Vigilance states govern brain-wide neural activity dynamics and reveal global neural tissue excitability profile

Abstract

Brain contains two broadly opposed cell subpopulations whose activity is positively or negatively correlated with arousal, here termed 'positive' and 'negative' neurons. The relative proportions of these subpopulations vary systematically across the brain: sensory areas are enriched in positive neurons, higher-order association and motor areas contain more negative neurons, and intermediate regions lie along a continuous gradient. This 'positive/negative neuron gradient' is expressed across both slow and infra-slow timescales in the awake resting brain of the mouse, with individual neurons maintaining consistent activity profiles across these temporal domains.

Transitions from low to high arousal modulate these subpopulations differently. Under low arousal, positive and negative neurons exhibit similar mean firing rates. With rising arousal, their mean rates diverge. The ratio of positive to negative neurons within a region determines the direction of the overall population-rate change: areas dominated by positive neurons increase their firing with arousal, whereas areas dominated by negative neurons show population-rate suppression. This 'firing-rate change gradient' maps directly onto large-scale resting state fMRI networks (as discovered in humans), providing a single-unit correlate of the default mode versus salience network distinction.

Slow and infra-slow neural activity propagates along the cortical information-processing hierarchy, mirroring both the positive/negative neuron distribution and the firing-rate change gradient. During wakefulness, these travelling waves emerge in higher-order association and motor cortices and spread toward sensory regions, forming a 'travelling-wave gradient' that may reflect local activity adaptation to global arousal signal and reveal the brain's large-scale excitability profile. We hypothesize that distortions of the travelling wave gradient can be used to map the seizure onset zone in focal epilepsies (ideally non-invasively using magnetoencephalography) and used as a biomarker of neurological and psychiatric disorders (including Parkinson's disease) that affect brain tissue excitability.