Wave propagation, dynamical richness and predictability under different brain states

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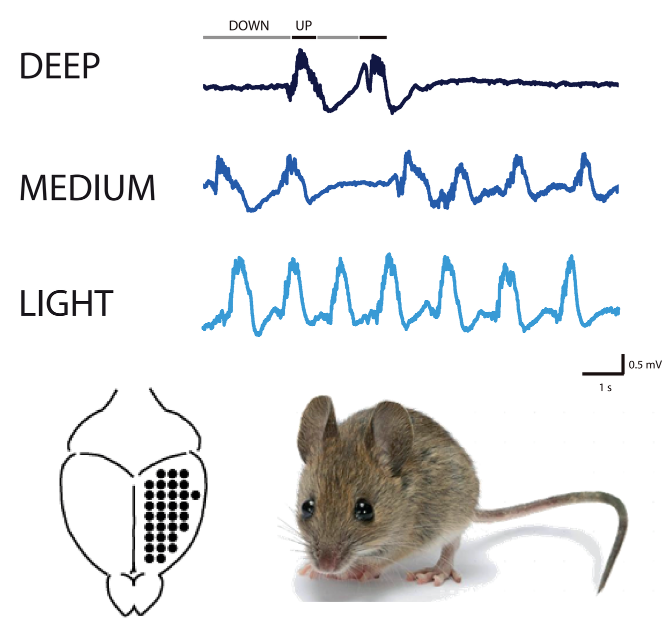
0 INTRODUCTION

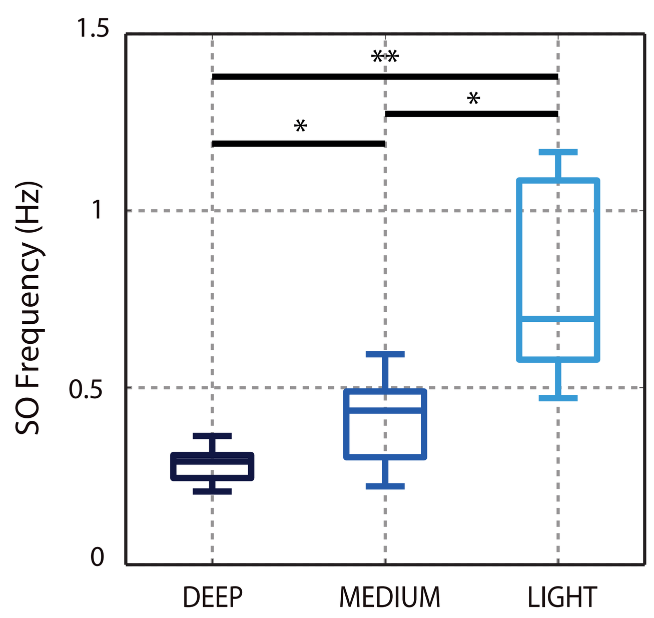
Propagating waves of cortical activity are dynamical patterns that occur across different brain states and are also present in unconscious states [1]. In this study we aimed to describe different brain states characterizing the changes occurring to the spatiotemporal dynamics of slow-wave activity in multichannel data. During the sleep-like slow oscillations (SOs, < 1Hz), activation waves propagate across the cortical network both *in vitro* [2] and *in vivo* in anesthetized animals [3]. By varying the anesthesia levels, it is possible to vary the brain state [4].

Here, we varied the anesthesia levels without departing from the slow-wave activity (SWA) regime. The emergent oscillatory activity ranged from lower (0.12 Hz) to higher (1.15 Hz) frequency for high to low anesthesia levels respectively. The repertoire of cortical spatiotemporal patterns of activity under different brain states, or under different levels of network excitability, provide us a good framework to study the network dynamics and its variation due to physiological and pathological conditions.

