Visual Coding of Local Orientation

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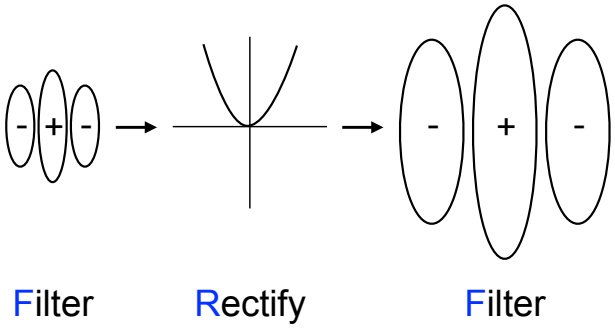
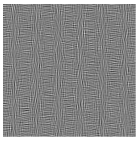
FRF Model



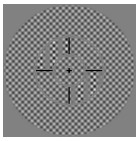
Filter Rectify Filter

Outline

- 2nd-order channels: bandwidth

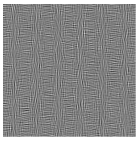


- 2nd-order channels: normalization

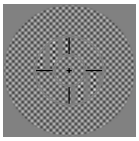


Outline

- 2nd-order channels: bandwidth



- 2nd-order channels: normalization

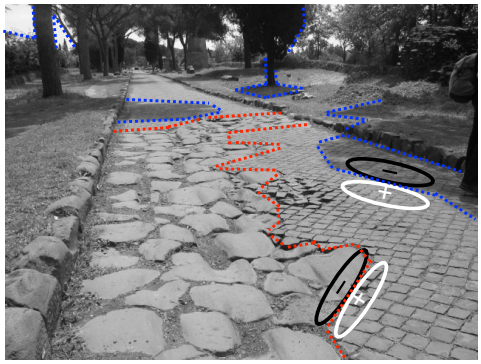


Neurons in primary visual cortex (V1) extract boundary information

Properties of visual boundaries:

- *orientation*
- *position*
- *scale*

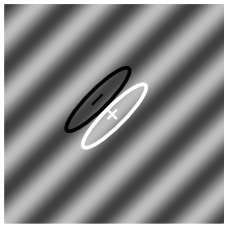
Boundary types in visual scenes: first-order and second-order



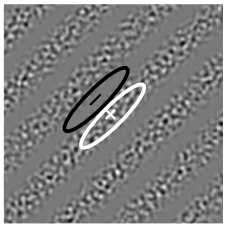
- First-order: vary in luminance
- Second-order: do *not* vary in luminance

Second-order boundaries are invisible to first-order (V1) neurons

First-order *(luminance)*



Second-order *(contrast)*



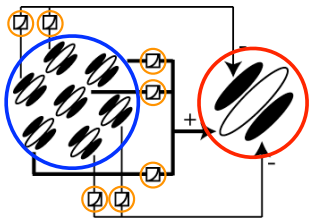
- Many different types of second-order boundaries: changes in contrast, texture, orientation, scale, motion; illusory contours...

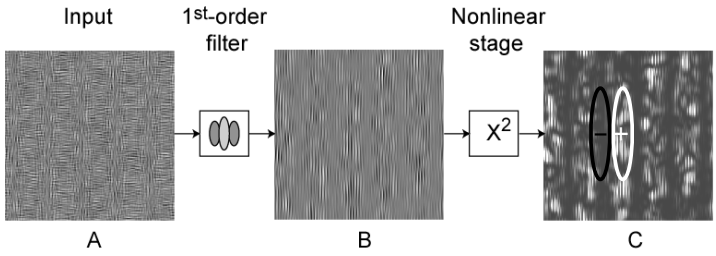
Computational models of boundary perception: filter-rectify-filter (FRF)

First stage: many small-scale first-order receptive fields

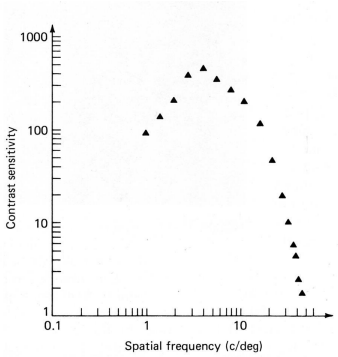
Rectify (threshold) output of first stage

