Bayesian Inference

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Bayesian Brain Hypothesis

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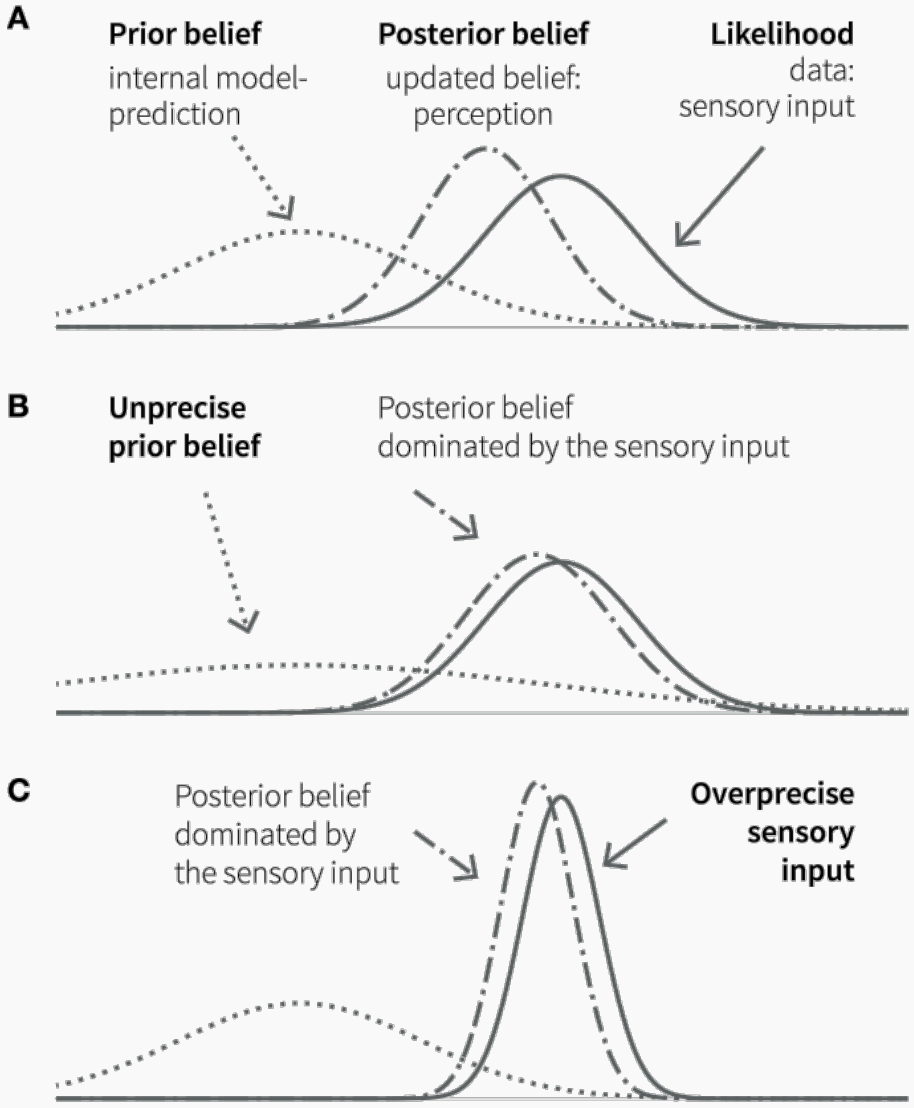
- Central nervous system uses the experience garnered over a lifetime
- Neither its sensory data nor its prior beliefs are completely reliable
- Thus the brain must use both sources of information, taking into account their uncertainty to perform its task

Bayesian Brain Hypothesis

- Contributions of the prior and likelihood to the posterior are weighted by their precision:

$$\Delta belief = \frac{precision\ of\ likelihood}{precision\ of\ prior} \times PE$$

- Probability distributions are often assumed to be of a kind that can be represented by a few “sufficient statistics” (i.e. mean & precision)



Bayesian Brain Hypothesis

- Statistics of natural sensory stimulation are also extremely complex

- However the environment itself contains hierarchical structure; (ex. phonemes, words, sentences)

- Hierarchical models explain complex patterns of low-level data features in terms of more abstract causes

Bayesian Brain Hypothesis

- Hierarchical generative models can use predictive coding to predict low-level data using their high-level descriptions (i.e. reconstructing the missing parts of an image)

- In predictive coding, a unit at a given level in the hierarchy sends messages to one or more units at lower levels, which predict their activity

Bayesian Brain Hypothesis

- Discrepancies between these predictions and the actual input are then passed back up the hierarchy in the form of prediction errors

- These prediction errors revise the higher-level predictions

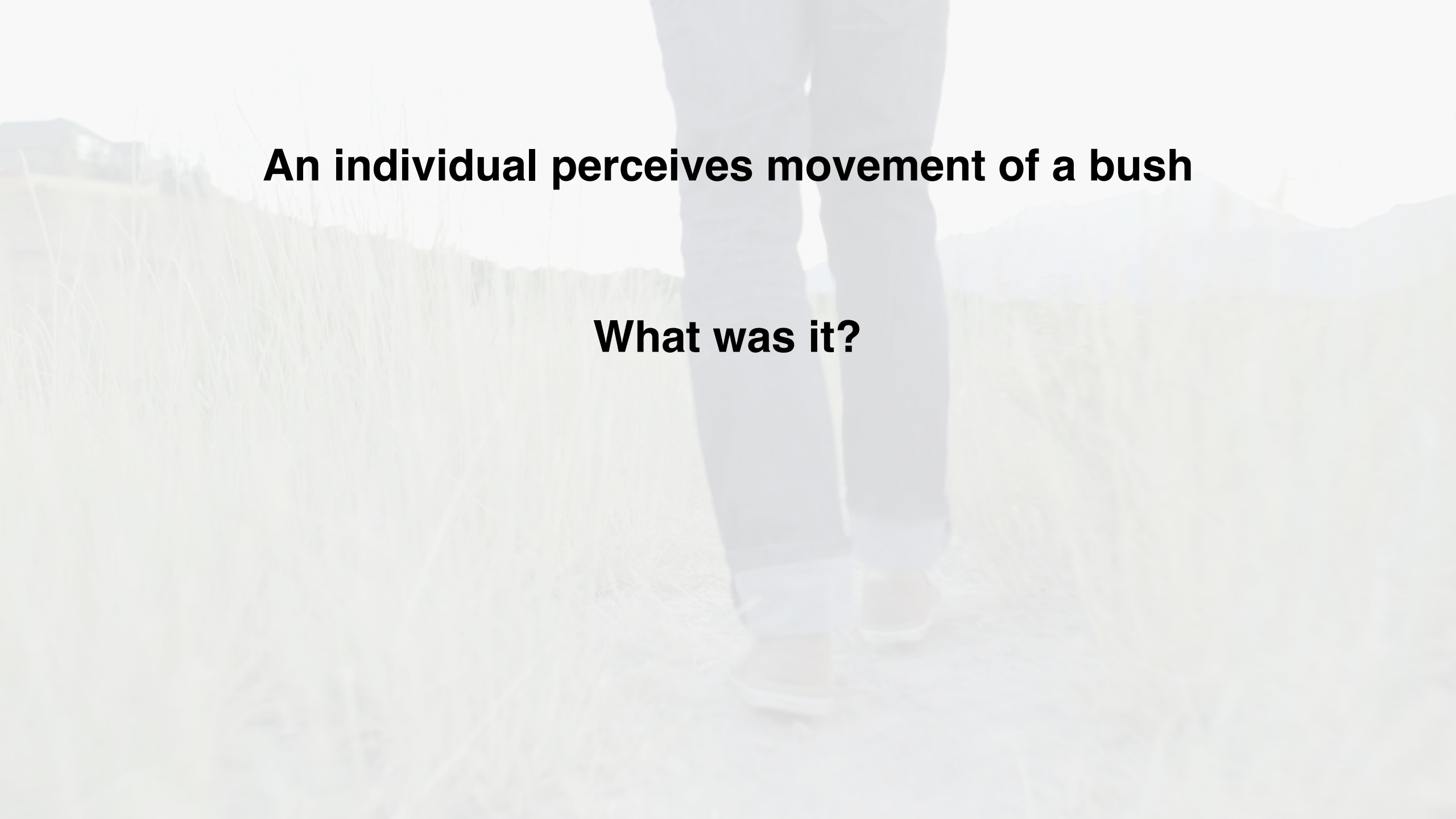
- Exactly which predictions ought to be changed to explain away a given prediction error is crucial

Bayesian Brain Hypothesis

- An approximately Bayesian solution to the problem is to make the biggest updates to the level whose uncertainty is greatest relative to the incoming data at the level below

- That is, if you are very uncertain about your beliefs, you ought to update your beliefs a lot relying on the information you obtain.

An individual perceives movement of a bush



An individual perceives movement of a bush

What was it?

