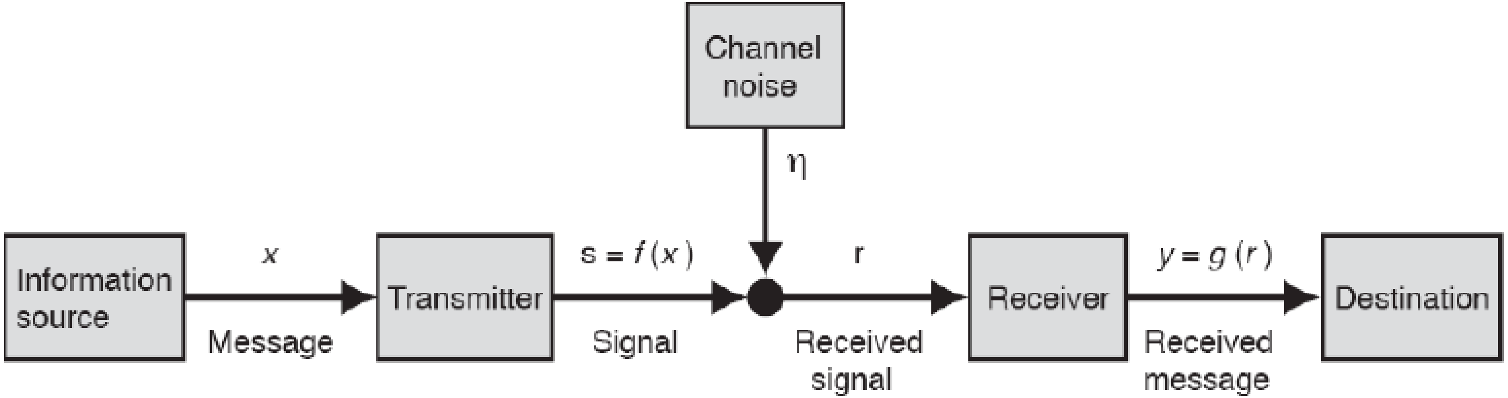
Electrosensory Midbrain Neurons Display Feature Invariant Responses to Natural Communication Stimuli

By: Aumentado-Armstrong et al. - 2015

Presented by: Katie, Marcelo, and Maria

What is coding

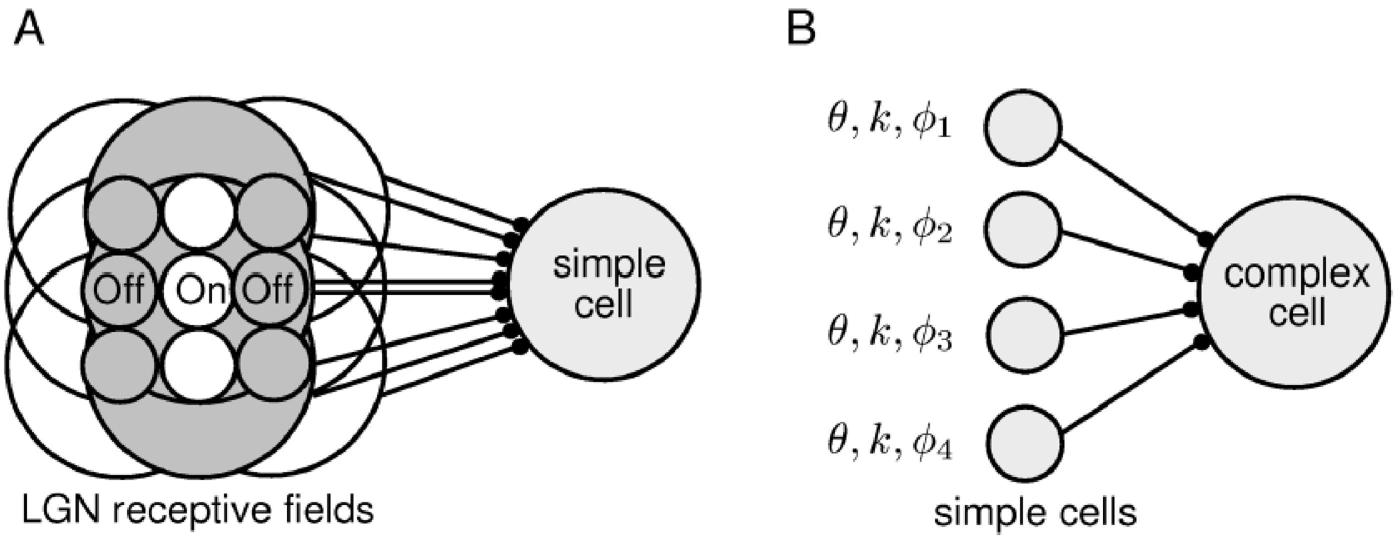
- Information is coded in the brain through a series of processes by changing the incoming information into another form or representation



