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Modelling the population of olfactory receptor neurons

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Introduction

Biological experiments have shown that olfactory receptor neuron responses to an odour stimulus vary substantially, even between two ORNs expressing the same receptor type [1]. This variation is likely the result of heterogeneity in geometrical as well as electrical and odour/receptor-dependent properties. The total response relayed to the olfactory bulb, which is a sum of many convergent ORN responses, will depend on the distribution of variation in single ORN responses. This distribution is not known, but may be estimated through modelling.

Methods

For modelling the ORNs we used biophysical equations based on experimental data [2], whose parameters belong to three different sets describing the odorant-receptor interaction (**R**; especially the dose at half-maximum conductance $C_{g/2}$ expressed in log molar), the geometrical shape and size (**G**) and the electrical characteristics (**E**) of ORNs. We let the parameters of these equations vary stochastically according to probability distributions which were chosen to correspond to experimental data, as established by Rospars et al [2]. The firing frequency distributions of a population of ORNs stimulated by a given odorant at various concentrations were investigated in two cases: (i) ORNs expressing a single olfactory receptor type (stochastic variation of only **G** and **E**), and (ii) a population of ORNs expressing many receptor types (stochastic variation of **G**, **E** and **R**). The current model only gives the steady-state frequency distributions as a function of the strength of the odour stimulus, and the stimulus is a single odorant.

Results

We find that the frequency distributions become rather different for the two cases. (i) The firing frequencies of a simulated population of ORNs expressing the same receptor – for instance, receptor neurons projecting to the same glomerulus in the olfactory bulb – are normally distributed. The mean value and standard deviation of the frequency distribution increase with odour stimulus strength, up to a limit. (ii) Frequency responses of a simulated population of neurons expressing different receptors are approximately lognormally distributed for weak odour stimuli and near normally distributed for strong odour stimuli. Both families of distributions can be described mathematically, with equations detailing the distribution of frequencies in the response depending on odour stimulus strength.

Conclusion

The current model is, to our knowledge, the first computational model of the population of ORNs – i.e. of what the olfactory bulb "sees". As the bulb is specialized for the type of input provided by the ORNs, we believe our model could be valuable both for generating input to computational models of the olfactory bulb, as well as for improving understanding of the olfactory system as a whole. Our mathematical descriptions are much simpler to implement than the original biophysical model, and can be used for both modelling and theoretical work.

References

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