A MANIFOLD OF HETEROGENEOUS VIGILANCE STATES ACROSS CORTICAL AREAS

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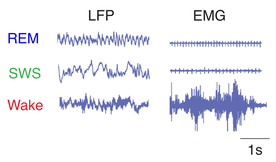
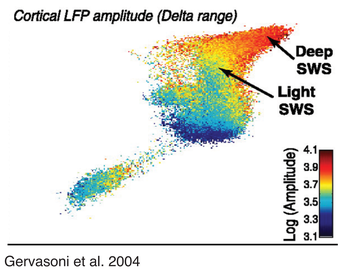
Canonical sleep/wake states insufficient



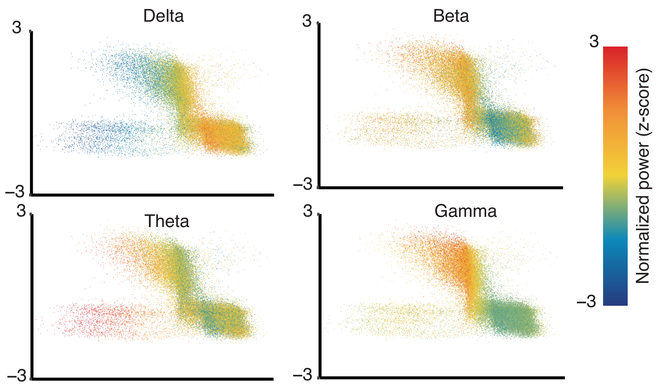
- Vigilance states are traditionally categorized as global REM, SWS, and Wake
- Omits transitions and micro-states

- Are vigilance states continuous on a manifold rather than distinct?(Gervasoni, et al. 2004)
- Can brain states be locally heterogeneous? (Soltani, et al. 2019)



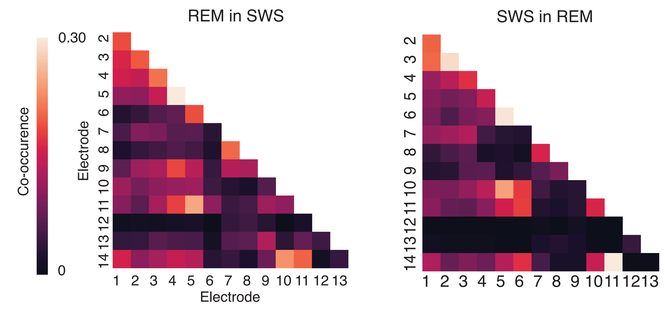
Gervasoni et al. 2004

Interpreting latent space through frequency bands



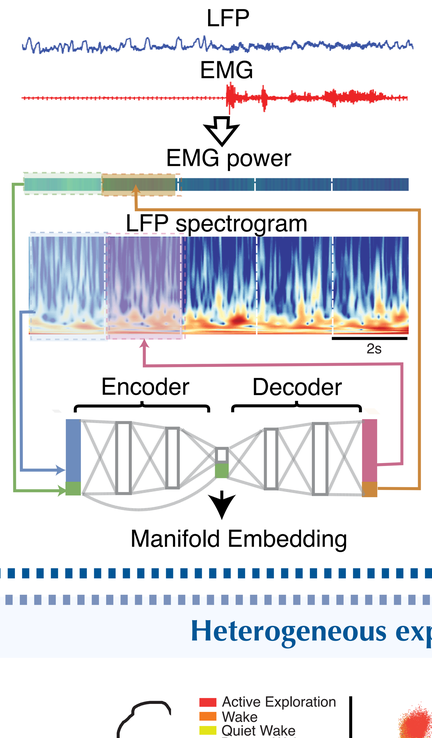
- Theta and delta bands are important for distinguishing REM and SWS.
- Gamma band is high powered in Wake.
- LFP frequency bands nonlinearly tile the latent space

Spatially heterogeneous microstates

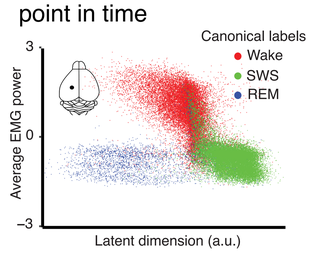


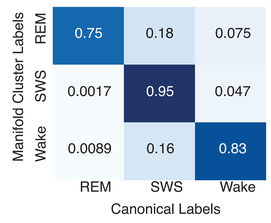
- Other non-global segments may be heterogeneous microstates
- We find co-occuring microstates between electrodes occur in specific patterns per microstate type
- Microarousals are global because they are defined by EMG power

Discovering vigilance states with variational autoencoders



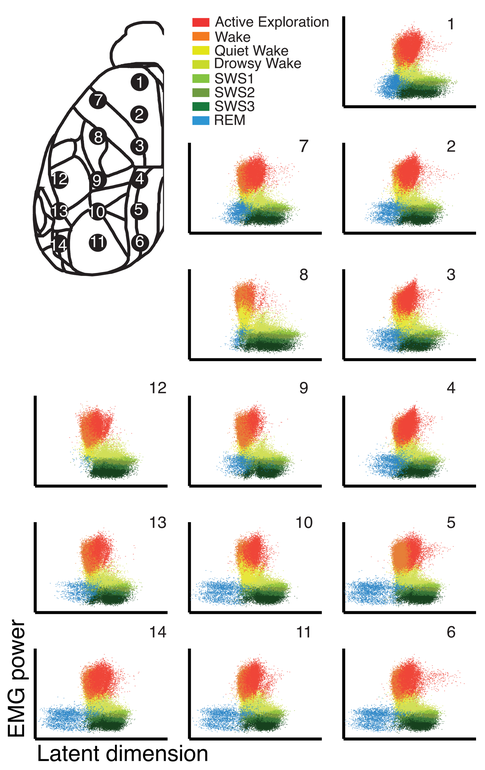
- We transform LFP & EMG signals into time-frequency spectra
- For each 2 second window, a 31-dimensional vector of LFP spectrogram and average EMG power provide an input to a variational autoencoder that predicts the next point in time

