Metacognition

Steve Fleming & Olivia Faull

metacoglab.org

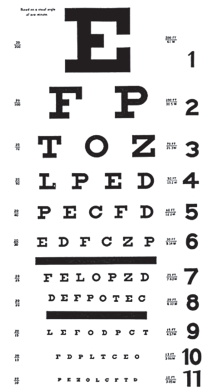
Examples of metacognition

Meta-memory

Do I know this topic?

Meta-perception

Am I seeing things clearly?

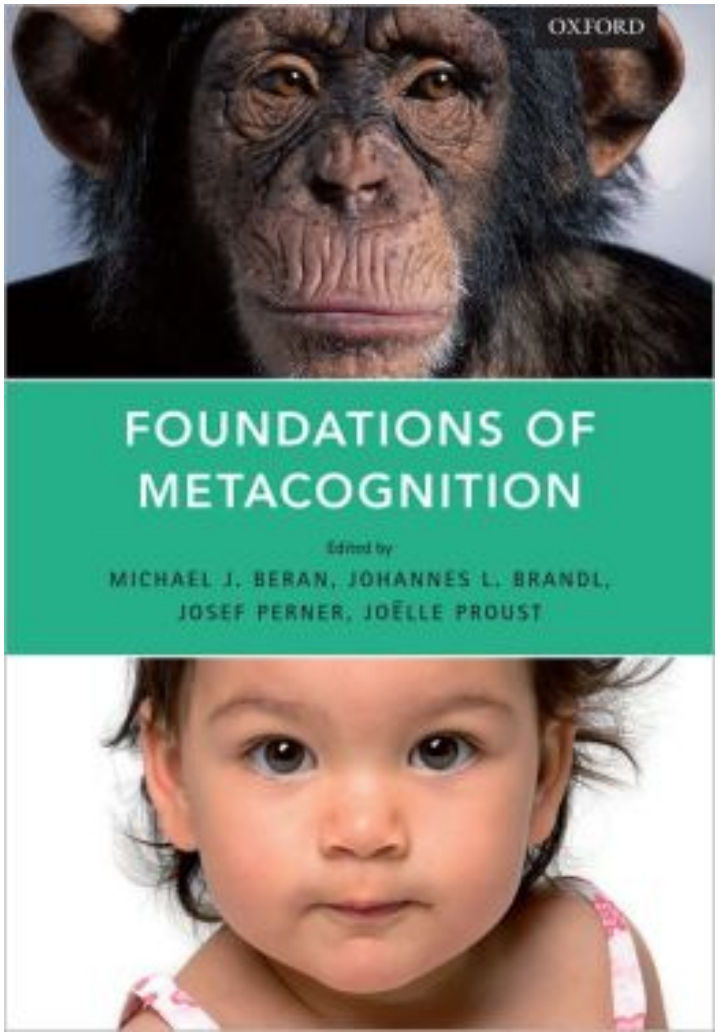


Why study metacognition?

- Inaccurate metacognitive knowledge of cognitive and physical impairments is common in **psychiatric** and **neurological** disorders and **healthy aging**

Insight = the capacity for accurate metacognition

A primer on measuring metacognition



BEHAVIOUR ⟷ METACOGNITIVE JUDGMENT

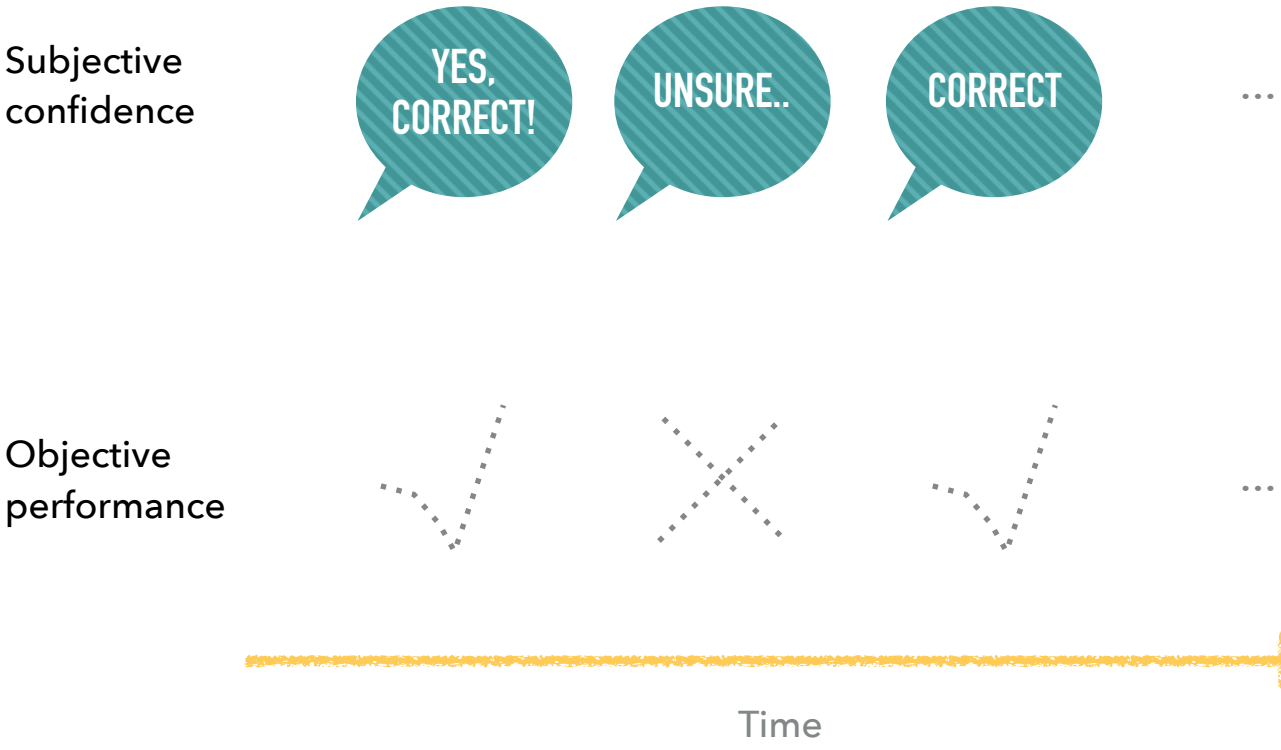
E.g. answer to exam question; response in a psychophysics experiment

E.g. **confidence** in getting the answer right

Quantifying metacognition

Not possible to assess metacognition from a single judgment

Need multiple judgments over time, examine **statistical association** between behaviour and metacognitive judgments

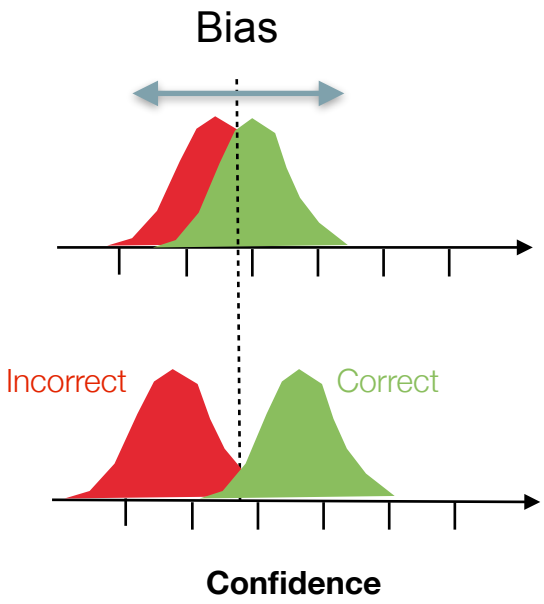


Metacognitive bias and sensitivity

Confidence in behaviour

Metacognitive bias

Metacognitive sensitivity



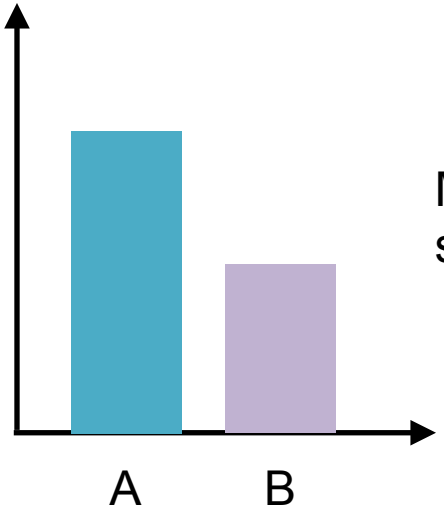
Other terminology in the literature:

Bias: calibration, confidence level, self-perceived ability, self-belief
Sensitivity: discrimination, resolution, metacognitive awareness, insight

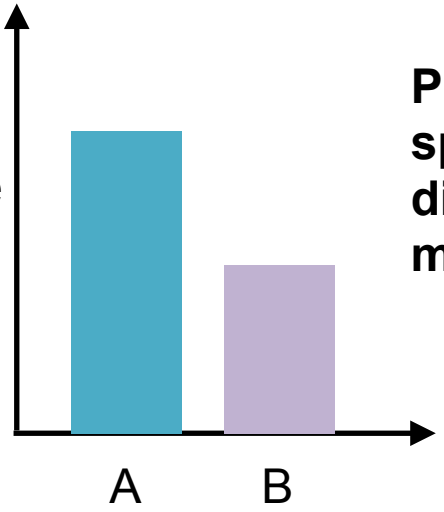
Fleming & Lau, 2014 *Frontiers*

Importance of controlling for performance

First-order performance

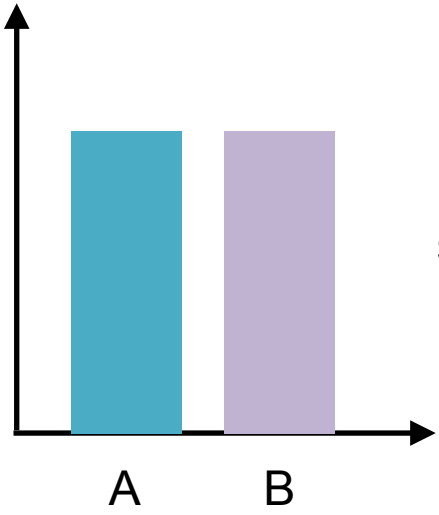


Metacognitive sensitivity

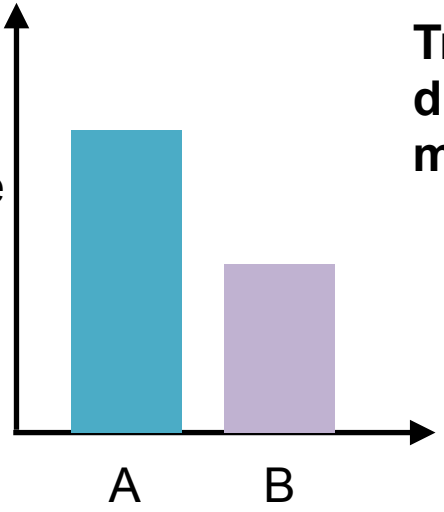


Possibly spurious difference in metacognition

First-order performance



Metacognitive sensitivity



True difference in metacognition

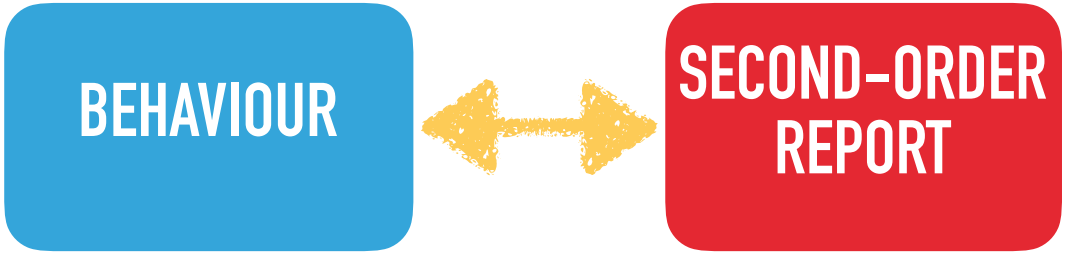
How to measure metacognitive sensitivity?

Ideal measure: should identify differences in metacognitive sensitivity, but be unaffected by metacognitive bias (overall confidence) or task performance

3 approaches:

1. Correlation approaches
2. Area under type 2 ROC (AUROC2)
3. Meta-*d'*

Quantifying metacognition (1) - correlation approaches



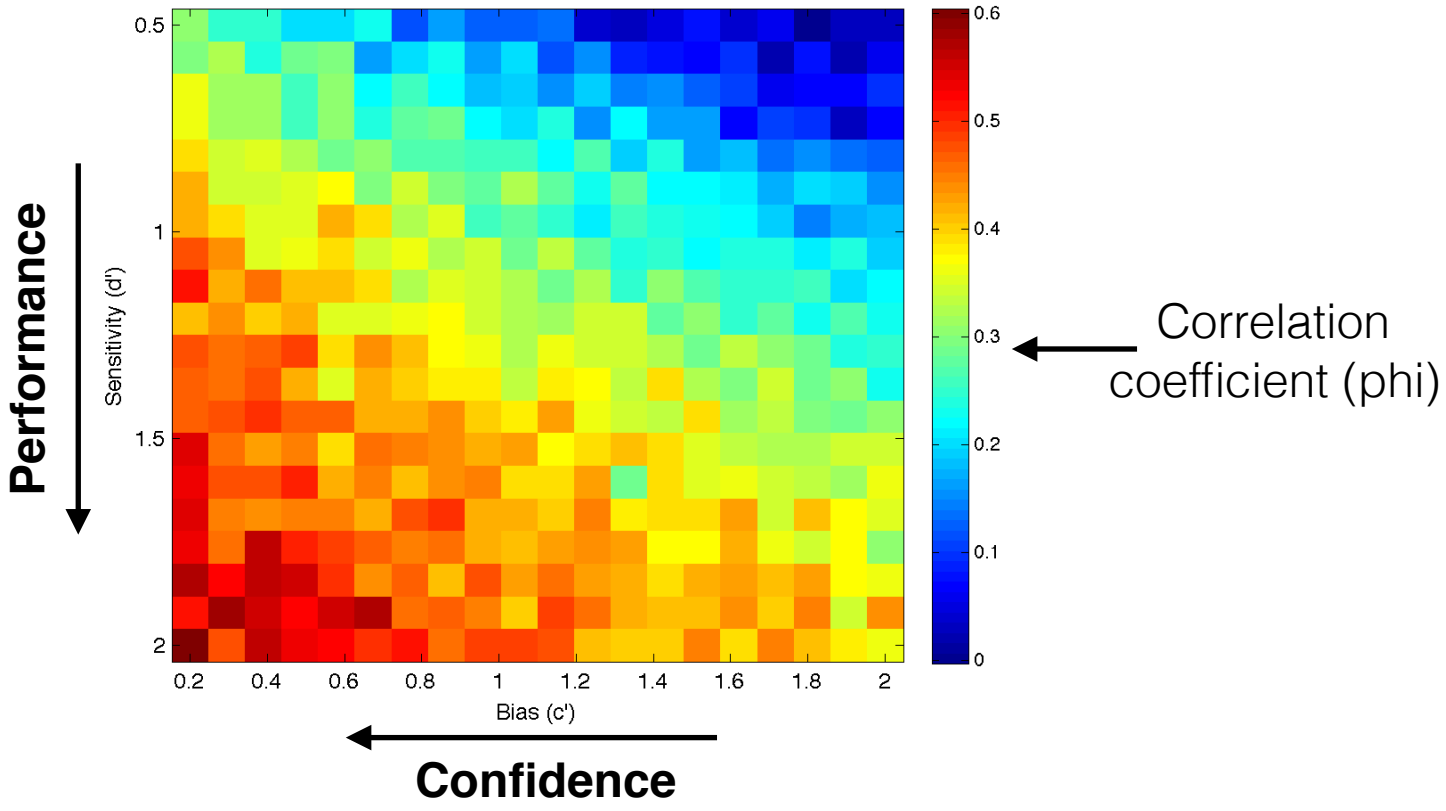
	High confidence	Low confidence
Correct	A	B
Incorrect	C	D

Decision = [1 0 0 1 1 0 1 0…]

Phi = corr(decision, confidence)

Confidence = [0 0 0 1 1 1 1 0…]

Problems with correlation approaches



Simple measures of association (gamma, phi) are not bias free, and confounded by performance (see Mason & Rotello, 2009; Fleming & Lau, 2014)

Should I use correlation measures?

