Competing spatiotemporal neural codes in the olfaction of the Manduca sexta moth

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Summary: Experiments across different species have shown that perception of odors in the olfactory system is associated with neural encoding patterns. The neurobiological mechanisms responsible for such encoding patterns, their transient dynamics and interactions are yet to be fully understood [1]. We show that a data-driven computational model reduction for the antennal (olfactory) lobe (AL) of the *Manduca sexta* moth reveals the nature of experimentally observed persistent spatial and temporal neural encoding patterns and its associated decision-making dynamics. The constructive framework reduces the evolution of the complex neural network to dynamics of competing codes (principal components - PC) obtained from experimental data, and thus guides studies of the dynamics of mixtures of odors and the role of inhibition in shaping the competition between neural codes. The resulting low-dimensional model is analyzed using dynamical systems theory and validated experimentally. We conclude that the mechanism responsible for the robust and persistent appearance of neural codes is a stable fixed point. As with our experiments, simulations are able to predict the decision boundaries for mixtures of two or more odors and determine the timescales of transients. By then varying the inhibition in the model, and experimentally in the AL via pharmacology, we identify the inhibition as the mechanism responsible for shaping the distinct neural codes.

Detailed description: The AL is comprised of a large number of excitatory (projection) and inhibitory (inter) neurons connected both globally and locally, rendering it a complex computational system that is incapable of revealing the underlying processes involved in olfaction [2]. However, experiments clearly indicate that key neural codes (PCs) involving global spatiotemporal behavior encode the critical dynamics of the olfaction system [1]. To obtain a reduced model, we propose to project the population of firing rate units - that models the dynamics of the AL - onto the prescribed set of *experimental* PCs. Essentially, the reduced model extracts the minimal set of dynamical variables necessary for describing the fundamental behavior of the olfactory system. Specifically, for N odors, N+1 dynamical variables are required: one for the time dynamics of each neural code, and one for the overall inhibitory firing rate. For a single odor input, we show that the deterministic reduced model is guaranteed to possess a *stable fixed point*, indicating the robust and persistent mechanism for odor selection. The transient dynamics associated with a convergence to a stable fixed point are verified in computations of the reduced model with noisy input and using experimental recordings projected onto the PCs. The selection of the odor is determined by the proximity of the fixed point to a decision region (shaded gray regions in Figure 1). Each time a stochastic trajectory crosses the decision boundary, evidence is integrated to make a decision for a specific odor. When the AL is subject to competing mixtures, the decision process becomes more complex as the stable fixed point is now in proximity to several decision boundaries. This allows the stochastic trajectory to visit distinct decision boundaries in sequential trials (See Figure 1). In the experiments, we vary the ratios between two odors and verify this prediction. The combined approach of modeling and experimental verification also elucidates the role of inhibition [3] as a mechanism to suppress orthogonal input to the neural codes – specifically noise and other insignificant odors. We indeed observe this effect both neurobiologically and behaviorally by blocking inhibition in the AL.

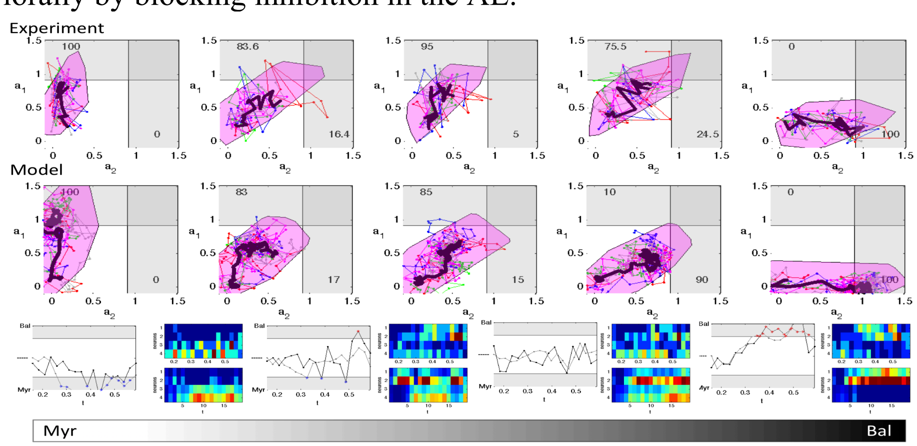

Figure 1. Top 2 rows: Comparison of experimental and model dynamics when ratio of odors is varied from pure `Myr' odor (leftmost) to pure `Bal' odor (rightmost). Bottom row: sample experimental and model trajectories (difference of dynamical variables and selective neurons FR) demonstrating the decision-making process in pure and mixtures of odors.

[1] Broome et al. Neuron 06', Riffell et al. PNAS 09' Cur. Bio 09', Laurent et al. Nat. Rev, Neu. 02', Neuron 05'
[2] Linster et al. J. of Neurophys. 05'
[3] Lei et al. Nat. Neur. 02'