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Mechanisms of Learning a Perceptual Decision

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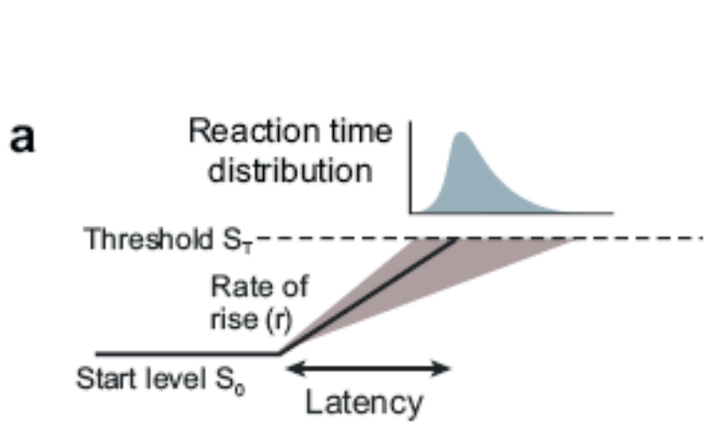
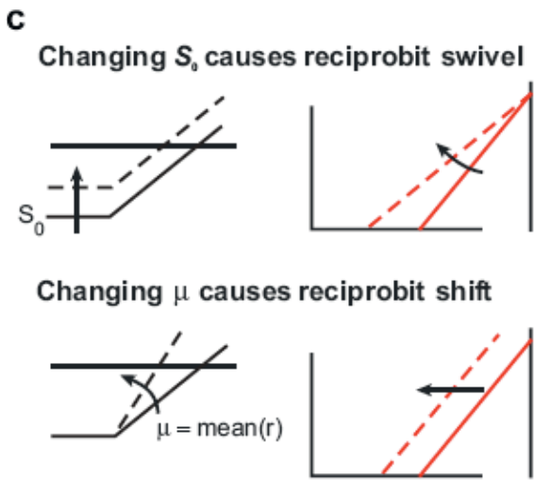
"It is a mistake to consider perception and learning separately because what one learns is strongly constrained by what one perceives, and what one perceives depends on what one has experienced."

- Horace Barlow, 1990

Perceptual decision-making

Categorical judgments about the presence or identity of a sensory stimulus





Perceptual learning

Relatively long-lasting changes to an organism's perceptual system that improve its ability to respond to its environment

Reinforcement learning

Learning how to map situations to actions to maximize reward

Perceptual decision-making

Categorical judgments about the presence or identity of a sensory stimulus

Banburismus and the Brain: Decoding the Relationship between Sensory Stimuli, Decisions, and Reward

This article relates a theoretical framework developed by British codebreakers in World War II to the neural computations thought to be responsible for forming categorical decisions about sensory stimuli.

- Gold & Shadlen, 2002

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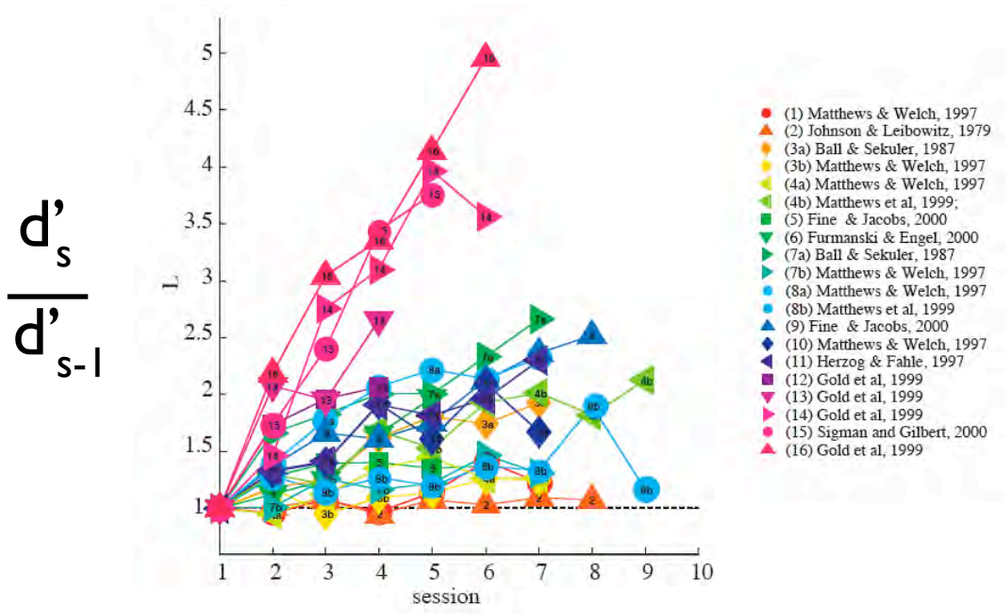

Fine & Jacobs, 2002

There is an impressive amount of converging evidence that experimental training leads to changes to very early stages of information processing.

- Goldstone, 1998

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Arguably, some of the most profound developments in psychology and neuroscience in the last two decades have stemmed from the use of normative ideas from reinforcement learning in thinking about and studying behavior and the brain.

$$V_{new} = V_{old} + \eta(outcome - prediction)$$

...[However], wholly different categories of learning, such as perceptual, stimulus–stimulus and episodic learning, do not use TD prediction errors.

- Niv & Schoenbaum, 2008

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Readout

How does the brain select and weigh the neural signals used to form decisions?

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Working hypothesis:

Reward-prediction errors can be used to adjust how population activity in sensory cortex is read out to form perceptual decisions, thereby improving perceptual sensitivity.

