

## **Final Report for NENS Exchange Grant.**

### ***General Information***

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Period of Stay: 15 November 2016 to 15 February 2017.

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Host Supervisor: Dr. Bernhard Englitz.

### ***Overview***

The main purpose of this project was to assess the perceptual effects of adaptation from a neuronal decoding perspective. Specifically, I followed this methodology:

1. Record the activity of a large sample of neurons from primary auditory cortex (A1) of the rat, in response to tones of 25 different frequencies in a neutral “control” condition, where they are presented in random and equiprobable manner (Figure 1A).
2. The responses of the population of neurons to these “control” tones will be used to tune a neuronal decoder, capable of determine the original frequency presented from the neuronal activity in A1 (Figure 2).
3. Also, stimulate each neuron with one or more “biased” sequences, the same as the control, but now one of the frequencies appears 50% of the times (every other position), and measure neuronal responses to each frequency again (see Figure 1B).
4. For each frequency in the sequence, use responses of all recorded neurons to this frequency in the context of the biased sequence, to “decode” the presumed frequency perception that this neuronal activity represents, that is, to determine the putative “perceived” frequency under adaptation (Figure 3A).
5. This decoding is carried out for each frequency (25), giving rise to a “psychophysical function” or “decoding bias” function, in which the difference between decoded (perceived) frequencies under the adapted and the unadapted conditions is plotted for each presented tone. This function will indicate if there is a systematic effect in how adaptation biases the perception of frequencies nearby the adaptor (Figure 3B).

The main result found in the data set was that adaptation induces a “repulsive shift” in perceived frequencies around the adaptor, much like in previous findings about orientation tuning in the visual system (Dragoi et al., 2000; Jin et al., 2005; Kohn and Movshon, 2004). That is, frequencies nearby the adaptor are perceived as farther away from the adaptor than they really are.

Additionally, this result has been replicated in a model simulation, to show that stimulus-specific adaptation of thalamo-cortical synapsis can explain the observations with great accuracy (Figure 4).

Finally, we are testing human subjects, using an appropriate behavioral paradigm to reveal if there is a bias effect in perceived frequency of the same direction that the one derived from the decoding analysis.

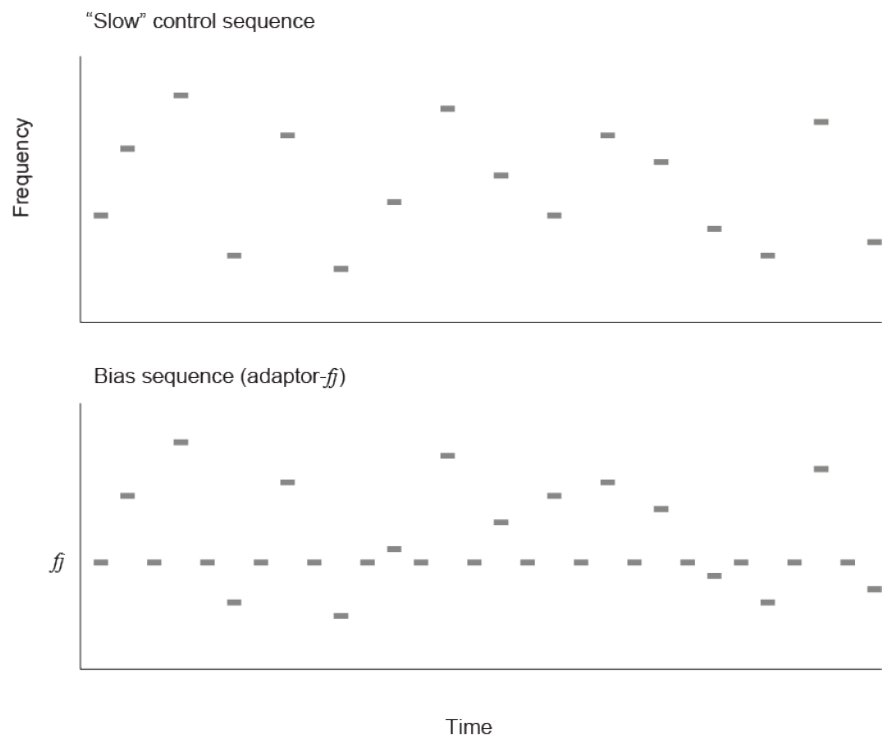
All these results are being adequately formatted into a manuscript, which will be sent out for publication in a high-profile journal, predictably by May-June this year. Our major limiting factor now is that we need to collect more data (that is, record more neurons), to have a more complete and homogeneous sample of neurons with many different frequency selectivity within A1, to confirm these results for all the frequencies, and to facilitate the decoding process so that all observations become statistically significant.

