CHANGE OF MIND

COMPUTATIONAL APPROACHES TO (MAL)ADAPTIVE CHANGES IN BELIEFS

Chris Mathys

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INTERACTING MINDS CENTRE (IMC)

AARHUS UNIVERSITY

THE CLINICAL-COMPUTATIONAL CHALLENGE

- **Psychotic experiences** are thought to emerge from various **interrelated patterns of disrupted belief updating**

- Patterns can be for example
  - Overestimating the **reliability of sensory information**
  - Misjudging **task volatility**
  - **Misclassifying** the cause of an observation

- While these kinds of aberrant inference form computational **substrates of psychotic experiences,** they are hard to conceptualize in a single computational framework

- However, they share the characteristic that they all relate to the **adaptation of beliefs, i.e. probabilistic predictions guiding action**

MODELS OF PRECISION-GUIDED BELIEF UPDATES

- In what follows, I will show an example of **generalized hierarchical Gaussian filtering**, a tool and framework that enables arbitrarily large networks of nodes coupled not only via their variance but also their means

- This is a solution in the **continuous realm** (**where** is something?)

- Different tools are needed in the **categorical realm** (**what** is something?)

- These realms are conceptually related by the role played by **precision** in **guiding belief updates**

- Models of categorical inference are crucial for the understanding of **delusions.** I will finish by showing some first steps in that direction

MORE ON WHERE AND WHAT

- As the world around us changes continually, we need to **adapt our beliefs** to keep up with environmental changes.
- This has both a **'where'** and a **'what'** aspect.
- On the **'where'** side, we need to track **how things move in space**, be that movements in a concrete space (e.g., an object in our field of vision) or in an abstract one (e.g., the probability of a certain event).
- On the **'what'** side, we need to update beliefs about **categories**
- E.g., categories **of events that have the same explanation** or cause.
- This is especially relevant in the computational modelling of **delusions,** where **events are attributed to causes in a maladaptive way.**

THE WHERE PATH: AN EXAMPLE (MIKUS ET AL., 2025)

- **Computational phenotyping:** estimating individual parameters which provide a trait-like characterization of underlying computational patterns and have the potential to guide psychiatric treatment

- We introduce a **novel hierarchical Bayesian model** that describes how individuals simultaneously update their beliefs about the task volatility and noise in observation

- We apply this model to data from a modified **predictive inference task** in a **test-retest study** with healthy volunteers (N=45, 4 sessions)

- We examine the relationship between model parameters and schizotypal traits
  - in a **larger online sample** (N = 437) and
  - in a cohort of **patients with schizophrenia** (N = 100).

Biological Psychiatry

Archival Report

Computational Phenotyping of Aberrant Belief Updating in Individuals With Schizotypal Traits and Schizophrenia

Nace Mikus, Claus Lamm, and Christoph Mathys

https://doi.org/10.1016/j.biopsych.2024.08.021

Nace Mikuš

Claus Lamm
(U Vienna)

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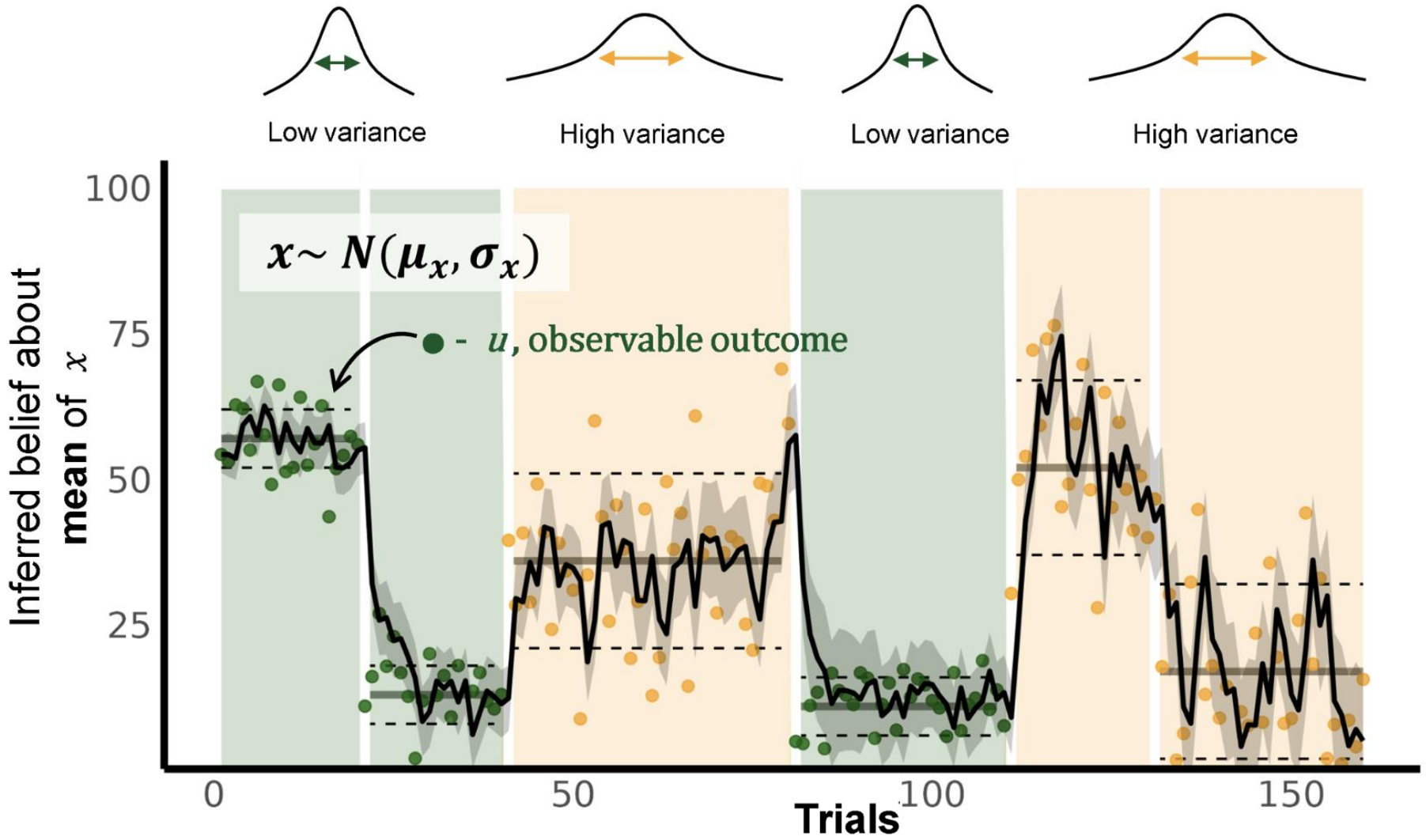
THE TASK


Low variance
High variance
Low variance
High variance
$x \sim N(\mu_x, \sigma_x)$
- u, observable outcome
Inferred belief about mean of x
100
75
50
25
0
50
100
150
Trials

THE COMPUTATIONAL PROBLEM

Is it A or B?

