# Does the subcortex make a decision?

# Readings for today

- Bogacz, R., & Larsen, T. (2011). Integration of reinforcement learning and optimal decision-making theories of the basal ganglia. Neural computation, 23(4), 817-851.

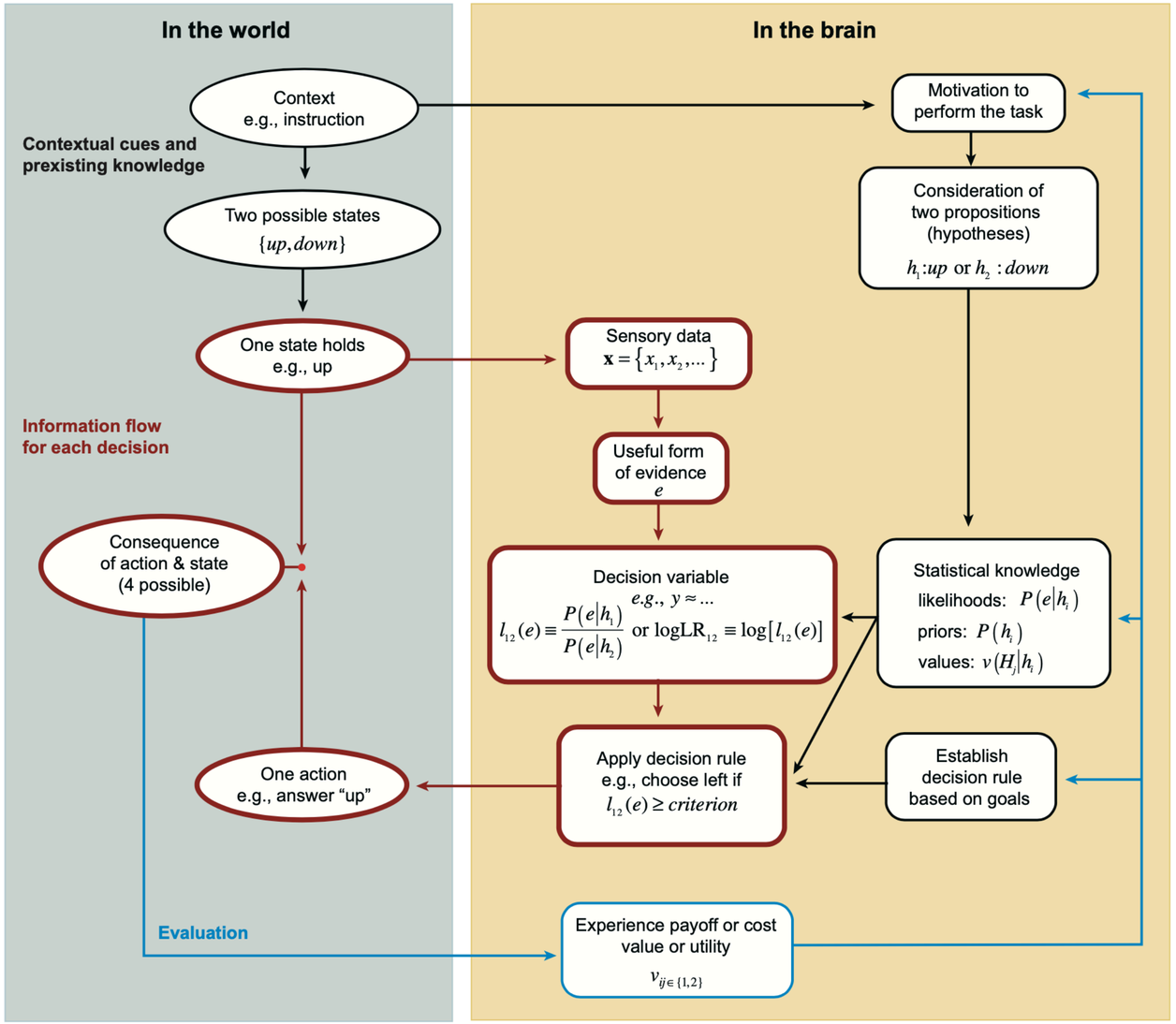
- Dunovan, K., Lynch, B., Molesworth, T., & Verstynen, T. (2015). Competing basal ganglia pathways determine the difference between stopping and deciding not to go. Elife, 4, e08723.

# Topics

- Cortical-subcortical loops as accumulators
- Control of certainty

# Cortical-subcortical loops as accumulators

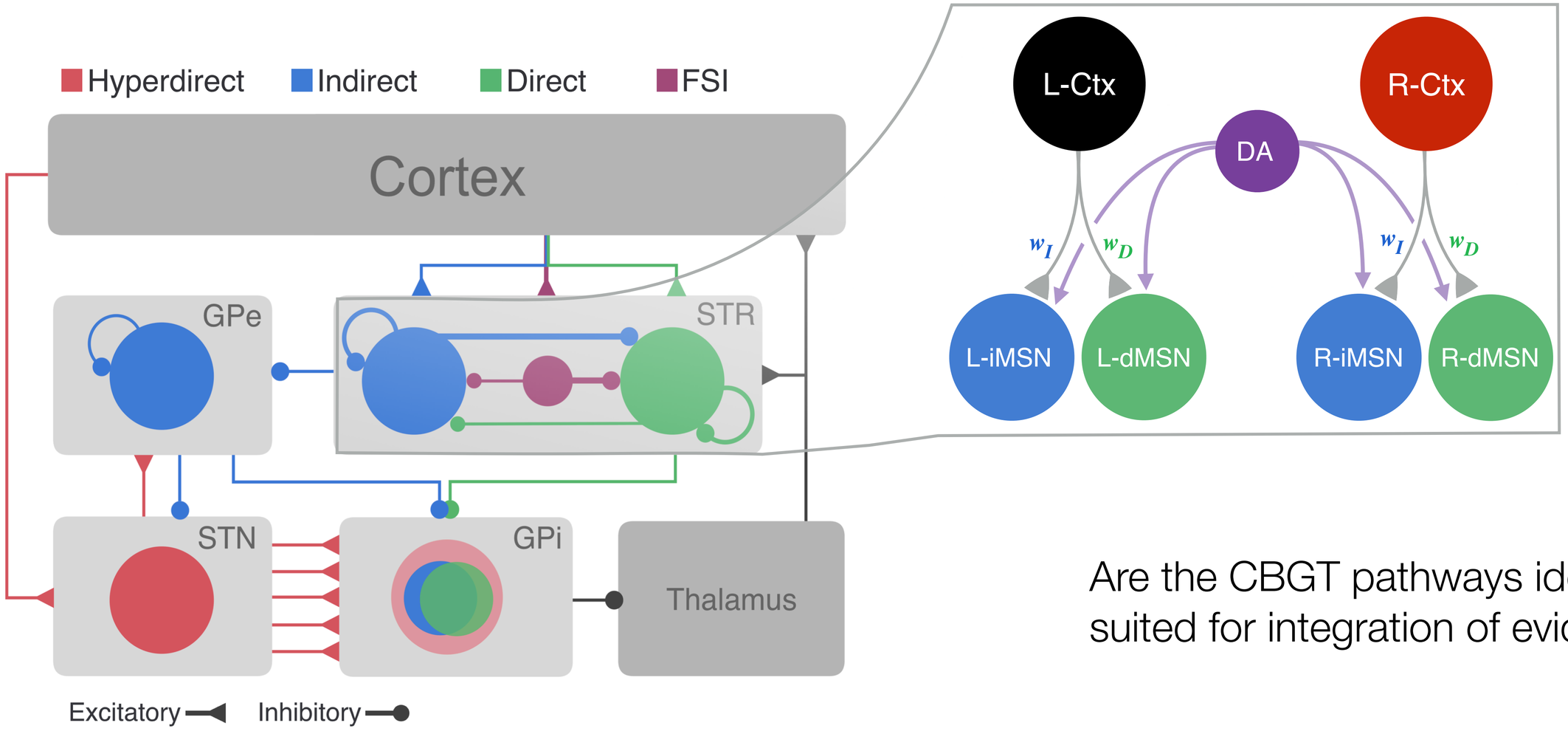
# Elements of making a decision






(Gold & Shadlen, 2007)

# Cortico-basal ganglia thalamic pathways




Str: striatum; GPe: external globus pallidus;
GPi: internal globus pallidus; STN: Subthalamic nucleus

Are the CBGT pathways ideally suited for integration of evidence?

# The sequential probability ratio test (SPRT)

1. On each sample *i*, evaluate logLR

$$w_i = \log\left(\frac{P(e_i \mid h_1)}{P(e_i \mid h_2)}\right)$$

2. Sum all logLR tests up to current observation

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

3. Determine stopping rule

$$y_n \geq \log\frac{1-\alpha}{\alpha}, \text{ then select } h_1$$

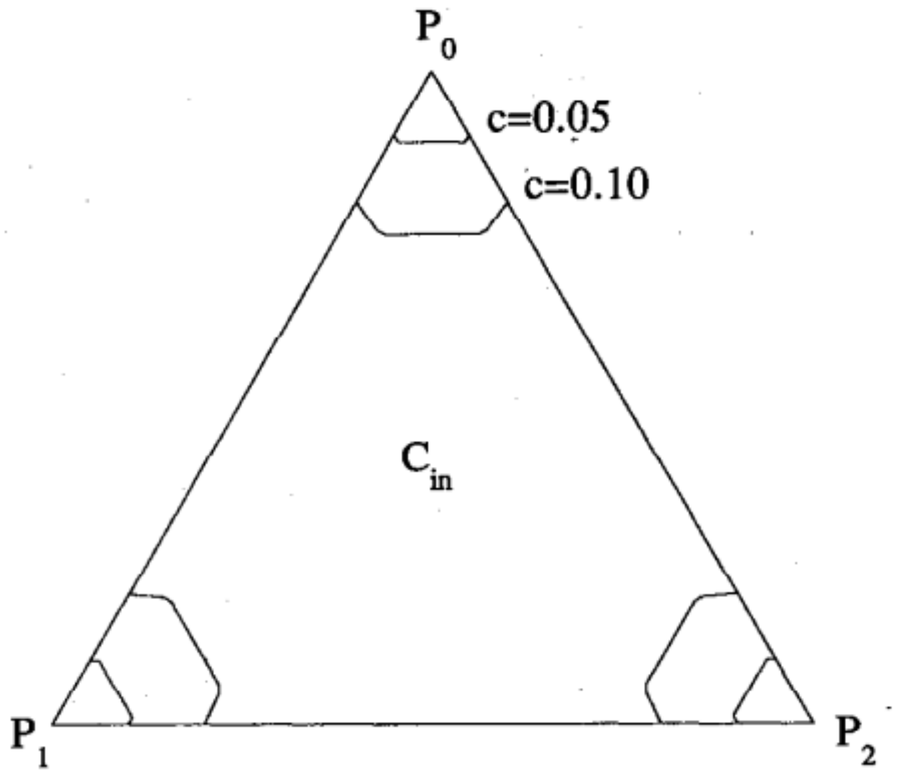
$$y_n \leq \log\frac{\beta}{1-\beta}, \text{ then select } h_2$$

$$\log\frac{\beta}{1-\beta} \leq y_n \leq \log\frac{1-\alpha}{\alpha}, \text{ continue sampling}$$