Trappenberg, 2010

From Dense to Sparse

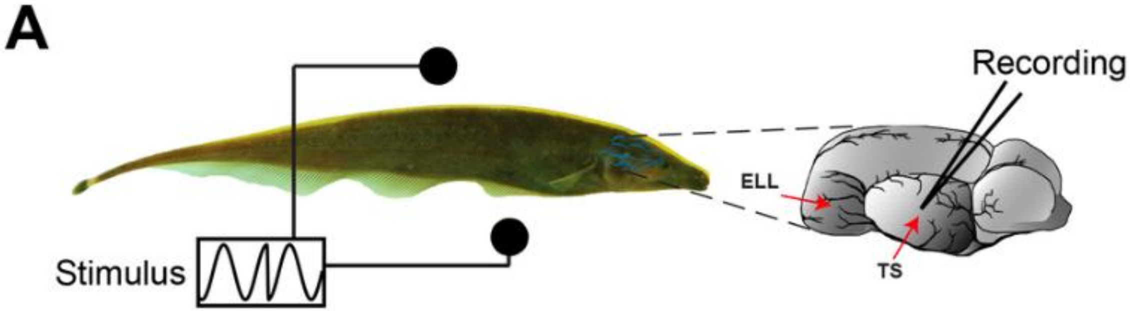
- Recall Hubel and Wiesel model for orientation selectivity in early visual processing



Apteronotus leptorhynchus

- Weakly electric fish
- Emit quasi-sinusoidal electric field
- Respond to changes of EOD by changing the firing rate

- Electrosensory lateral line lobe (ELL)
  - Pyramidal neurons
  - Hindbrain
- Torus semicircularis (TS)
  - Midbrain
  - Similar to Inferior Colliculus

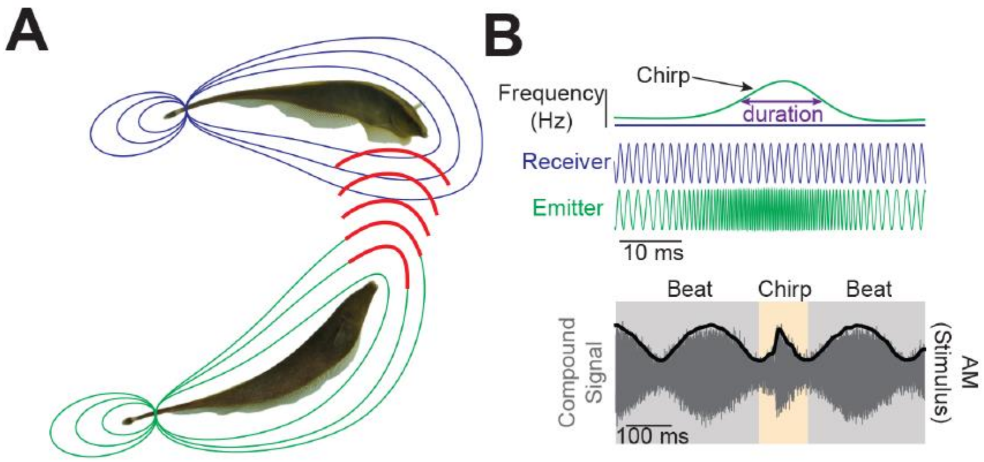


Beats and Chirps

Beat - when two fish come into contact it creates a change in sinusoidal amplitude

Chirp - occur on top of a beat and give rise to very different waveform, a form of communication between fish

