Dissociating confidence bias and confidence noise in perceptual and knowlegde-based decisions

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Introduction

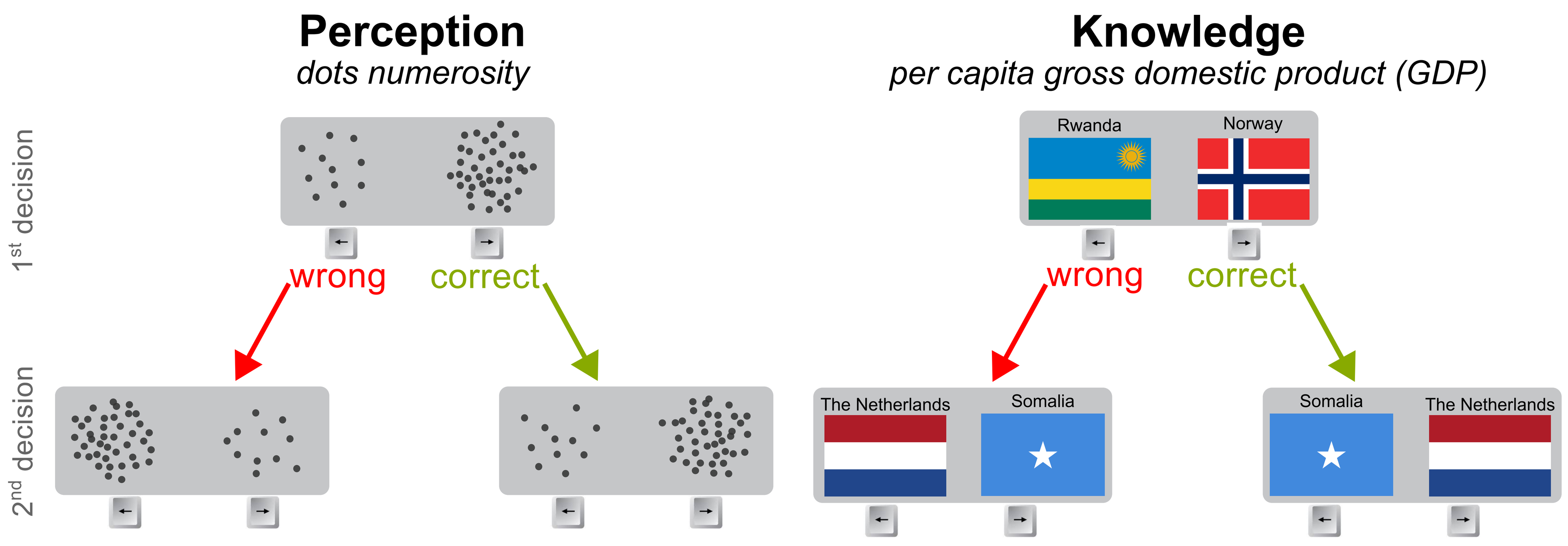
People often misjudge how reliable their decisions are, leading to *confidence errors.*

Confidence errors can arise from *confidence bias*, a stable tendency to over- or under-estimate one's certainty, as well as from *confidence noise*, which reflects trial-to-trial variability around this baseline.

Do confidence errors reflect more bias or noise — and does this differ between perceptual and knowledge-based decisions?

To answer this, we tested how well confidence bias and noise explain errors in a *dual-decision* task [1], where participants are required to use confidence in a prior decision to inform expectations about subsequent choices

'Dual-decision' tasks



Two decisions per trial: the correct response in the 2nd decision (← vs →) is determined by accuracy in the 1st decision.

Confidence as a prior: confidence in the 1st decision serves as a prior to guide the 2nd decision.