1 METHODS

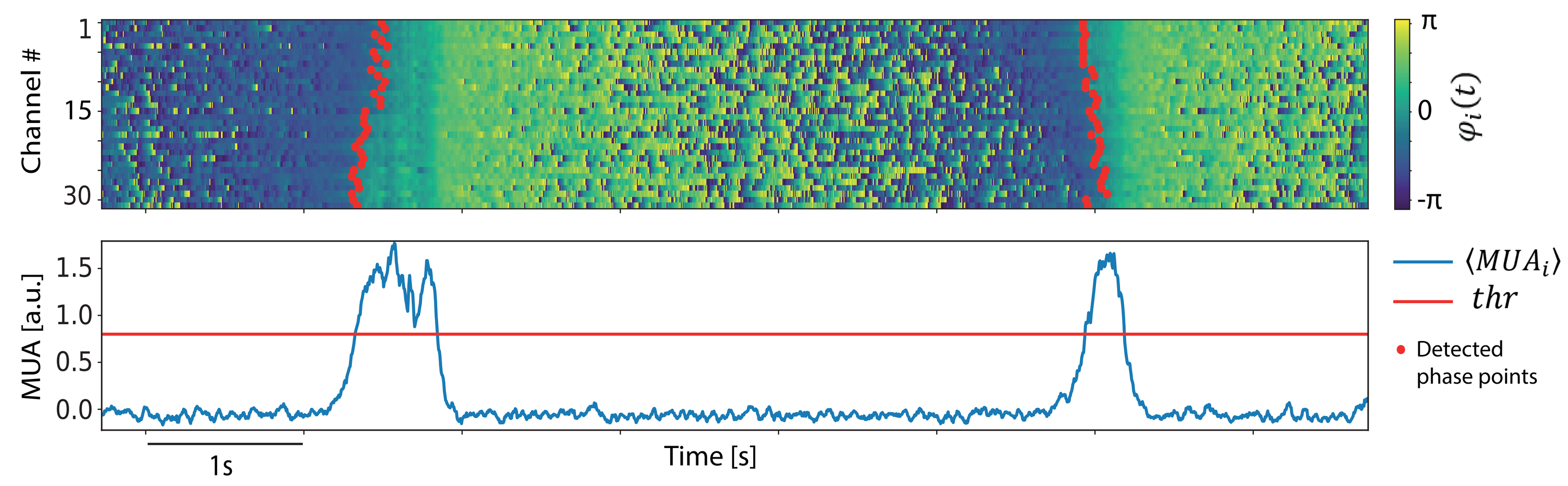
• **Experimental setup:** extracellular local field potentials (LFPs) recorded with a 32ch multielectrode array (MEA) placed on the surface of the brain of mice (n=5) anesthetized at three different levels.





• **Wave propagation:** given $x_i(t)$ the multiunit activity (MUA) at channel i computed as in [3], its analytic expression is obtained through the Hilbert transform and used to compute the instantaneous phase at each electrode.

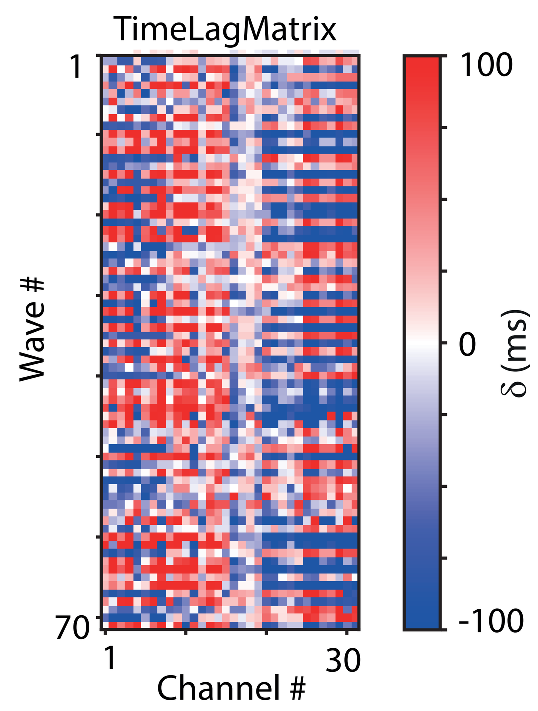
$$z_i(t) = x_i(t) + jH[x_i(t)] \qquad \varphi_i(t) = \angle z_i(t) = \arctan\left[\frac{Im(z_i(t))}{Re(z_i(t))}\right]$$