- **Pros:**
  - Very simple, can be used with pretty much any design (just need to define trials as correct vs. incorrect)
  - Useful if one wants to establish presence (vs. absence) of metacognition

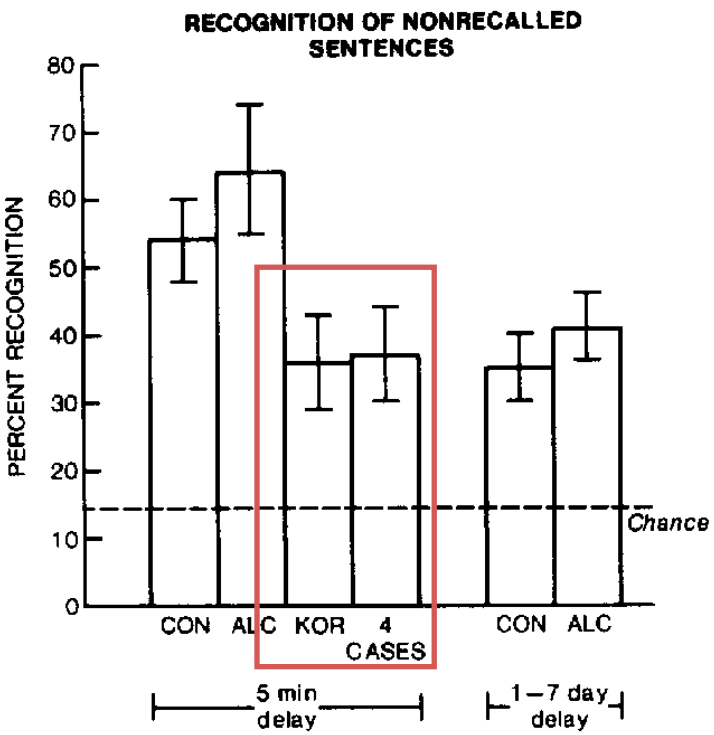
- **Cons:**
  - Confounded by performance
  - Confounded by confidence bias
  - Need to be careful in matching these influences if comparing phi/gamma between conditions

Journal of Experimental Psychology:
Learning, Memory, and Cognition
1986, Vol. 12, No. 3, 452-460

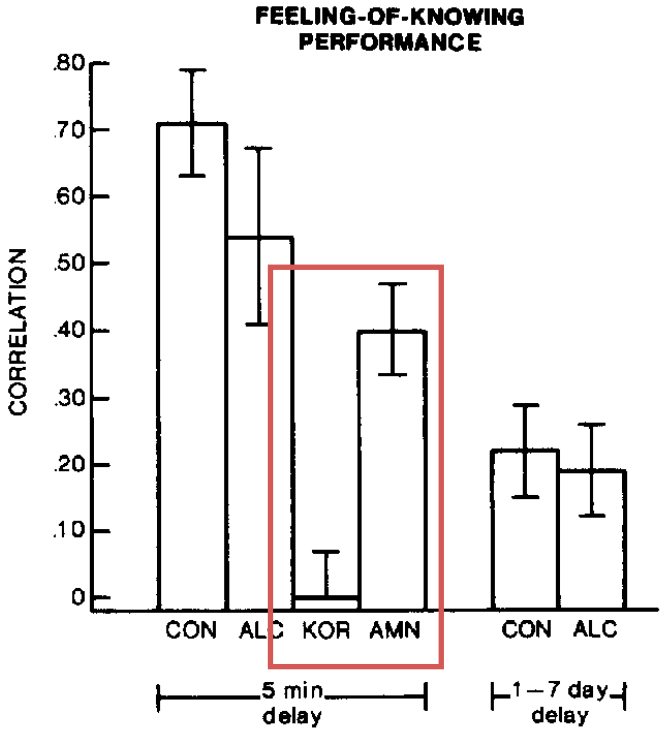
0278-7393/86/$00.75

Memory and Metamemory: A Study of the Feeling-of-Knowing Phenomenon in Amnesic Patients

Arthur P. Shimamura and Larry R. Squire
Veterans Administration Medical Center, San Diego and Department of Psychiatry, University of California, San Diego, School of Medicine



Task performance



Metacognitive sensitivity (performance-confidence correlation)

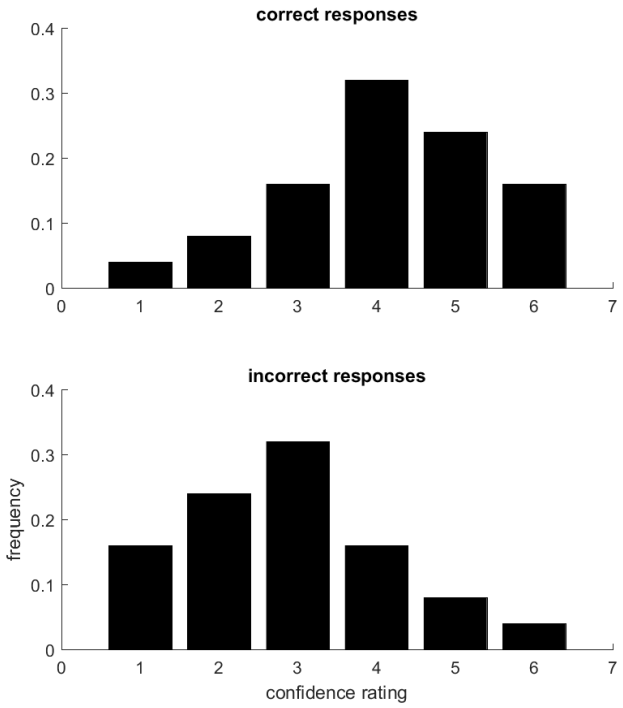
Quantifying metacognition (2) - AUROC2

Two Types of ROC Curves and Definitions of Parameters*

F. R. Clarke, T. G. Birdsall, and W. P. Tanner, Jr.
Electronic Defense Group, University of Michigan, Ann Arbor, Michigan
(Received February 26, 1959)

Type 2 receiver operating characteristic (ROC) curves are a compact representation of metacognitive sensitivity

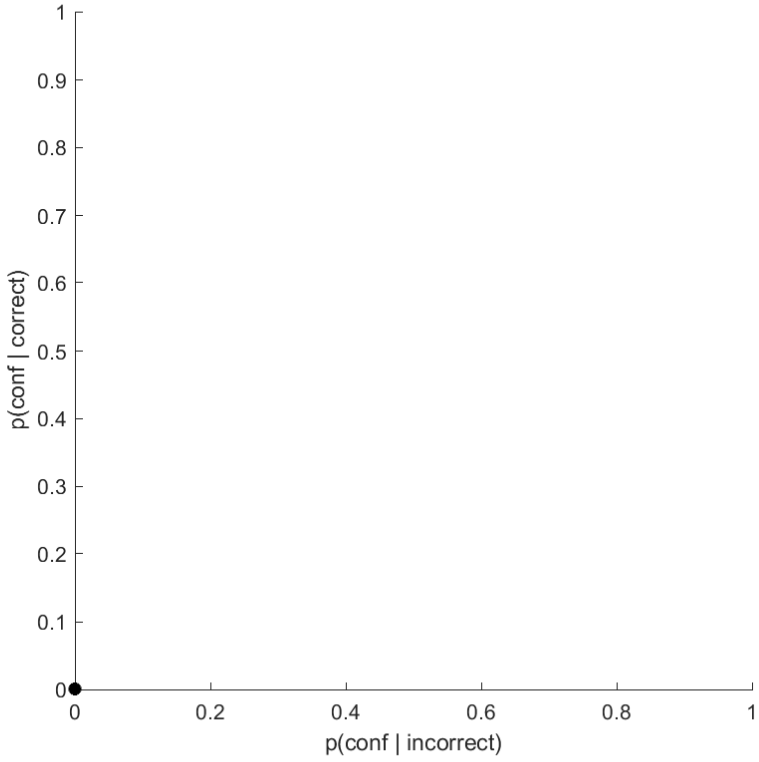
In general, the more distinct the confidence distributions for correct and for incorrect responses are, the more insight one has into the quality of individual decisions



with thanks to Matan Mazor

Clarke, Birdsall & Tanner (1959) *J Acoust Soc Am*; Galvin et al. (2003) *Psych Bull Rev*

