UNIVERSITY OF CAMBRIDGE

GETTING COMPUTATIONAL ABOUT 'CONTEXT' IN AUTISM: LEARNING, UNCERTAINTY & NEURAL GAIN

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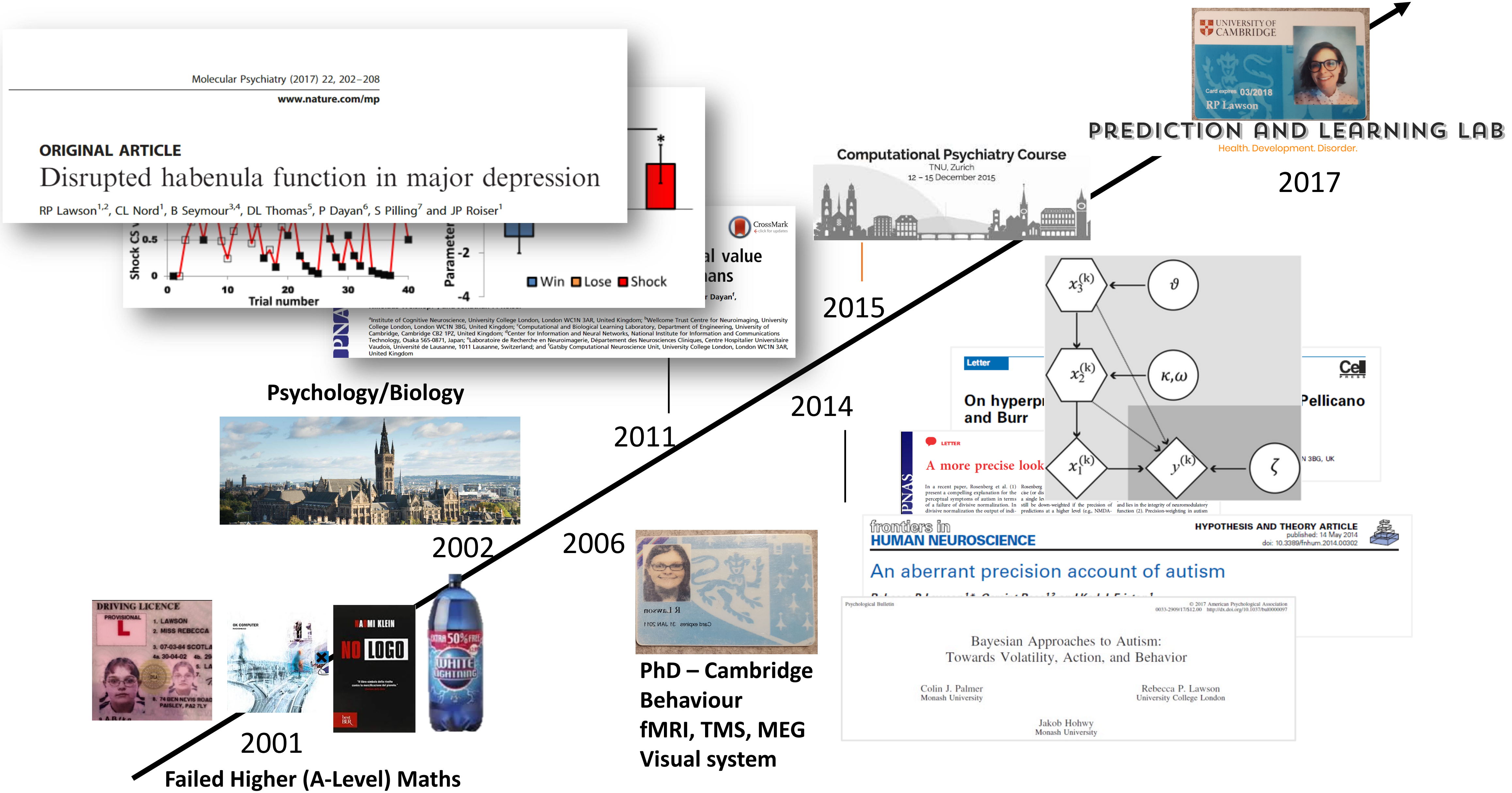
University of Cambridge, Department of Psychology

5th August 2019

@beckyneuro #cpczurich2019

My journey towards computational models of autism



DSM-5 Diagnosis

A. Persistent deficits in social communication and social interaction

- Social emotional reciprocity
- Nonverbal communication
- Understanding and forming relationships

B. Restricted, repetitive patterns of behaviour, interests, or activities

- Repetitive motor movements
- Rituals and strict routines
- Fixated interests
- Hyper or hypo sensory sensitivity

C. Symptoms must be present in the early developmental period

D. Symptoms cause clinically significant impairment in social, occupational, or other important areas of current functioning.

E. These disturbances are not better explained by intellectual disability (intellectual developmental disorder) or global developmental delay.

Two big psychological ideas

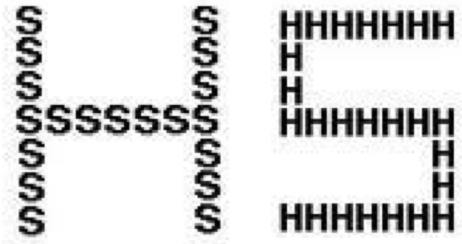
Context

“self-other processing”

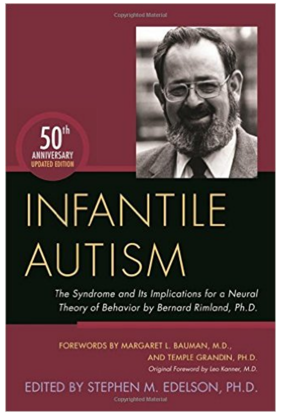
-Theory of Mind (Baron- Cohen, Frith and Leslie,1985):
difficulty understanding the mental states of others.

“Coherence”

-Weak Central Coherence (Frith, 1989): limited ability to understand context or to "see the big picture”

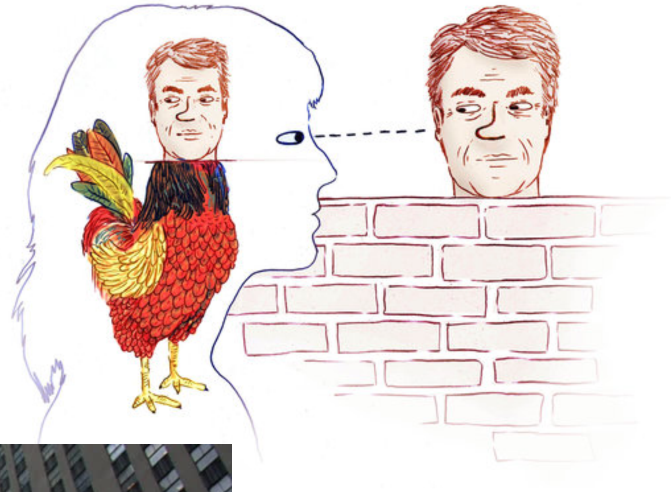


Bernard Rimland (1964)



"It is possible to trace its diversity of symptoms and manifestations to a single critical disability: The child with early infantile autism is grossly impaired in a function basic to all cognition: ***the ability to relate new stimuli to remembered experience*****.** … The child is thus virtually divested of the means for deriving meaning from his experience… He cannot integrate his sensations into a comprehensible whole"

Sensory inputs are ambiguous



When we are presented with ambiguous information, our prior expectations constrain the sensory information out there in the world **and help us come to the most likely percept:** our best guess about the scene in front of us.

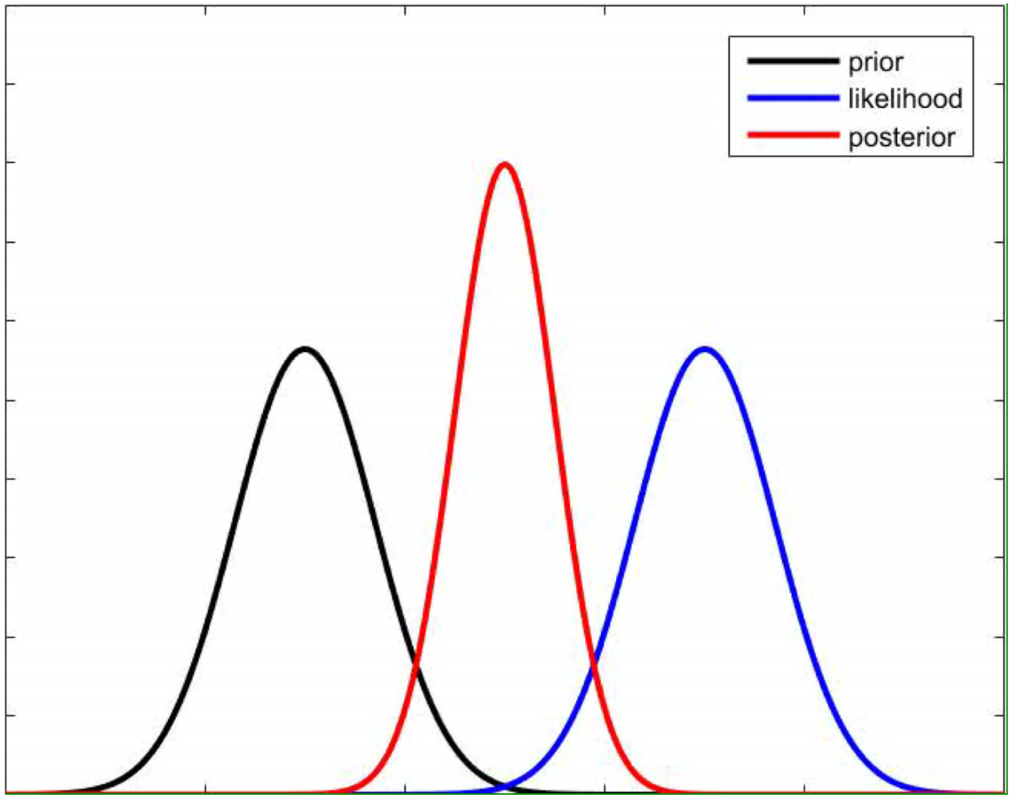
Opinion

When the world becomes 'too real': a Bayesian explanation of autistic perception

Trends in Cognitive Sciences October 2012, Vol. 16, No. 10

Elizabeth Pellicano[1,3] and David Burr[2,3]

- In autism the world is "too real" because of reduced prior precision.



Data Outline

Experiment 1 & 2

- Spatial context – psychophysics – divisive normalisation

Experiment 3 & 4

- Temporal context – HGF – hierarchical Bayesian learning

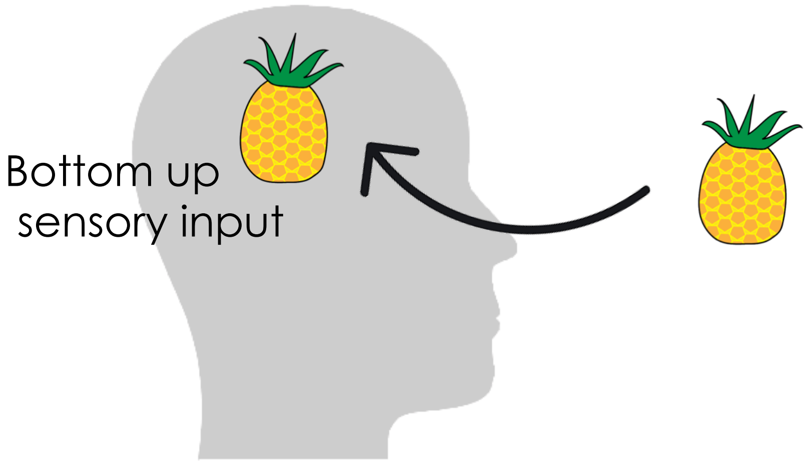
Experiment 5

- Metacognitive context – -HMeta-d – signal detection framework

Autism as a variant of 'optimal' Bayesian Inference

Structural priors and spatial context

"default" expectations – Series and Seitz, Front Hum Neuro, 2013



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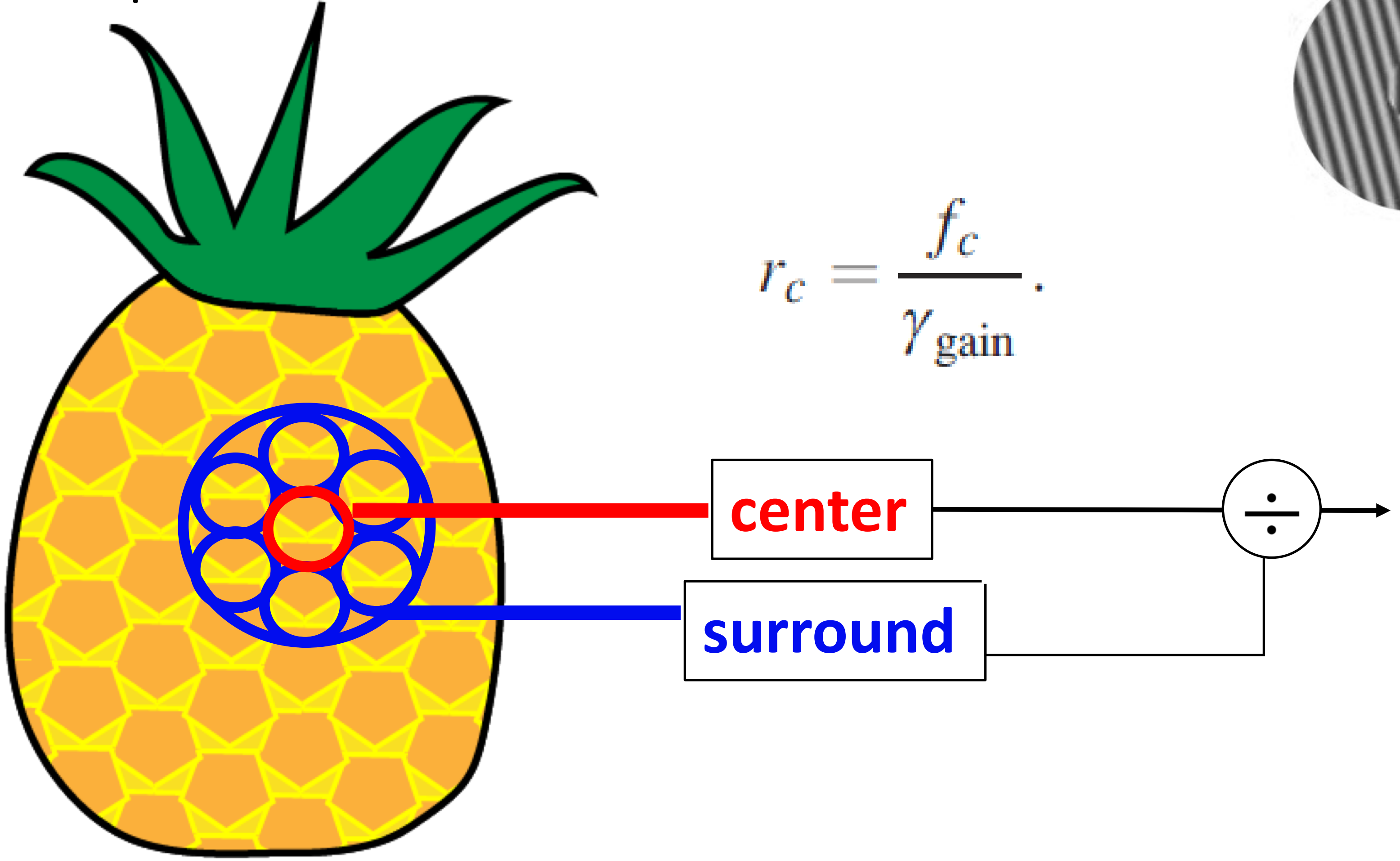
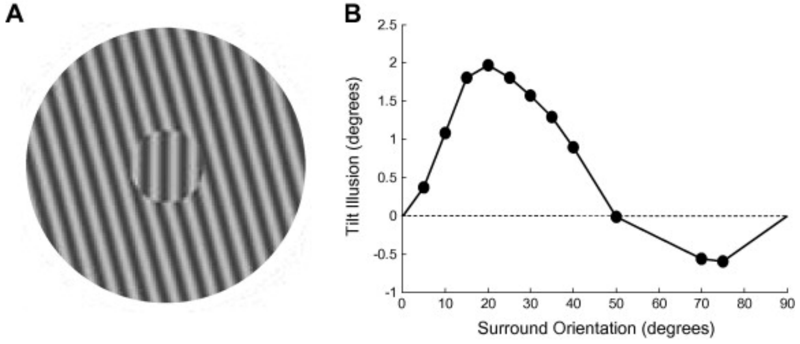
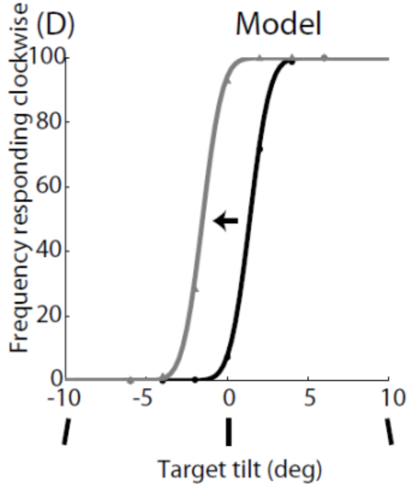
“default” expectations – Series and Seitz, Front Hum Neuro, 2013