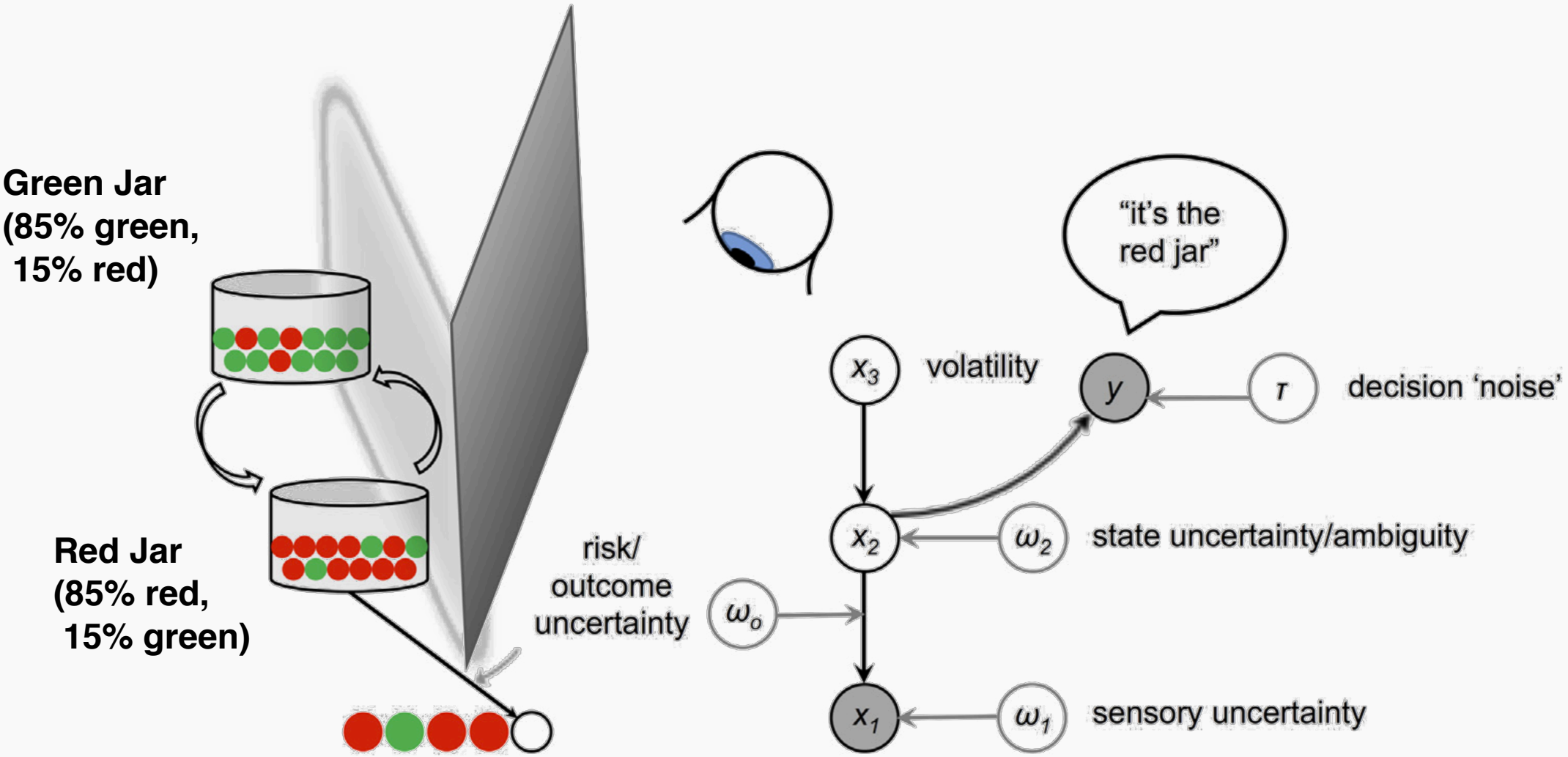
An individual perceives movement of a bush

What was it?

1) **Bush didn’t actually move**
2) **Wind was moving the bush**
3) **Animal was moving the bush**
4) **A man hiding in the bush moved it**

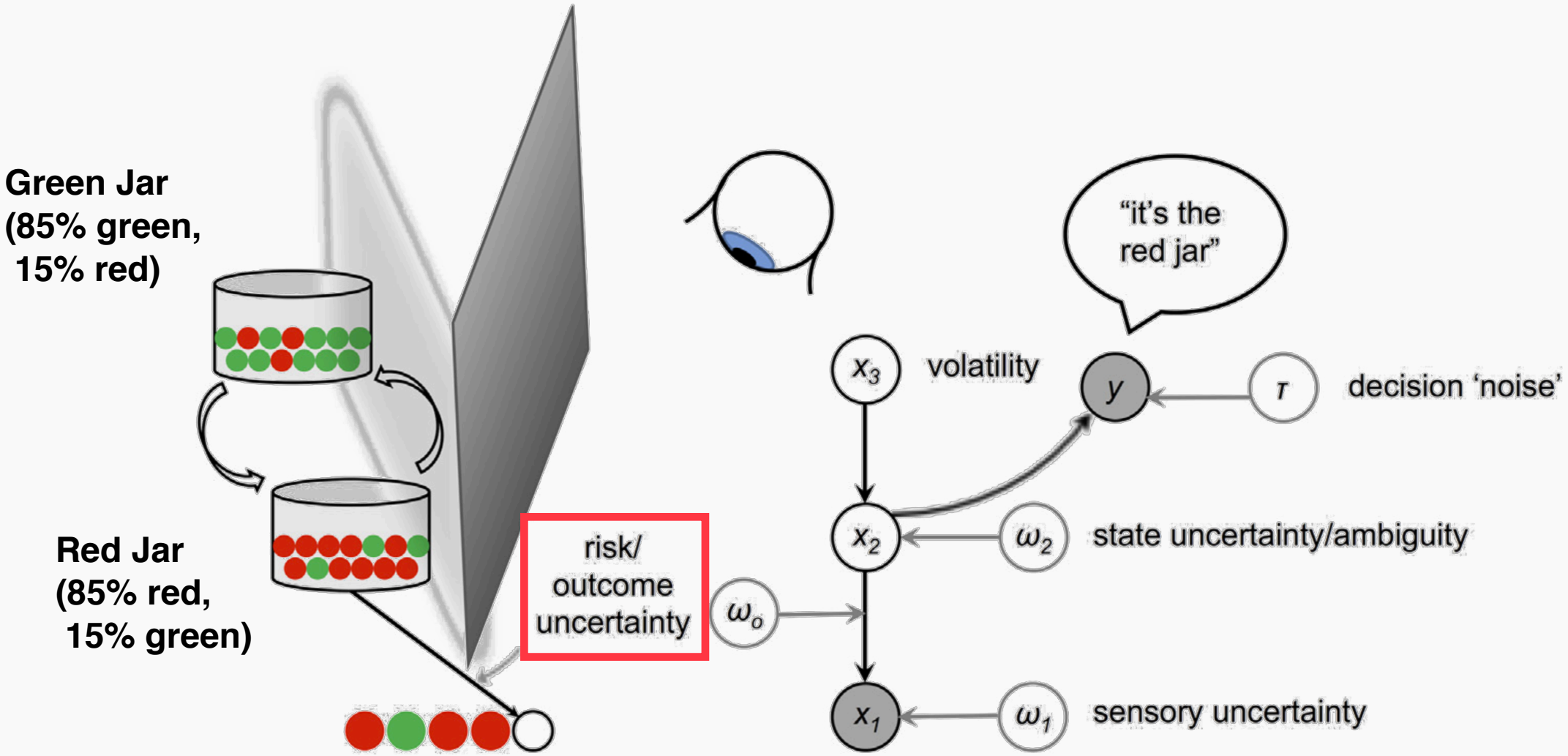
1) Did it really move?
2) Was it really the wind?
3) Is there any animals living nearby?

