Efficient coding in auditory cortex determines target detection behavior

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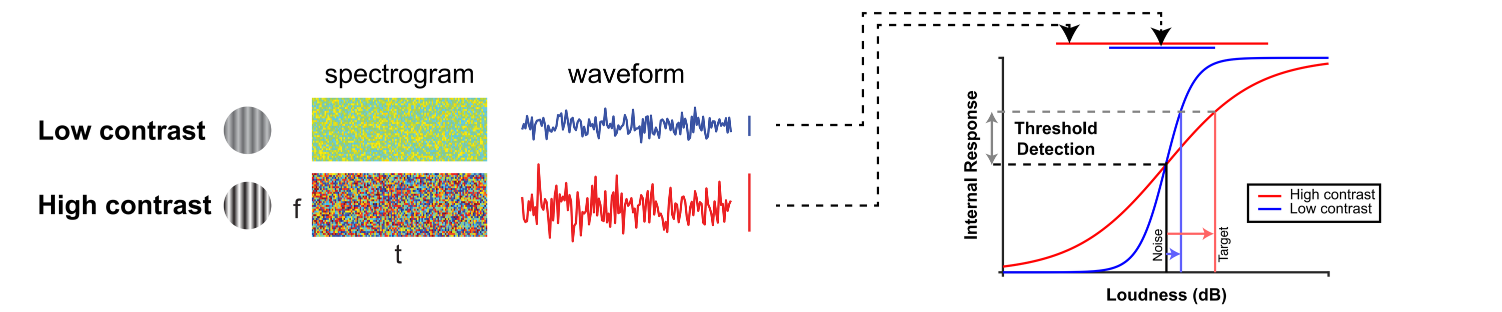
Background

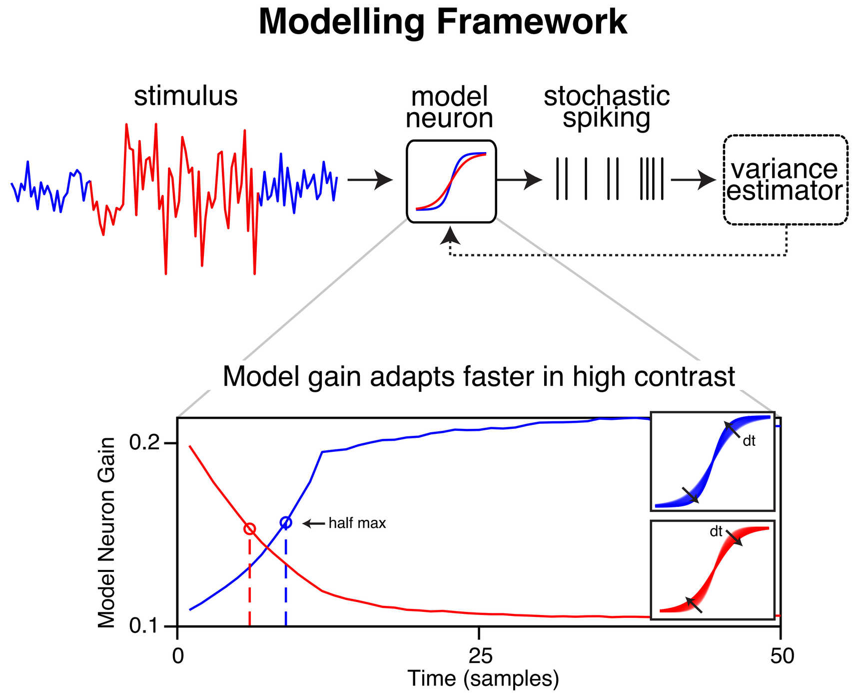
Efficient coding theory hypothesizes that neural systems are optimized to minimize the number of spikes needed to transmit sensory signals (Barlow, 1961). Given this constraint, it is necessary for sensory neurons to adapt their limited dynamic range to encode varying dynamic ranges of incoming information with high fidelity. In the auditory system, **contrast gain control** is a well-documented hallmark of efficient coding in the face of sensory variability. Neurons in auditory cortex (ACtx) adjust their gain to better encode acoustic stimuli with different variability, ie. different contrasts (Rabinowitz et al., 2011; 2013; Cooke et al., 2018; Lohse et al., 2020). However, it is unclear whether gain control in auditory cortex directly contributes to auditory percepts, and there is no current framework linking the neural phenomena to behavioral performance. **Here we chronically record populations of neurons in mice trained to perform a contrast-dependent detection task, and present a theoretical framework of efficient gain control to link our neural and behavioral findings.**