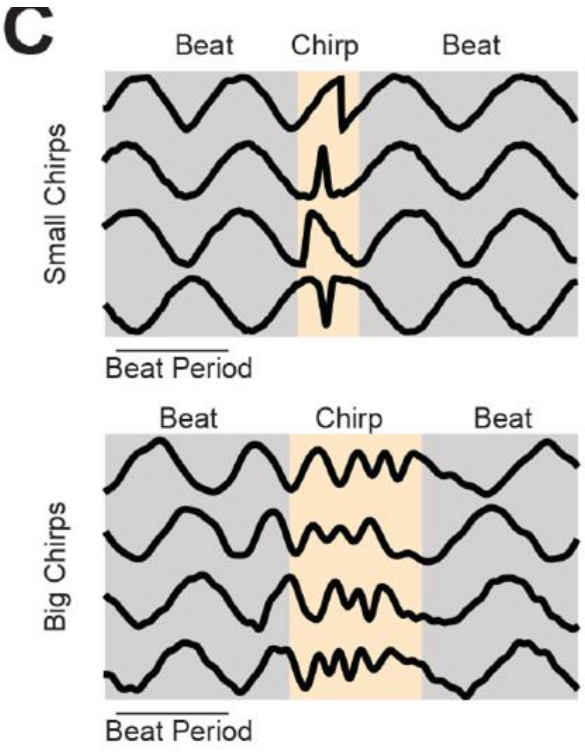
Sexual dimorphism gave rise to different EOD frequencies

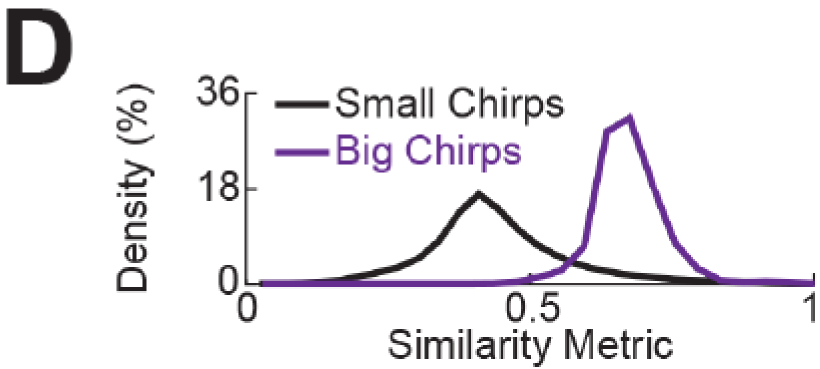


Hypothesis

- Midbrain electrosensory neurons can respond selectively and in an invariant manner to different stimuli
    - This response invariance is the result of non-linear integration from hindbrain electrosensory input

Quantifying heterogeneities in electrocommunication stimuli





- (C) Larger differences in small chirp associated waveforms than in big chirp
- (D) Quantified differences between small and big chirp waveforms using similarity index

Response of TS neurons to small and big chirps

What did they do?

- Quantified response of neurons using chirp selectivity index (CSI), Victor-Purpura distance metric (VPD) and feature invariance index (FI)

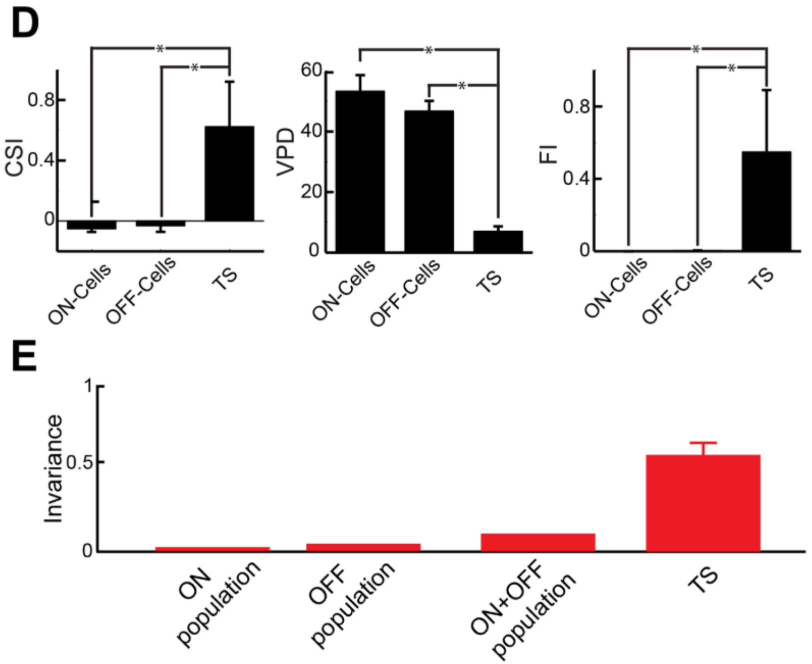
What did they find?