Type 2 ROCs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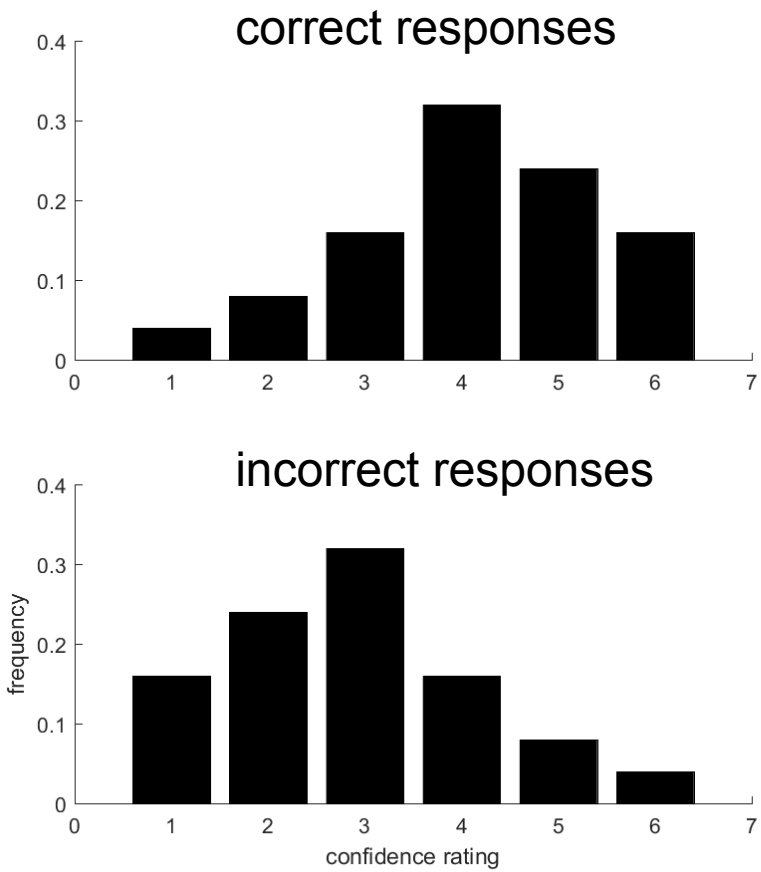
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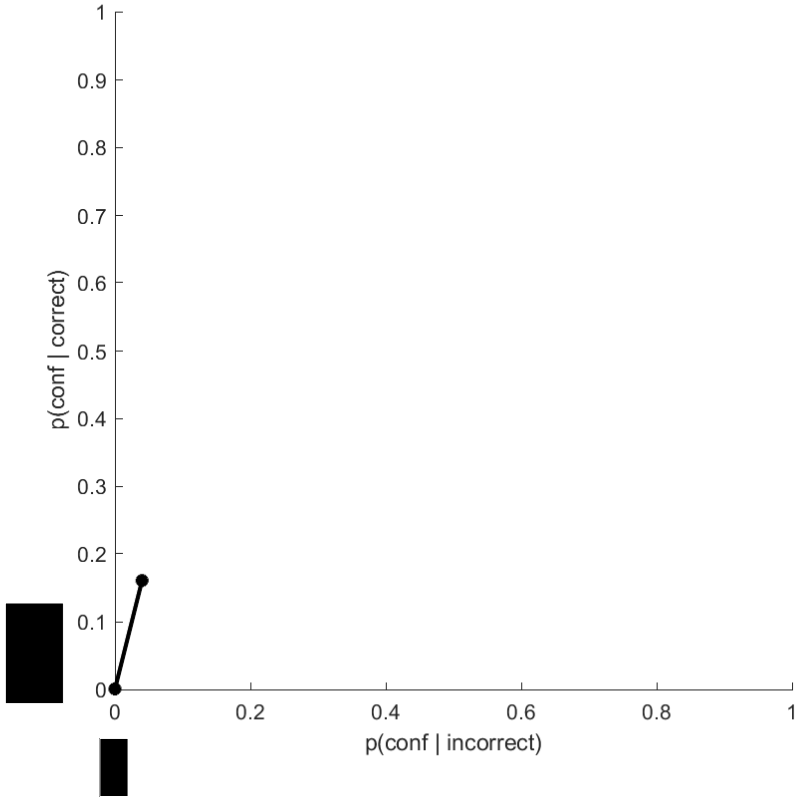
Type 2 ROCs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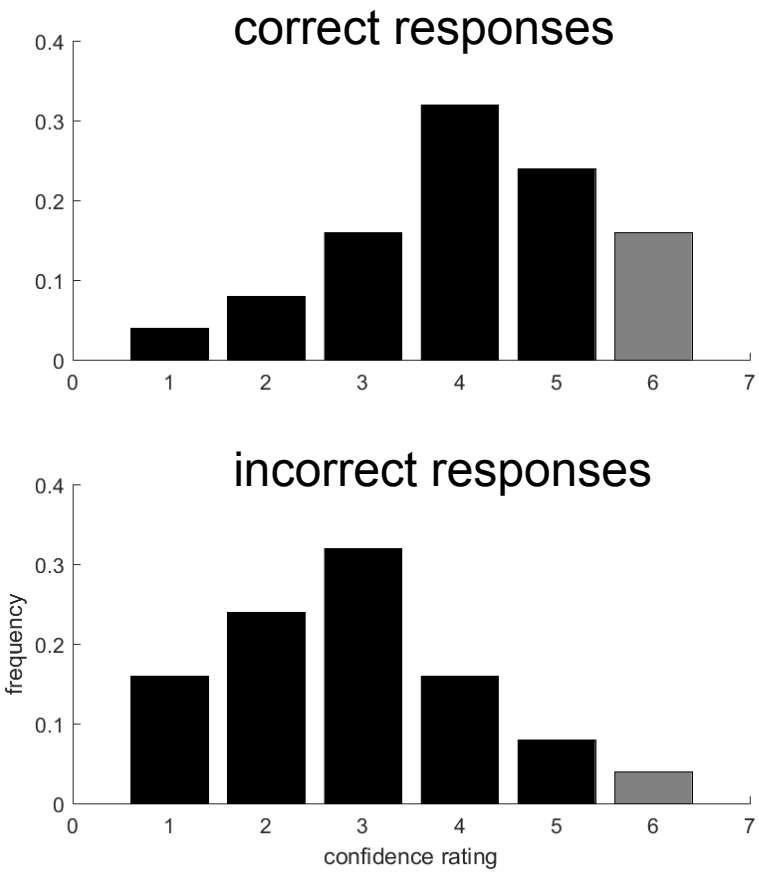
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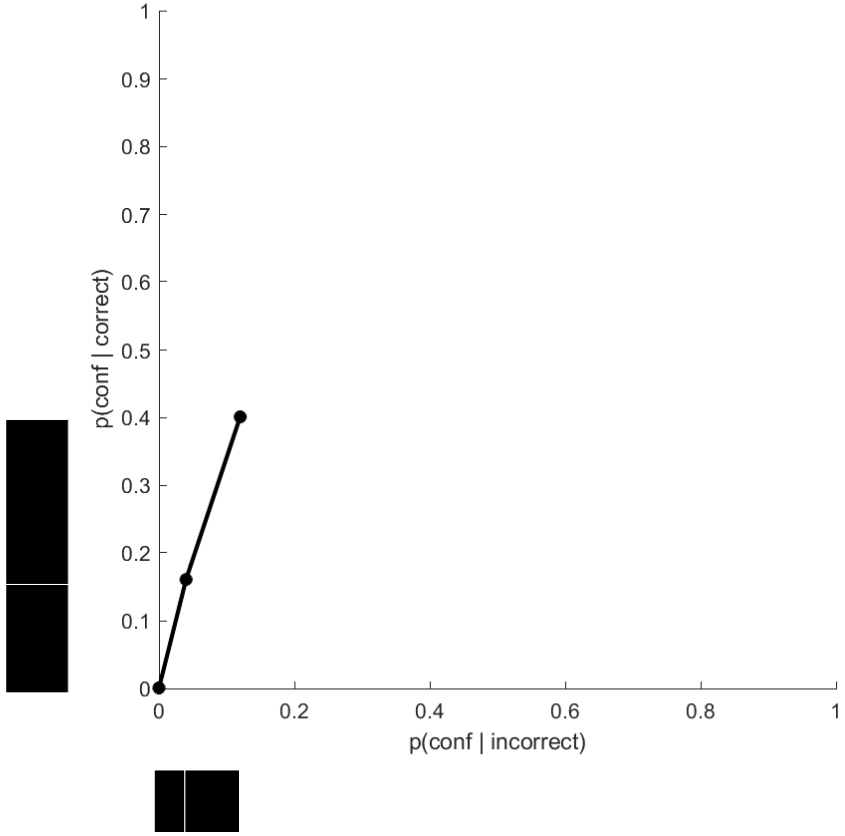
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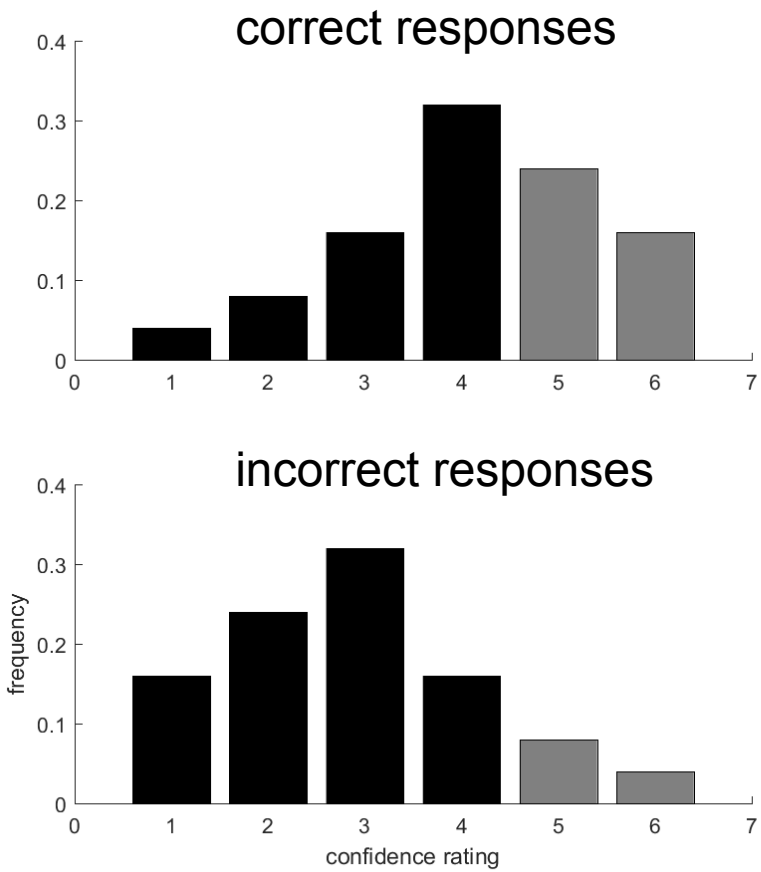
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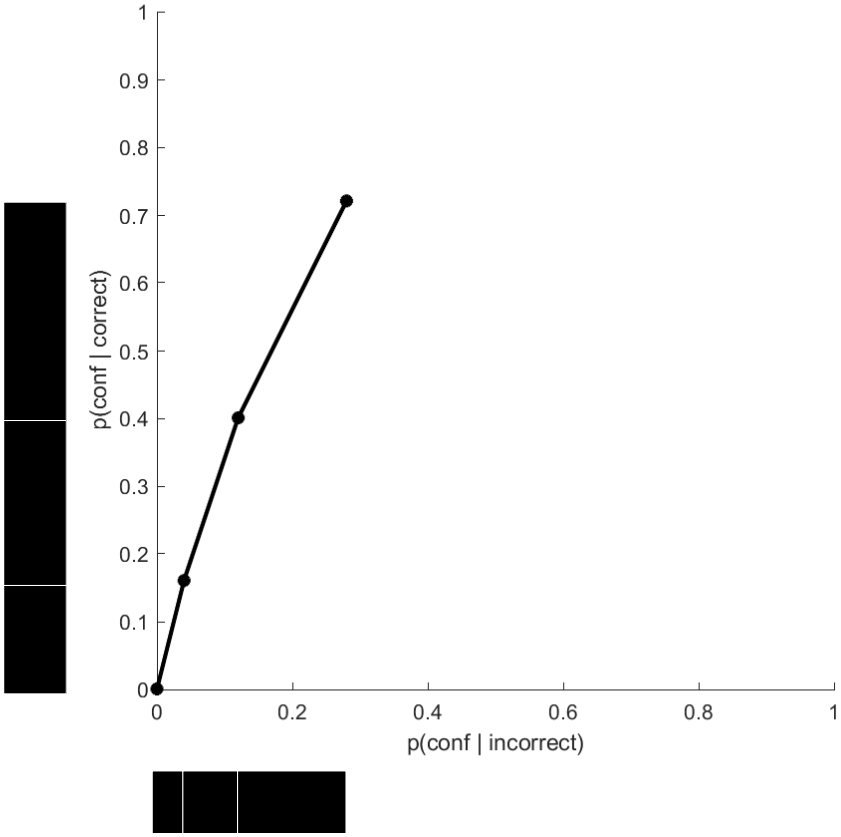
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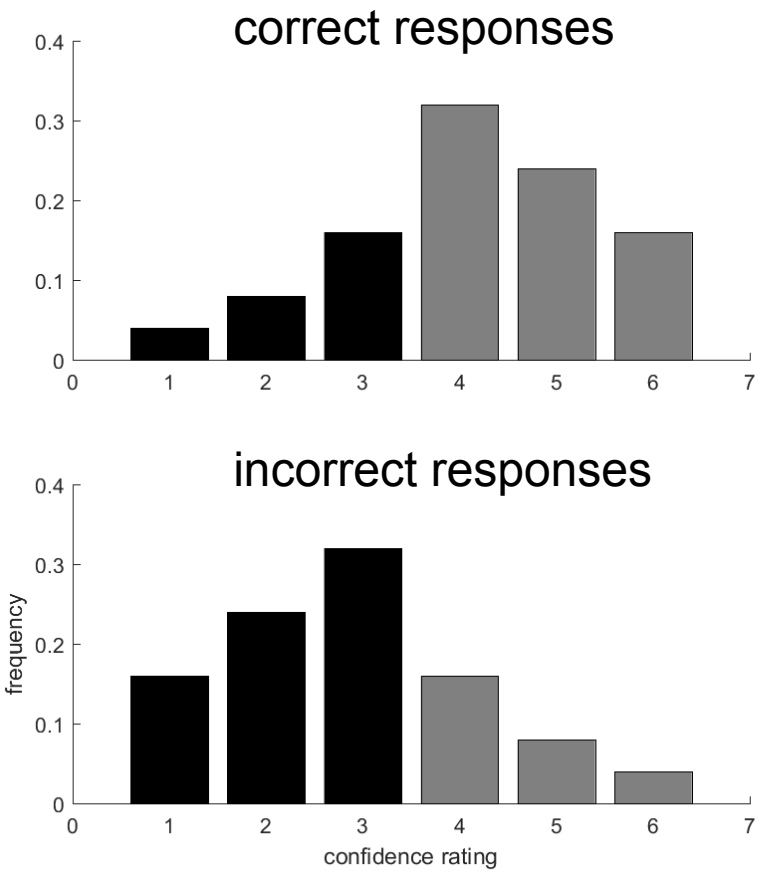
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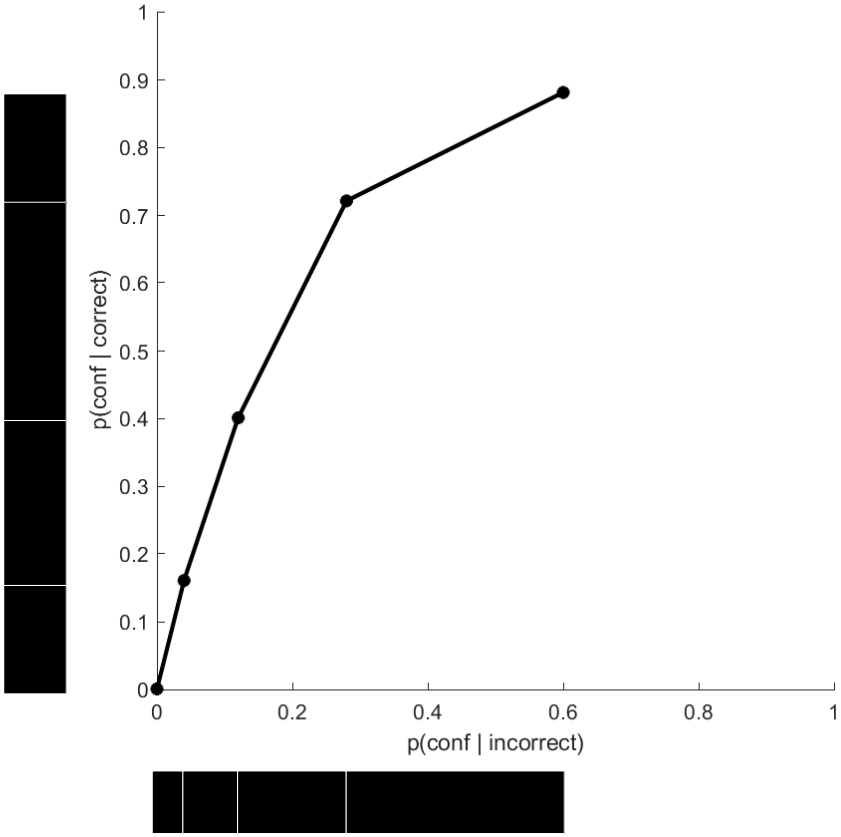
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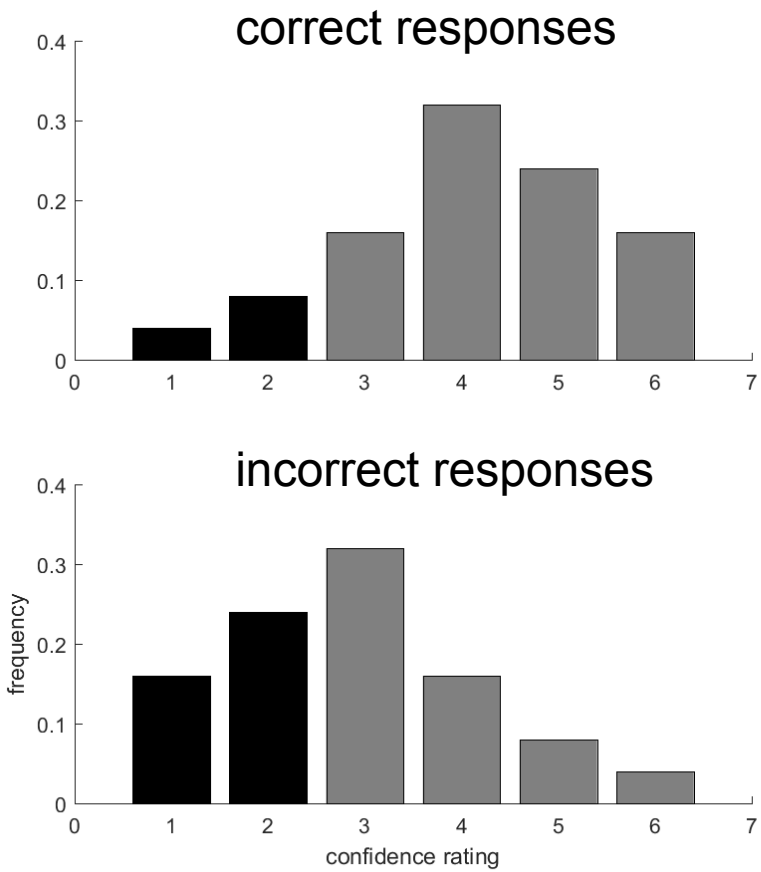
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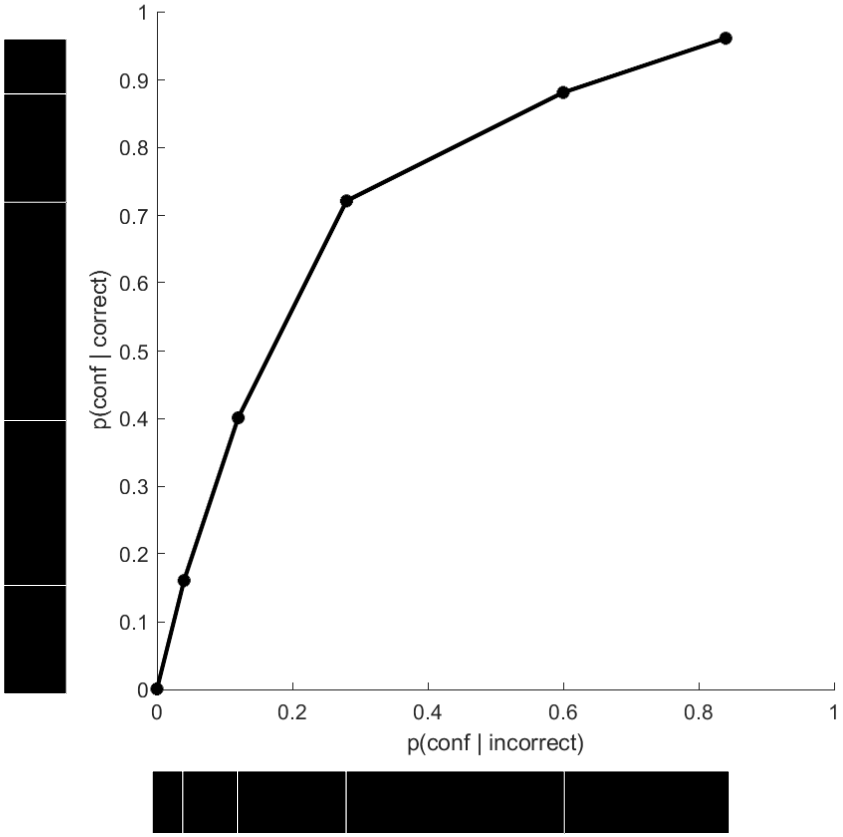
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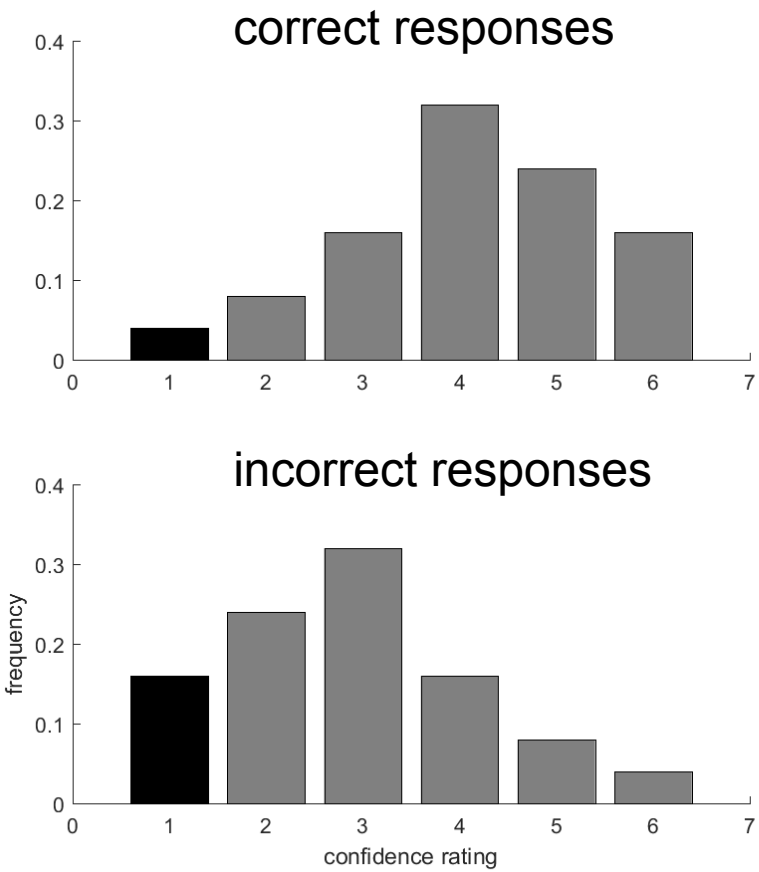
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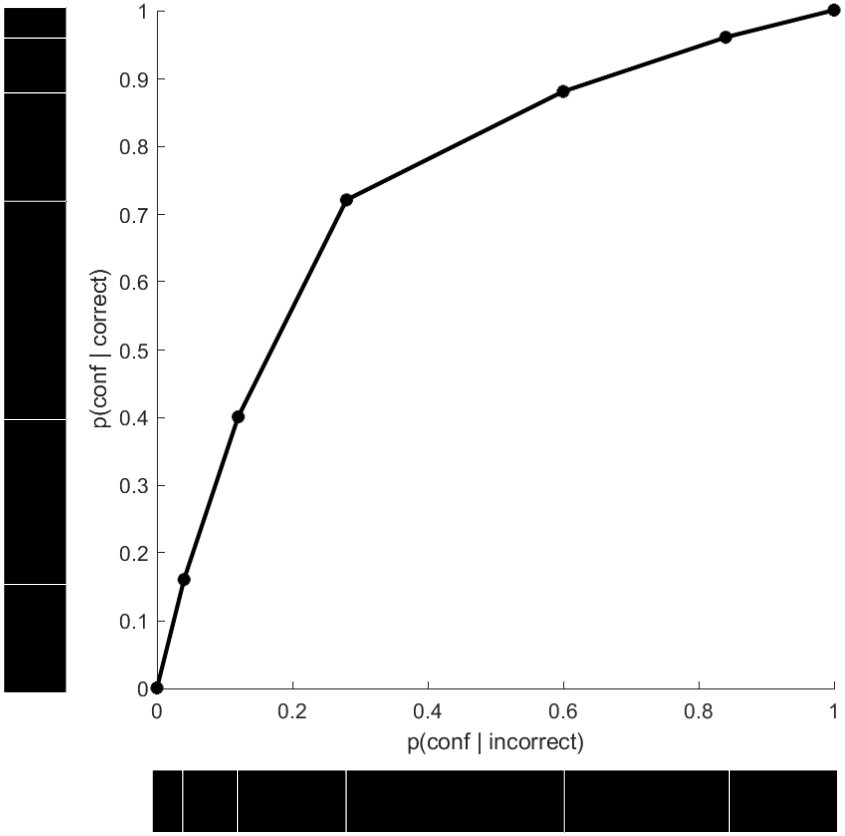
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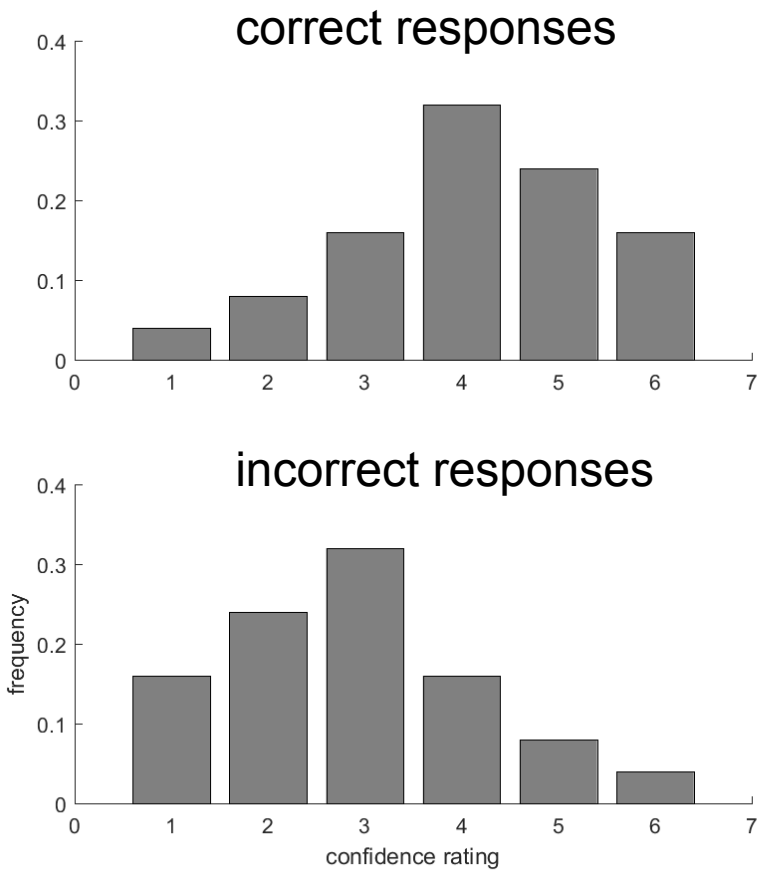
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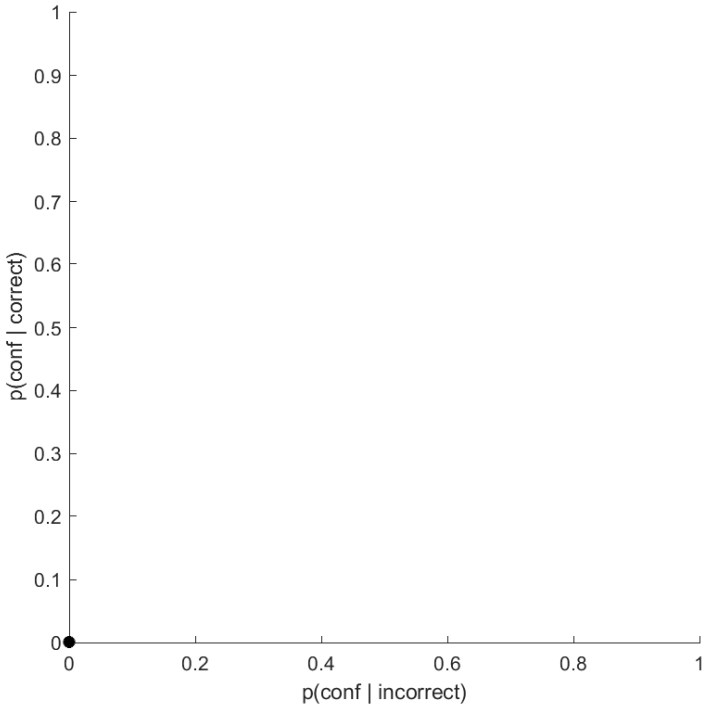

