Machine Learning Approaches for Estimating Cortical States in the Awake Mouse

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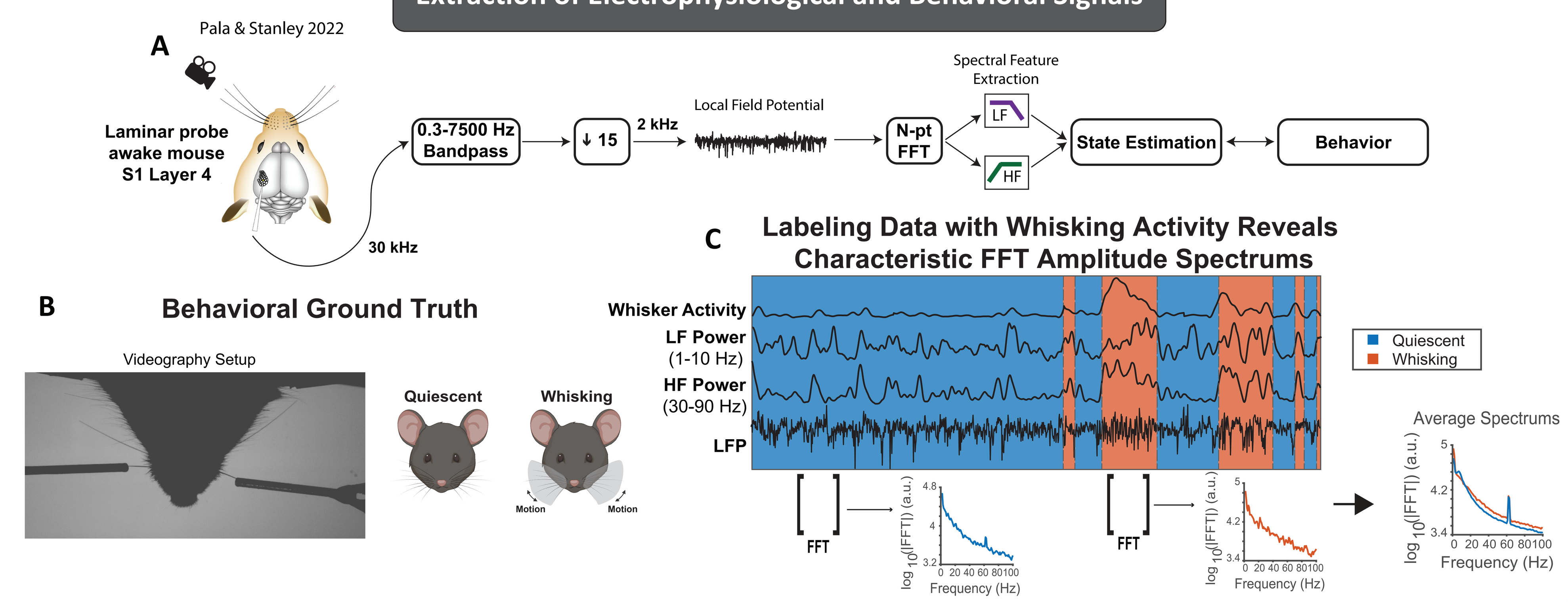
Background