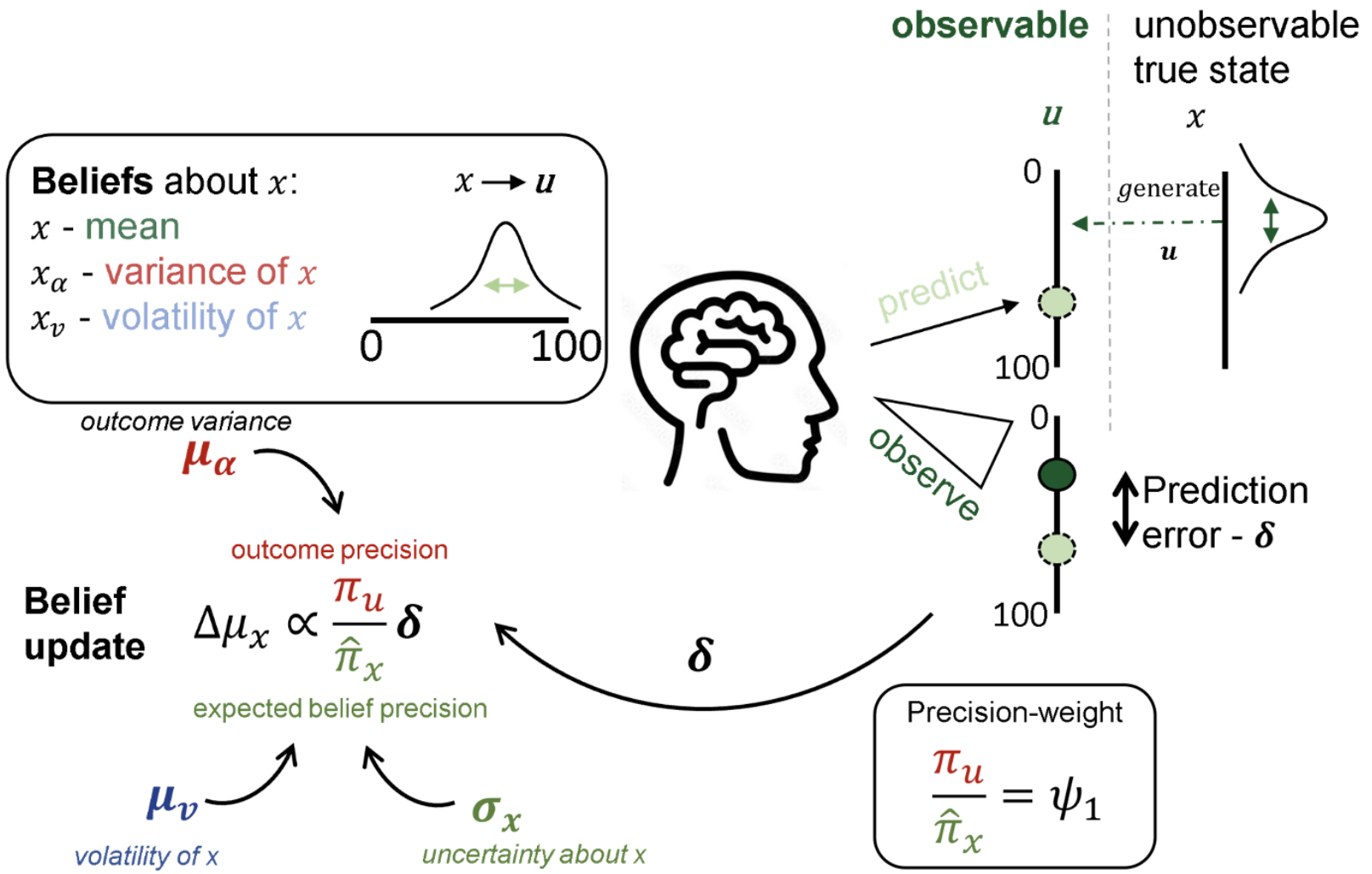
A. My prediction errors are noise. Adjusting my predictions wouldn't help to reduce future prediction errors – and might even make them worse.

B. My prediction errors reflect a change in my environment. Adjusting my predictions will help to reduce future prediction errors.

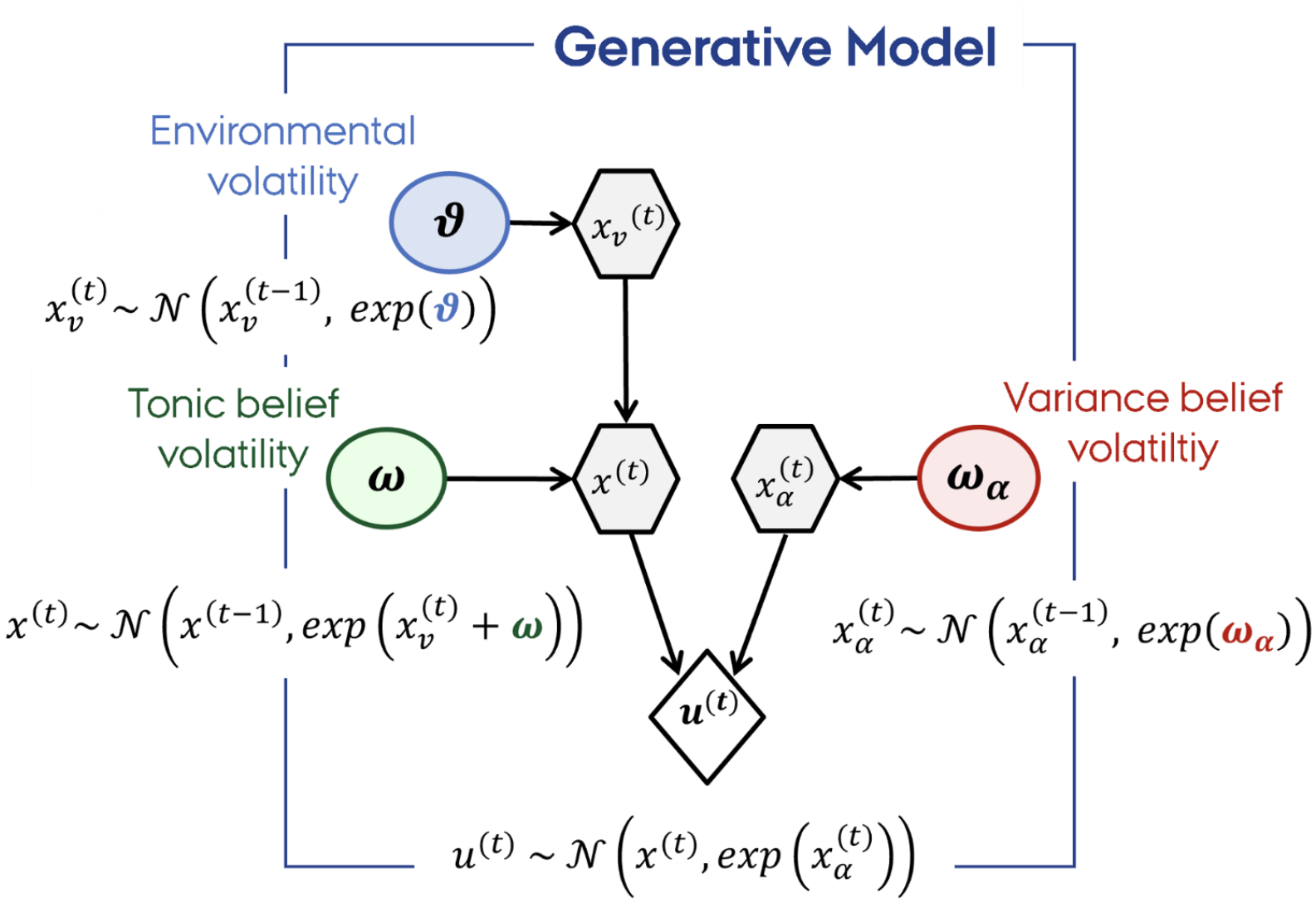
Or a combination of both?

And if that, how much of A and B is there?

