A MANIFOLD OF HETEROGENEOUS VIGILANCE STATES ACROSS CORTICAL AREAS

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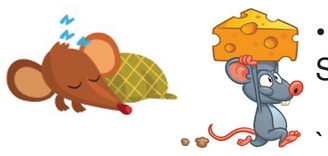
What defines sleep and wake states?

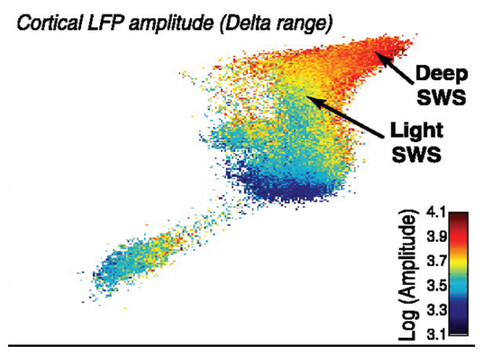


• Vigilance states are traditionally categorized as global REM, SWS, and Wake

• This omits transitions and microstates

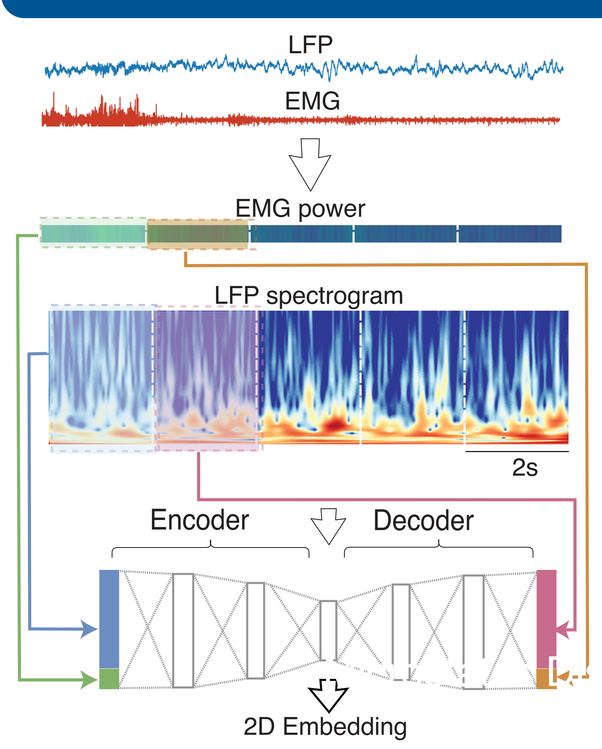
• Evidence for manifold rather than distinct states (Gervasoni, et al. 2004)

• Evidence of local brain states (Soltani, et al. 2019)



Gervasoni et al. 2004

Discovering vigilance states with variational autoencoders

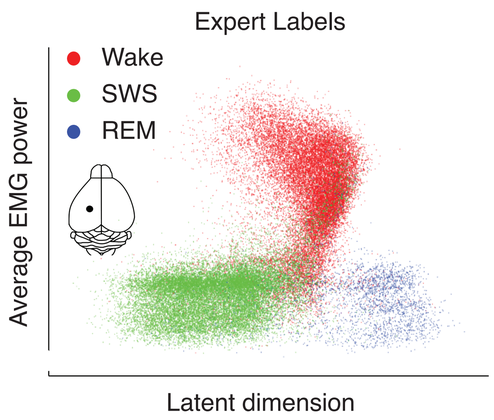


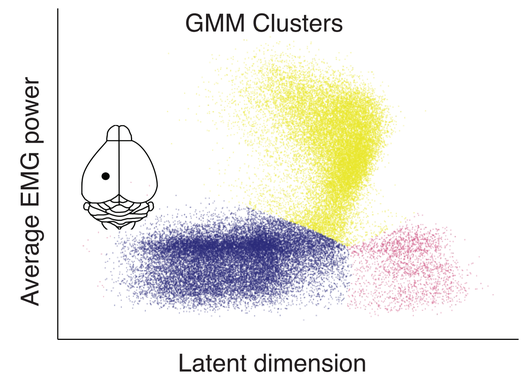
• We transform LFP & EMG signals into time-frequency spectra

