A neuronal network model for the detection of binary odor mixtures

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Introduction

In many lepidopteran species, males are attracted to females by pheromones, which typically are blends of two or more components mixed to a certain ratio. Odour information processing occurs in a set of modified glomeruli (the Macroglomerular Complex of the Antennal Lobe, MGC), only found in males and selectively responding to pheromone compounds [1]. Individual component-specific signals are received from Olfactory Receptor Neurons (ORNs) by the MGC Local Neurons (LNs), processed and transmitted by Projection Neurons (PNs) to higher brain centres [2, review in 3].

We aimed to demonstrate some of the essential principles of odour blend recognition by simulating the known structure and neurophysiological properties of MGC in a minimalistic *in silico* model.

Methods

We constructed a minimal model, consistent with the known electrophysiology and structure of the MGC, that selectively responds to a blend of pheromone components in a fixed ratio over a range of concentrations (fig. 1).

One underlying principle essential in eliciting the expected response is the **competition between LNs**, ensured through inhibitory interconnections between all groups of primary LNs.
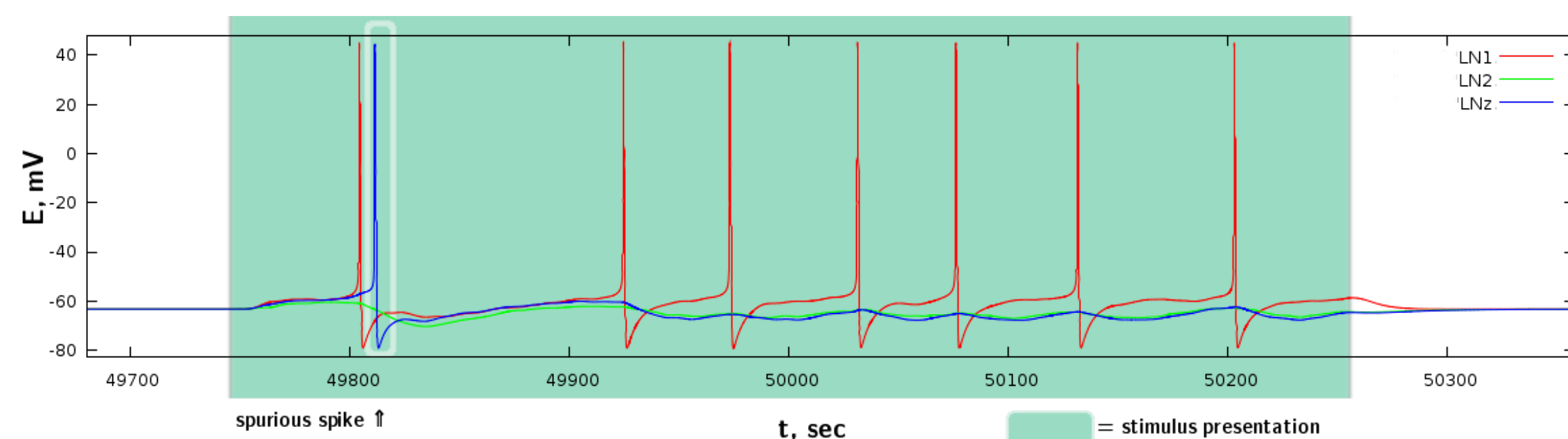
Fig 2. The number of neurons in the model needs to be large enough to minimise instances of false positives due to irregularities inherent in the stochasticity of ORNs' firing.