- Some (n=9) TS neurons responded selectively to both small and big chirp waveforms
- CSI = 1
- VPD = 1.19
- FI = 0.99
- Thus, TS neurons display invariant responses to electrocommunication stimuli

Responses of ELL pyramidal neurons to chirps

What did they do?

- Recorded ELL pyramidal neuron responses to same stimuli presented to TS neuron
- Quantified the responses of ON and OFF-type ELL cells to chirps using CSI, VPD, and FI



TS Neuron Model

$$C \cdot \frac{dV}{dt} = -g_K n^4 \cdot (V - E_K) - g_{Na} m^3 h \cdot (V - E_{Na}) - g_L \cdot (V - E_L) + I(t)$$

$$\frac{dV}{dt} = \frac{1}{C}\left(I_{Na} + I_{KDR} + I_h + I_T + I_{leak} + I_{syn} + I_{bias} + \sigma_{noise}\, \xi(t)\right)$$

$$I_{Na} = -g_{Na}\, m_\infty^3(V)(0.85 - n)(V - E_{Na})$$

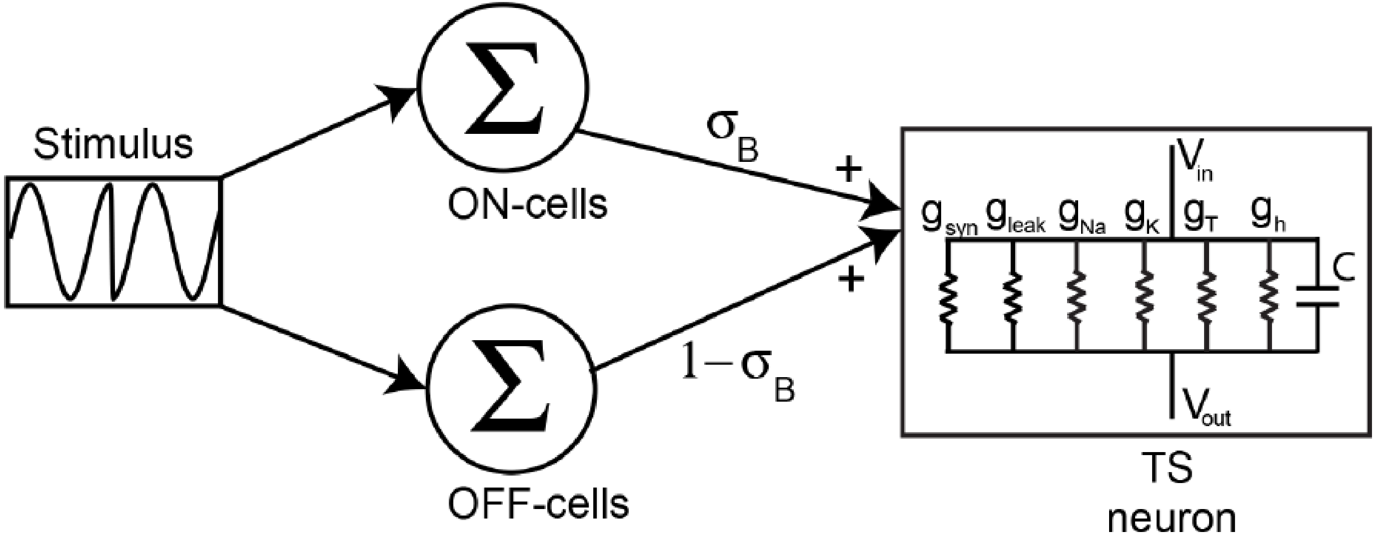
$$I_{KDR} = -g_k\, n^4\,(V - E_K)$$

$$I_h = -g_h\, h(V - E_h)$$

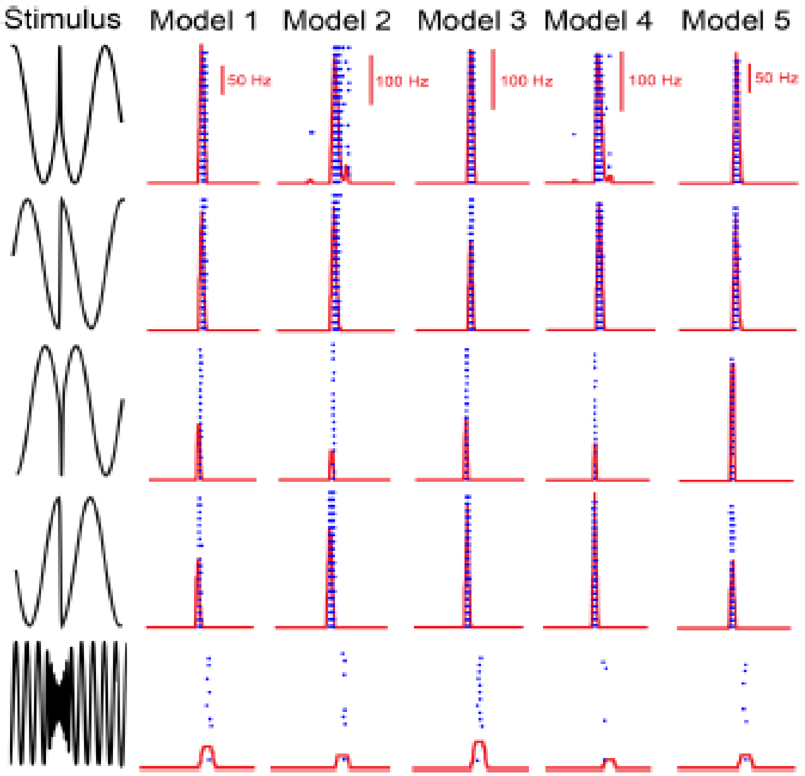
$$I_T = -g_T\, s_\infty^3(V)\eta\,(V - E_{Ca})$$