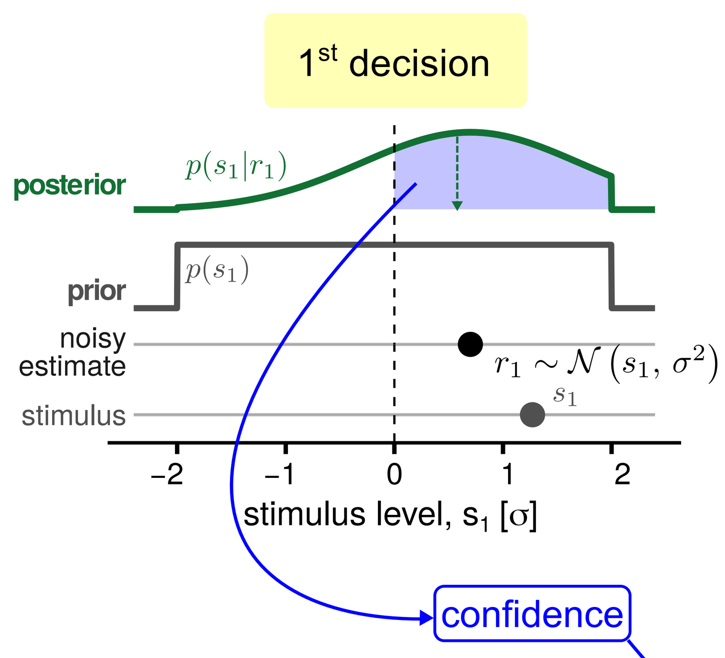
Assessing confidence biases: the frequency of → responses in the 2nd decision, compared to the optimal frequency, reveals participants' confidence biases.

Datasets

Study	N	N trials	Stimuli	Method
Lisi et al [1]	29	900	Motion — orientation	Constant stimuli
Lisi et al [1]	19	500	Temporal duration	
Constant et al [2]	21	720	Motion	Staircase (3 levels)
Constant et al [2]	25	720	Motion	Staircase (3 levels), 2 sec. delay between decisions
Study 1	21	150	GDP	Staircase + jitter
Study 2 (part 1)	23	250	GDP	Staircase, within-participants design
Study 2 (part 2)	23	250	dots-numerosity	
Study 2 (part 3)	14	250	Food calories	

Across all studies, participants used effectively the dual-decision structure to improve performance in 2nd decision compared to 1st.

Computational analysis



Participants decide whether the stimulus value s_1 exceeds threshold (e.g., whether the dot numerosity difference is > 0).

In the 1st decision the prior is uniform:

$$p(s_1 > 0) = p(s_1 < 0) = \frac{1}{2}$$

Performance depends on irreducible noise σ (e.g. sensory noise).

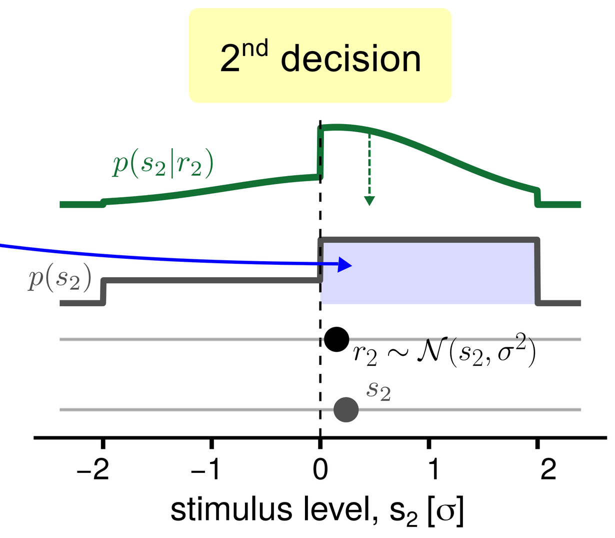
For a Bayesian observer, confidence is the posterior probability that s_1 lies in the chosen semi-interval.

