Visual adaptation as inhibitory reweighting

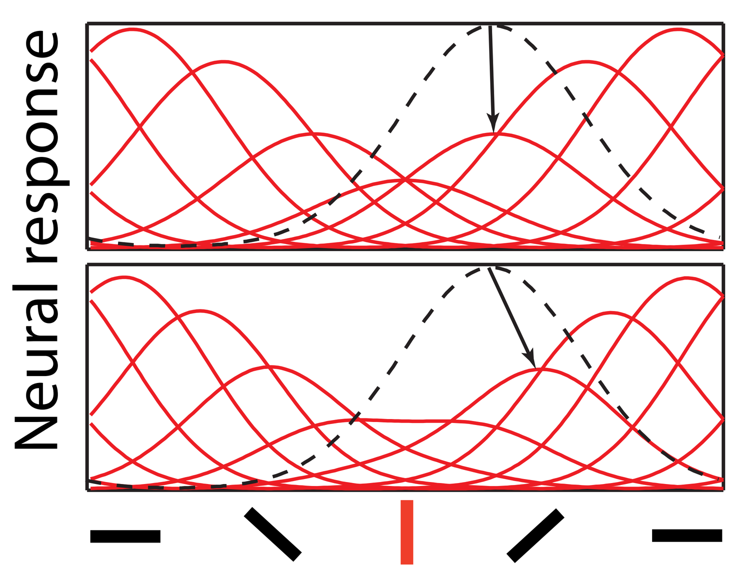
Zachary M. Westrick, David J. Heeger, Michael S. Landy
Dept. of Psychology & Center for Neural Science, New York University

Pattern adaptation

Adaptation to an oriented pattern leads to orientation-tuned suppression and repulsion of tuning curves in V1

(| = adapting orientation)

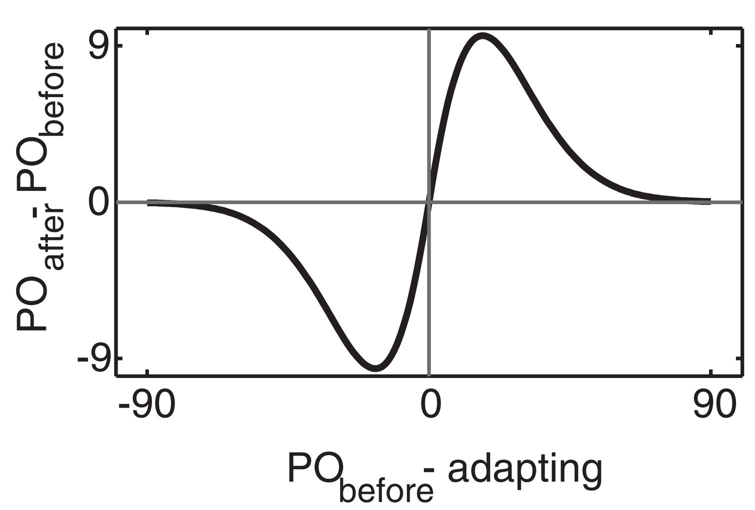
Tuning changes characterized as:



Neuron-specific: suppression only

Stimulus-specific: suppression and preferred orientation (PO) shifts

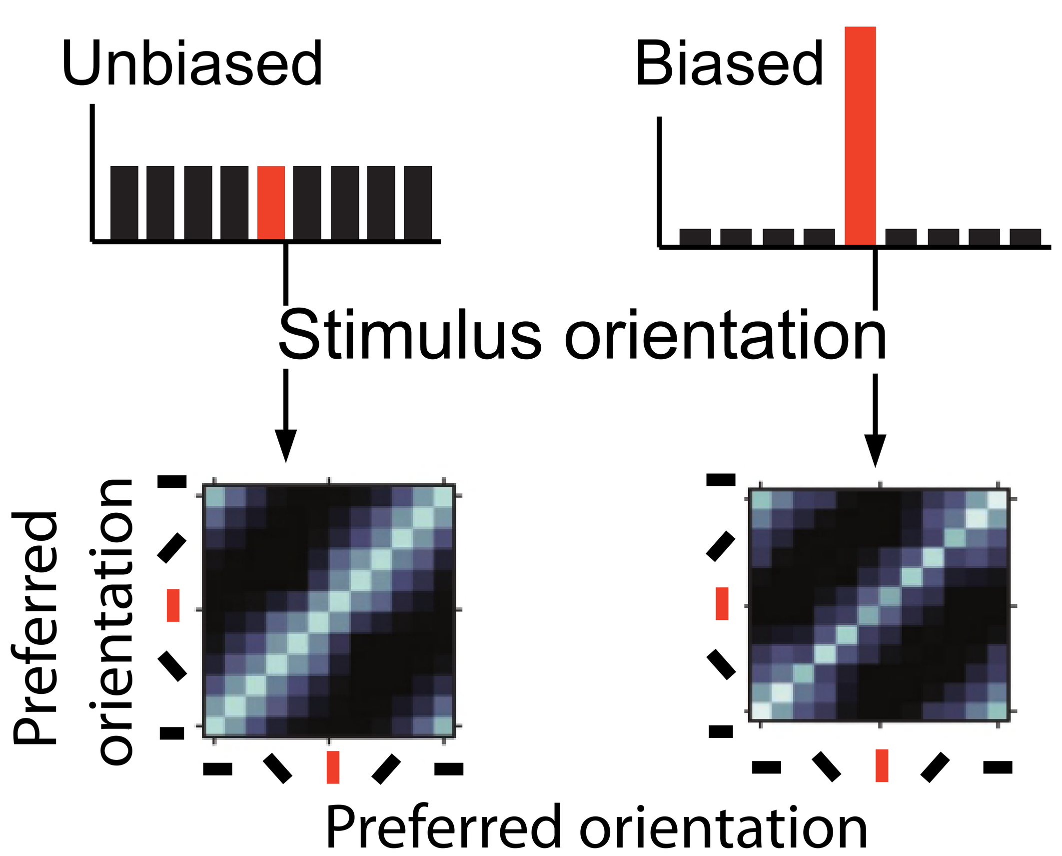
Data largely support stimulus-specific suppression