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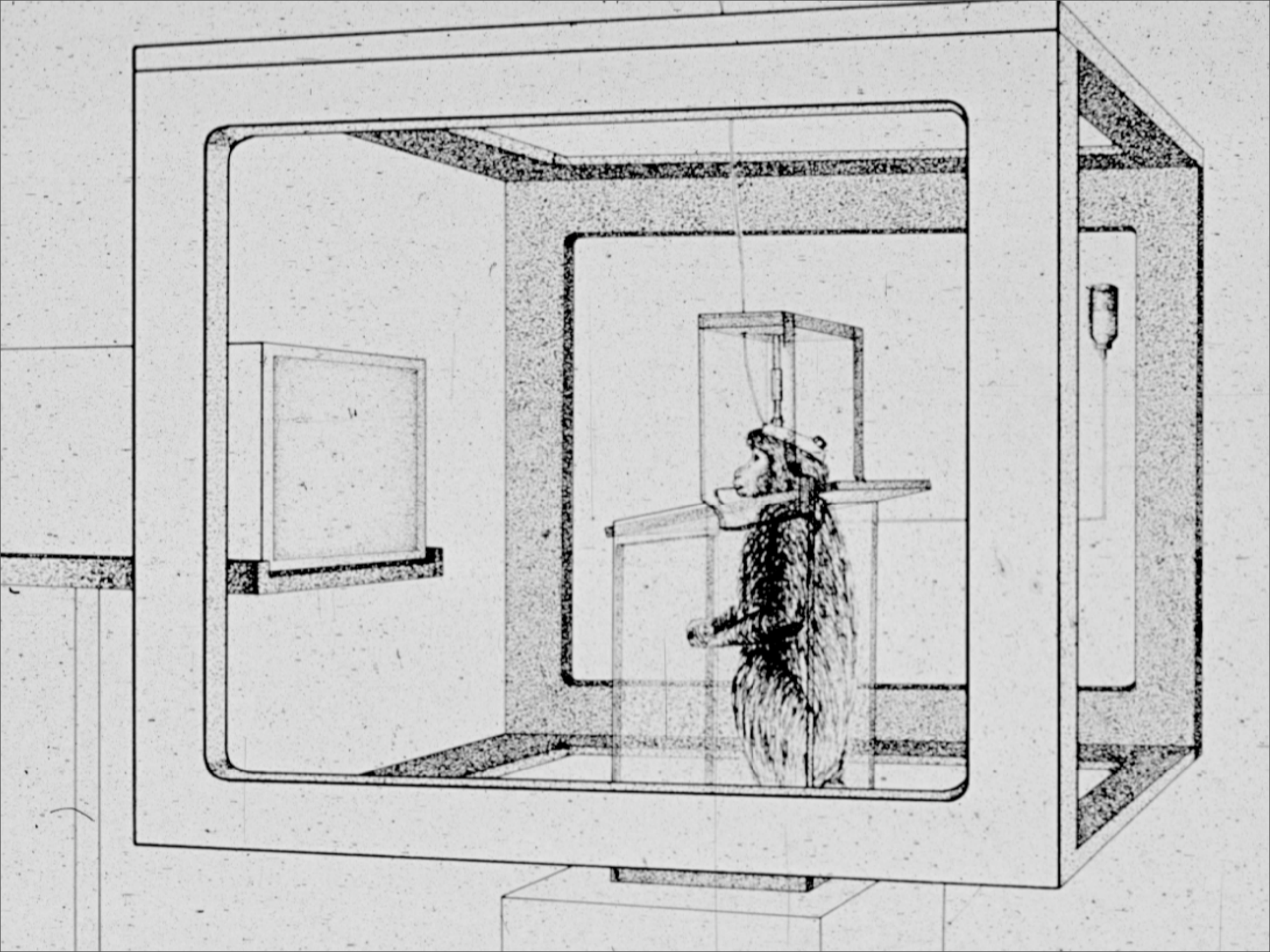