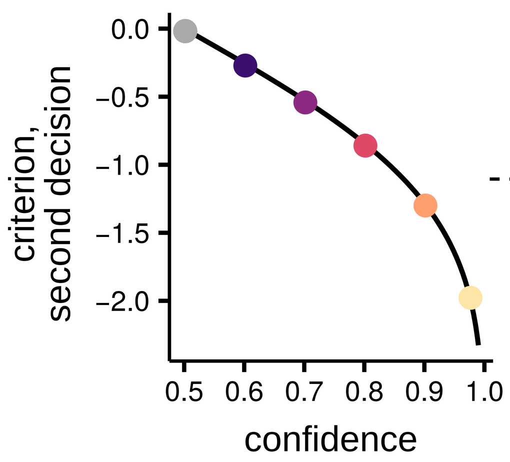
$$\text{confidence} = \int \frac{p(r_1 \mid s_1)\, p(s_1)}{p(r_1)} ds_1$$

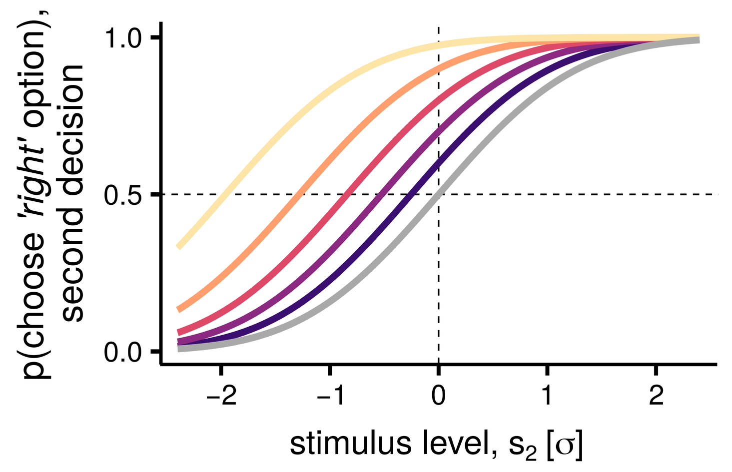
In the 2nd decision, the prior depends on the confidence that the 1st decision was correct.

The Bayesian observer shifts the decision criterion based on confidence in the 1st decision

$$\theta_2 = \sqrt{2}\sigma \ \text{erf}^{-1}(1 - 2 \times \text{confidence})$$



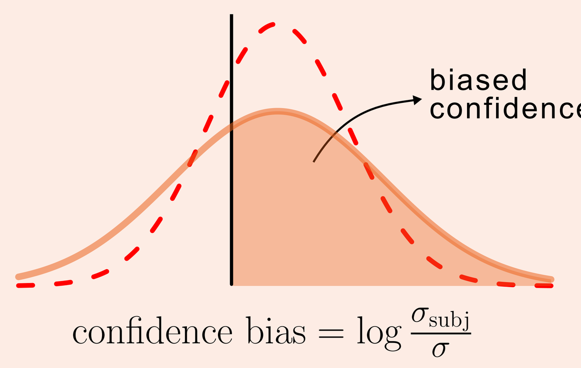




Modelling confidence *bias* and confidence *noise*

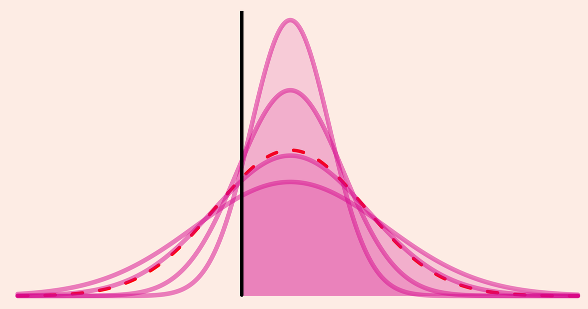
In the 'standard' Bayesian model the only free parameter is the irreducible uncertainty (the noise standard deviation σ).

The Bayesian model can be augmented with a **confidence bias** assuming it uses an inaccurate estimate (σ_{subj}) of its own internal noise.



$$\text{confidence bias} = \log \frac{\sigma_{\text{subj}}}{\sigma}$$

To model **confidence noise**, internal noise estimates are allowed to vary randomly across trials — a concept known as *meta-uncertainty* [3].