• For each 2 second window, a 31-dimennsional vector of LFP spectrogram and average EMG power provide an input to a variational autoencoder that predicts the next point in time

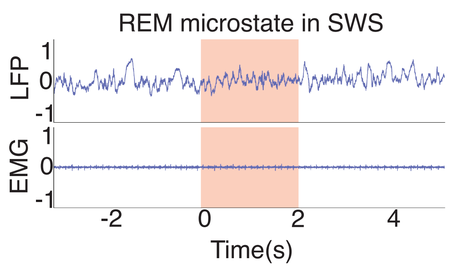
• The 2D embedding separates 3 basic states as verified by expert labels

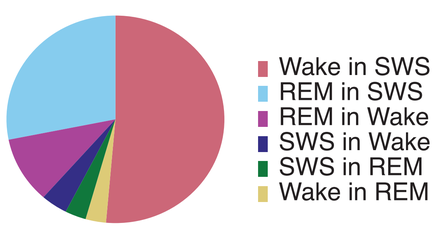
• Clustering by Gaussian Mixture Model (GMM) has 82% agreement with expert labels, matching inter-expert agreement

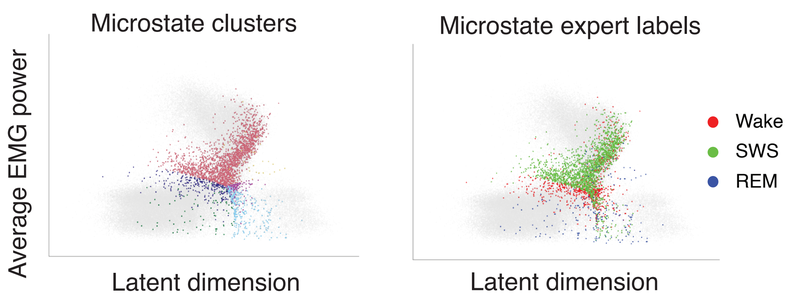




Detecing microstates



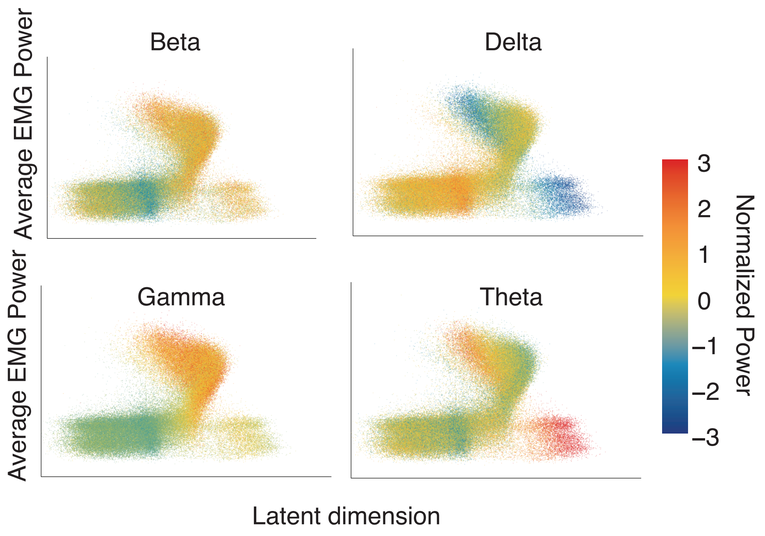




• We define micro-states as any state of 6 seconds or less within another state

• Microstates account for less than 3% of time

Interpreting latent space through LFP frequency bands