(Gold & Shadlen, 2007)

# The multihypothesis SPRT (MSPRT) algorithm




Variant of the SPRT that allows for evaluating more than 2 hypotheses.

$$P(x(t)) = \sum_{i=1}^{N} P_i(t-1)\,P(x(t)|H_i).$$

posterior prior likelihood

Applying a log transform allows for reframing this to being framed in neural firing rates

$$\log P(x(t)|H_i) = g x_i(t) - b(t),$$

$g = (I_+ - I_-)/\sigma^2$

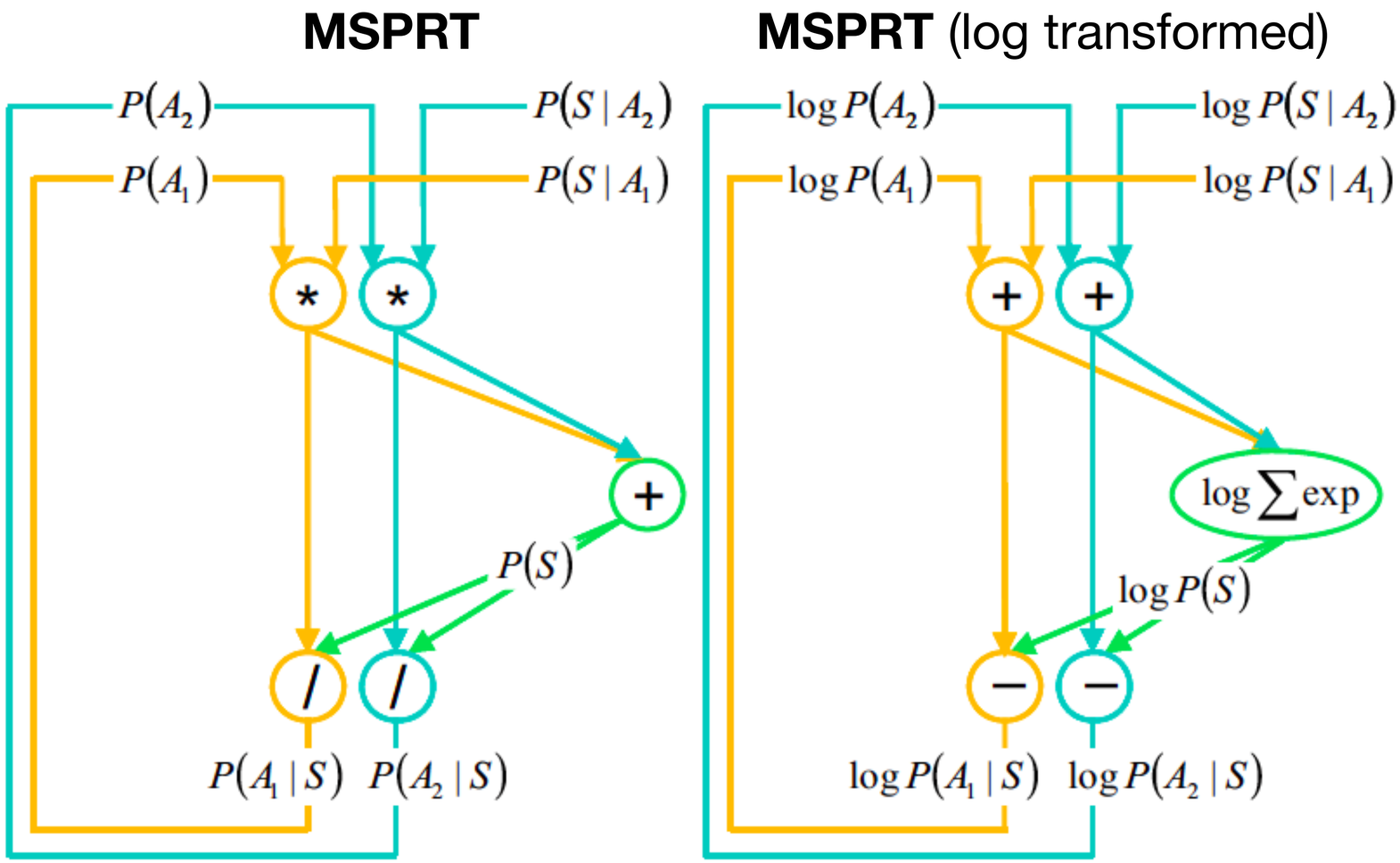
Sensory evidence

Scalar (same for all hypotheses)



(Baum & Veeravalli, 1994)

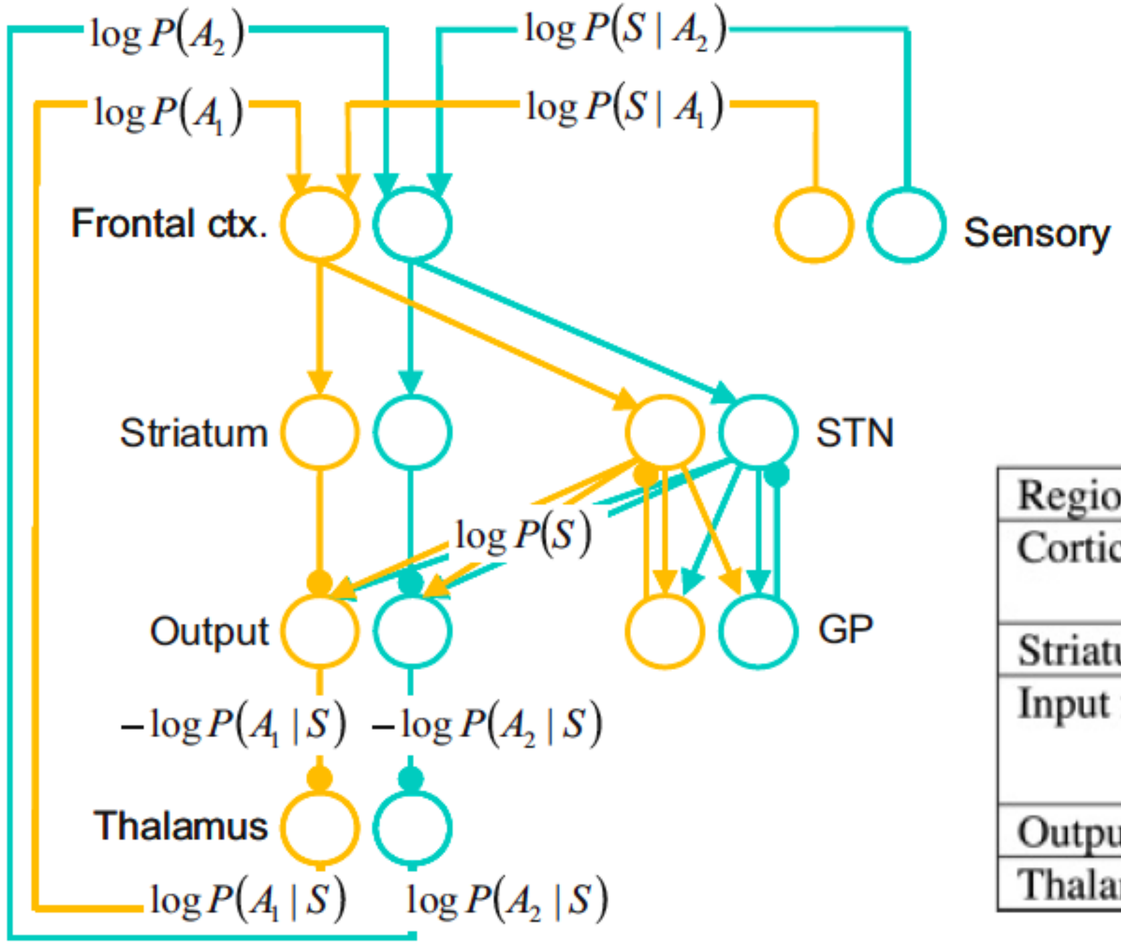
# The multihypothesis SPRT (MSPRT) algorithm






(Bogacz & Larsen, 2011)

# A neural instantiation of the MSPRT




Based off of the topology of excitatory & inhibitory connections, you can map CBGT dynamics to the MSPRT algorithm.