Second stage: Sum rectified output with large-scale receptive field

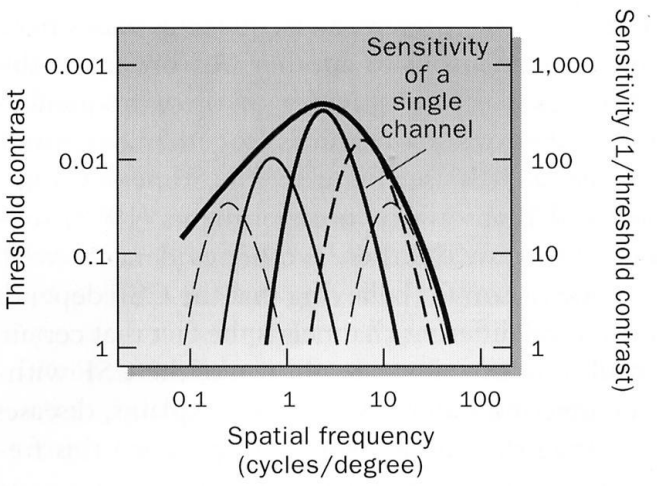




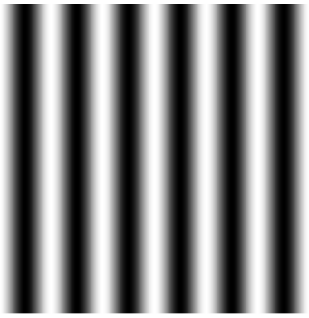
The contrast sensitivity function (CSF)

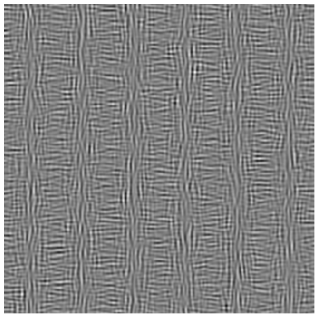


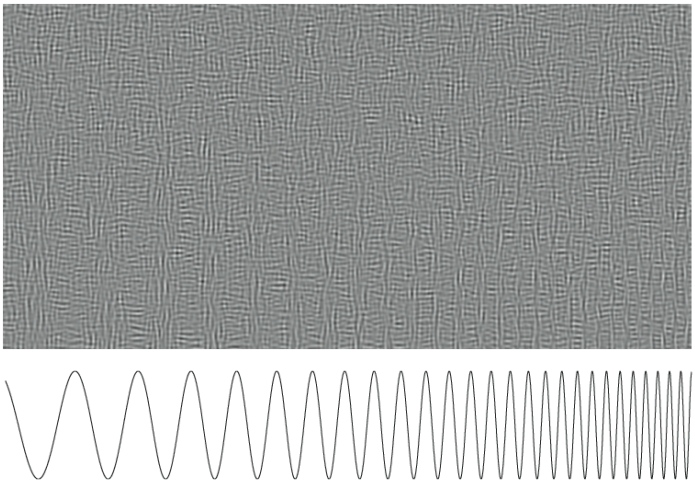
(Campbell & Robson, 1968)



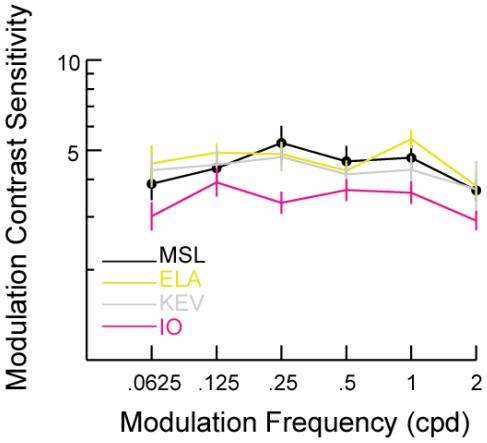
Typical Stimulus for measuring CSF: Sine wave grating