Acoustic Contrast | Gain Control

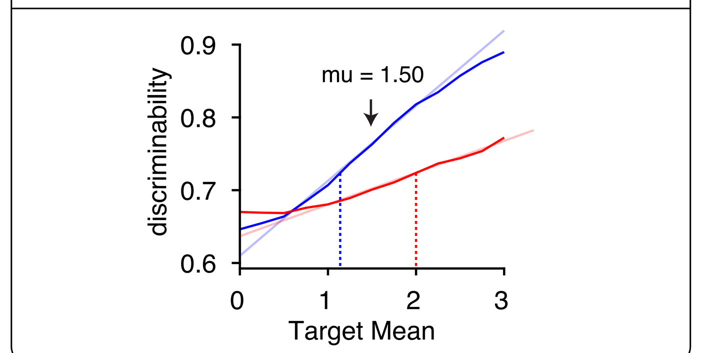


Efficient Coding Model Predictions

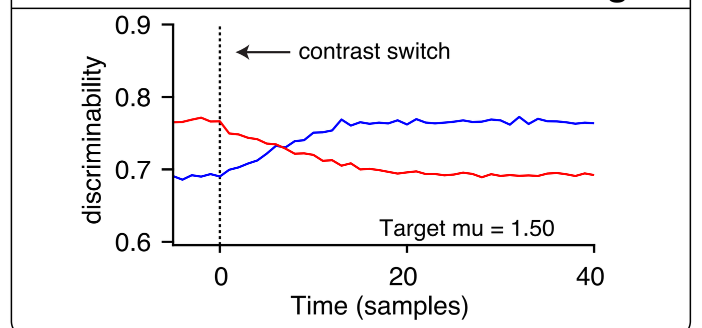
Modelling Framework



1. Detection is better in low contrast

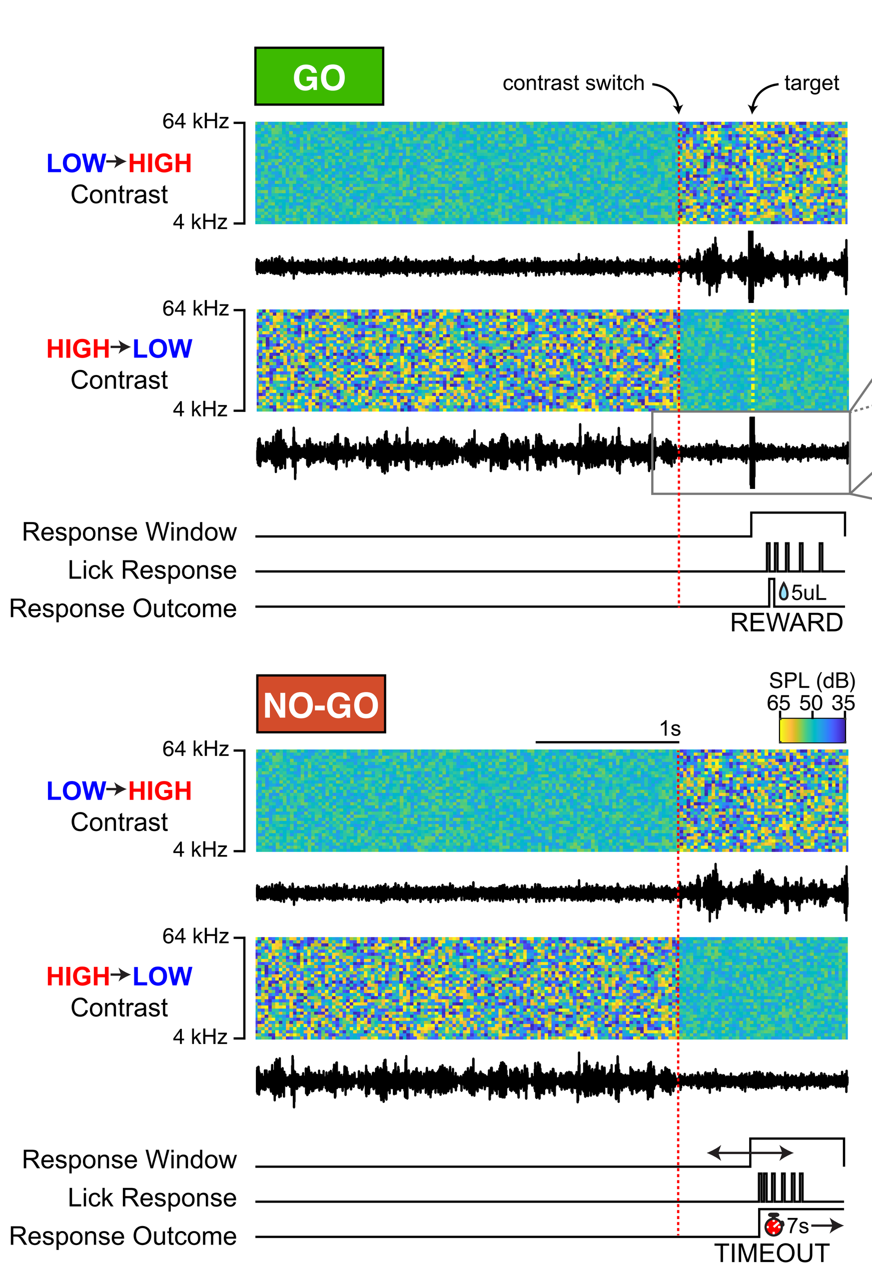


2. Performance timecourses diverge