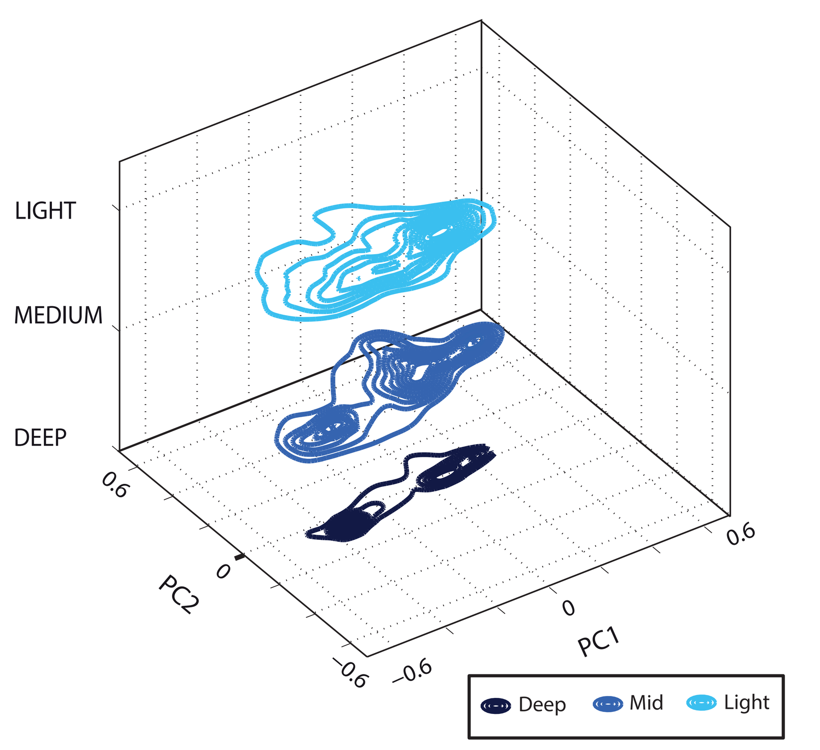


Waves in each channel were detected as time points related to a given phase crossing [5] and the collections expressed as **TimeLagMatrices** of relative phase latencies between local activation onsets

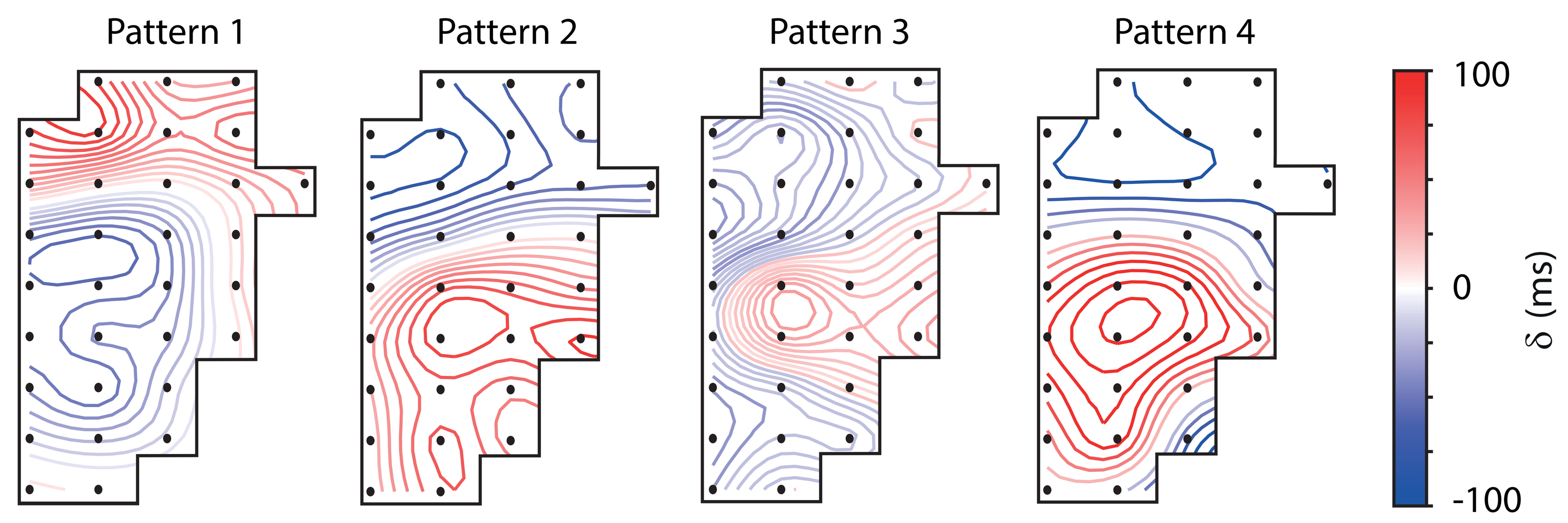
2 RESULTS

• **Dynamical richness:** Principal Component Analysis (PCA) of the TimeLagMatrices under each anesthesia level.