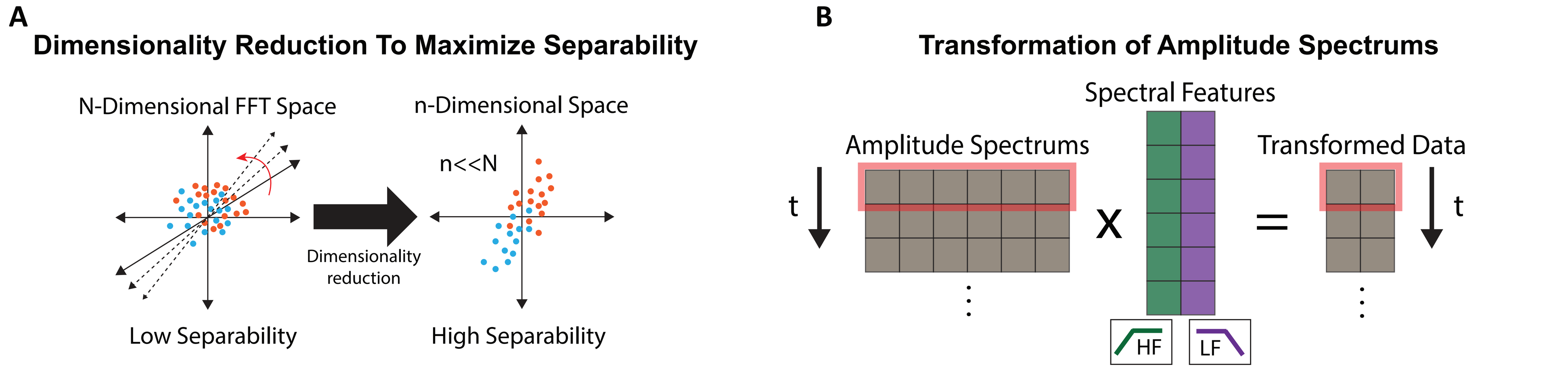
Local cortical activity patterns, or ***cortical states***, vary with behavioral context. Importantly, these cortical states profoundly modulate cortical function, e.g., by shaping sensory processing across various sensory modalities (Harris & Thiele 2011; Poulet & Crochet 2019). Though there has been much effort to characterize cortical states, they are typically defined in an *ad hoc* manner that is unsuitable for robust, ***real-time estimation***. For example, a common approach is to threshold on the ratio of power between a canonical low-frequency (LF; 1-10 Hz) and high-frequency (HF; 30-90 Hz) band (Sederberg, et al. in prep.).

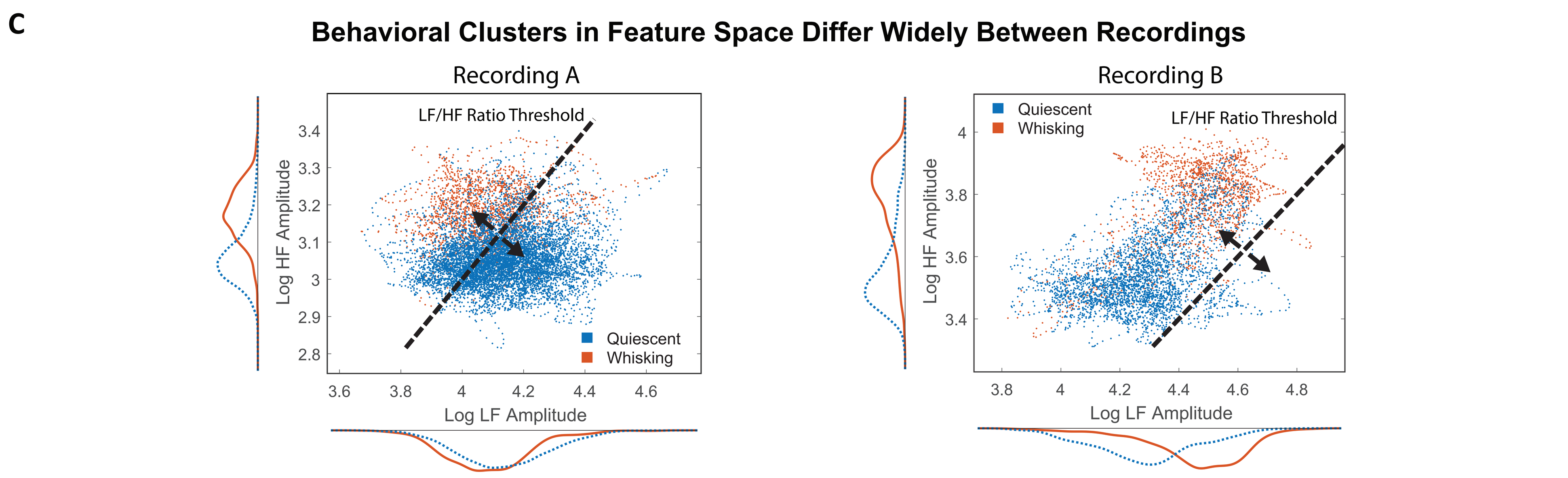
Here we use data-driven approaches to estimate cortical states from real-time accessible LFP signals. We build unsupervised models of cortical state that leverage both the statistical and temporal structure of the data to increase ***robustness across animals***. Finally, we use behavioral videography as a ground truth proxy for cortical state to evaluate model efficacy.