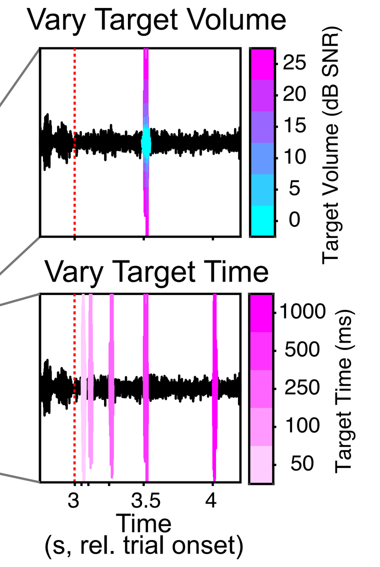


Materials and Methods

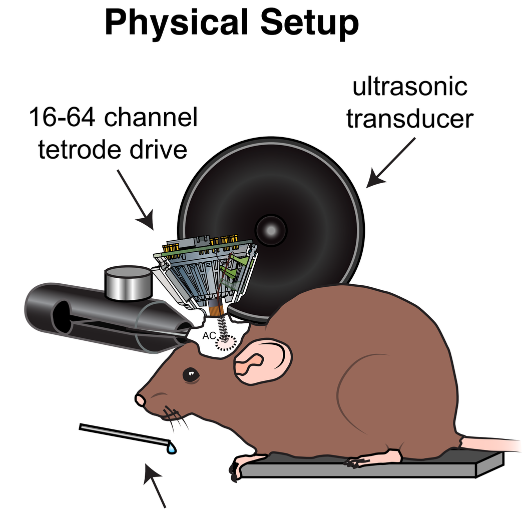
GO/NO-GO Task Design



Target Design

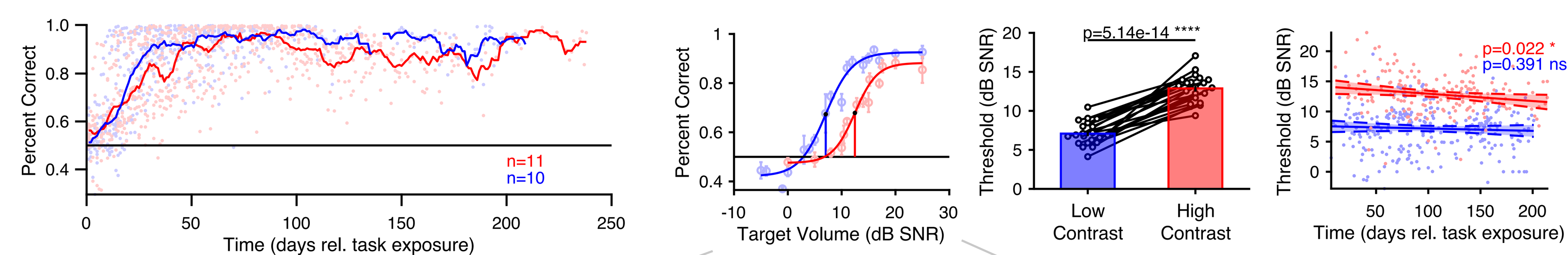


Physical Setup

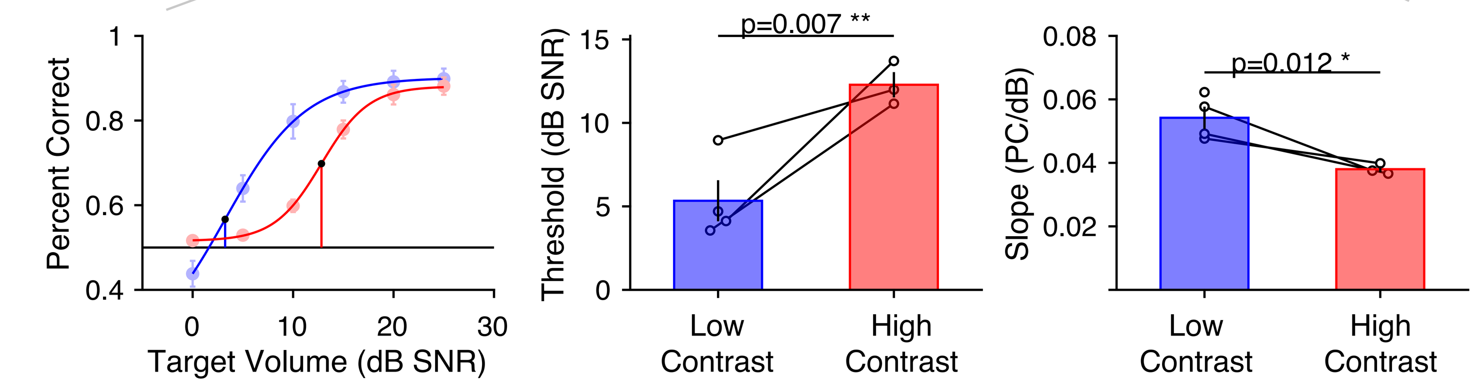