1) Bush didn’t actually move
2) Wind was moving the bush
3) Animal was moving the bush
4) A man hiding in the bush moved it



Possible uncertainty changes in schizophrenia:

$\uparrow \omega_2, \tau, \quad \downarrow \omega_1, \omega_o$



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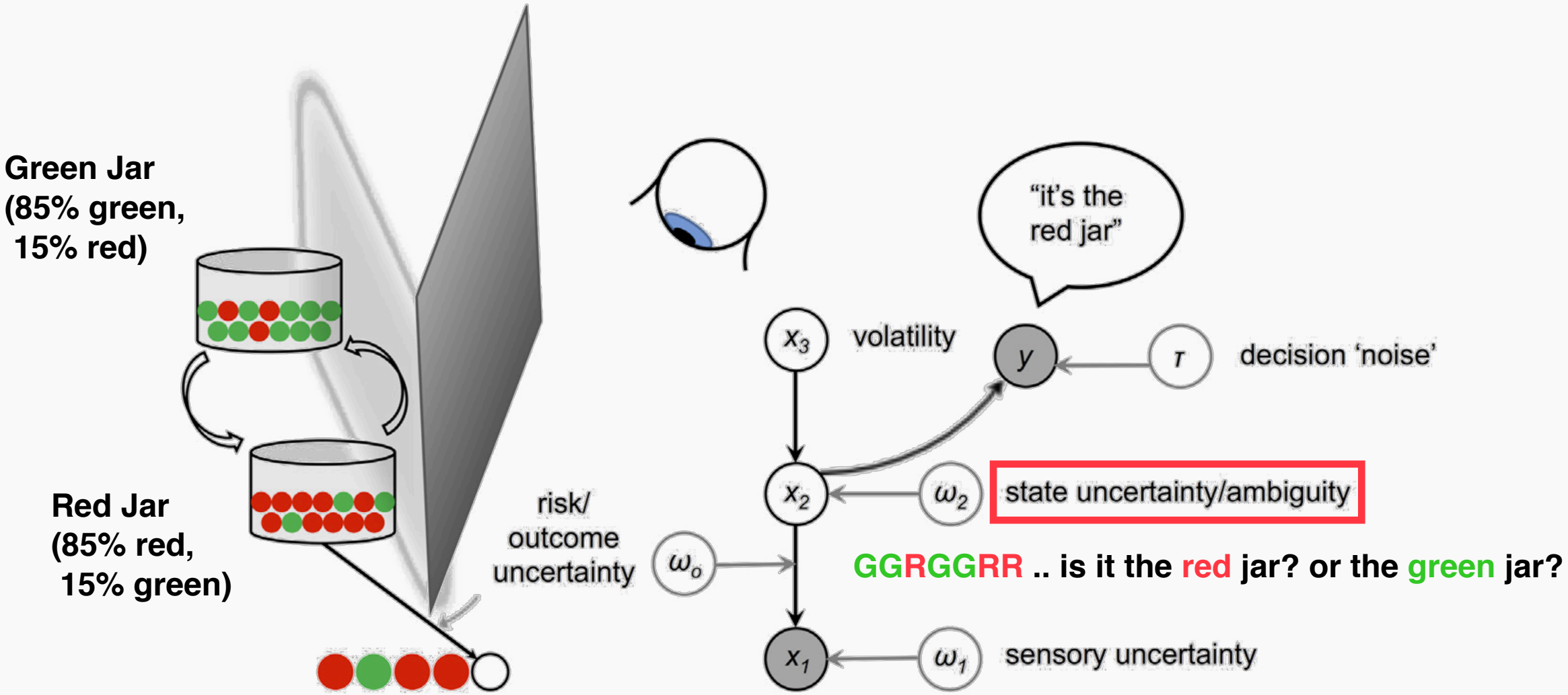

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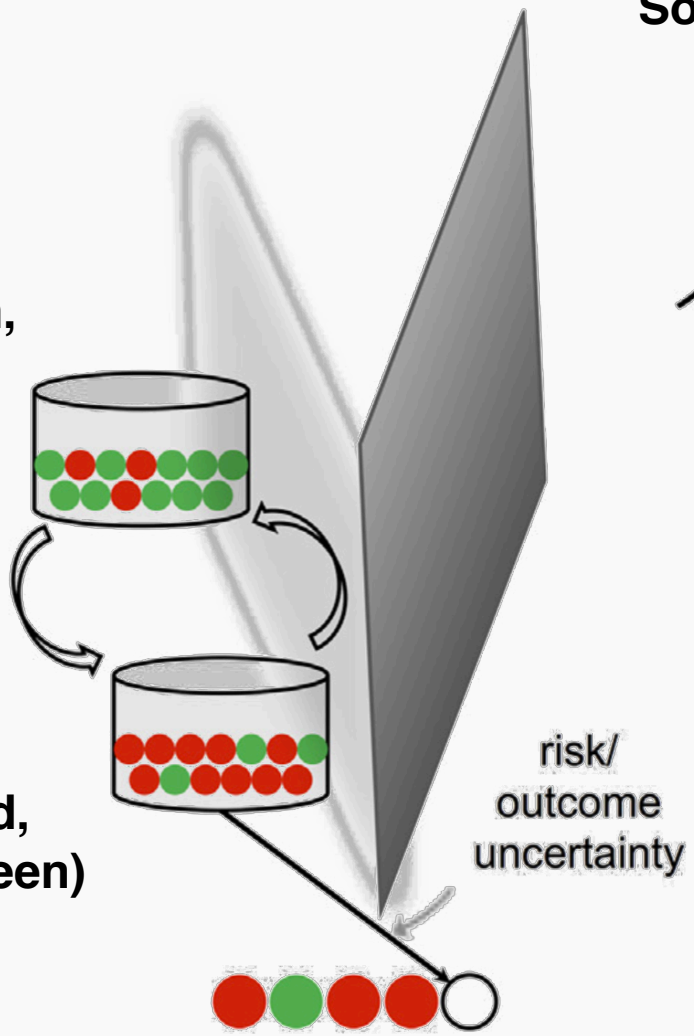
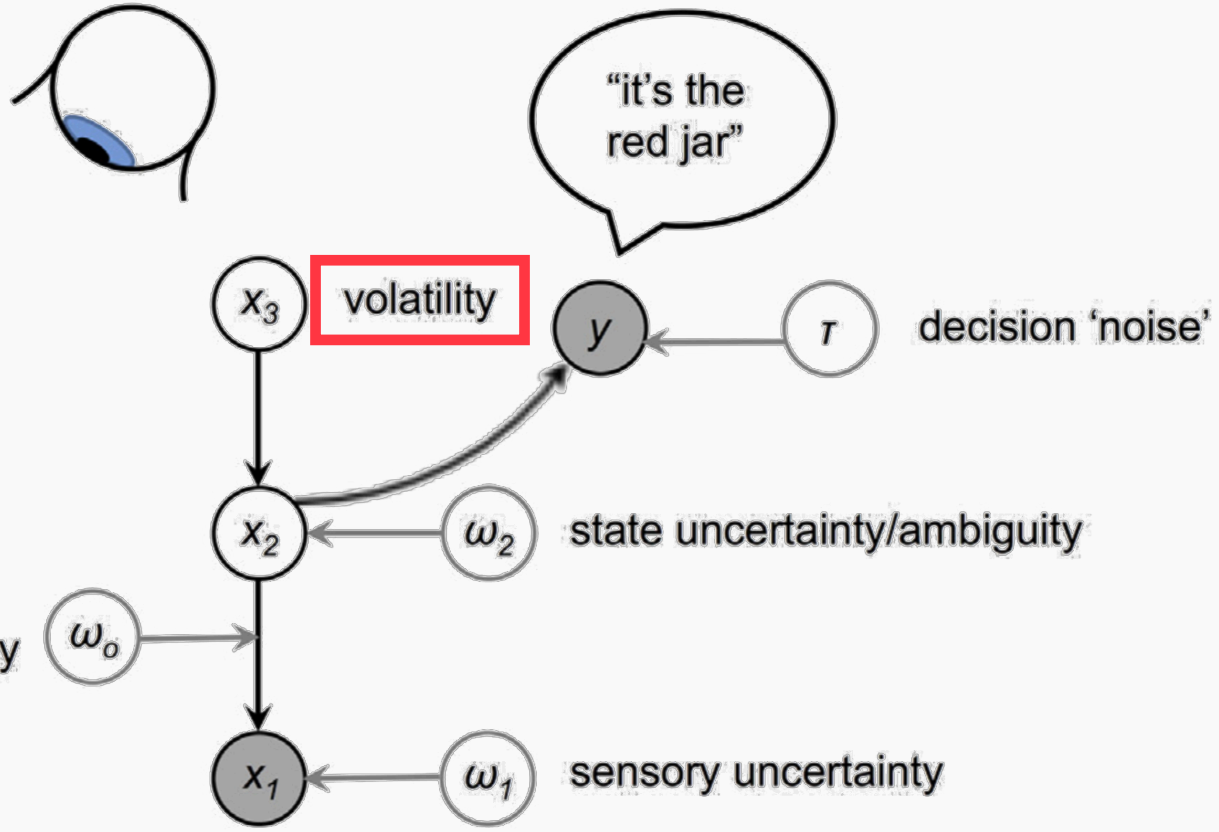
Someone might have changed the jar during the experiment!