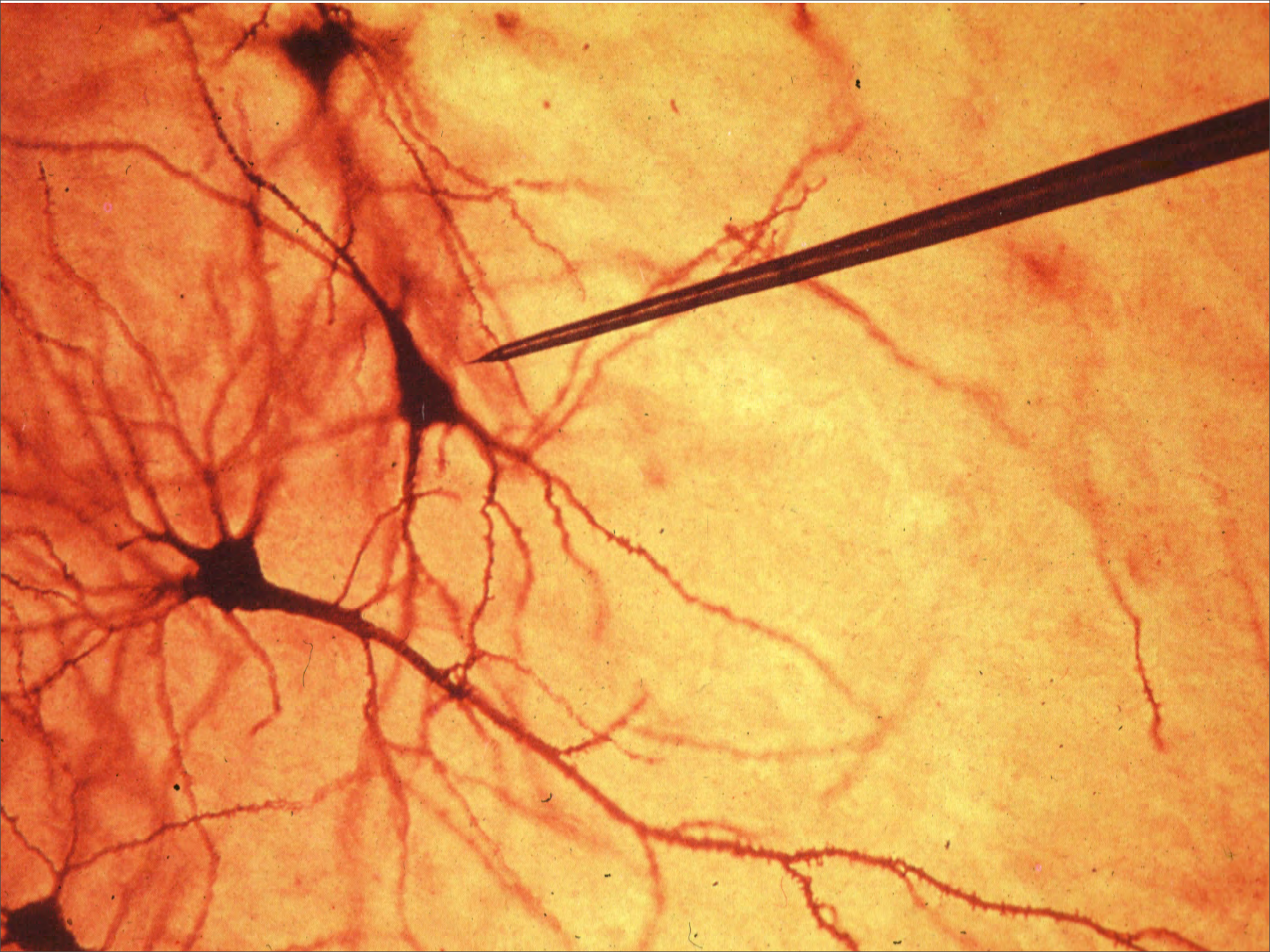

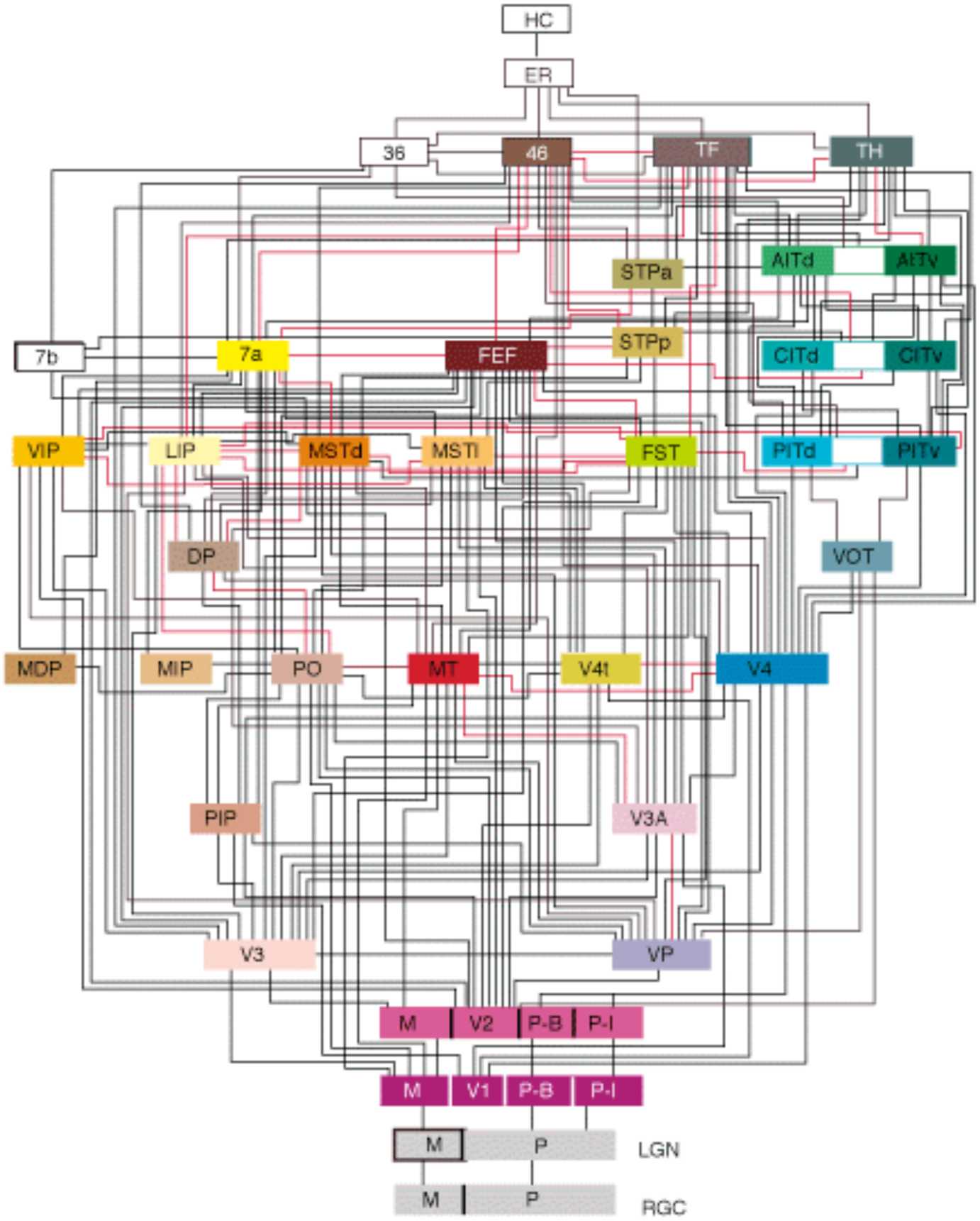

Felleman and Van Essen, 1991

Perceptual decisions: Banburismus

Message 01: KCOW WKLE BNVE UGBF POIJ ASJD ...
Message 02: UIHG NCDJ WQPO LNVD BNJV HFNE ...
Message 03: MNVE WUIE NJLC EJKU BGER EIUF ...
Message 04: BEFB FCEL ISEB LOAN HAXZ POLQ ...
Message 05: WPOC BYUE GLWF NEWB FNEU QWED ...
Message 06: HEBD WFLN UASV JCBL KJNO CVEV ...
Message 07: NEDJ SJLS JDNK LENJ LSJD BFFV ...
Message 08: TYRI EWBC KEJW OZNF KCPQ WOIQ ...
Message 09: JFOE IUEW NBVC ZMXE EDNB EVFW ...
Message 10: HPIO UVEW EJFN LEWI UHRN ULIE ...
Message 11: NMZX BCVU HDEE LIJV MSAN LUBV ...
Message 12: NMCD EHNF ECSN IEFL VENS OIHN ...
Message 13: OAIS JCEU ICWI UNGV BTIO UERG ...
...

Problem:

How to decide between two alternatives, given readily available but uncertain evidence?

- **Compute "weight of evidence"**
- **Accumulate**
- **Stop at pre-defined threshold**

Perceptual decisions: Banburismus

Message 01: KCOW WKLE BNVE UGBF POIJ ASJD ...
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...

"A deciban or half-deciban is about the smallest change in weight of evidence that is directly perceptible to human intuition. I feel that it is an important aid to human reasoning and will eventually improve the judgments of doctors, lawyers and other citizens."

IJ Goode

- **Compute "weight of evidence"**
- **Accumulate**
- **Stop at pre-defined threshold**

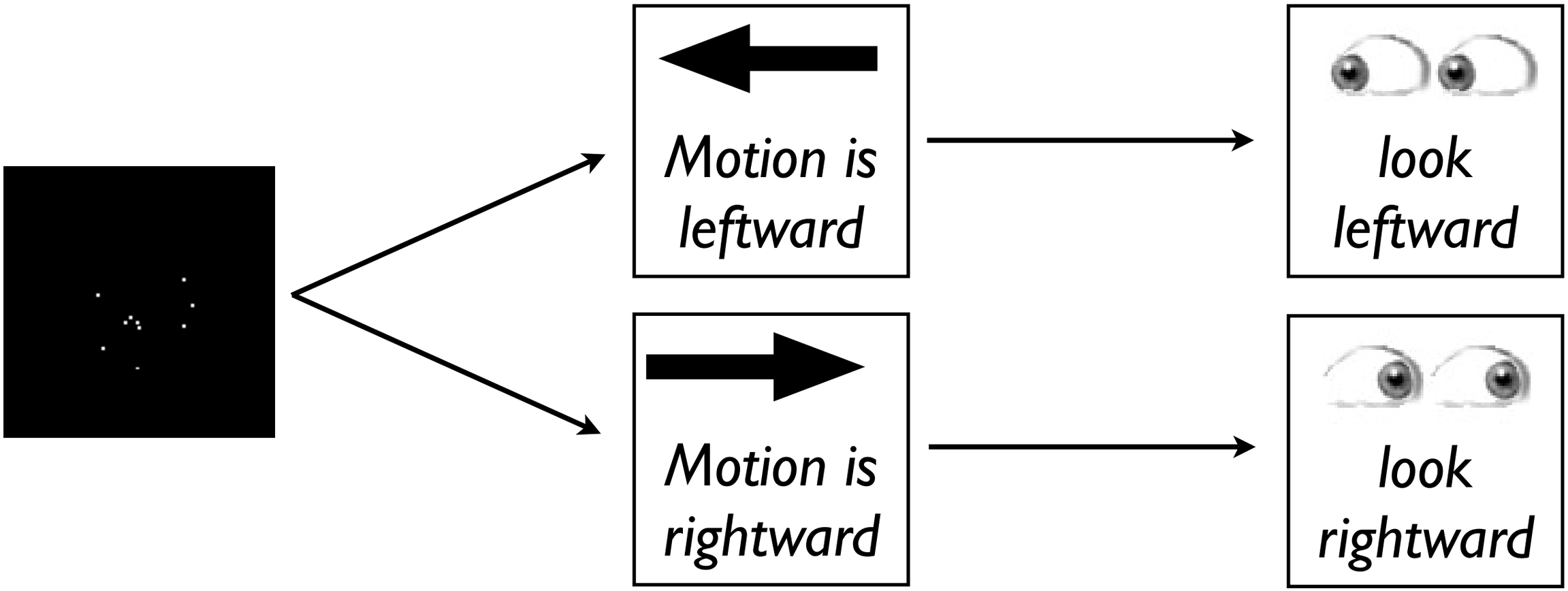
Turing: "Banburismus"