Behavioral performance is consistent with gain control

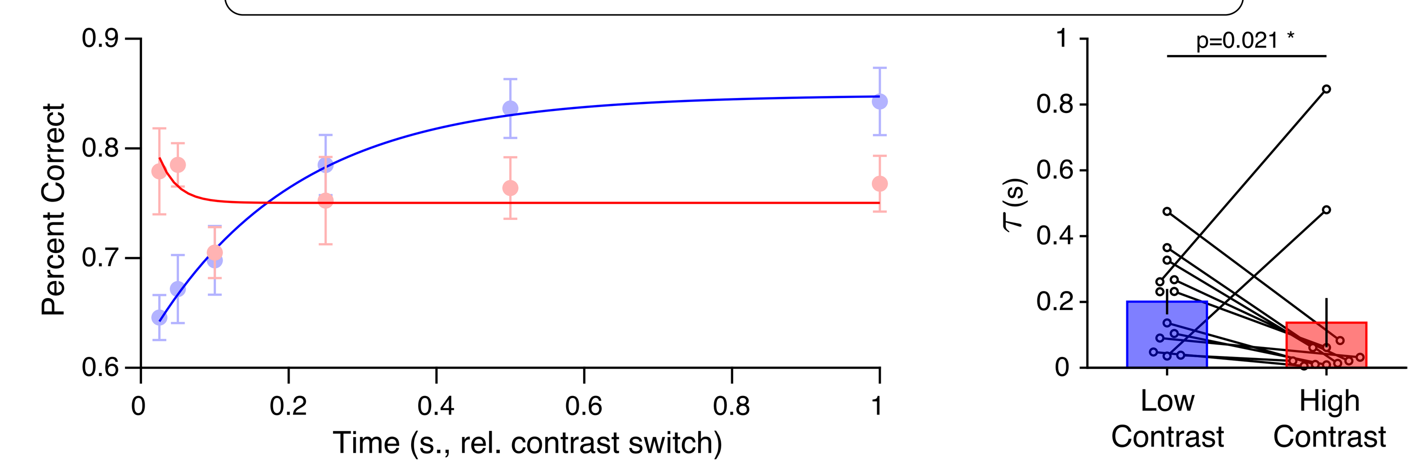
Performance over time | Detection thresholds are lower in low contrast



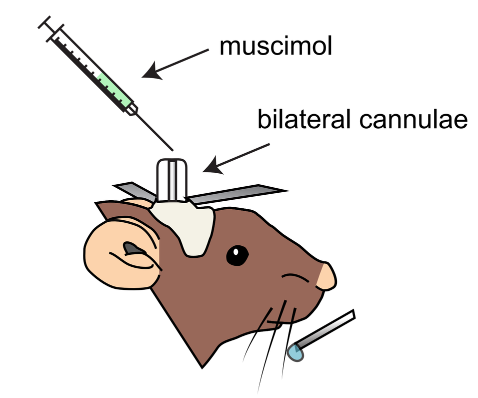
1. Psychometric slopes are steeper in low contrast and thresholds are lower in low contrast



