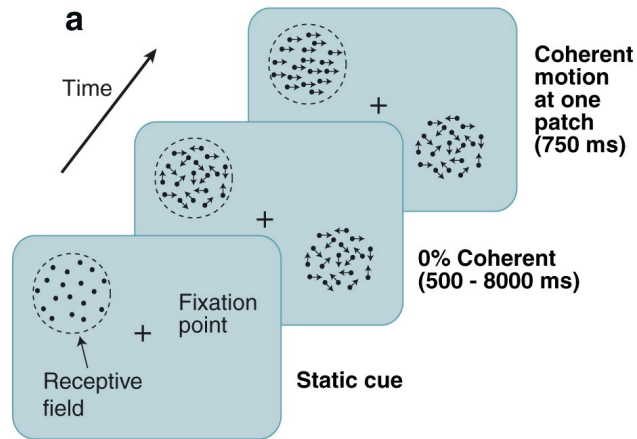


LIP as evidence accumulator?

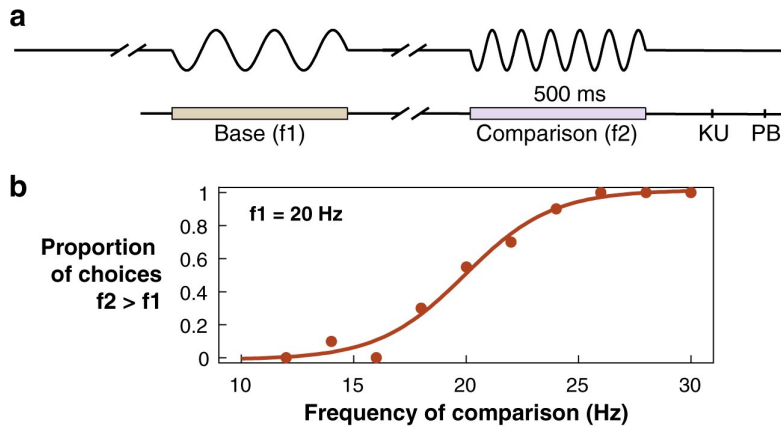


More paradigms of [perceptual] decision making

Motion detection



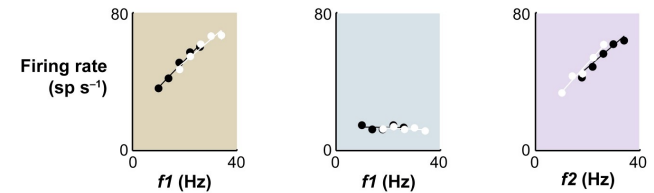
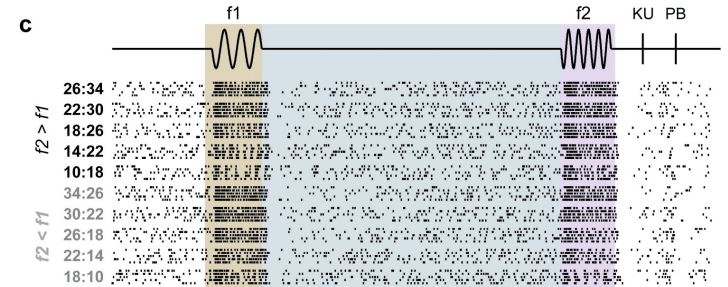
Vibrotactile frequency discrimination (VTF)



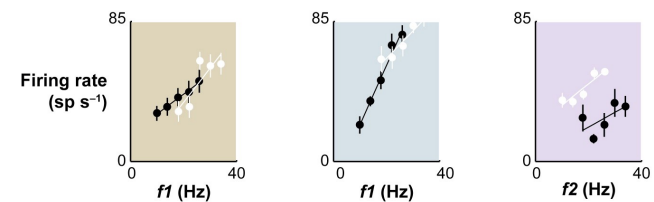
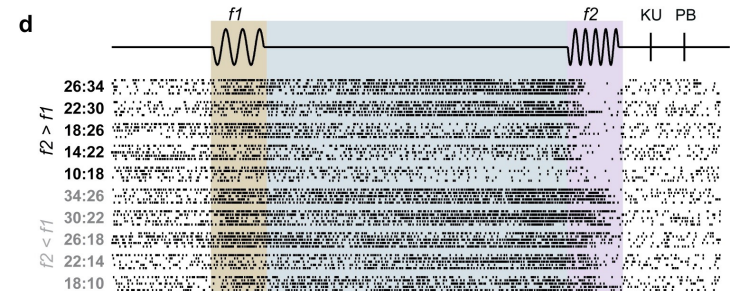
Mountcastle,
Ronulfo Romo

Requires working memory (unlike the RDM)