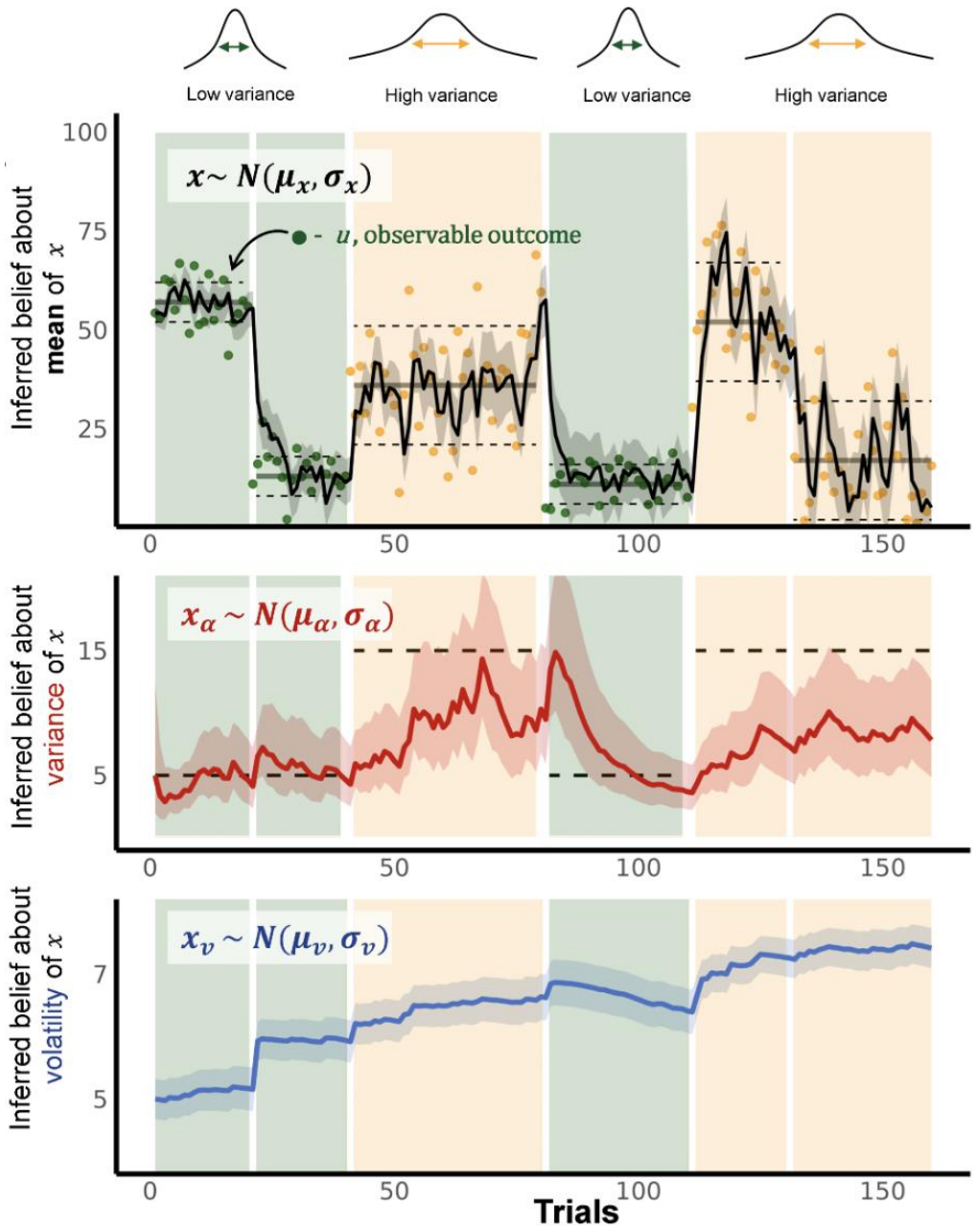
THE COMPUTATIONAL PROBLEM



THE MODEL


Generative Model
Environmental volatility
ϑ
$x_v^{(t)}$
$x_v^{(t)} \sim \mathcal{N}\left(x_v^{(t-1)}, exp(\vartheta)\right)$
Tonic belief volatility
ω
$x^{(t)}$
$x_\alpha^{(t)}$
ω_α
Variance belief volatiltiy
$x^{(t)} \sim \mathcal{N}\left(x^{(t-1)}, exp\left(x_v^{(t)} + \omega\right)\right)$
$x_\alpha^{(t)} \sim \mathcal{N}\left(x_\alpha^{(t-1)}, exp(\omega_\alpha)\right)$
$u^{(t)}$
$u^{(t)} \sim \mathcal{N}\left(x^{(t)}, exp\left(x_\alpha^{(t)}\right)\right)$

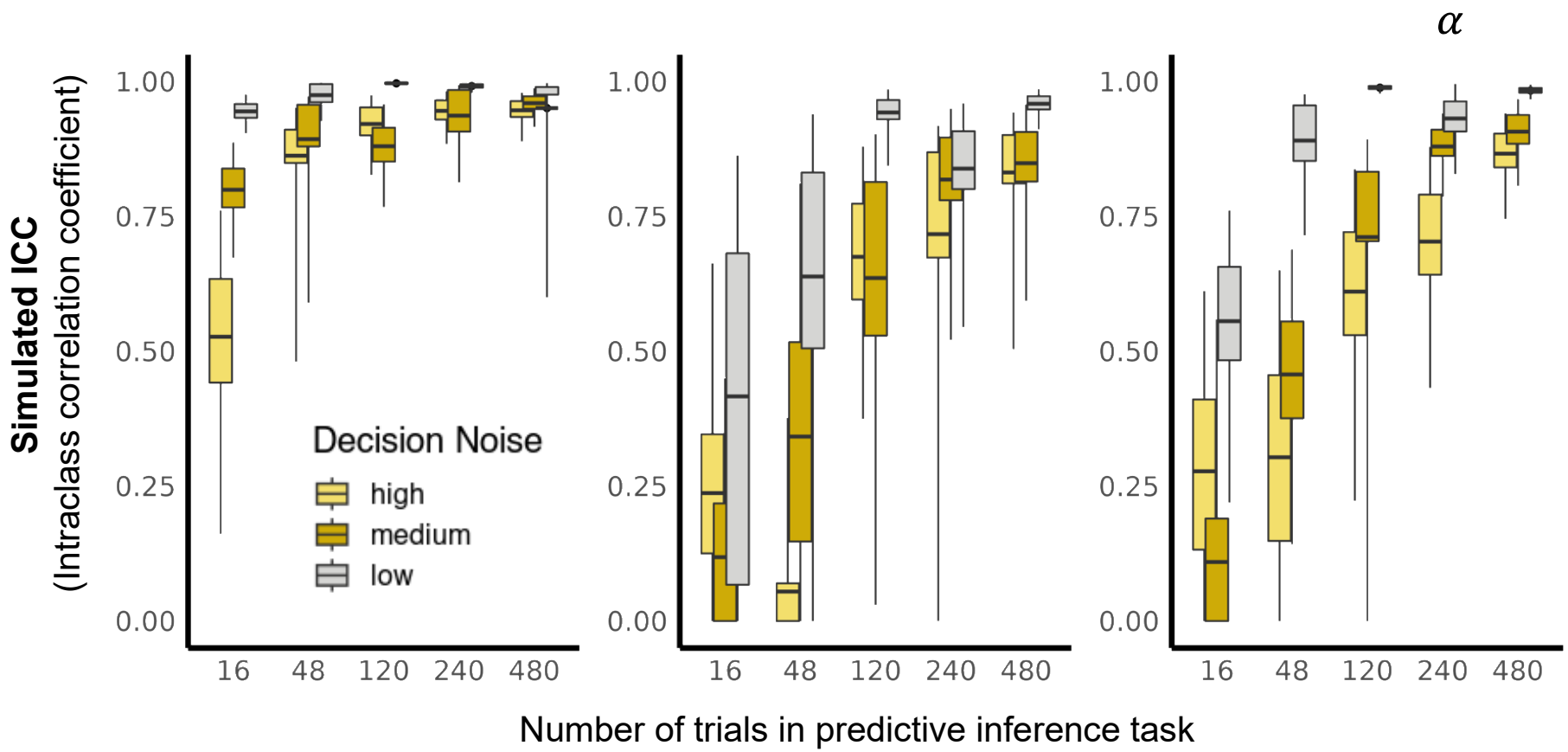
INFERRED BELIEFS



THE PLAN

- **Simulation study:** establish recoverability of parameters in a test-retest setting
- **Experiment 1:** longitudinal design to establish reliability of parameter estimates (test-retest in healthy volunteers)
- **Experiment 2:** replicate and extend Experiment 1 in a larger sample of healthy participants
- **Experiment 3:** extend to data set of patients with schizophrenia