Shift in preferred orientation as a function of orientation relative to adapter is S-shaped

Schematic of typical effects taken from Jin et al. (2005)

Maintenance of covariance structure in adaptation



Cat V1:
Neural covariance structure in an environment of randomly sampled gratings is nearly the same when the distribution of gratings across orientation is uniform (left) and when it is highly biased (right)

Suggests homeostatic regulation of joint response structure is critical in adaptation

Figures from Benucci et al. (2013)

Model

Normalization model

$$R_i = \frac{I_i^2}{s + \sum W_{ij} I_j^2}$$

Divisive normalization provides a gain-control mechanism between orientation tuned neurons

Feedforward input I_i: Gaussian orientation tuning curve with typical (30 deg) orientation bandwidth

Weight W_{ij} reflects the contribution of neuron j to neuron i's normalization pool.

Weight update

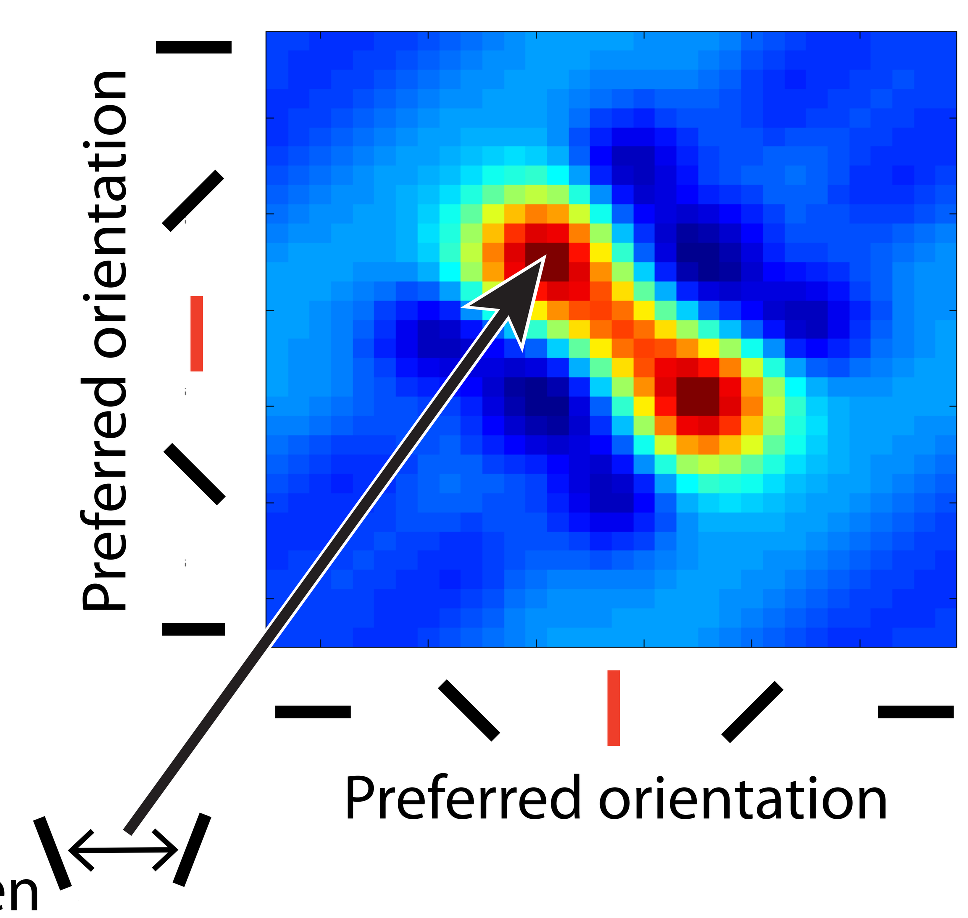
$$W_{ij}(t) = W_{ij}(t-1) + \alpha[R_i R_j - E(R_i R_j)]$$

