Influence of inhibitory circuits on the frequency tuning of mitral cells

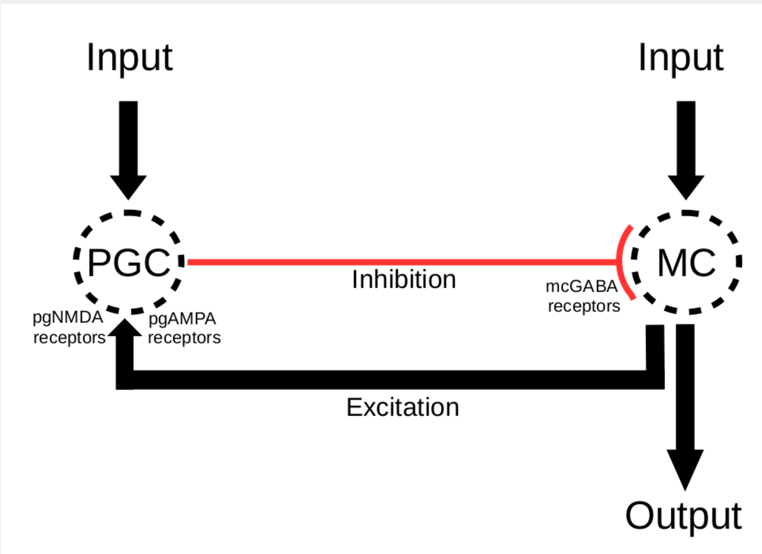
Rebecca Miko, Christoph Metzner and Volker Steuber

University of Hertfordshire, AL10 9AB, UK

Motivation

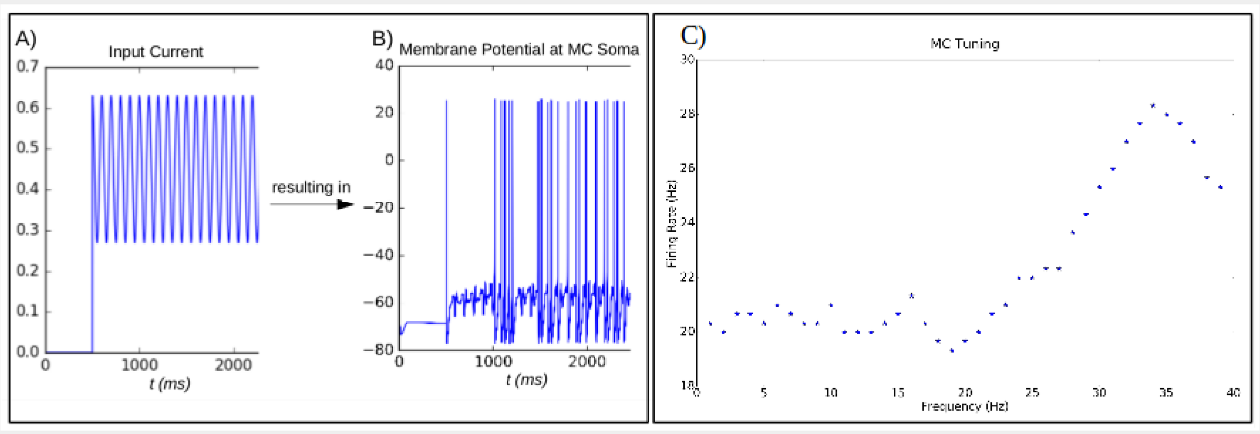
The olfactory bulb (OB) is responsible for receiving, processing and relaying olfactory information (odours). Naturalistic odour stimuli have a rich temporal structure, caused by turbulent airflow. Recent studies show that this structure contains information about the olfactory scene [1,2]. It has been suggested that animals might exploit this structure and extract information [3]. Some of this information may lie in the frequency content of the stimuli [2], therefore we studied input frequency dependent responses of mitral cells (MCs) in the OB. Specifically, we investigated whether MCs show frequency tuning and, if they do, how different components of the glomerular layer circuitry shape and determine the tuning.

Model



- Used a model of the OB (modified from [4]).
- Modeled MC - PGC (periglomerular cells), focusing on recurrent and feed - forward inhibition in the glomerular layer.

Method



- Used sinusoidal currents of varying frequencies as input, using the equation:

$$y(t) = c sin(2\pi f t + \varphi) + 0.18. \quad (1)$$

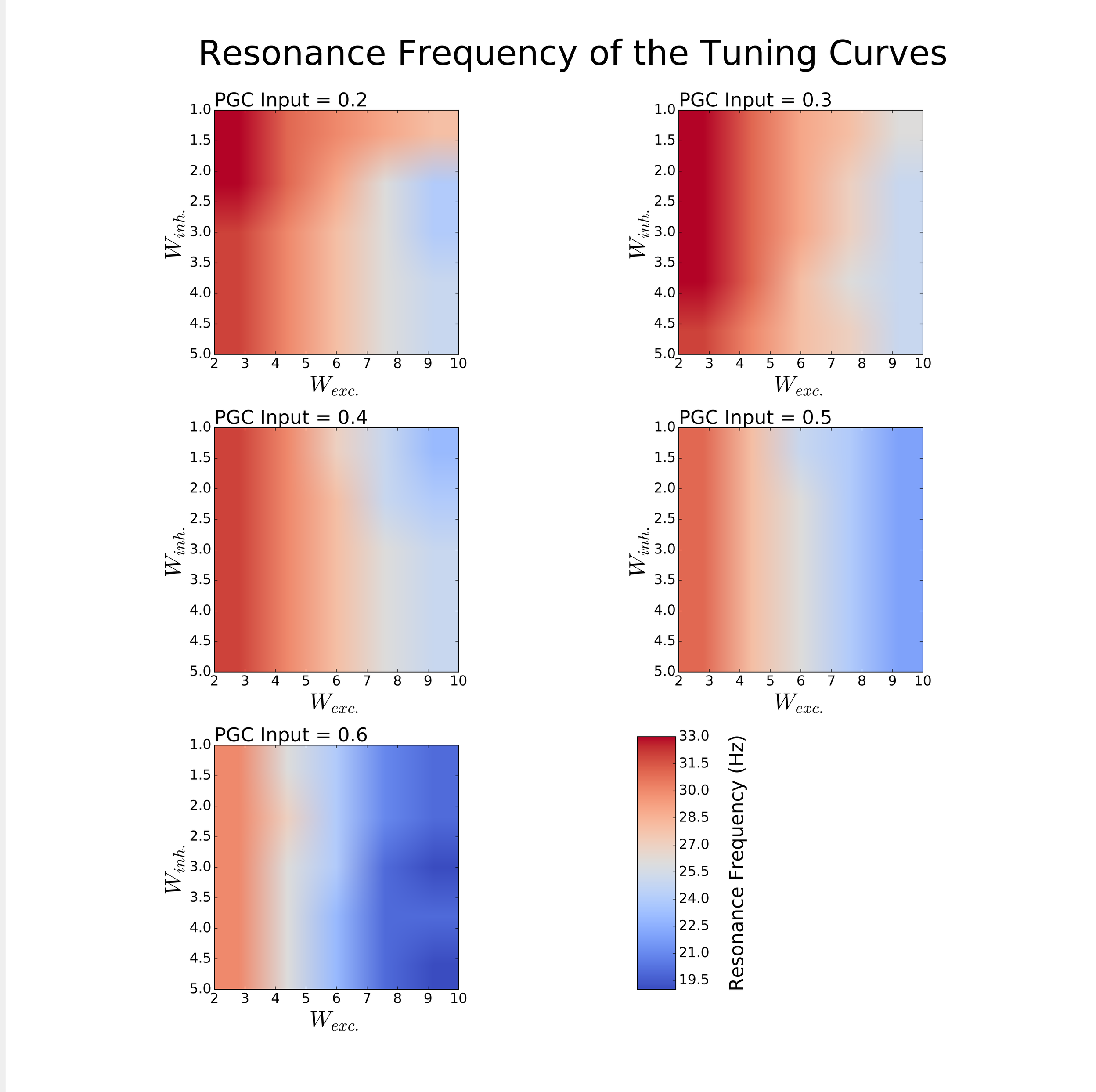
- Phase $(\varphi) = 0$ and strength of input to MC $(c) = 0.45nA$.
- PGC input strength was adjusted by multiplying $0.45nA$ by the values: $0.2, 0.3, 0.4, 0.5$ and 0.6.
- MC - PGC excitation strength varied using W_{exc} values: $2.0, 4.0, 6.0, 8.0$ and 10.0.
- PGC - MC inhibition strength varied using W_{inh} values: $1.0, 2.0, 3.0, 4.0$ and 5.0.
- Frequency (f) of input ranged between 1.0Hz and 40.0Hz (with step size 1.0).
- Parameter combinations: PGC input strength, MC - PGC excitation strength and PGC - MC inhibition strength.
- Constructed frequency tuning curves.

References

[1] Celani, A., Villermaux, E. and Vergassola, M.: Odor landscapes in turbulent environments. Physical Review X, 4(4), p.041015, 2014.
[2] Schmuker, M., Bahr, V. and Huerta, R.: Exploiting plume structure to decode gas source distance using metal-oxide gas sensors. Sensors and Actuators B: Chemical, 235, pp.636-646, 2016.
[3] Jacob, V., Monsempès, C., Rospars, J.P., Masson, J.B. and Lucas, P.: Olfactory coding in the turbulent realm. PLoS Computational Biology, 13(12), p.e1005870, 2017.
[4] Li, G. and Cleland, T.A.: A two-layer biophysical model of cholinergic neuromodulation in olfactory bulb. Journal of Neuroscience, 33(7), pp.3037-3058, 2013.
[5] Brea, J.N., Kay, L.M. and Kopell, N.J.: Biophysical model for gamma rhythms in the olfactory bulb via subthreshold oscillations. Proceedings of the National Academy of Sciences, 106(51), pp 21954-21959, 2009.