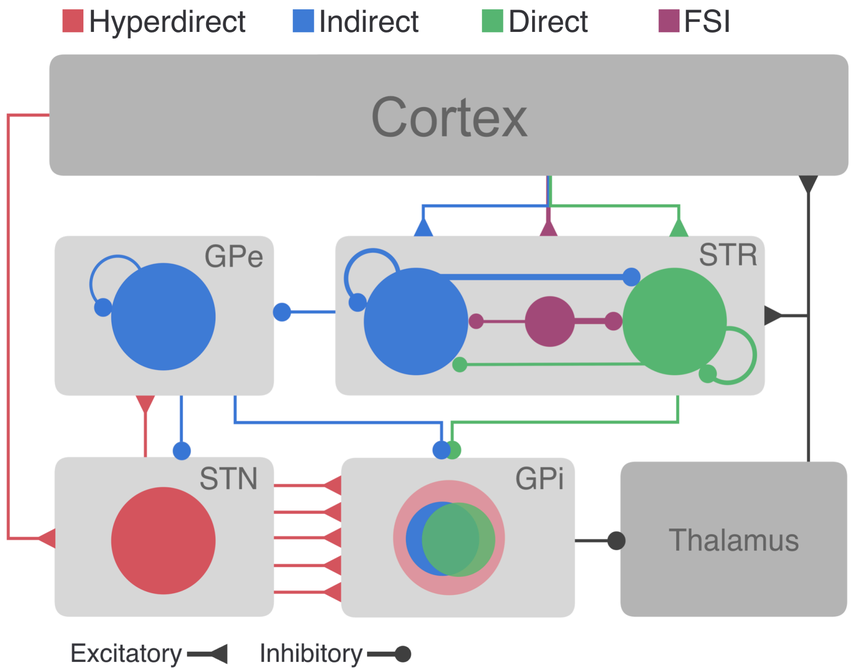
| Region | Equation |
|---|---|
| Cortical integrators | $INT_i(0) = \log 1/N + c$<br>$INT_i(t) = TH_i(t-1) + g\, x_i(t)$, for $t>0$ |
| Striatum | $STR_i(t) = INT_i(t)$ |
| Input from STN and GP | $SG(t) = \log \sum_{i=1}^{N} \exp INT_i(t)$ |
| Output nuclei | $OUT_i(t) = -STR_i(t) + SG(t)$ |
| Thalamus | $TH_i(t) = c - OUT_i(t)$ |

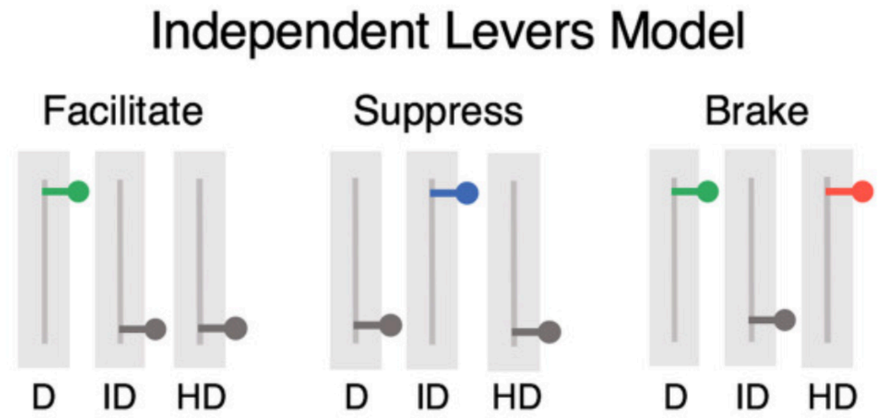


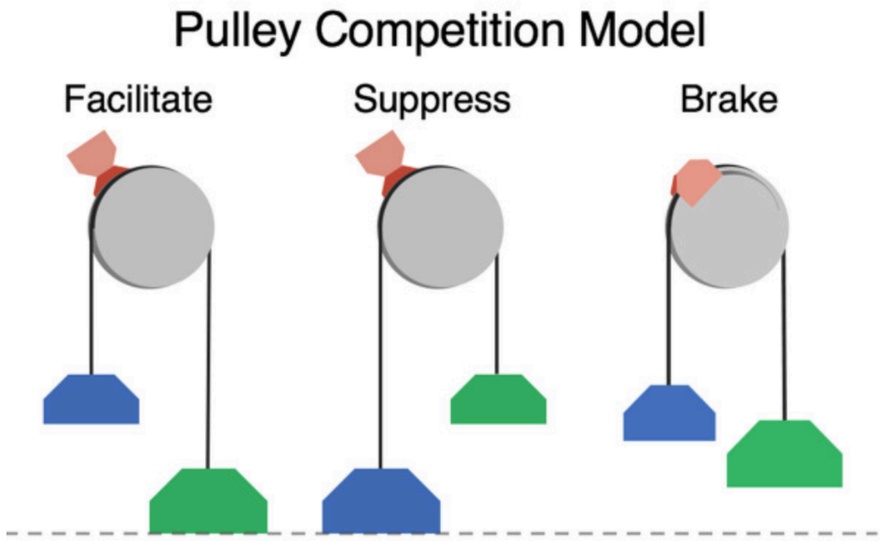
(Bogacz & Larsen, 2011)

# Control of certainty

# Believers & Skeptics



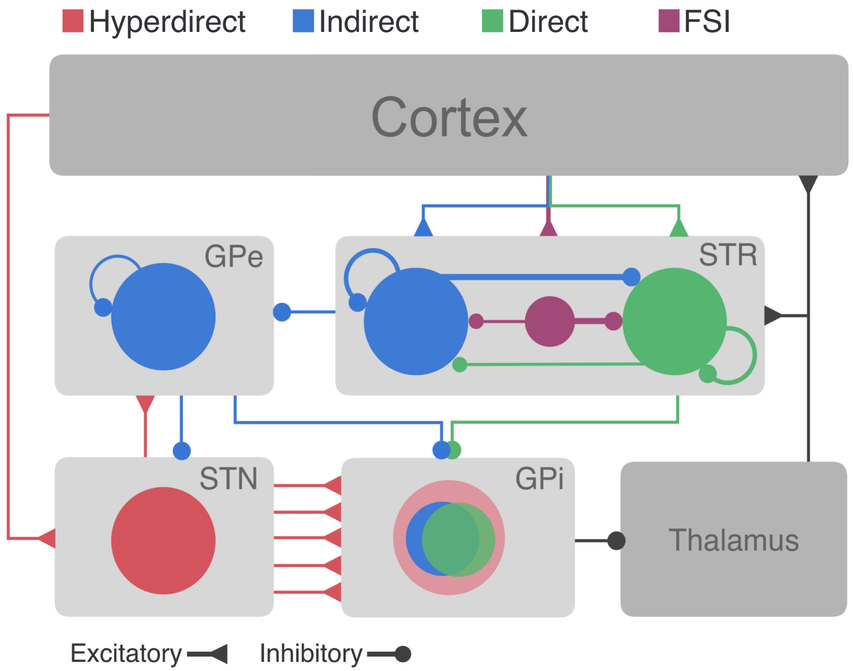



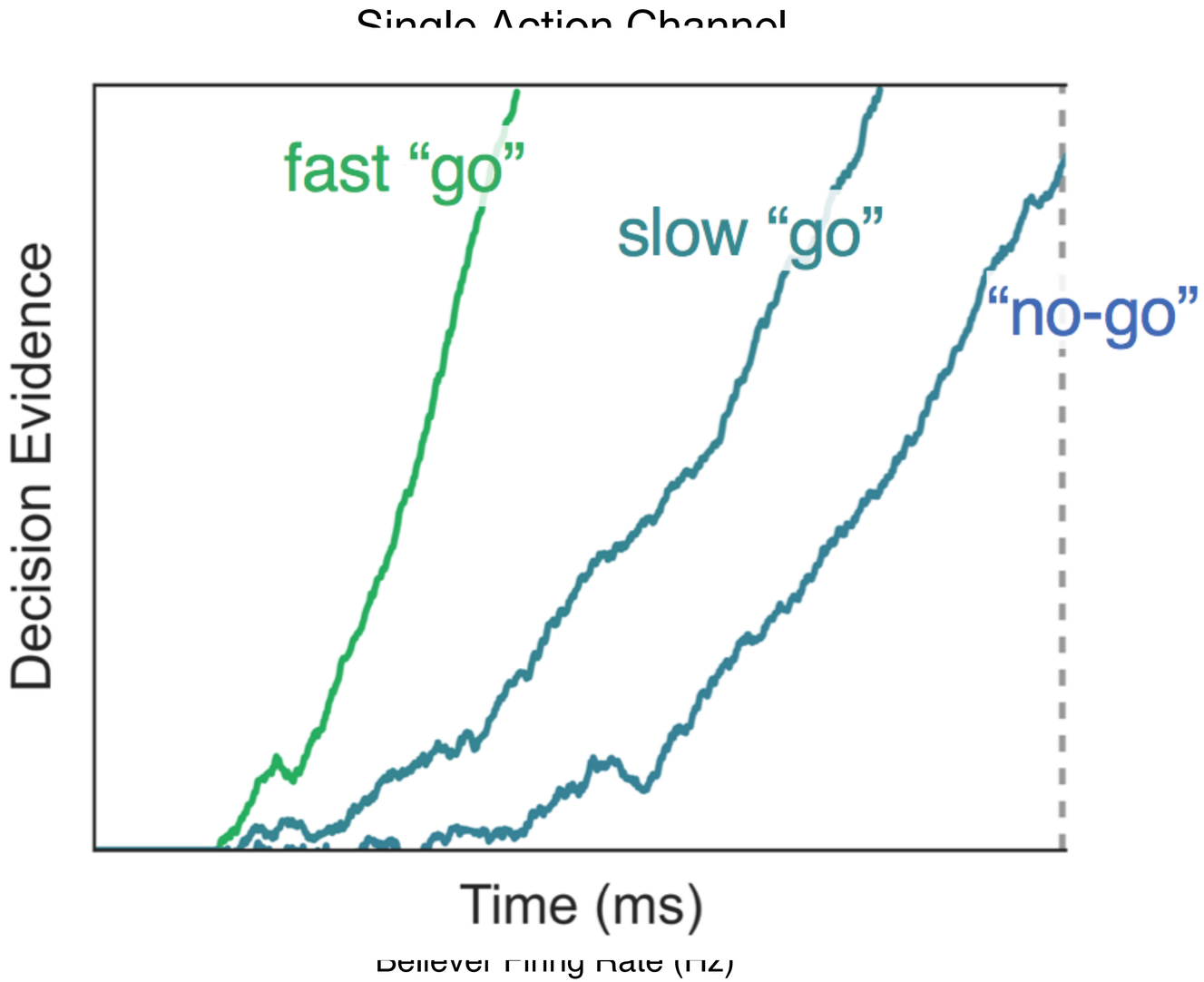






(Dunovan & Verstynen, 2016)