Wald, Bernard: SPRT

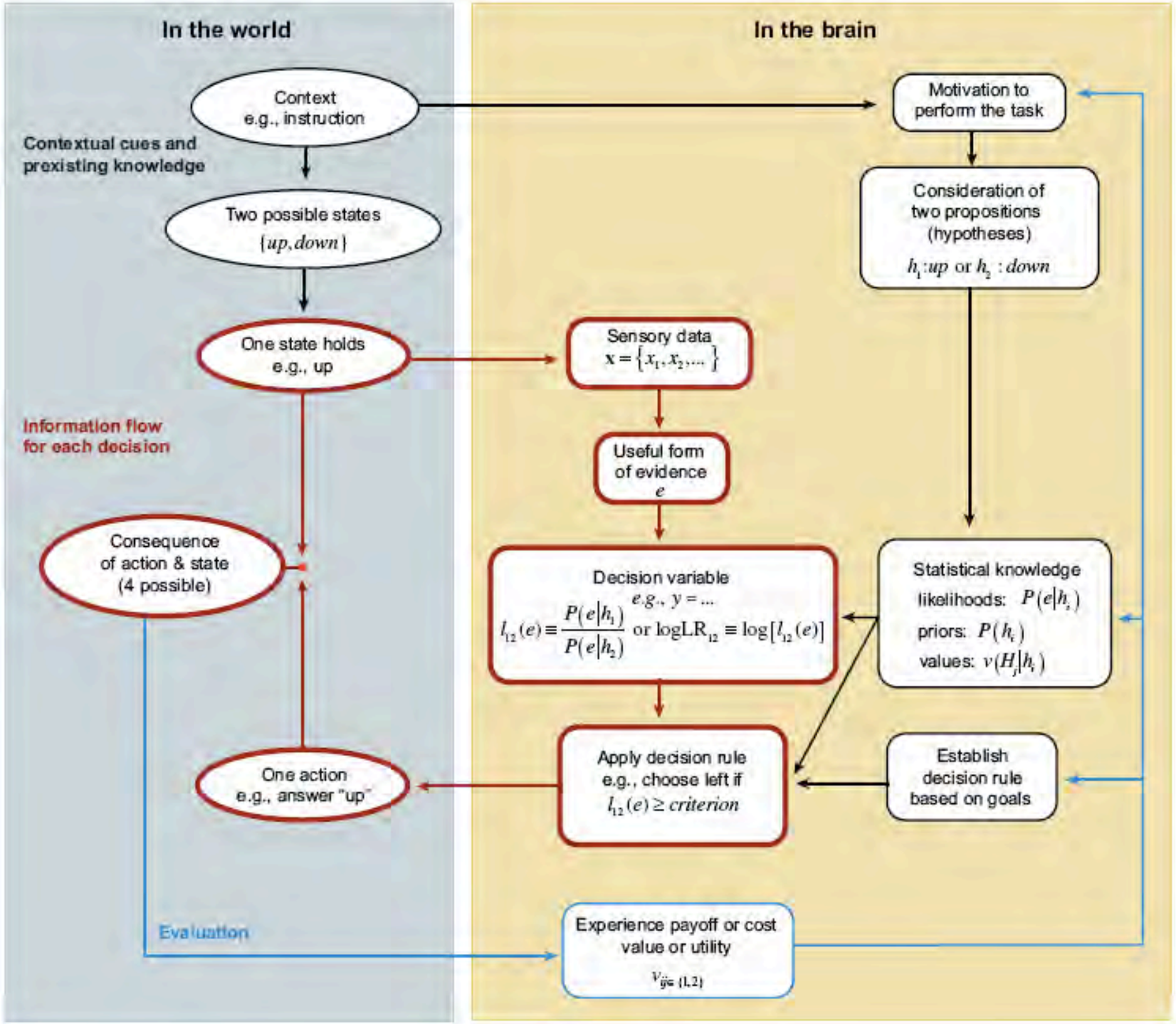
Optimal in the sense that for a fixed error probability (threshold), this procedure guarantees the smallest number of samples; i.e., RT

- **Compute "weight of evidence"**
- **Accumulate**
- **Stop at pre-defined threshold**

Perceptual decisions: direction discrimination



- **Compute "weight of evidence"**
- **Accumulate**
- **Stop at pre-defined threshold**



Gold and Shadlen, 2007

Perceptual decisions: direction discrimination

Sensory "evidence"

