Retinal adaptation to spatial correlations

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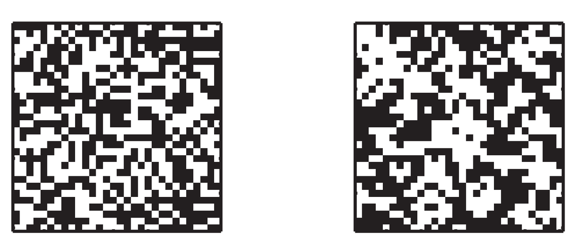
1. Introduction

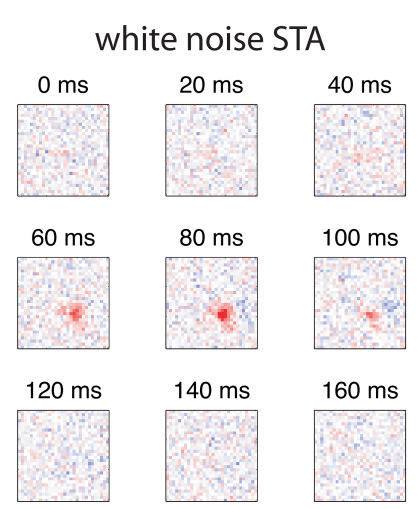
Retinal ganglion cell (RGC) receptive fields are traditionally described in terms of an excitatory center with a concentric inhibitory surround. More recent white noise experiments do not show strong surrounds (Chichilnisky & Kalmar, 2002). This might be evidence for weakening of the surround in the absence of correlations, as predicted by efficient coding theory. We tested for such adaptation by measuring receptive fields using white and exponentially correlated noise.

2. Receptive fields

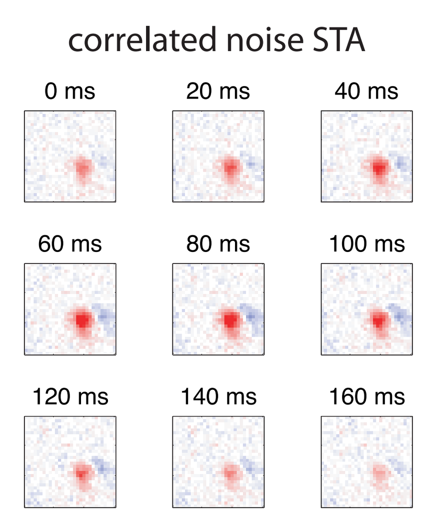
We measured receptive fields using white noise (**below left**) and exponentially correlated noise (**below right**) checkerboards. Using a multi-electrode array, we were able to record from many cells simultaneously. **Right:** Centers for 22 ON cells in a single piece of tissue cover the area from which we recorded.



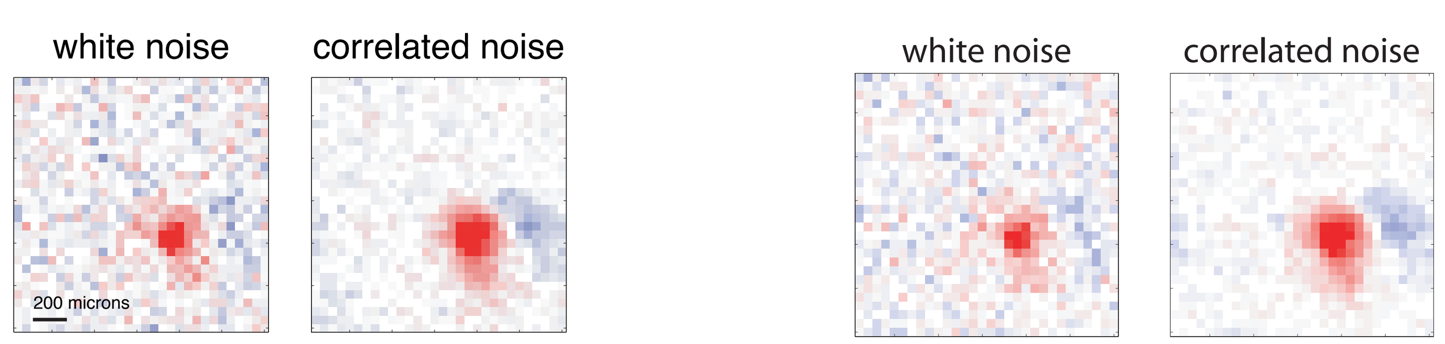
white noise — exponentially correlated noise



The spike-triggered averages (STAs) for an example cell using white noise (**left**) and correlated noise (**right**) show a clear ON-center response (red) plus an inhibitory region to one side (blue). This "surround" forms a patch rather than a concentric ring around the center.