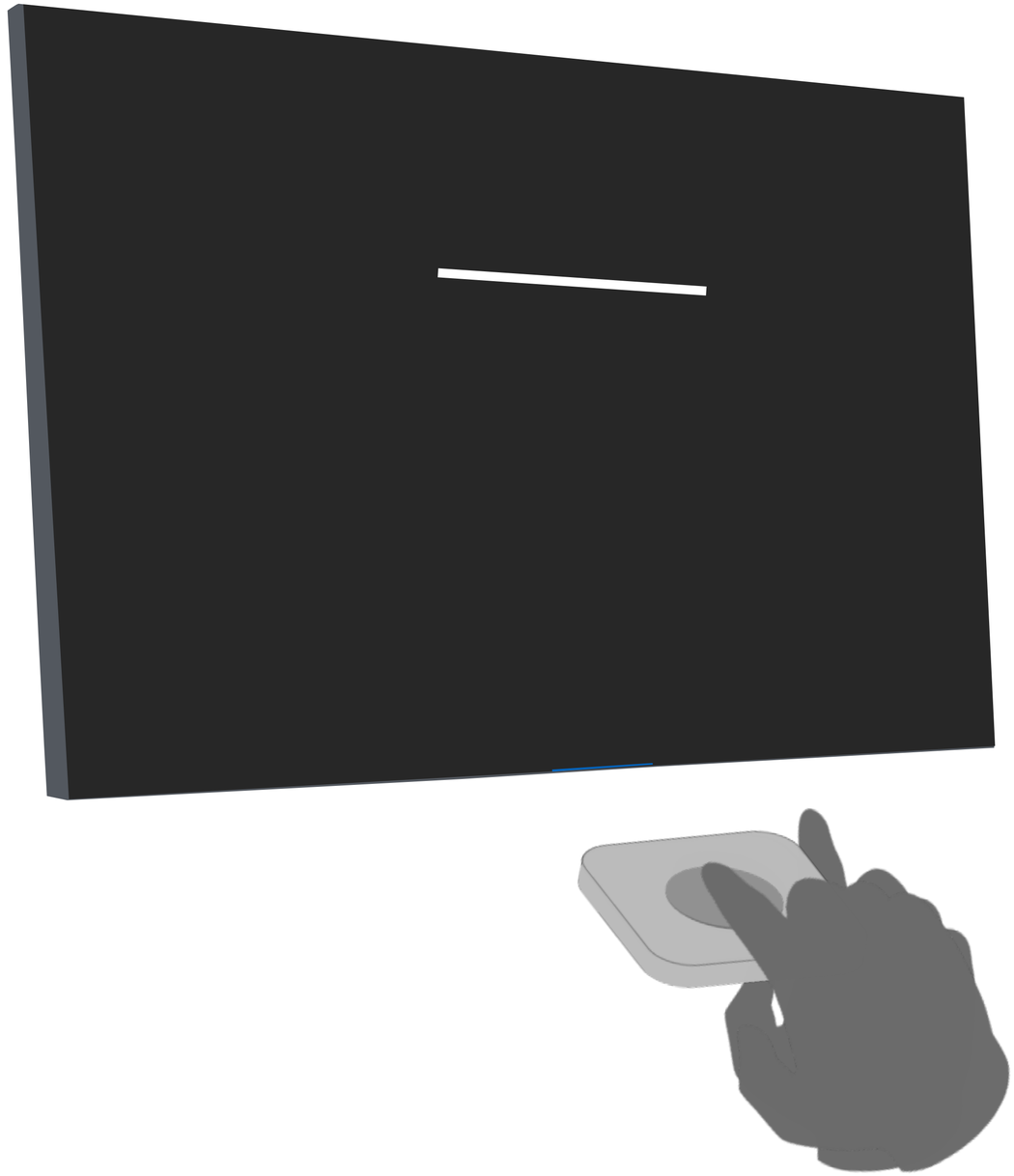
# Competition to drift rates



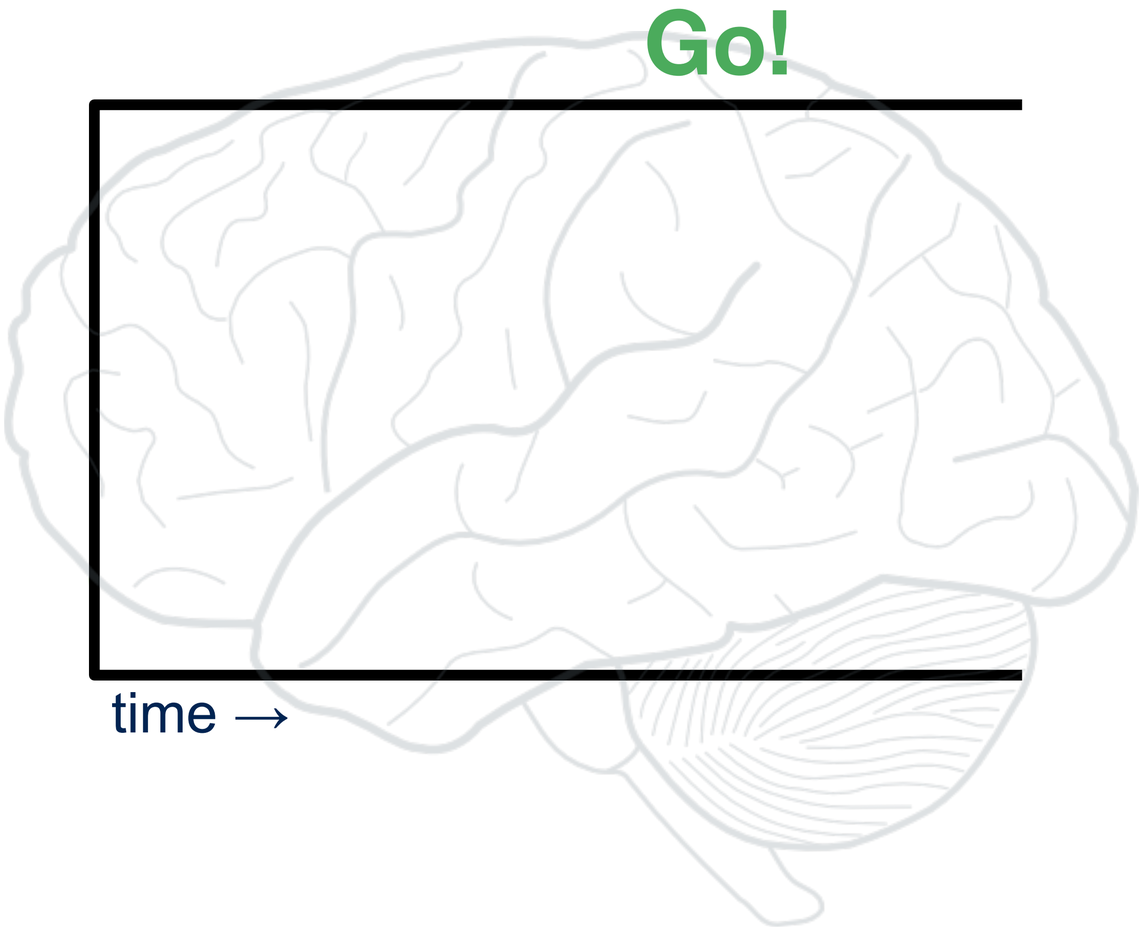



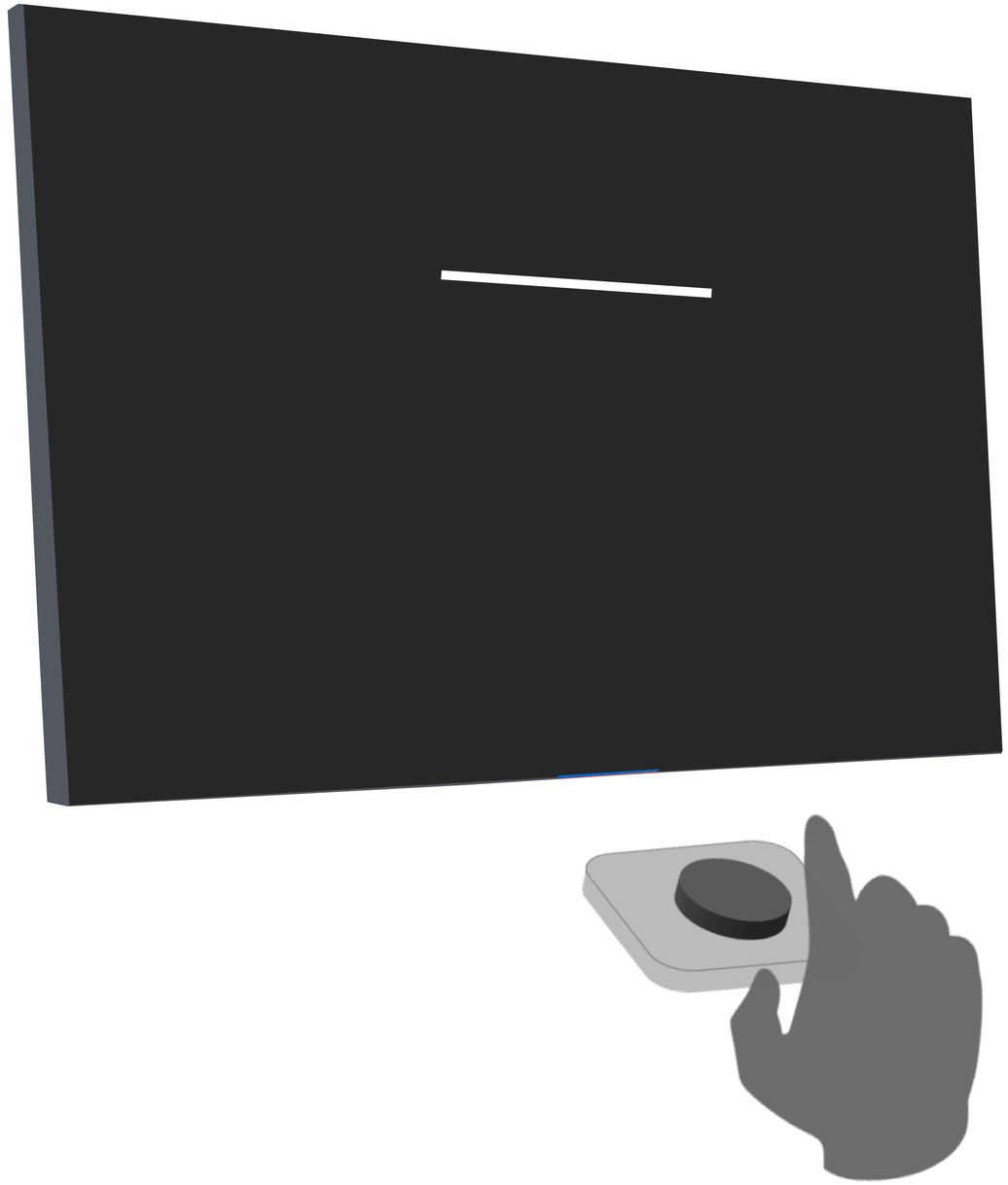



(Dunovan & Verstynen, 2016)