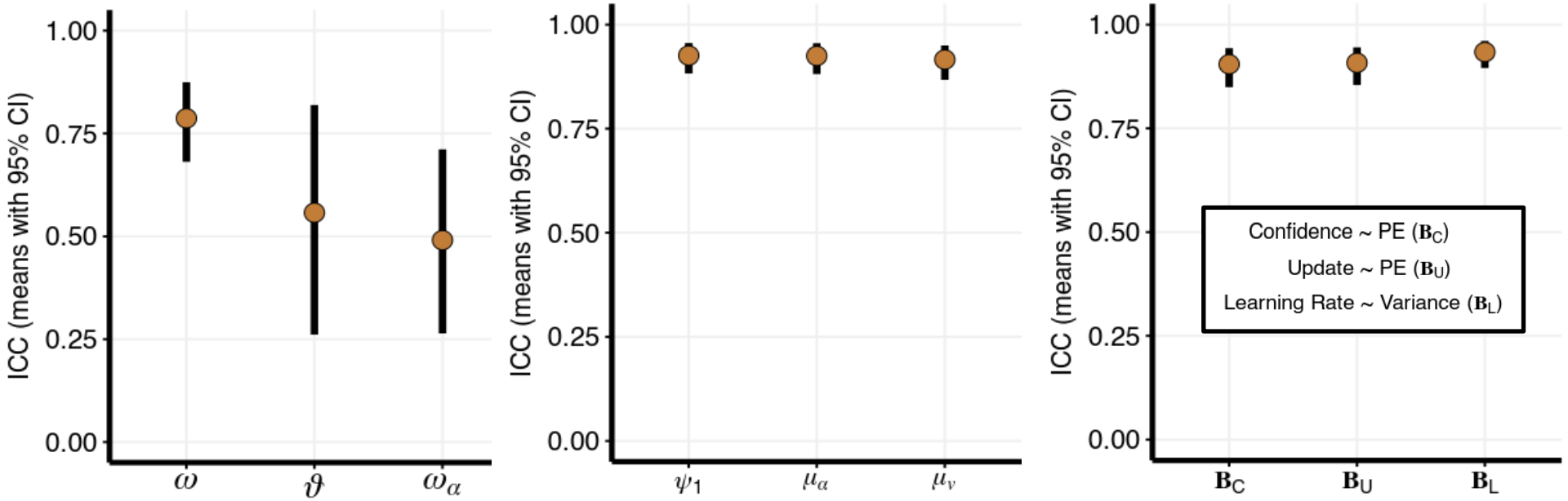
SIMULATION: TEST-RETEST PARAMETER RECOVERY



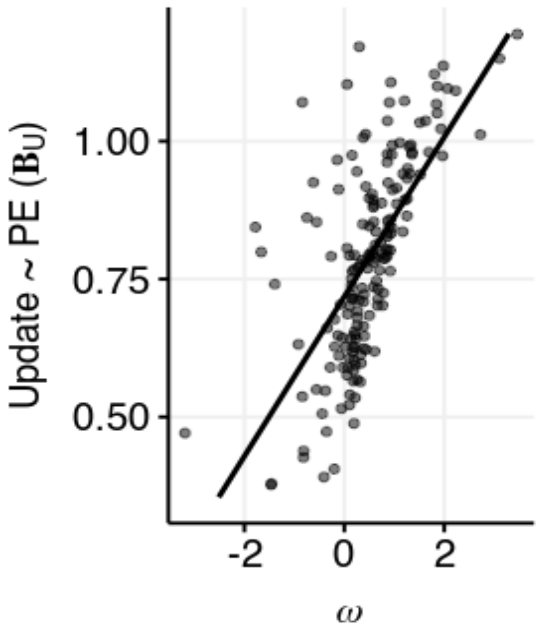
EXPERIMENT 1

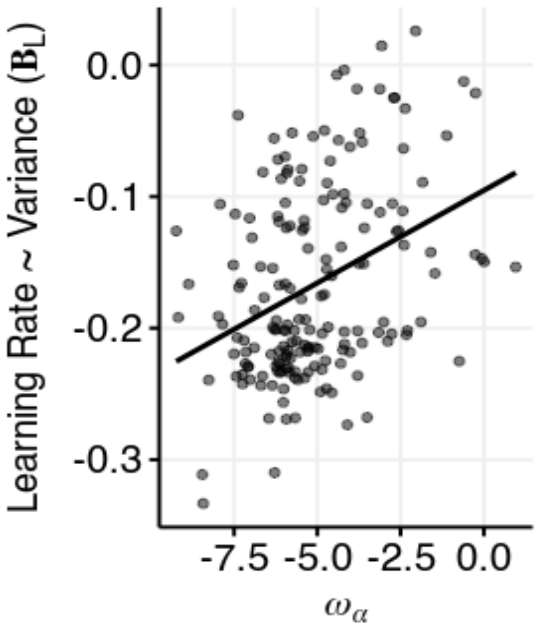
- **Predictive Inference Task** repeated (in different configurations) **four times** (N=45, healthy volunteers)
- Sessions at least **one week apart**
- Performance rewarded
- **Both mean and standard deviation** of sampling distribution change randomly
- **Peters Delusion Inventory** (PDI) in third session

