Distinct Inhibitory Spatial Scales Improve Information Transmission in the Retina

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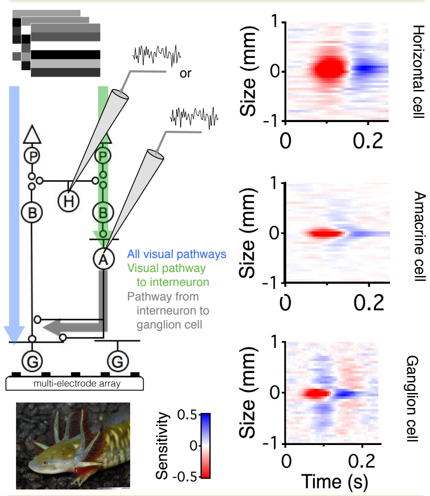
Introduction

The linear – or classical – receptive field is the stimulus dimension encoded with the highest average sensitivity, giving a compact description of the neural code. In ganglion cells, the linear receptive field encodes natural scenes efficiently, maximizing the information transmission given a constraint on the output firing rate. Despite decades of investigation, the spatiotemporal properties of the linear receptive field surround have not been quantitatively assigned to interneurons.

Our experimental results show that horizontal and narrow-field amacrine cells contribute synchronously to the retinal ganglion cell linear receptive field surround, but they do so at different spatial scales. What benefit is there for two interneuron pathways to combine linearly to create the receptive field surround?

Methods



References

[1] Atick and Redlich, "Towards a Theory of Early Visual Processing", Neural Computation 2: 308-320 (1990).

[2] Tkacik G et al, "Natural images from the birthplace of the human eye", PLoS ONE 6: e20409 (2011).

More information

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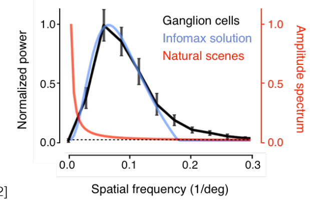
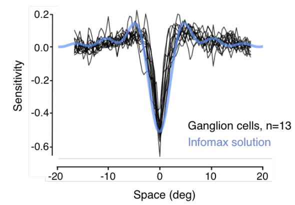
Efficient coding

Efficient coding solution matches the ganglion receptive field.

Tkacik Natural Image Database [2]





In a linear system

$$r = F(s + N_{\text{input}}) + N_{\text{output}}$$

where the statistics of *s* are drawn from natural scenes.

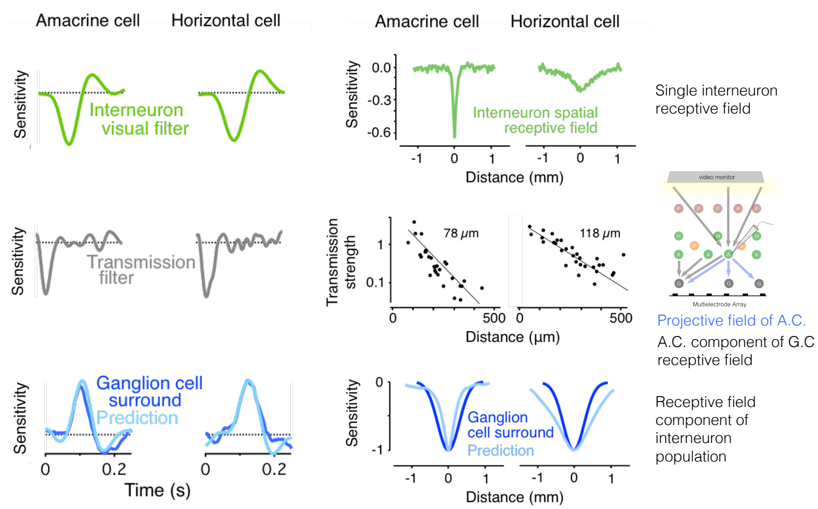
Maximize mutual information

$$I(r;s) = H(r) - H(r|s)$$

over all possible filters *F*, while constraining the output variance.

Analytically find the optimal filter as a function of the input power spectrum, input noise variance, and output noise variance. [1]

Interneuron Contributions to the Receptive Field Surround



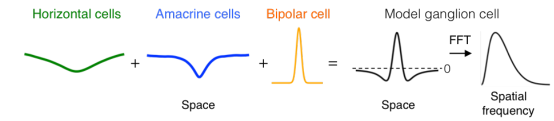
Single interneuron receptive field

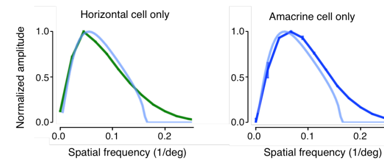
Projective field of A.C.

A.C. component of G.C receptive field

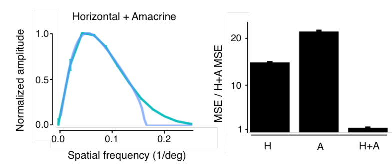
Receptive field component of interneuron population

Efficiency of receptive field surrounds composed of one or two interneuron pathways



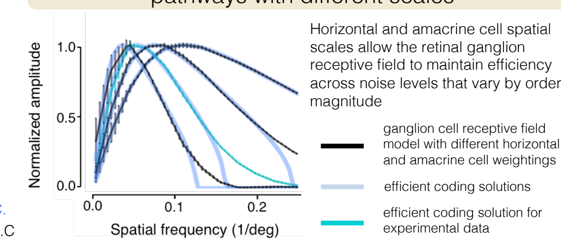


A combination of horizontal and narrow-field amacrine cells is more efficient than horizontal or amacrine cells alone.



Mean Squared Error (MSE) between efficient coding solution and receptive field composed of horizontal cells, or amacrine cells, or both.

Flexibility of receptive fields from two interneuron pathways with different scales



Horizontal and amacrine cell spatial scales allow the retinal ganglion receptive field to maintain efficiency across noise levels that vary by orders of magnitude

Conclusions

- A combination of horizontal and amacrine cells is more efficient than using either cell type alone.
- Two inhibitory pathways with synchronous temporal properties but different spatial scales allow efficient information transmission under a wide range of conditions.

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