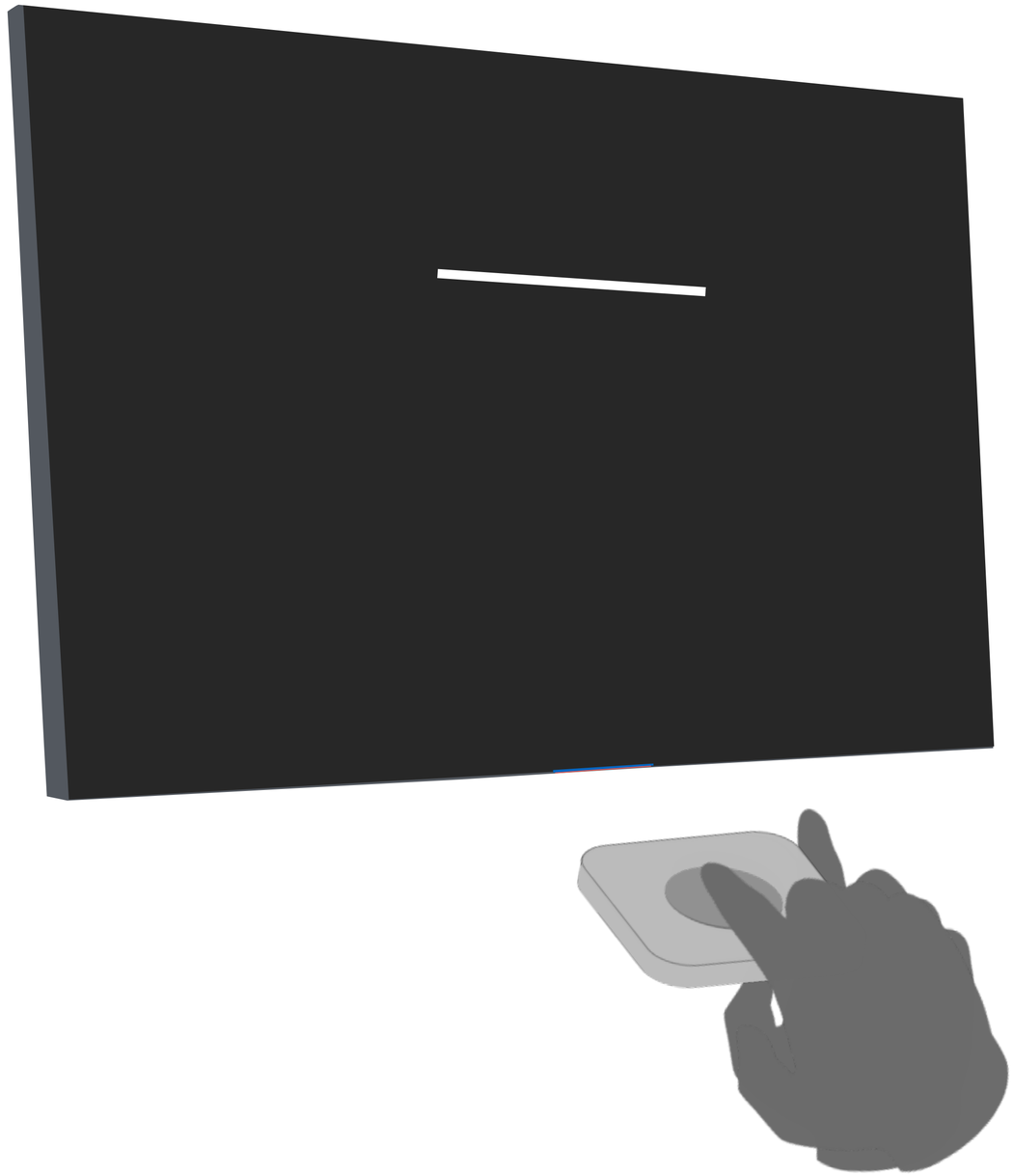



Go!
time →

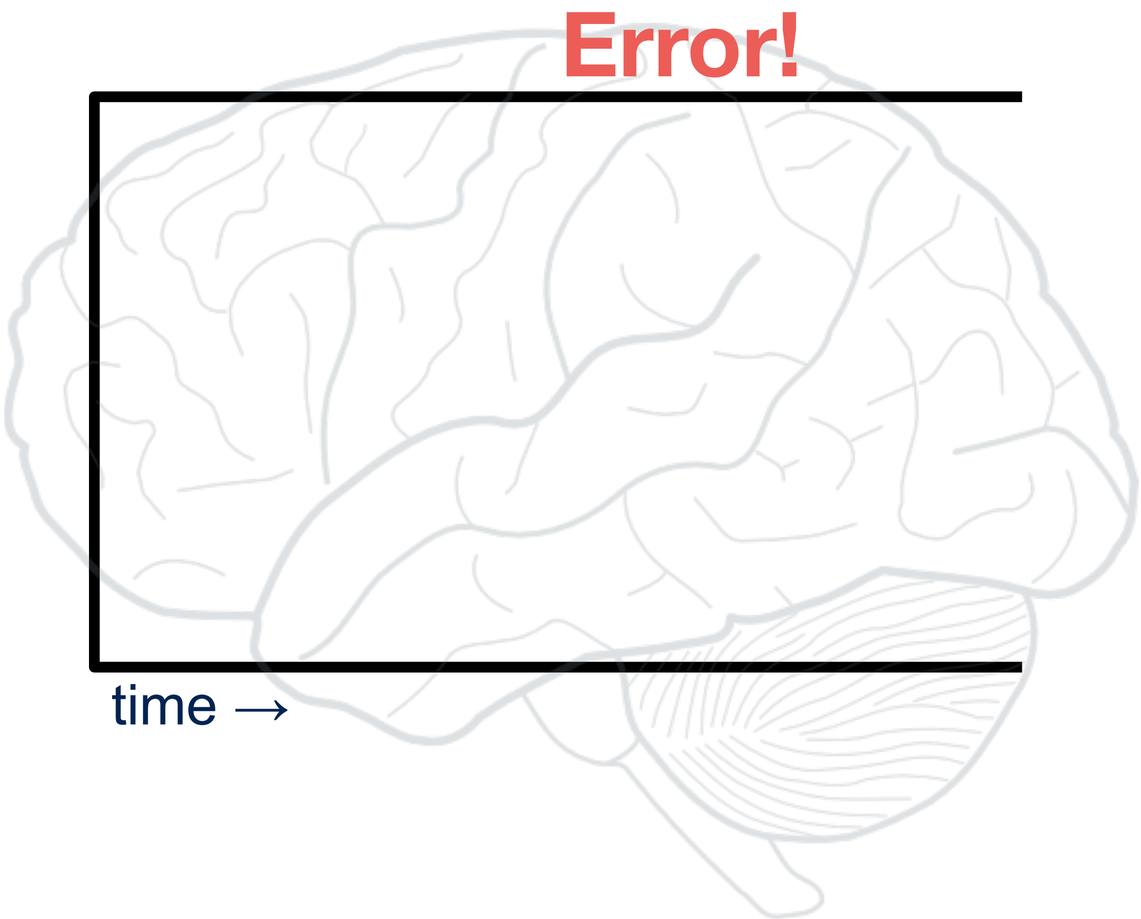


Stop!