Inhibitory weight between neurons i and j increased whenever the product of neural responses from those neurons exceeds the expectation of this product (under the unbiased stimulus environment)

Adjusts normalization weights to maintain response product structure, not covariance

Weights following adaptation

$W =$



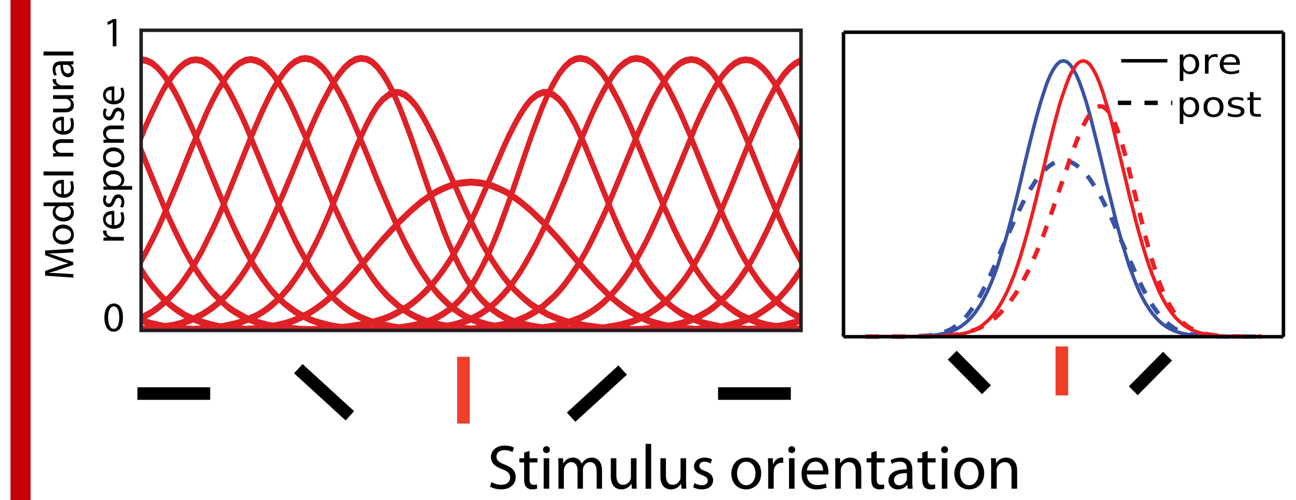
Normalization weights between neurons tuned to opposite flanks of the adapting orientation are increased following adaptation.

This leads to tuning-curve repulsion

Normalization weights on neurons tuned near the adapter are increased on balance, leading to tuning-curve suppression