$$r_c = \frac{f_c}{\gamma_{\text{gain}}}.$$





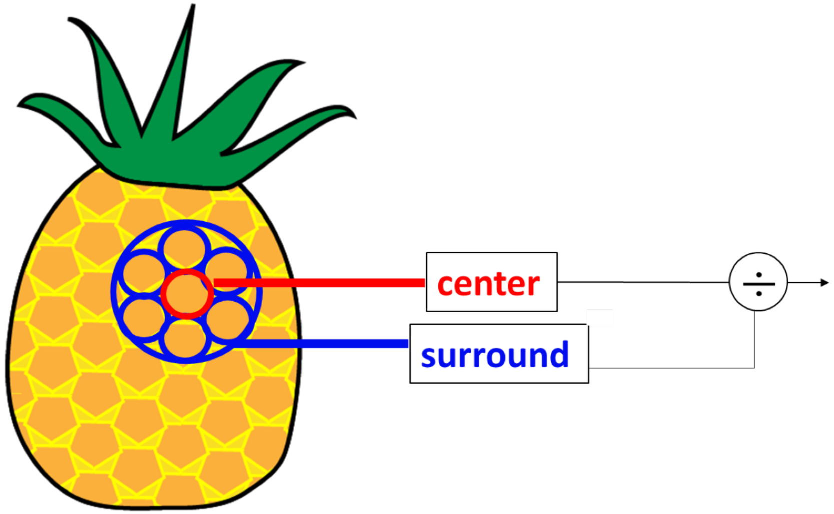


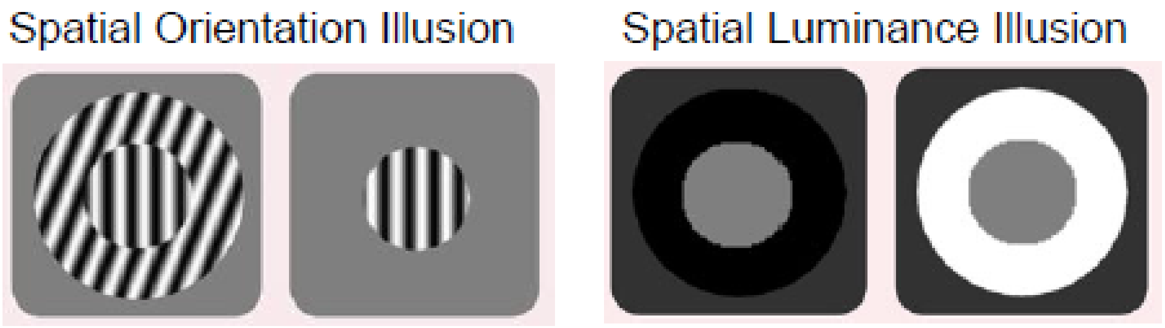
Clifford, 2014, Cohen-Cagli et al., 2012, PLOS Comp. Bio; Schwartz et al, 2009, JOV

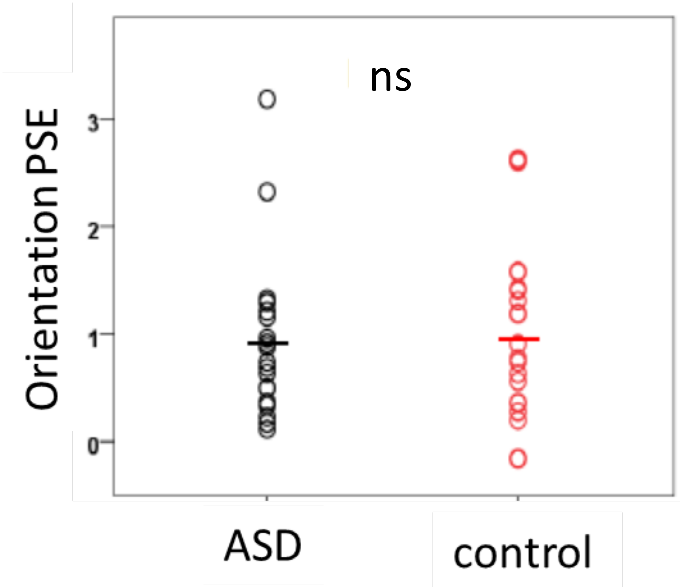
No effects of spatial context on autistic perception

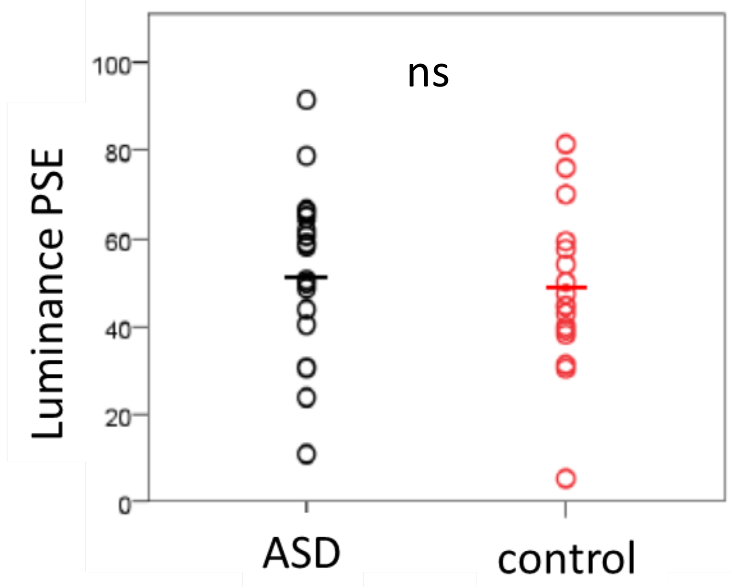
Structural priors and spatial context

- Orientation and luminance









In prep. [preliminary data]

Autism as a variant of ‘optimal’ Bayesian Inference

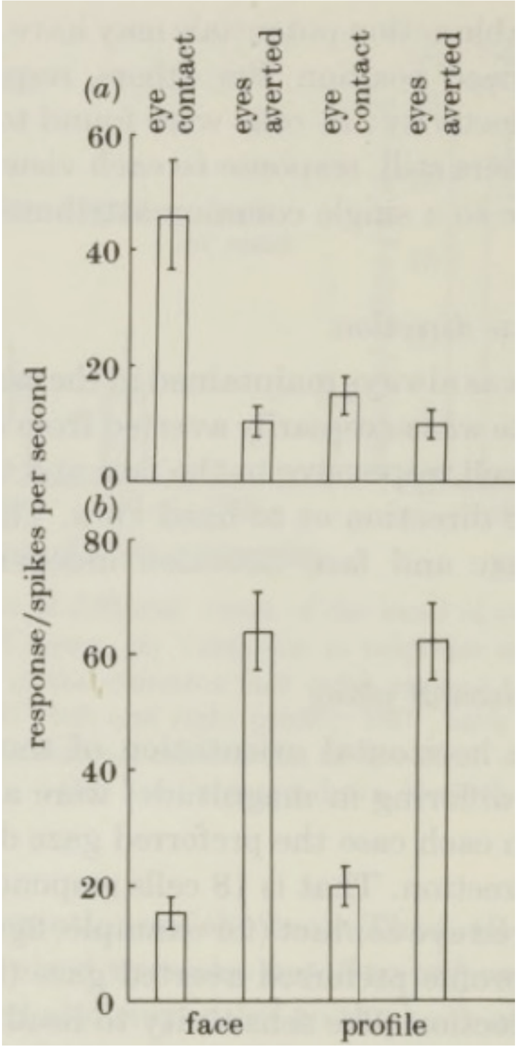
Structural priors and spatial context

- eye gaze direction

Difficulties representing, understanding and responding to eye gaze are hallmark features of autism.

Local spatial structure to how eye gaze direction is encoded in the brain.

Pools of neurons in the anterior superior temporal sulcus tuned to left, direct and right eye gaze – Perret et al, Proc. Roy. Soc, 1985

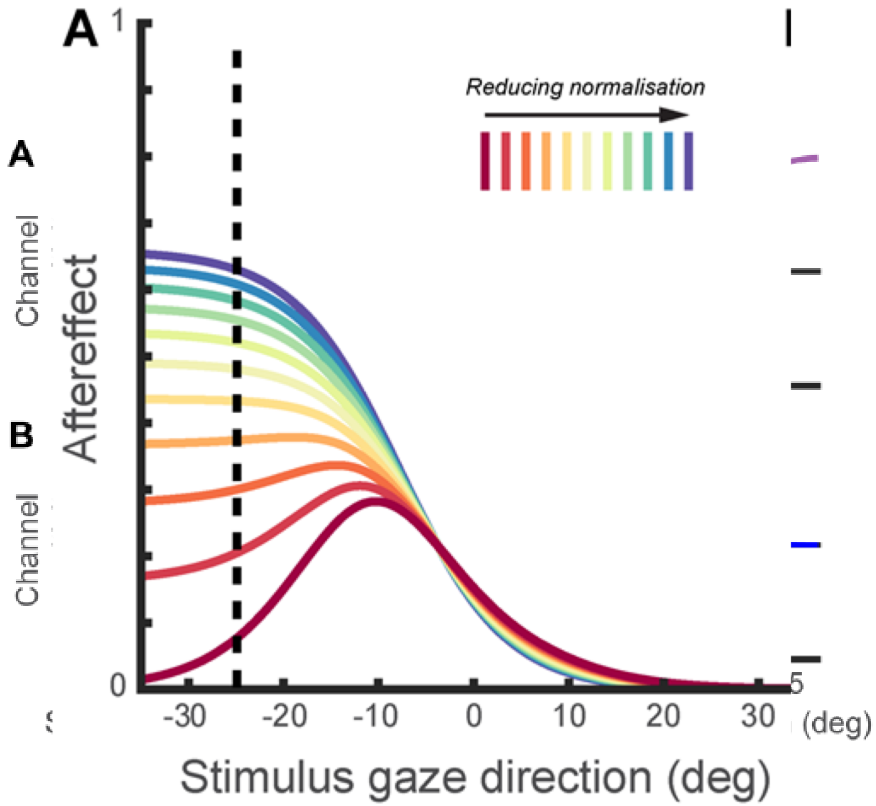


Perhaps normalisation across these pools of neurons – spatial context - is not constraining eye gaze perception in autism?

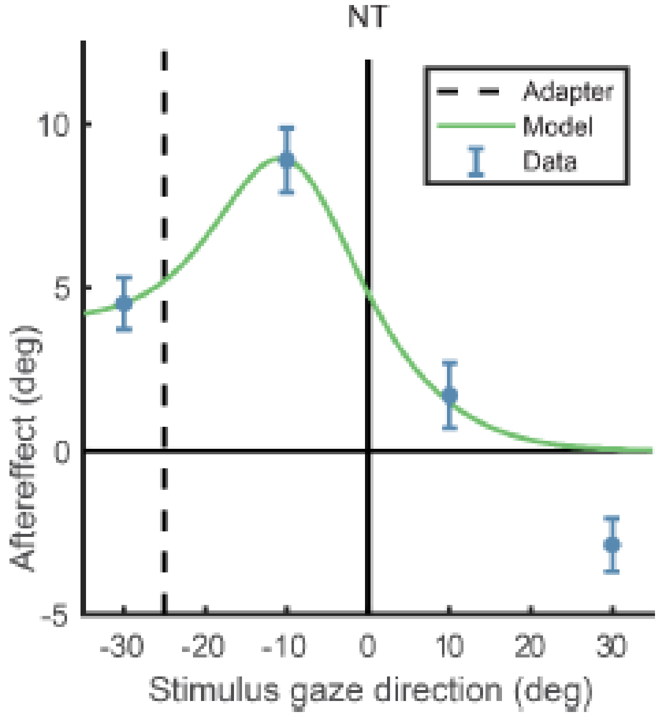
No effect of spatial context on gaze perception in autism

Structural priors and spatial context

- Preserved normalisation



$$M(d) = \frac{R(d) - L(d)}{w + (1 - w)(R(d) + L(d) + C(d))}.$$



Best-fitting model parameters	NT		ASD				
	Mean	SD	Mean	SD	*t* (df)	*p*	*BF*$_{01}$
w	0.21	0.29	0.28	0.37	-.78 (53)	.44	1.89

Palmer*, Lawson* et al, Cortex, 2018

Growing evidence that **structural priors and local spatial context** effects on vision preserved in autism.

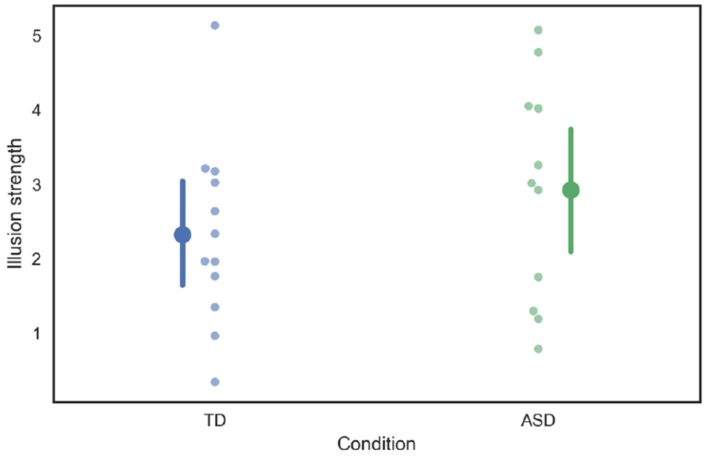
SCIENTIFIC REPORTS

OPEN

Intact perceptual bias in autism contradicts the decreased normalization model

9 February 2018

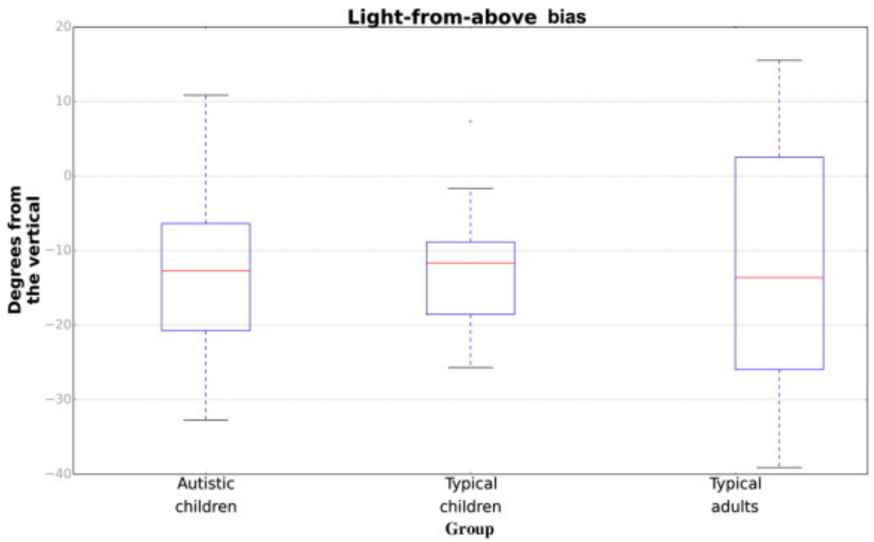
Sander Van de Cruys[1,2], Steven Vanmarcke[1,2], Jean Steyaert[2,3] & Johan Wagemans[1,2]



ELSEVIER
Journal of Experimental Child Psychology
Volume 161, September 2017, Pages 113-125

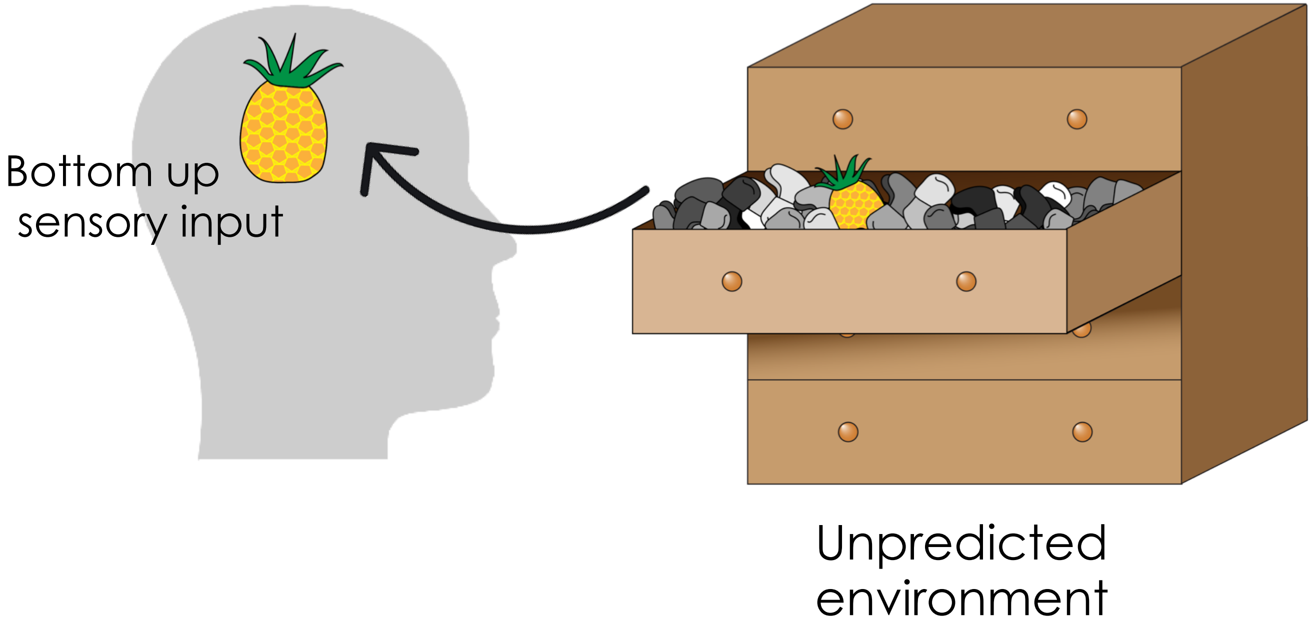
The light-from-above prior is intact in autistic children