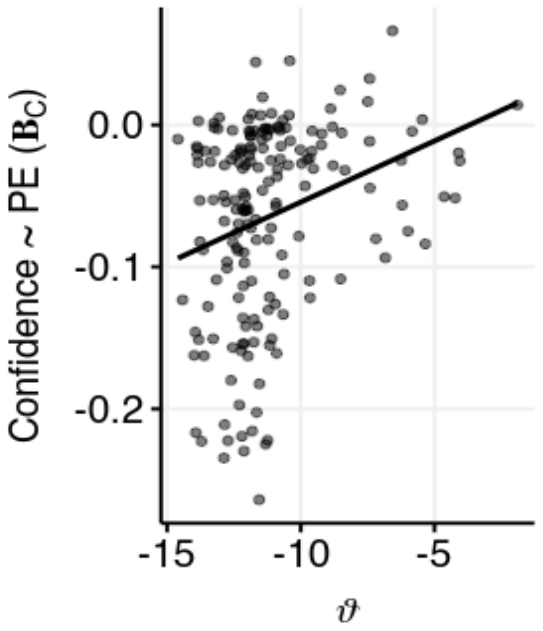
EXPERIMENT 1

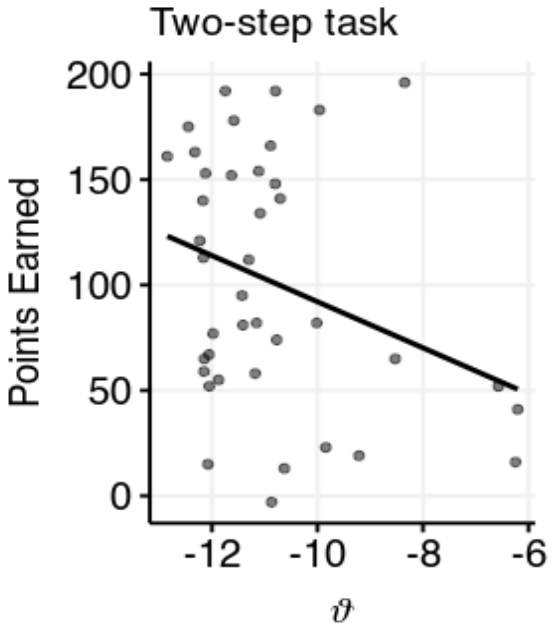


EXPERIMENT 1









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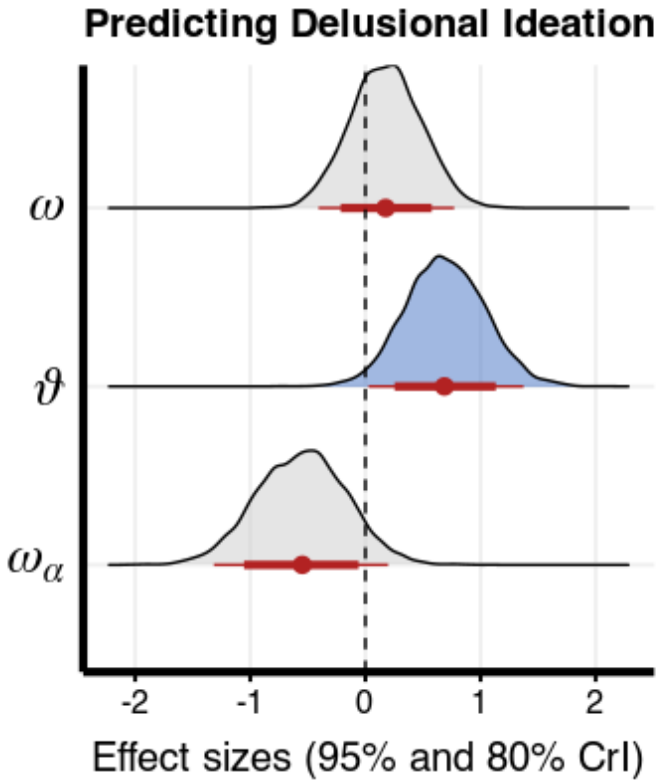
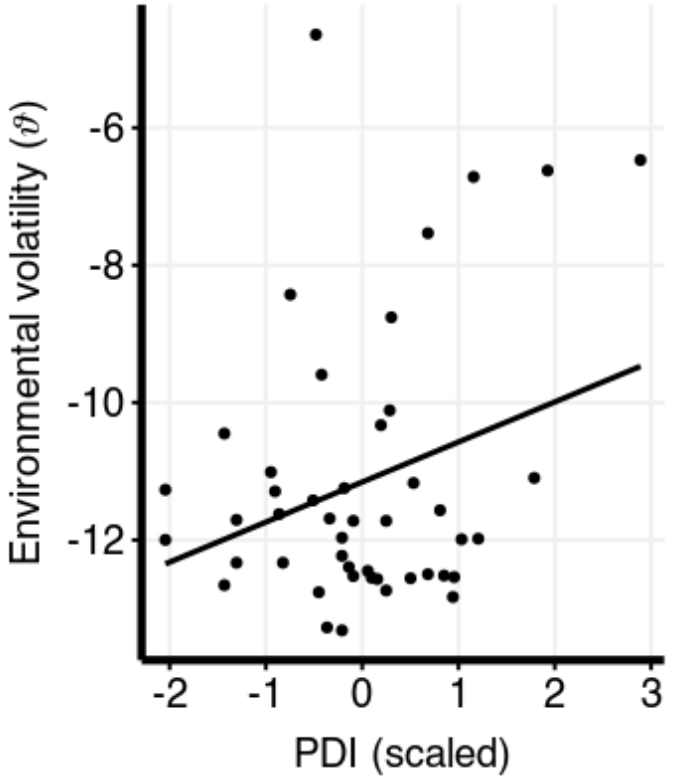
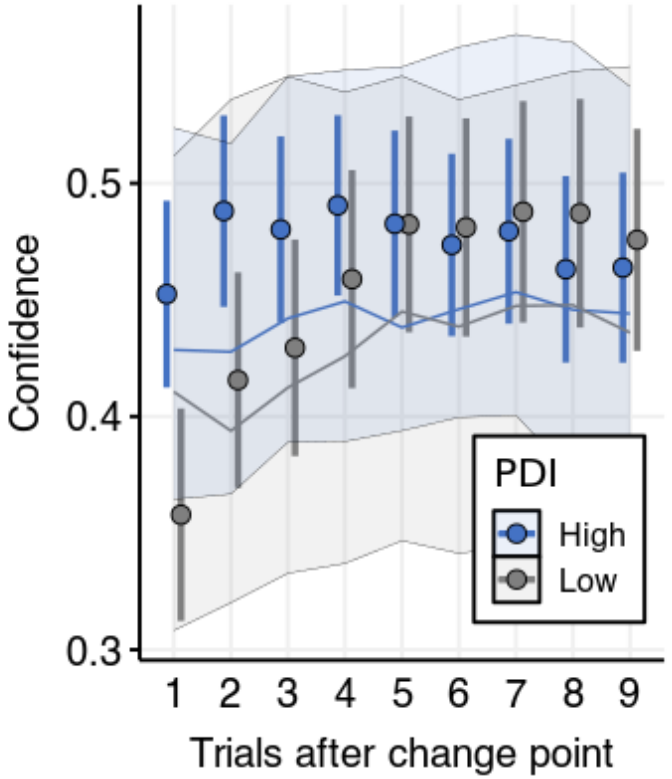






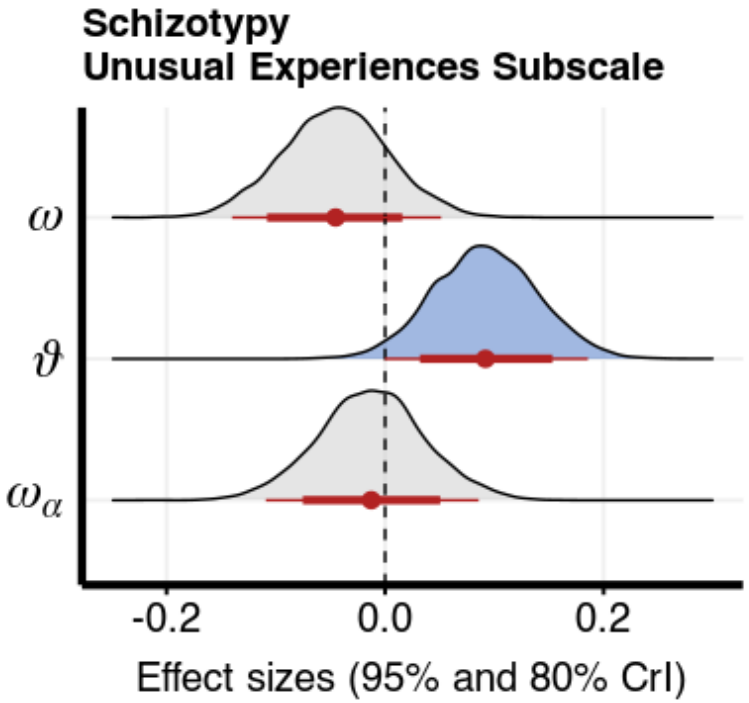
EXPERIMENT 2

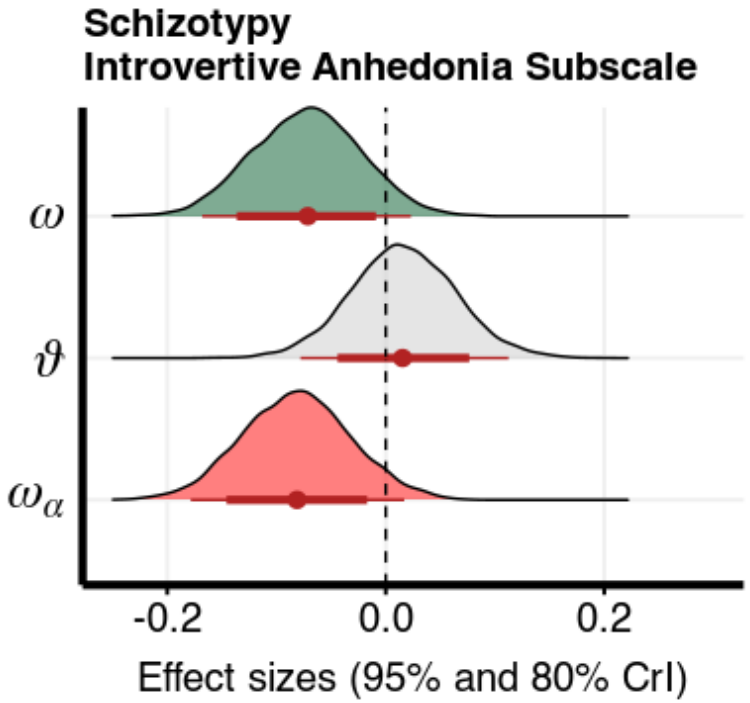
- **Reanalysis** of the data from Seow, T. X. F., & Gillan, C. M. (2020). Transdiagnostic Phenotyping Reveals a Host of Metacognitive Deficits Implicated in Compulsivity. *Scientific Reports*, *10*(1), 2883. https://doi.org/10.1038/s41598-020-59646-4