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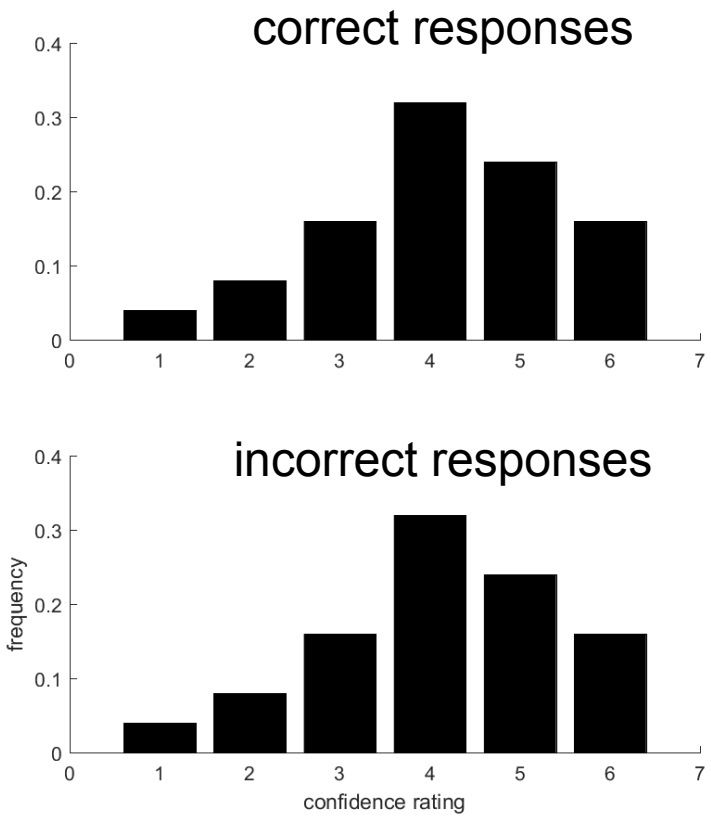

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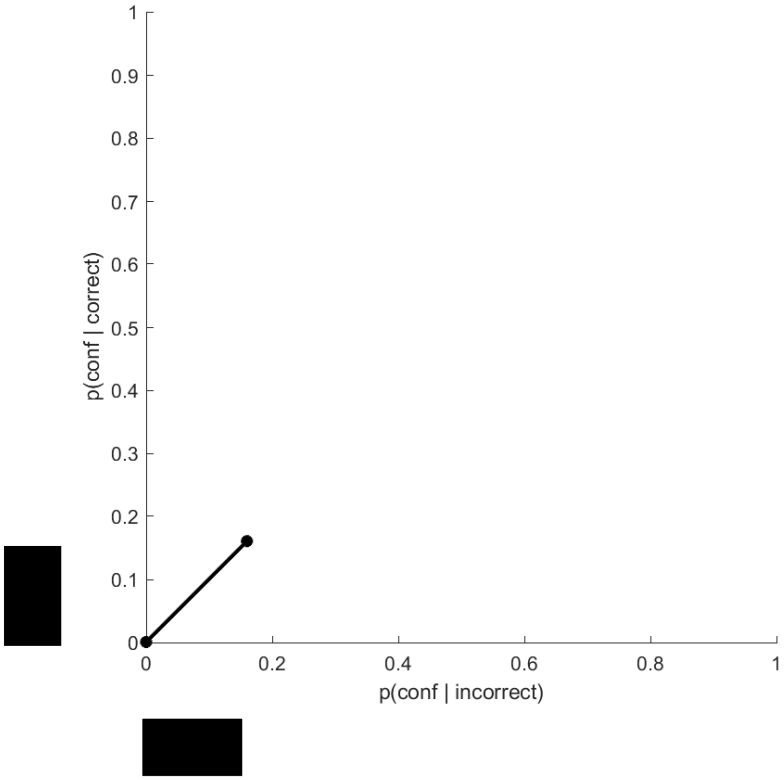

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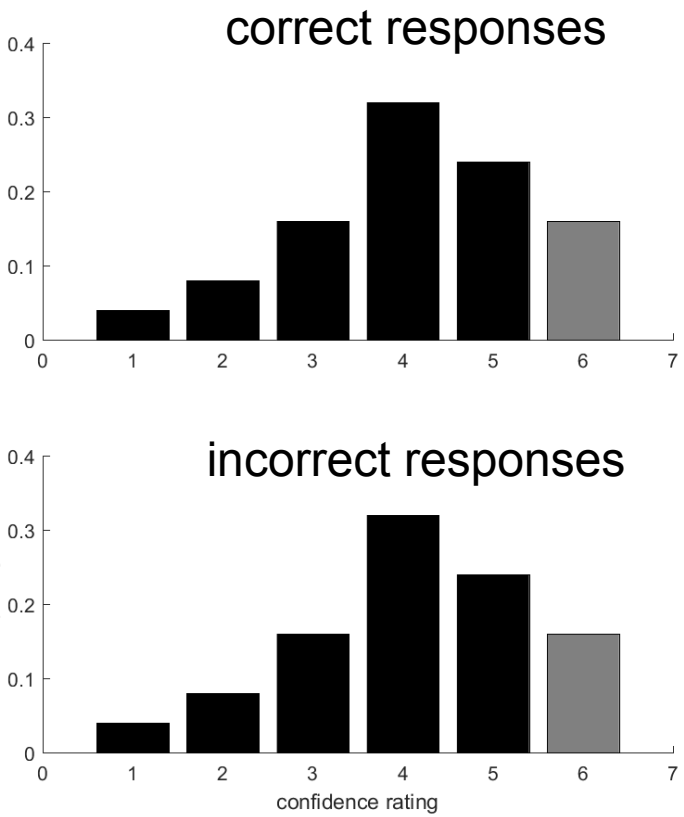

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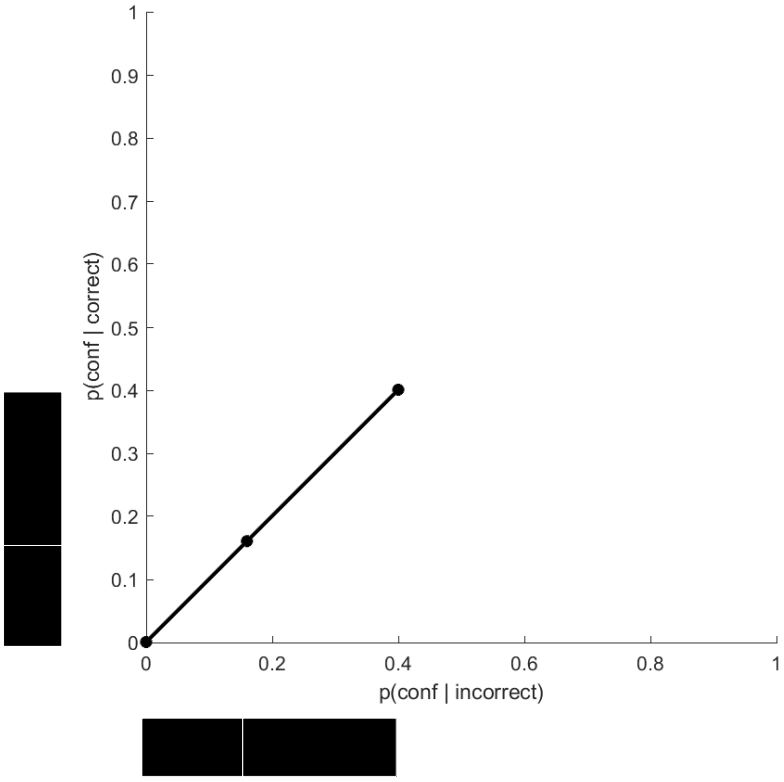

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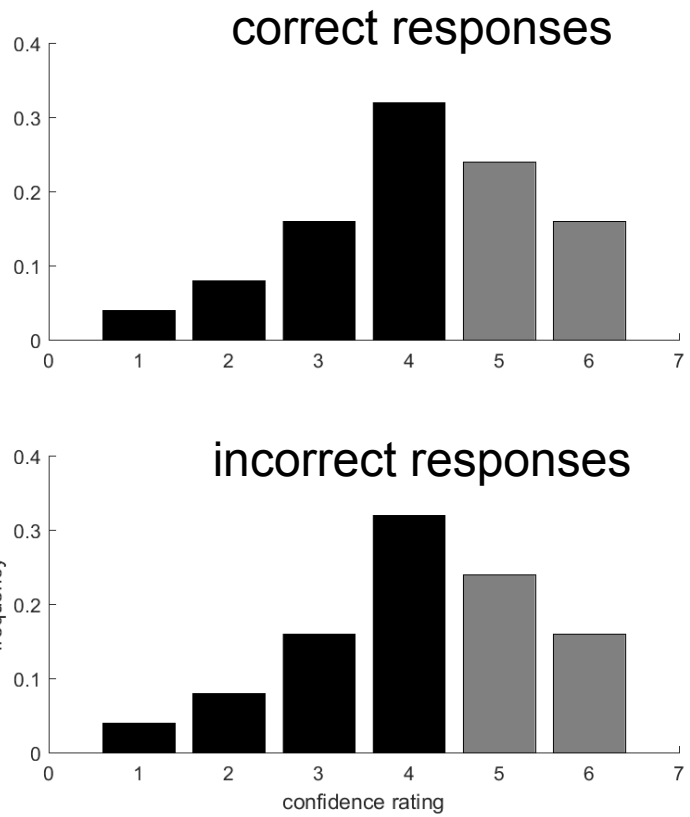

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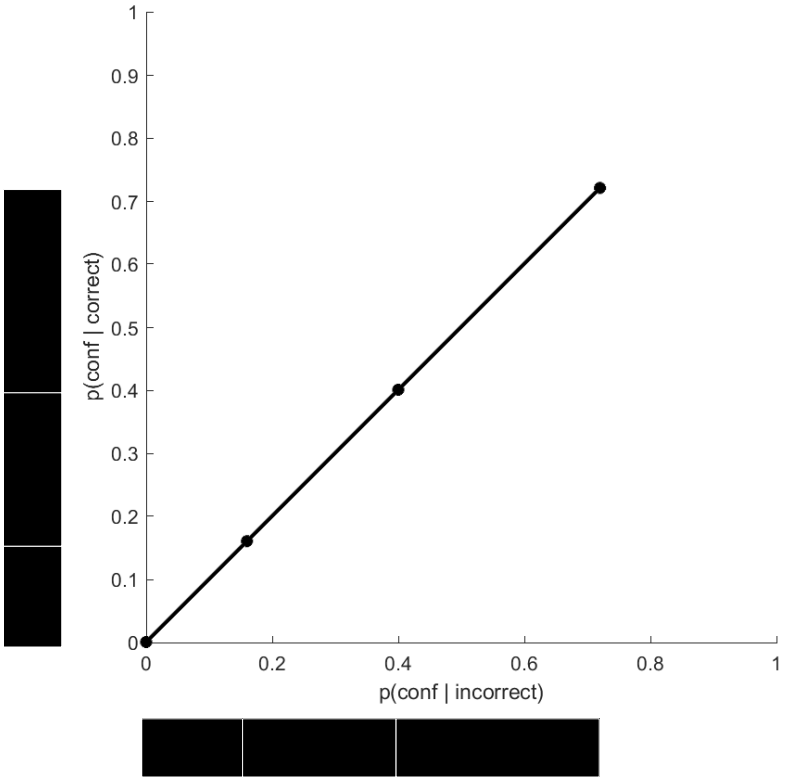

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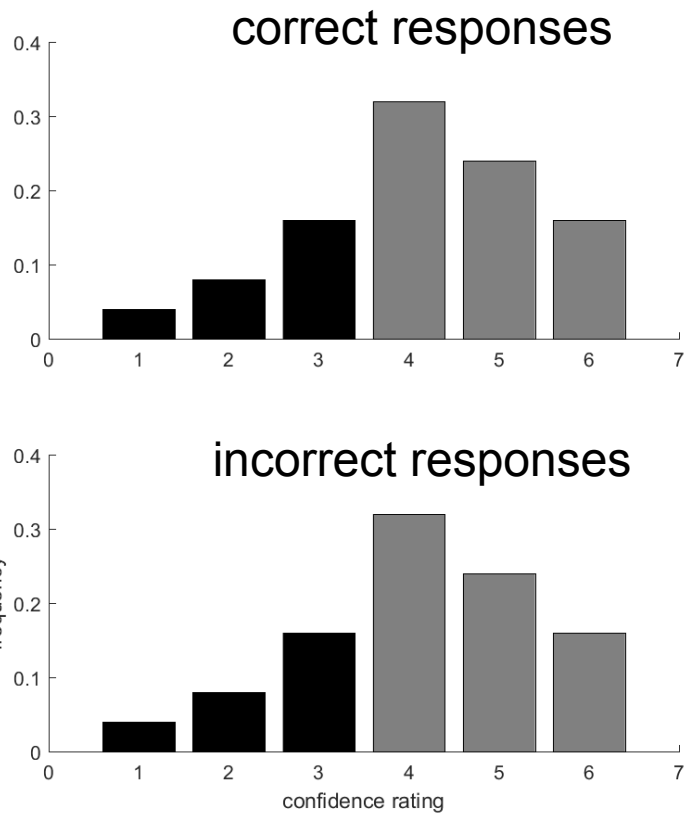

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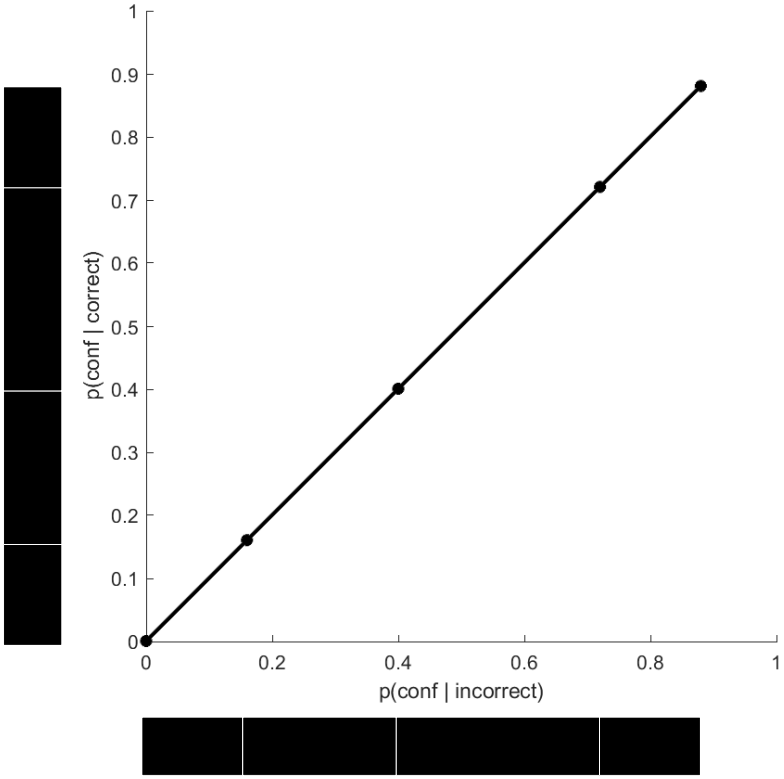

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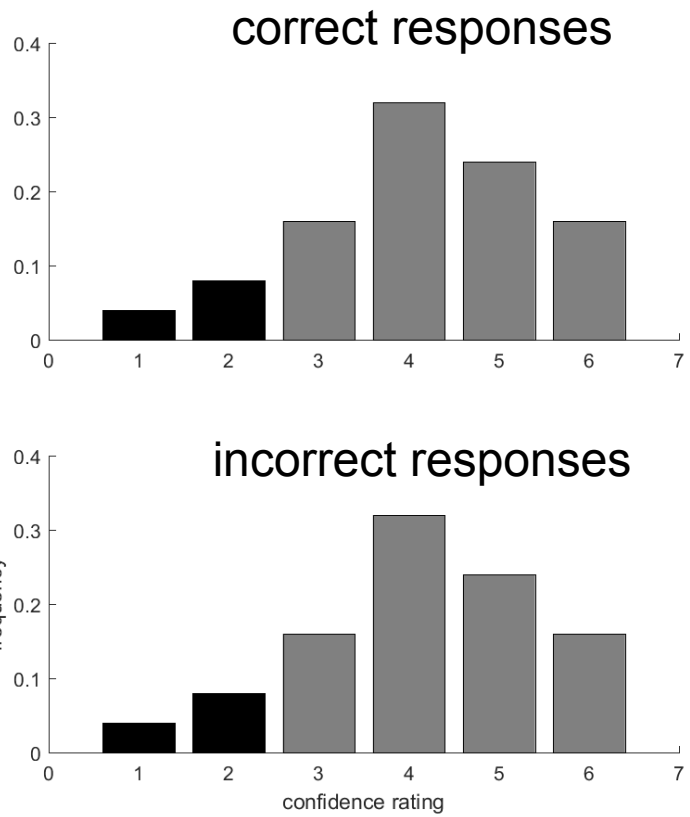
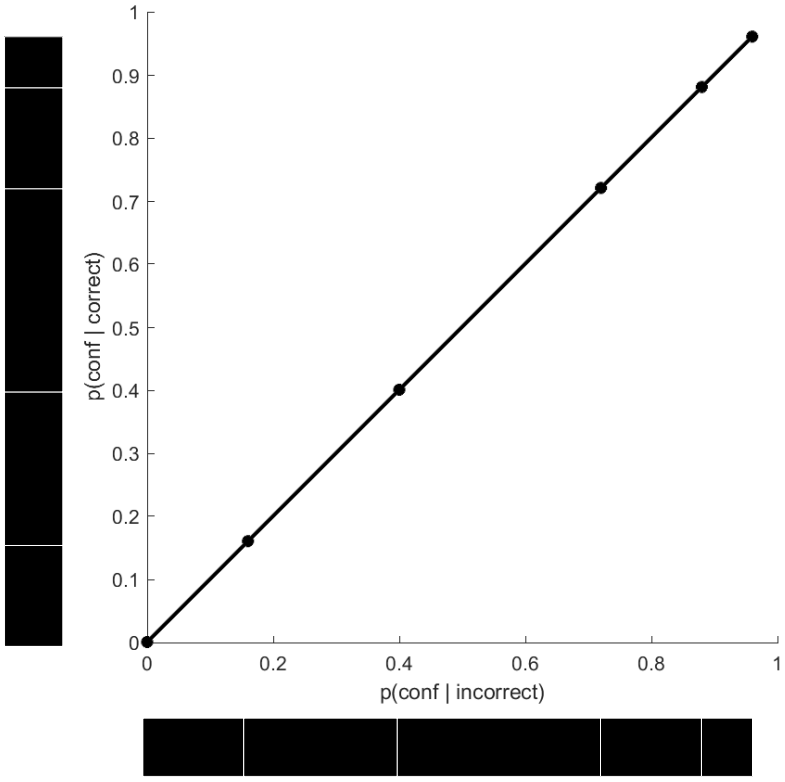