2. Adaptation improves performance in low contrast, and decreases performance in high contrast (at a faster rate)

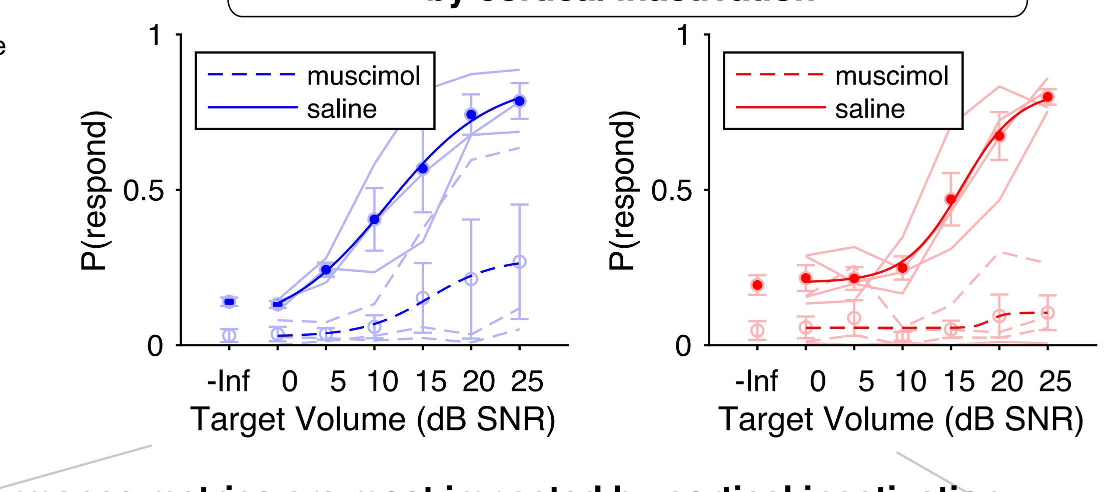


ACtx is necessary for behavioral performance

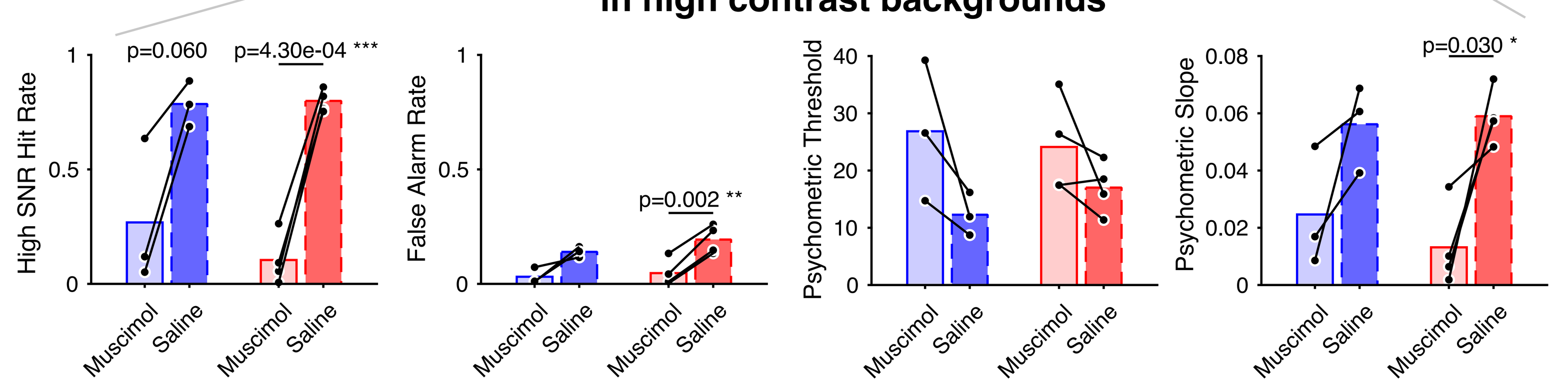


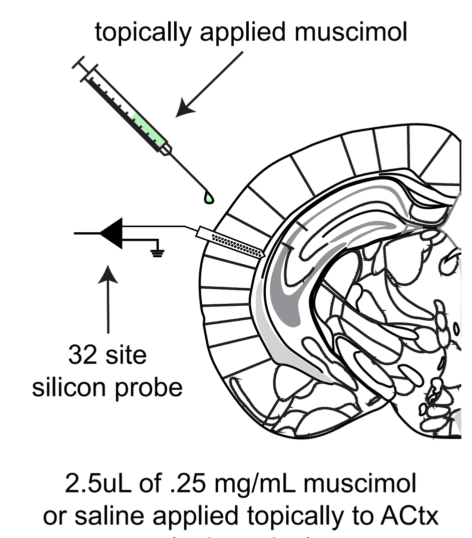
400-500nL of .25 mg/mL muscimol or saline injected bilaterally in ACtx

