Slow Oscillations (SO) as The Default Activity Pattern of the Cerebral Cortex [1]

Phenomenology
- Multiscale Slow Oscillations (SOs)
  - From the neuronal level, to the whole brain (slow waves), through the local network level.
- Energetic activity under functional disconnection
  - Static Densities

Key Dynamical Features
- Relaxation-oscillator behaviour
- Interoceptive fluctuations between two alternating metastable attractors: UP and DOWN states.
- Spatio-temporal propagation
- The travelling UP/DOWN wavefront reveals properties of the underlying network.

- Slow oscillations (SO)
  - A general regime of asynchrony prevails during the AS, were not for the occurrence of some UP-like bursts of activity (AS).

Motivation
- Can we detect other network states emerging from the SO regime?
- Candidates: UP
- States which emerge when the UP/DOWN regime abates away.

Experimental Model and Cortical Slice Recordings

Extracellular recordings in coronal cortical slices of the forest’s primary visual cortex

From SO to an Awake-Like State (AS) [3]

Pharmacological Modulations
- Addition of Carbachol (1.5 μM)
- Norepinephrine (50 μM)
- Reduction of extracellular Calcium (0-8.0-9 nM)

- Experimental model to explore the transitions from the SO state towards, largely asynchronous states: emulating the transitions from unconsciousness to consciousness.

LFP and MUA

Extracellular recordings are usually decomposed into Local Field Potential (LFP) and Multi-Unit Activity (MUA).

- LFP results from afferent neuronal activity (e.g., from the thalamus and sensory areas).
- Only units in the vicinity of the electrode contribute to the MUA (a different active region).
- High frequencies of the recording.

Estimating the MUA

Theoretical motivation: high-frequency spectral components of the population firing rate are asymptotically proportional to the individual firing rate of the neurons involved [8].

- The MUA may be estimated as the relative power changes in the high frequencies (200-2000 Hz).

Measuring the Evolution of Locally Estimated Densities

Neuronal Network State = MUA’s Probability Density.

- When estimated from different electrode groups, with varying time baselines, densities reflect different spatial and temporal scales.

Kolmogorov-Smirnov test statistic (Ks).

For a set of channels \( C = \{c_1, ..., c_N\} \) (consider \( T_F \)), the estimated probability density of the values taken by the signals \( X^C \), \( 1 \leq i \leq N \), altogether, over a period \( T \) of length \( T \).

- Temporal evolution of these densities to be measured by their relative change against a static density \( T_0 \), estimated over a baseline period \( T_B \).

- The time-series \( K^C \) is defined in a suitable subsampling setting, as the KS statistic between the evolving and the static densities.

- As a spatio-temporal filter that is distribution-free.

\[ K^C = d_{K-S}(X^C, T_F), \]

where \( T_F \) is an interval of length \( T \) containing \( T_B \).

Spatial Clustering of Multi-Unit Activity Densities

Statistical densities estimation during long baseline periods (≥ 300 s) offers a static spatial image of the network.

- SO’s static densities are a mixture of DOWNs and UP-states densities.
- While SO are dominated by DOWNs subdensities, very similar across channels, UPs exhibit a richer variety, which depends on their cortical location.

- Differences between groups of electrodes on different layers tend to increase in the AS condition, namely for IG-layer’s signals.

- Interestingly, UP-density variability provokes AS’s.

- The clustering of high-activity states (UPs and AS) seems to reflect the laminar structure of the slice.

- UP-states activity anticipates the awake-like state.

Densities’ Spatial Clustering

Electrode grouping, hierarchical cluster analysis of the MUA densities over a long baseline period.

- Clusters are finer apart in the AS condition than in the SO’s.
- As clusters to be organized hierarchically, according to afferent cortical layers.

- UP’s clusters to be a deformation path between SO and AS.

- The clustering of high-activity states (UPs and AS) seems to reflect the laminar structure of the slice.

- UP-states activity anticipates the awake-like state.

A Glippe into the Spatial Temporal Propagation of MUA Densities

Unified analysis of the MUA’s spatio-temporal evolution under different dynamical regimes: in absence of wave-front (AS) and periodic activity (SO).

SO: a whimsical propagating wave

AS: spherical coordinated activity arises amid synchrony

References