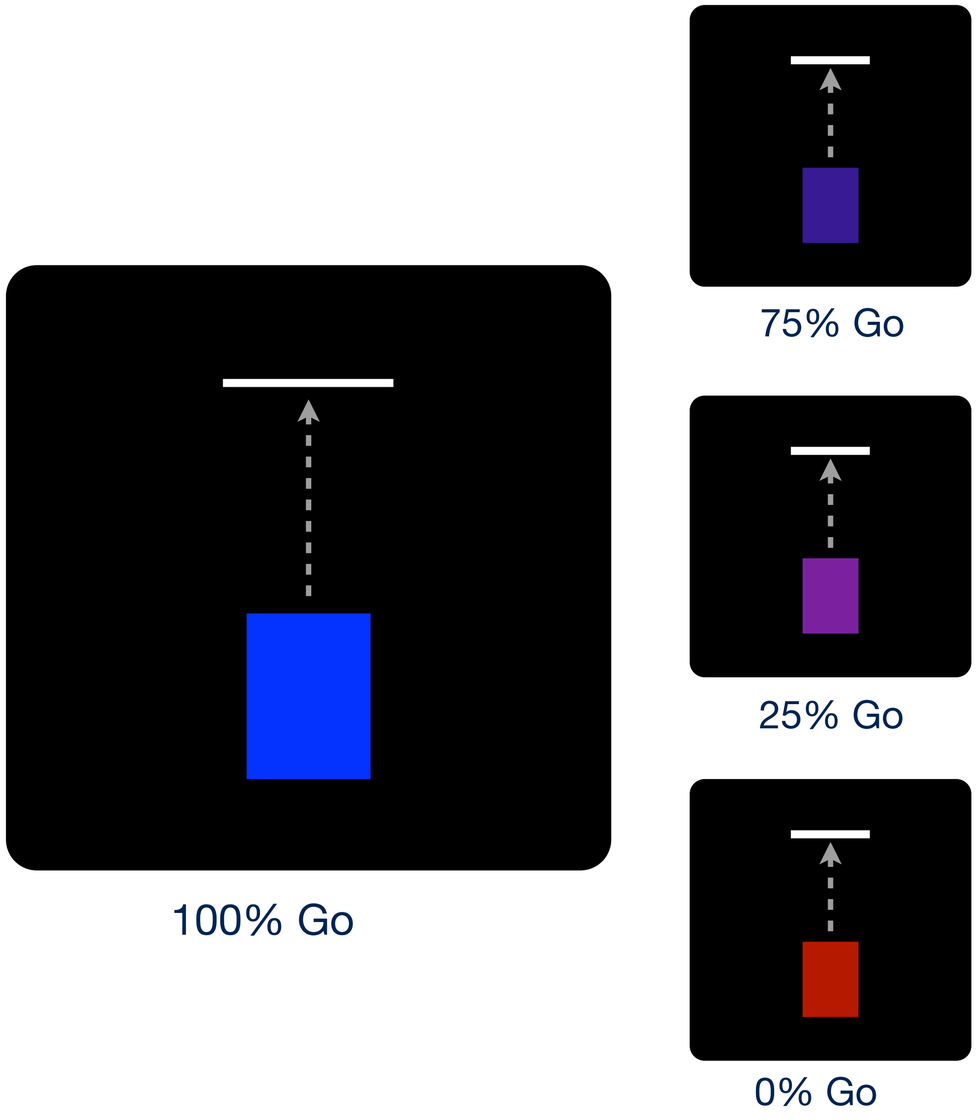
time →

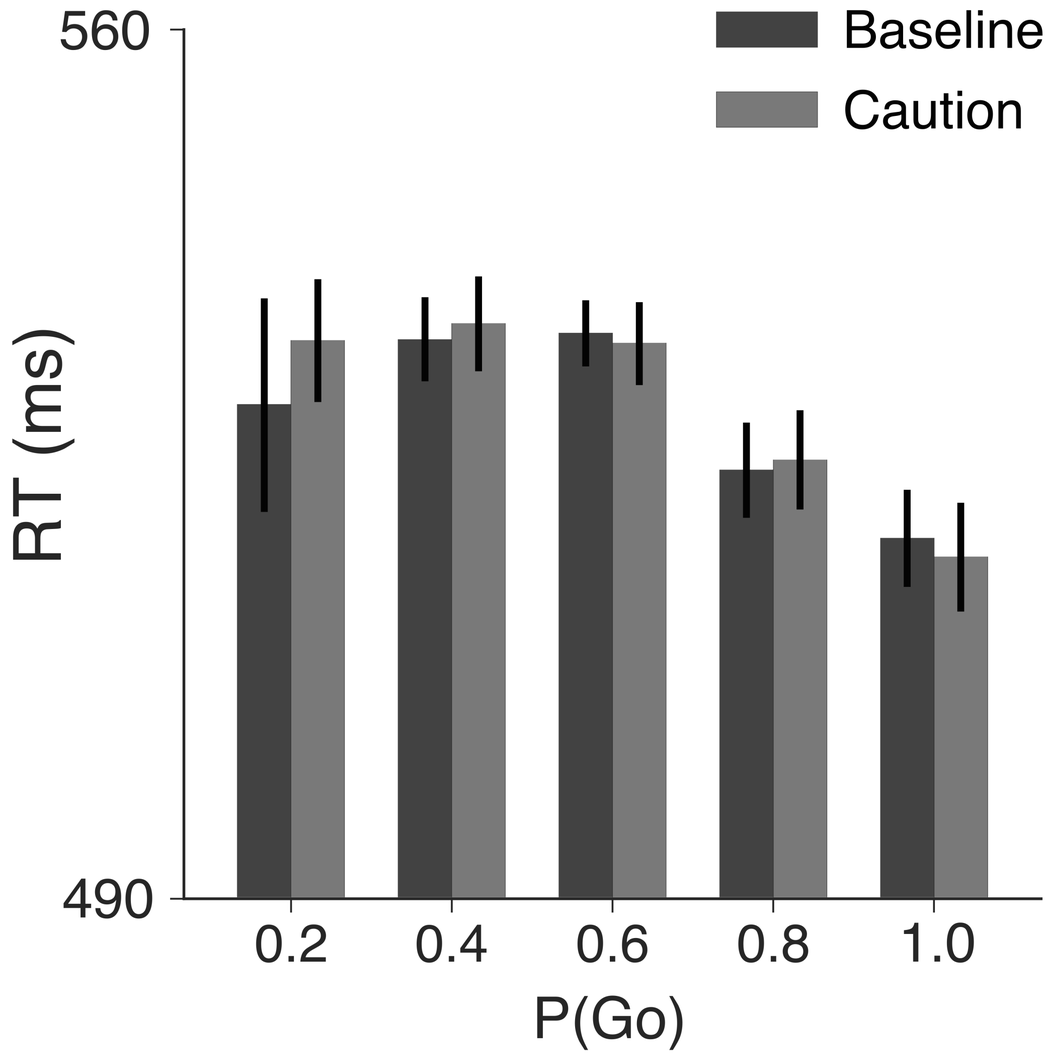





Error!
time →

# Proactive control

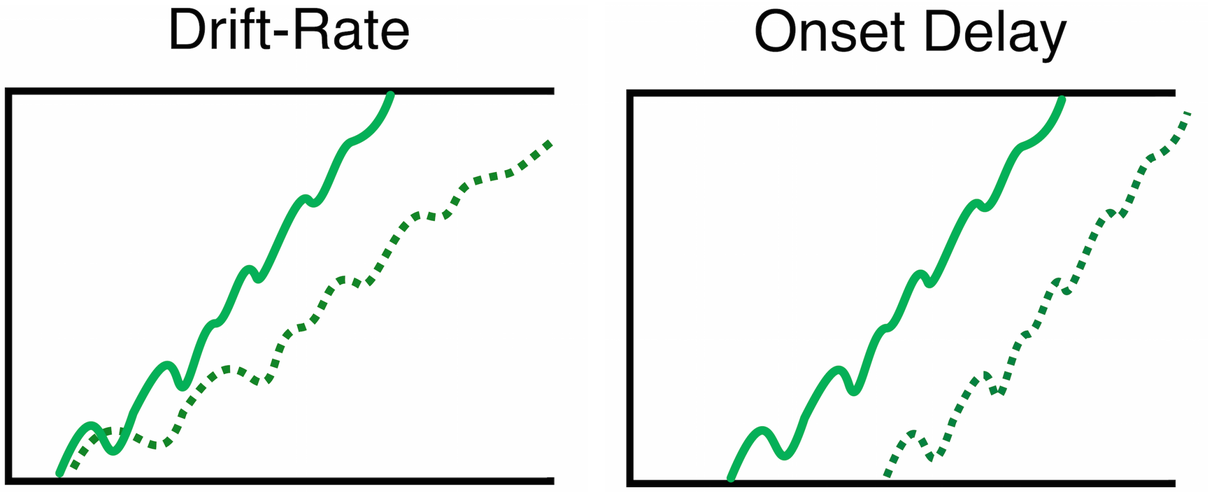


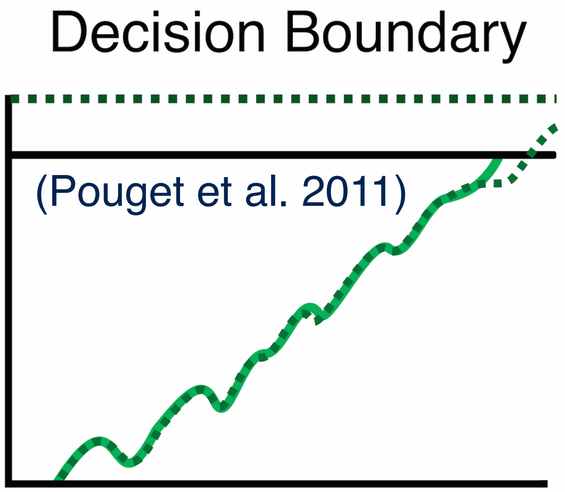



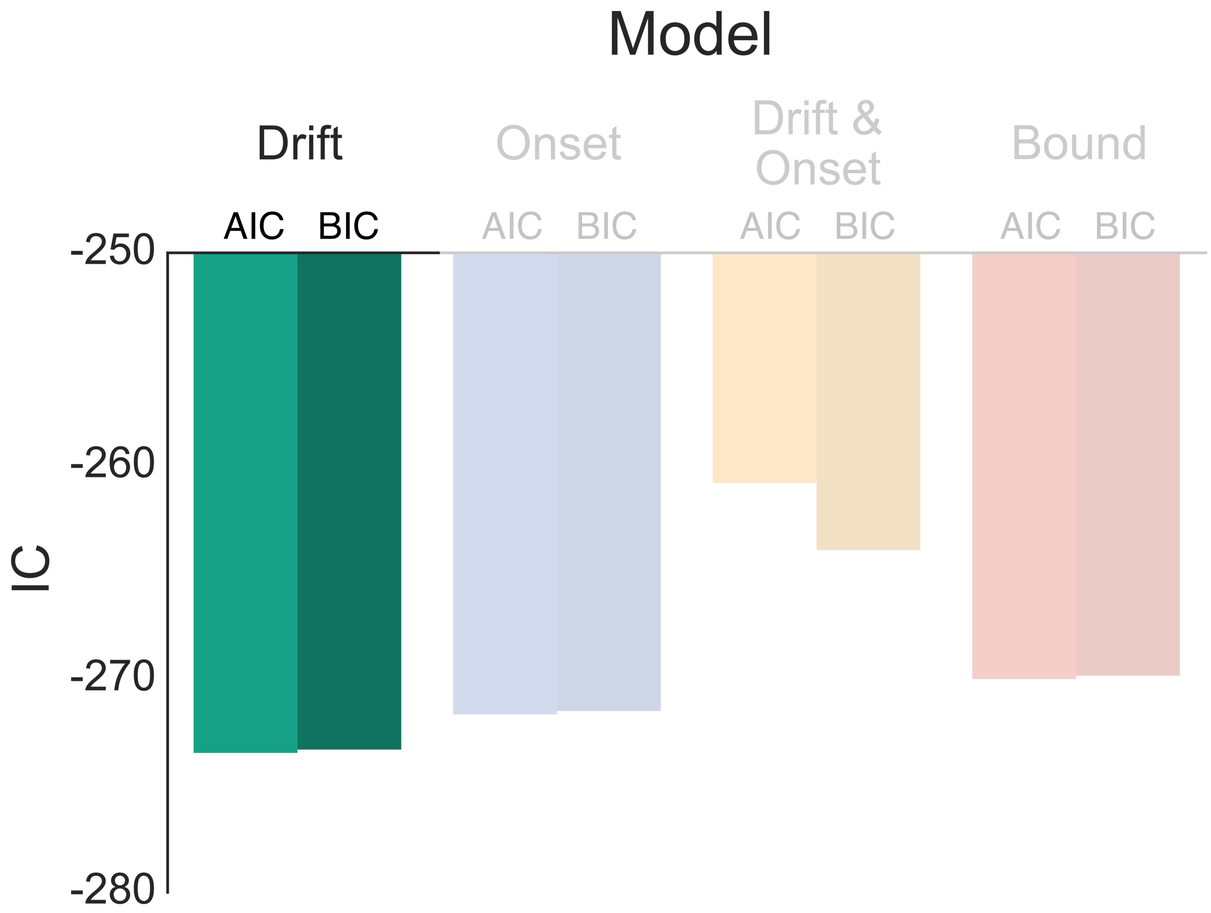



(Dunovan et al. 2015)