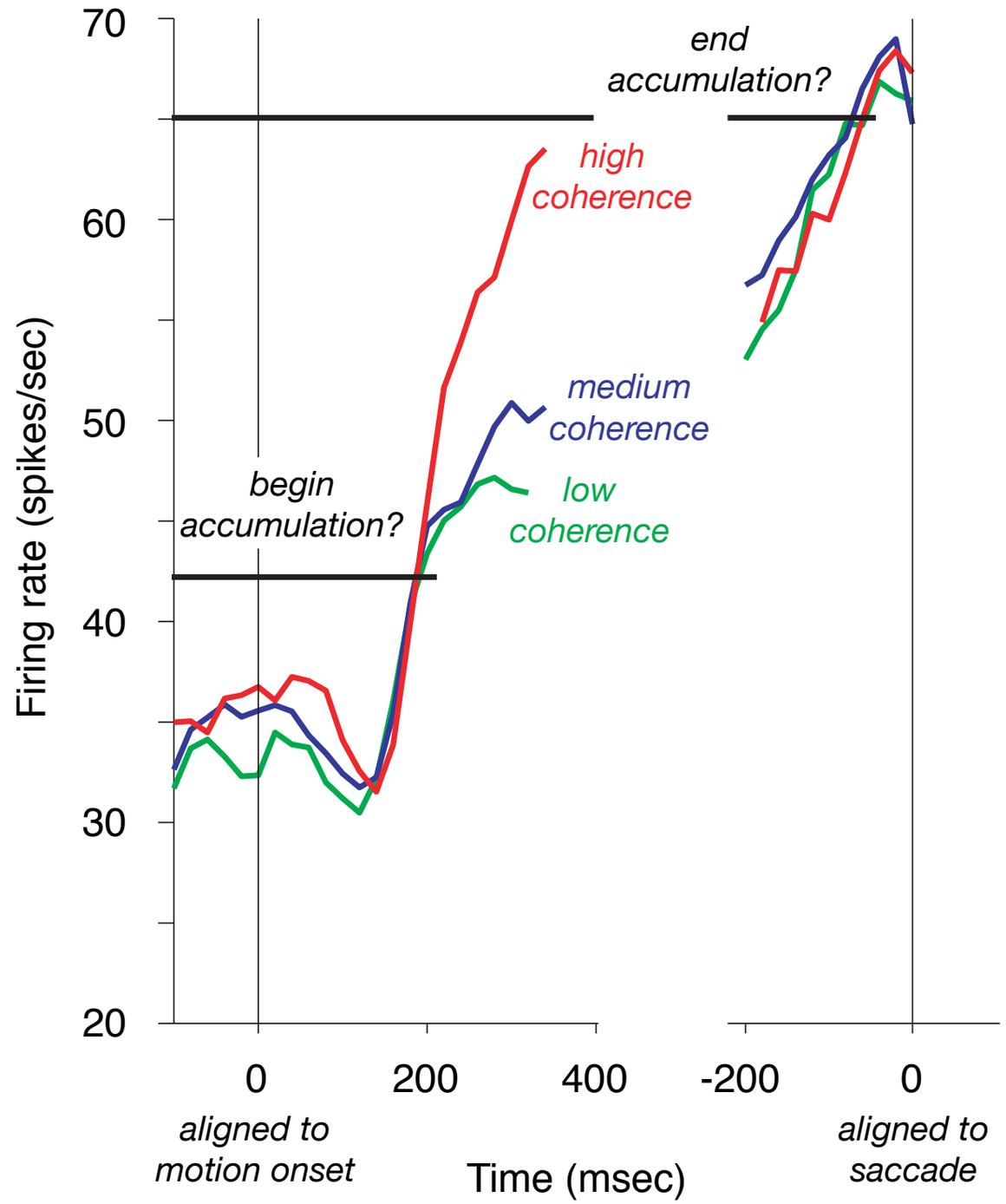
"decision variable"

MT → LIP

SC

FEF

(oculomotor areas)



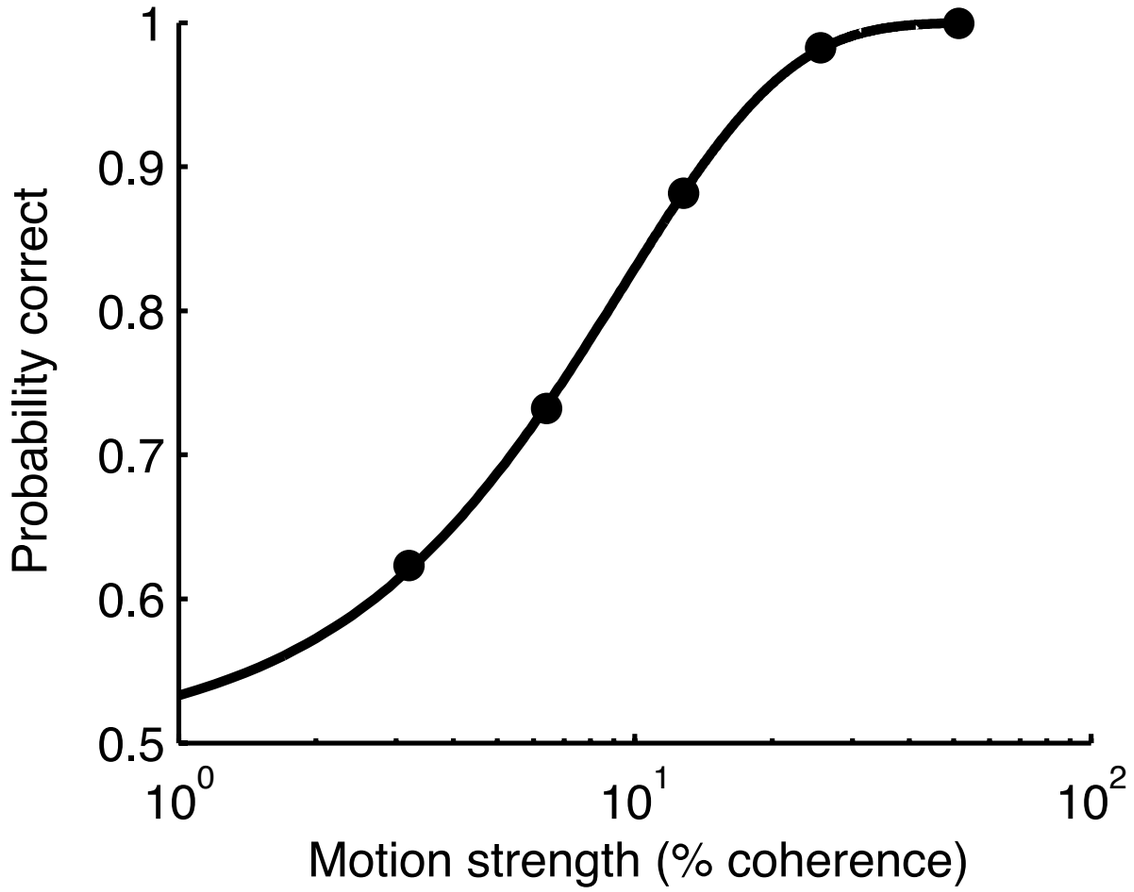
- **Compute "weight of evidence"**
- **Accumulate**
- **Stop at pre-defined threshold**