$$I_{leak} = -g_{leak}(V - E_{leak})$$

Modeling TS neuron responses

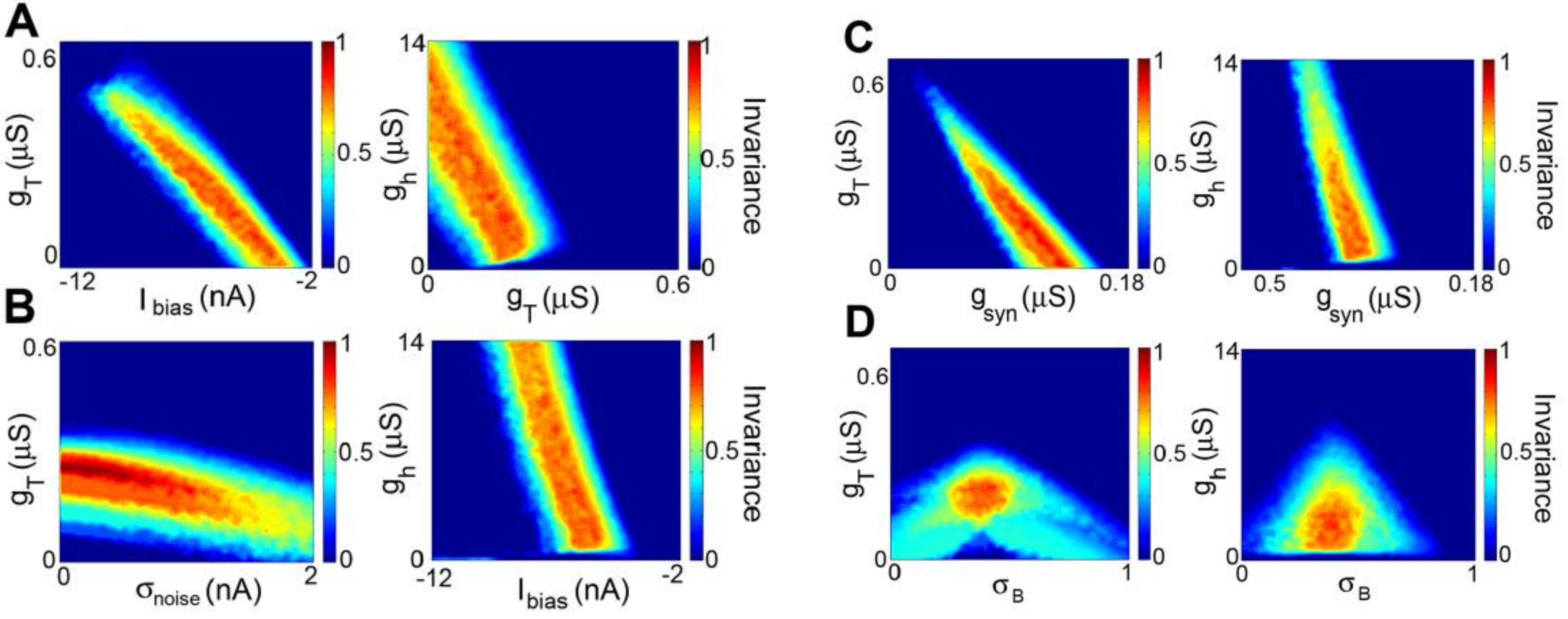


Feature Invariant Responses in Model

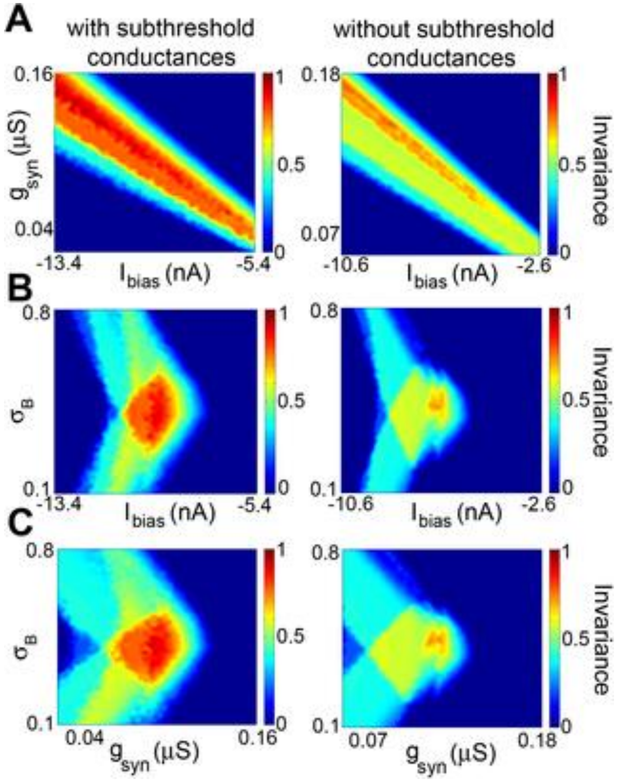


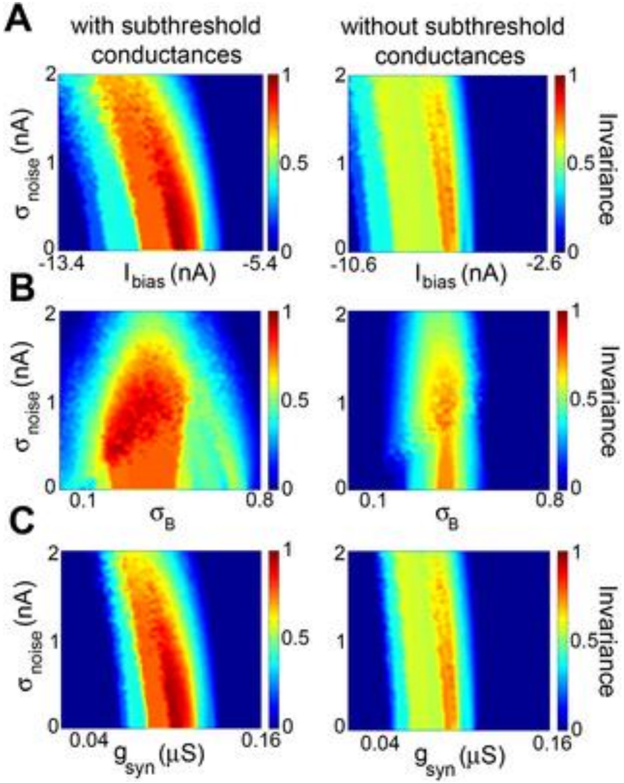
Parameters	Model 1 (0.90)	Model 2 (0.79)	Model 3 (0.91)	Model 4 (0.77)	Model 5 (0.89)
$\boldsymbol{\sigma}_B$	0.42	0.41	0.35	0.40	0.42
I_{bias}	-9.4	-6.6	-18.1	-5.2	-6.5
g_{syn}	0.10	0.13	0.16	0.10	0.09
g_h	0.24	0	0.48	0.02	0
g_T	2.10	0	3.99	0	5.6