To simulate the presentation of the two pheromone components with different concentrations, the firing rate (λ) of the ORNs' Poisson oscillators was set, simultaneously for both ORN groups, to a range of values. All combinations of $\lambda = 0.01..0.10$ Hz at 0.01 Hz increments were presented.
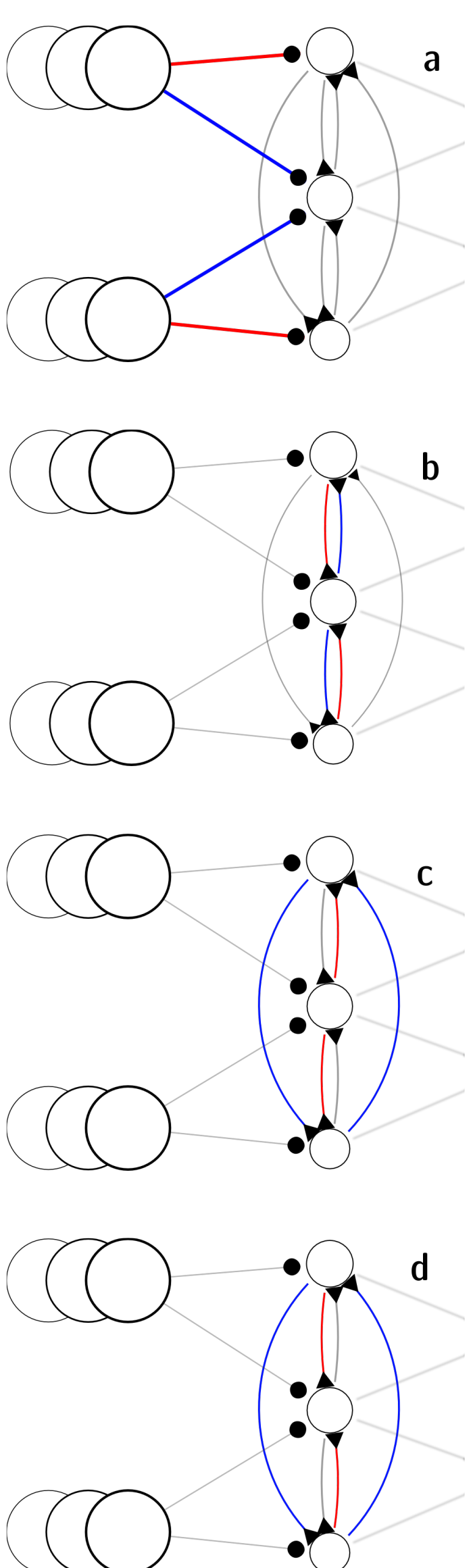
Simulations were set up in batches. To tune the model to detect and correctly respond to the 1:1 stimulus ratio, we varied the **synaptic strength** of a pair of related (one per batch) connections (fig. 3).

The response of the model was measured as a **spike density** of PN at midpoint of stimulus presentation. Results from each batch were thus gathered in a matrix of spike density values (one for each pair of synaptic strengths being tuned).

Results and Conclusions

Batch (a) established that a minimum compounded absolute strength of connections between ORNs and primary LNs is necessary for properly 'engaging' the generalist LN and thus eliciting a response of the model. Also, the balance of synaptic strengths appeared to shape the 'sensitivity strip' across the stimulus concentration gradient (*cf.* fig. 4a and 4b), the **ORN-LNgen connection needing to be ~65% the strength of each of the ORN-LNsp** for a sufficient response.

Batches (b-d) achieved a fairly uniformly narrow strip, such as shown on fig. 2b). **Generalist-specialist, specialist-generalist and inter-specialist connections must have balanced synaptic strengths in a ratio close to 0.92:1.20:1.10** (for the 1:1 stimulus component ratio). LN interconnections appear essential in narrowing the generalist LN response, failing which the model loses specificity to the component ratio.