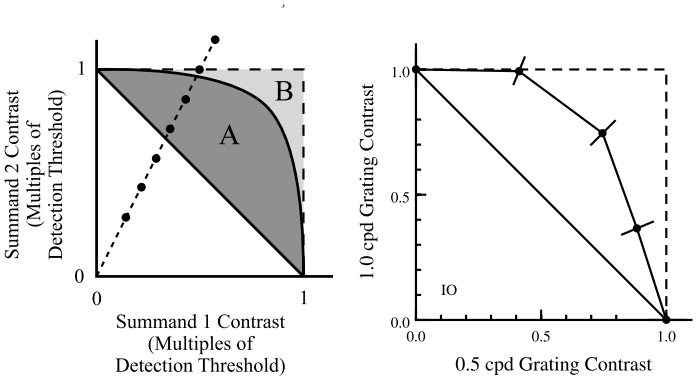


2nd-order contrast sensitivity function



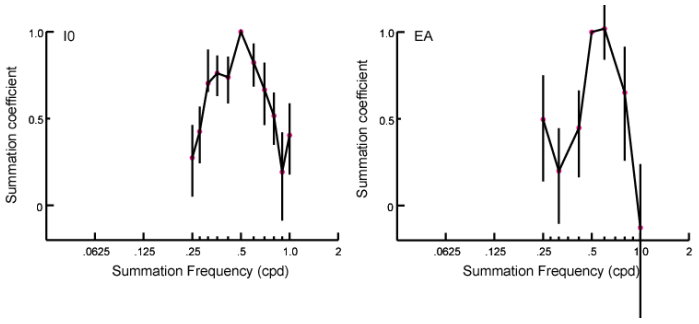
Landy & Oruç, *Vis Res*, 2002

2nd-order summation



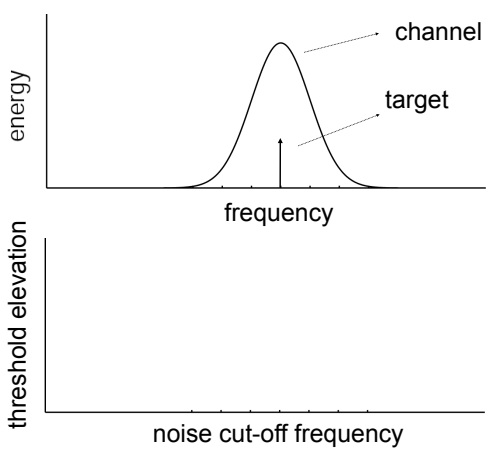
Landy & Oruç, *Vis Res*, 2002

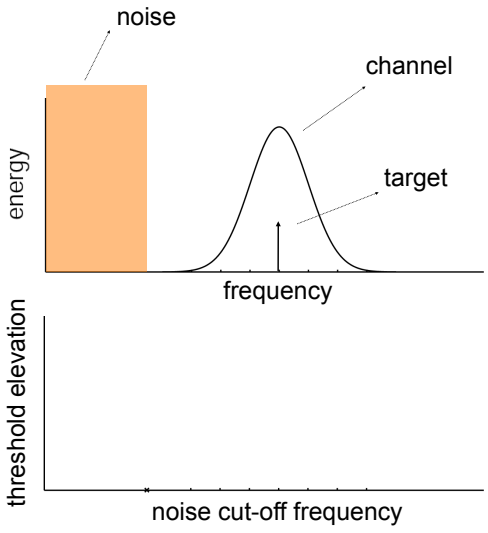
