Spontaneous neuronal network dynamics reveals circuit's functional adaptations for behavior

Sebastian Romano*†[1] and Germán Sumbre‡[1]

[1]Zebrafish Neuroethology Group; Institut de Biologie de l'ENS; INSERM U1024, CNRS UMR 8197 (ZNG) – Ecole Normale Supérieure de Paris - ENS Paris – France

Abstract

In the absence of sensory stimulation sensory brain areas remain highly active. Notably, this spontaneous neuronal activity is spatiotemporally structured, according to the coarse functional and anatomical circuitry. Furthermore, structured spontaneous activity influences brain computations, since its structure is only mildly modulated by sensory inputs and it partially accounts for the variability of stimulus-evoked neuronal responses. Nevertheless, the neuronal interactions underlying these spontaneous activity patterns, and their biological relevance, remain elusive. Here, we addressed these open questions.
We used two-photon calcium imaging of intact non-anesthetized transgenic zebrafish larvae expressing pan-neuronally GCaMP3 to monitor the neuron-to-neuron spontaneous activity fine-structure in the optic tectum. The vertebrate optic tectum, analogous to the mammalian superior colliculus, contains functional sensory maps of the external world, and it is involved in spatial detection, attention and the generation of commands for orienting motor behaviors. In zebrafish, the tectum is the most complex visual region, and is essential for visually guided prey detection and capture.

We observed that spontaneous tectal activity was organized in topographically compact neuronal clusters. However, the latter were not a mere collection of neighboring neurons but represented true functional assemblies, specifically grouping functionally similar neurons. Collectively, they reflected the tectal retinotopic map, even in the absence of retinal inputs. Furthermore, we showed that assemblies represent all-or-none-like cooperative sub-networks shaped by competitive dynamics, a mechanism suited for their efficient and robust coordinated recruitment. Notably, the spontaneous assemblies were tuned to the same angular sizes and spatial positions as larva's prey-detection performance in behavioral assays, arguing for their behavioral relevance. Our results reveal that structured spontaneous activity represents sensory functional maps that emerge from the circuit's intrinsic non-linear dynamics. Spontaneous activity patterns reflect advantageous neuronal mechanisms that promote the extraction of biologically relevant visual features and assure robust circuit functioning in noisy natural environments.

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*Speaker
†Corresponding author: sromano@biologie.ens.fr
‡Corresponding author: sumbre@biologie.ens.fr