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Spontaneous activity in the developing retina emerges at a critical state between local and global functional connectivity

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Patterned, spontaneous neural activity is observed in many parts of the developing nervous system, and is known to play an important role in its development and maturation [1]. It is still unclear whether simply the presence of a certain level of neural activity is sufficient for normal development, or whether specific spatio-temporal features of the activity are also relevant. To address this question, we use computational modeling and multielectrode array recordings to investigate in detail the properties of retinal waves. Retinal waves are spontaneous, propagating activity patterns found in the immature retina of many vertebrate species [2,3], which display highly random initiation points, sizes and trajectories [4]. Here we propose a biophysically realistic model for early-stage, acetylcholine-mediated retinal waves, which reproduces these properties and offers a simple explanation in terms of a model from statistical mechanics. In this model, neurons in a recurrently connected network produce spontaneous bursts, which can trigger propagating waves when neighbouring neurons are sufficiently excitable. Neural excitability is regulated through a slow after-hyperpolarization (sAHP) current operating on two different temporal scales [5]. As a result, the network exhibits competition between a desynchronizing effect of spontaneous, cell-intrinsic bursts, and the synchronizing effect of synaptic transmission during propagating retinal waves. Cell-intrinsic bursts decouple the retinal network through activation of the sAHP current, and we show that the network is capable of operating at a transition point between purely local and global functional connectedness. Comparison with a simple mean-field model shows that this corresponds to a percolation phase transition. Analysis of multielectrode array recordings of retinal waves in turtles and mice confirms that, at this point, their properties, in particular. the scale free nature of the activity patterns are reliably predicted by the model. These results indicate that early-stage retinal waves are regulated according to a very specific principle, which maximizes randomness and variability in the resulting activity patterns. Since retinal waves are known to influence the development of both the retinal network [2] and of higher visual brain centers [6], we suggest that such activity may be required since it contains events on all length scales, and is unbiased with respect to scale or sequence of events. In addition, the scale-free character of retinal waves could present the visual system with an early opportunity to adapt to the statistics later also encountered in natural images.

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