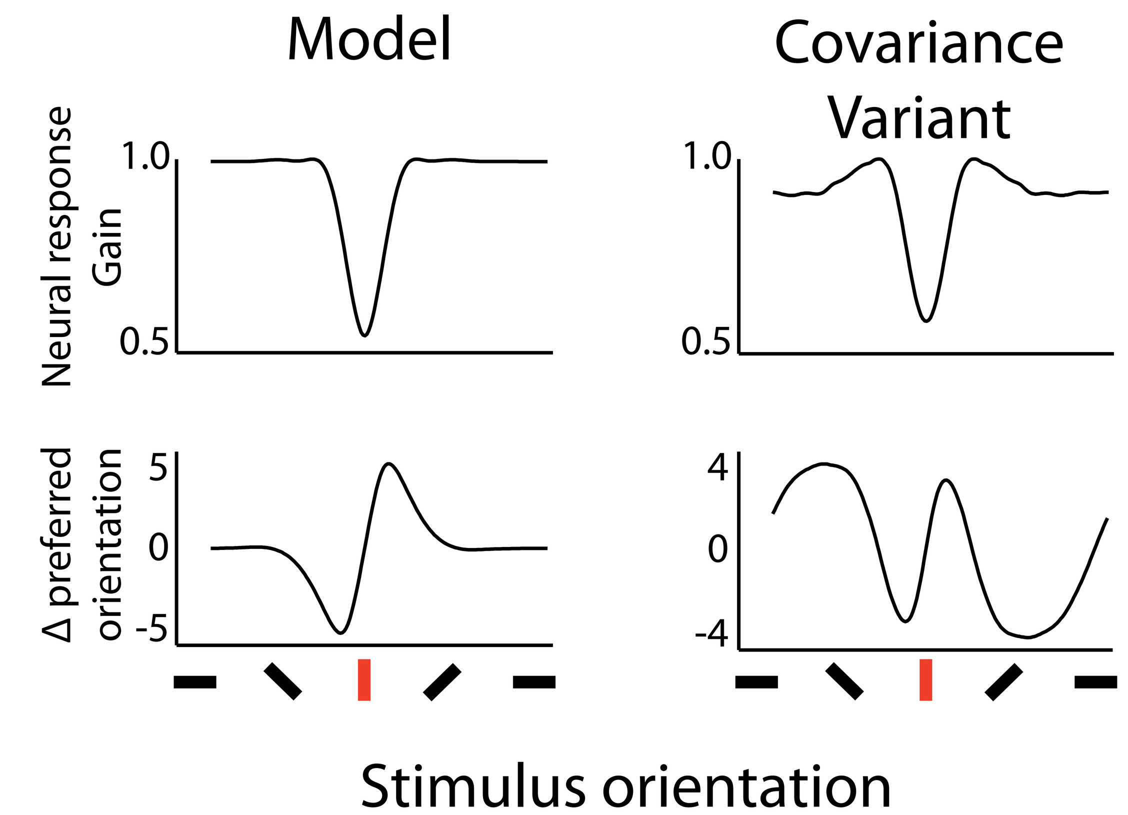
Simulation results

Model replicates tuning curve suppression, repulsion, and homeostatic covariance structure, with no free parameters



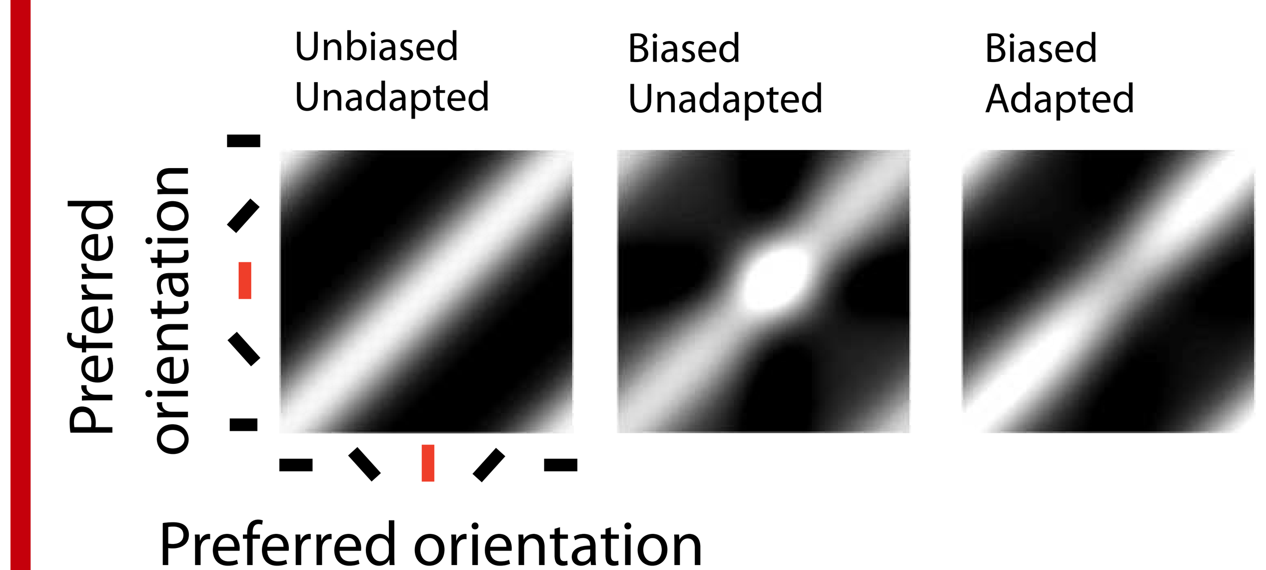
Neurons tuned to adapter, and flanking neuron

Adaptation leads to suppression and repulsion



Alternative model that adjusts weights based on homeostatic maintenance of covariance does not produce realistic tuning curve shifts

Maintenance of covariance structure in simulated adaptation



Model restores diagonal covariance structure, despite not explicitly maintaining covariance

References

Benucci, A., Saleem, A. B. & Carandini, M. (2013) Adaptation maintains population homeostasis in primary visual cortex. *Nature Neuroscience*, 16, 724-729.

Jin, DZ., Dragoi, V., Sur, M. & Seung, HS. (2005) Tilt aftereffect and adaptation-induced changes in orientation tuning in visual cortex. *J Neurophysiol*, 94, 4038-50