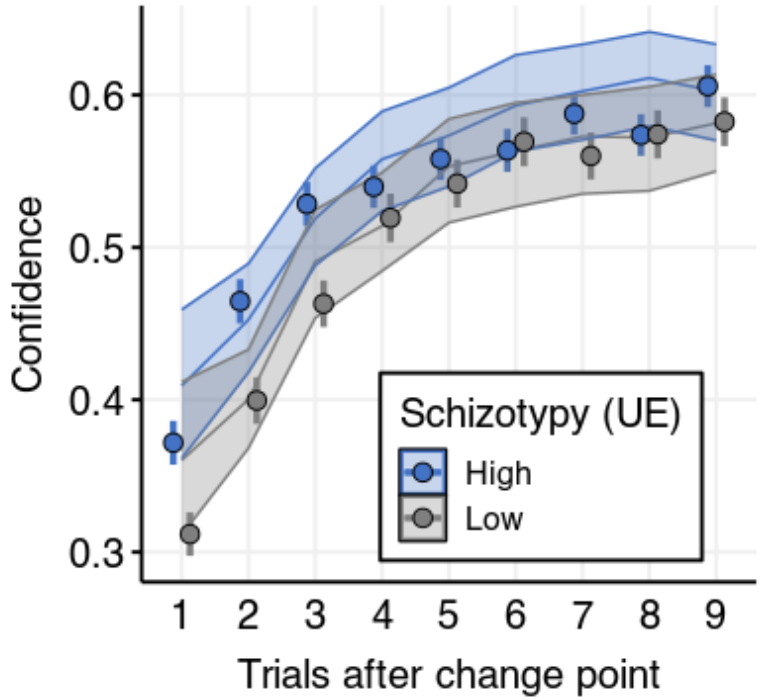
- **Task very similar** to Experiment 1, some details different (e.g., constant standard deviation, but varying volatility, different cover story)

- N = 437 (MTurk), various psychometrics

EXPERIMENT 2







EXPERIMENT 3

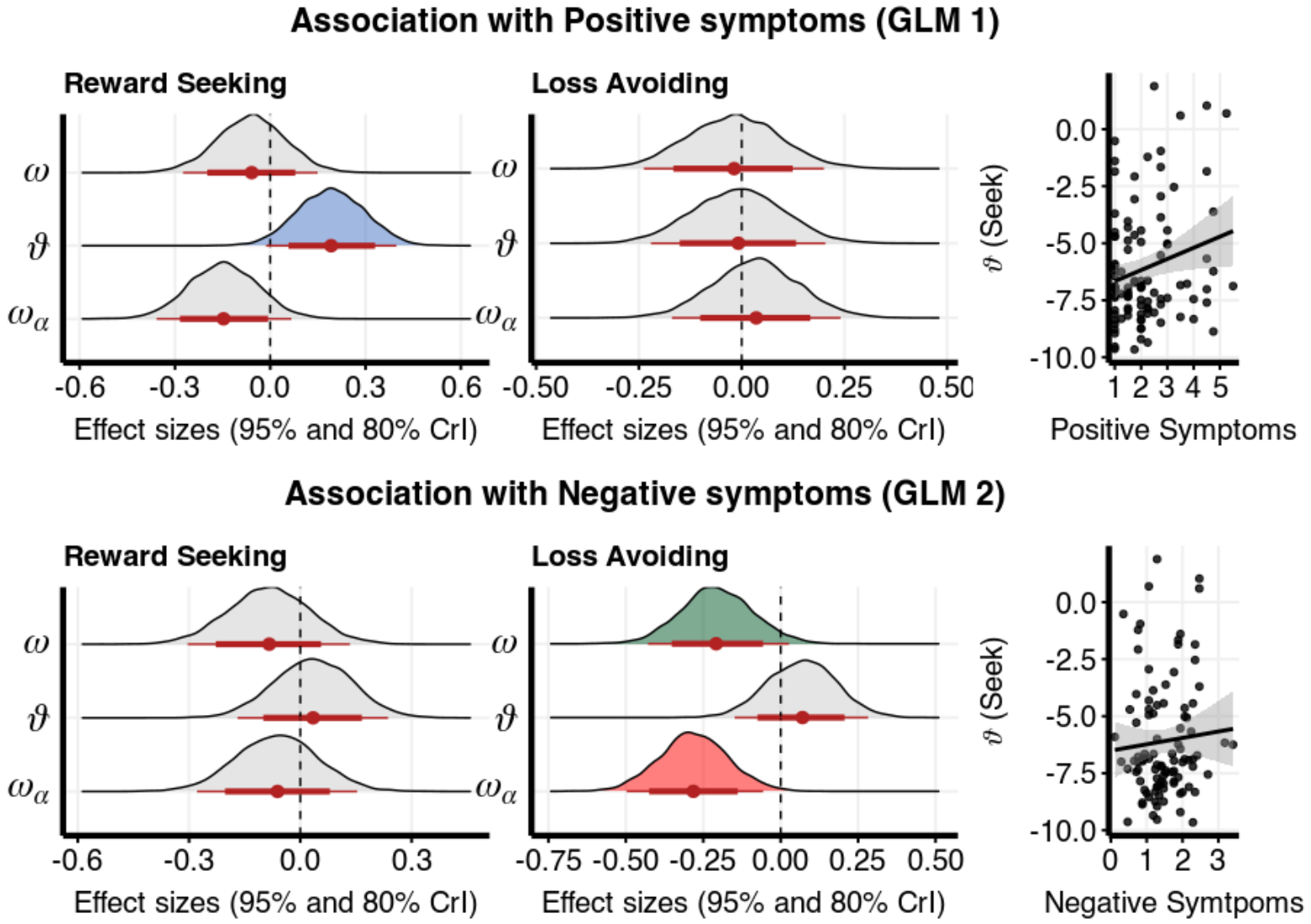
- **Reanalysis** of the data from Nassar, M. R., Waltz, J. A., Albrecht, M. A., Gold, J. M., & Frank, M. J. (2021). All or nothing belief updating in patients with schizophrenia reduces precision and flexibility of beliefs. *Brain*, *144*(3), 1013–1029. https://doi.org/10.1093/brain/awaa453

- Participants with a diagnosis of **schizophrenia or schizoaffective disorder** (N=100), stable outpatients, most of them on antipsychotic medication.

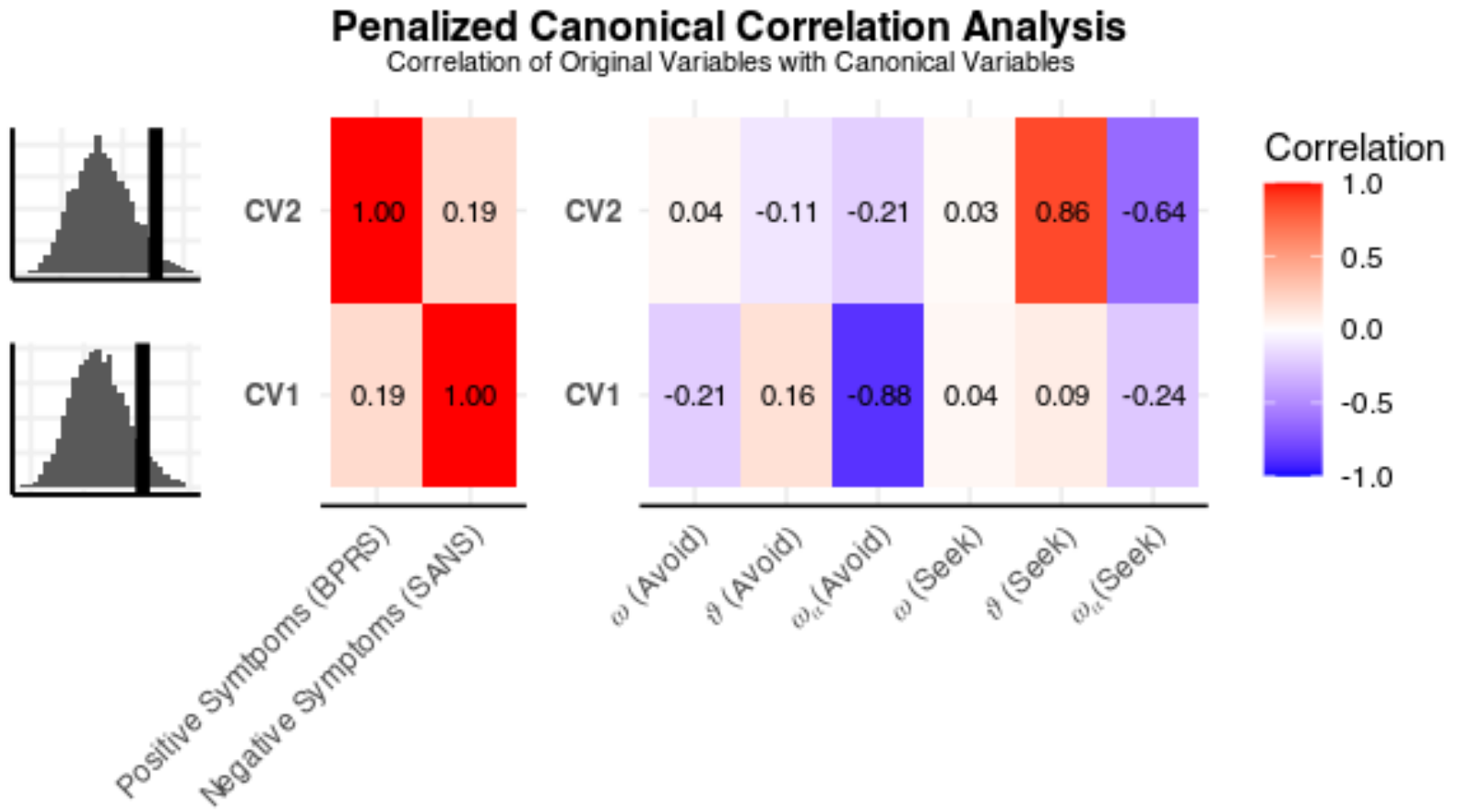
- **Two sessions** of Predictive Inference Task (100 trials each): **appetitive** (win reward) and **aversive** (avoid loss)