Fig 3. Connections tuned in the simulations.
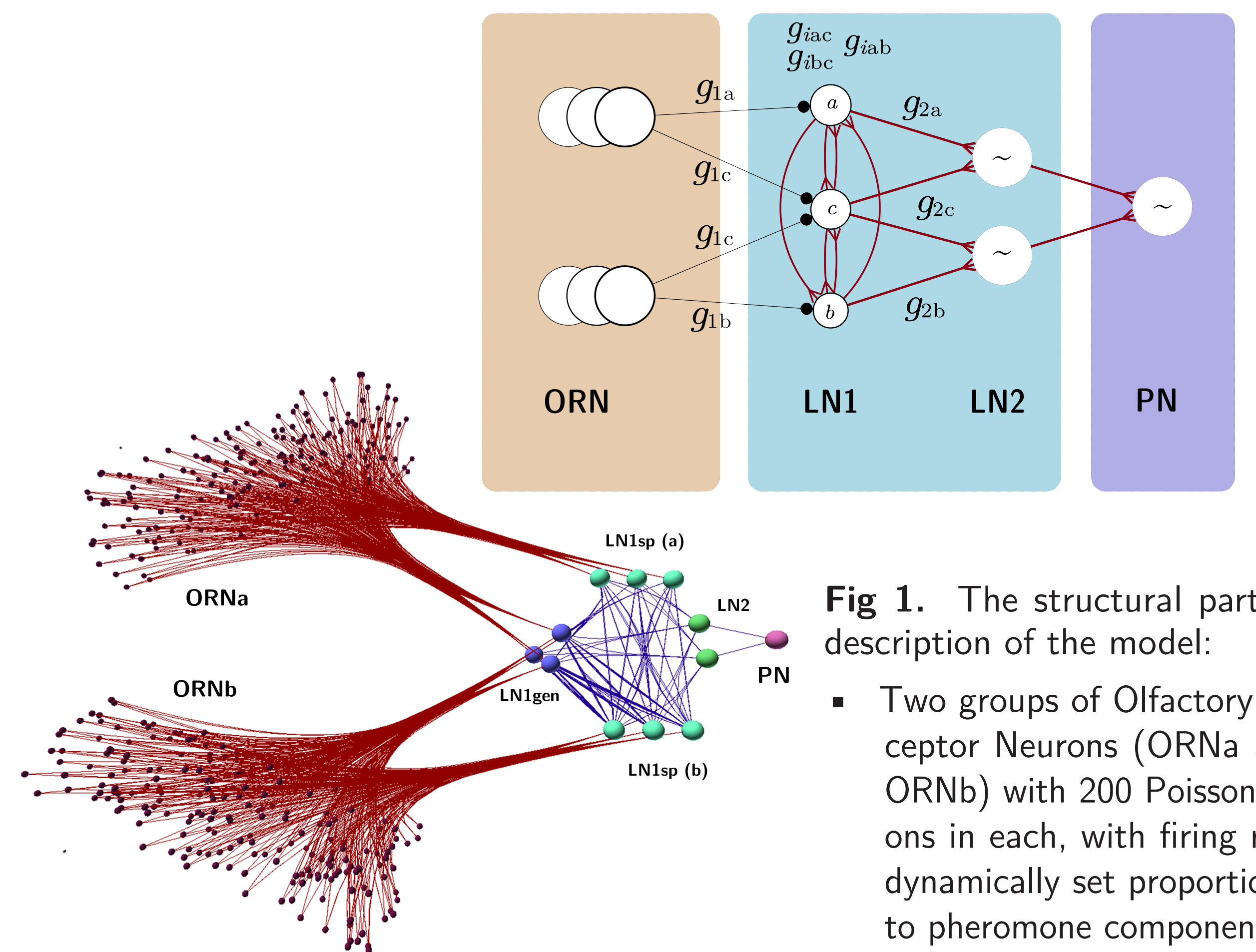
Acknowledgments

Fig 1. The structural parts and description of the model:

- Two groups of Olfactory Receptor Neurons (ORNa and ORNb) with 200 Poisson neurons in each, with firing rate dynamically set proportional to pheromone component concentration.
- Two primary specialist Local Neurons (LN1sp), each receiving connections from *ca* 1/3 of the ipsilateral ORN group, and a generalist LN (LN1gen) receiving connections from both ORN groups. All inter-LN connections are inhibitory.
- Two secondary LNs, intrinsically active through a constantly applied DC current of 0.1 nA, and receiving inhibitory input from primary LNs.
- One projection neuron (PN), also intrinsically active, inhibited by the two secondary LNs in such a way that both of them need to be silent simultaneously to disinhibit the PN.
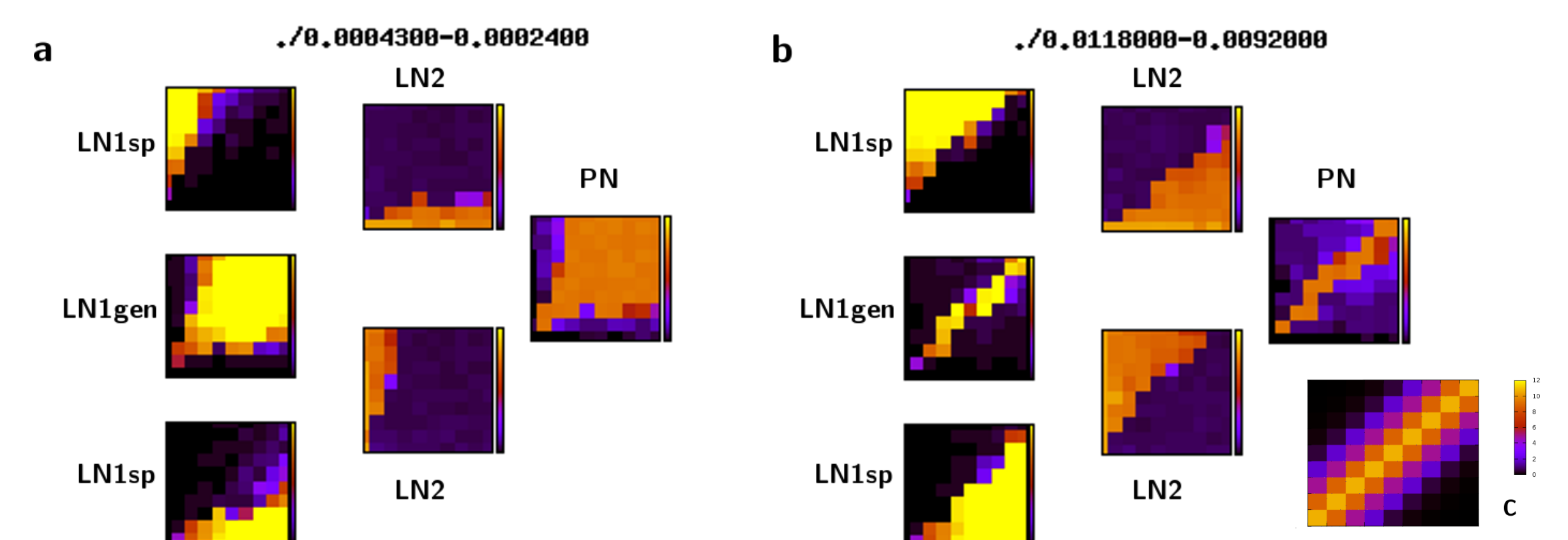
Fig 4. (a) Results from batch a, showing good engagement of LN1gen (and hence, of PN), but definitely lacking in selectivity. This run's values were used in subsequent batches. (b) Another example demonstrating good selectivity for the target stimulus ratio (1:1) along the entire concentration gradient. (c) is a target response profile, against which PN's response matrix is compared to produce a 'success functional' for each parameter combination.