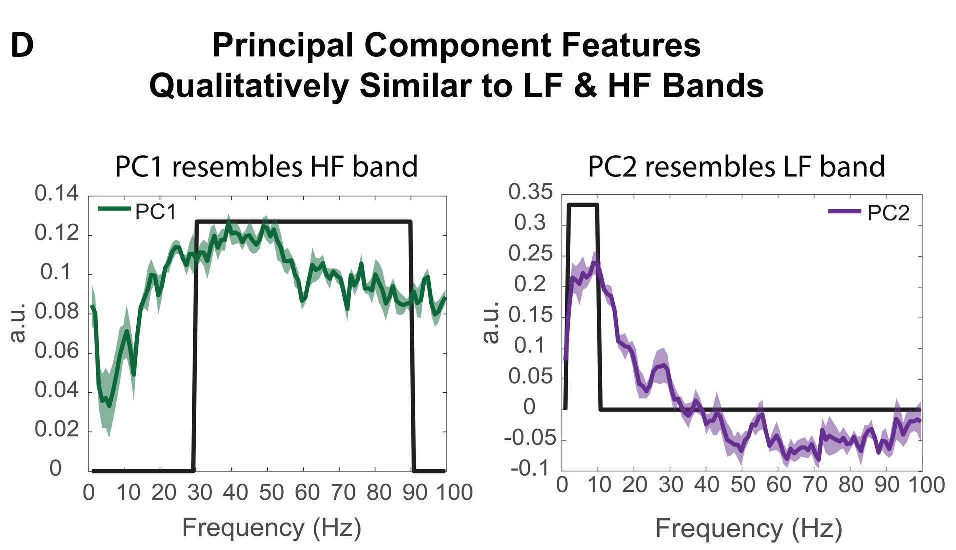
Extraction of Electrophysiological and Behavioral Signals