- Positive symptoms rated using the **Brief Psychiatric Rating Scale** (BPRS); negative symptoms rated using the **Scale for Assessment of Negative Symptoms** (SANS)

EXPERIMENT 3



EXPERIMENT 3



THE GENERALIZED HGF

- Easily configurable **network of HGF nodes**

- **Two** kinds of coupling:
  - Parent node targets mean value of child node **(value coupling)**
  - Parent node targets variance of child node **(volatility coupling)**

- Value coupling can be **nonlinear** (e.g. ReLU, saturation coupling, etc.)

- Nonlinear coupling can be any function which is twice continuously differentiable almost everywhere

- Removes previous limitations on e.g., Dirichlet-categorical models

THE GENERALIZED HGF

arXiv > cs > arXiv:2305.10937v1

Computer Science > Neural and Evolutionary Computing

[Submitted on 18 May 2023]

The generalized Hierarchical Gaussian Filter

Lilian Aline Weber, Peter Thestrup Waade, Nicolas Legrand, Anna Hedvig Møller, Klaas Enno Stephan, Christoph Mathys

https://arxiv.org/abs/2305.10937v1

Lilian Weber
(U Oxford)

GENERALIZED HGF SOFTWARE: HIERARCHICALGAUSSIANFILTERING.JL

- A Julia package (https://julialang.org) for the easy construction of arbitrarily large HGF models whose **nodes** are connected via either **mean** or **variance coupling**
- Sister (or rather: mother) package **ActionModels.jl** for constructing response models
- Both are part of **the ComputationalPsychiatry GitHub organization**
- Parameter estimation via **Turing.jl** (https://turing.ml), a powerful general-purpose sampler which allows for **hierarchical parameter estimation**
- The most **common HGF models** (3-level binary, 2-level continuous, JGET, etc.) are **pre-implemented** for convenience
- Most of the hard work done by **Peter Thestrup Waade** and **Lilian Weber**

Peter Thestrup Waade

Lilian Weber
(U Oxford)

https://github.com/ComputationalPsychiatry/HierarchicalGaussianFiltering.jl

GENERALIZED HGF SOFTWARE: PYHGF

- Similar in functionality to HierarchicalGaussianFiltering.jl, but written in **Python**
- Package for the easy construction of arbitrarily large HGF models whose **nodes** are connected via either **mean** or **variance coupling**
- The most **common HGF models** (3-level binary, 2-level continuous, JGET, etc.) are **pre-implemented** for convenience
- Most of the hard work done by **Nicolas Legrand** and **Lilian Weber**

Nicolas Legrand

Lilian Weber
(U Oxford)

https://pypi.org/project/pyhgf/

THE WHAT PATH: A TEASER

Contents lists available at ScienceDirect

Schizophrenia Research

journal homepage: www.elsevier.com/locate/schres

A generative framework for the study of delusions

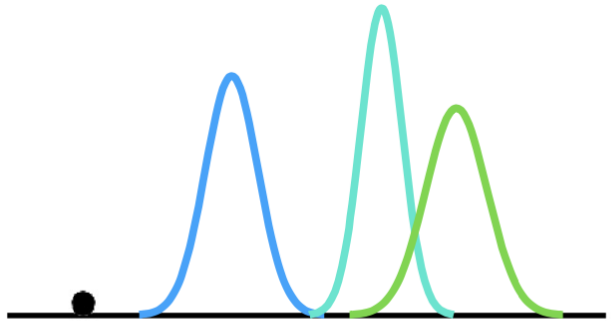
Tore Erdmann [a], Christoph Mathys [b,c,*]

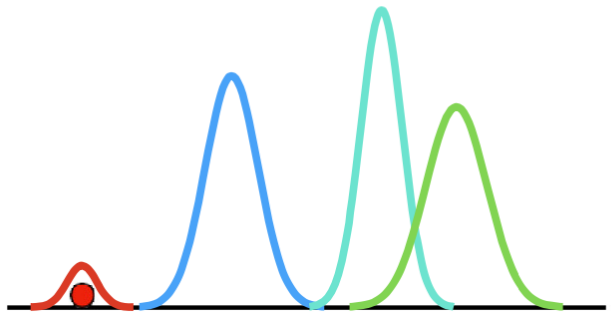
[a] Scuola Internazionale Superiore di Studi Avanzati (SISSA), Via Bonomea 265, 34136 Trieste, Italy
[b] Interacting Minds Centre, Aarhus University, Jens Chr. Skous Vej 4, 8000 Aarhus C, Denmark
[c] Translational Neuromodeling Unit (TNU), Institute for Biomedical Engineering, University of Zurich and ETH Zurich, Wilfriedstrasse 6, 8032 Zurich, Switzerland

Tore Erdmann

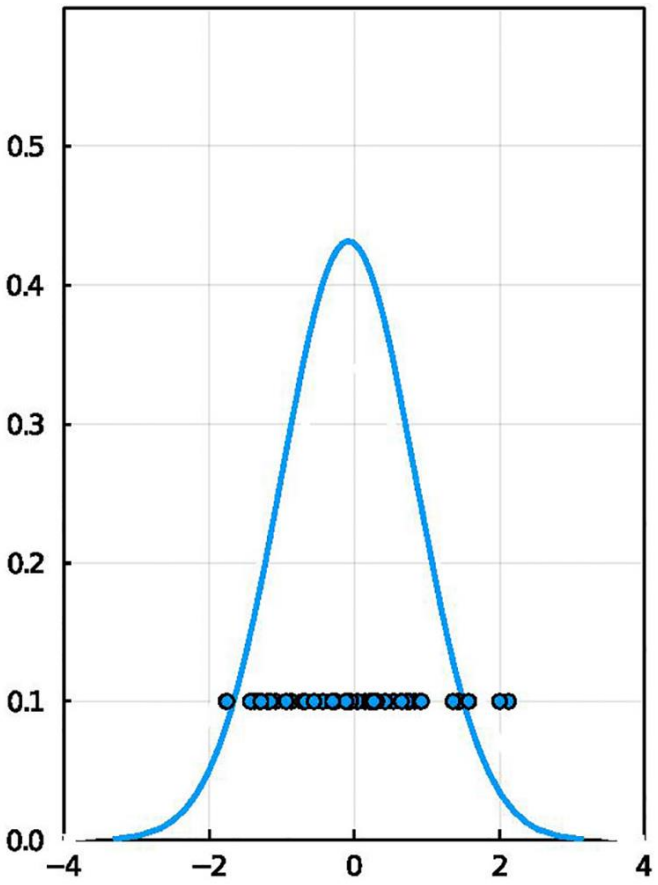
https://doi.org/10.1016/j.schres.2020.11.048

EXPLAIN AWAY OR INTEGRATE?