# Models



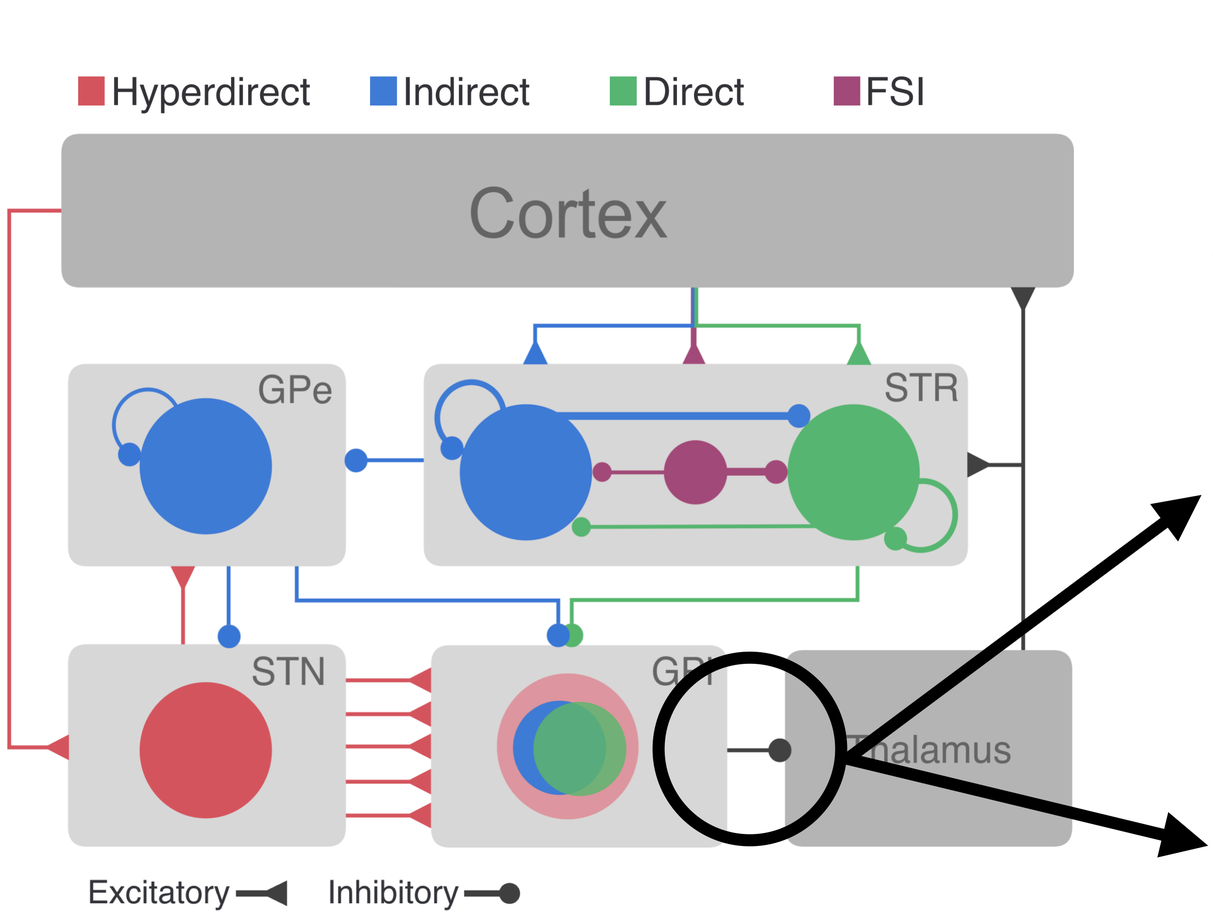



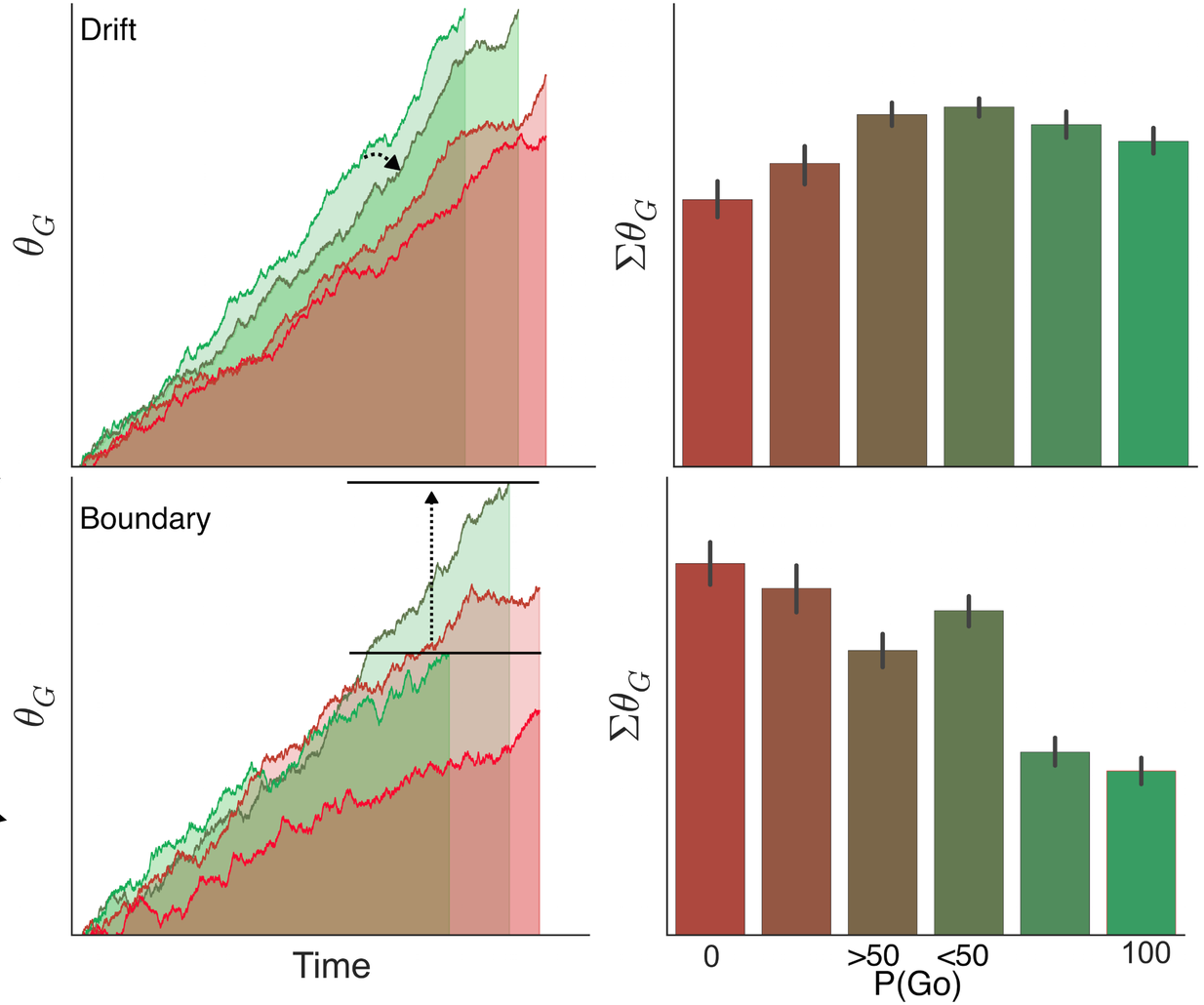






(Dunovan et al. 2015)

# Predicting CBGT output






(Dunovan et al. 2015)

# Predicting CBGT output

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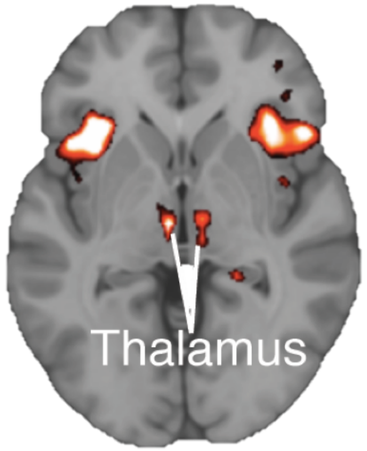