Psychometric performance is suppressed by cortical inactivation



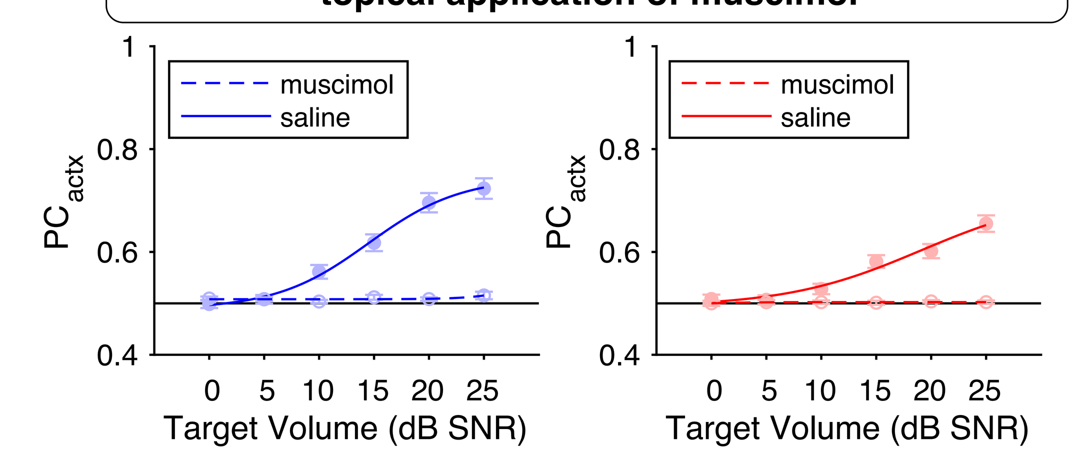
Task performance metrics are most impacted by cortical inactivation in high contrast backgrounds





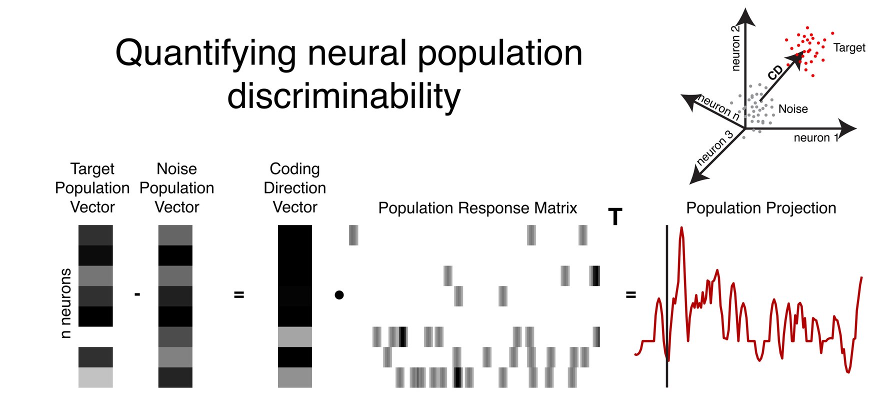
2.5uL of .25 mg/mL muscimol or saline applied topically to ACtx (naive mice)

Neurometric performance in ACtx is suppressed after topical application of muscimol