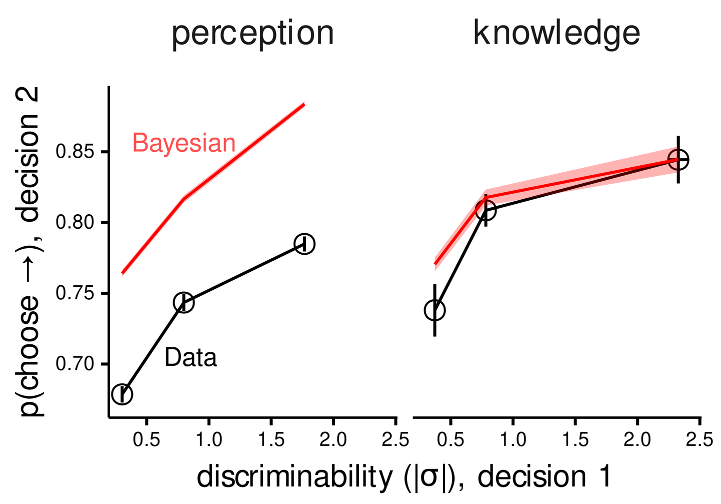


Trial-by-trial fluctuations in the observer estimates of its own noise σ_{subj} are assumed to follow a log-normal distribution:

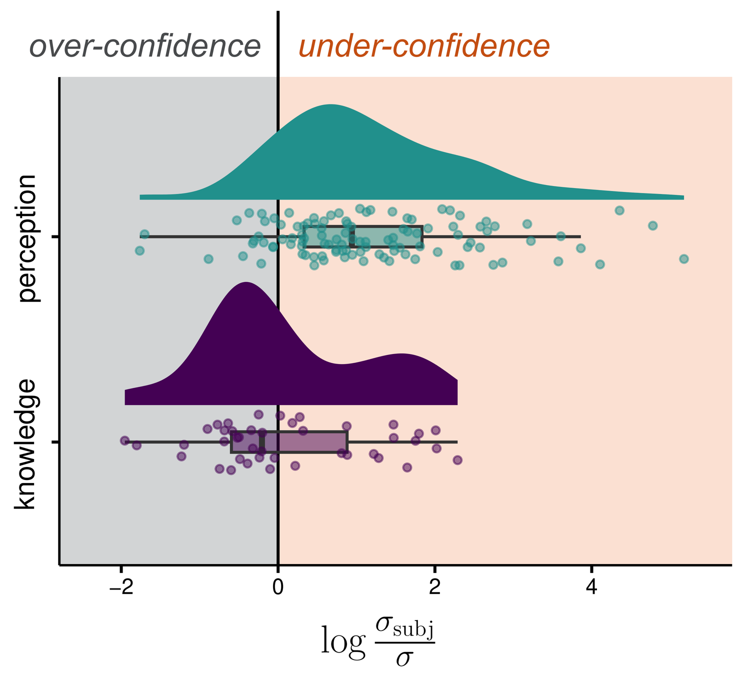
$$\sigma_{\text{subj}} \sim \text{LogNormal}\left(\log \frac{\sigma^2}{\sqrt{\sigma_m^2 + \sigma^2}}, \log\left(\frac{\sigma_m^2}{\sigma^2} + 1\right)\right)$$