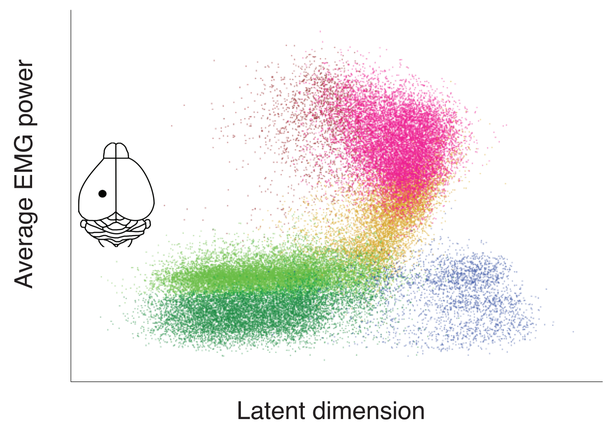
•Theta and delta bands are important for distinguishing REM and SWS.

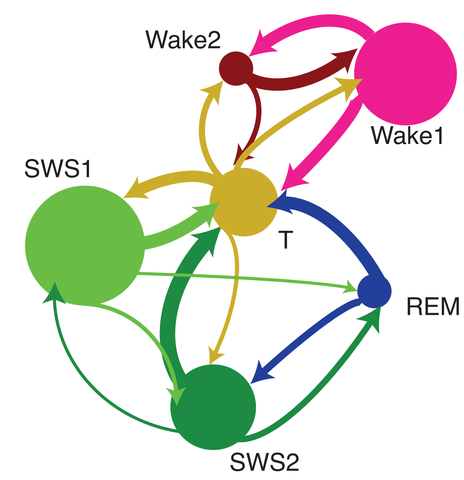
• Gamma band is high powered in Wake.

• LFP frequency bands nonlinearly tile the latent space

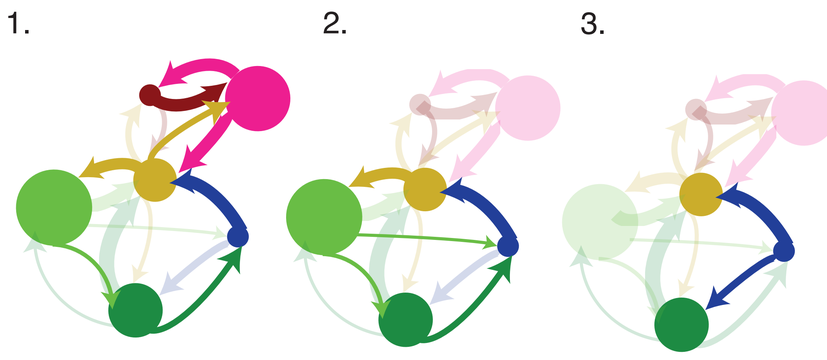
Dynamics of state transitions revealed by HMM

• Substates & transition states can be discovered by fitting a Hidden Markov Model
• We identified six states including 2 substates of SWS, 2 substates of Wake, 1 REM state, and one transition state.

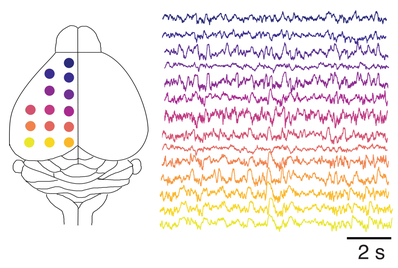




1. Any transition from wake to sleep and vice versa passes through the transition state
2.There is no transition from wake to REM without passing through SWS
3. There is no transition from REM to SWS1