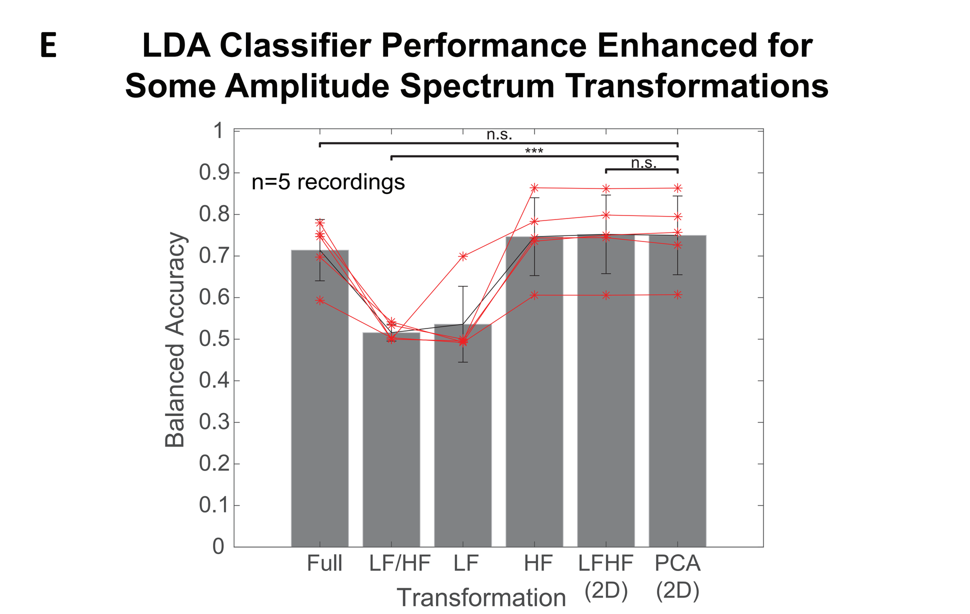


Emergent Low-Dimensional Features Robustly Separate Behavioral Epochs

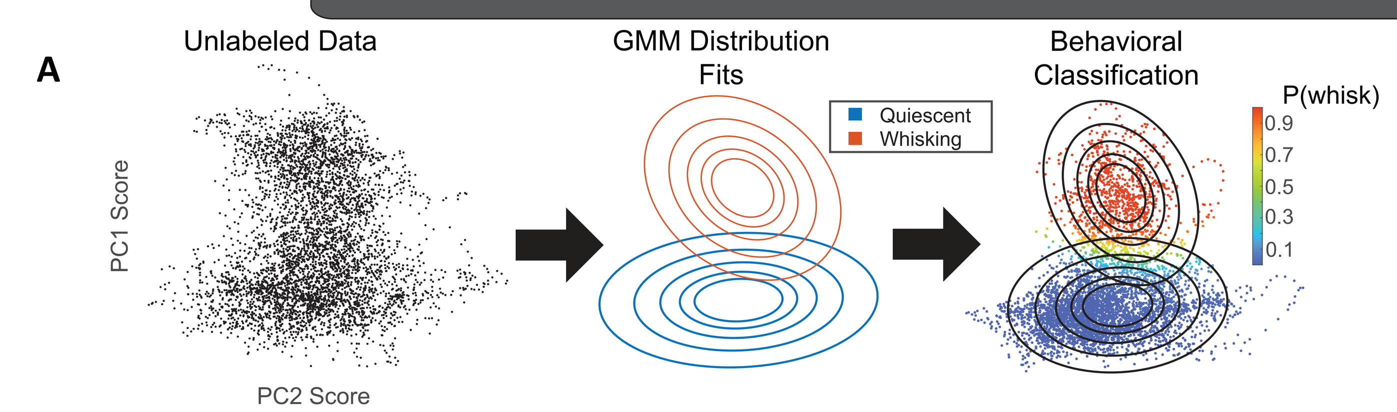


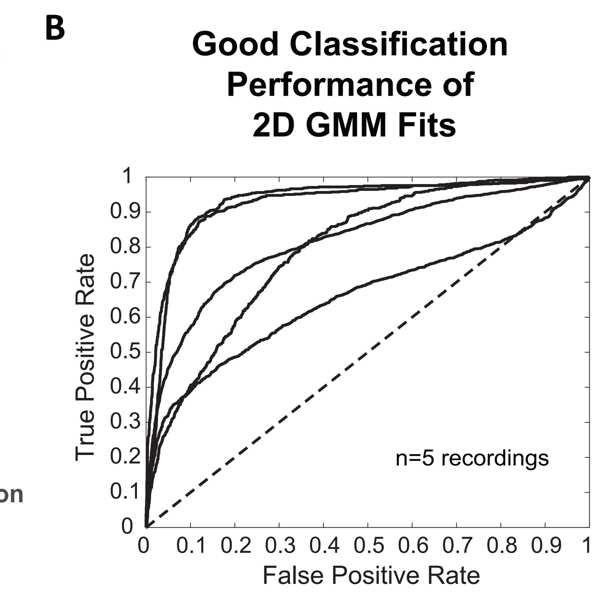