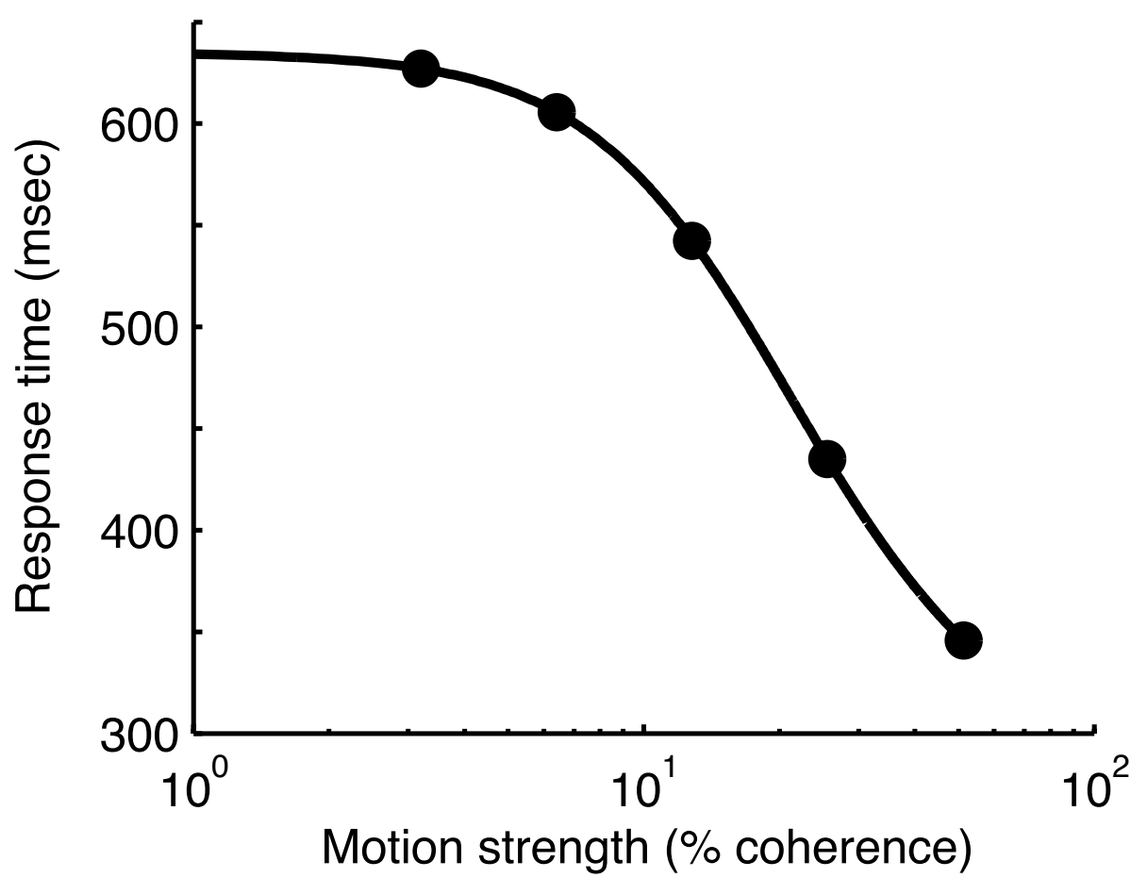
Gold and Shadlen, 2002

Perceptual decisions: direction discrimination

$$p_i = \frac{1}{1 + e^{-2B|\mu_i|}}$$

$$t_i = \tanh(B|\mu_i|)$$





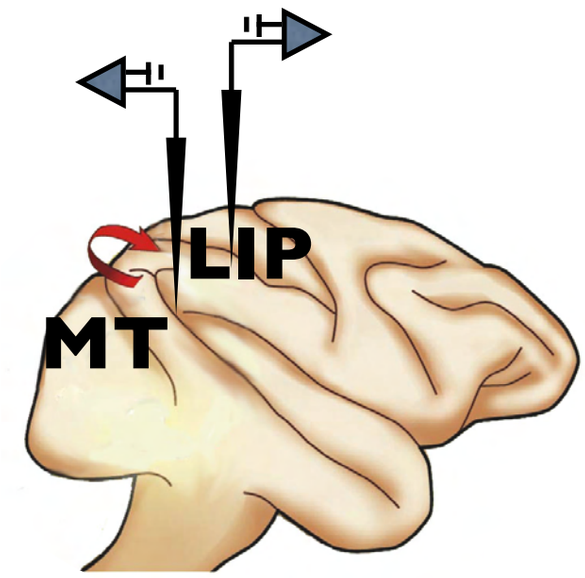
- **Compute "weight of evidence"**
- **Accumulate**
- **Stop at pre-defined threshold**

Gold and Shadlen, 2002

Perceptual learning: physiology

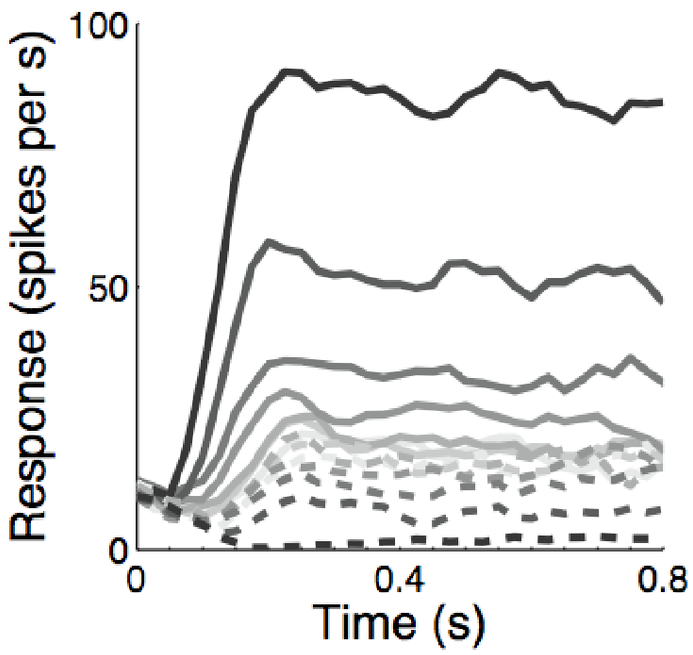
evidence in area MT

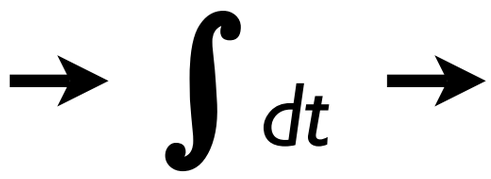
- Sensory neurons tuned for the direction of motion
- Neuronal sensitivity matches behavioral sensitivity
- Electrical microstimulation biases performance
- Lesions impair performance