Abigail Croydon[a, 1], Themelis Karaminis[a, b, 1], Louise Neil[a], David Burr[c, d], Elizabeth Pellicano[a, d]



Autism as a variant of 'optimal' Bayesian Inference

Temporal context – we need to talk about volatility



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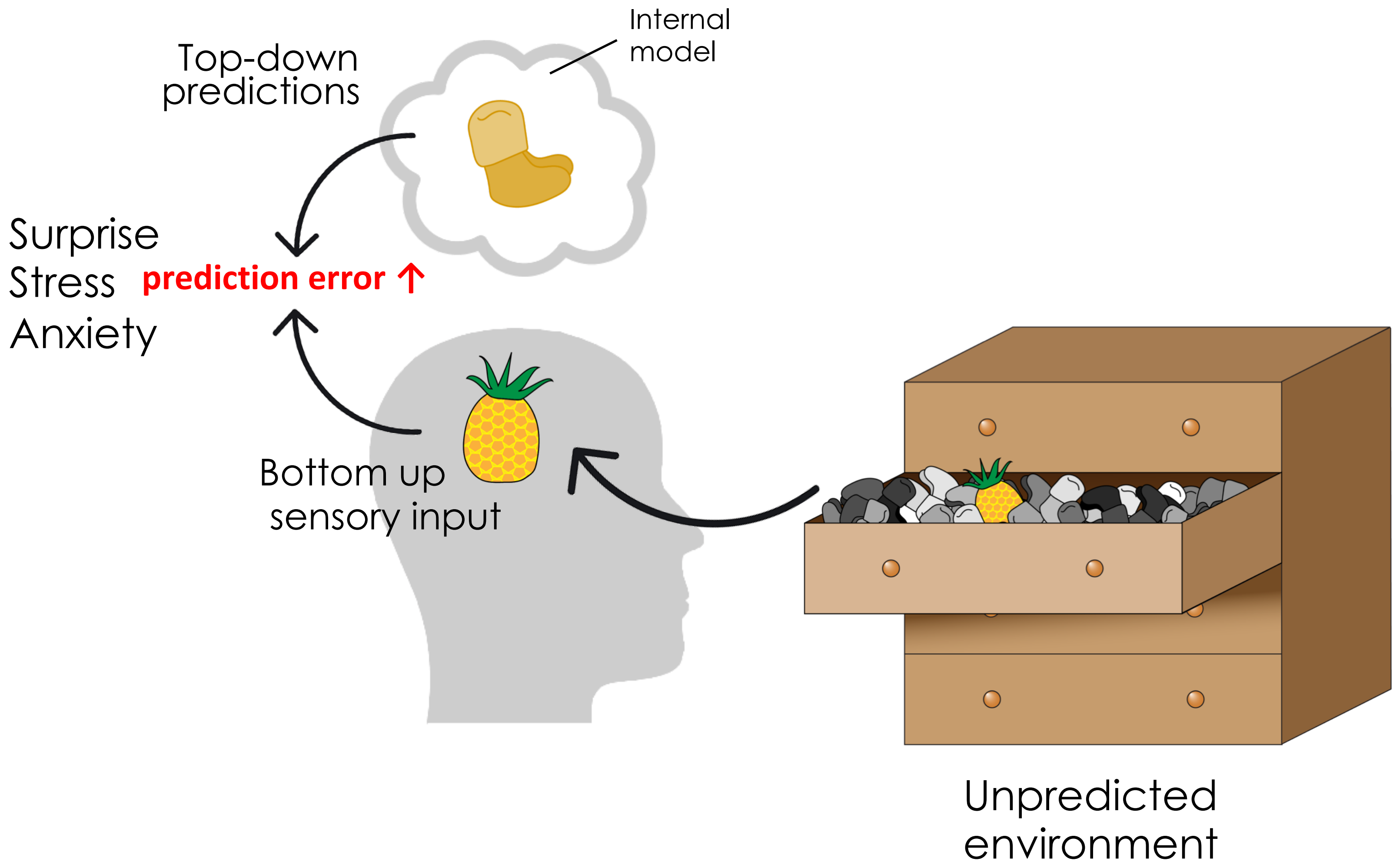

Friston, Lawson & Frith, TiCs, 2014; Lawson, Rees & Friston, Front Hum Neuro, 2014; Lawson, Friston & Rees, PNAS, 2015; Palmer, Lawson & Hohwy, Psychol Bulletin, 2017

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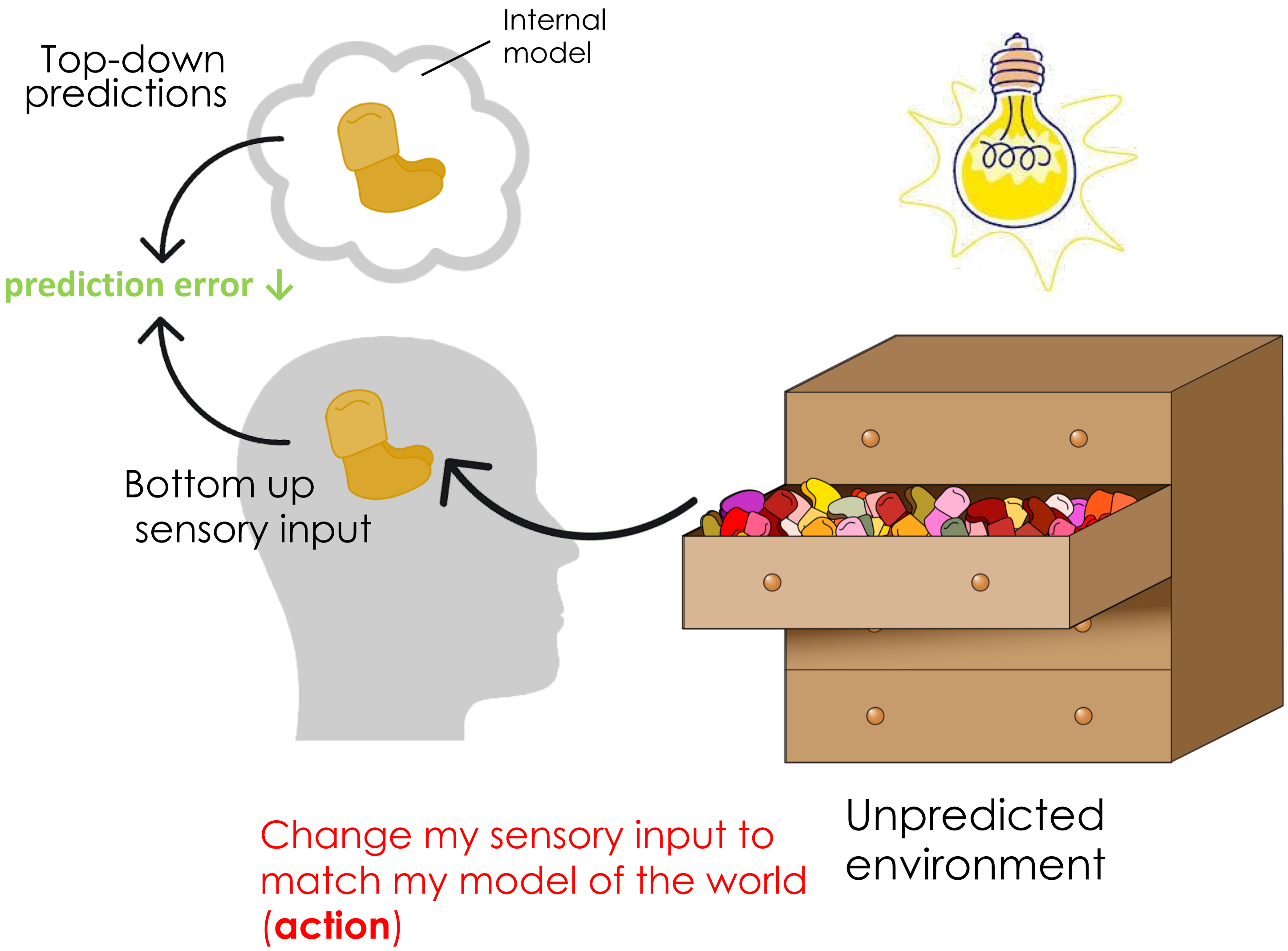

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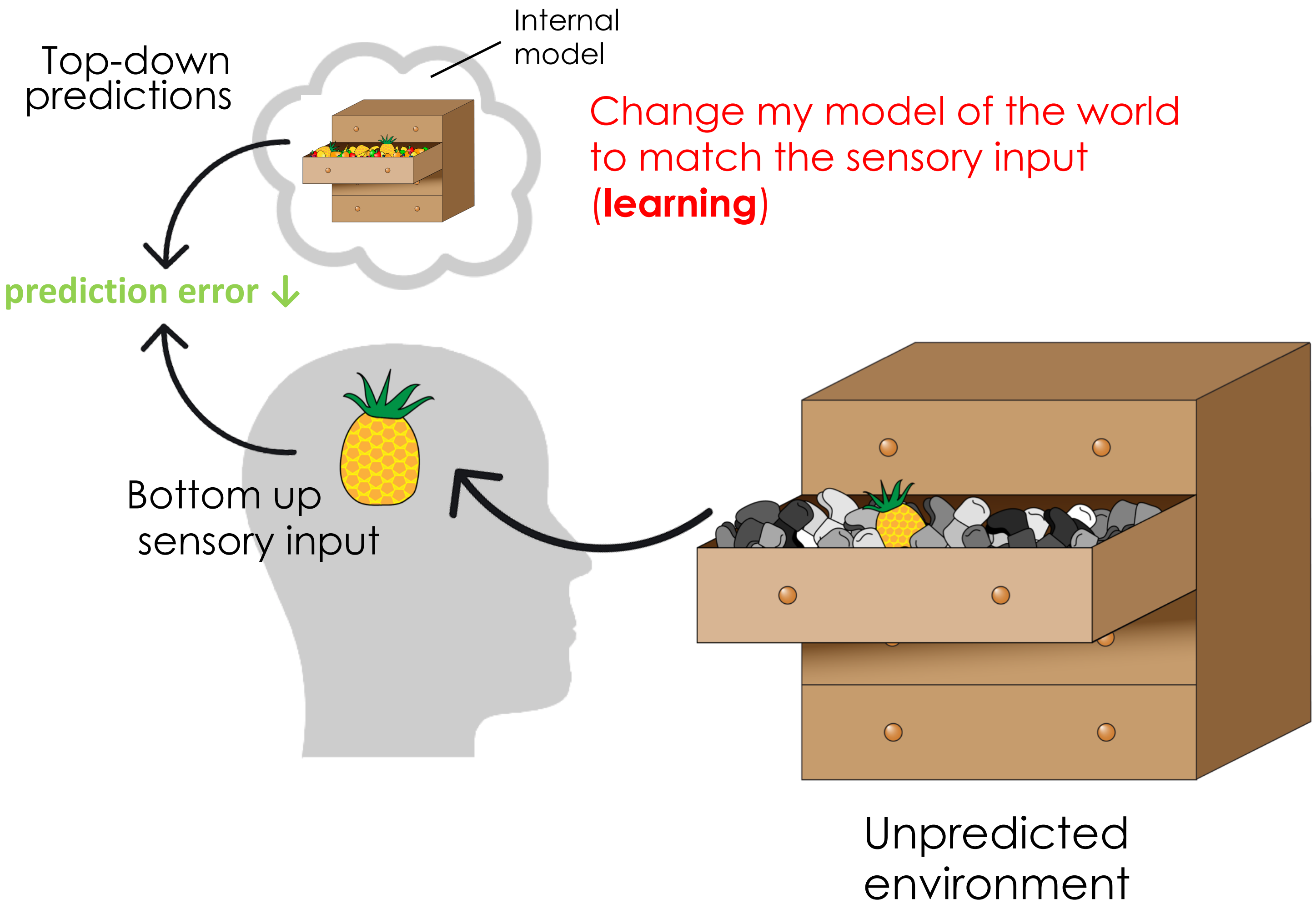

Change my model of the world
to match the sensory input
(**learning**)

Friston, Lawson & Frith, TiCs, 2014; Lawson, Rees & Friston, Front Hum Neuro, 2014; Lawson, Friston & Rees, PNAS, 2015; Palmer, Lawson & Hohwy, Psychol Bulletin, 2017

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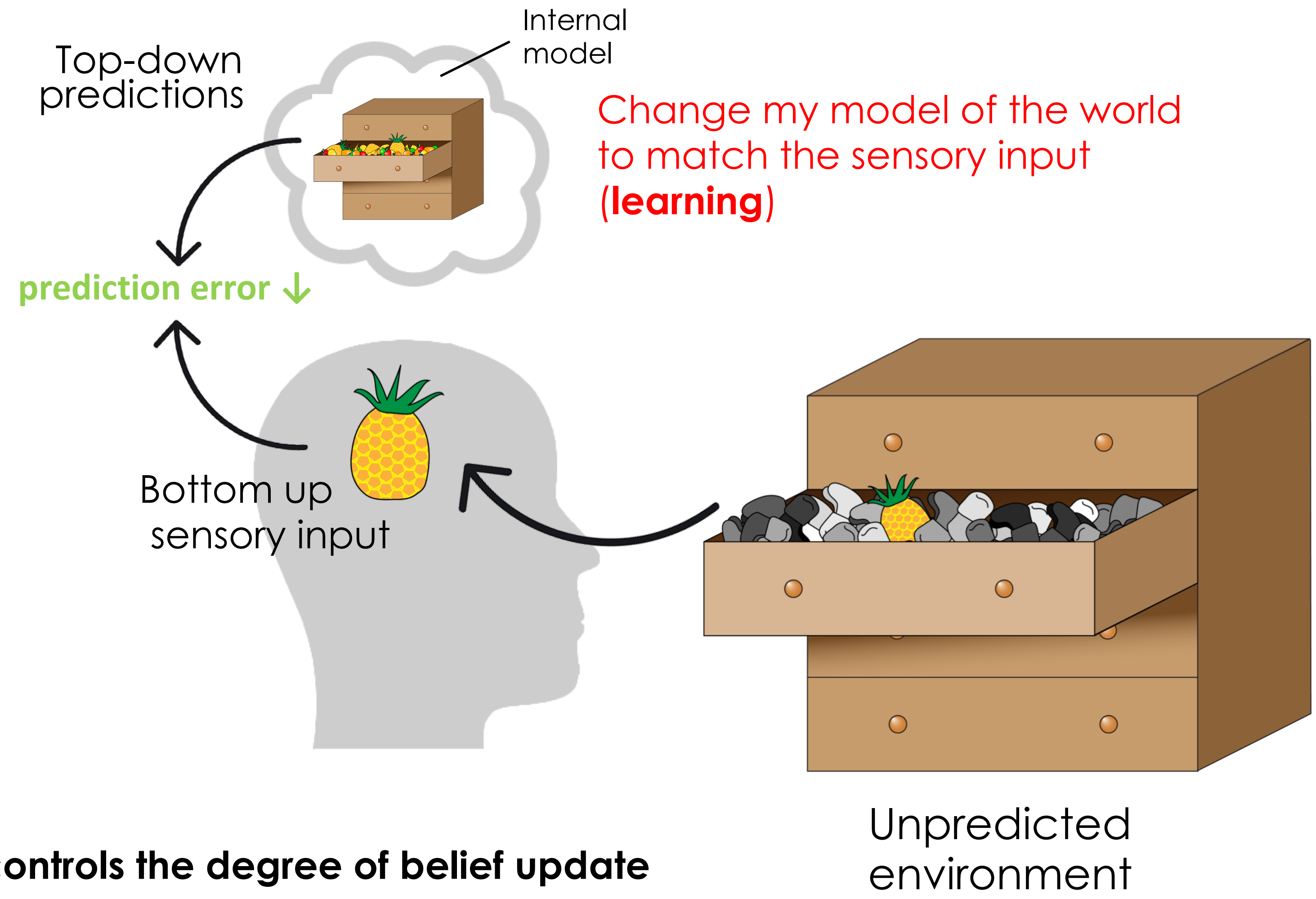

Change my model of the world to match the sensory input (**learning**)