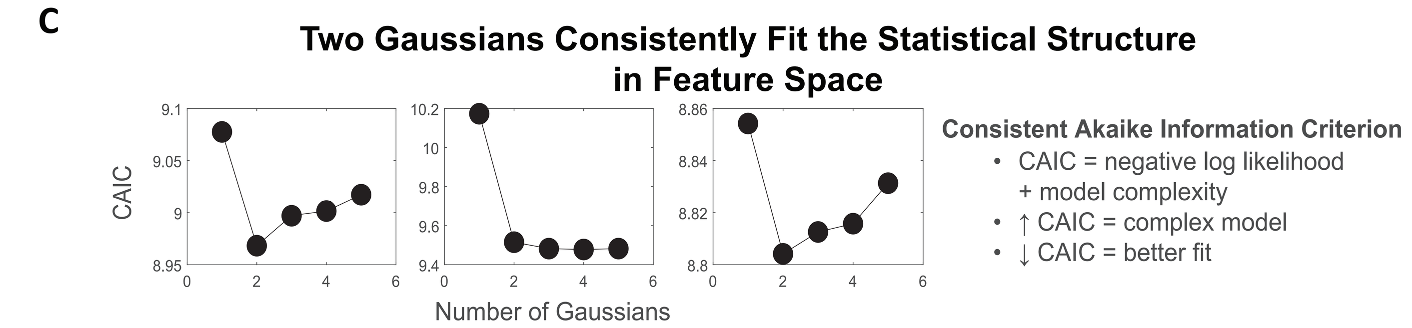




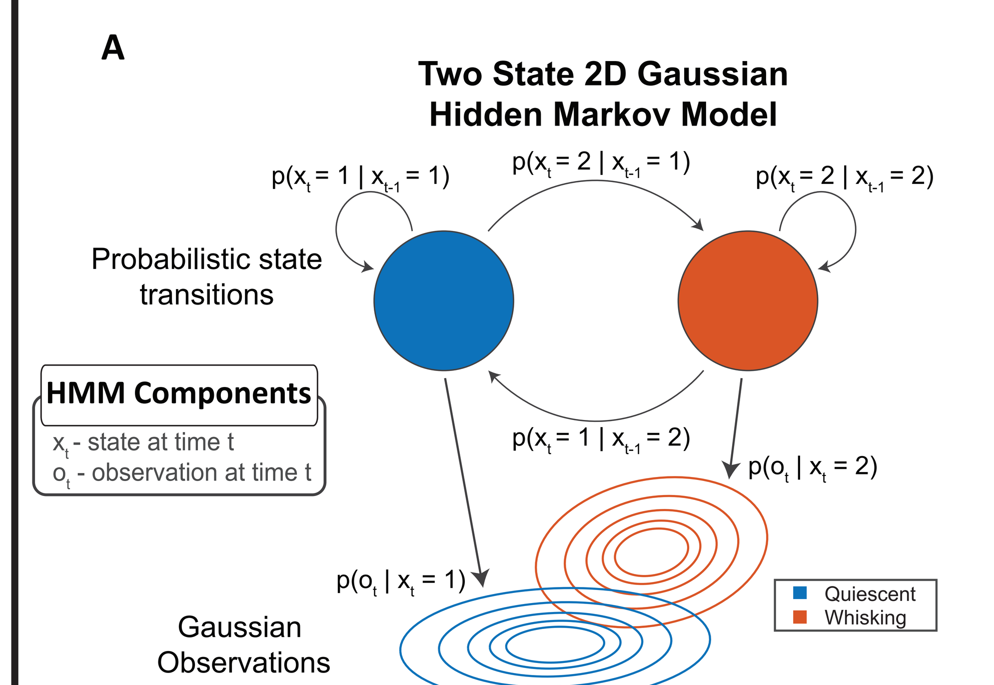
Unsupervised Gaussian Mixture Model Clusters Recapitulate Behavioral Clusters