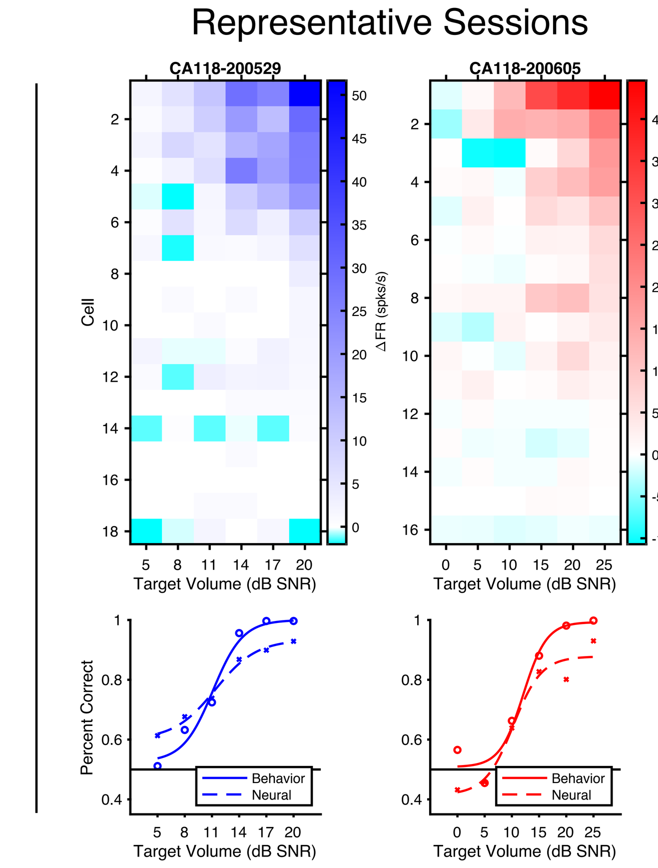


Population activity in ACtx predicts individual performance

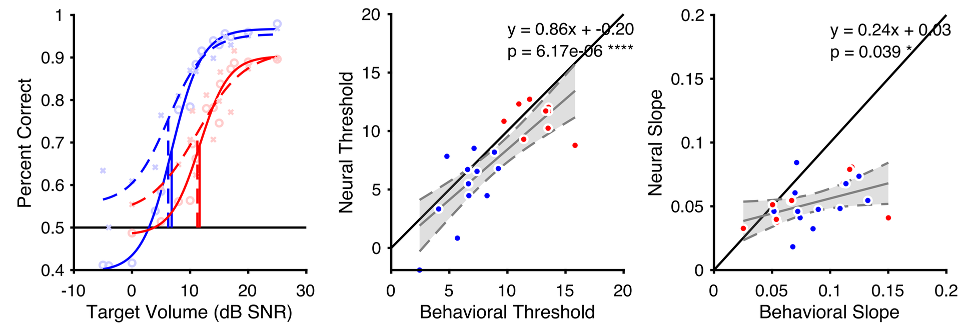
Quantifying neural population discriminability



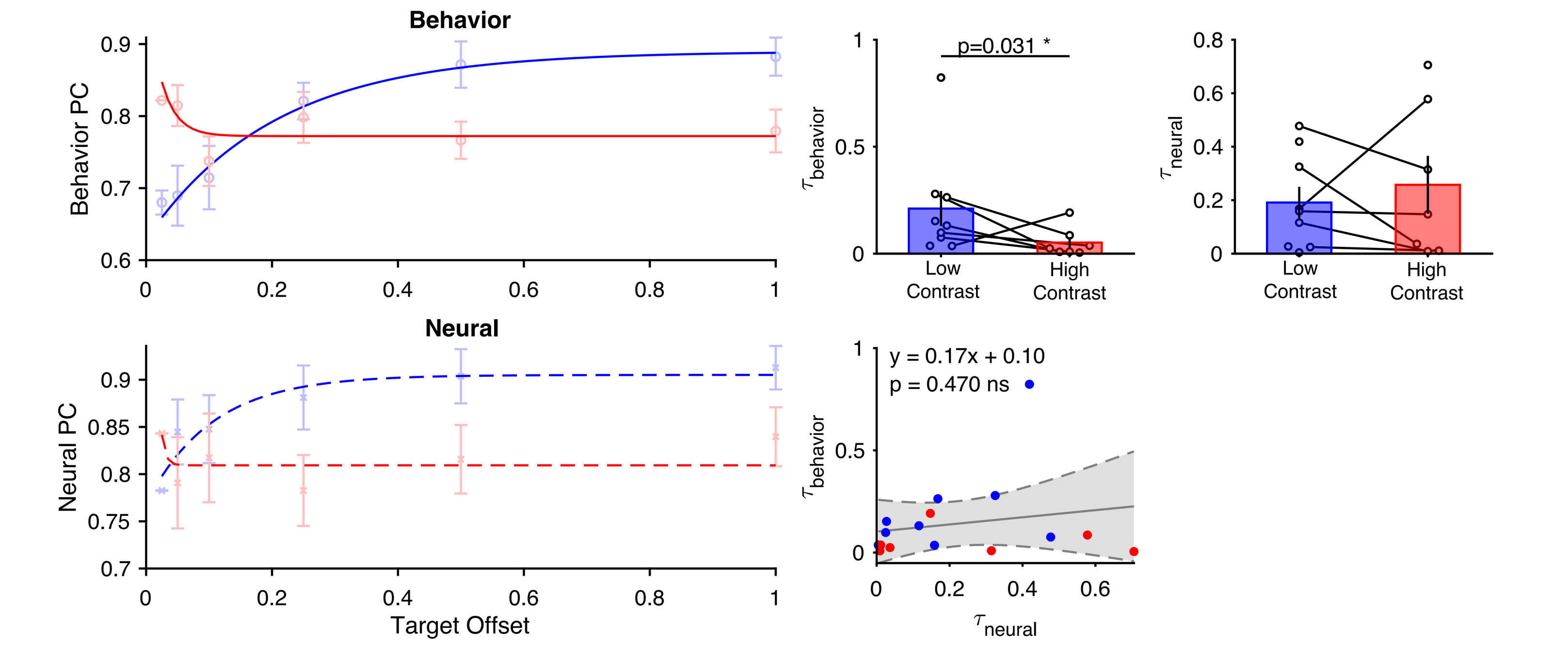
Representative Sessions



Population activity predicts individual variability in psychometric performance

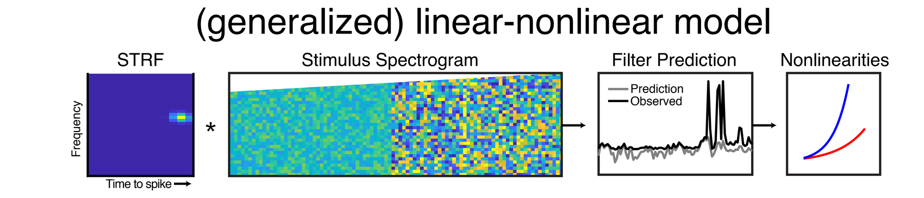


Population timecourses are qualitatively similar to behavioral detection timecourses but we do not observe the same temporal asymmetries