“precision” controls the degree of belief update

$$\Delta \text{belief} \propto \frac{\text{precision}_{\text{input}}}{\text{precision}_{\text{prior belief}}} \times \text{prediction error}$$

Friston, Lawson & Frith, TiCs, 2014; Lawson, Rees & Friston, Front Hum Neuro, 2014; Lawson, Friston & Rees, PNAS, 2015; Palmer, Lawson & Hohwy, Psychol Bulletin, 2017

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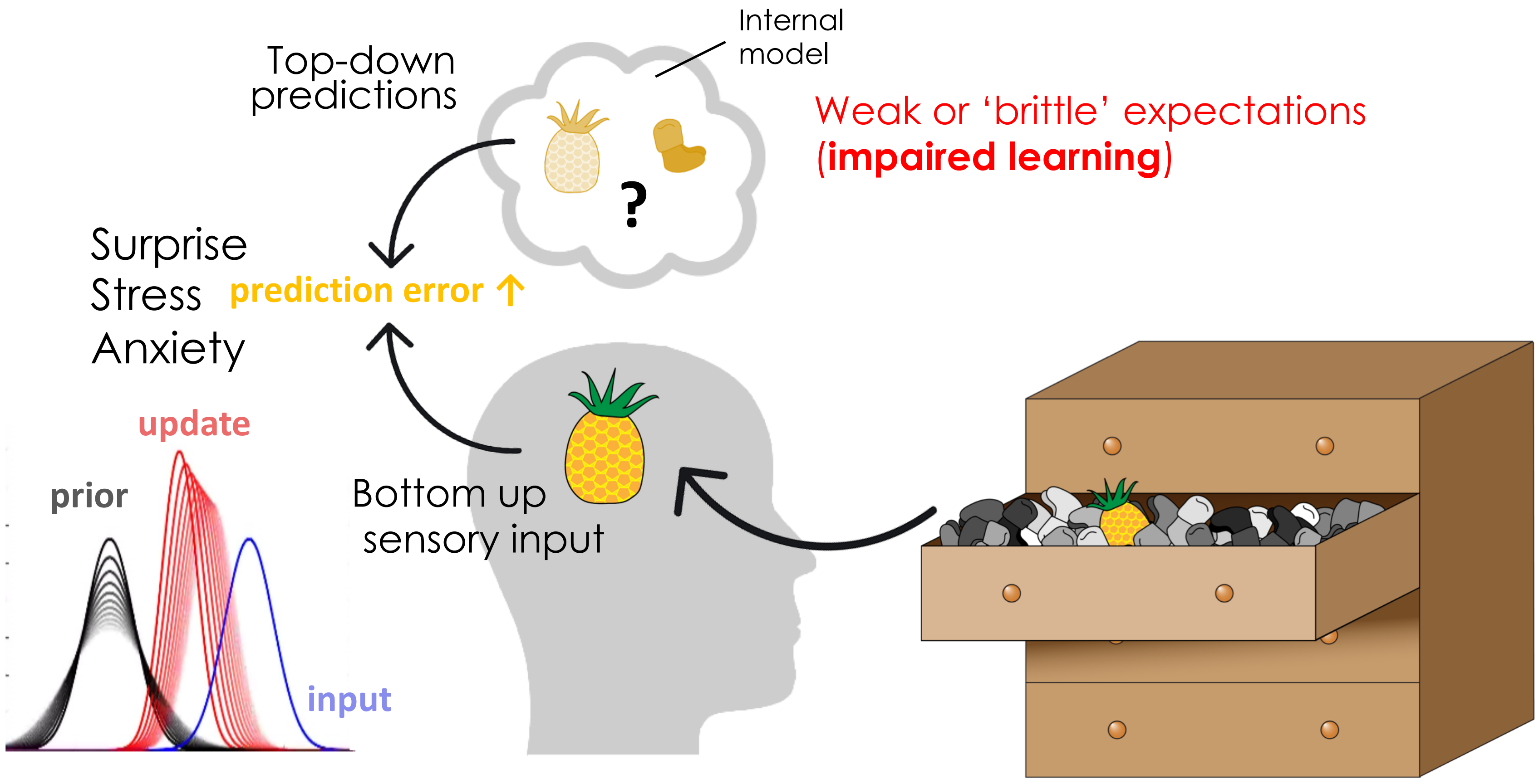

Unpredicted
environment

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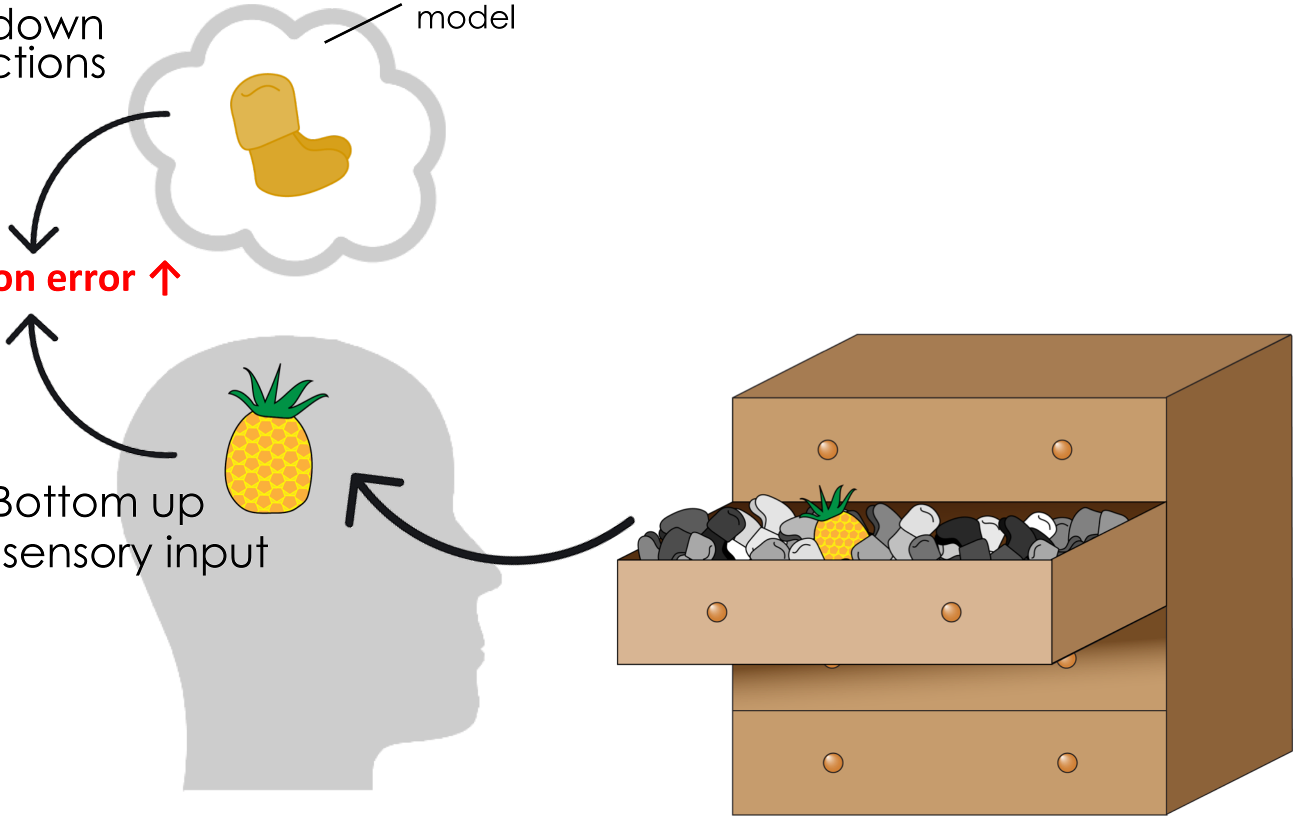

4 year old nephew

= volatility
= expect the unexpected

Friston, Lawson & Frith, TiCs, 2014; Lawson, Rees & Friston, Front Hum Neuro, 2014; Lawson, Friston & Rees, PNAS, 2015; Palmer, Lawson & Hohwy, Psychol Bulletin, 2017

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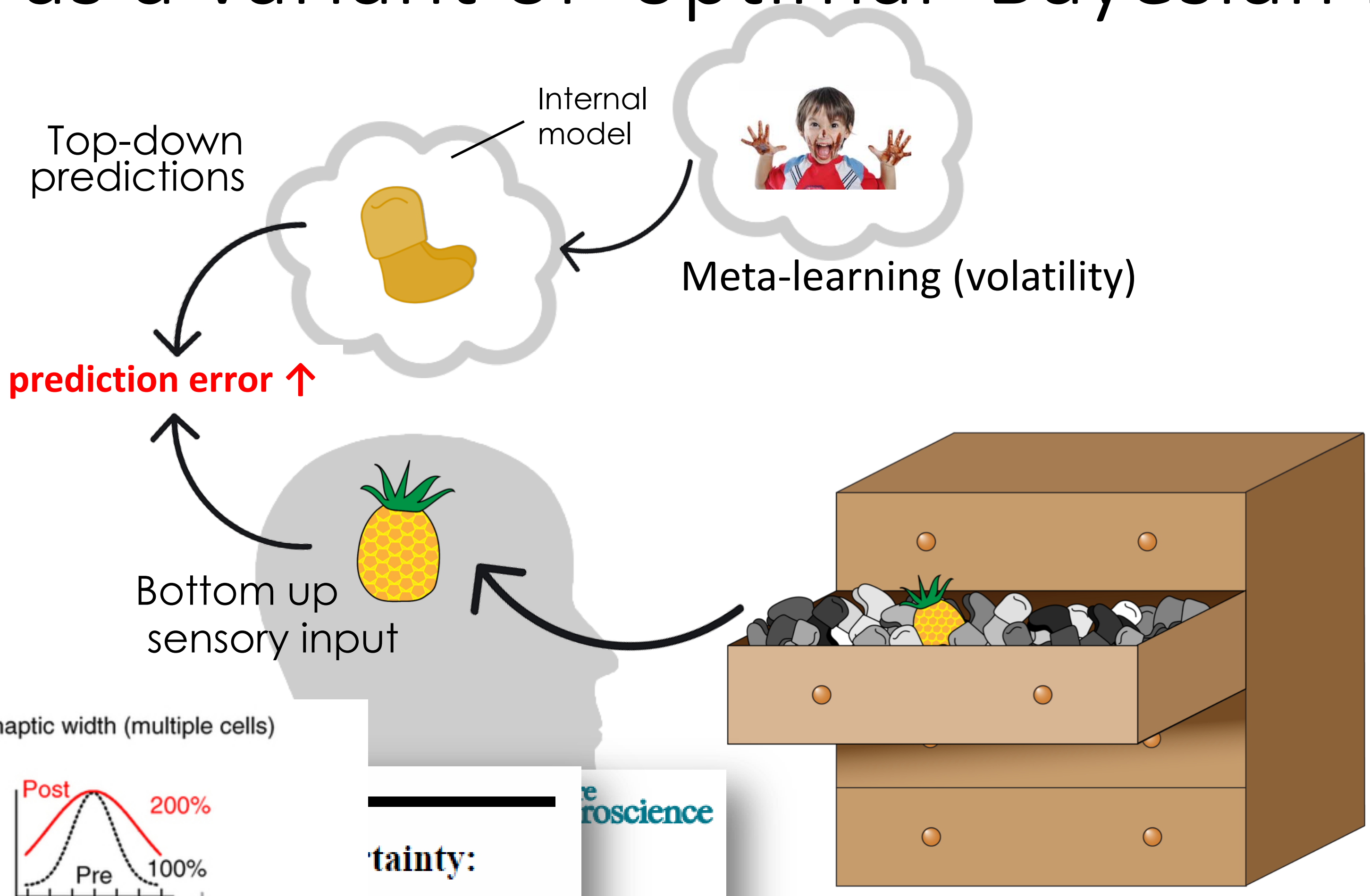

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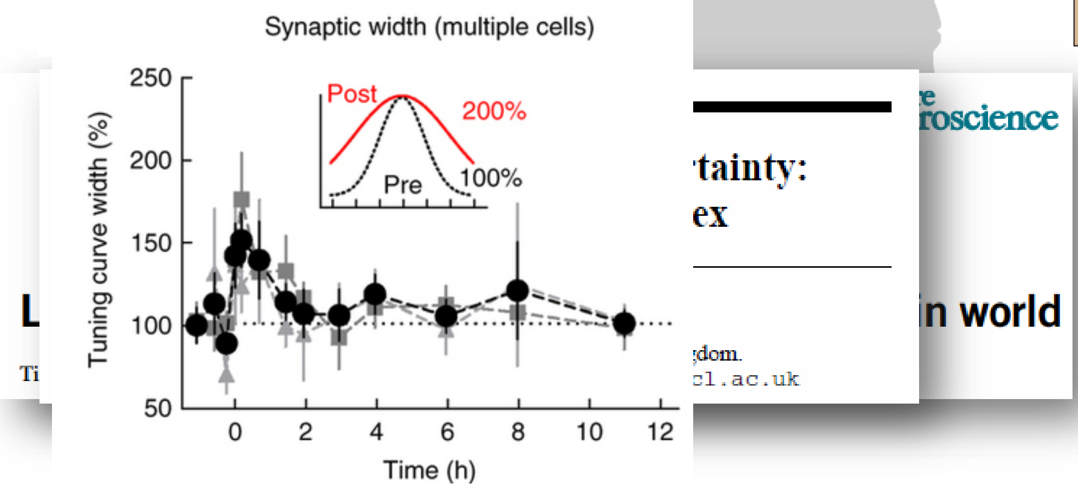
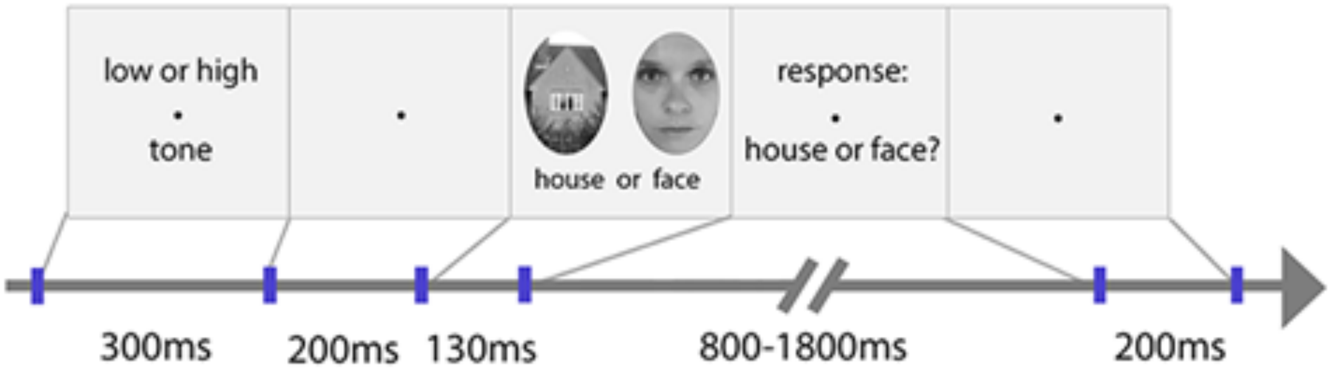