Results

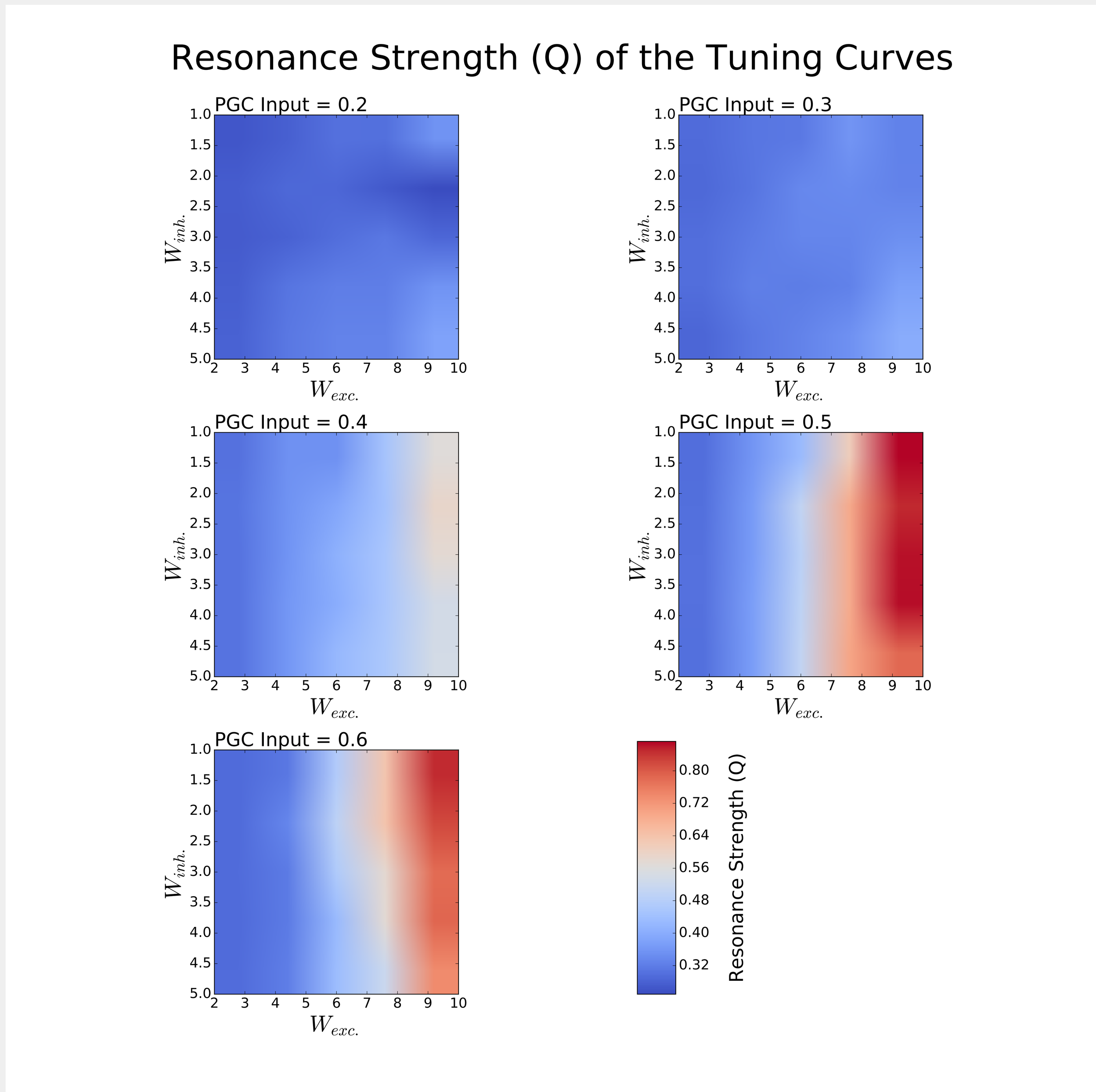
- Extracted the peak resonance frequency (RF).



- Extracted the resonance strength (RS) of the tuning Q, measured as:

$$Q = \frac{(F_{max} - F_{min})}{< F >} \quad (2)$$

- F_{max} and F_{min} is maximum and minimum firing rate.
- $< F >$ is mean firing rate over all measured frequencies.



- RF decreased as the excitation of the PGC increased (both from input and the MC).
- Strength of PGC inhibition onto the MC did not have a strong effect.

Discussion

- RS increased with the strength of the excitatory connection, when the PGC received sufficient external input.
- Suggest the MC can show frequency tuning.
- Depends on the strength of the excitatory synaptic input to the PGC, which provides inhibitory input to the MC.

r.miko@herts.ac.uk