Type 2 ROCs



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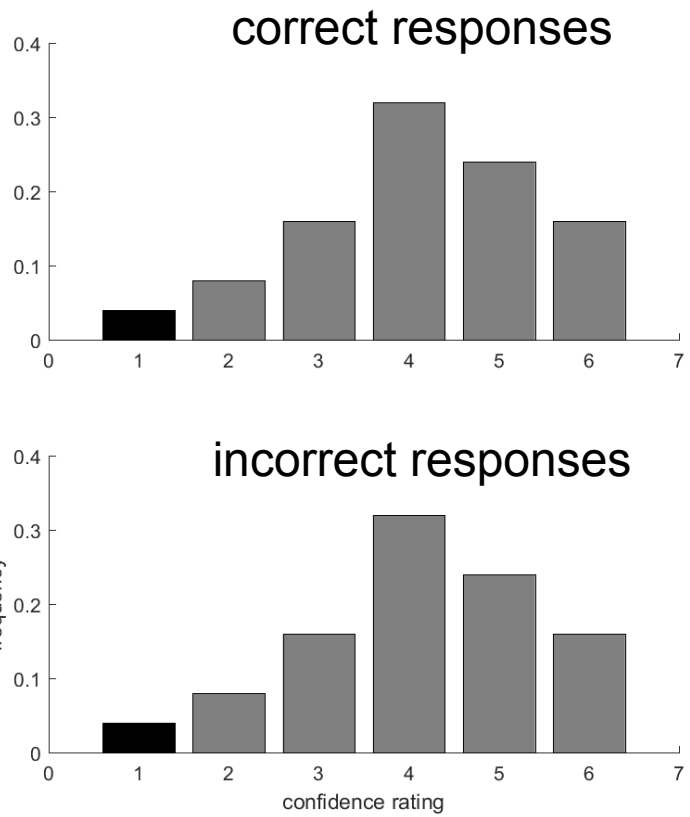
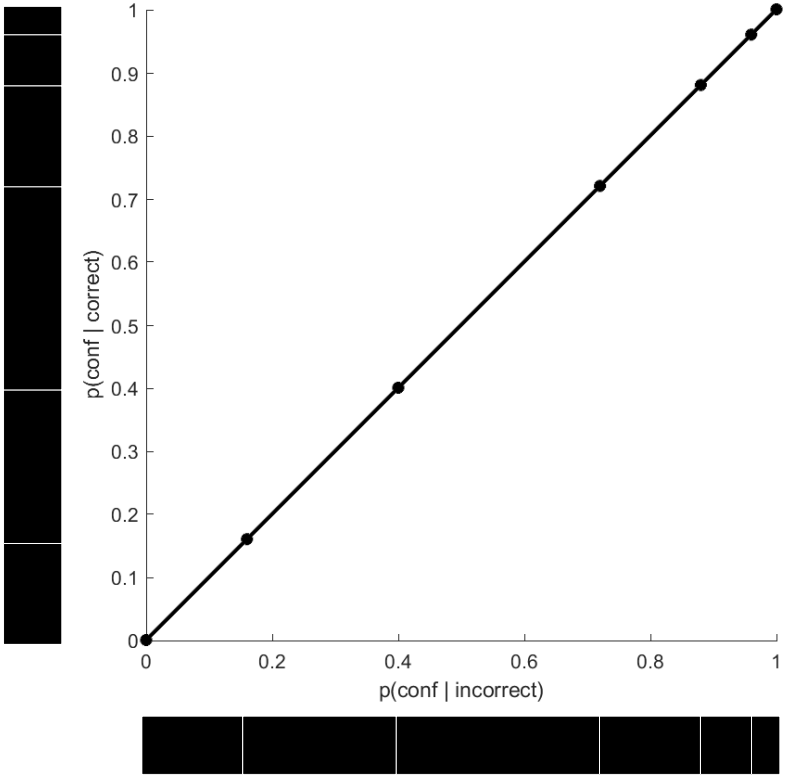


Type 2 ROCs



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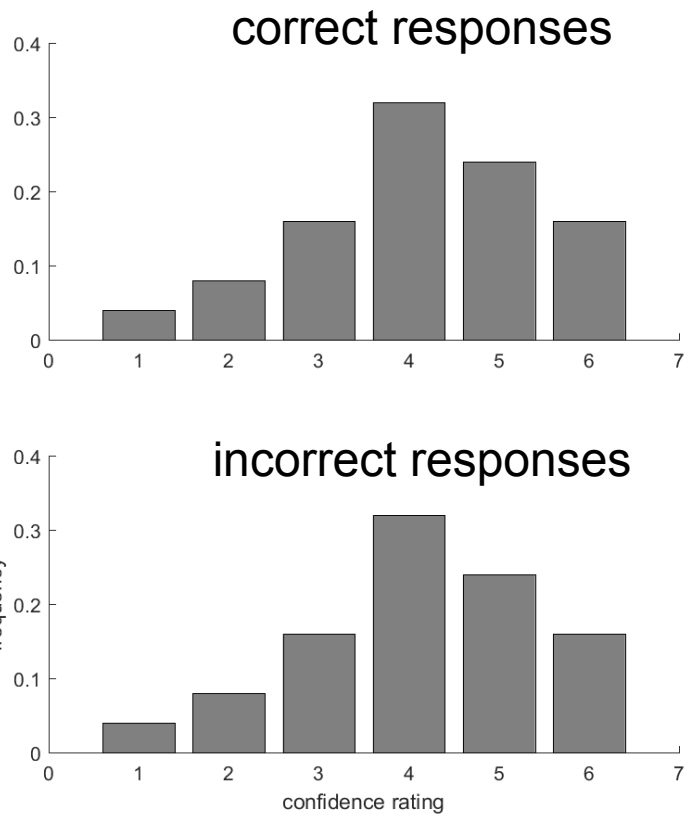


Type 2 ROCs

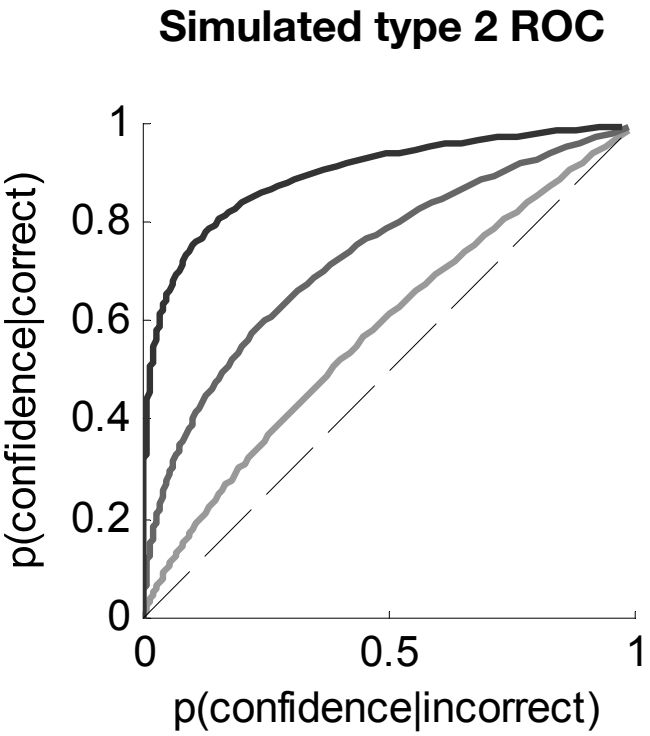
- Simple measure of metacognitive sensitivity
- Theoretically independent of metacognitive bias (overall confidence)
- **BUT *not* independent of performance…**

Type 1 performance

d' = 0.5

d' = 1.5

d' = 3.0

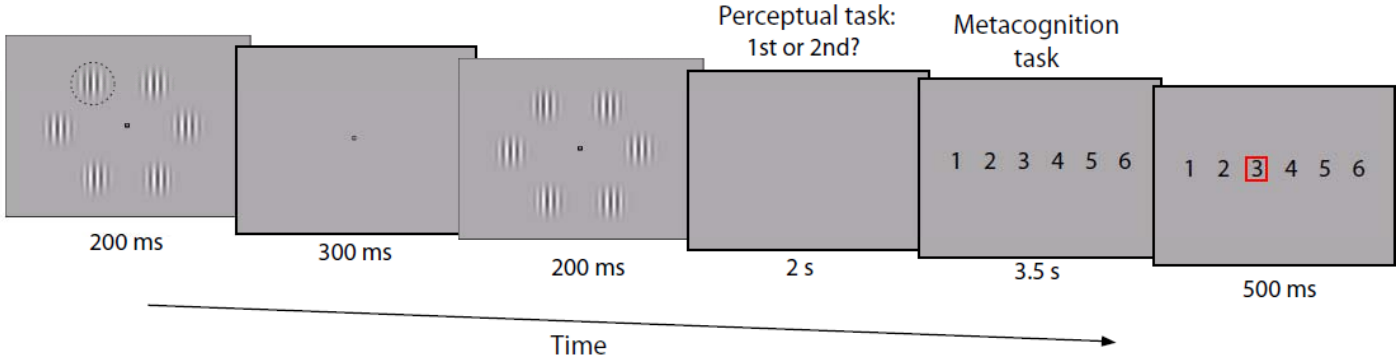


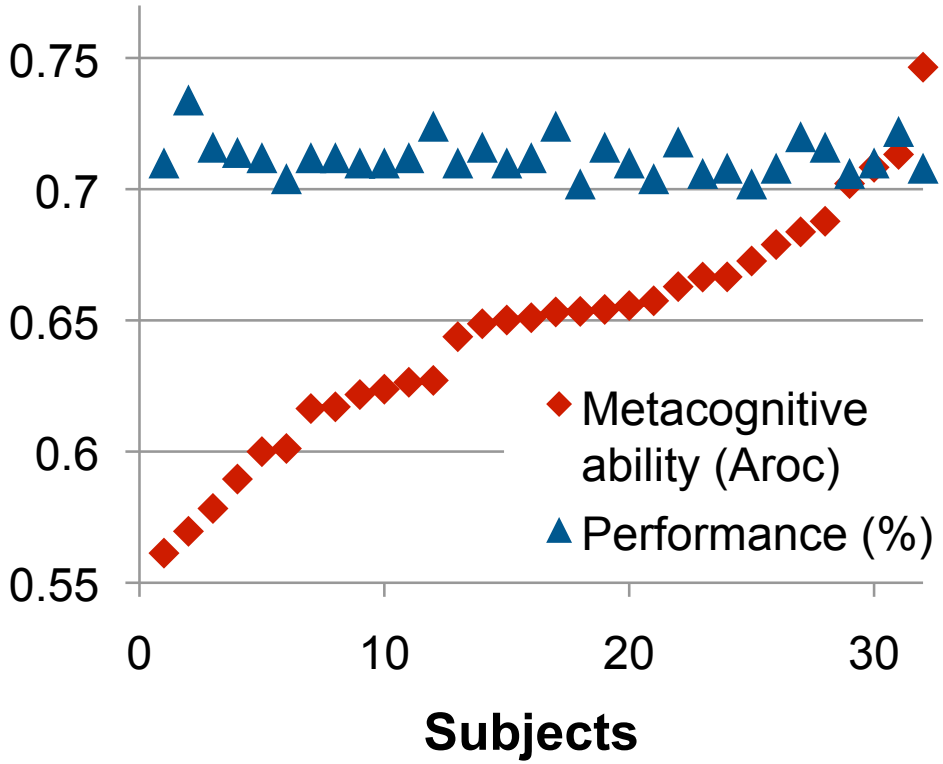
Should I use AUROC2?

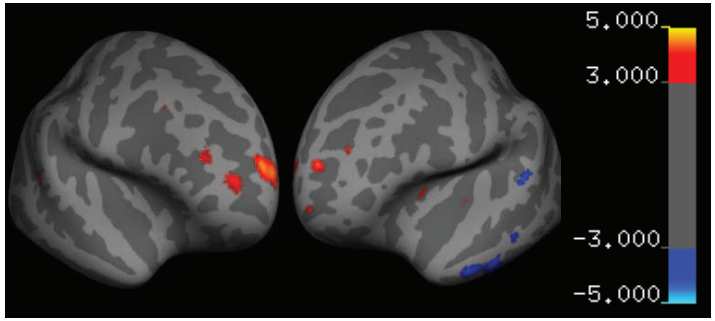
- **Pros:**
  - Non-parametric measure of sensitivity, can be used with pretty much any design (correct vs. incorrect)
  - Independent of metacognitive bias in most circumstances

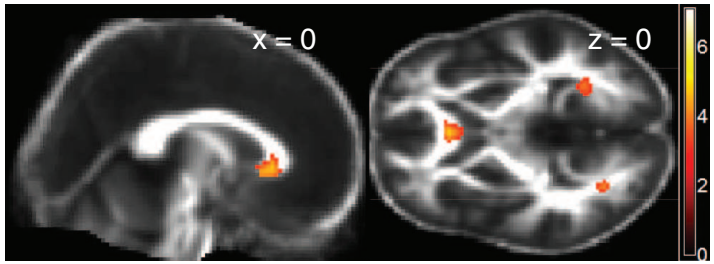
- **Cons:**
  - Confounded by performance
  - Also affected by response criterion (though not usually a major issue in many experimental designs
  - Needs performance-controlled paradigm, or control for performance in analysis (e.g. multiple regression)

Empirical example







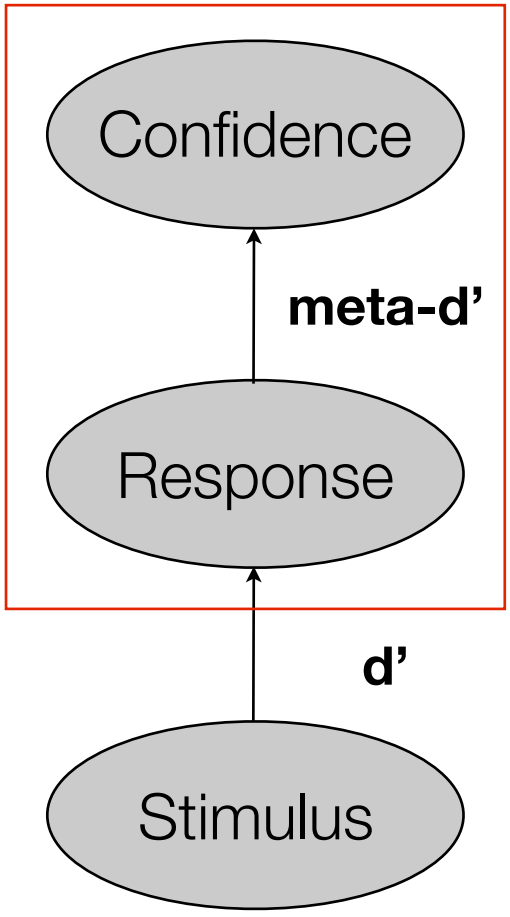


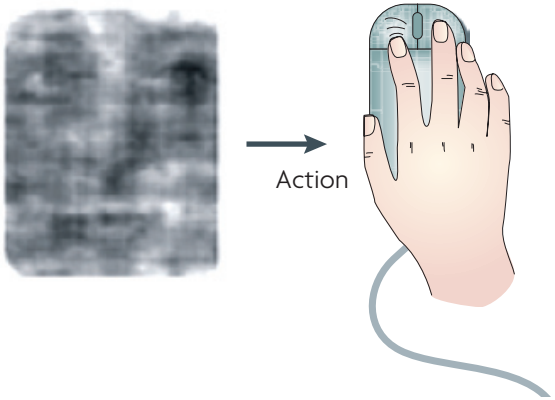
Fleming et al. (2010) *Science*

Quantifying metacognition (3) - meta-d’

Metacognitive sensitivity

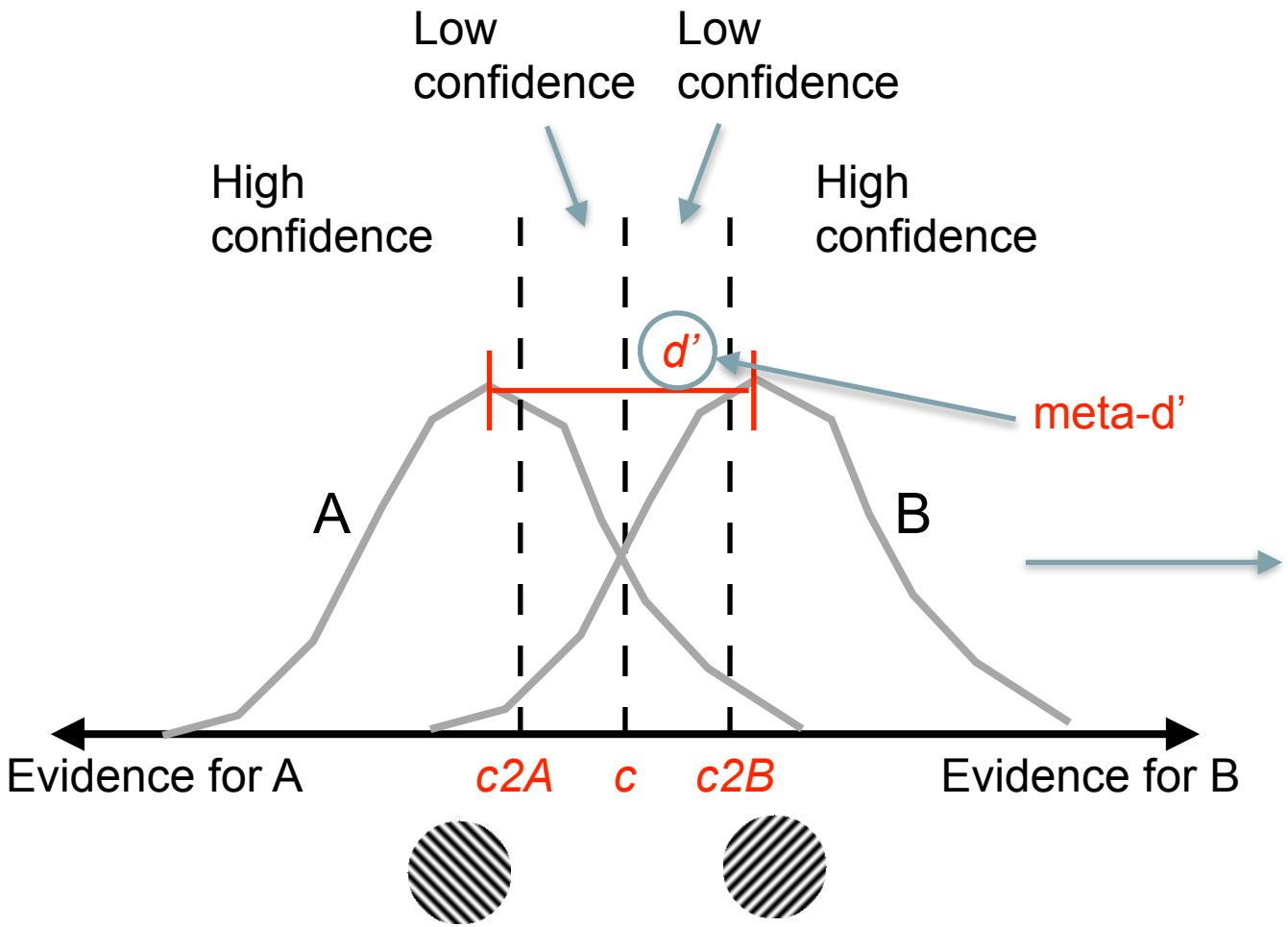
First-order sensitivity



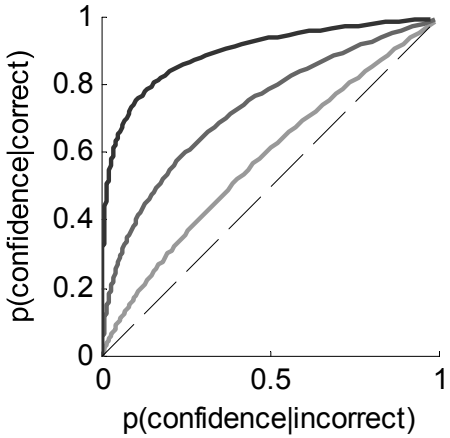


Maniscalco & Lau (2012) *Consciousness & Cognition*; Fleming (2017) *Neuroscience of Consciousness*