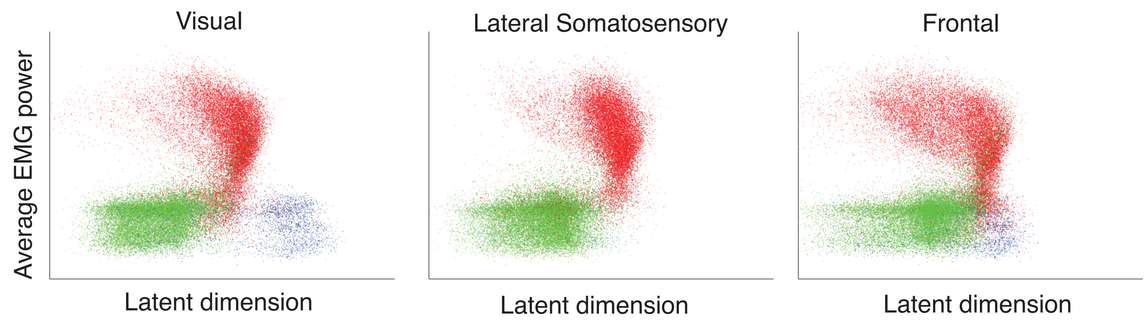


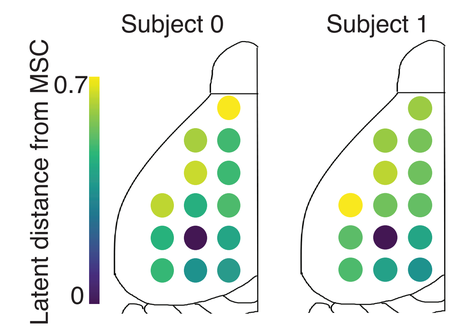
Heterogeneous expression of states across the cortex



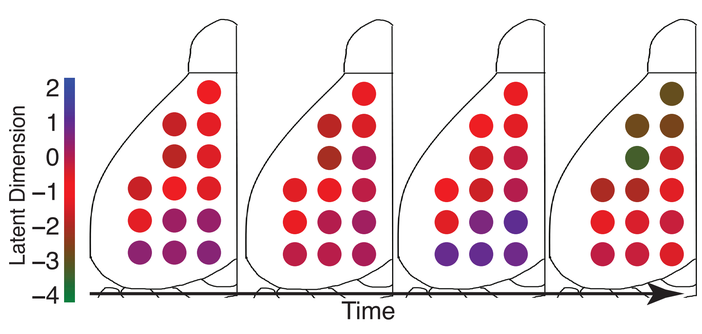
• We apply the model trained on the LFP from medial somatosensory cortex to LFP signal from other electrodes

• Different regions show differences in the expression of the three states, such as absence of REM in lateral somatosensory cortex and existence of Gamma-heavy wake in frontal

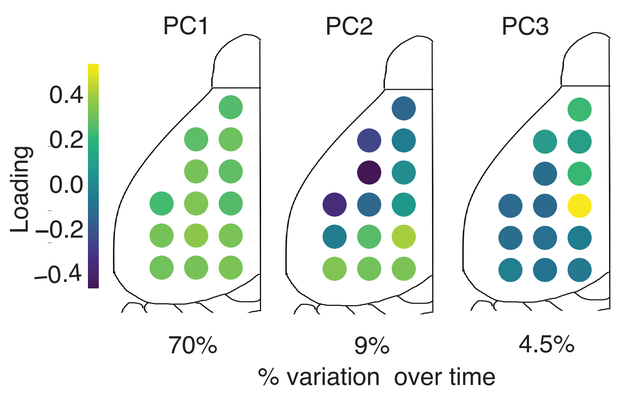




Variations in latent encodings per electrode are reproduceable across subjects



Different cortical areas can exhibit different states at the same time.



Global state changes account for 70% of the variation over time

Any deviations from the unifofrm global state show a division between the medial posterior, lateral frontal, and medial frontal

Conclusions

• Variational autoencoders provide a powerful framework for characterizing a manifold of vigilance states
• There is hetereogenity in the expression of states is present across the cortex and the coexistence of different states in different areas.
• Future work will focus on further characterizing the dynamics governing each global state made up of several local states

Acknowledgments

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