Correlated noise and white noise STAs (**below left**) for the same cell are not directly comparable due to the correlations present in the former stimulus. To address this issue, we used STRFlab (strflab.berkeley.edu) to make maximum likelihood extimates of the spatiotemporal receptive fields (STRFs, **below right**).

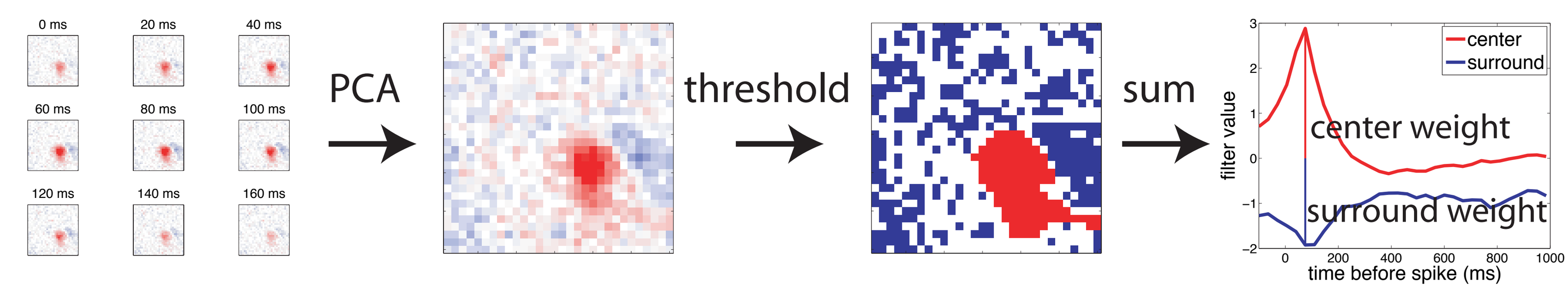


(We also analyzed our data using an alternative "recorrelation" method. This method is not described in detail here but can be discussed upon request.)

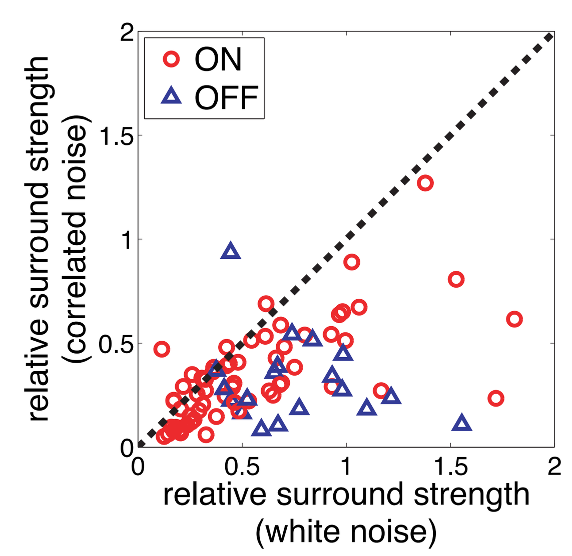
3. Surround strength

Our receptive fields are generally not well fit as a difference-of-gaussians model, so we developed a measure of relative surround strength that does not depend on fitting.

For each spatiotemporal receptive field, we first used principal components analysis to create a single spatial frame (**below left**). We then applied a threshold and a majority vote algorithm to find pixels that belonged to the center and surround regions (**center**). Next we took the sum of the pixels in each region at each timepoint to generate temporal receptive fields for the center and surround (**right**). The surround strength was quantified as the ratio of the peak of the surround timecourse to the peak of the center timecourse.



$$\text{relative surround strength} = \frac{\text{surround weight}}{\text{center weight}}$$