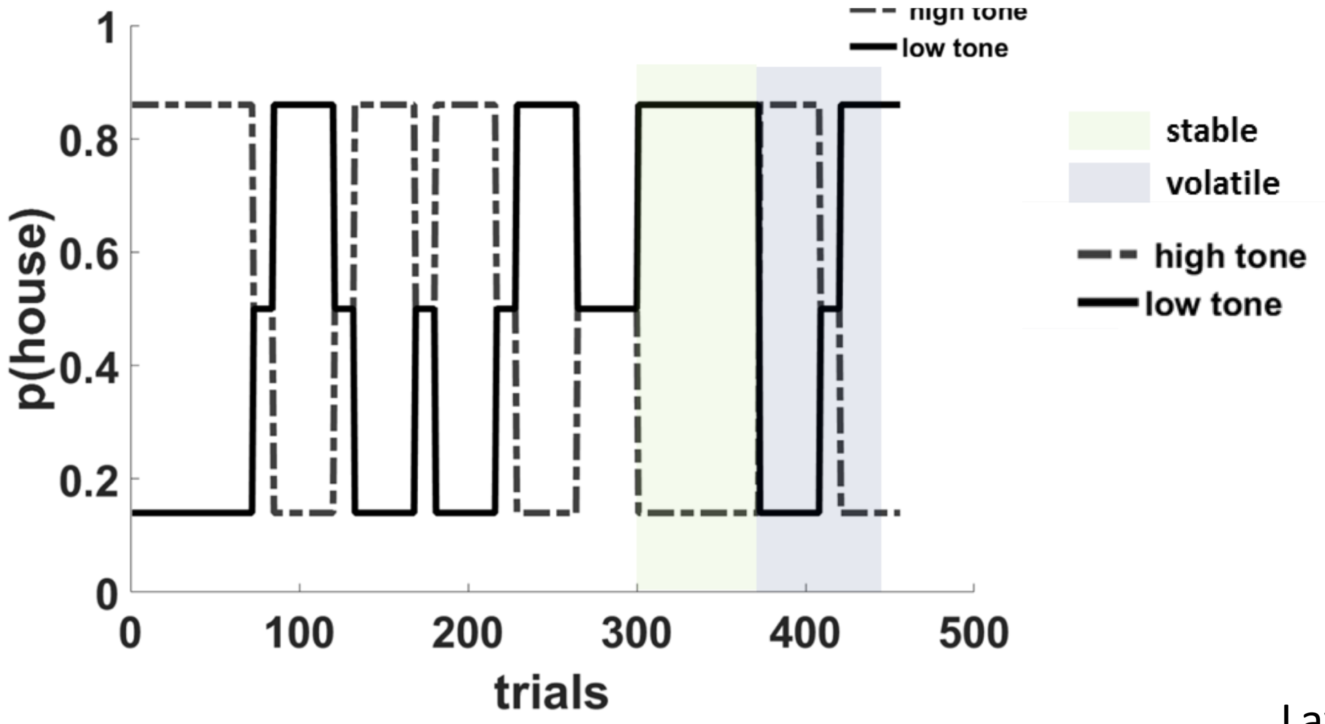
Martins et al, Nature Neuro, 2016

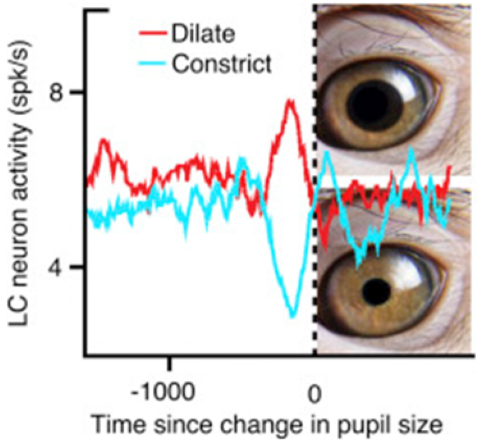
Friston, Lawson & Frith, TiCs, 2014; Lawson, Rees & Friston, Front Hum Neuro, 2014; Lawson, Friston & Rees, PNAS, 2015; Palmer, Lawson & Hohwy, Psychol Bulletin, 2017

Learning what to expect (in autism)

weighting predictions against prediction errors



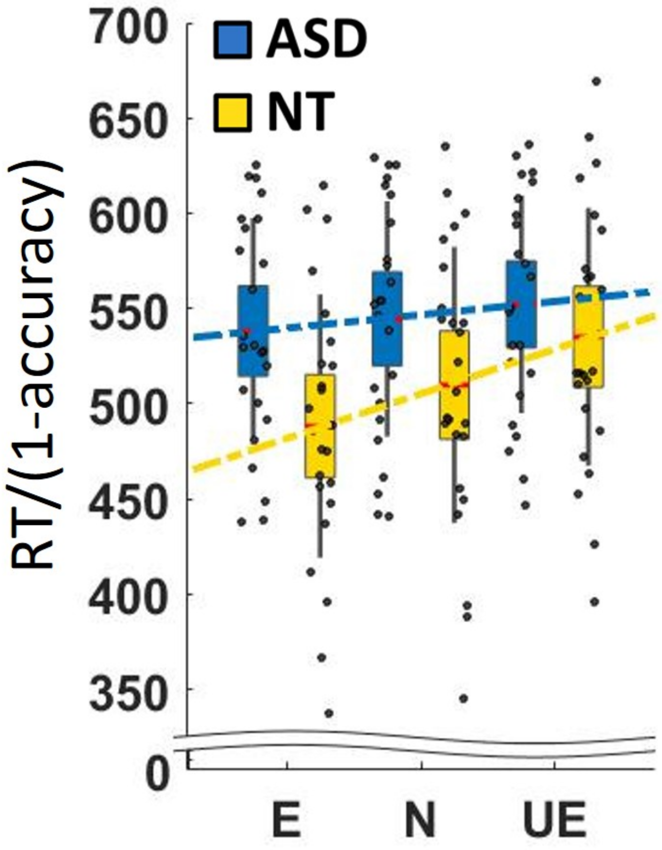


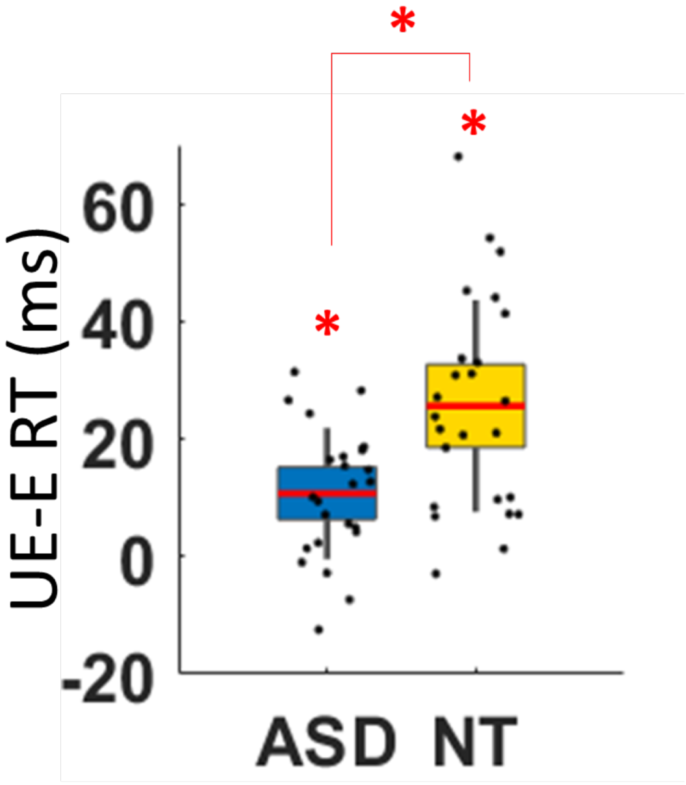


Lawson et al, 2017, Nature Neuroscience.

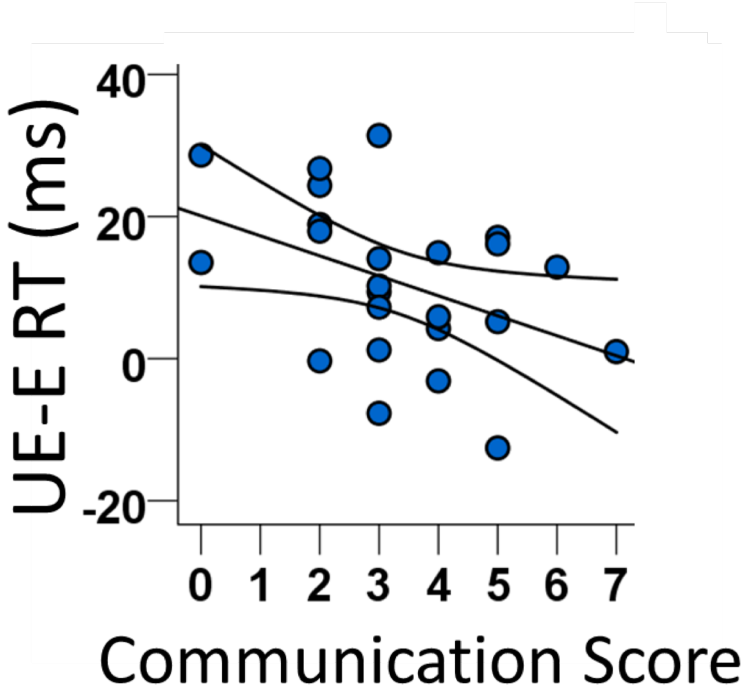
Reduced “surprise” in autism

Reduced influence of expectations on behaviour in autism



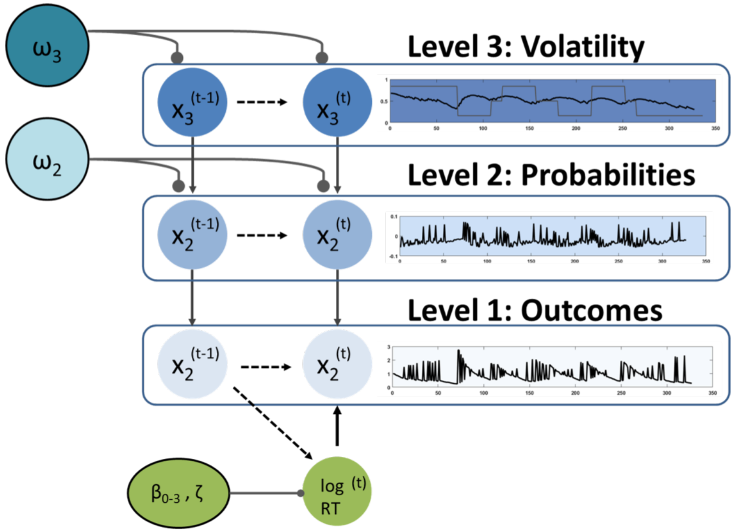


...predicts ‘communication’ difficulties



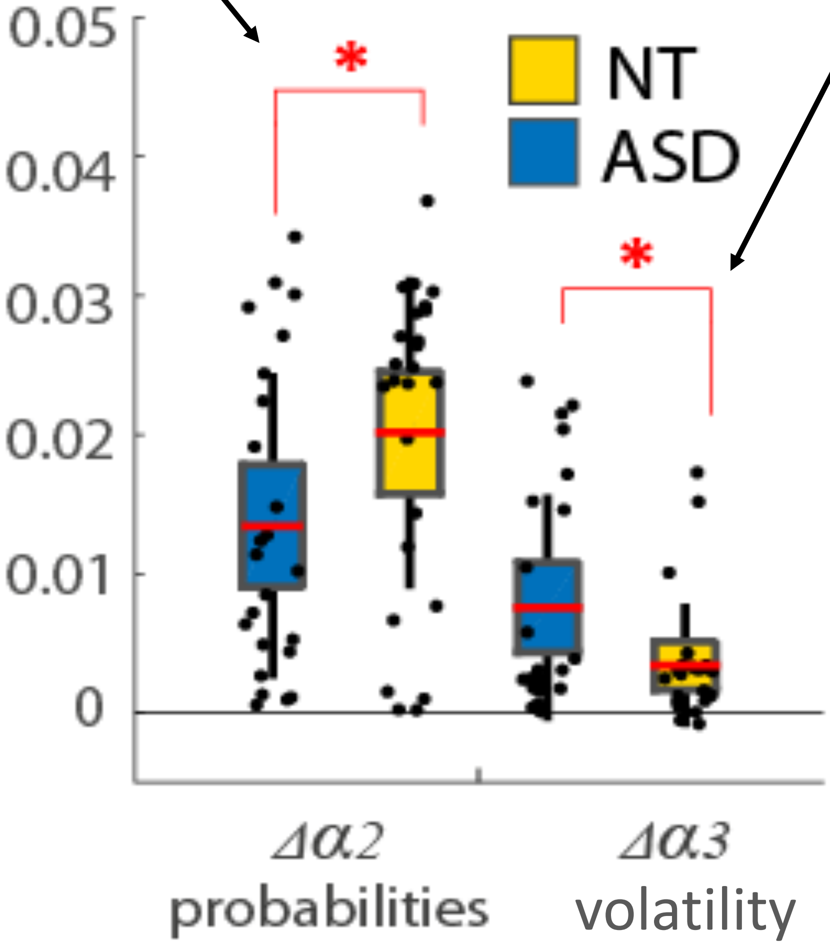
Lawson et al, 2017, Nature Neuroscience.

Modelling learning under uncertainty

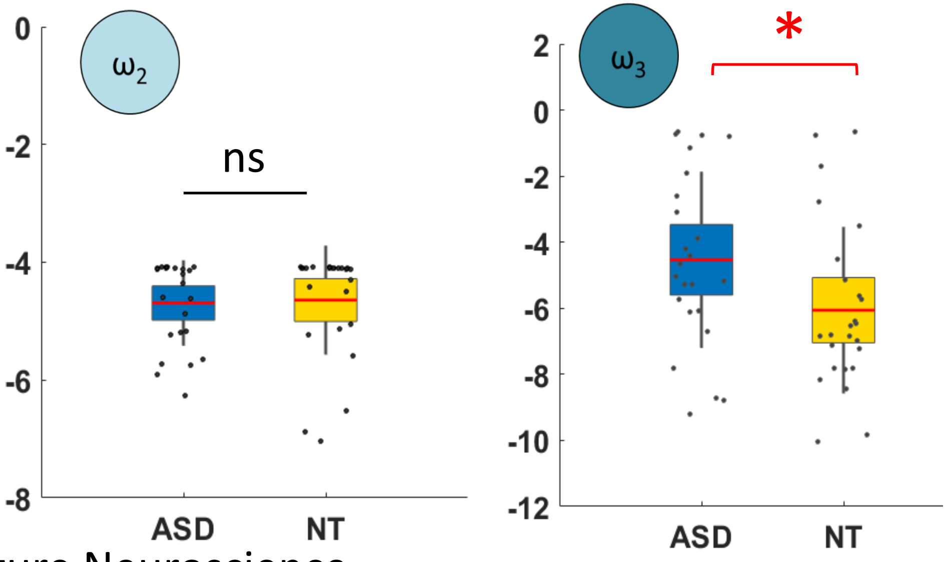


Decreased probability learning rate update when probabilities switch in autism

Increased volatility learning rate update when probabilities switch in autism



Increased 'tonic' volatility of beliefs in autism



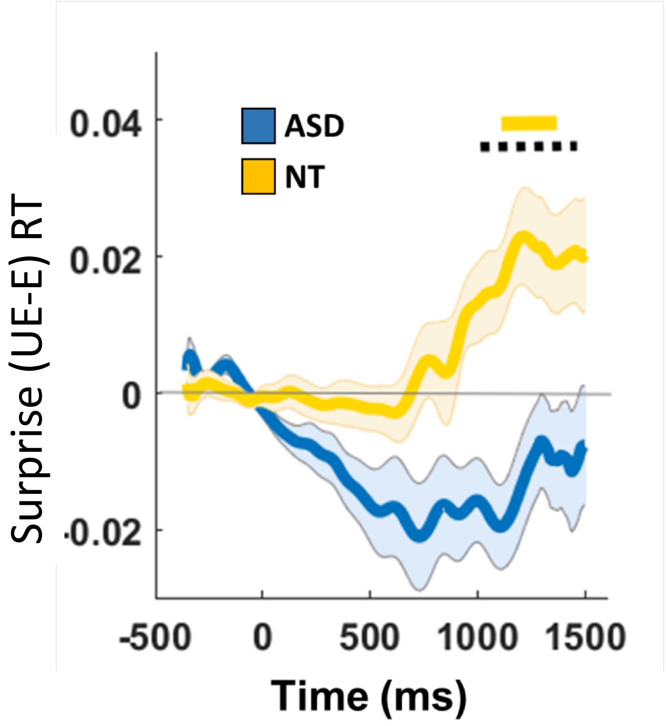
Lawson et al, 2017, Nature Neuroscience.

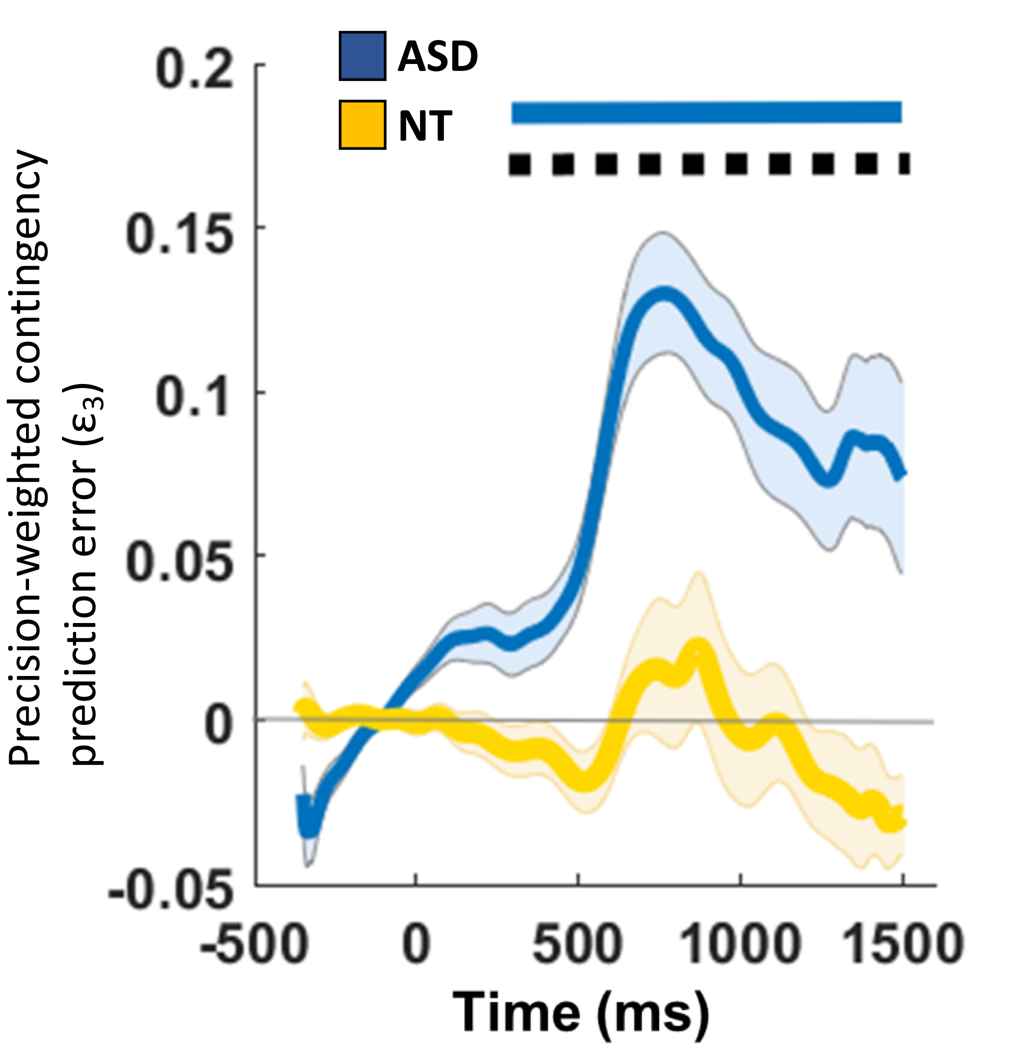
Phasic NA prediction errors

Heightened NA encoded surprise in autism

This analysis asks "how did the NA system encode surprise when participants were actually surprised"?