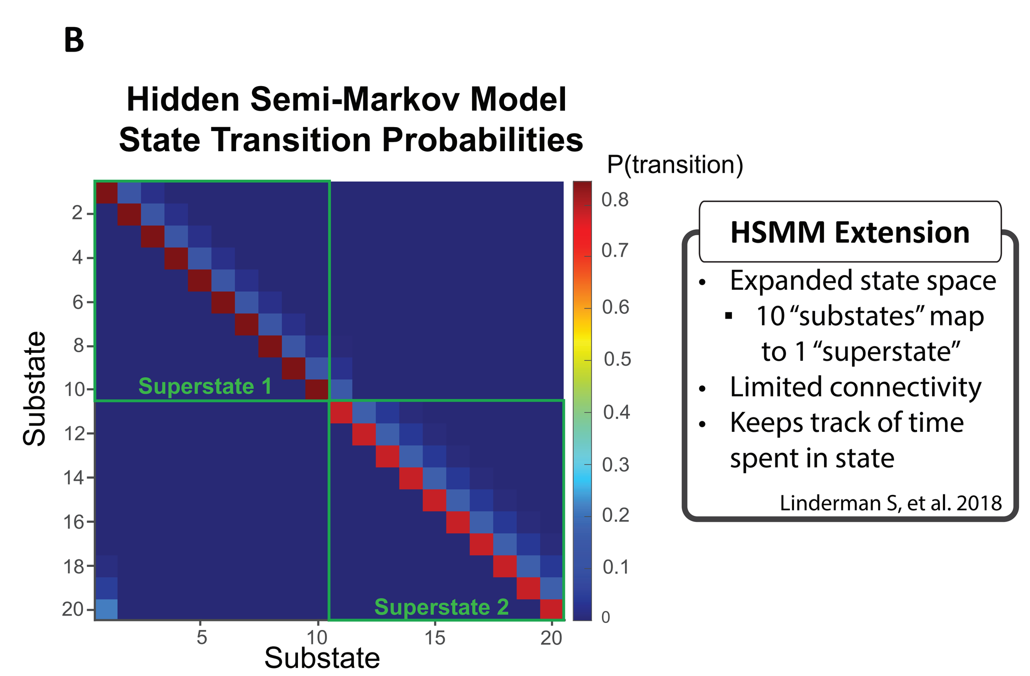


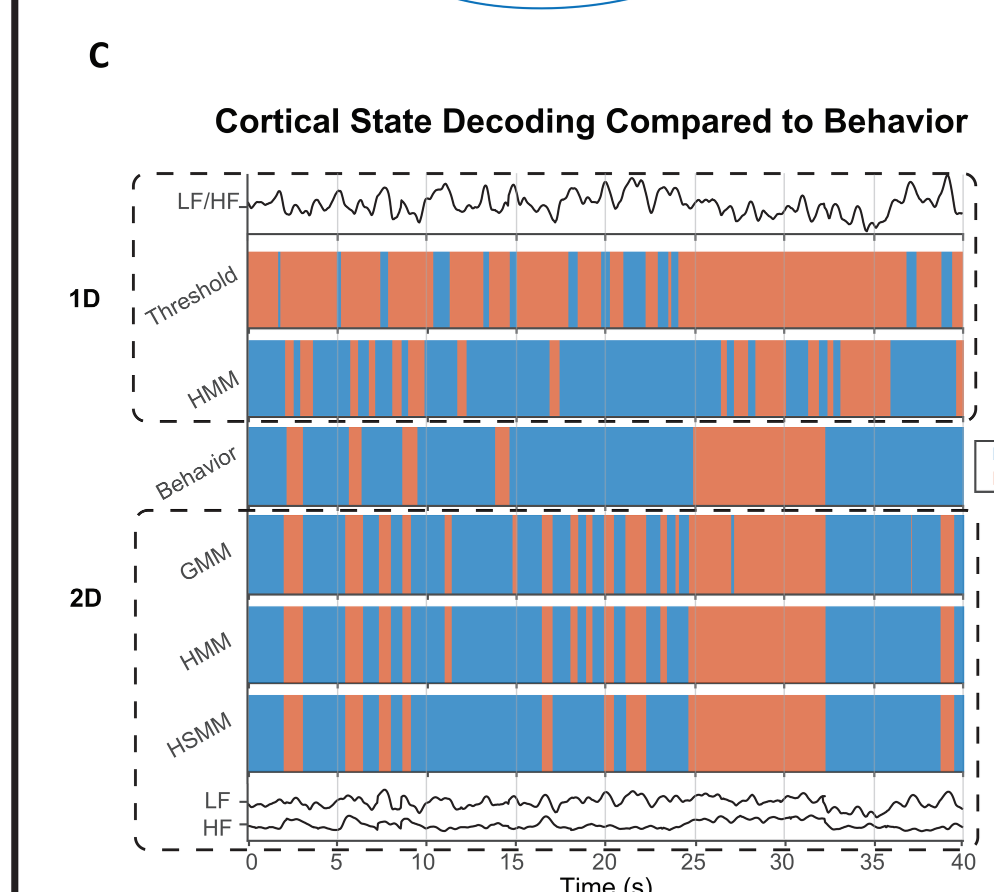


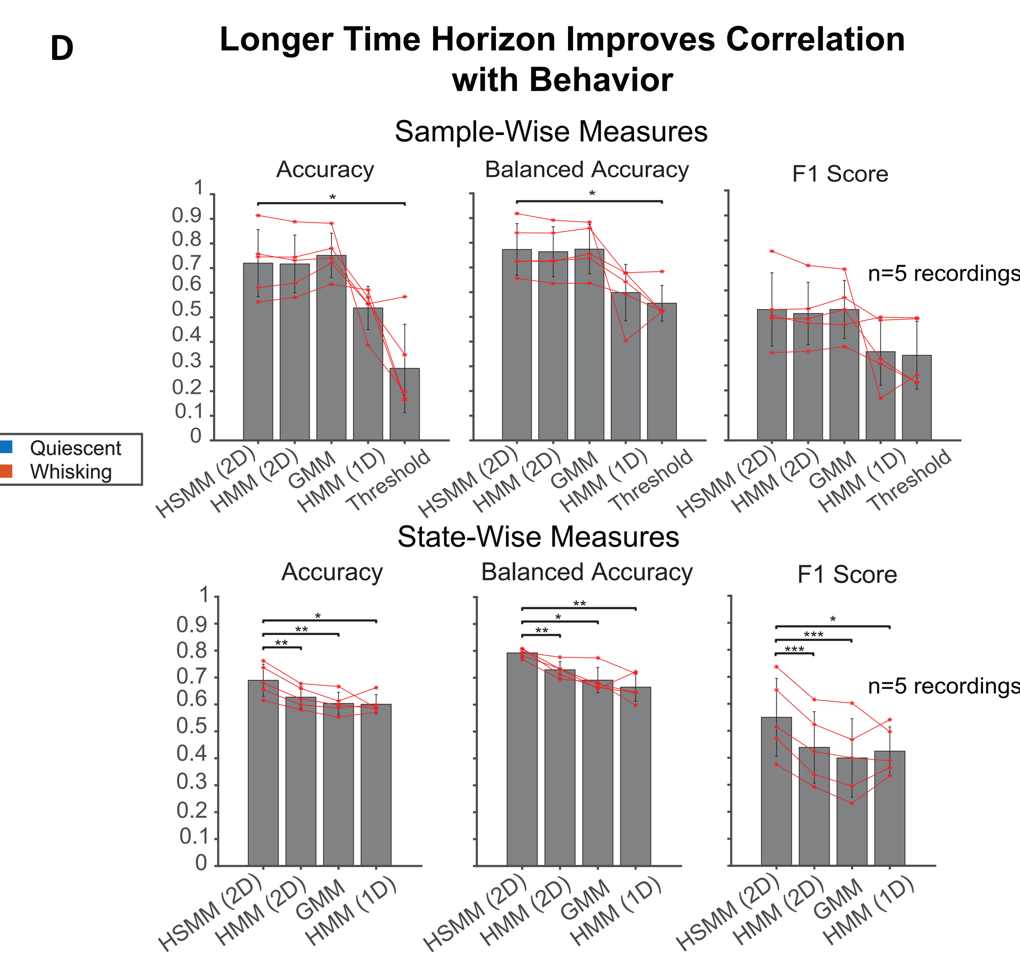


Leveraging Temporal Dynamics of State Transitions Increases Correlation Between Decoded and Behavioral States









Summary

- Cortical states are well separated in low-D spaces derived from PCA and canonical LF & HF bands
  - However, the LF/HF ratio does not robustly separate cortical states across all animals
- Unsupervised clustering models recapitulate behaviorally labeled clusters
- Leveraging temporal information improves cortical state estimation
- Future Directions: (1) Real-time Algorithms, (2) Multichannel LFP, (3) Pupillometry

References

[1] Harris, K. D. & Thiele, A. Cortical state and attention. Nat Rev Neurosci 12, 509–523 (2011). [2] Poulet, J. F. A. & Crochet, S. The Cortical States of Wakefulness. Front Syst Neurosci 12, 64 (2019). [3] Pala, A., & Stanley, G. Ipsilateral stimulus encoding in primary and secondary somatosensory cortex of awake mice. J Neurosci 42(13), 2701–2715 (2022). [4] Sederberg, A., Pala, A., & Stanley, G. B. Linking states of the local field potential and spiking activity through temporal dynamics (in preparation). [5] Linderman, S., Antin, B., Zoltowski, D., & Glaser, J. SSM: Bayesian Learning and Inference for State Space Models (0.0.1). https://github.com/lindermanlab/ssm (2018).