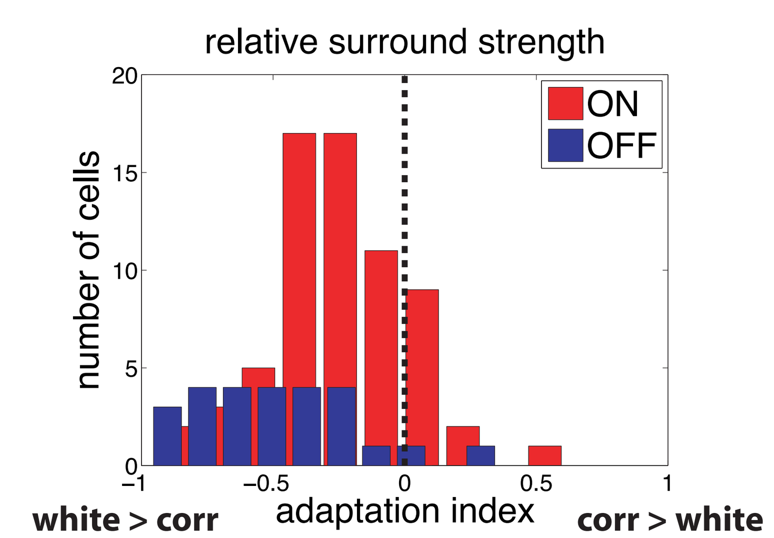


Left: Scatterplot of surround strengths shows that, overall, cells tend to have stronger surrounds under white noise than under correlated noise. N = 67 ON cells, 26 OFF cells.

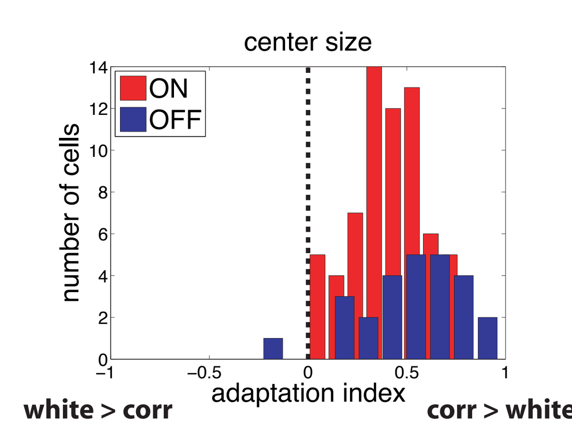
Right: We computed an adaptation index

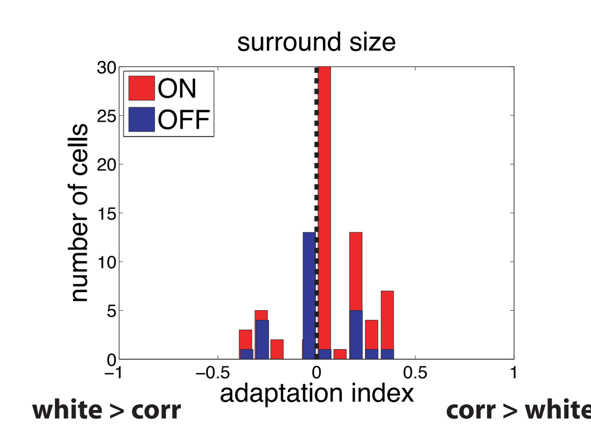
$$\frac{\text{corr} - \text{white}}{\text{corr} + \text{white}}$$

for each cell. In both ON and OFF cells, most receptive fields have stronger relative surrounds under white noise than under correlated noise.



This difference in surround strength was produced by a larger center under correlated noise than under white noise (**near right**) with no change in surround size (**far right**).