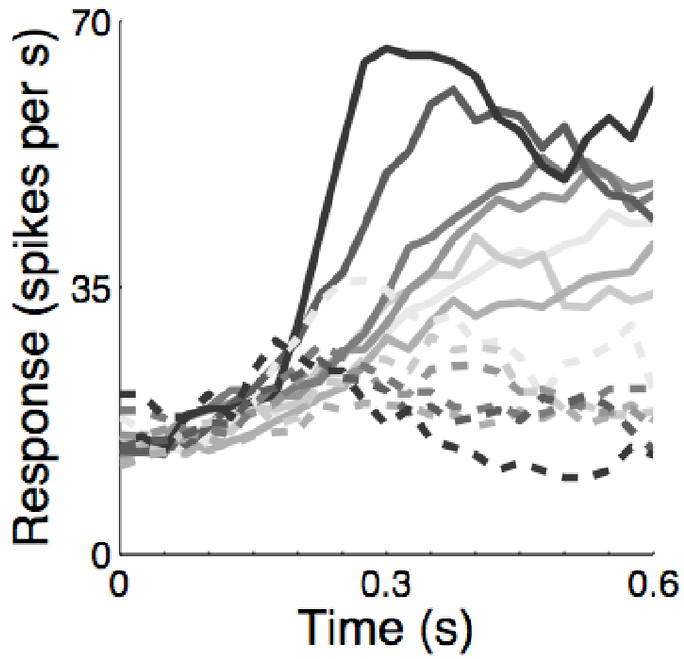


decision in area LIP

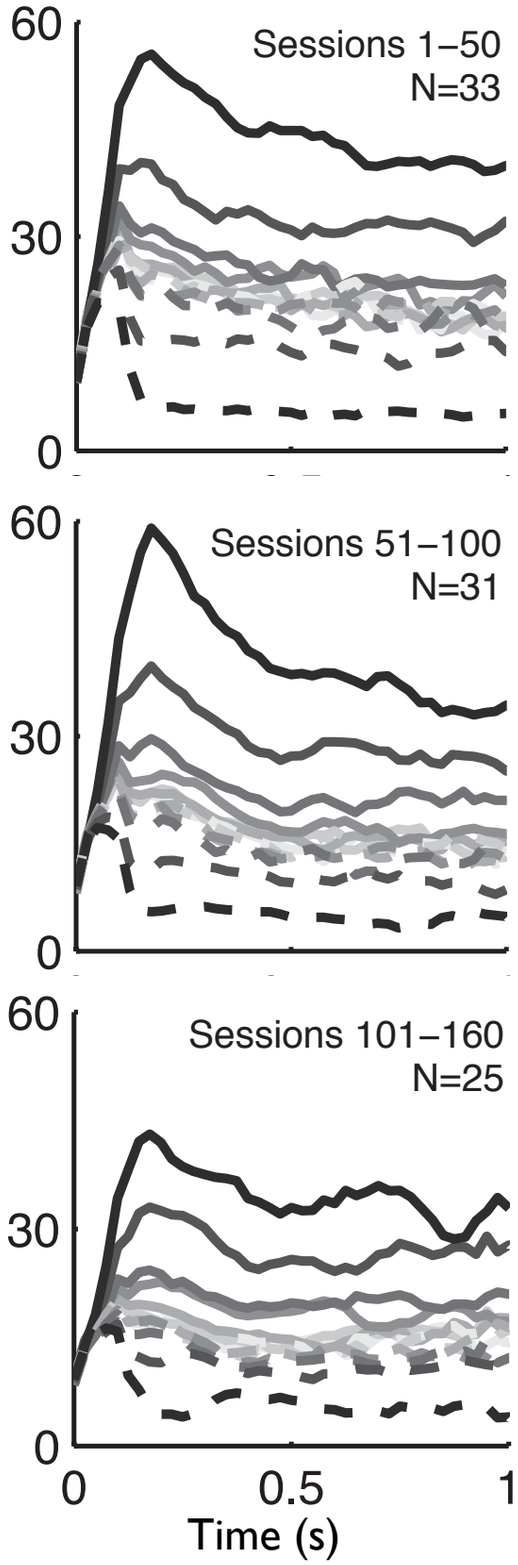
- Sensory-motor neurons tuned for the location of saccade targets
- Activity during motion viewing reflects accumulation of motion information into categorial choice
- Electrical microstimulation biases performance







Perceptual learning: physiology

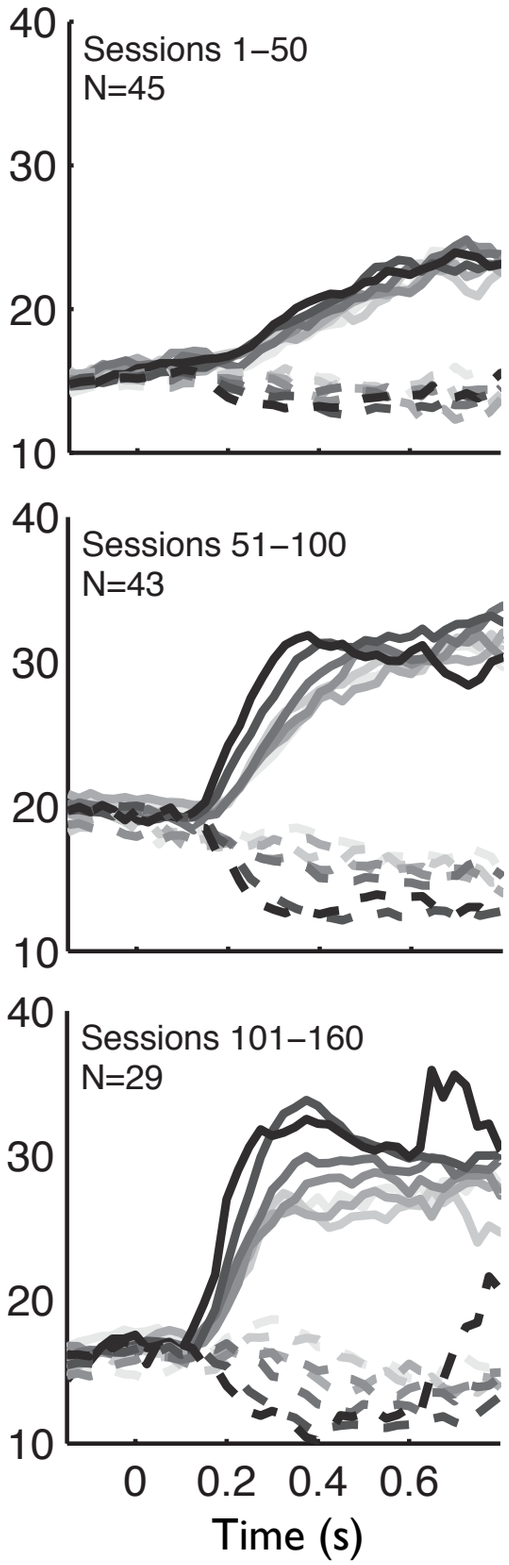


MT
Activity
(sp/s)