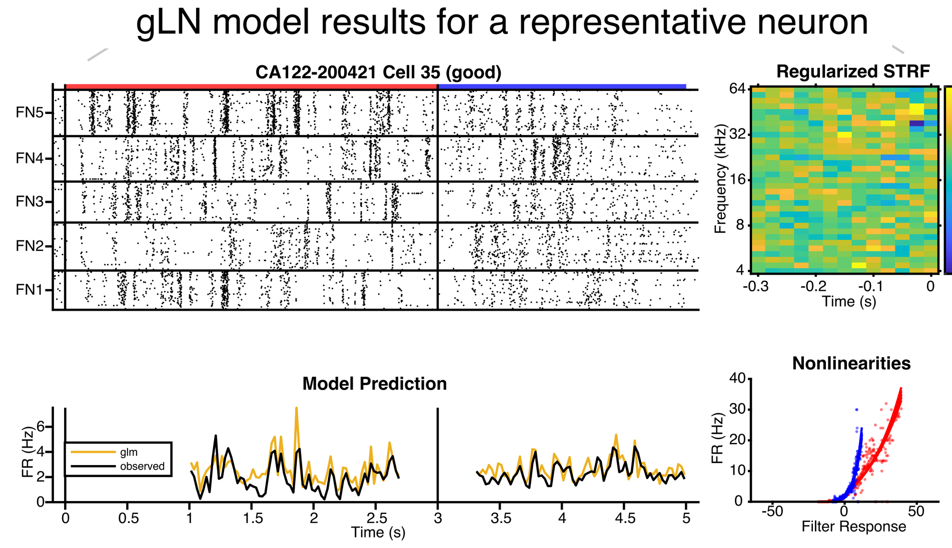


Gain in ACtx also predicts individual performance

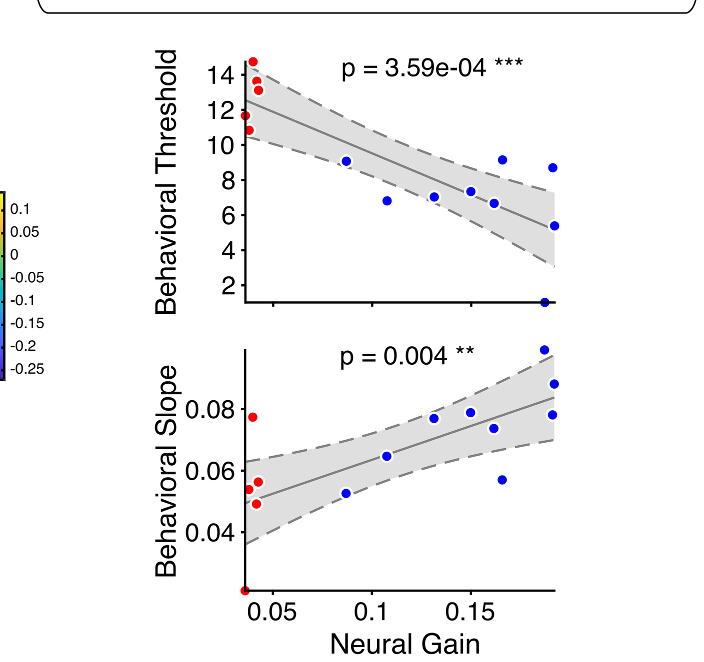
(generalized) linear-nonlinear model



gLN model results for a representative neuron



Amount of ACtx gain in individual mice predicts their psychometric threshold and slope



Conclusions

1) A normative model of contrast gain control predicts contrast-dependent changes in psychometric performance and specific patterns of behavioral adaptation.

2) We designed a novel target-in-noise detection task to show the model predicts observed contrast-dependent behavioral changes.

3) Muscimol inactivation experiments show necessity of ACtx in performing this task.

4) Chronic recordings of population activity in ACtx show that population representations predict behavioral variability across mice.

5) Estimated amount of cortical gain during the task predicts individual differences in behavior.

Acknowledgements

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