where σ_m is the *confidence noise* parameter

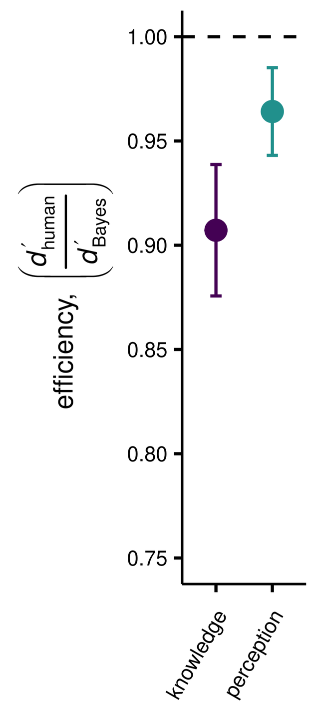
Results



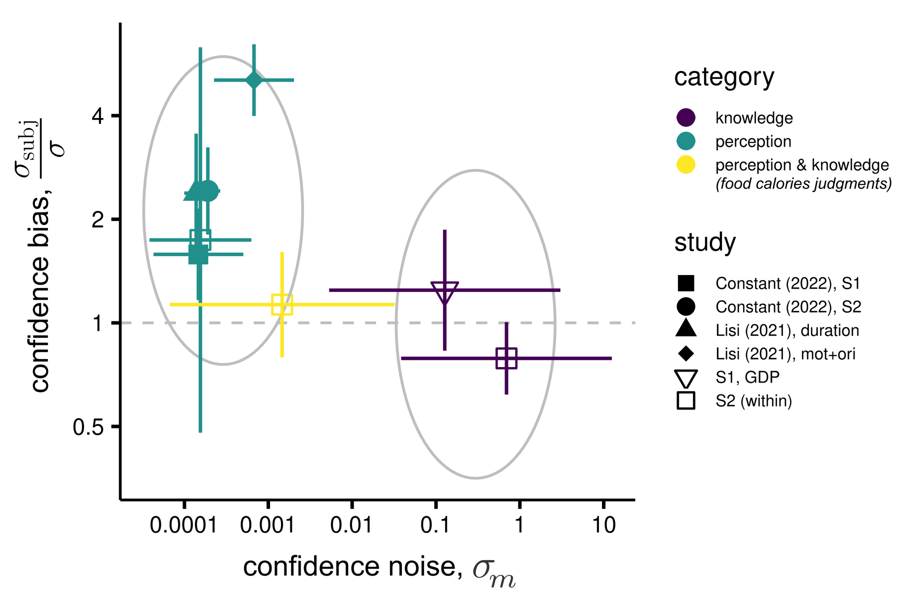
Participants chose → less than predicted by the 'standard' Bayesian model, but only in perceptual decisions.



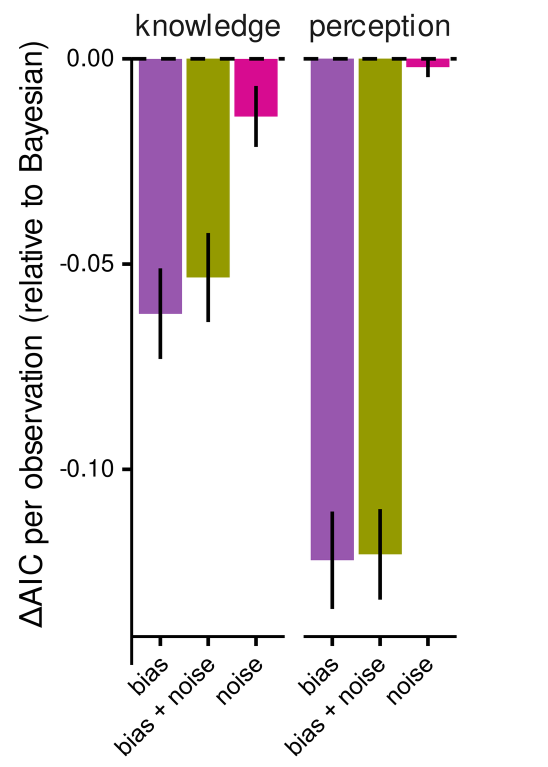
Confidence bias fits reveal ***systematic under-confidence in perception****, not in knowledge.*



Despite under-confidence, perceptual performance was not impaired.



Parameter estimates suggest that ***confidence noise accounts for more errors in knowledge than in perception tasks.***



Only in knowledge tasks does confidence noise outperform the 'standard' Bayesian model. Overall, confidence bias provides the best fit.

Discussion

Data from previous studies using the dual-decision task show consistent **under-confidence in perceptual decisions** (e.g., motion, duration, orientation tasks).