GGRGGRRRRRGGGRGGGGGGRGGGGGG

Green Jar (85% green, 15% red)

Red Jar (85% red, 15% green)





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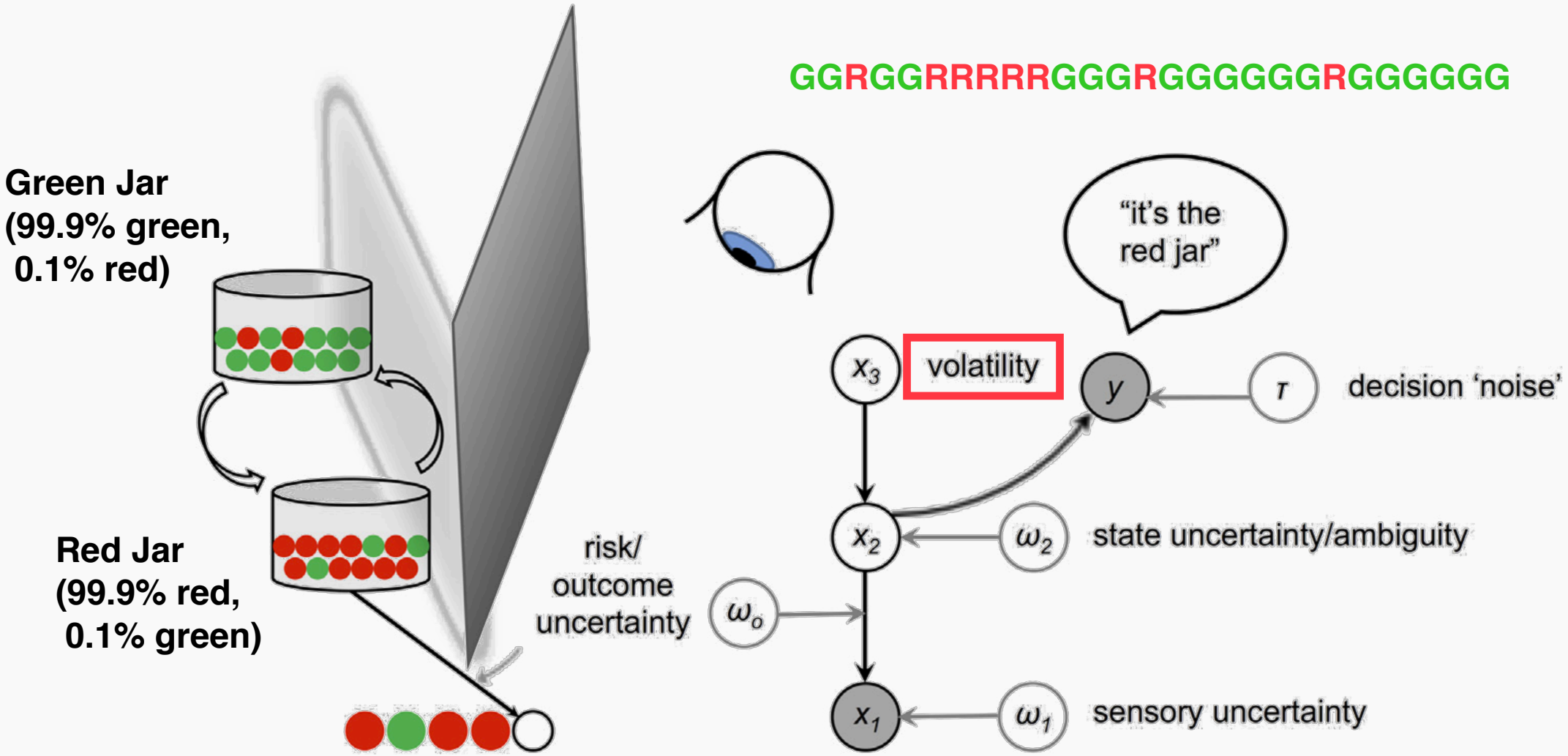

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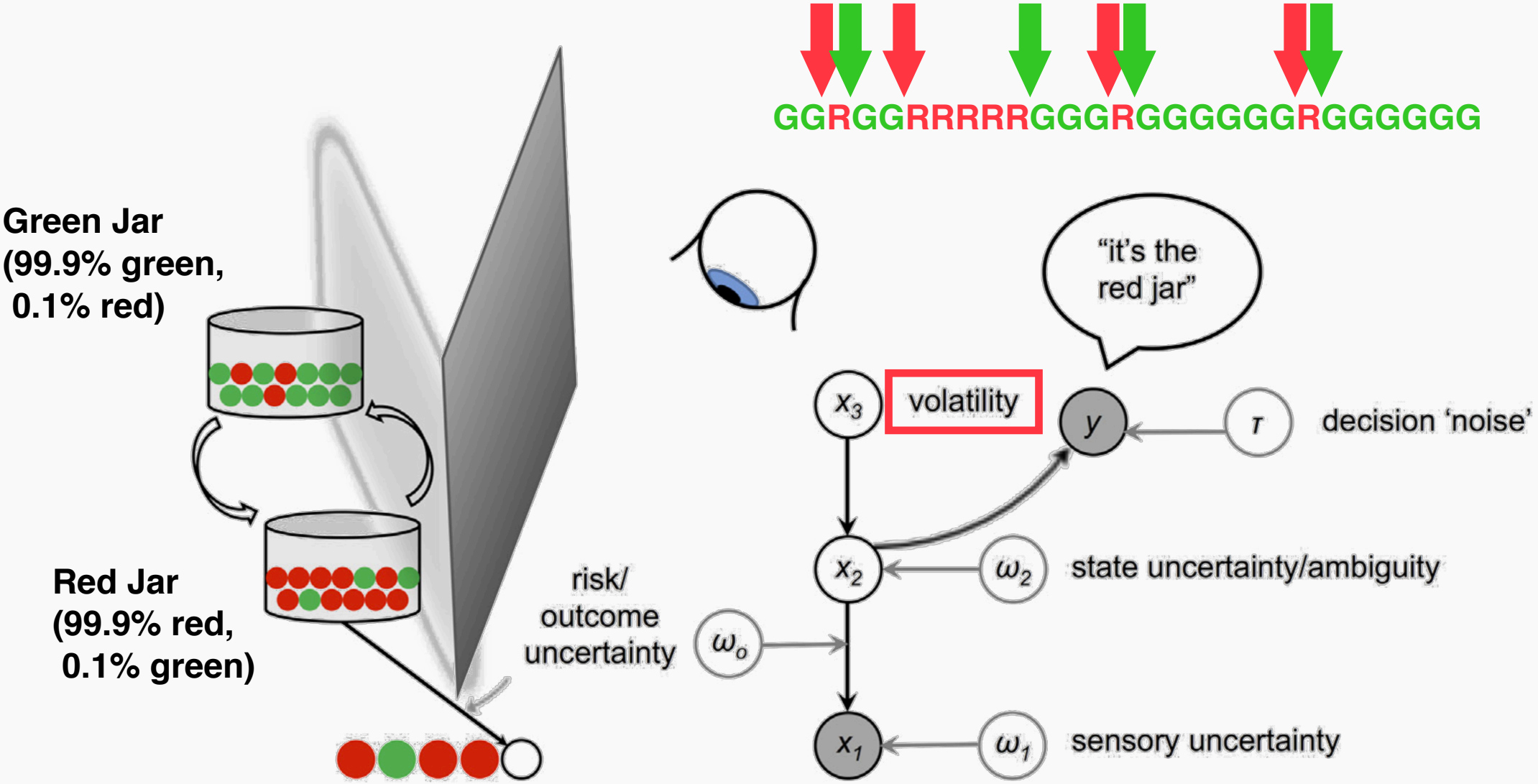

