

DOCTORAL THESIS

Complex spatiotemporal dynamics and wave propagation of the slow oscillations in the mouse cerebral cortex

Liang, Yuqi

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Abstract

The brain is a complex system which consists of billions of neuron cells and gives rise to diverse neural dynamics spatially and temporally. Spontaneous neural activities construct the foundation for various cognitive processing. However, caused by the limitation spatiotemporal resolution and coverage of recording methods in experiments, the organization of spatiotemporal dynamics of the self-organized brain activity remains largely unknown. Current experimental technique can optically image population voltage transients generated by pyramidal neurons across cortical layer 2/3 of the mouse dorsally with a genetically encoded voltage indicator. Such data provided unique opportunities to investigate the structure–dynamics relationship to elucidate the mechanisms of spontaneous brain activity. The aim of this thesis is to develop a systematic understanding of spatiotemporal mechanism in the mouse cortex by analyzing voltage imaging data, in collaboration with neuroscientist Dr. Knöpfel from the Imperial College London.

Local oscillation properties such as duration, amplitude and oscillation forms were studies on the cortex-wide scale and be compared among brain states. Wakefulness modulated the excitability of the neural activity which influenced the duration of the oscillation and the transition of different half wave types. Relatively larger amplitude of parietal cortex reflected stronger neural activity determined by structural hierarchy. Motifs of the oscillations showed

consistency in different brain states which indicated typical pathways of the wave propagations.

Dynamical properties of various waves and their interactions in sedated mice were investigated. Based on phase velocity fields, there were only a small number of large-scale, cortex-wide plane wave and synchrony (standing wave) patterns during Up-Down states. Interactions of local sources and sinks can generate saddles, and interactions of local wave patterns with large plane waves can induce a change of their wave propagating direction. Local wave patterns emerged at preferred spatial locations. Specifically, sources were predominantly found in cortical regions with high cumulative input through the underlying connectome. The findings revealed the principled spatiotemporal dynamics of Up-Down states and associated them with the large-scale cortical connectome.

Waking from deep anesthesia to consciousness increased the number of local wave patterns and made the spatiotemporal dynamics more complex. Although the active state increased the wave propagation speeds, the average speed decreased because of the interaction and collapse of wave patterns. Not affected by the brain states, the two principal modes with the highest variance remained stable. The first mode represented the large waves spreading across the cortex forward or backward while the second mode corresponded to the waves propagating in opposite direction in the frontal and parietal cortex. An infra-slow frequency of the wave number might reflect the bold flow and oxygenation.

The characterizations presented in this thesis can be used to predict and guide measurement and analysis of large-scale brain activity. The analysis of cortex-wide neural dynamical patterns builds foundation for further investigation of their functional implications.

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