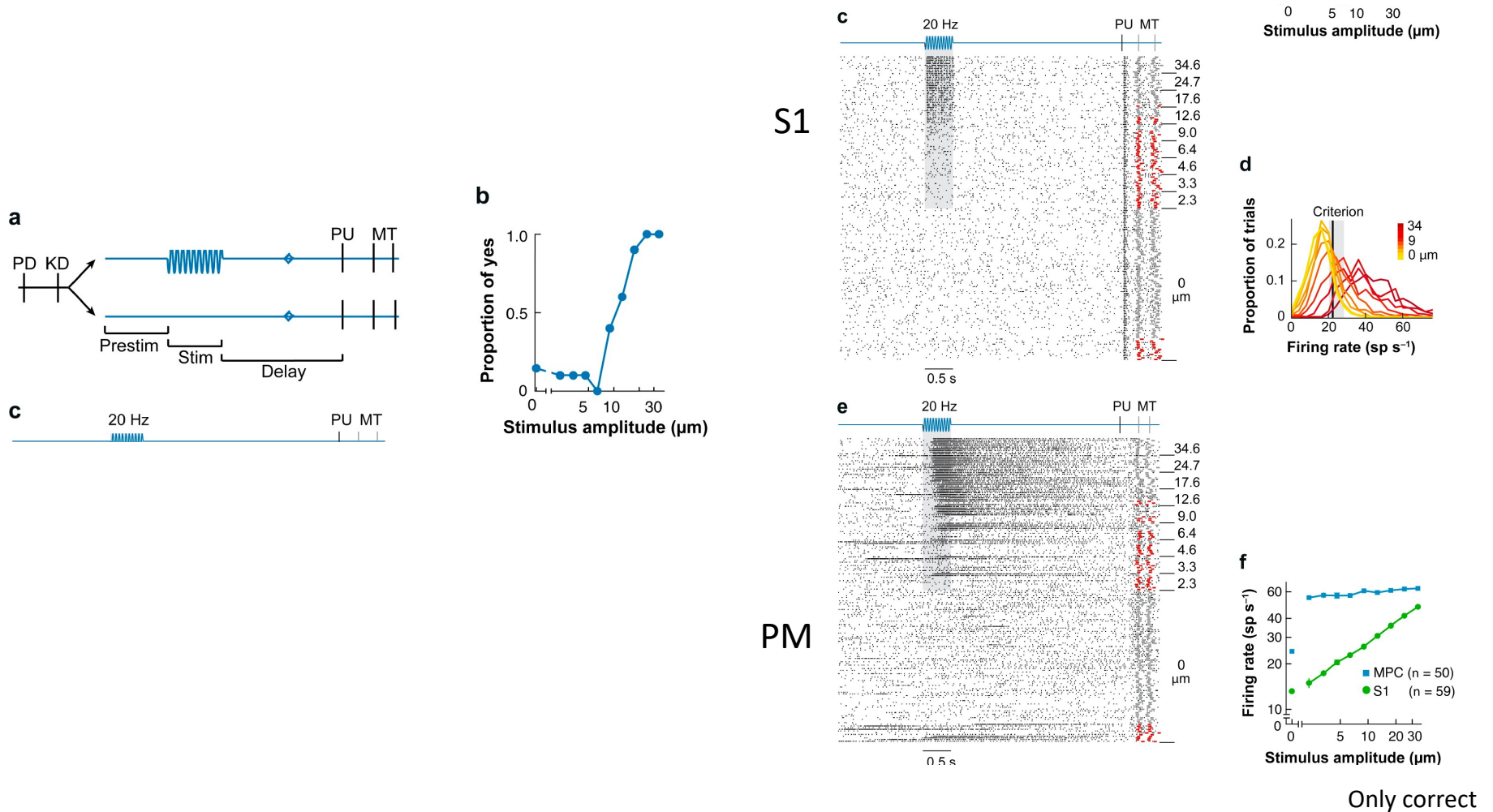
S1



PM



VTF detection



Main sources to read

- [Neuronal correlates of a perceptual decision.](#)
Newsome WT, Britten KH, Movshon JA. ; Nature. 1989 Sep 7;341(6237):52-4.
- [The neural basis of decision making.](#)
Gold JI, Shadlen MN. ; Annu Rev Neurosci. 2007;30:535-74.
- [Decision making as a window on cognition.](#)
Shadlen MN, Kiani R. ; Neuron. **2013** Oct 30;80(3):791-806
- [Dissociated functional significance of decision-related activity in the primate dorsal stream.](#)
Katz LN, Yates JL, Pillow JW, Huk AC. ; Nature. 2016 Jul 14;535(7611):285-8
- [Single-trial spike trains in parietal cortex reveal discrete steps during decision-making.](#)
Latimer KW, Yates JL, Meister ML, Huk AC, Pillow JW. ; Science. 2015 Jul 10;349(6244):184-7