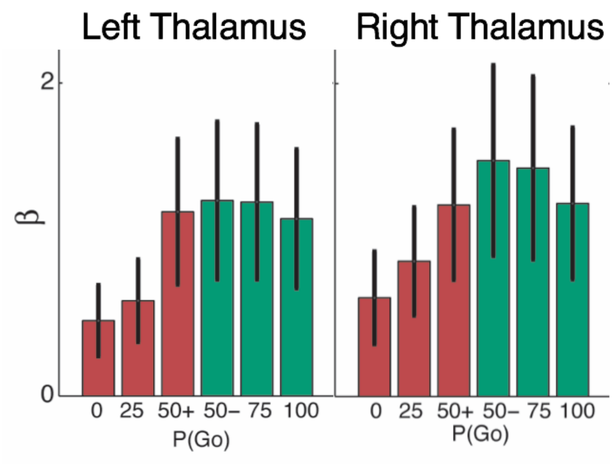


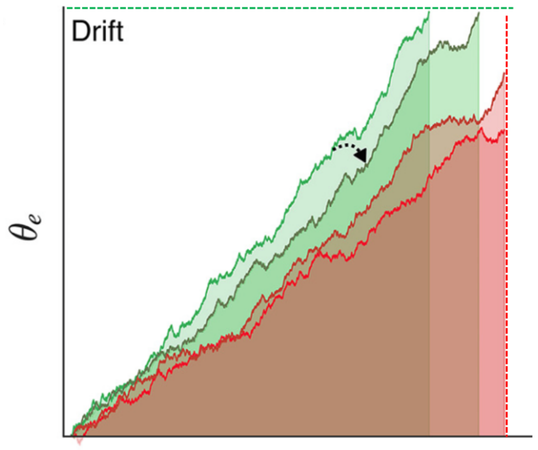


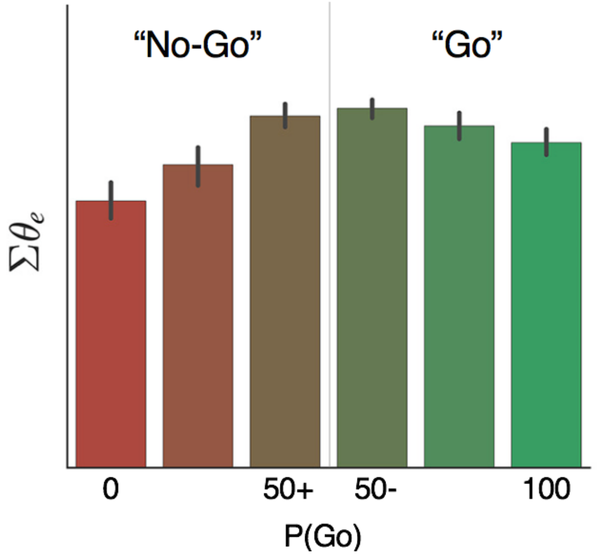


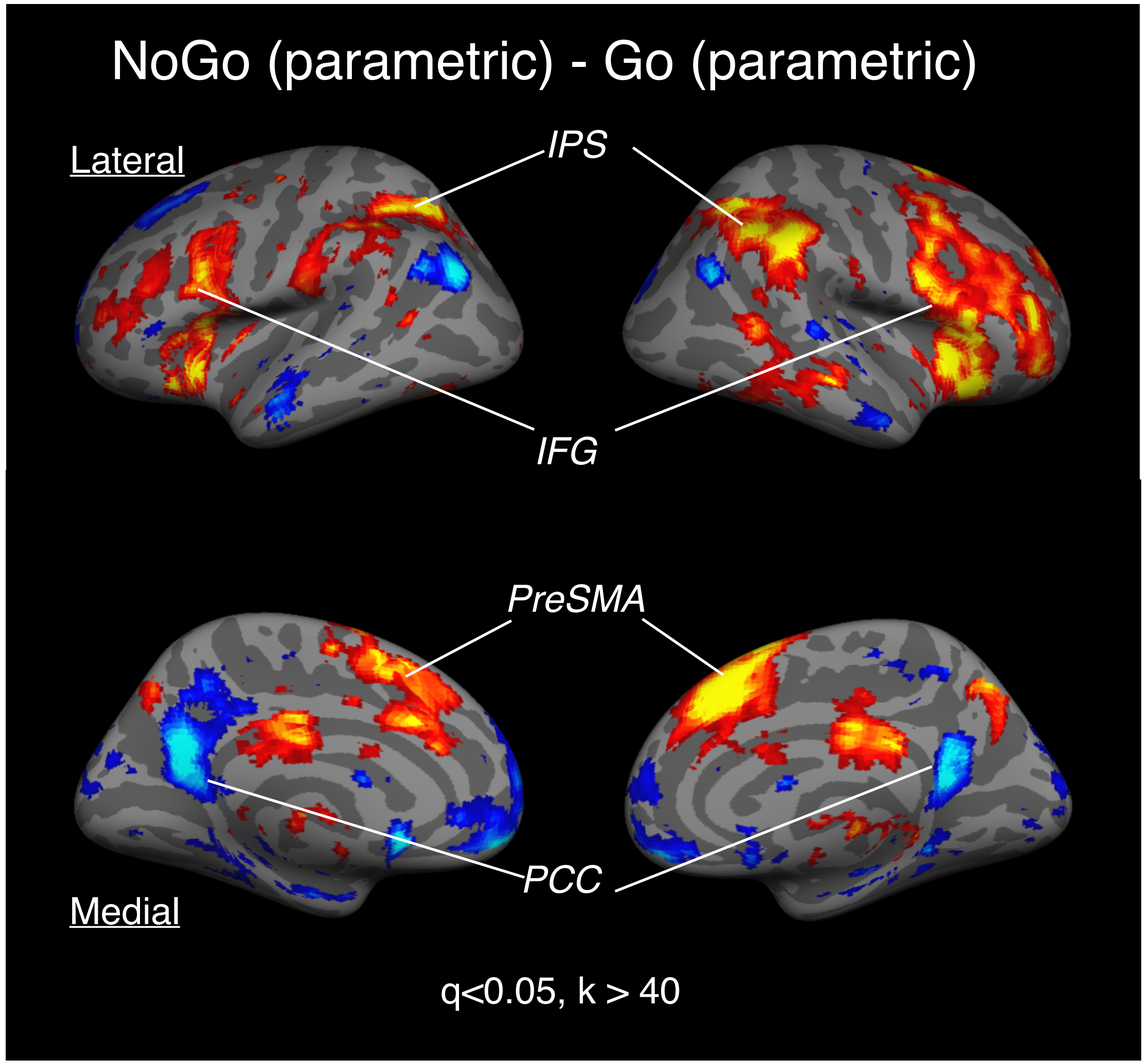




(Dunovan et al. 2015)

# Causal evidence?

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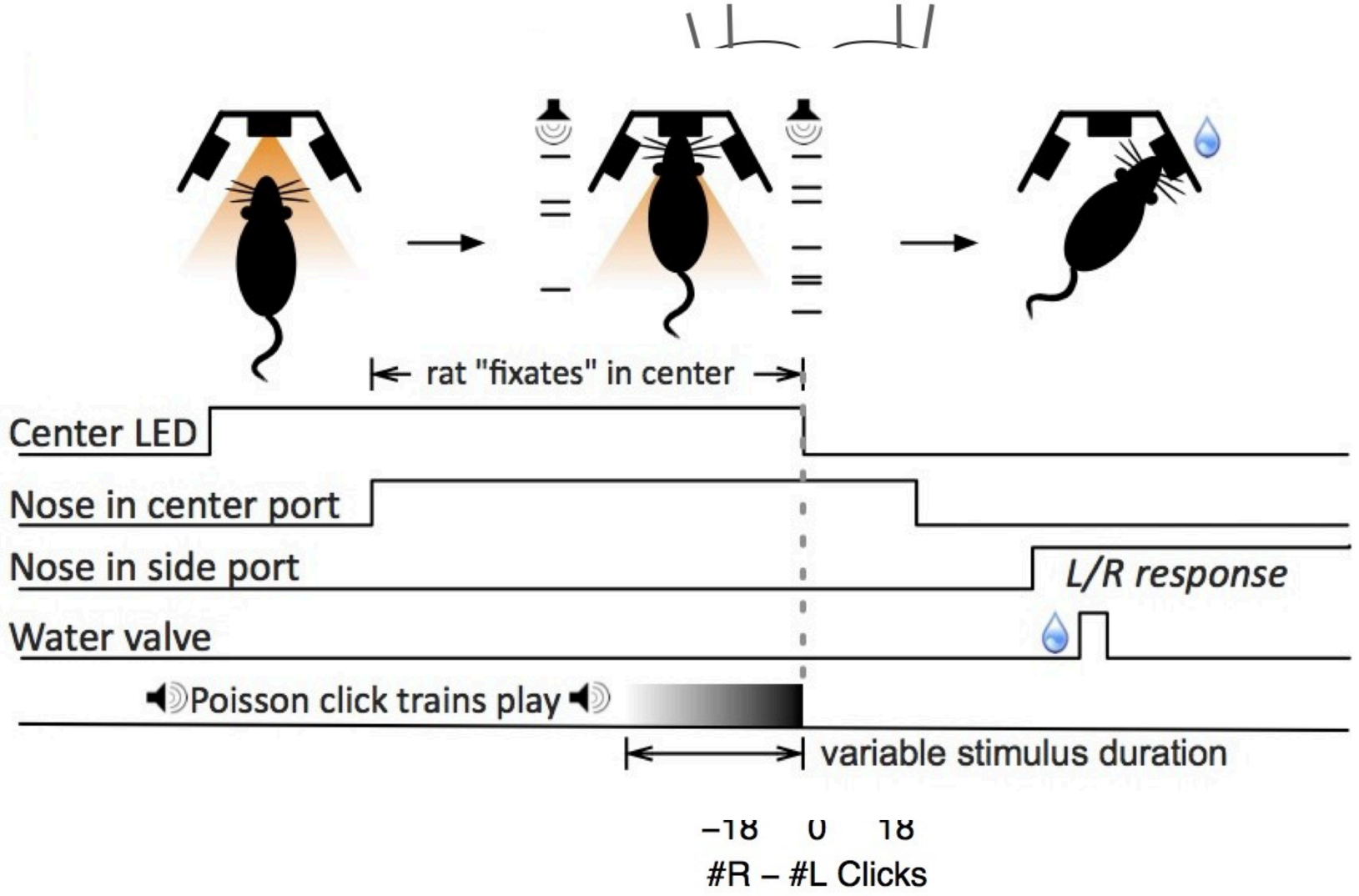




(Yartzev et al. 2018)

# Take home message

- The CBGT loops have an ideal architecture for accumulating evidence.
- CBGT network activity tracks with certainty and the drift rate.
- Disruption of the CBGT network disrupts evidence accumulation.

# Lab 5: CBGT networks

URL: https://github.com/CoAxLab/BiologicallyIntelligentExploration/tree/main/Labs