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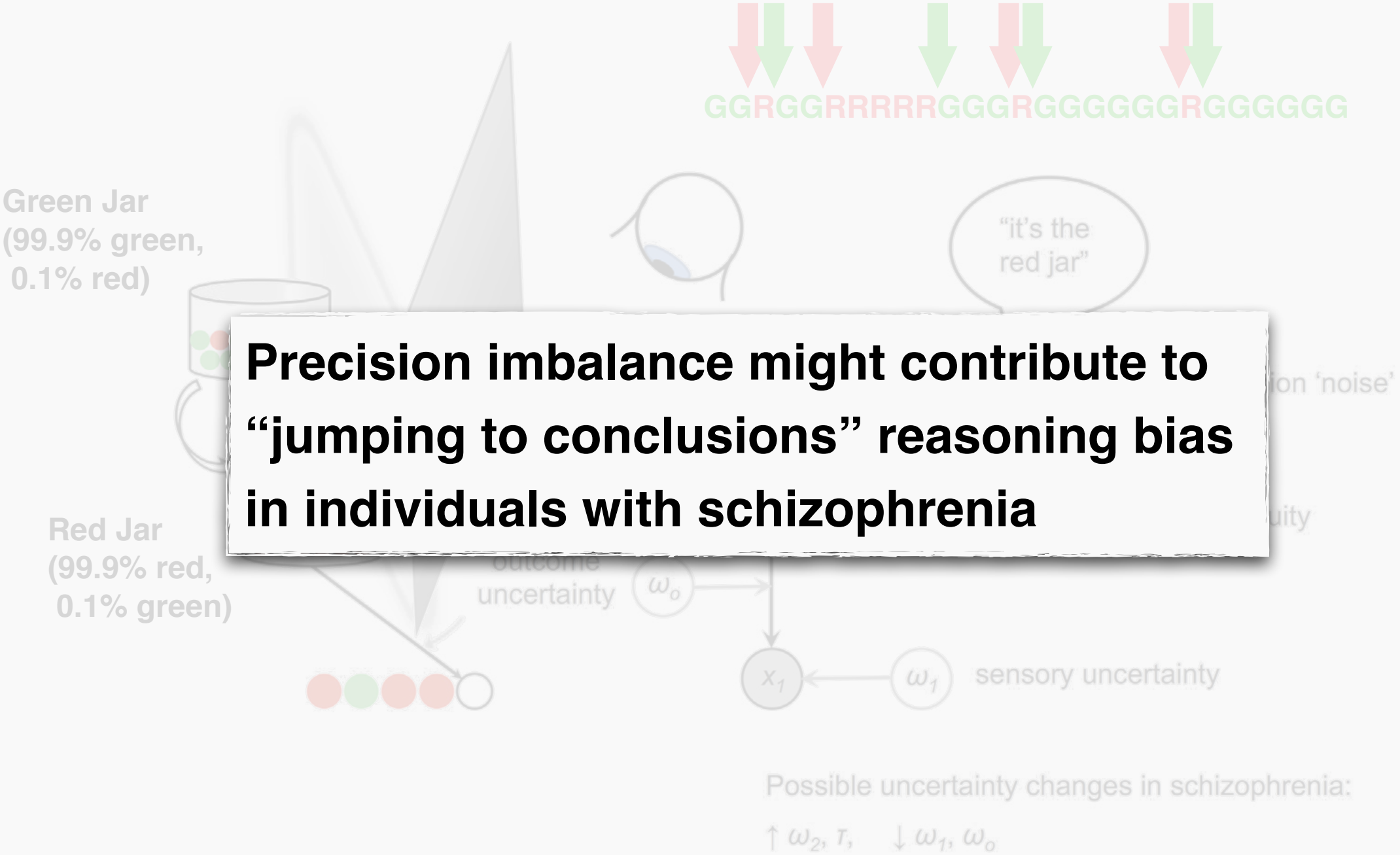


Precision imbalance might contribute to "jumping to conclusions" reasoning bias in individuals with schizophrenia

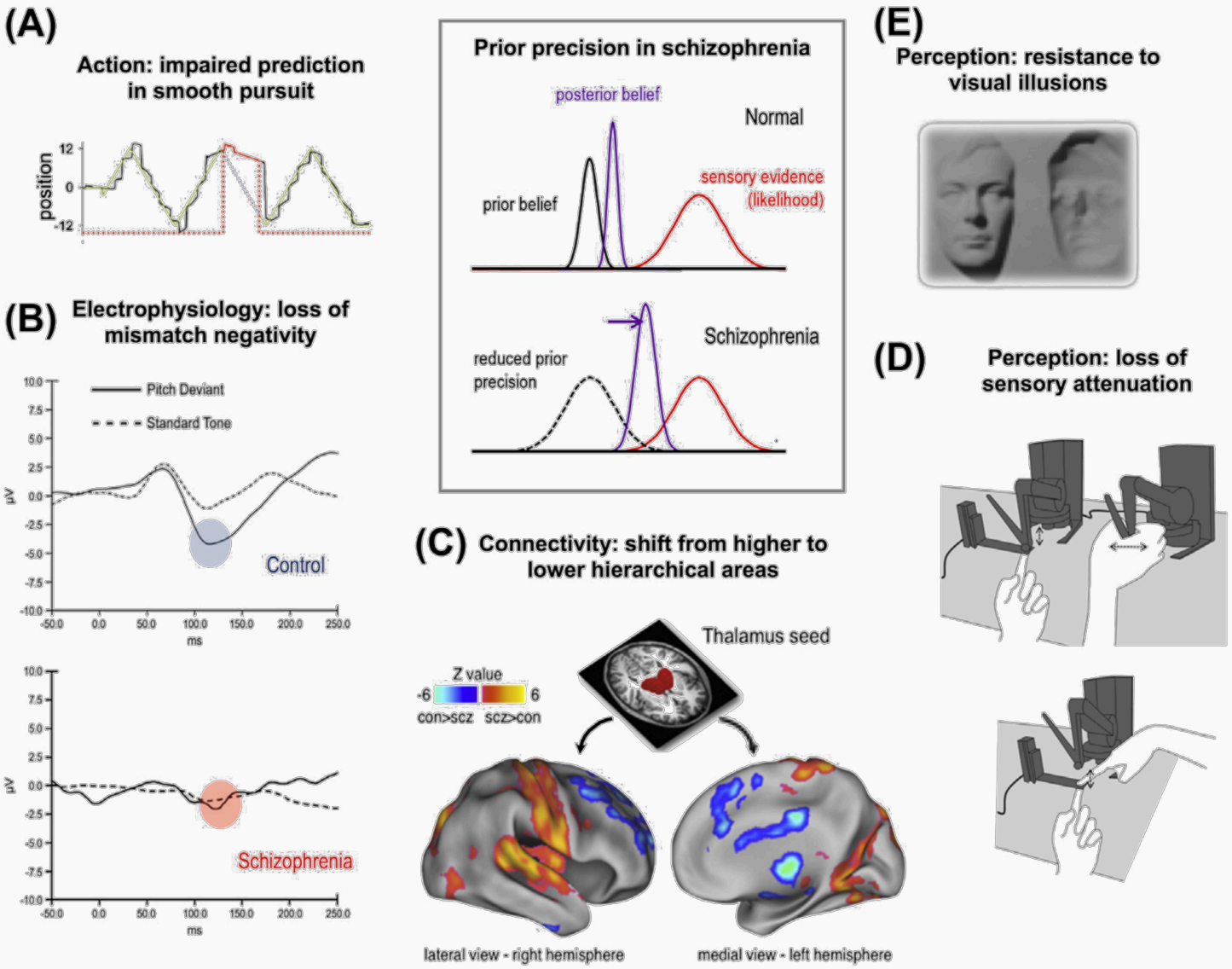
Main neurobiological abnormalities in SCZ

- Hypofunction of NMDA-R (PFC, hippocampus, and likely elsewhere)
- Reduced synthesis of GABA by inhibitory interneurons in PFC
- Hypoactivation of D1 receptors in PFC
- Collectively, these abnormalities can reduce synaptic gain in PFC or hippocampus (i.e. around the top of the cortical hierarchy)

Main neurobiological abnormalities in SCZ

- In SCZ, higher order regions of cortex have diminished connectivity to the thalamus relative to controls, whereas primary sensory areas are coupled strongly with this region
- Increased E/I balance in higher hierarchical areas might increase their connectivity with lower ares, but decrease SNR (i.e. precision)
- This corresponds to a loss of influence of the model's more abstract priors over more concrete sensory data

Main neurobiological abnormalities in SCZ



Main neurobiological abnormalities in SCZ

- Loss of high level precision in brain's hierarchical model might result in diffuse, generalized cognitive problems & over-attention to sensory stimuli