In knowledge-based decisions, we found no group-level under-confidence: unlike perception, **participants were as likely to be over- as under-confident**, consistent with classic overconfidence effects [4].

This difference was replicated in a within-subject design.

Under-confidence in perception did not impair performance. Compared to knowledge tasks, efficiency was similar or slightly higher).

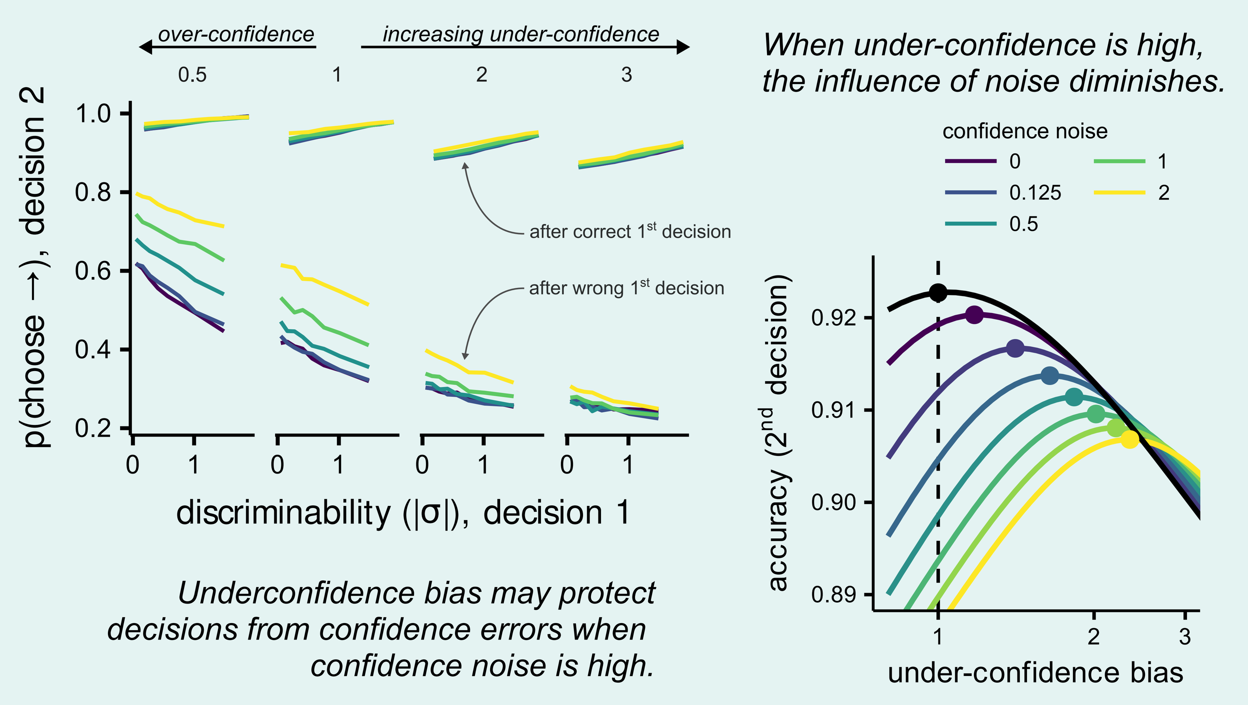
We introduced a model with confidence *noise* — trial-to-trial variability in internal noise estimates (e.g., sensory or knowledge uncertainty)

Confidence noise explained more errors in knowledge tasks. Noise estimates were significantly higher for knowledge than perception.

Bias and noise interact: under-confidence may offset noisy confidence estimates, suggesting it could be an adaptive strategy in perception.

Preliminary data from a food calorie comparison tasks suggest some domains blend perceptual and knowledge features, showing intermediate levels of noise and bias. Broader testing of more knowledge-based task is needed.

Interactions between confidence bias and confidence noise.



Underconfidence bias may protect decisions from confidence errors when confidence noise is high.

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