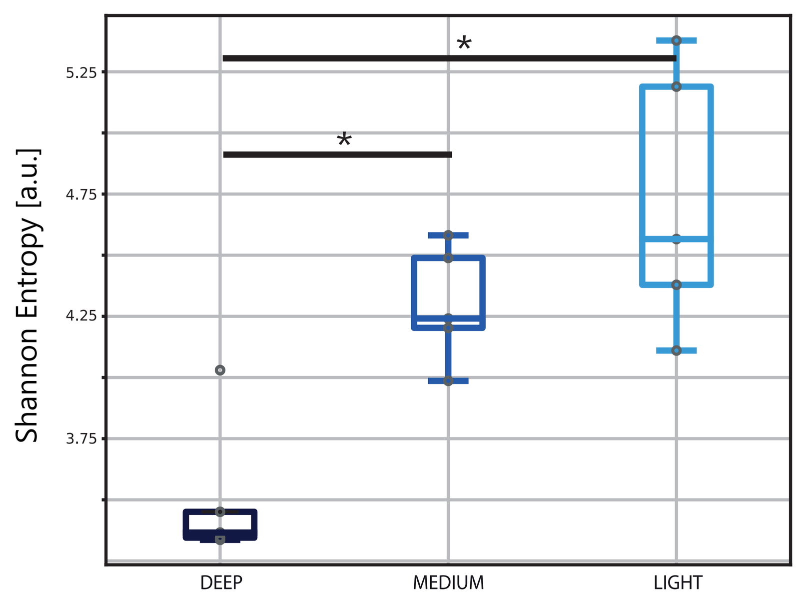


• **Predictability:** we identified 4 main spatiotemporal patterns of propagation using a k-means algorithm. The same centroids were used for all the subjects in each experimental condition to group similar waves and a thin-plate spline interpolation was used to reconstruct the mean Phase latency map of each cluster.



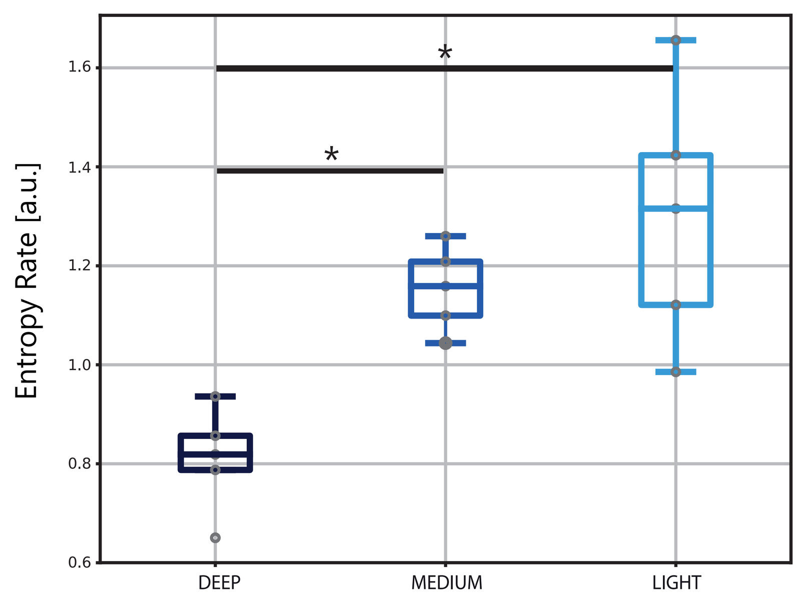
• The Shannon Entropy of the probability distribution of the waves projected into the PC1-PC2 plane was computed to estimate the dynamical richness of each anesthesia level as:

$$S = -\sum_i P_i \log_2 P_i$$



• We computed the sequence of occurrence of the 4 patterns for each subject in each anesthesia level and quantified the sequence predictability using the Entropy rate for the corresponding pattern probabilities as:

$$E = -\sum_{ij} \mu_i P_{ij} \log_2 P_{ij}$$



3 CONCLUSIONS

1) Using anesthesia it is possible to modulate cortical dynamics within the SWA regime.

2) The wave propagation patterns and their sequence change together with the brain state.

3) The dynamical richness and the unpredictability of cortical activity increase when we move from deeply unconscious states towards wakefulness.

References: [1] Sanchez-Vives, Maria V., et al., "Shaping the default activity pattern of the cortical network." Neuron. 2017, 94.5. 993-1001. [2] Sanchez-Vives, Maria V., and David A. McCormick. "Cellular and network mechanisms of rhythmic recurrent activity in neocortex." Nature neuroscience. 2000, 3.10. 1027. [3] Ruiz-Mejias, Marcel, et al. "Slow and fast rhythms generated in the cerebral cortex of the anesthetized mouse." Journal of Neurophysiology. 2011. [4] Tort-Colet, Núria, et al. "Attractor competition enriches cortical dynamics during awakening from anesthesia." BioRxiv. 2019, 517102. [5] Muller, Lyle, et al. "The stimulus-evoked population response in visual cortex of awake monkey is a propagating wave." Nature communications. 2014, 5, 3675.

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