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Seminar/Talk

The emergence of contrast invariance in cortical circuits

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Neurons in the primary visual cortex (V1) encode the orientation and contrast of visual stimuli through changes in firing rate (Hubel and Wiesel, 1962). Their activity typically peaks at a preferred orientation and decays to zero at the orientations that are orthogonal to the preferred. This activity pattern is re-scaled by contrast but its shape is preserved, a phenomenon known as contrast invariance. Contrast-invariant selectivity is also observed at the population level in V1 (Carandini and Sengpiel, 2004). The mechanisms supporting the emergence of contrast-invariance at the population level remain unclear. How does the activity of different neurons with diverse orientation selectivity and non-linear contrast sensitivity combine to give rise to contrast-invariant population selectivity? Theoretical studies have shown that in the balance limit, the properties of single-neurons do not determine the population activity (van Vreeswijk and Sompolinsky, 1996). Instead, the synaptic dynamics (Mongillo et al., 2012) as well as the intracortical connectivity (Rosenbaum and Doiron, 2014) shape the population activity in balanced networks. We report that short-term plasticity can change the synaptic strength between neurons as a function of the presynaptic activity, which in turns modifies the population response to a stimulus. Thus, the same circuit can process a stimulus in different ways –linearly, sublinearly, supralinearly – depending on the properties of the synapses. We found that balanced networks with excitatory to excitatory short-term synaptic plasticity cannot be contrast-invariant. Instead, short-term plasticity modifies the network selectivity such that the tuning curves are narrower (broader) for increasing contrast if synapses are facilitating (depressing).Based on these results, we wondered whether balanced networks with plastic synapses (other than short-term) can support the emergence of contrast-invariant selectivity. Mathematically, we found that the only synaptic transformation that supports perfect contrast invariance in balanced networks is a power-law release of neurotransmitter as a function of the presynaptic firing rate (in the excitatory to excitatory and in the excitatory to inhibitory neurons). We validate this finding using spiking network simulations, where we report contrast-invariant tuning curves when synapses release the neurotransmitter following a power- law function of the presynaptic firing rate. In summary, we show that synaptic plasticity controls the type of non-linear network response to stimulus contrast and that it can be a potential mechanism mediating the emergence of contrast invariance in balanced networks with orientation-dependent connectivity. Our results therefore connect the physiology of individual synapses to the network level and may help understand the establishment of contrast-invariant selectivity.

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Online

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