Nonlinear signal amplification at genetically-identified central synapses

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In order to understand how diverse computations arise from neural assemblies, it will be important to integrate synaptic and circuit-level approaches. Ideally, we would like to examine both the in vivo tuning of specific neurons and the properties of synapses interconnecting them. Here we describe the properties of identified central synapses in an invertebrate brain circuit, and show how these distinctive properties can shape the in vivo computations performed by this circuit. The model circuit we use is the Drosophila antennal lobe, a brain region analogous to the vertebrate olfactory bulb. Olfactory receptor neurons (ORNs) provide input to the antennal lobe and postsynaptic projection neurons (PNs) carry the output of this circuit [1, 2]. One virtue of this circuit is that specific types of ORNs and PNs as well as the synapses connecting them can be genetically labeled and identified for functional characterization.

In vivo, this antennal lobe circuit performs several fundamental computations on olfactory signals [3]. First, the circuit increases the signal-to-noise ratio of odor-evoked spike trains. Individual PN spike trains are more reliable than individual ORN responses. Second, this circuit performs a nonlinear transformation on odor-evoked ORN signals. Weak ORN responses are powerfully amplified in PNs, but strong ORN inputs are not amplified to the same degree. Third, the antennal lobe preferentially transmits information about odor onset. Whereas ORNs show maintained responses to odors, PNs only respond robustly to odor onset. Here we show that the unusual properties of ORN-PN synapses can at least partially explain all these features. The synapse between ORNs and PNs is very strong, reflecting a large number of vesicular release sites and a high probability of release. This is likely one reason why weak ORN odor responses are amplified in PNs and why PN odor responses are reliable. Moreover, as expected from a high probability of release, ORN-PN synapses depress profoundly to strong ORN stimulation. This helps explain why PN odor responses are transient, and why weak ORN odor responses are amplified more powerfully than strong responses. Furthermore, because of synaptic depression, synaptic charge in PNs is more broadly tuned than the original distribution of ORN stimulus frequencies. Thus, we propose that synaptic depression is also likely to be a major reason why PNs are more broadly tuned to odors than the presynaptic ORNs.

References