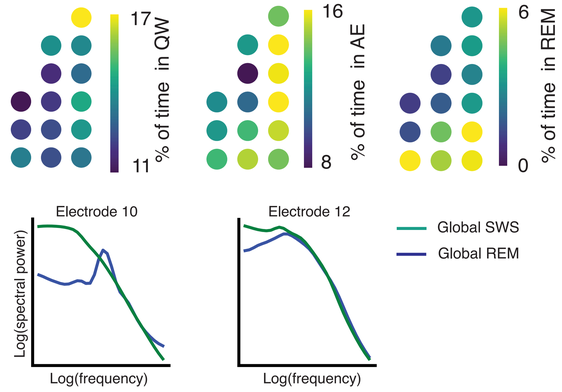




- The 2D embedding separates 3 basic states.
- Clustering by GMM agrees with Wake, SWS, and REM states identified by canonical algorithms.

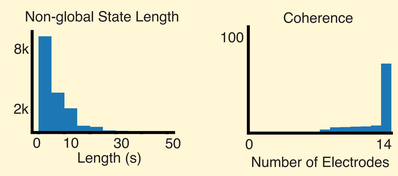
Heterogeneous expression of states across the cortex

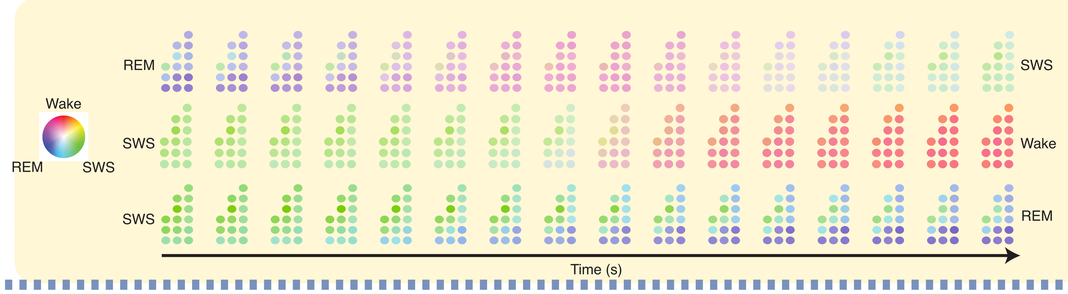




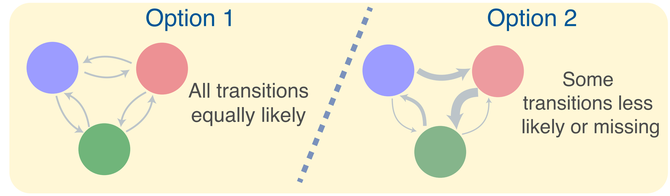
- REM sleep (blue) is missing or partial for lateral electrodes
- Active exploration is more prominent in medial frontal

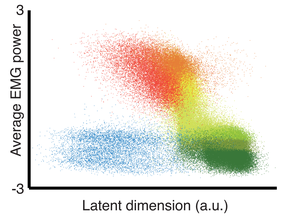
Stereotyped spatiotemporal patterns





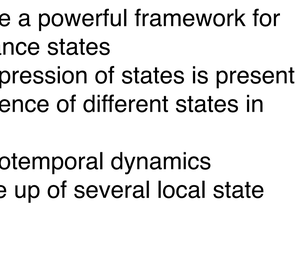
HMM reveals substates and transition patterns



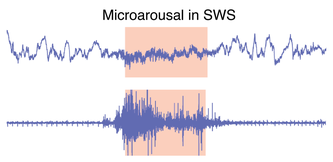


- Substates & transition states can be discovered by fitting a Hidden Markov Model
- We identified 8 states including 4 substates of SWS, 1 REM state, and 4 substates of Wake.

- Any transition from wake to sleep and vice versa passes through the quiet/drowsy wake
- There is no transition from wake to REM without passing through SWS
- There is no transition from REM to lighter SWS

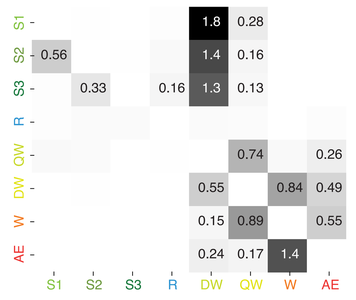


Microstates only occur in certain states



- We define microstates as any state of 6 seconds or less within another state

- Microstates account for less than 3% of time
- Microstates follow transition patterns
- Microwake occurs in drowsy and quiet wake



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.
- We have characterized the spatiotemporal dynamics governing each global state made up of several local state

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