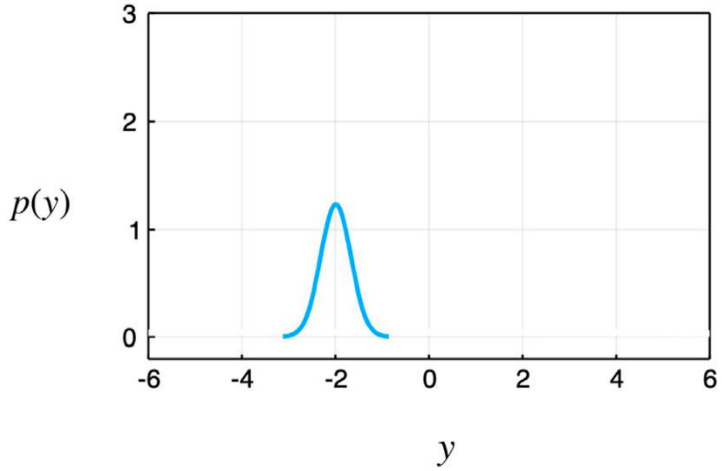




A SINGLE CAUSE OR SEVERAL?

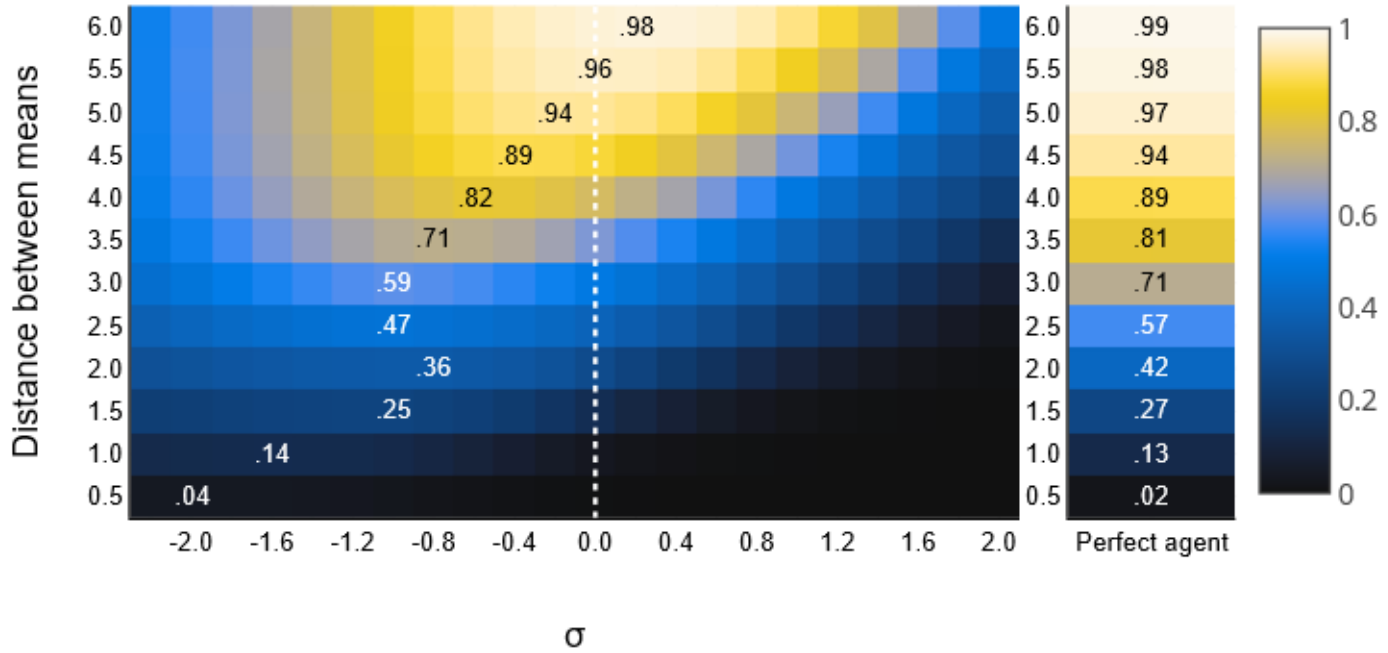


PROTECTING A CENTRAL BELIEF



THE WHAT PATH: A TEASER

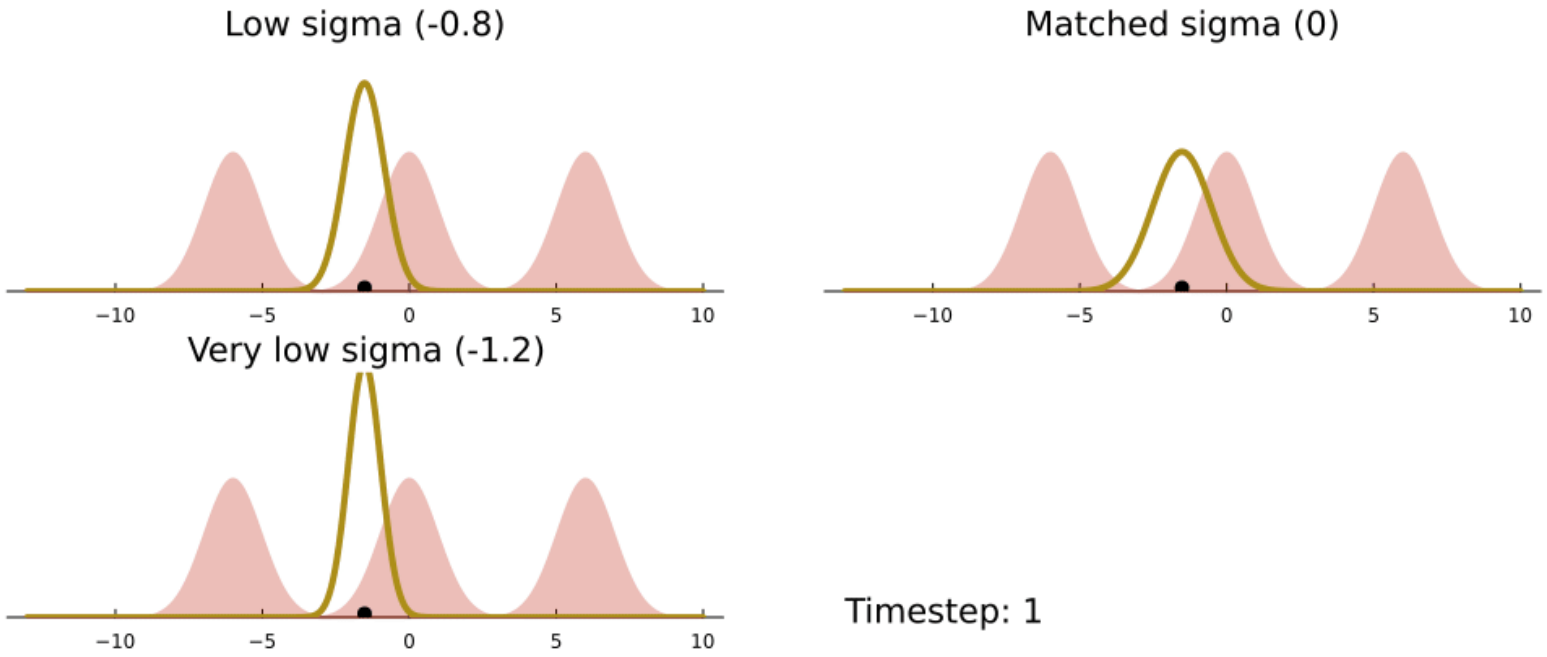
- Heatmap of the mean-adjusted Rand index across 10k simulations
- Perfect agent (knows parameters of simulation) for comparison
- Sigma is difference in **precision** between environment and agent's expectation
- Distance between means operationalizes **ambiguity** of environment
- **Key observation: in ambiguous environments, causal attribution works better with higher expected precision**



Christoffer Lundbak Olesen

THE WHAT PATH: A TEASER

- Example with **very low ambiguity** (6 standard deviations between means)
- Because of the inherent randomness of observations, **a 'delusion' arises** on the far left in all models
- The matched-sigma agent deals with this gracefully, and the maladaptive belief disappears quickly
- **In lower-sigma agents, the maladaptive belief is much more persistent**



Thanks

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