Quantifying metacognition (3) - meta-d'



Type 2 ROC

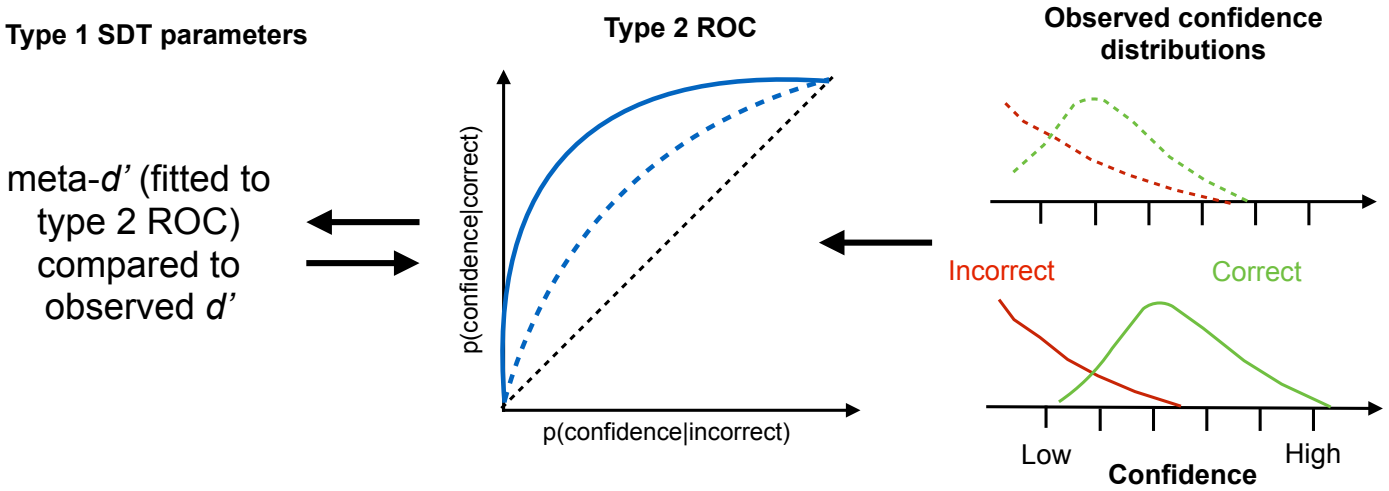


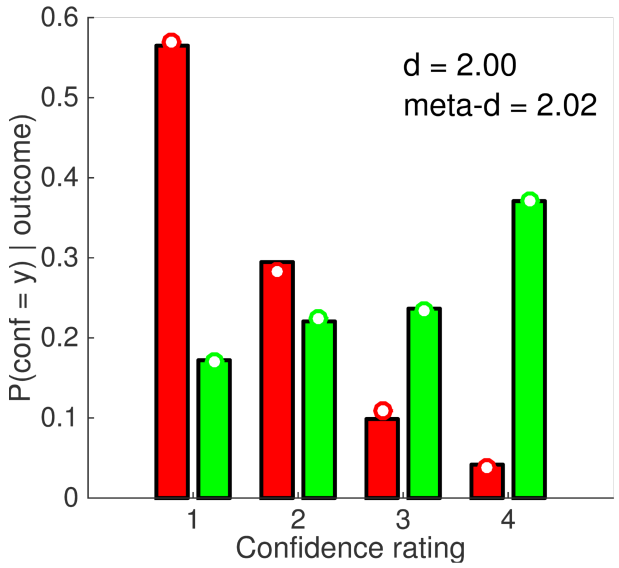
Find parameter set that best fits subjects' type 2 ROC

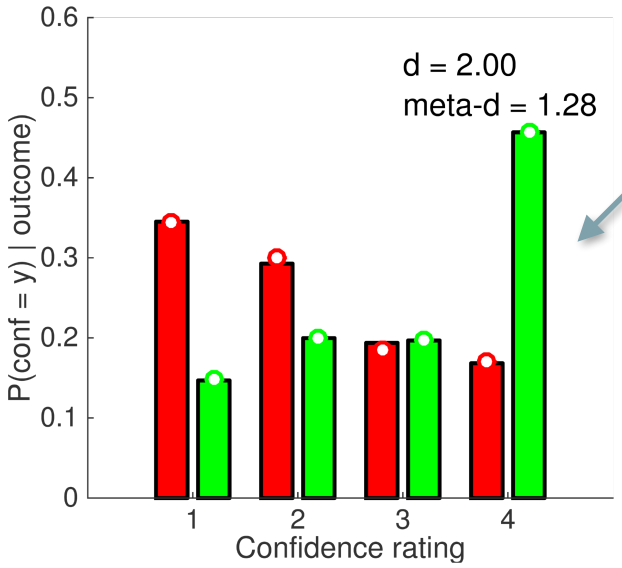
The area under each segment of the curve gives a probability of using a given confidence level

Green & Swets (1966); Maniscalco & Lau (2012) *Consciousness and Cognition*

Quantifying metacognition (3) - meta-d'







Gaussian noise added to confidence ratings

meta-d'/d' = metacognitive efficiency

Maniscalco & Lau (2012) *Consciousness & Cognition*; Fleming (2017) *Neuroscience of Consciousness*

Taxonomy of metacognitive measures

- **Metacognitive bias** - changes in confidence level despite matched performance (e.g. mean confidence)
- **Metacognitive sensitivity** - how closely one's confidence ratings discriminate between correct and incorrect judgments (e.g. confidence-accuracy correlation; type 2 ROC)
- **Metacognitive efficiency** - subjects' metacognitive capacity given a particular level of task performance (e.g. meta *d' / d'*)

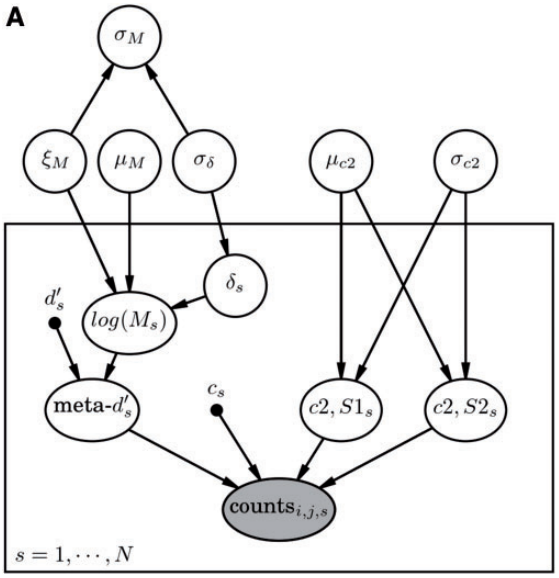
Fleming & Lau (2014) *Frontiers in Neuroscience*

Should I use meta-*d'*?

- **Pros:**
  - Provides principled metric for metacognitive sensitivity in generative model
  - Takes into account both type 1 and type 2 biases
  - Metric is in units of type 1 d', easy to control for performance (e.g. using meta-d'/d')

- **Cons:**
  - Currently only developed for 2-choice discrimination tasks (need to specify 2 x 2 stimulus/response table)
  - Equal-variance Gaussian assumptions may not hold for some tasks
  - Biased estimates with low trial numbers; use HMeta-d!

HMeta-d toolbox



GitHub

metacoglab / HMeta-d

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HMeta d tutorial

Edit | New Page

Steve Fleming edited this page on 30 May 2017 · 3 revisions

#Welcome to the HMeta-d wiki!

Fitting of group-level data in the HMeta-d toolbox requires identical data preparation to that required when obtaining single-subject fits using MLE or SSE using Maniscalco & Lau's MATLAB code (http://www.columbia.edu/~bsm2105/type2sdt/). This page therefore starts with a short tutorial on preparing data for estimating single-subject meta-d', before explaining how to input data from a group of subjects into the hierarchical model.

#Preparing confidence rating data

Data from each subject need to be coerced into two vectors, nR_S1 and nR_S2, which contain confidence-rating counts for when the stimulus was S1 and S2, respectively. Each vector has length k*2, where k is the number of ratings available. Confidence counts are entered such that the first entry refers to counts of maximum confidence in an S1 response, and the last entry to maximum confidence in an S2 response. For example, if three levels of confidence rating were available and nR_S1 = [100 50 20 10 5 1], this corresponds to the following rating counts following S1 presentation:

- responded S1, rating=3 : 100 times
- responded S1, rating=2 : 50 times
- responded S1, rating=1 : 20 times
- responded S2, rating=1 : 10 times
- responded S2, rating=2 : 5 times
- responded S2, rating=3 : 1 time

This pattern of responses corresponds to responding "high confidence, S1" most often following S1 presentations, and least often with "high confidence, S2". A mirror image of this vector would be expected for nR_S2. For example, nR_S2 = [3 7 8 12 27 89] corresponds to the following rating counts following S2 presentation:

- responded S1, rating=3 : 3 times
- responded S1, rating=2 : 7 times
- responded S1, rating=1 : 8 times
- responded S2, rating=1 : 12 times
- responded S2, rating=2 : 27 times
- responded S2, rating=3 : 89 times

Together these vectors specify the confidence stimulus x response matrix that is the basis of the

Pages 1

Find a Page...

HMeta d tutorial

+ Add a custom sidebar

Clone this wiki locally

https://github.com/metacc

https://github.com/metacoglab/HMeta-d

Fleming (2017) *Neuroscience of Consciousness*

Advantages of hierarchical approach

1. Point estimates of meta-d' are noisy, particularly with small numbers of trials; frequentist estimates of hit/false alarm rates fail to account for uncertainty in these rates
2. A hierarchical Bayesian approach is the correct way to combine information about within- and between-subject uncertainty, each subject mutually constrains the group fit
3. When fitting SDT models to data, padding (edge correction) is often applied to avoid zero cell counts; generative multinomial model avoids this
4. Testing group-level hypotheses is straightforward. E.g. can directly compare posterior distribution over metacognitive sensitivity for patients and controls

Fleming (2017) *Neuroscience of Consciousness*

Hierarchical model for meta-*d'* (HMeta-d)

$$\mu_{c2} \sim \mathcal{N}(0, 10)$$

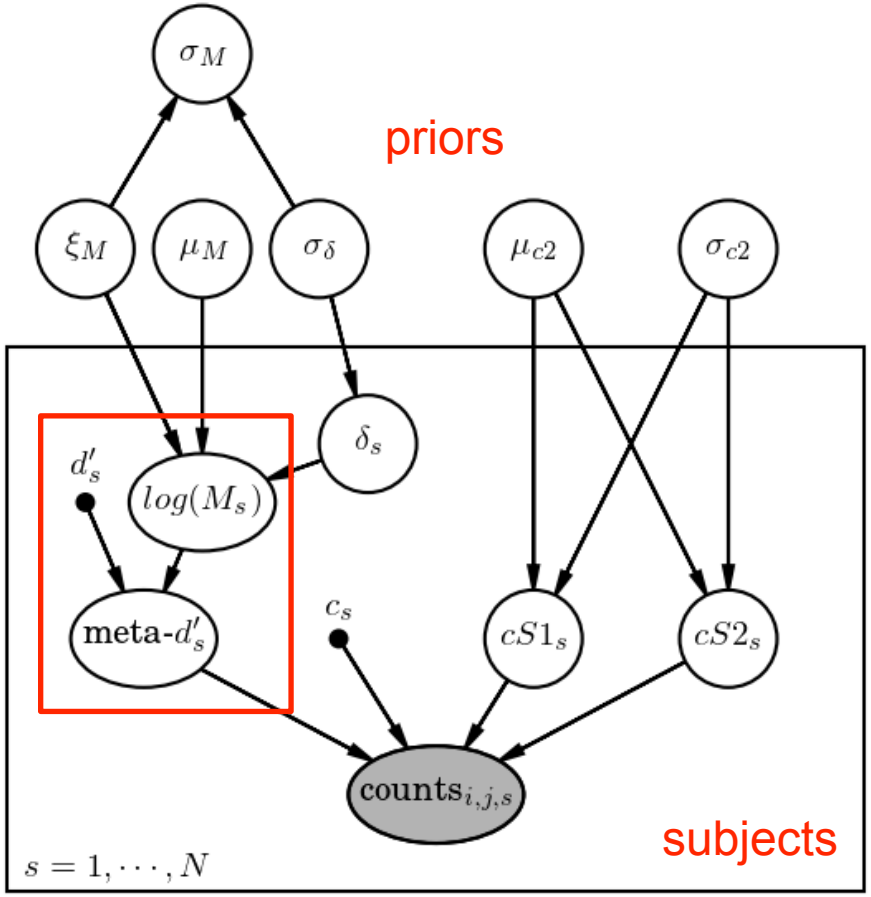
$$\sigma_{c2} \sim \mathcal{HN}(10)$$

$$\mu_M \sim N(0, 1)$$

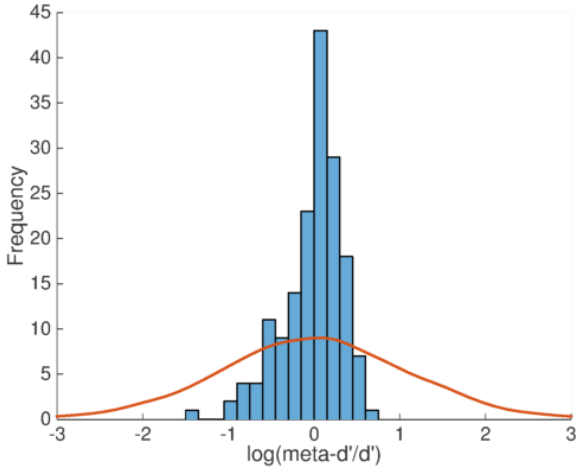
$$\sigma_M = |\xi_M| \times \delta_s$$

$$\xi_M \sim Beta(1,1)$$

$$\sigma_\delta \sim \mathcal{HN}(1)$$



direct estimation of meta-d'/d'

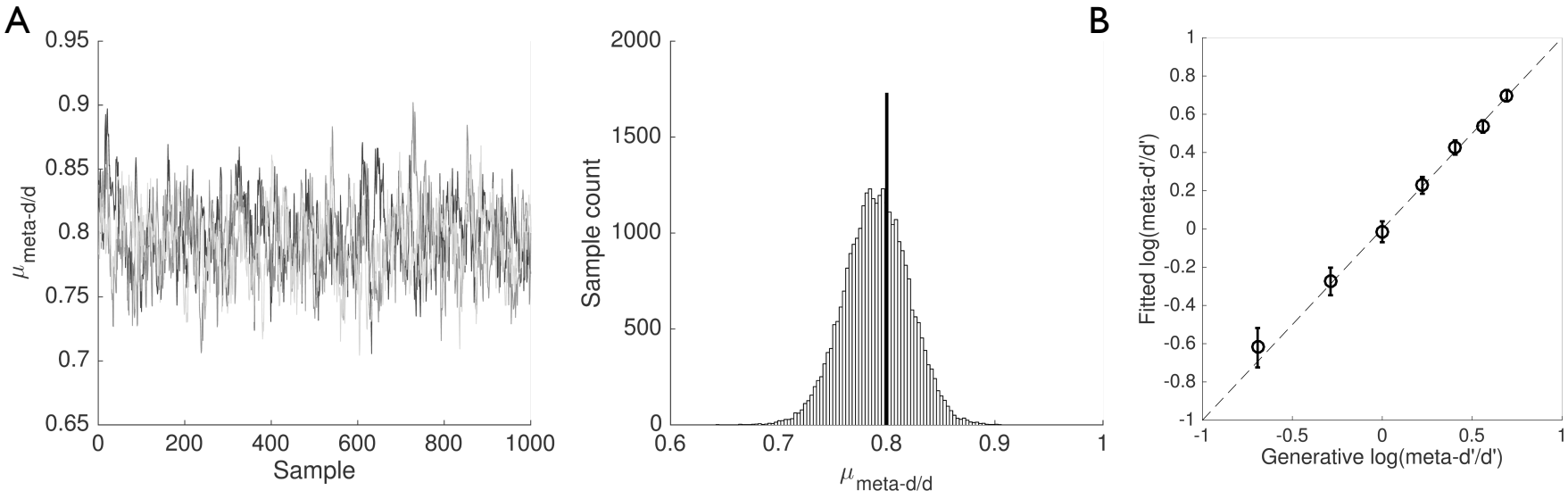


Fleming (2017) *Neuroscience of Consciousness*

Hierarchical model for meta-*d'* (HMeta-d)