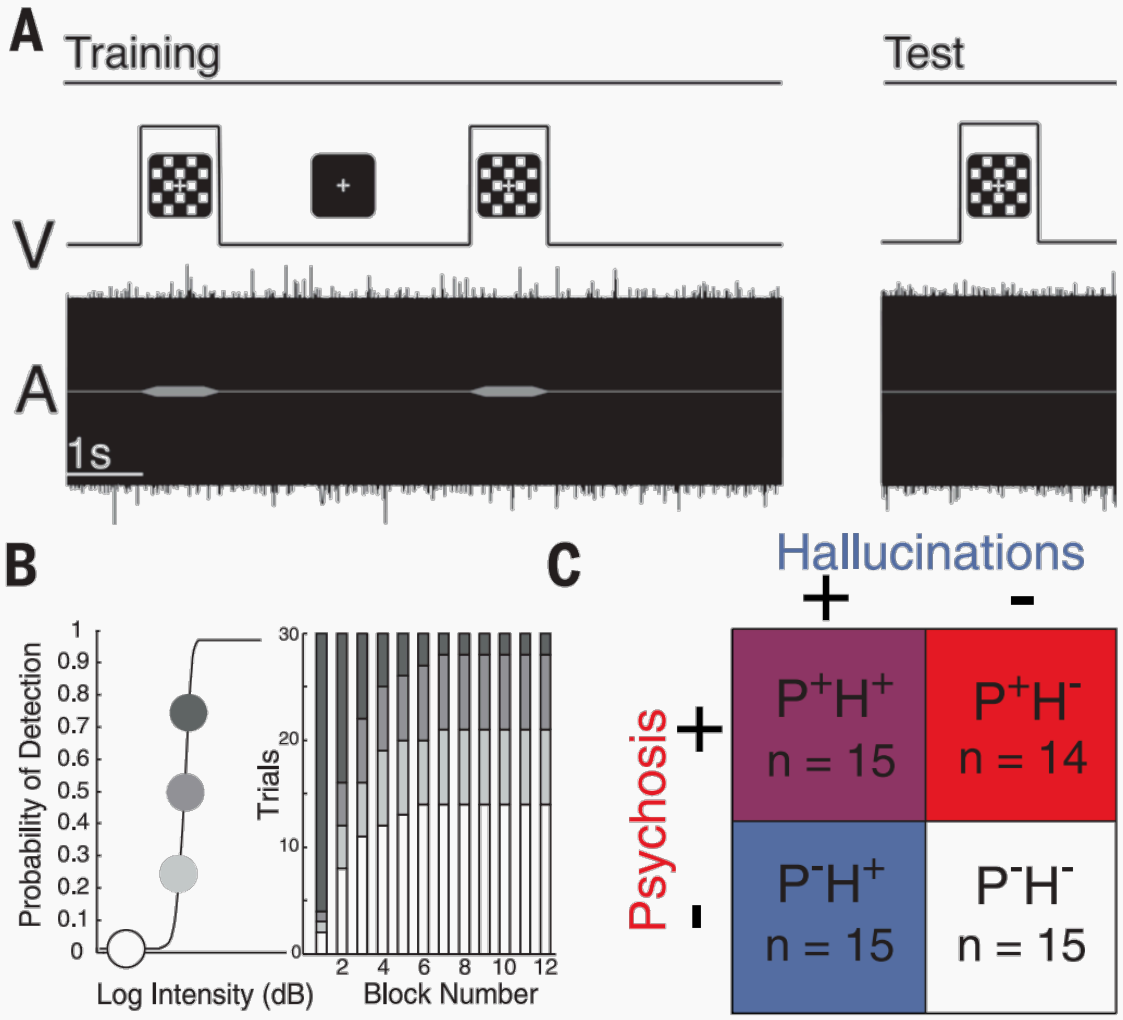
- Additionally, it could lead to the formation of more specific unusual beliefs as the reduced high-level precision permits updates to beliefs that are larger and less constrained

NEUROSCIENCE

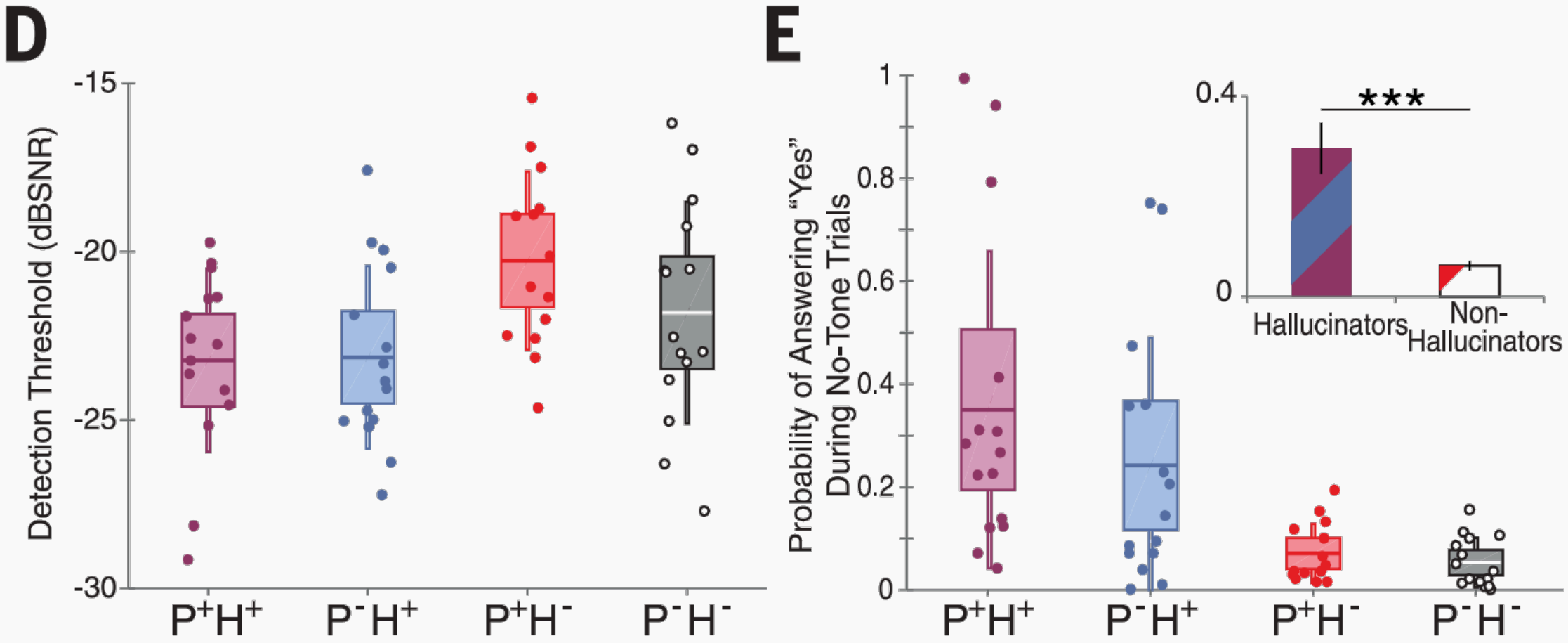
Pavlovian conditioning–induced hallucinations result from overweighting of perceptual priors

A. R. Powers,[1] C. Mathys,[2,3,4] P. R. Corlett[1*]

AR Powers *et al*. (2017) - Experimental Paradigm



AR Powers *et al*. (2017) - Results



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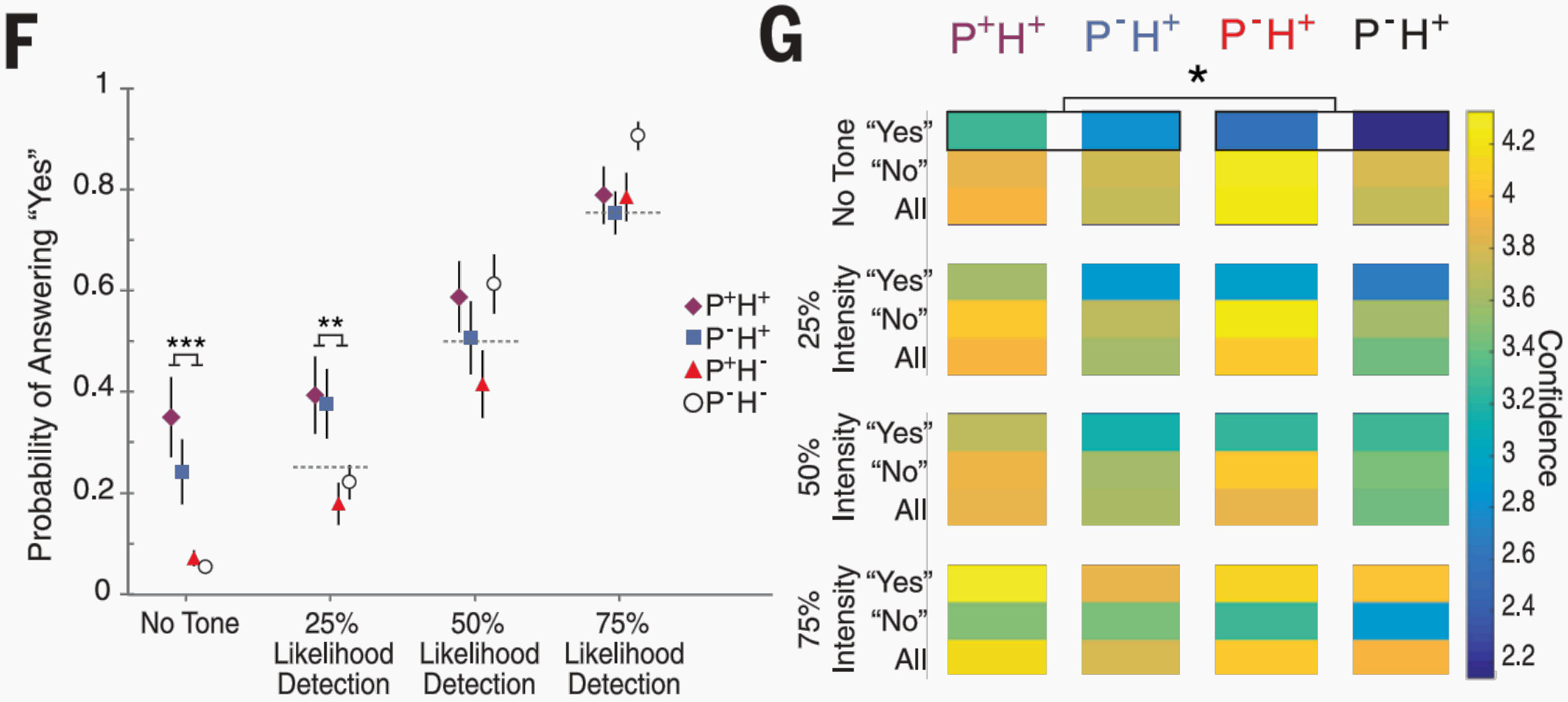