early training

middle training

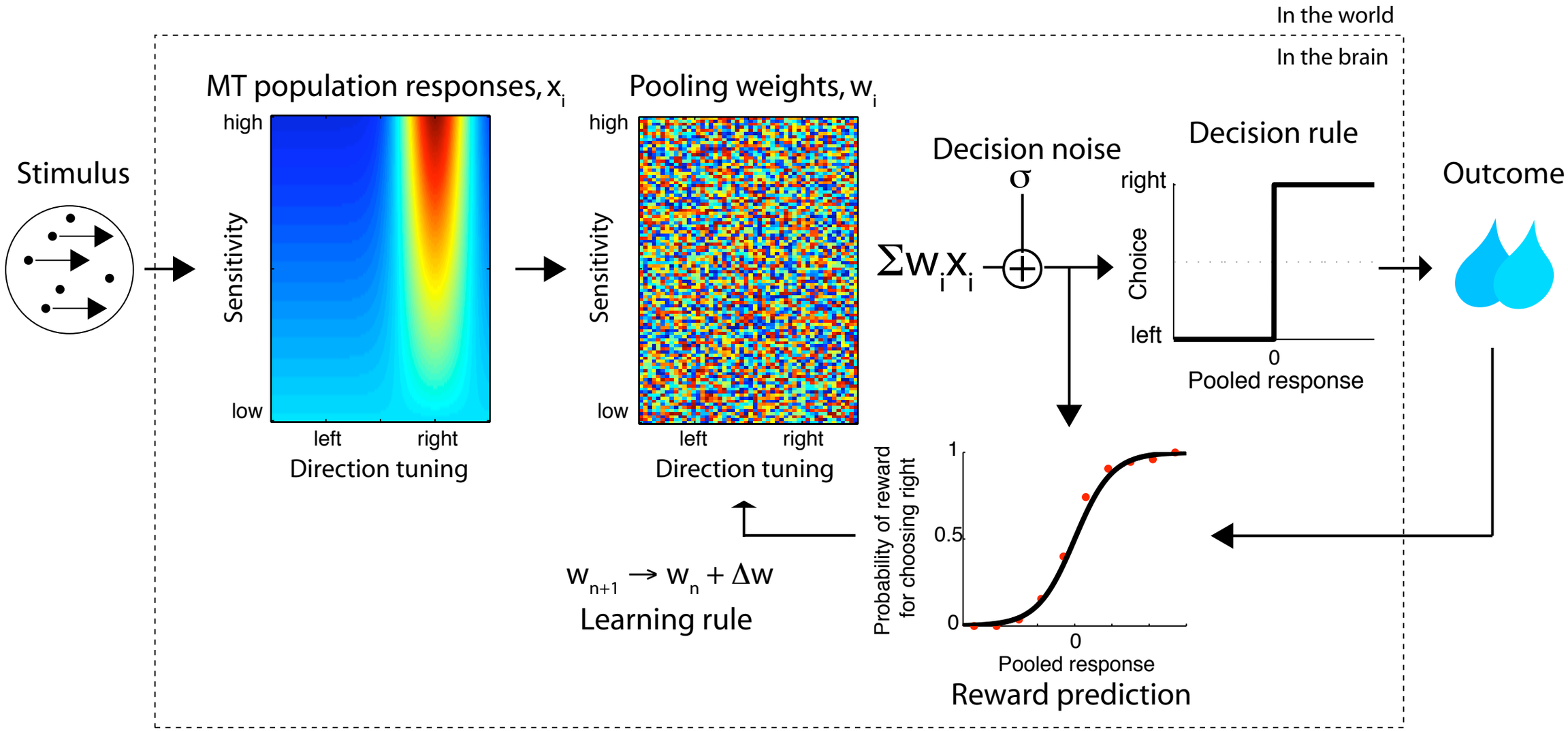
late training



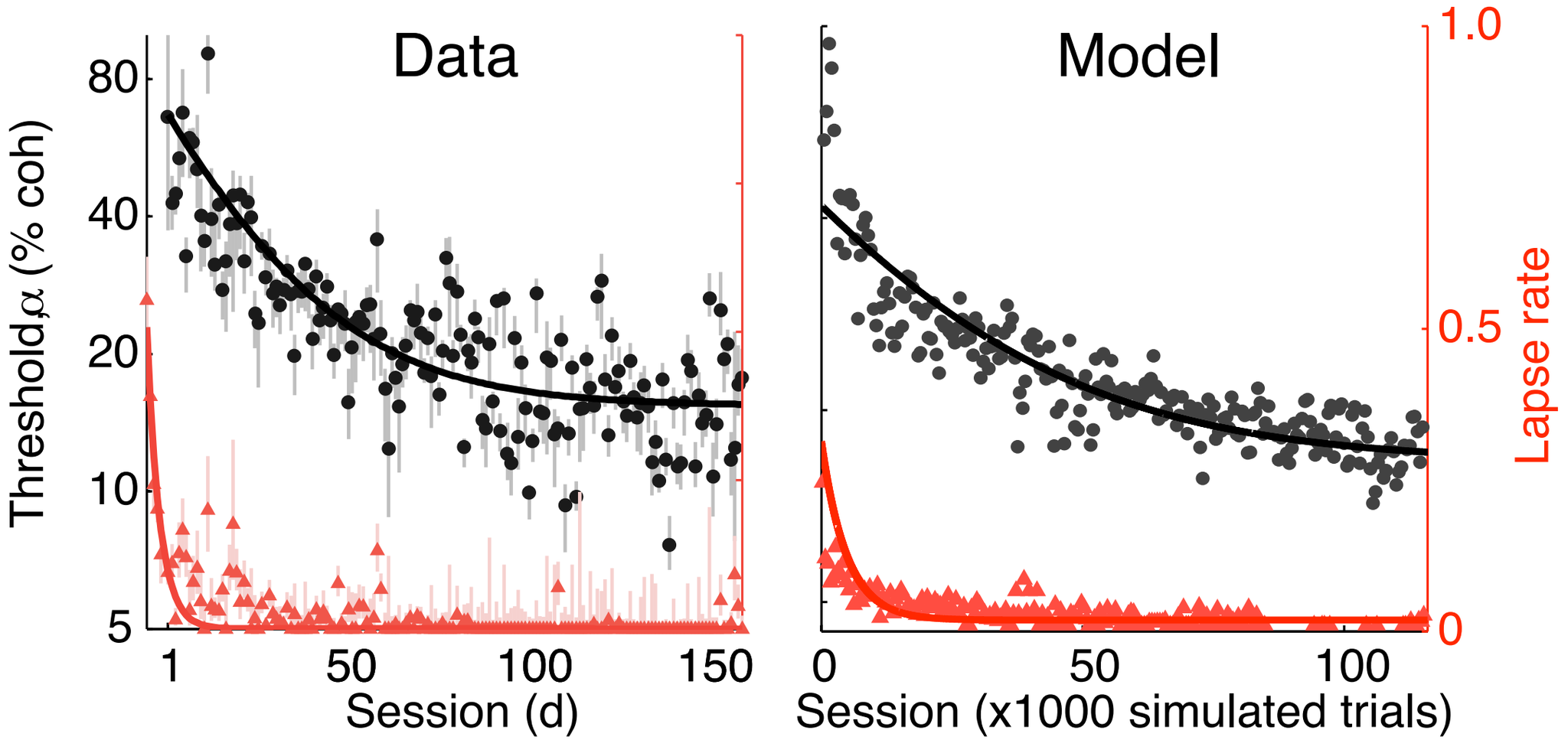
LIP
Activity
(sp/s)

Law & Gold, 2008

Reinforcement learning: a working model



Reinforcement learning: a working model



Reinforcement learning: assessment of optimality