2nd-order summation

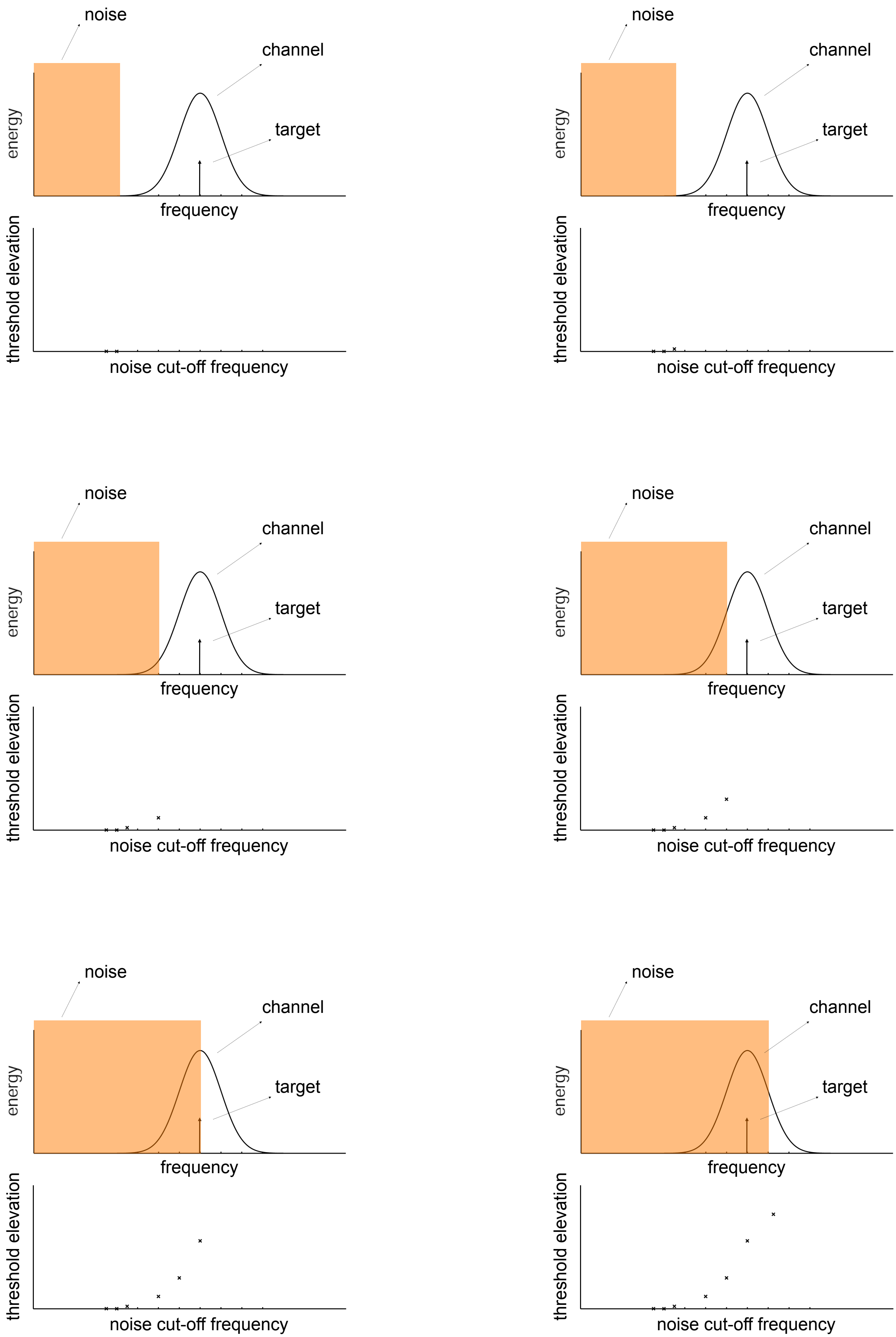


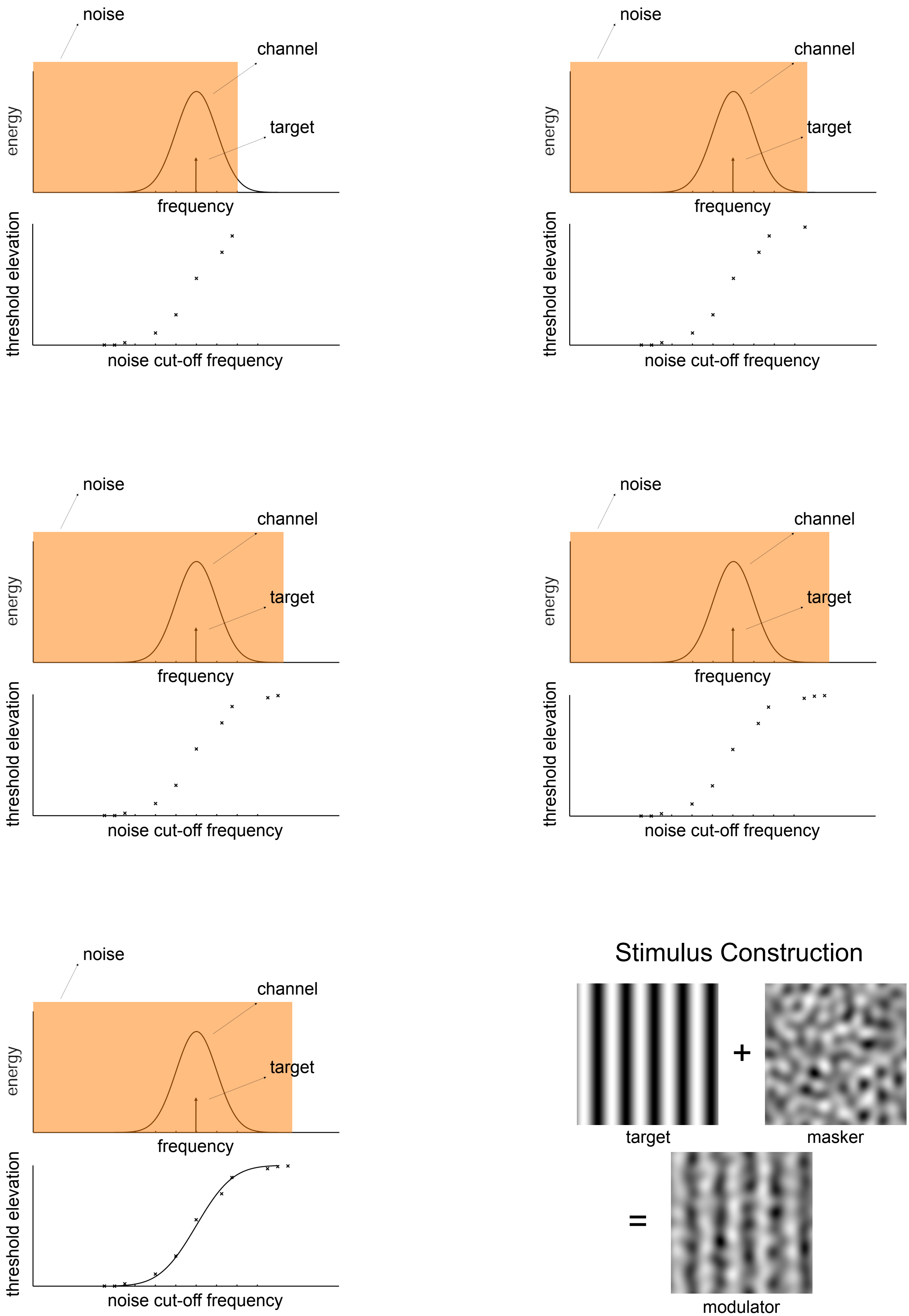
Landy & Oruç, *Vis Res*, 2002

Critical band masking






noise
channel
target
energy
frequency
threshold elevation
noise cut-off frequency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target