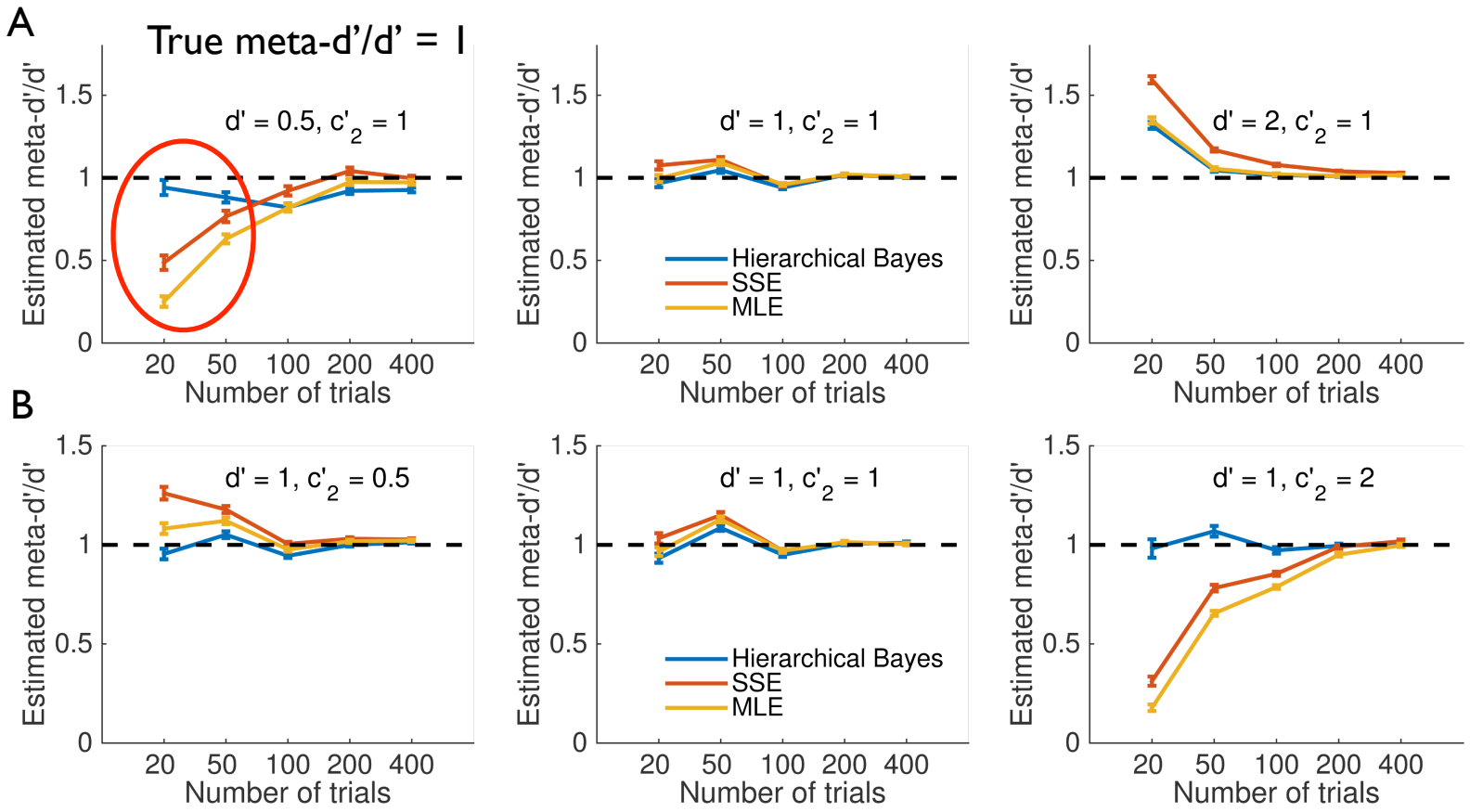
Code and tutorial available at https://github.com/smfleming/HMeta-d

MCMC samples of group-level metacognitive efficiency:



Fleming (2017) *Neuroscience of Consciousness*

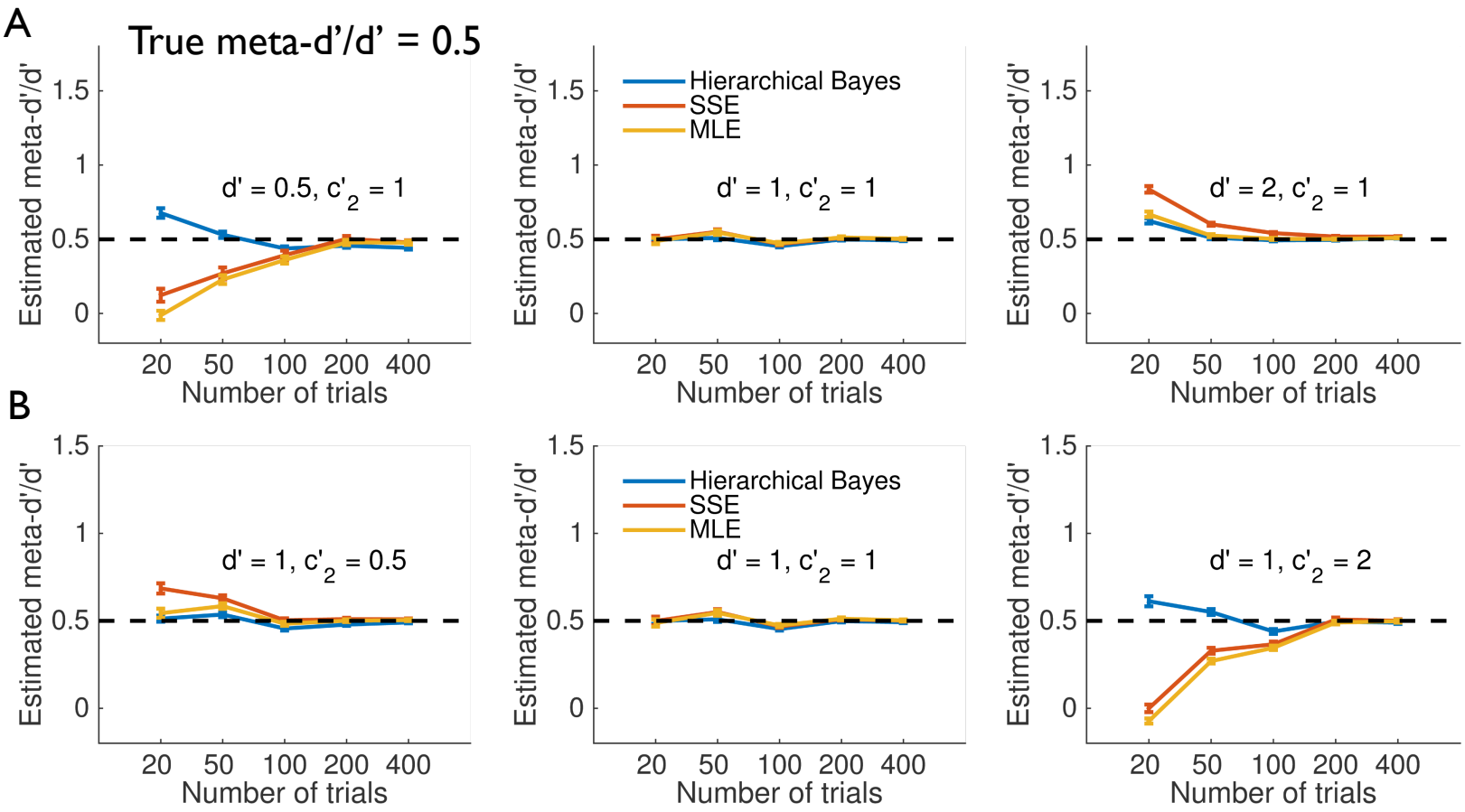
Hierarchical model for meta-*d'* (HMeta-d)



Point-estimate approaches underestimate metacognitive efficiency when (type 1) d' is low

Why is HMeta-d better? Shrinkage to prior OR capitalises on hierarchy across subjects…

Fleming (2017) *Neuroscience of Consciousness*



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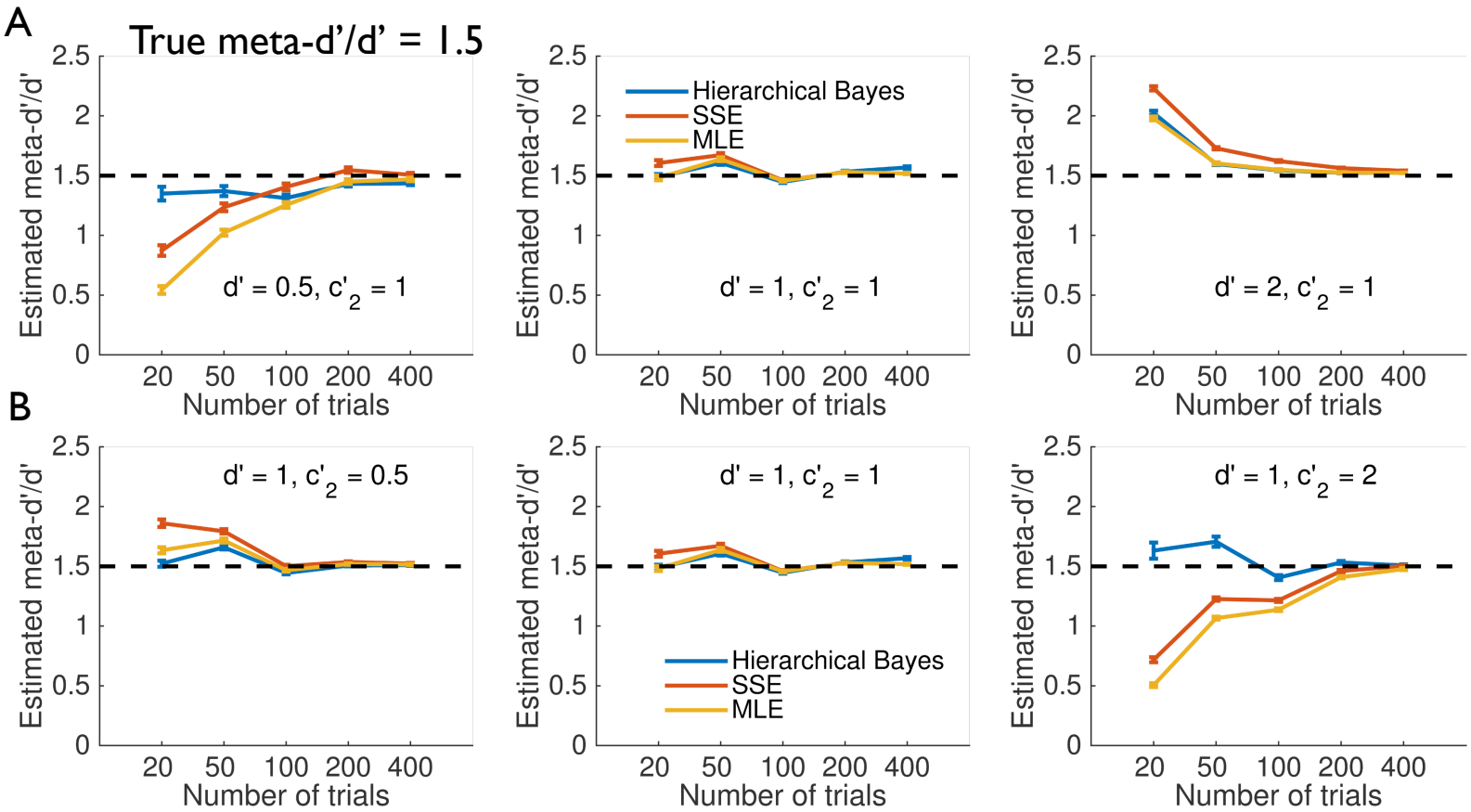

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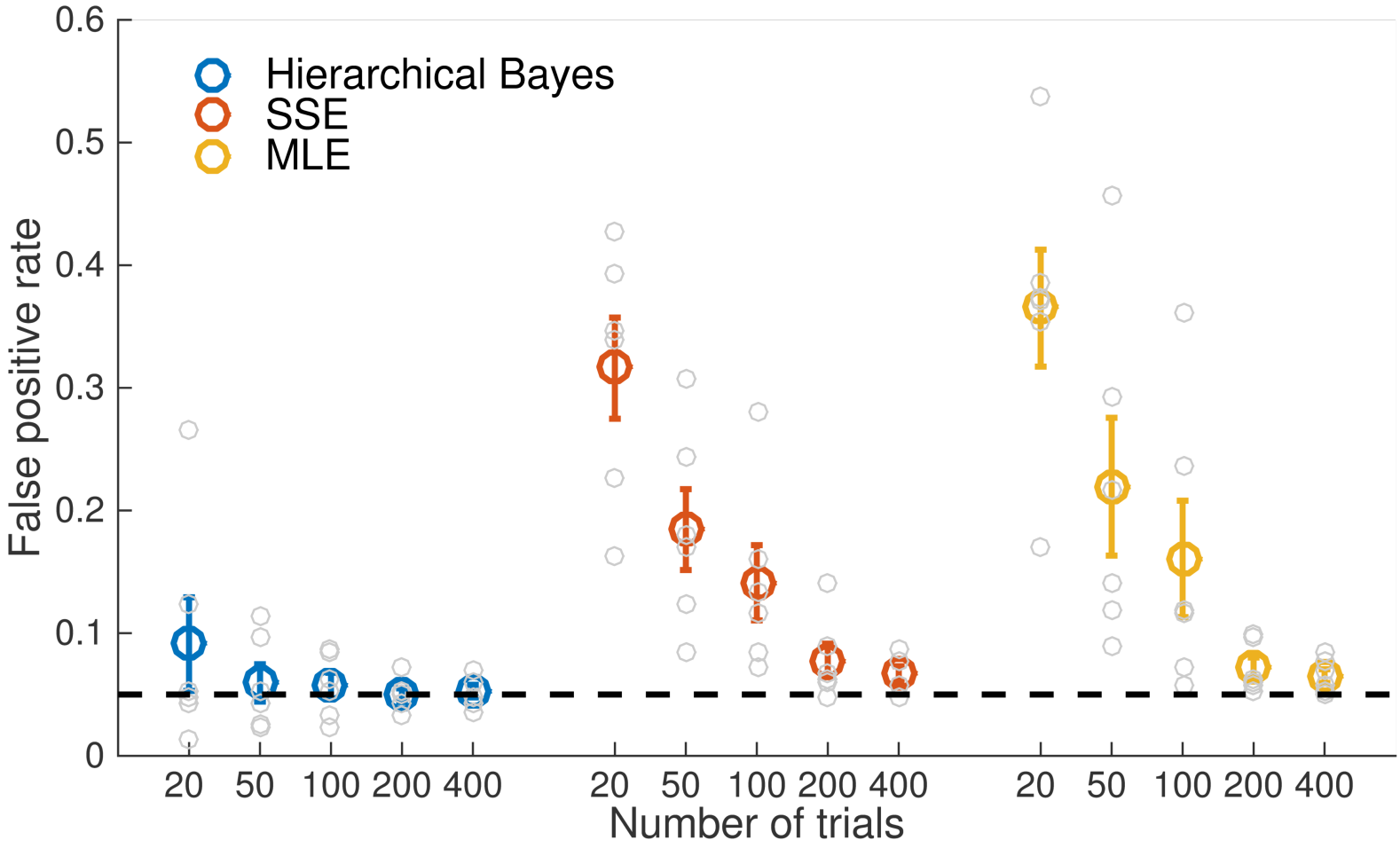
Hierarchical model for meta-*d'* (HMeta-d)



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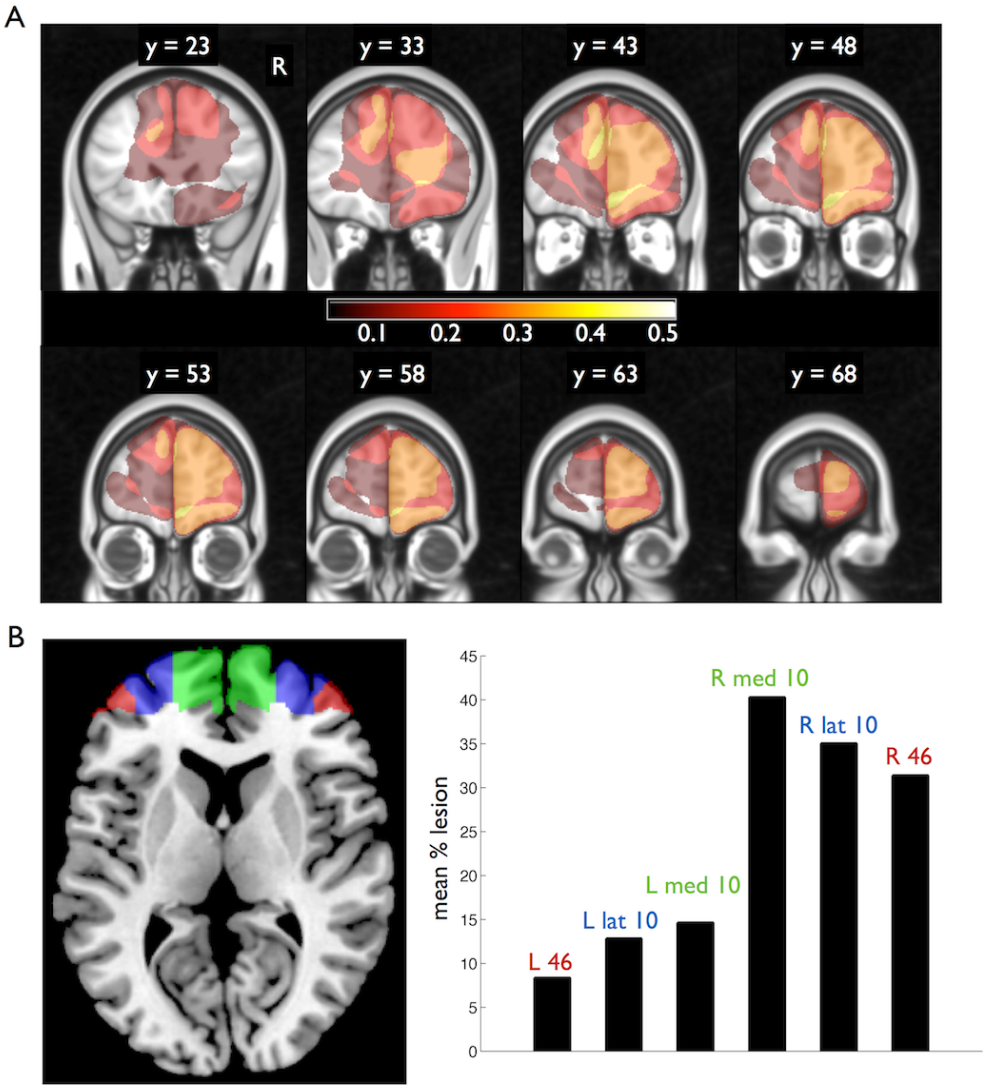
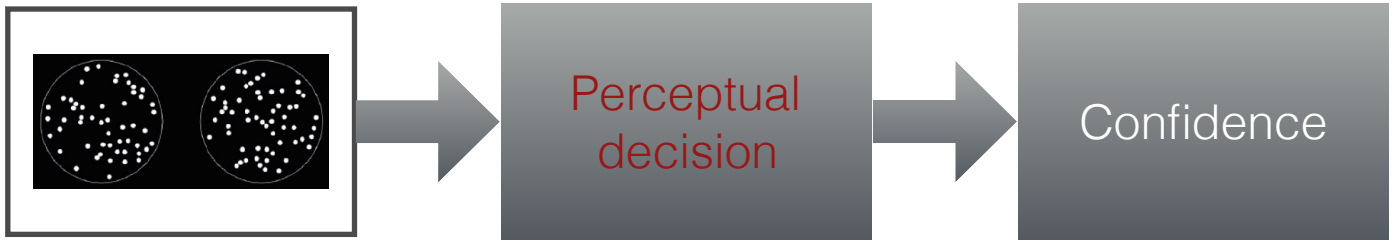
Empirical example



