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Dynamical evolution of spatiotemporal patterns in mammalian middle cortex

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Background

Neural systems think through patterns of activity. We have recently discovered that in an isotropic preparation of tangential slices of the middle cortical layers of mammalian brain, spontaneously organizing episodes of activity demonstrate a dynamical evolution: such episodes initiate with irregular and chaotic wave activity, followed by the frequent emergence of plane and spiral waves, and terminate with the recurrence of irregular wave patterns [1].

Methods

We have employed techniques drawn from experimental fluid dynamics to better understand these phenomena. In voltage sensitive dye imaging from fields of neurons, we applied an empirical eigenfunction approach, using singular value decomposition (SVD) in both amplitude and spatial frequency domain.

Results

The temporal structure of such modes emphasize the crystalline nature of the brain lattice – neurons are fixed in space, and 'wave' activity is a function of the phase relationships of the firing neurons. Calculating the effective dimensionality as in [2] we find that the dynamics tend to concentrate into a small number of dominant coherent modes as these episodes organize, and then disseminate onto a larger number of modes prior to termination.

For modes composed of voltage amplitude or spatial frequency, the dynamics of these phenomena show a monotonic and significant decrease in dimension during the middle of the events (ANOVA: amplitude, $F = 1950$, $p < 0.00001$; frequency, $F = 2058$, $p < 0.00001$), and post-hoc Tukey multiple comparison testing confirms that there is a significant decrease in dimensionality during the middle of these episodes.

Conclusion

This analysis demonstrates that a key factor in this dimensional evolution is not the appearance of qualitative spirals or plane waves, but rather depends on more subtle features within the interactions of these neurons. Further work to define the relevant order parameters that control the evolution of these spatiotemporal dynamics will lead to a better understanding of cortical information processing.

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