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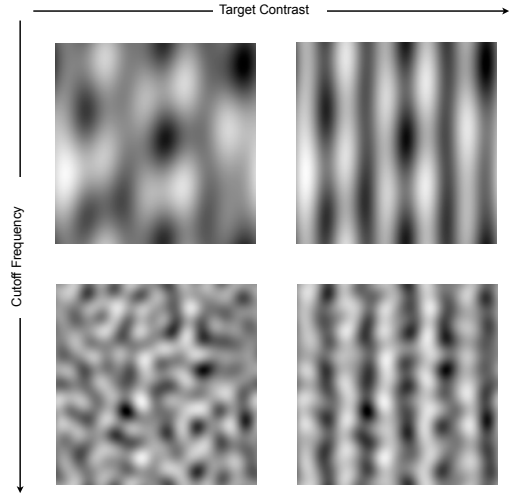
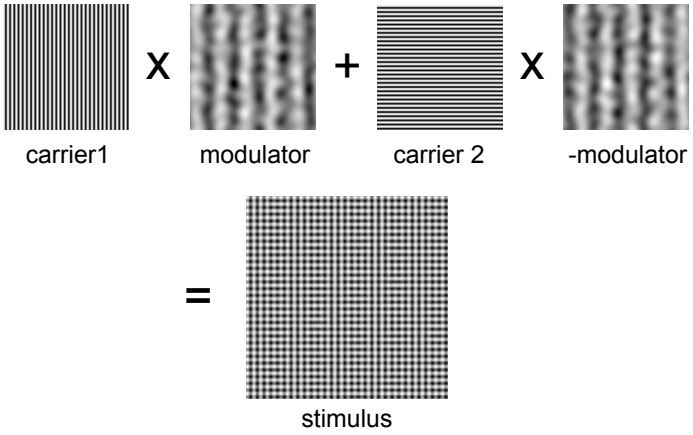
threshold elevation
noise cut-off frequency
noise
channel
target
energy
frequency
threshold elevation
noise cut-off frequency
Stimulus Construction
target
+
masker
=
modulator