In each graph, x- and y-axes represent the Poisson firing rate of the ORNs in the range of 10–100 Hz, and the spike density of the neurons are color-coded from black to yellow. It can be seen that the PN largely follows generalist LN, and both fire only when concentrations are equal.
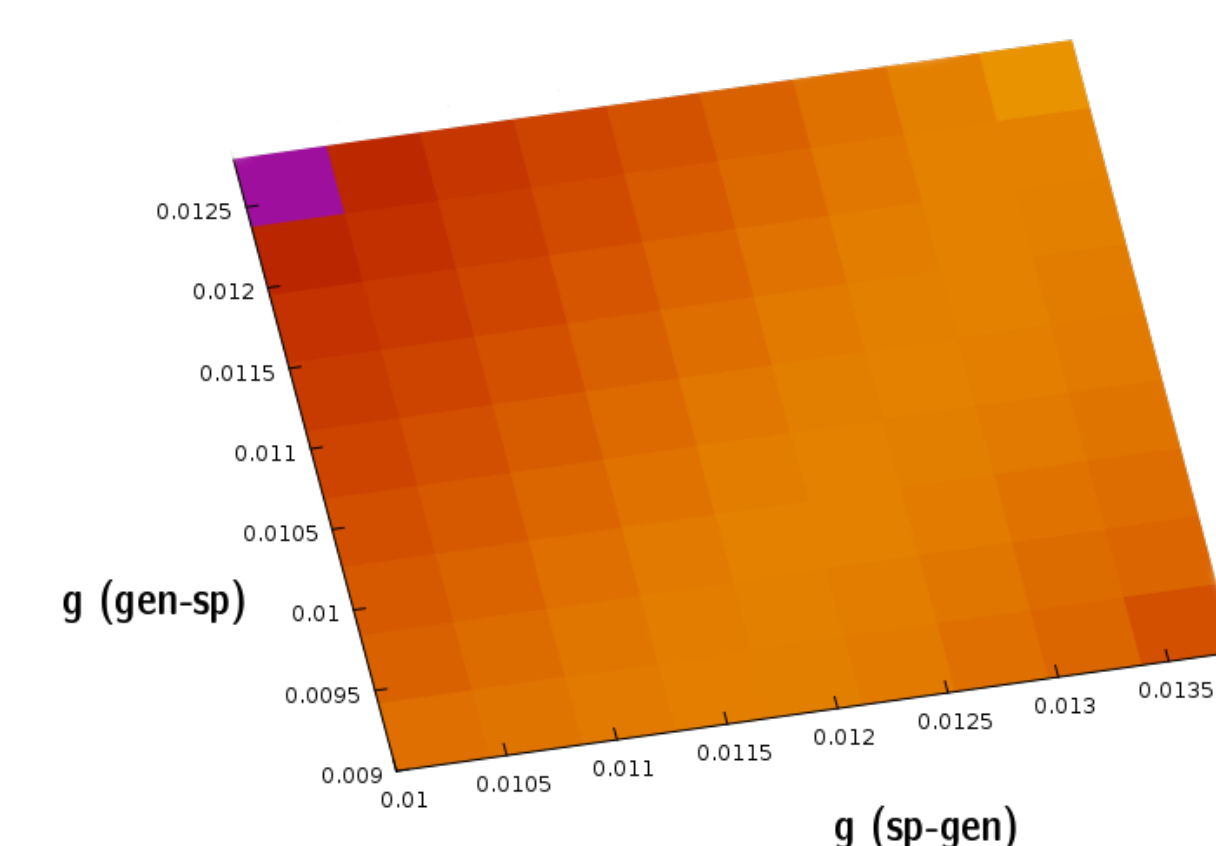
Fig 5. Estimation of response accuracy using sp-gen : gen-sp parameter pair (fig.3b). The matrix of 'success functional', resulting from PN's response profile convoluted with the target profile (fig. 4c).

References

1. Hansson BS, Christensen TA & Hildebrand JG. 1991. Functionally distinct subdivisions of the macroglomerular complex in the antennal lobe of the male sphinx moth Manduca sexta. *J Comp Neurol*, **312**(2):264-78.
2. Christensen TA & Hildebrand JG. 1987. Male-specific, sex pheromone-selective projection neurons in the antennal lobes of the moth Manduca sexta. *J Comp Physiol*, **160**(5):553-69.
3. Hansson BS & Anton S. 2000. Function and morphology of the antennal lobe: New developments. *Annu Rev Entomol*, **45**:203-31.