Odor Coding and Neural Plasticity in the Locust Olfactory System

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Intracellular recordings *in vivo* from locust antennal lobe (AL) projection neurons (PNs) revealed that individual PNs phase-lock with population oscillations at times that depend on the stimulus. It was shown that there is a fine structure to the timing of PN action potentials within the population response that is stable over trials and is different for different PNs (Laurent, 1996). Kenyon cells of the mushroom body - postsynaptic target of PN afferents - decode stimulus-specific spatio-temporal patterns of PN activity (Perez-Orive et al., 2004). The coordinated and information-rich fine temporal structures observed across ensembles of olfactory PNs during odor stimulation emerge as a function of experience (Stopfer and Laurent, 1999). This structure is missing from the spike trains of PNs during initial stimulation with novel odors, but quickly appears when the stimulus is repeated, suggesting that the information coding strategy changes as a stimulus becomes familiar. The functional significance of these modifications and their underlying mechanisms are unknown.

In a realistic computational model of the AL (Bazhenov et al., 2001), we proposed and tested ideas about the sites and potential functions of the AL plasticity responsible for fast odor learning. Activity-dependent facilitation of AL inhibitory synapses was sufficient to simulate physiological recordings of fast learning. Only a fraction of synapses, those activated by the odorant, were modified following stimulation with a single odor. Therefore, activity-driven facilitation during repetitive stimulus presentations created a temporary network structure "tuned" specifically for the repeated stimulus. To examine the functional significance of odor learning in the AL we applied stimuli with added "noise". The network with synaptic plasticity responded with reliable spatio-temporal patterns from trial to trial despite the noisy input. The network lacking fast plasticity, however, responded with patterns that varied across trials, reflecting the input variability. We showed that input-specific plasticity within AL synaptic interconnections can substantially reduce the effects of noise, exploiting the fact that noise differs from one trial to the next and thus, each time, activates untrained (weak) synapses. Plasticity at inhibitory synapses only was sufficient to improve the reliability of PN responses against noisy input to LNs. To diminish the effect of noise present in PN inputs also, plasticity in excitatory synapses within the AL network was required as well.

Our study indicates that synaptic plasticity in the AL can fine tune and optimize network structure to increase the information content and reliability of odor representations for repeatedly encountered odors, as occurs in natural plumes. The absence of fast LN-mediated inhibition during presentations of novel odors prevents PNs from synchronizing, but, at the same time produces more intense bursts of spikes during the initial phase of the response, leading to potentially broader but less specific responses in the mushroom body. A buildup of fast inhibition enables AL oscillations, thus improving odor discrimination. Facilitation of both inhibition and excitation endows the network with a resistance to noise, insuring more reliable responses in the AL, and presumably, in downstream targets, to repeated odors.

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References:

Bazhenov M, Stopfer M, Rabinovich M, Abarbanel HD, Sejnowski TJ, Laurent G (2001) Model of cellular and network mechanisms for odor-evoked temporal patterning in the locust antennal lobe. Neuron 30:569-581.

Laurent G (1996) Dynamical representation of odors by oscillating and evolving neural assemblies. Trends Neurosci 19:489-496.

Perez-Orive J, Bazhenov M, Laurent G (2004) Intrinsic and circuit properties favor coincidence detection for decoding oscillatory input. J Neurosci 24:6037-6047.

Stopfer M, Laurent G (1999) Short-term memory in olfactory network dynamics. Nature 402:664-668.