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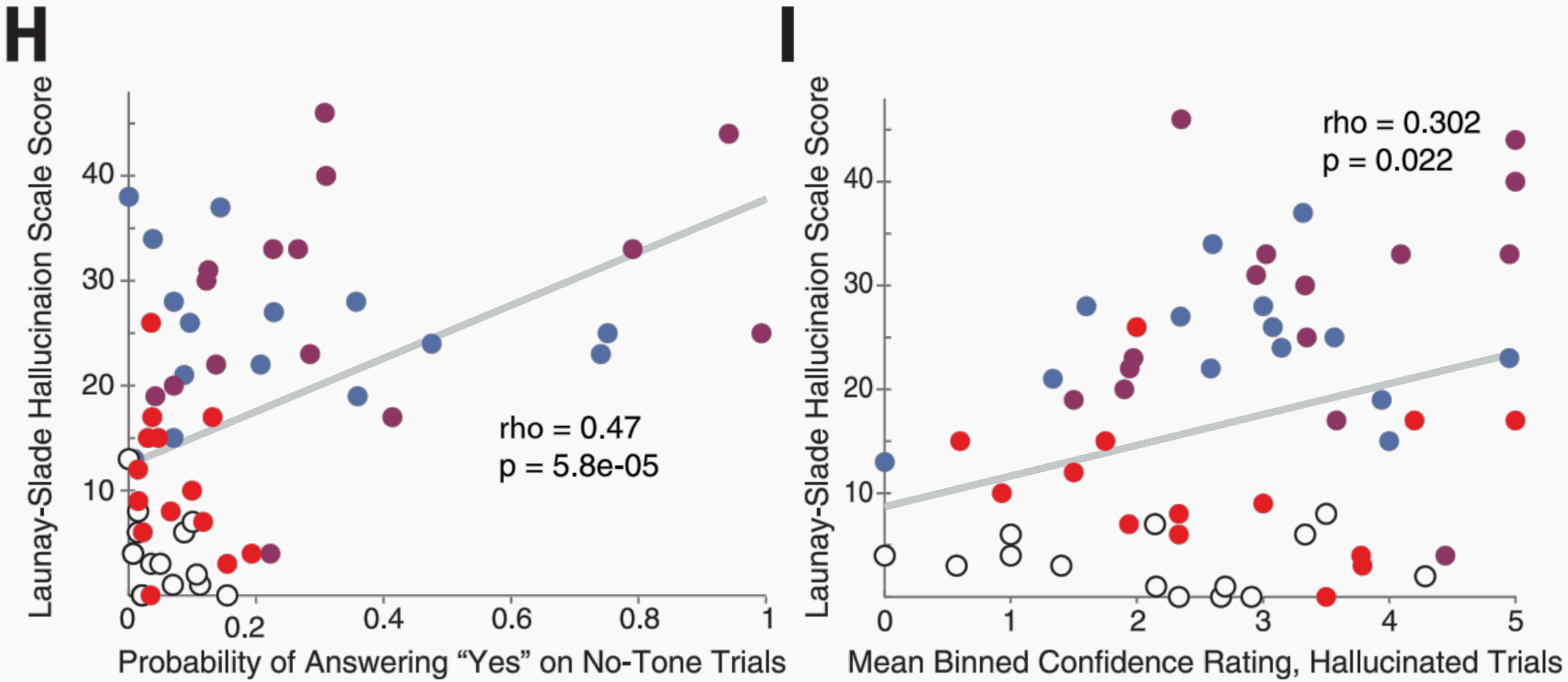

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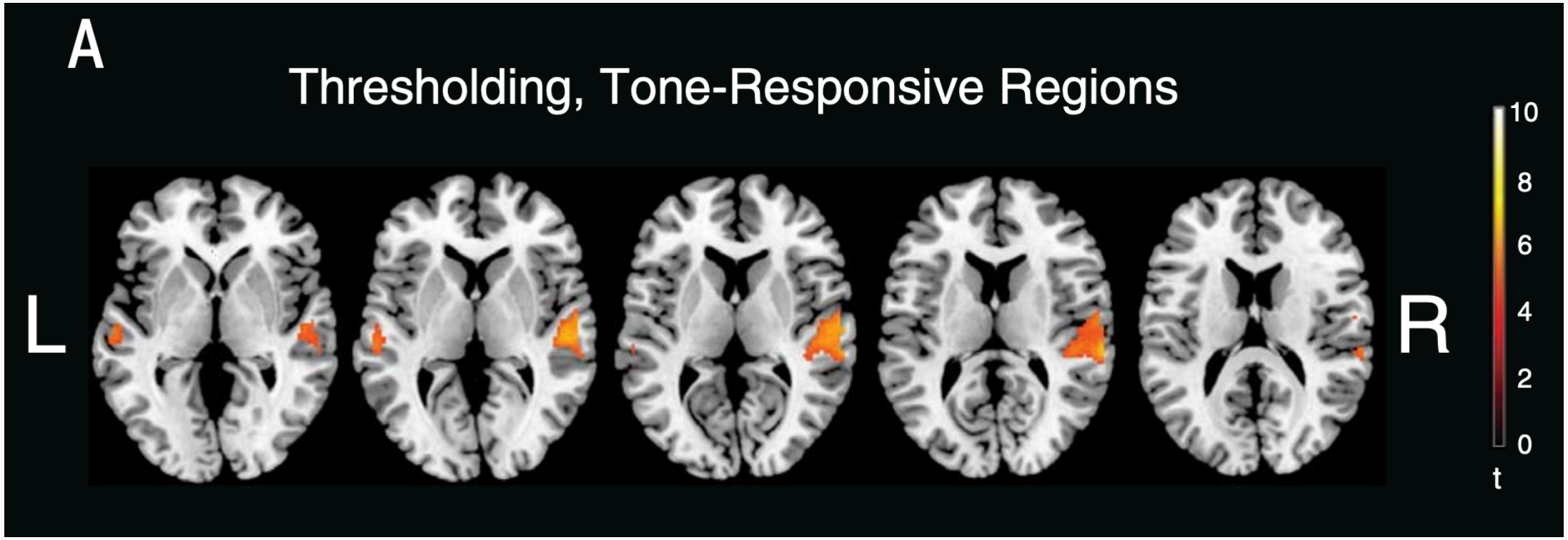