This analysis asks "how did the NA system represent surprise when participants "ought" to have been surprised"? (assuming everyone learns the same)

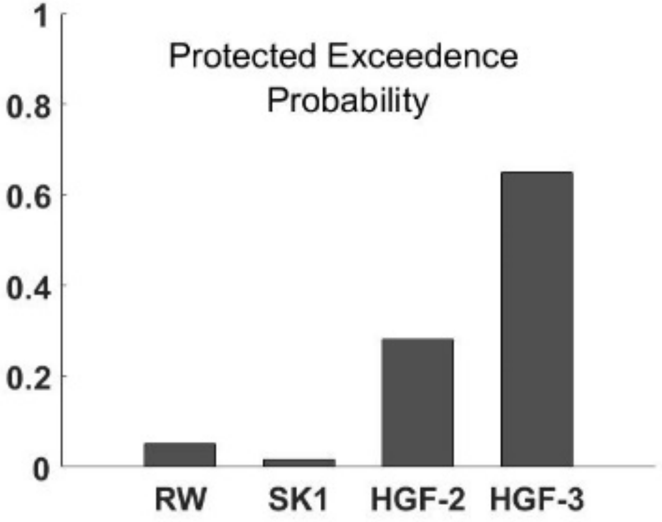


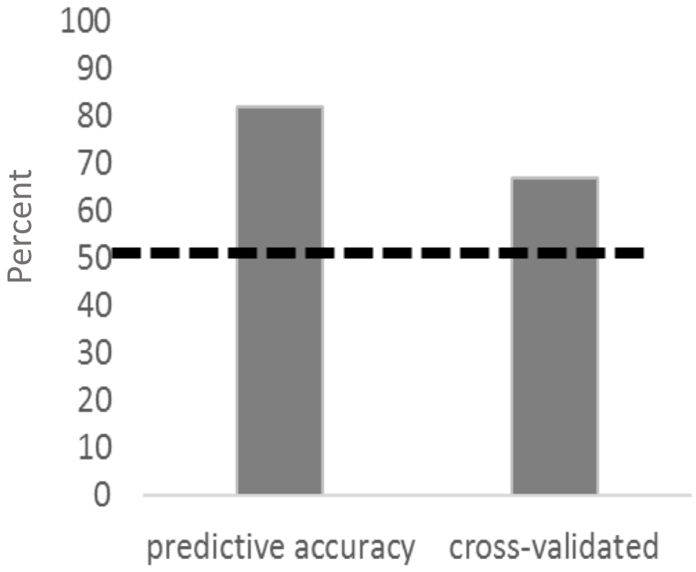


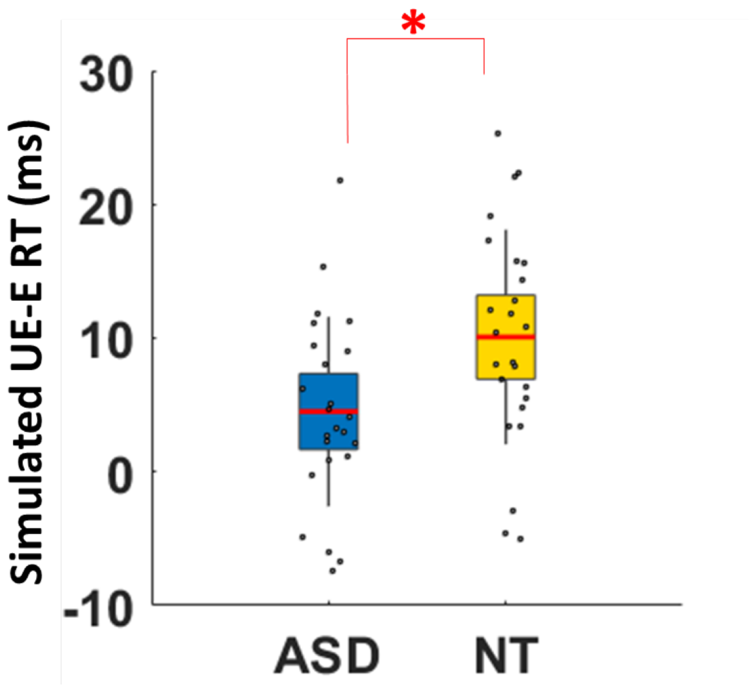
Lawson et al, 2017, Nature Neuroscience.

Is the model any good?

Validation







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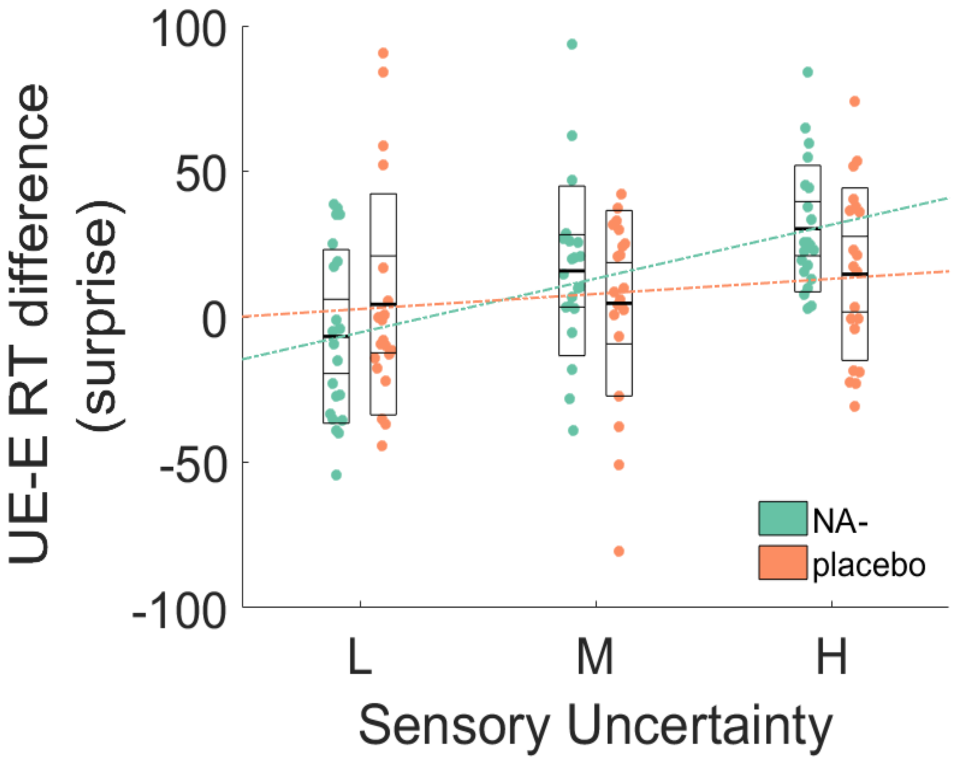
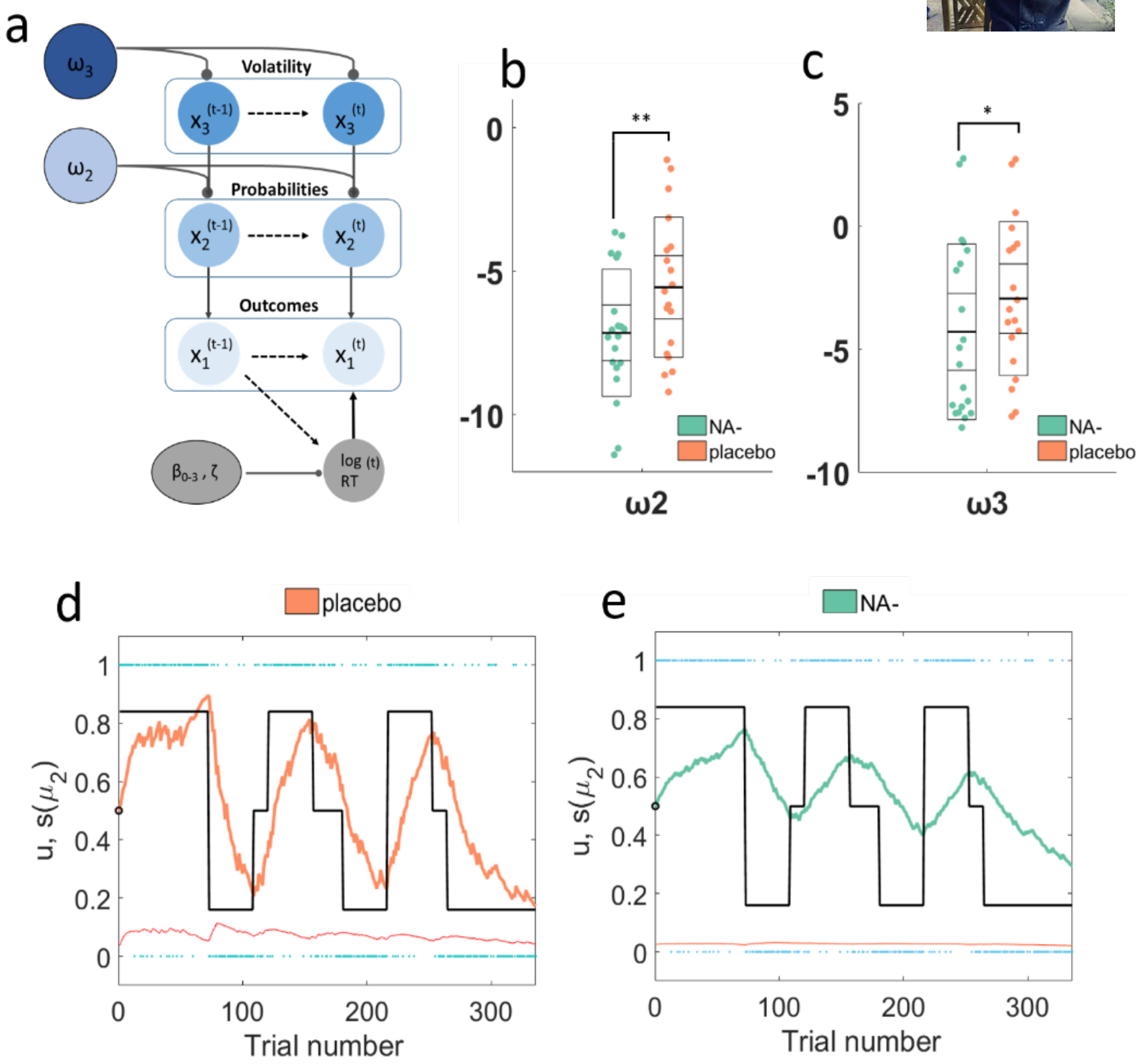
Direct manipulation of NA

vs





Lawson et al, in prep [preliminary data]

Direct manipulation of NA

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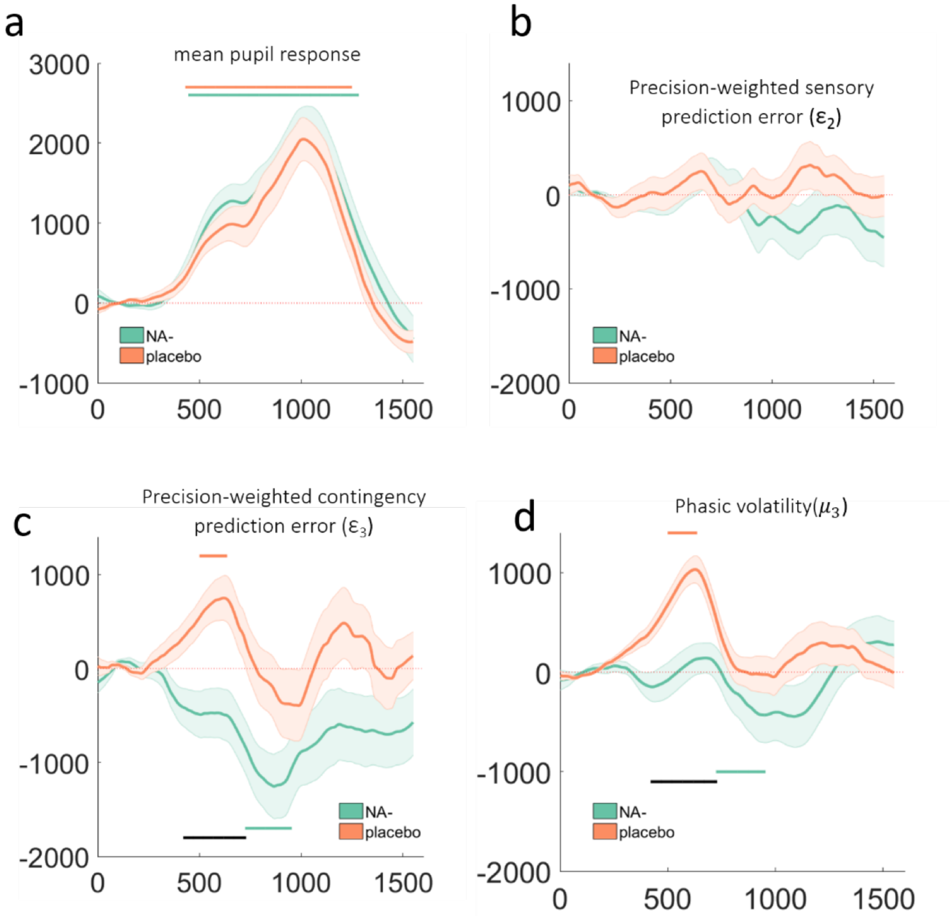