Fleming, Ryu, Golfinos & Blackmon *Brain* (2014)

	aPFC (N=7)	TL (N=11)	HC (N=19)*
Sex	2 F / 5 M	6 F / 5 M	4 F / 15 M
Handedness	7 R / 0 L	10 R / 1 L	17 R / 2 L
	Mean (SD)	**Mean (SD)**	**Mean (SD)**
Age (years)	43.1 (15.8)	43.6 (9.2)	42.3 (16.4)
Time Since Lesion (years)	2.2 (2.3)	4.3 (3.2)	N/A
Lesion volume (cm^3)	98.1 (108.6)	41.0 (18.5)	N/A
Full-Scale IQ	96 (17)	102 (12)	112 (16)
	SS Mean (SD)	**SS Mean (SD)**	**SS Mean (SD)**
Verbal Index (VCI)	105.9 (17.2)	109.1 (12.5)	117.1 (14.3)
Perceptual Reasoning (PRI)	96.1 (15.3)	96.8 (13.7)	105.4 (16.2)
Working Memory (WMI)	95.3 (17.2)	102.5 (13.9)	106.6 (16.7)
Processing Speed (PSI)	92.5 (14.4)	98.9 (10.2)	99.6 (14.1)
Verbal Memory (CVLT-II DR)	84.8 (20.6)	80.1 (18.3)†	99 (20.8)
Attention / Set-shifting (TMT-B)	84.4 (25.2)	93.1 (20.4)	95.2 (19.9)

Fleming, Ryu, Golfinos & Blackmon *Brain* (2014)

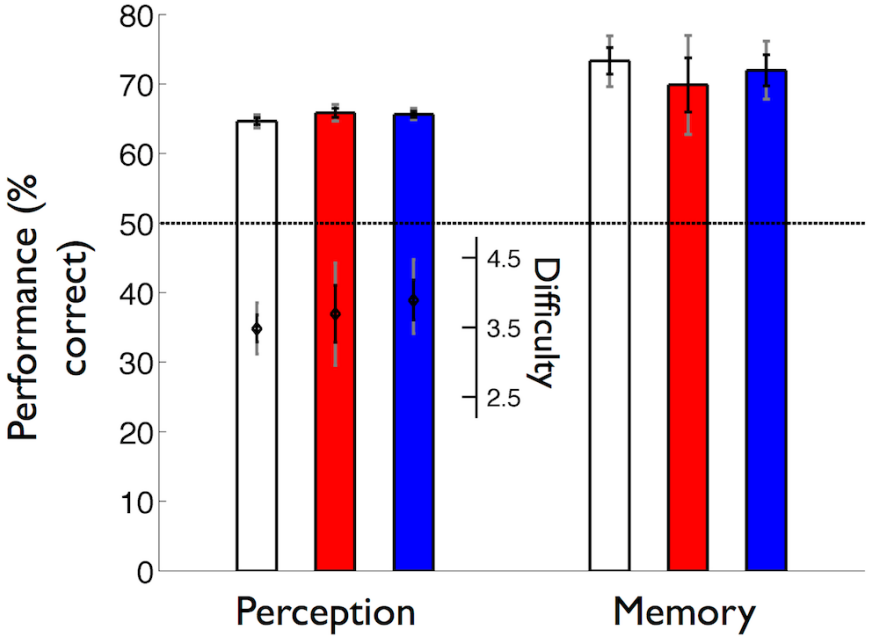


More dots, L or R?

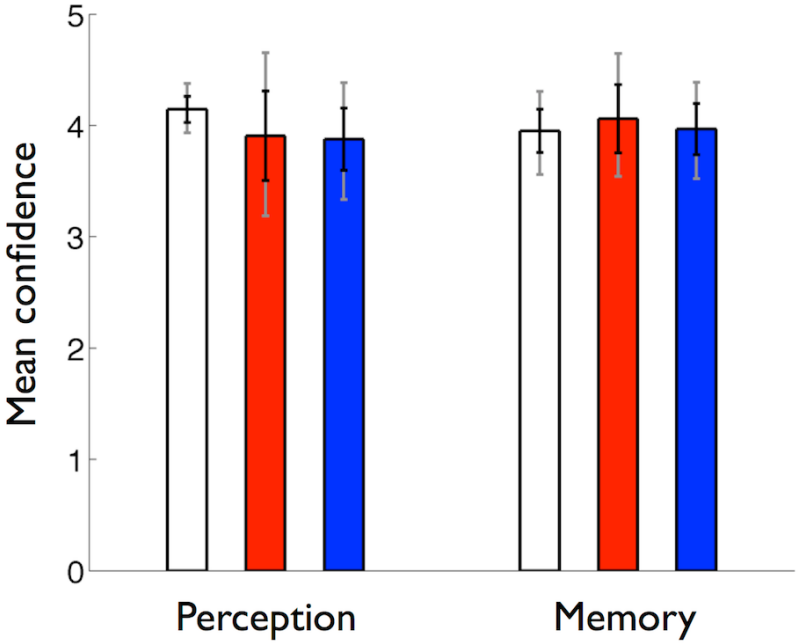
Old, L or R?

Fleming, Ryu, Golfinos & Blackmon *Brain* (2014)

Performance



Confidence

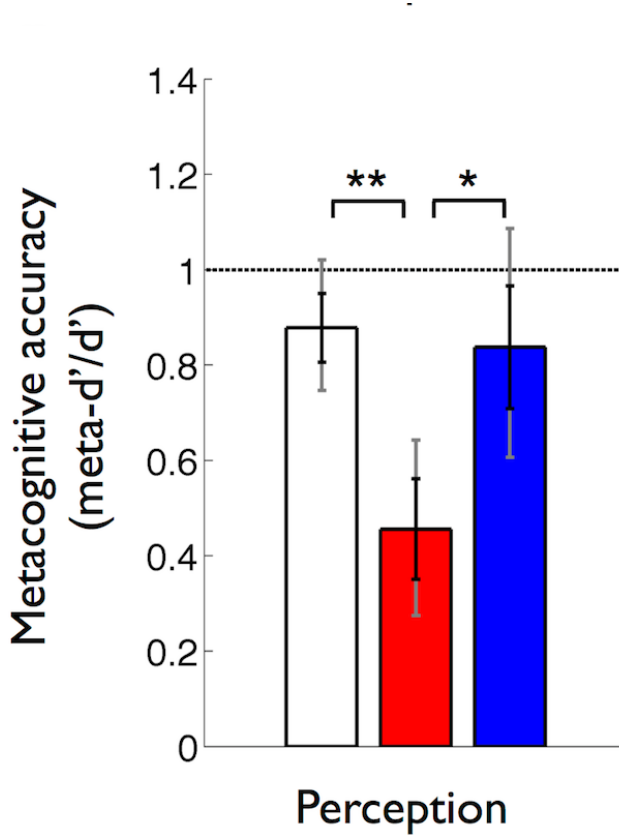


healthy controls

aPFC lesion

TL lesion

Fleming, Ryu, Golfinos & Blackmon *Brain* (2014)



healthy controls

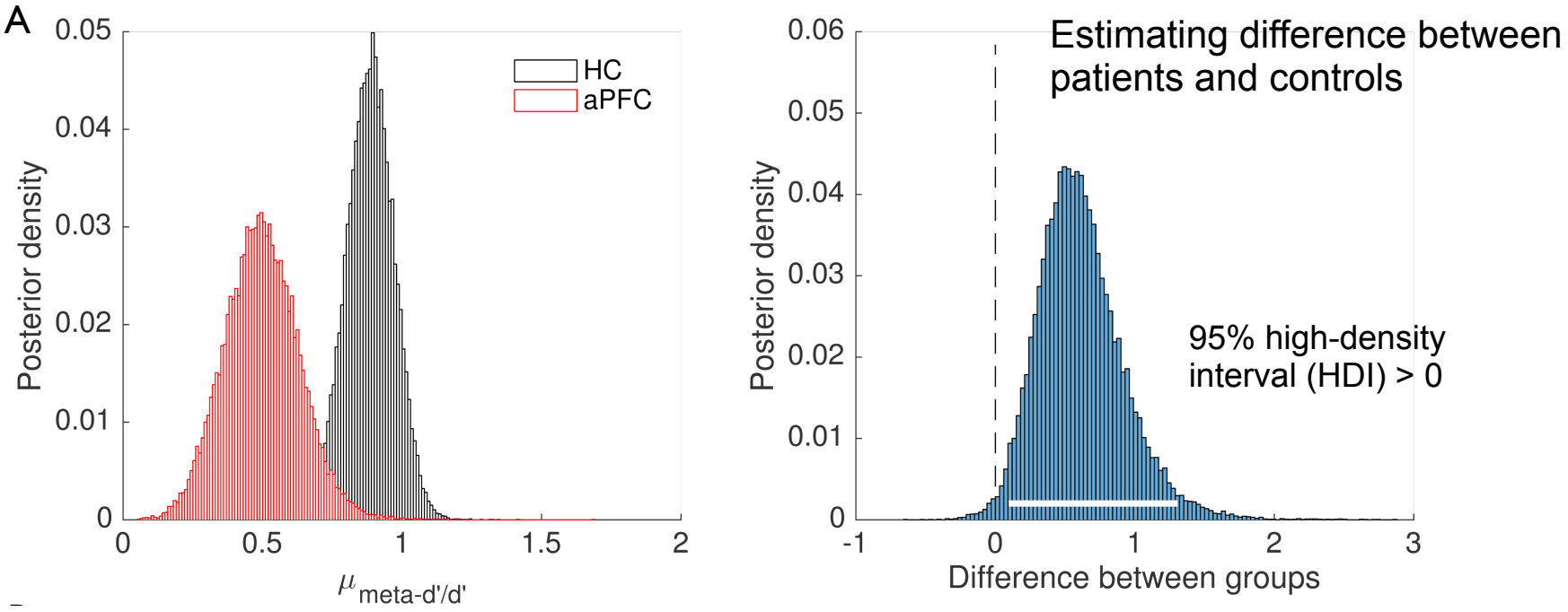
aPFC lesion

TL lesion

Why no metacognitive deficit for memory following aPFC lesion?
Redundancy? Reorganisation? Intact parietal cortex may compensate?

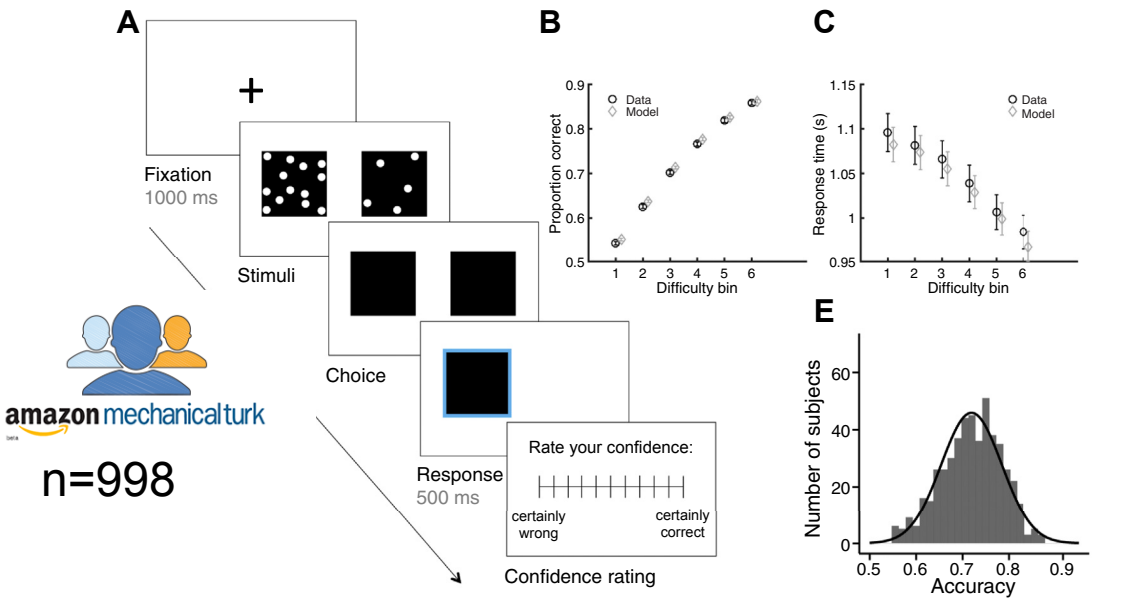
Fleming, Ryu, Golfinos & Blackmon *Brain* (2014)

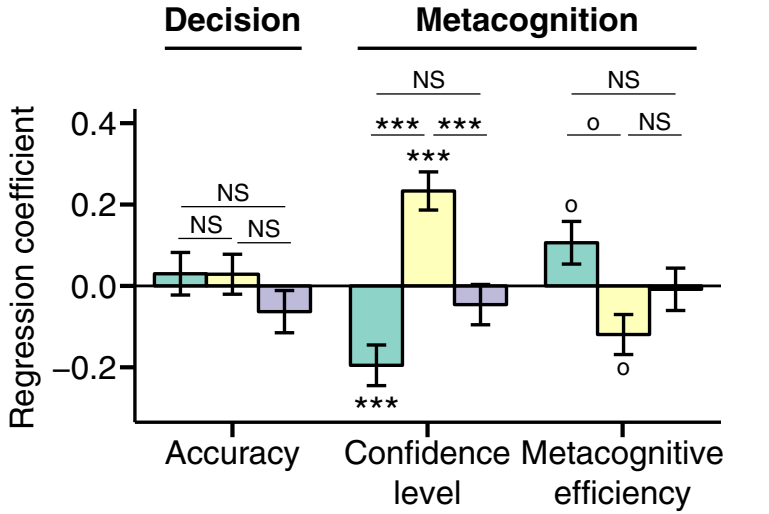
Re-analysis using HMeta-d



Fleming (2017) *Neuroscience of Consciousness*

Metacognition and computational psychiatry



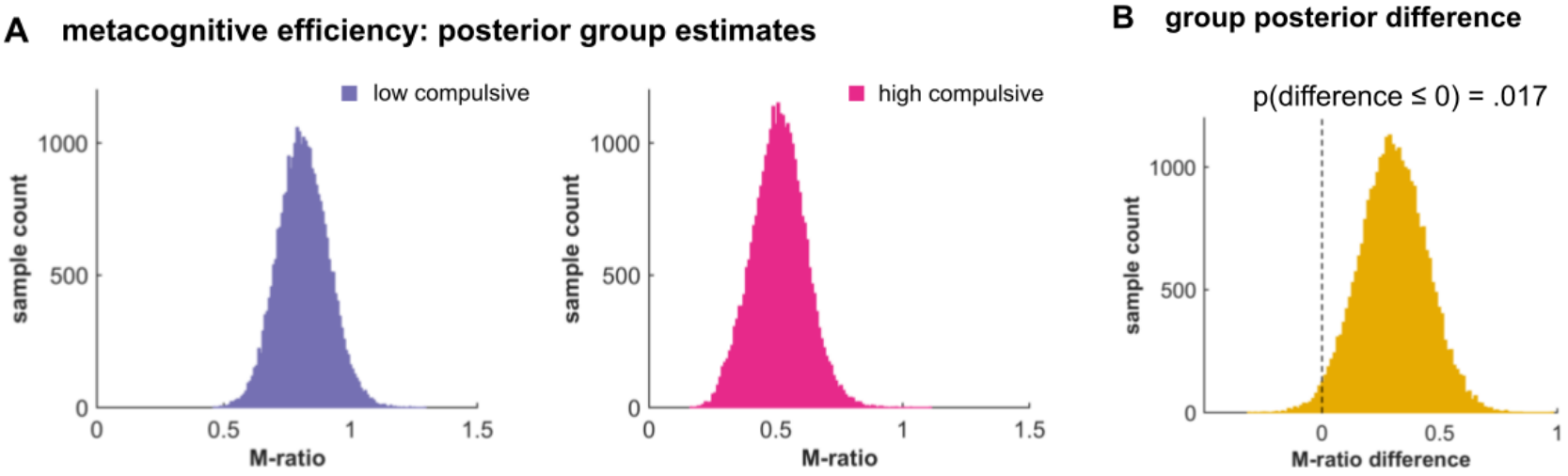


Rouault et al. (2018) *Biol Psych*

Weak links to symptoms **Strong links to symptoms**

Evidence → Decision → Metacognitive evaluation

Metacognition and computational psychiatry



Hauser, Allen et al. (2017) *Sci Reports*

Over to you!

- Open Matlab
- Navigate (in Matlab) to the folder where you saved the downloads for this tutorial
- Open the main script (preferably the “live script” version, i.e. cpc_metacog_tutorial.mlx)
- Run through the instructions in the code