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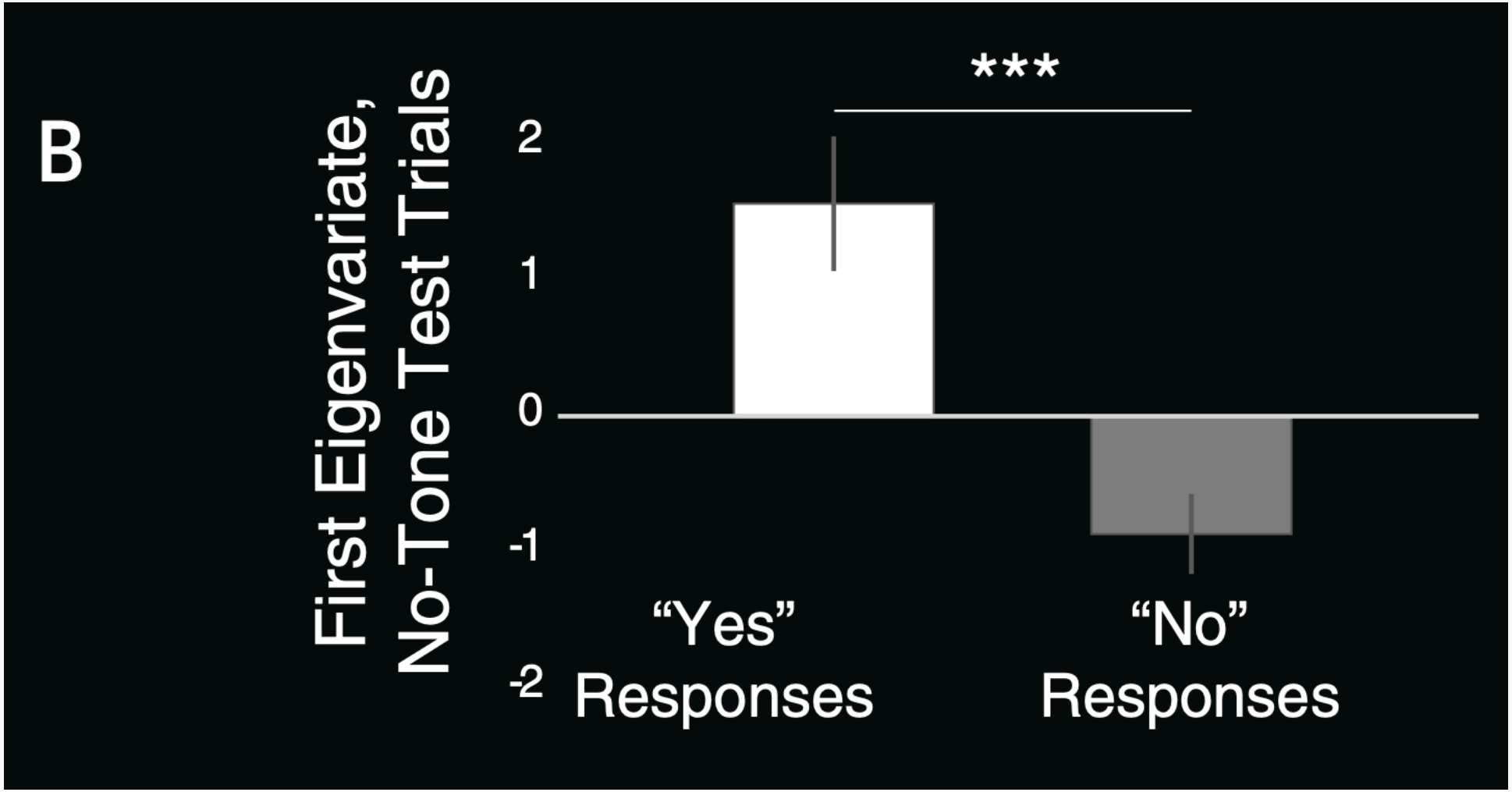
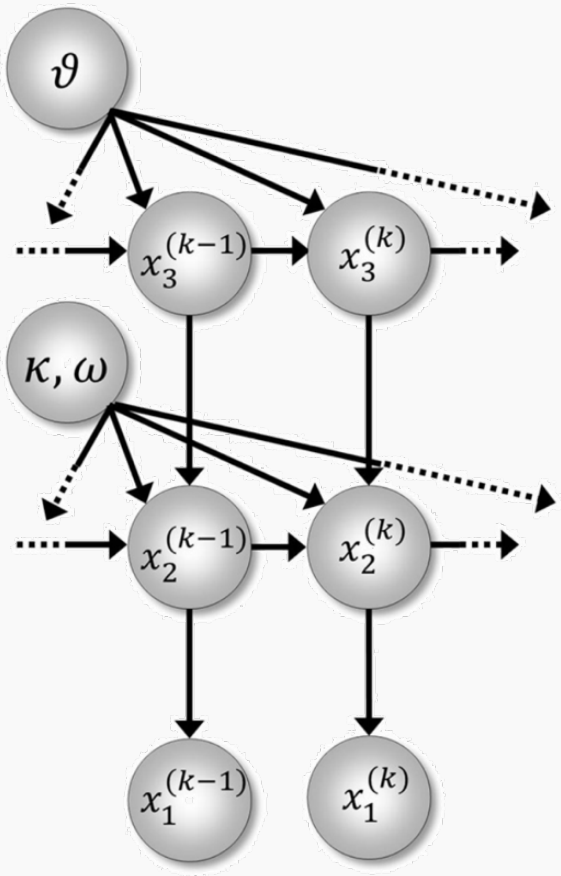
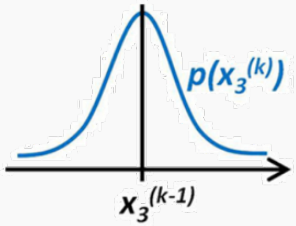
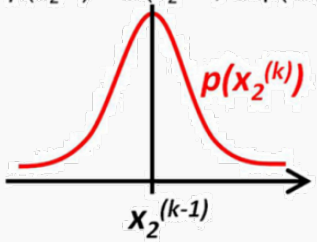
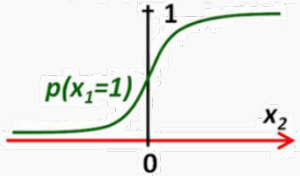


AR Powers *et al.* (2017) - HGF



State of the world	Model	
Log-volatility x_3 of tendency	Gaussian random walk with constant step size ϑ	$p(x_3^{(k)}) \sim N(x_3^{(k-1)}, \vartheta)$ 
Tendency x_2 towards category "1"	Gaussian random walk with step size $\exp(\kappa x_3+\omega)$	$p(x_2^{(k)}) \sim N(x_2^{(k-1)}, \exp(\kappa x_3+\omega))$ 
Stimulus category x_1 ("0" or "1")	Sigmoid trans-formation of x_2	$p(x_1=1) = s(x_2)$ $p(x_1=0) = 1-s(x_2)$ 

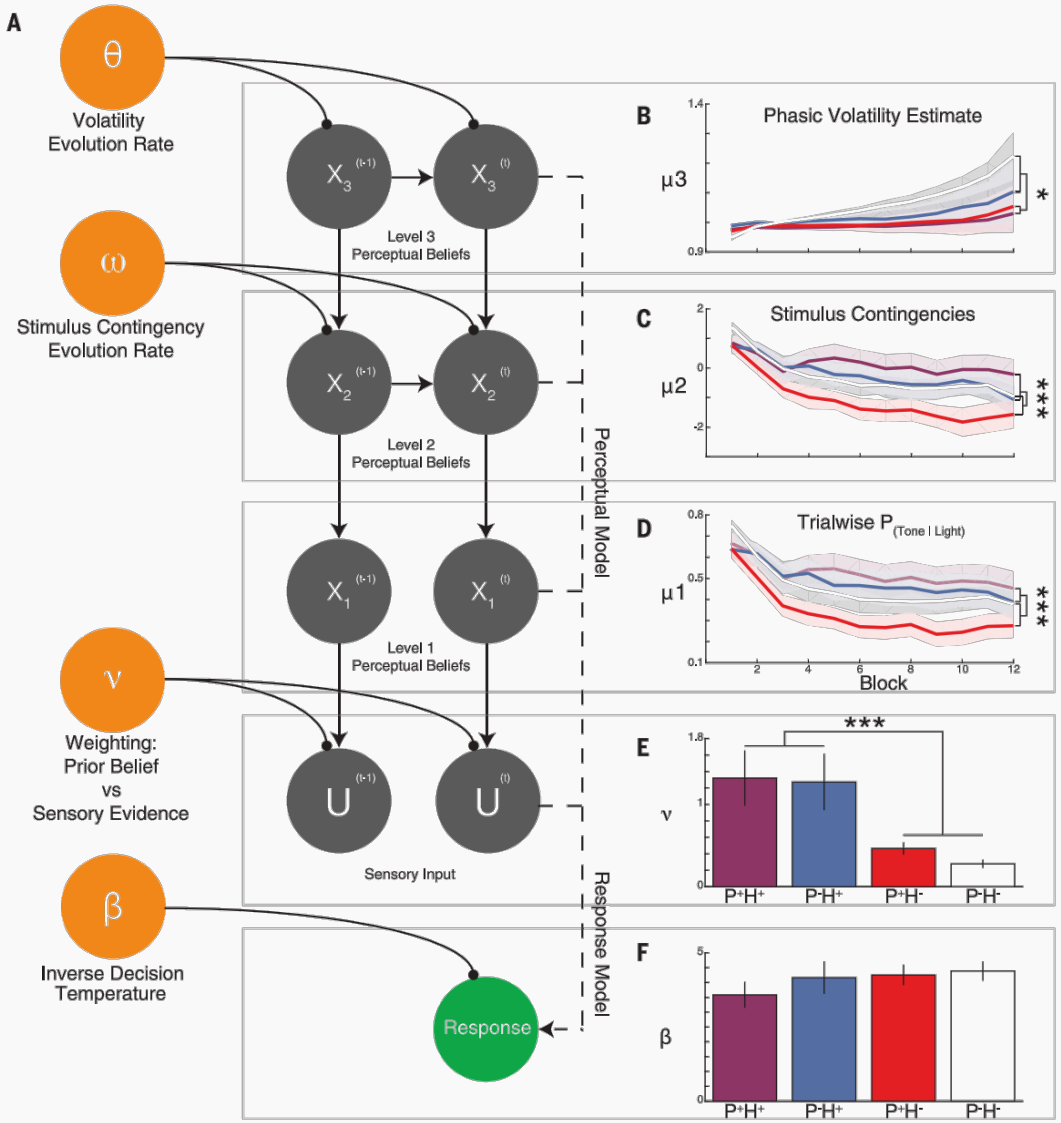
AR Powers *et al*. (2017) - HGF

$$belief = prior + \frac{1}{1+v}(observation - prior)$$

$$v < 1 \longrightarrow observation > prior$$

$$v = 1 \longrightarrow observation = prior$$

$$v > 1 \longrightarrow observation < prior$$

$$f(x) = \frac{1}{e^{-\beta(V_1 - V_0)}}$$

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