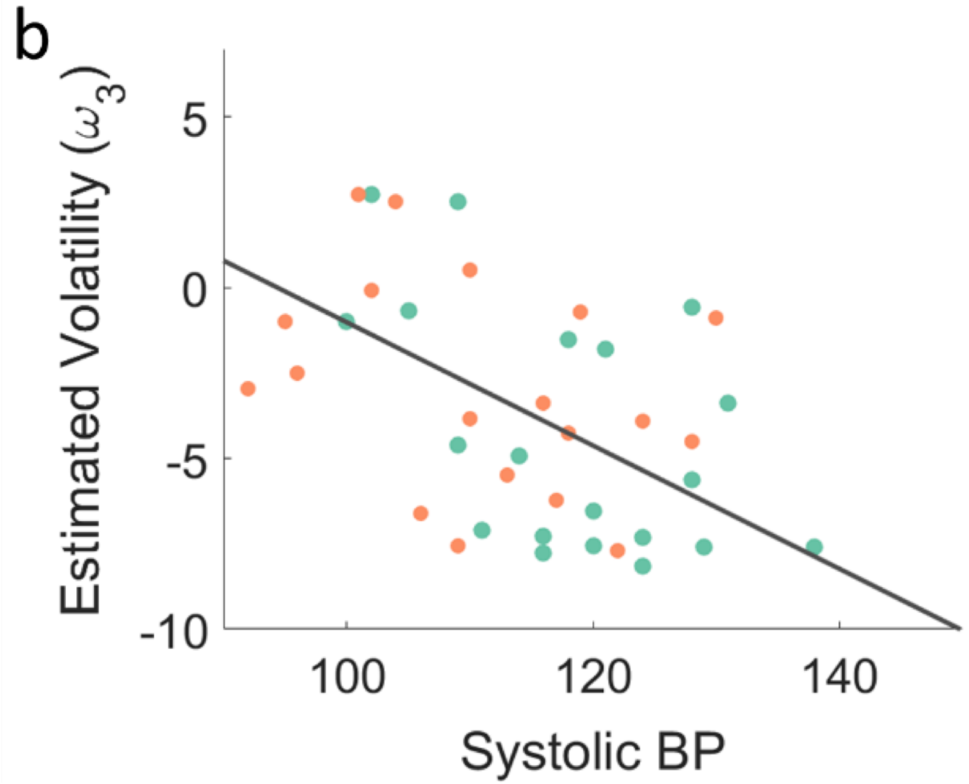

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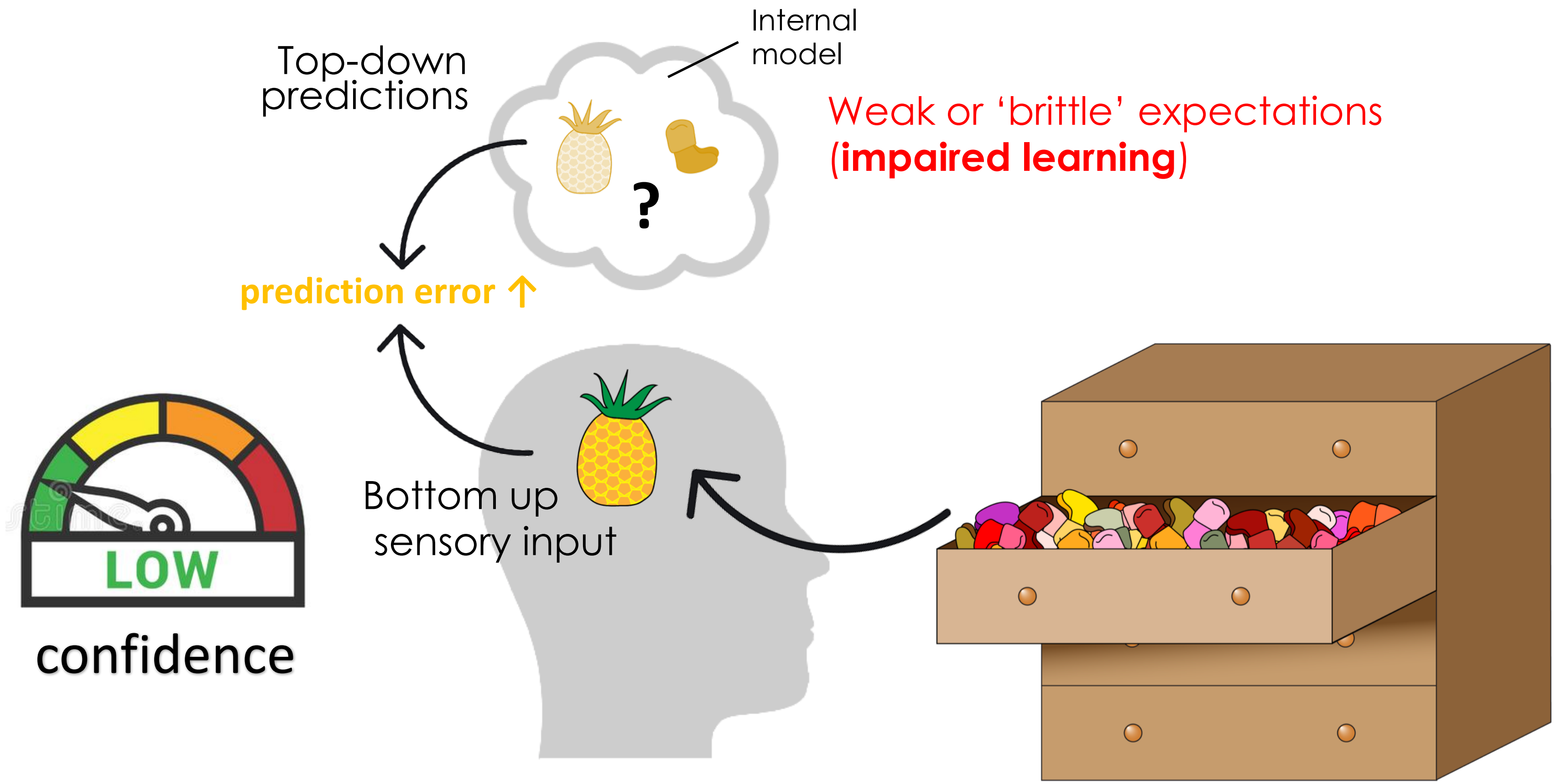
Autism as a variant of 'optimal' Bayesian Inference



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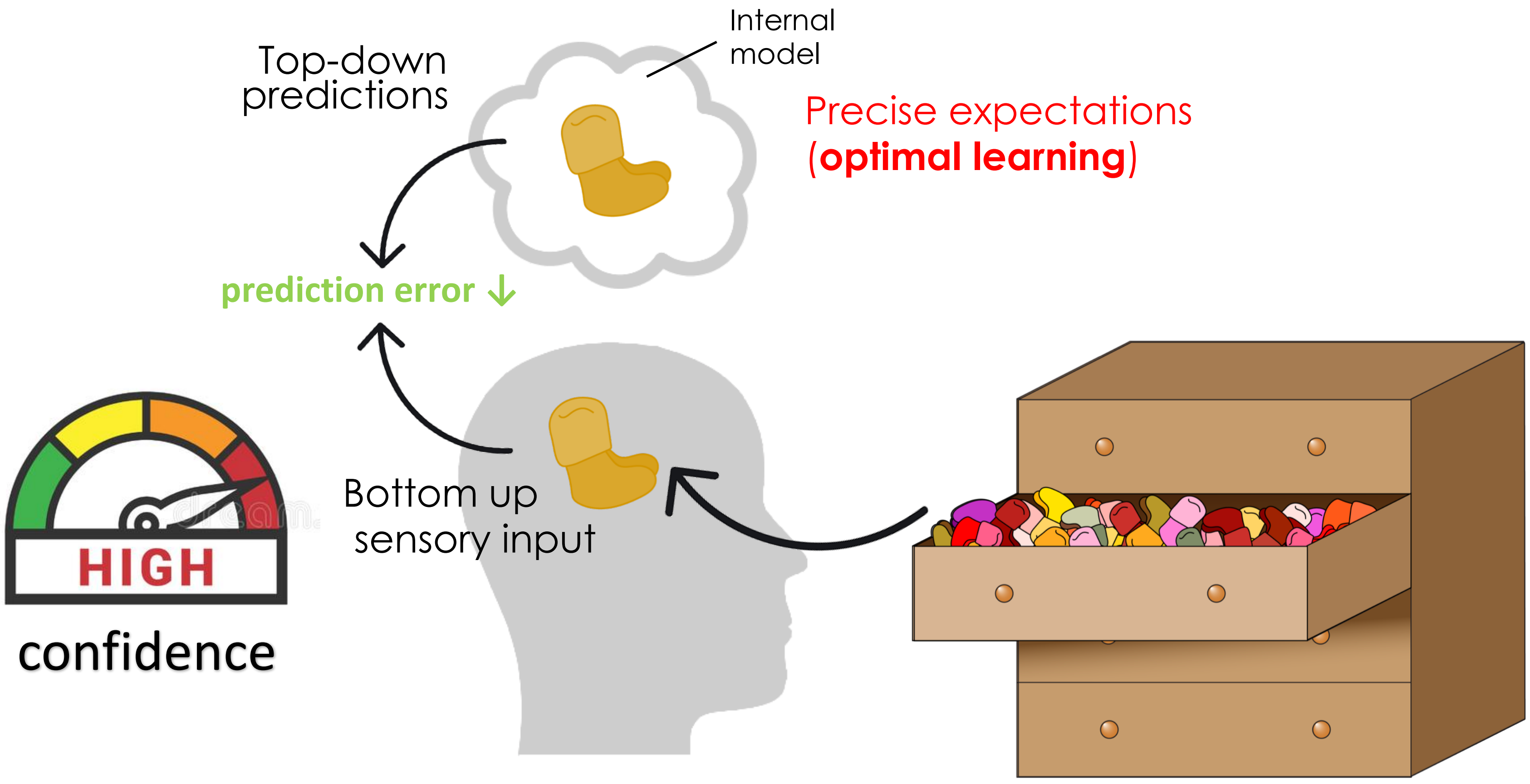

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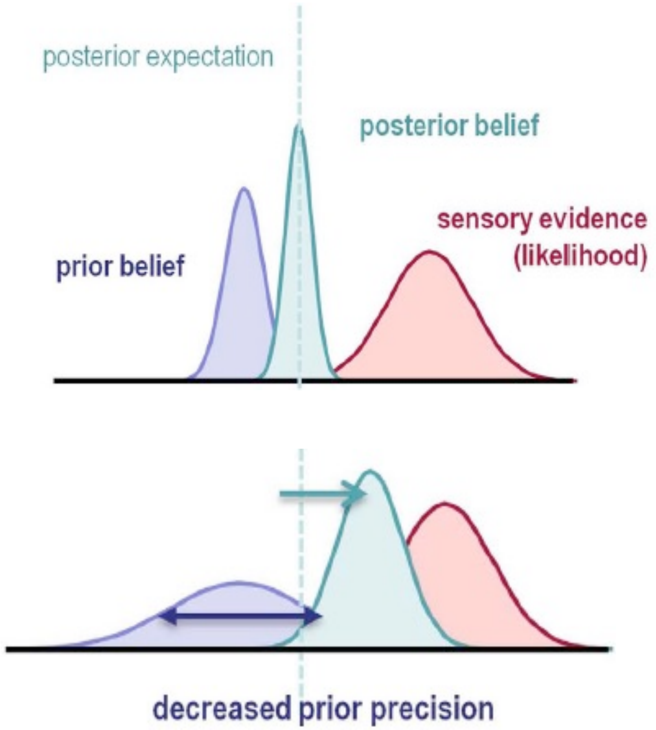
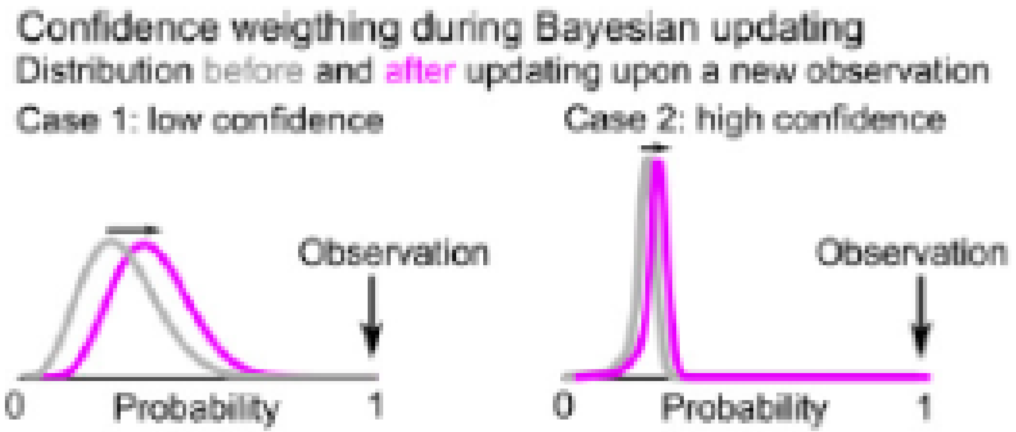
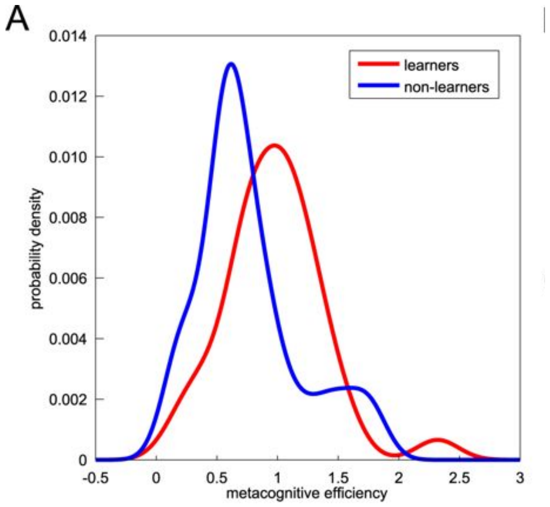
Perceptual confidence in autism





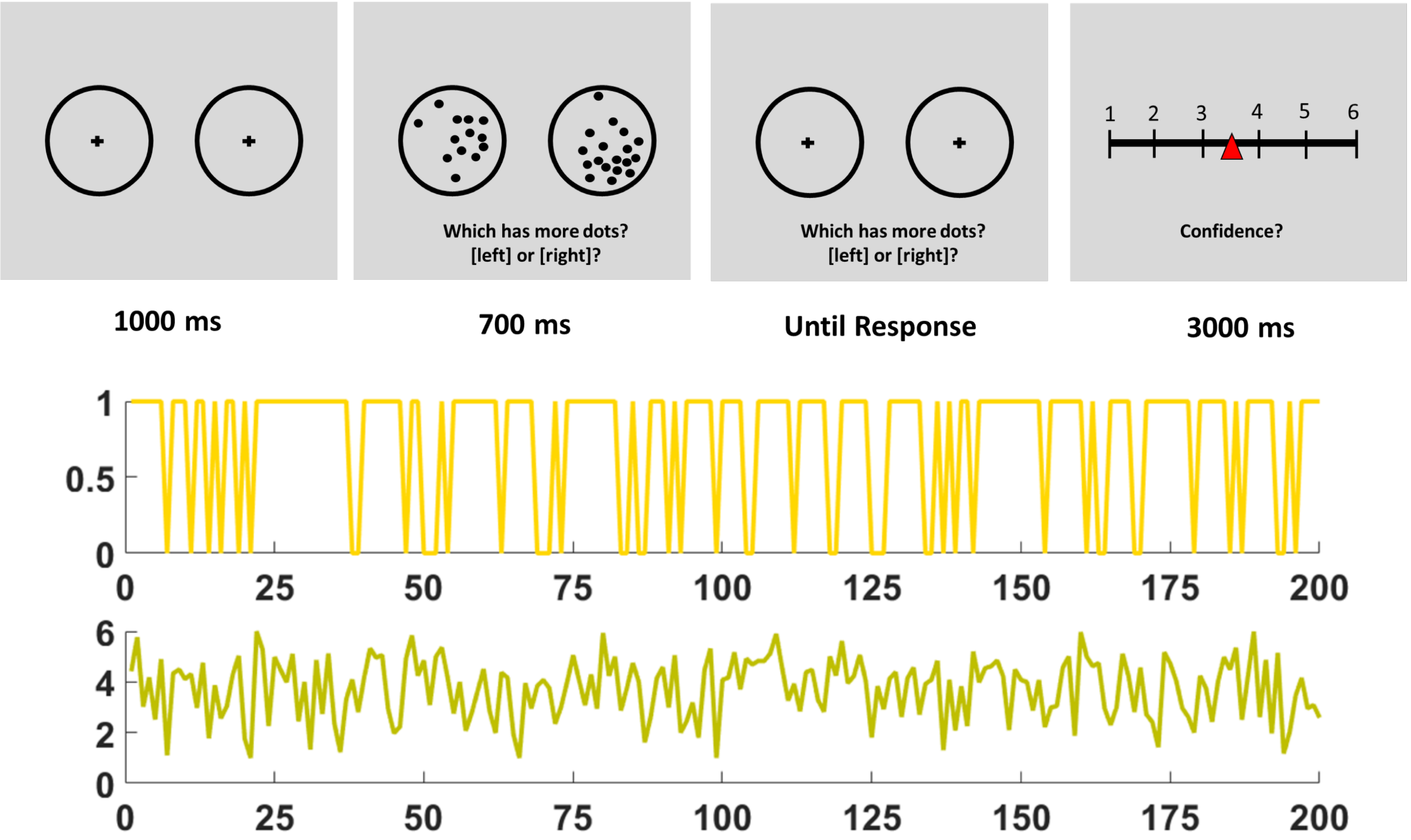
Meyniel & Dehaene, PNAS, 2017



"[we propose that in autism] there is a failure of beliefs (estimated precision) about beliefs (predictions) that is, formally, a failure of metacognition"
Friston, Lawson & Frith, 2012, Trends in Cognitive Sciences