### Figure 1: Stimulation paradigm.

We used 25 frequency steps between 2 and 32 kHz (4 octaves range, 6 freqs/octave density), and control sequences were random presentations of each one with 12 repetitions (25 x 12 = 300 stimulus presentations or “trials”)

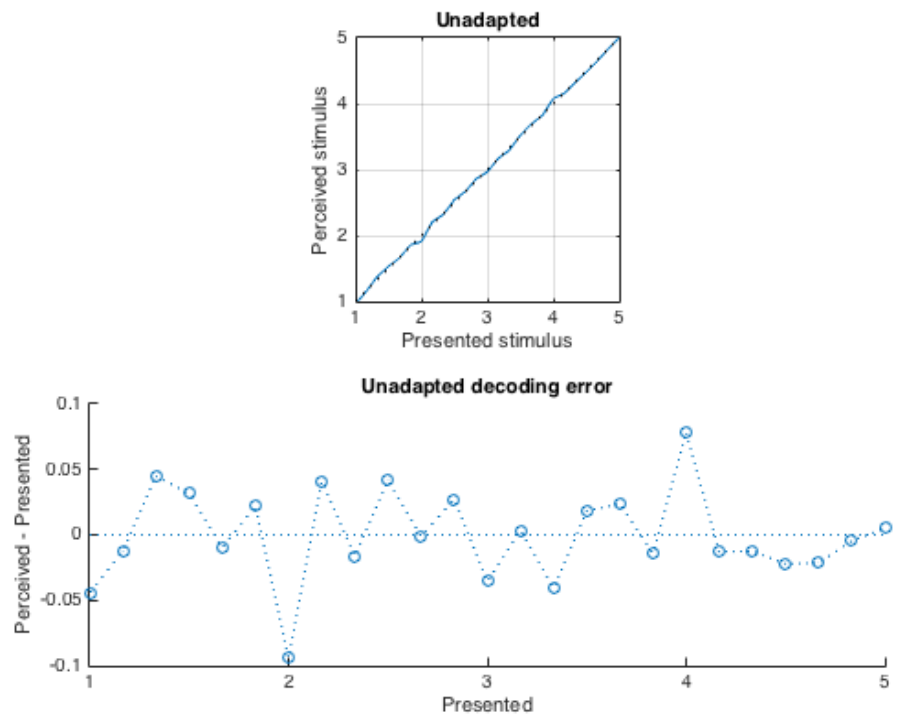
We used 5 of these frequencies as adaptors (2, 4, 8, 16 and 32 kHz) in 5 separate “bias sequences. The bias sequences were like the control sequences, but starting with 20 repetitions of the adaptor, and then interleaving one adaptor between every two tones;

thus, bias sequences were 620 stim long. The presentation rate of the bias sequences was 6 Hz (6 stim/s, or 167 onset-to-onset interval).



### Figure 2: Decoder

This figure (A) shows the decoded (perceived) frequency (on the y-axis), computed from the responses of the 100 model AC neurons to each presented frequency (on the x-axis). The reliability of the decoder is demonstrated by the “decoding line” running very close to the identity diagonal. Figure (B) shows the decoding error for each frequency, which is no larger than 0.1 octaves in any case, and less than 0.04 octaves on average.



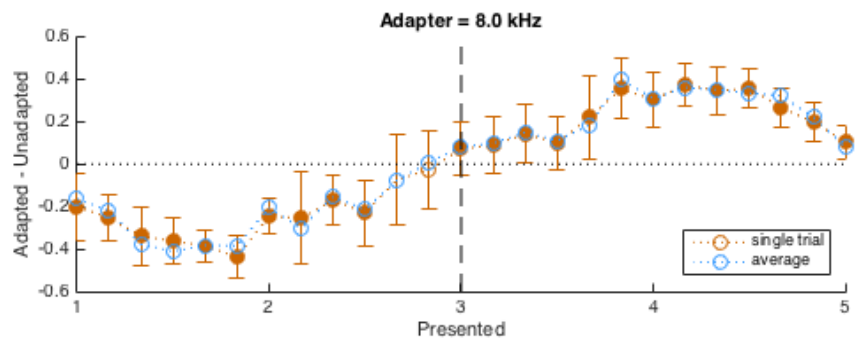
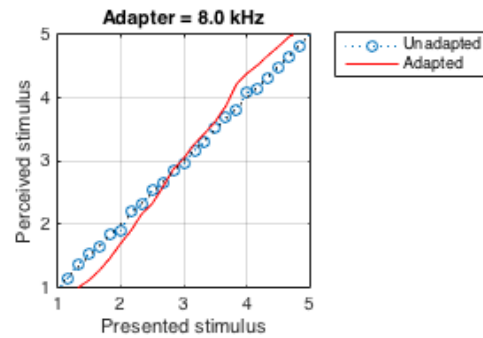
**Figure 3: Decoding under adaptation**

This figure demonstrates the use of the decoder to compute the perceived frequency under adaptation for each presented frequency.