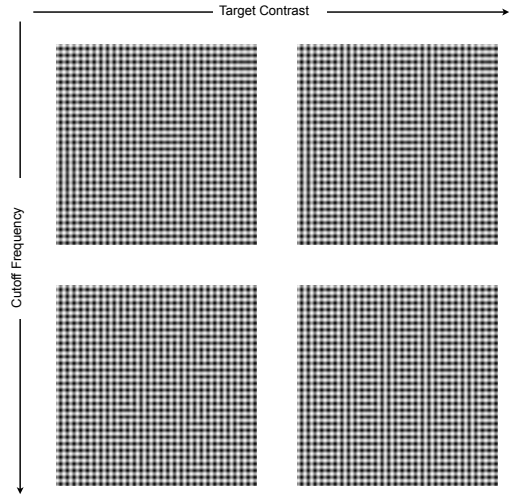
Low-pass noise modulators



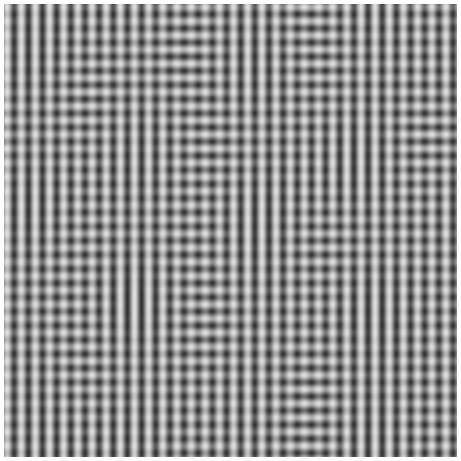
Stimulus Construction 2



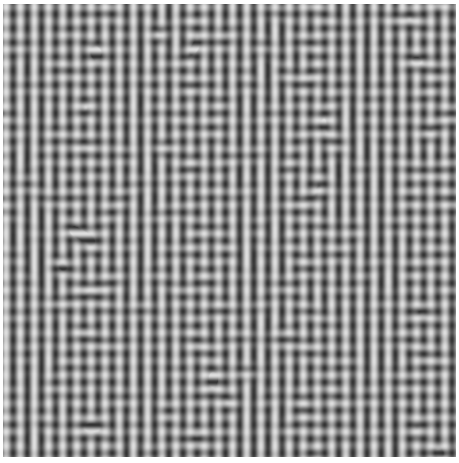
Low-pass noise texture stimuli



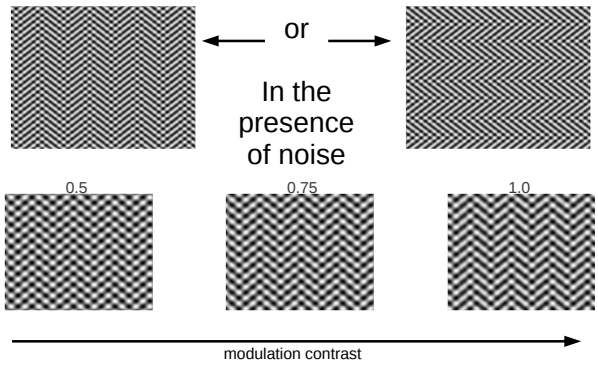
High target contrast, low noise cutoff



High target contrast, high noise cutoff

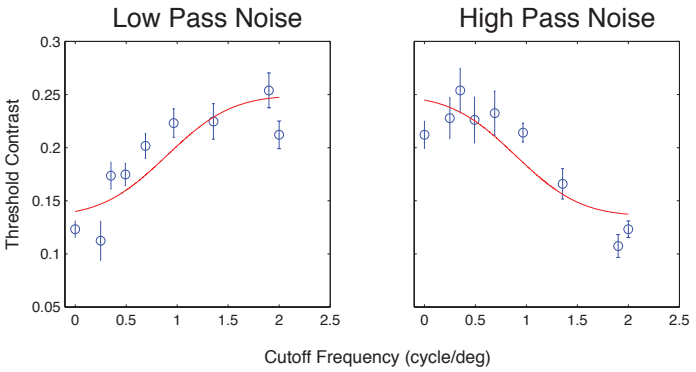


Task: 2nd-order orientation discrimination



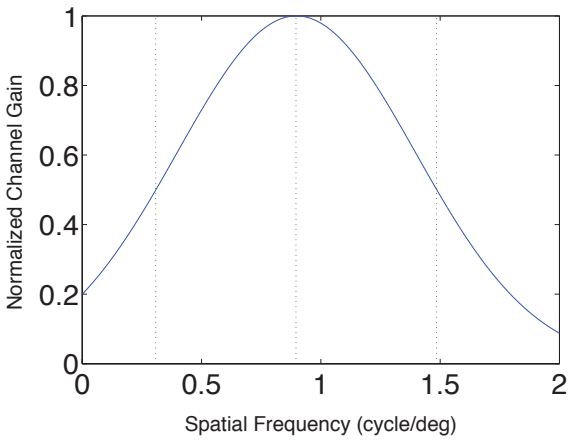
At threshold (75% correct) signal to noise ratio is constant

Sample Data



Westrick & Landy, in prep.