Hainguerlot et al, Sci Reports, 2018

Perceptual confidence in autism



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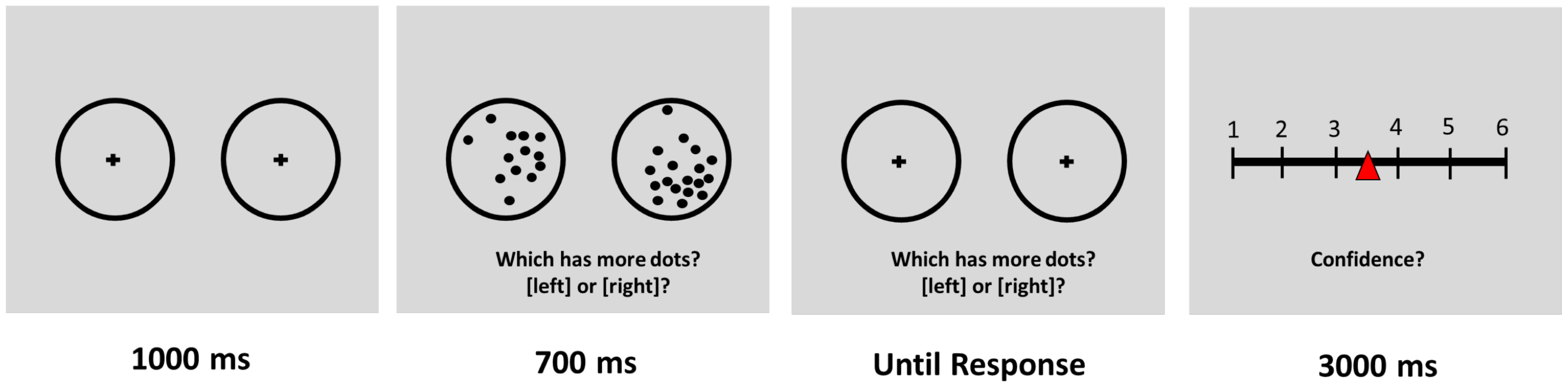
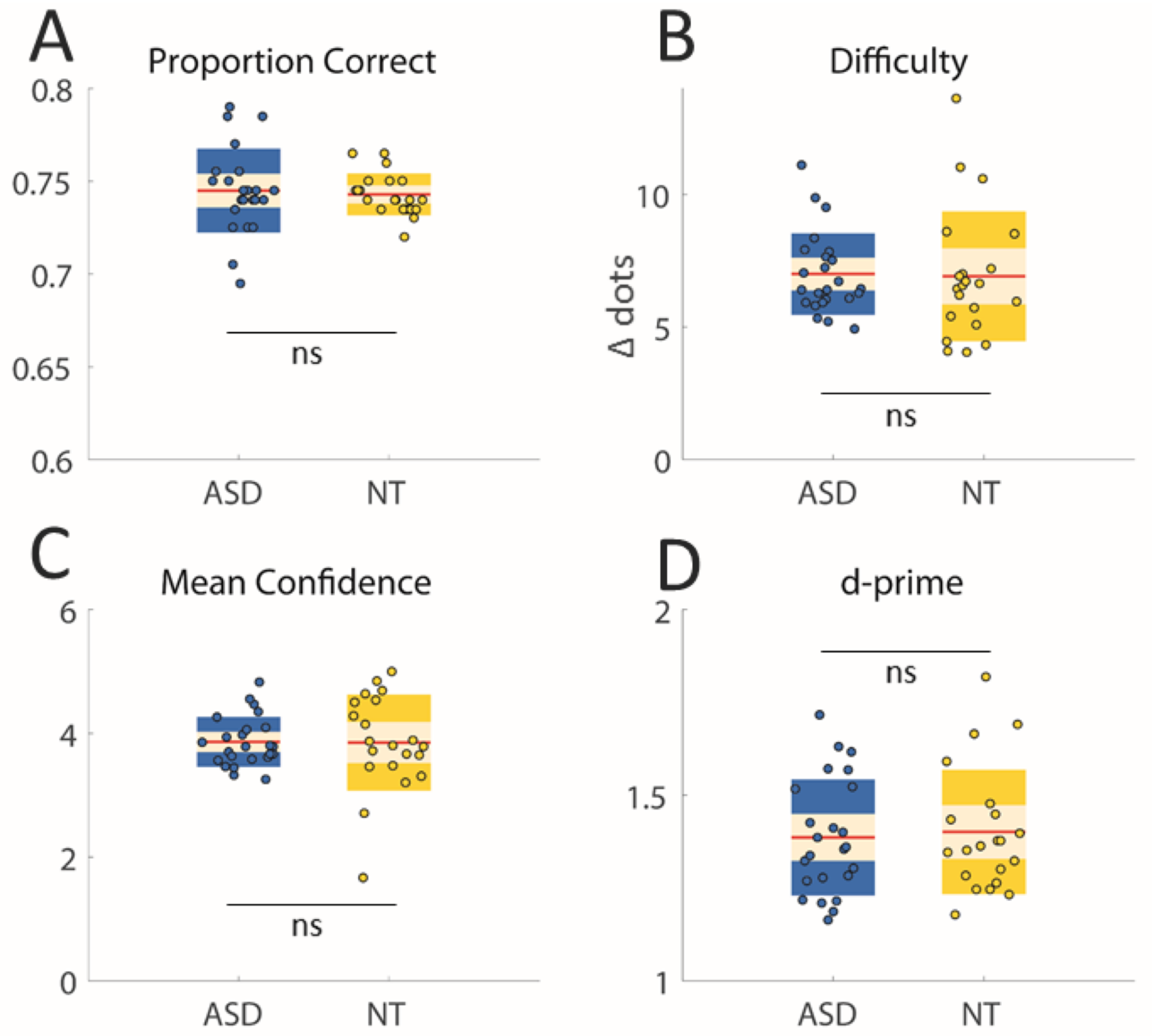


d-prime
Measure of sensitivity the extent to which subjects can distinguish which circle contains more dots (type-1 sensitivity)

meta d-prime
is a measure of type-2 sensitivity, in other words, the extent to which subject confidence can discriminate correct from incorrect judgements

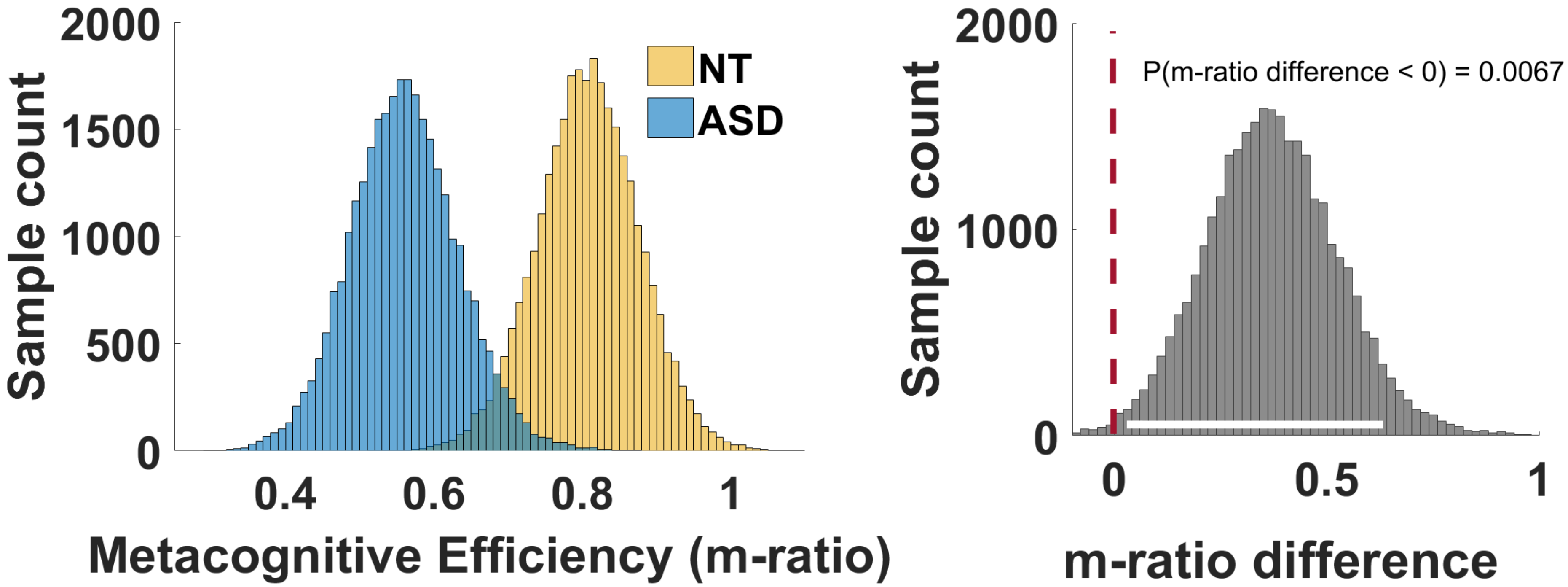
Lawson et al, in prep [preliminary data]

Matched perceptual performance



Lawson et al, in prep [preliminary data]

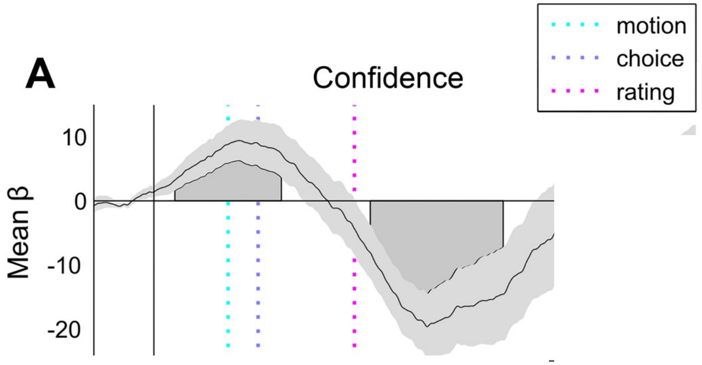
Reduced metacognitive efficiency in autism



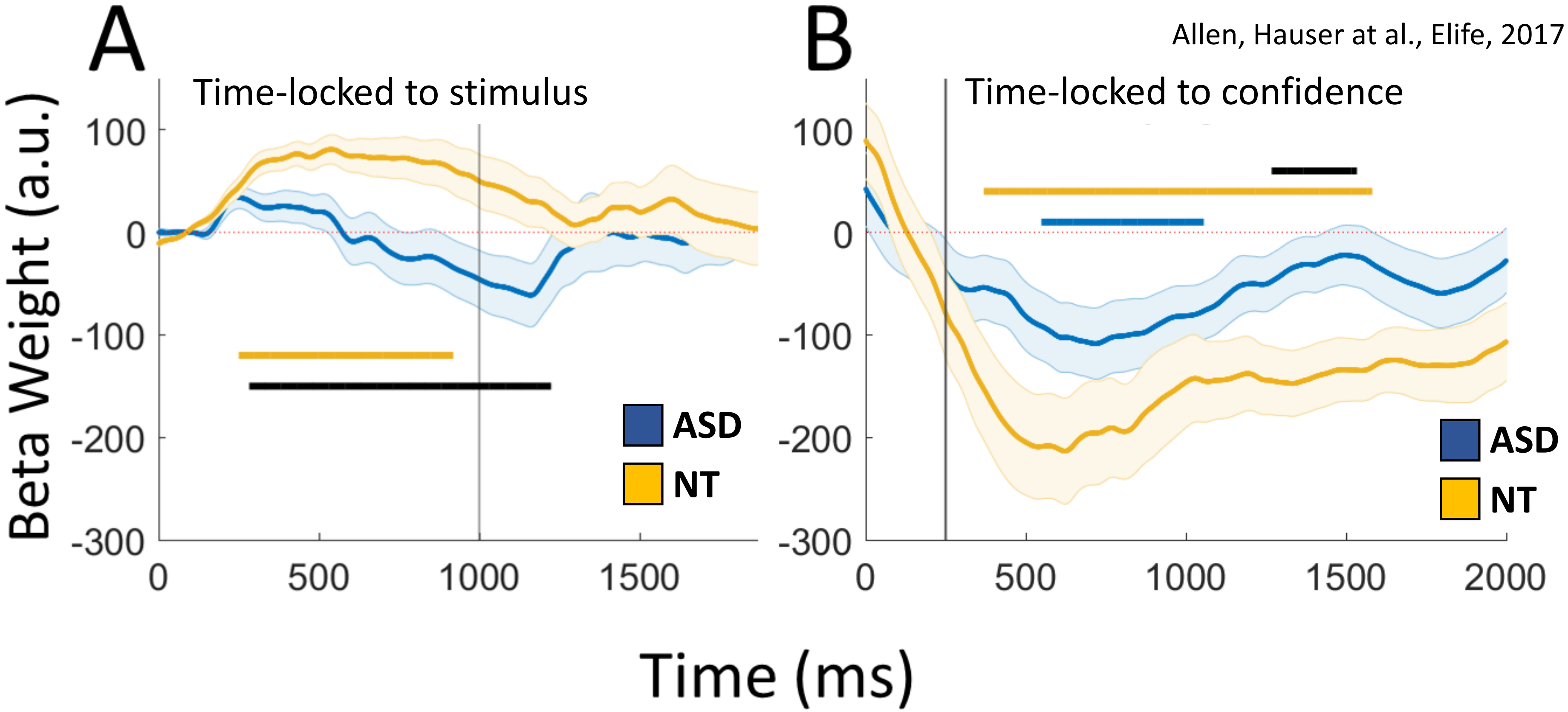
m-ratio: meta d'/d'

Lawson et al, in prep [preliminary data]

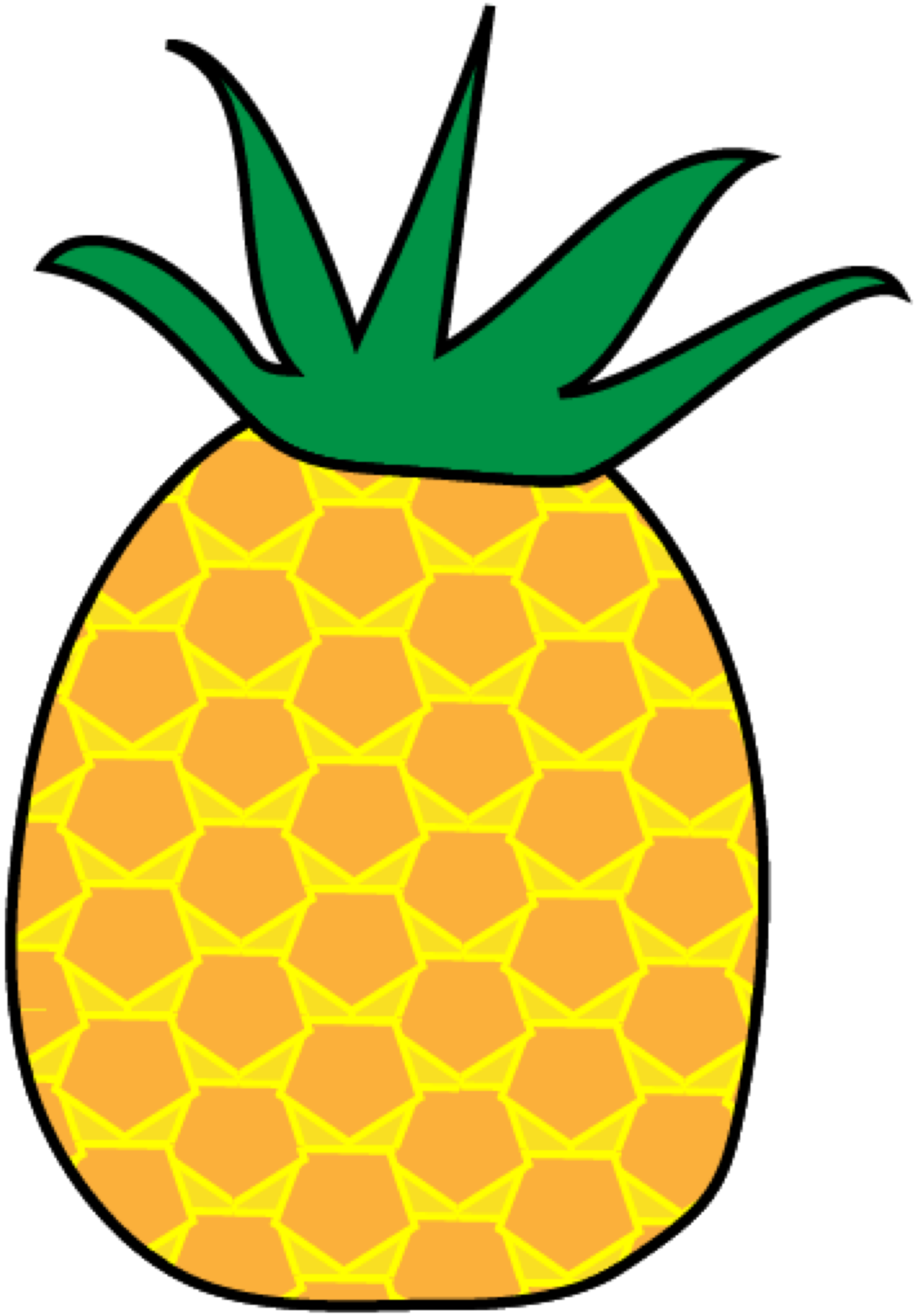
Diminished confidence-linked NA response in ASD?



Allen, Hauser at al., Elife, 2017



Lawson et al, in prep [preliminary data]



Summary

- Temporal context and spatial context are reliable predictors of our neural and behavioural responses to upcoming stimuli.
- Normalisation (local spatial gain control) for non-social and social stimuli seems to be preserved in autism
- Computational models that capture the process by which expectations are learned indicate that adults with autism over estimate the variability of the sensory environment. This prevents the stable learning of certain prior expectations.
- Pupillometry in autism and pharmacology in healthy adults implicate the integrity of the noradrenaline system for changing the gain on sensory responses to appropriately weight the influence of prior beliefs.
- Explicit measures of confidence, a proxy read out of certainty in prior perceptual reports, can be used to show metacognitive inefficiency in autism – a poor correspondence between accuracy and confidence.
- Pupillometry linked to confidence ratings again implicates heightened NA function in autism, relative to neurotypical participants.

Neurodevelopment

- If we have prediction errors, then we have to have predictions (i.e. a model of the world)
- We build this model in development.
- Model optimisation through activity-dependent pruning and maintenance of neuronal connections that are specified epigenetically.
  - *A failure of precision mediated associative learning could produce an over-pruned/chronically under connected cortical hierarchy*
- Neurodevelopmental insult to precision at (presumably) lower sensory areas will prevent or obstruct the building of deep models of the world in higher cortical areas.

Baby PaL

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