The effects of adaptation on perceived frequency can be assessed by comparing the decoded stimuli (perceived frequency) in the unadapted (control, in blue), and adapted conditions (in red). For frequencies away from the adaptor, decoded stimulus is the same for unadapted and adapted conditions.

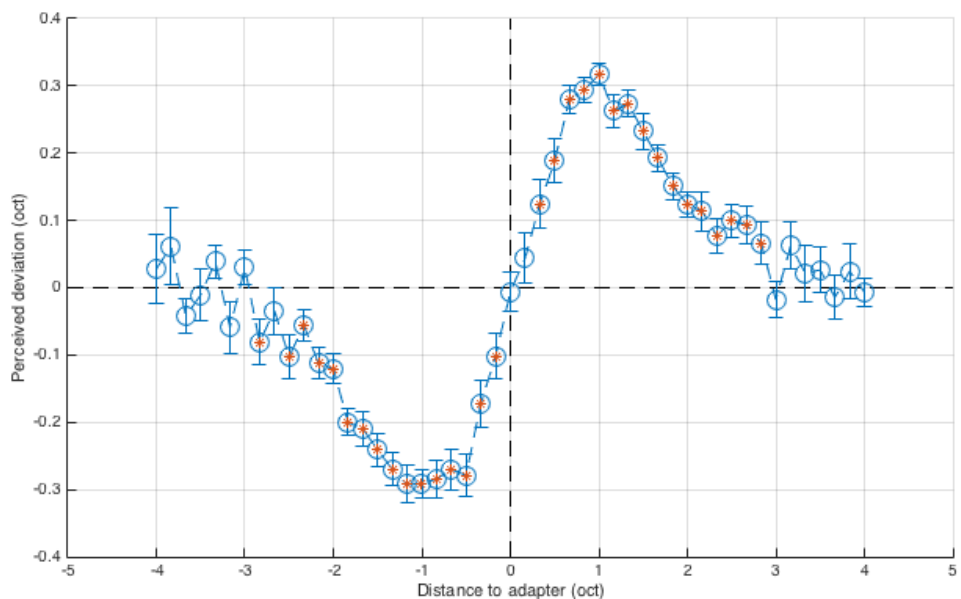
However, there is a characteristic bend of the decoding function under adaptation (the red curve), forming a sigmoid with respect to the unadapted condition.

Panel B, shows the shift in perceived frequencies (octaves) under adaptation (Bias - Control). The adaptor frequency is represented by the dashed line. Frequencies below the adaptor (Presented < Adaptor) tend to be decoded (perceived) as though they were of a lower frequency than they really are, whereas frequencies above the adaptor (Presented > Adaptor) are decoded (and thus putatively perceived) as though they were higher in pitch. This is therefore a “repulsive” effect, since the effect of the adaptor is to perceive nearby frequencies as though they were further away from the adaptor than they really are.



**Figure 4: Model simulations**

This figure shows the simulated shift in decoded frequency under adaptation, using a simple model of stimulus-specific adaptation (SSA) in thalamocortical synapses. The simulations are in close agreement with the neuronal data, suggesting that SSA is



a strong candidate mechanism underlying this perceptual effect.

### ***Personal Benefits***

This NENS Exchange Grant for a training stay has been pivotal in my professional development, taking my PhD to a new level of excellence. This stay at Neurophysiology Department in Radboud University (Nijmegen), under the supervision and guidance of Prof. Bernhard Englitz, has been extremely productive and beneficial for my personal interests. I have learned and developed computational techniques, in the fields of neuronal decoding for stimulus reconstruction, as well as computer-assisted model simulations of neuronal populations. This knowledge will become, from now on, a basic asset of my own lab in Salamanca, where we record a lot of neuronal activity, yet up until now we used to analyze all these data in very simple ways. Now, we will be able to extract more information and results from our data, and interpret it in more sophisticated ways. Therefore, this new knowledge will lead not only to the publication of one manuscript in the near future, but of many more along the following years, thus increasing the productivity of our own lab, and of the University of Salamanca as a whole. I cannot imagine how to make more of a short three-months stay in a foreign university.

### ***References***

- Dragoi, V., Sharma, J., Sur, M., 2000. Adaptation-induced plasticity of orientation tuning in adult visual cortex. *Neuron* 28, 287–298.
- Jin, D.Z., Dragoi, V., Sur, M., Seung, H.S., 2005. Tilt aftereffect and adaptation-induced changes in orientation tuning in visual cortex. *J. Neurophysiol.* 94, 4038–4050. doi:10.1152/jn.00571.2004
- Kohn, A., Movshon, J.A., 2004. Adaptation changes the direction tuning of macaque MT neurons. *Nat. Neurosci.* 7, 764–772. doi:10.1038/nn1267



Ph.D. Candidate Javier Nieto-Diego with Prof. Bernhard Englitz, after a highly fruitful scientific discussion in Dr. Englitz's office.