Estimated Channel

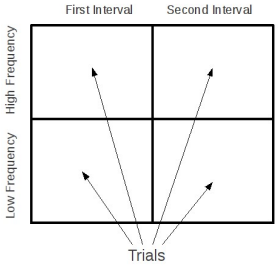


Westrick & Landy, in prep.

2x2 Detection/Discrimination Task

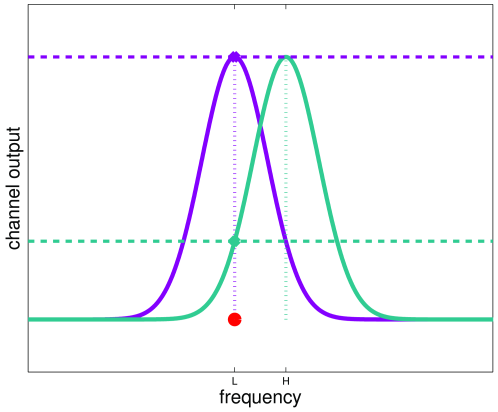
(Watson & Robson)

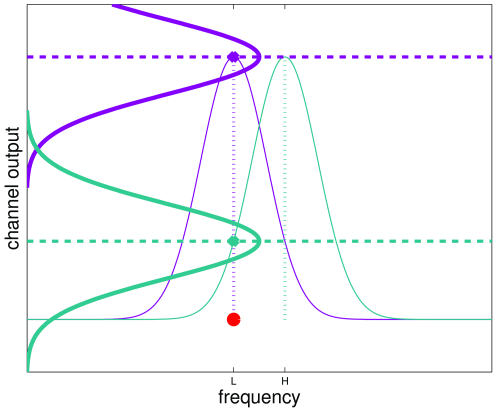
- 2x2 AFC
- Method of Constant Stimuli
- Same stimuli, always horizontal
- Subjects report interval and frequency

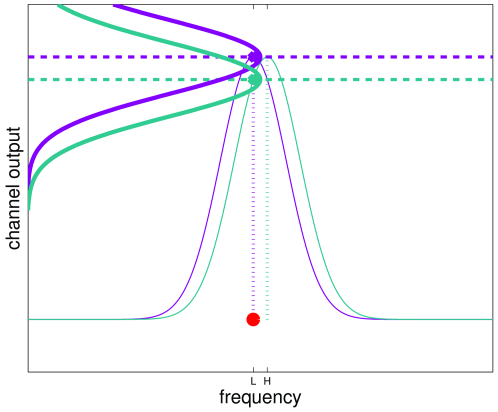


identification = discrimination → frequency tuning (labelled lines)

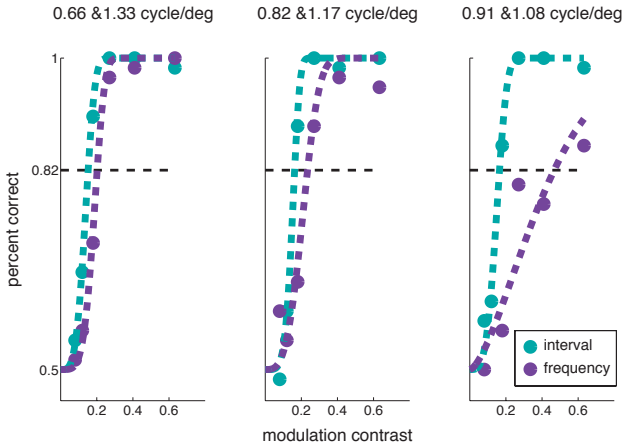
fit channel bandwidth under signal detection model