Effect of Varying Model Parameters

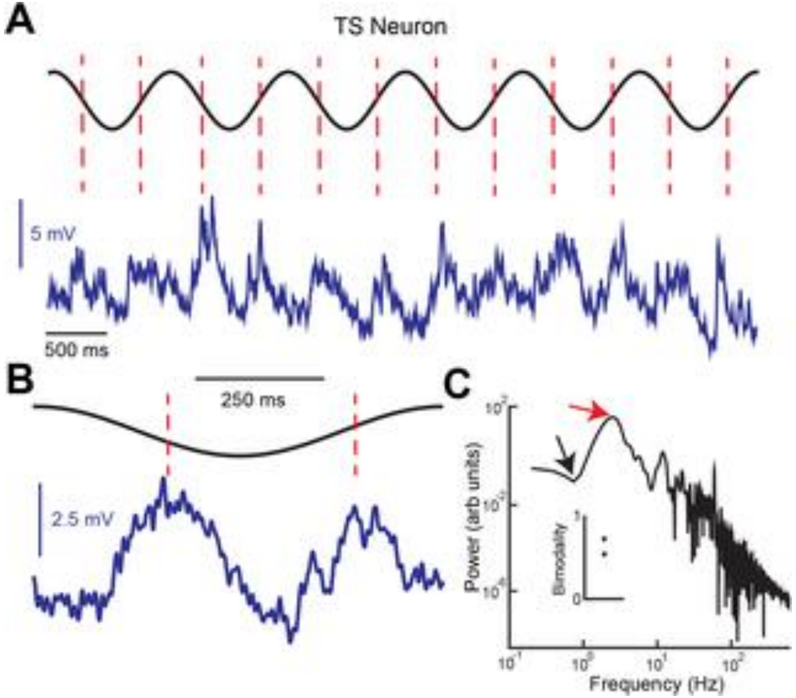


Increasing the Set of Invariance Parameters





Verifying the Model



Wanted to test:

1) Whether a spiking nonlinearity was enough to produce feature invariance
2) If maximum feature invariance is obtained when the model neuron receives both ON and OFF cell inputs

Summary of Results

- Hindbrain responds with heterogeneities, but found some TS (midbrain) neurons displayed feature invariant responses
- Subthreshold membrane conductances enhanced the robustness of the feature invariant response
- Verified model predictions through experiments
    - TS neurons responded to membrane depolarizations during the rising and falling phase - suggesting that they do receive input from both ON- and OFF-type ELL pyramidal neurons

Significance

- Cited 16 times
- First experimental evidence
- As mentioned in the paper, could be useful in AI
- Understanding invariance may also help in understanding brain disorders

Strengths

- In-depth list of future directions
  - Determine what subset of TS neurons respond with feature invariance
  - Potential use in AI

Limitations

- Did not compare subsets of TS neurons (9/137 had feature invariance)
  - Would have liked to see a comparison to show this

Questions?

References

Aumentado-armstrong, T., Metzen, M. G., & Sproule, M. K. J. (2015). Electrosensory Midbrain Neurons Display Feature Invariant Responses to Natural Communication Stimuli. *PLoS Computational Biology*, *11*(10), 1–28. http://doi.org/10.1371/journal.pcbi.1004430

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