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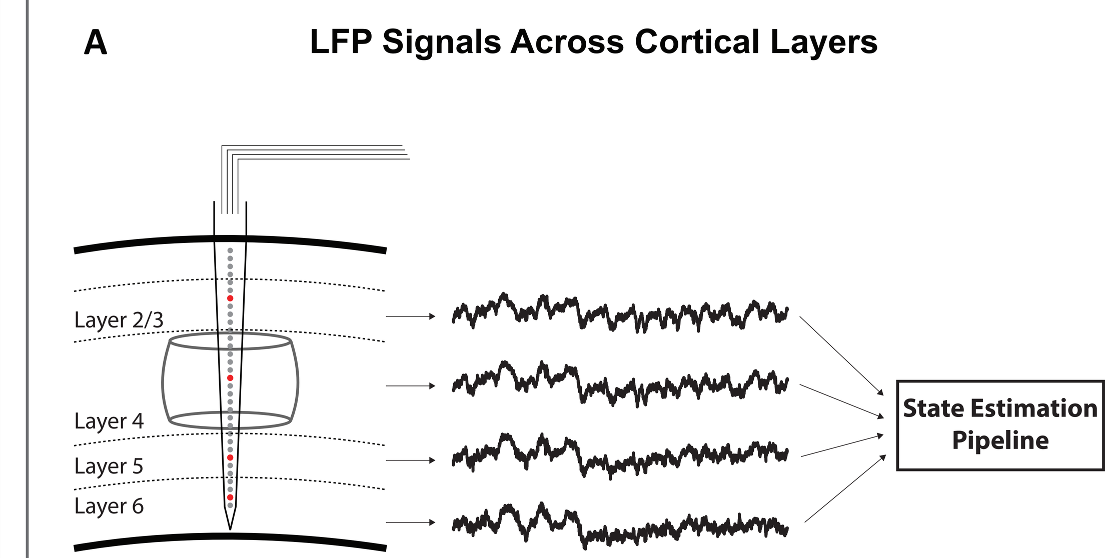
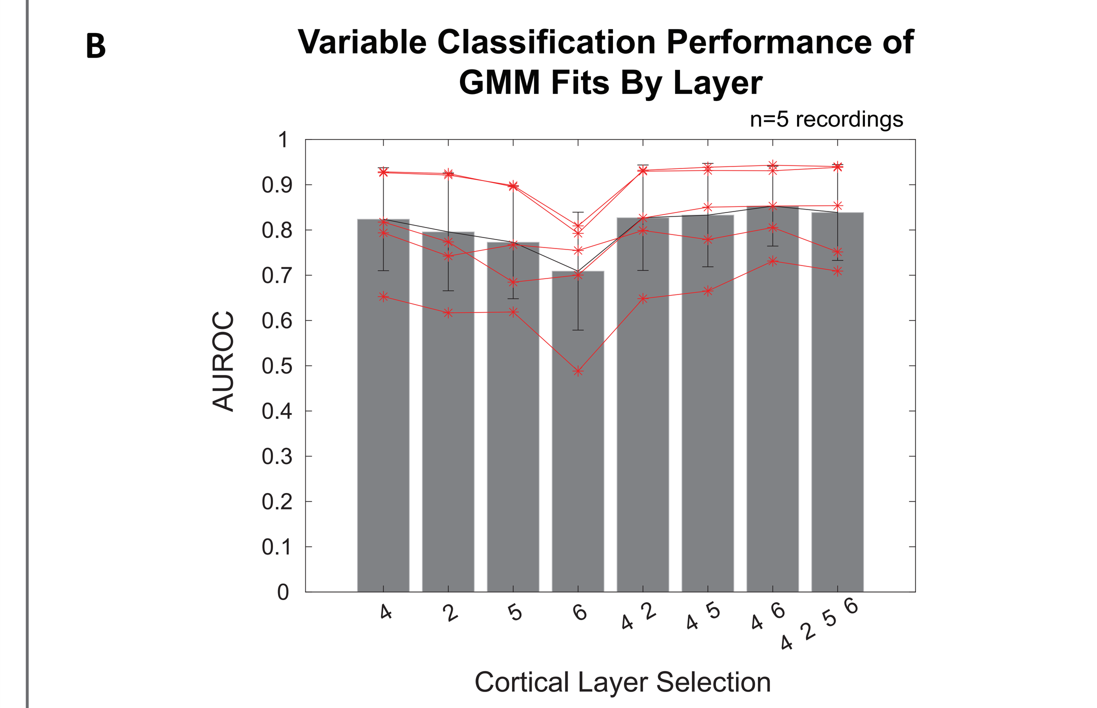
Future Directions and Preliminary Results

Multichannel LFP Analysis





Real-time State Estimation