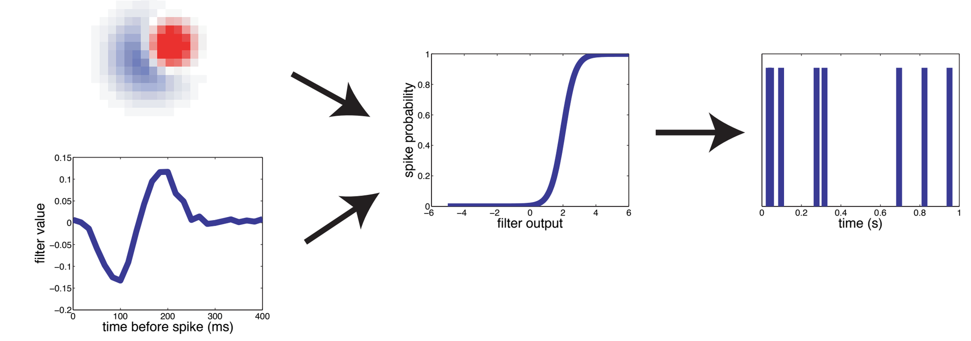


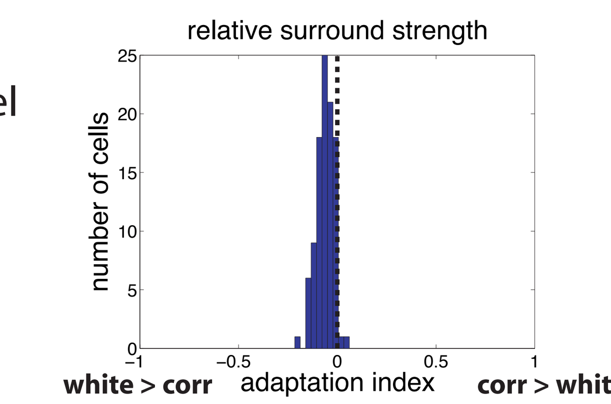


(Our recorrelation method produces the same results.)

4. Validation on model

We built a linear-nonlinear model (**right**) using a biphasic temporal kernel and a difference-of-gaussians spatial filter and then used experimental stimuli to generate STRFs from which we recovered the model center and surround.





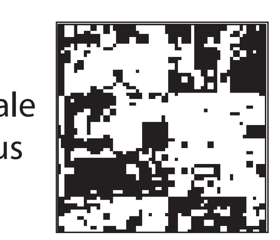
Right: Surround strength adaptation indices for model neurons (computed as in panel 3) are clustered near zero, indicating that our method of recovering surround strength does not produce bias in the results.

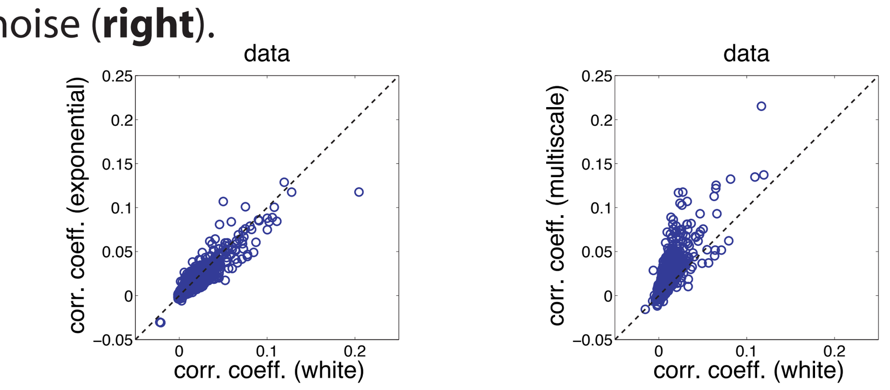
(Our recorrelation method does not produce bias either.)

5. Output correlations

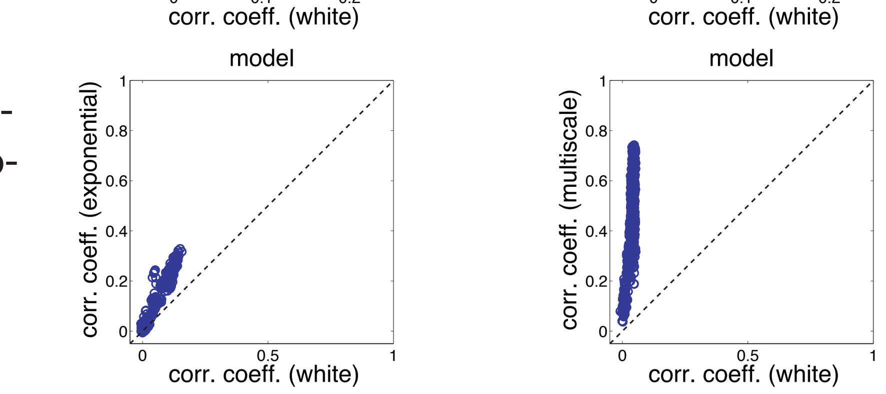
Pairwise output correlations are similar for exponentially correlated noise and white noise (**below middle**). Using a more strongly correlated, multiscale stimulus (**left**), output correlations are stronger than for white noise (**right**).

multiscale stimulus





Using a model neuron with no adaptation, stimulus correlations produce greater increases in output correlations (**right**) than is seen in real neurons.



6. Conclusions

(A) Relative surround strength is higher during white noise than during correlated noise.

(B) Despite this, retinal output is more decorrelated than in a static linear-nonlinear model.

References:
Chichilnisky & Kalmar (2002). Functional asymmetries in ON and OFF ganglion cells of primate retina. J Neurosci, 22(7): 2737-2747.

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