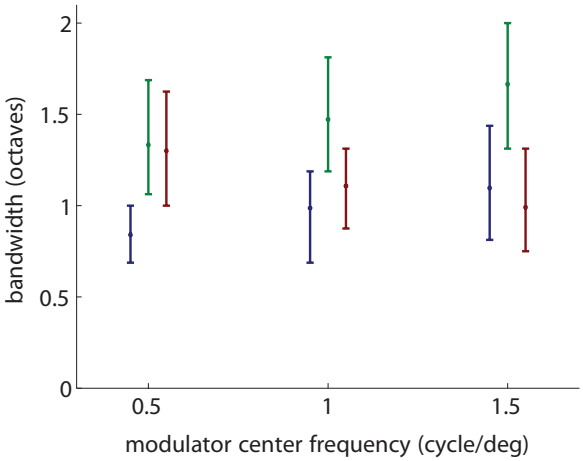




Sample Data



Estimated bandwidths

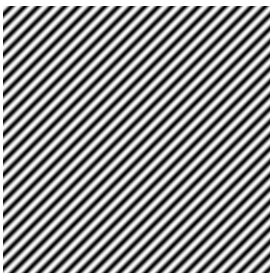


Two Problems

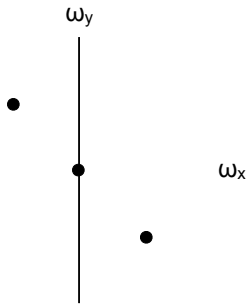
- The measured CSF is flat but it *should* be low-pass
- The critical-band masking experiment, on closer examination, is consistent with *all-pass* 2nd-order filters

Stimulus generation: one carrier

Space



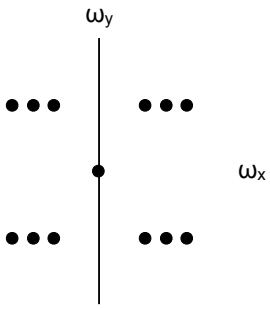
Spatial frequency



Stimulus generation: two modulated carriers

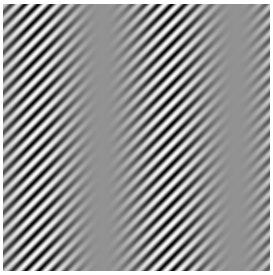
Space

Spatial frequency

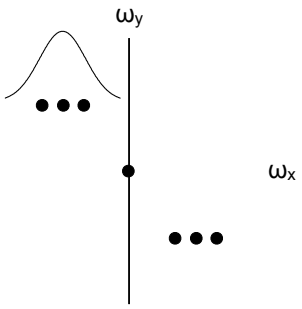


FRF model: F_1

Space

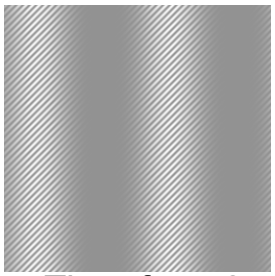


Spatial frequency

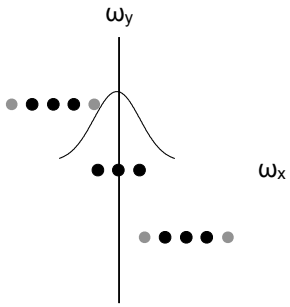


FRF model: R (squaring)

Space

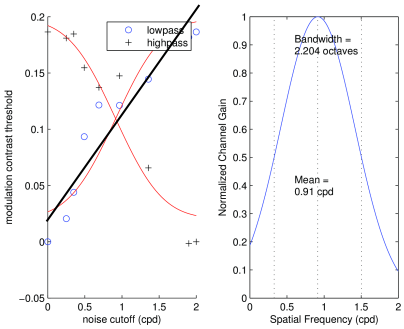


Spatial frequency



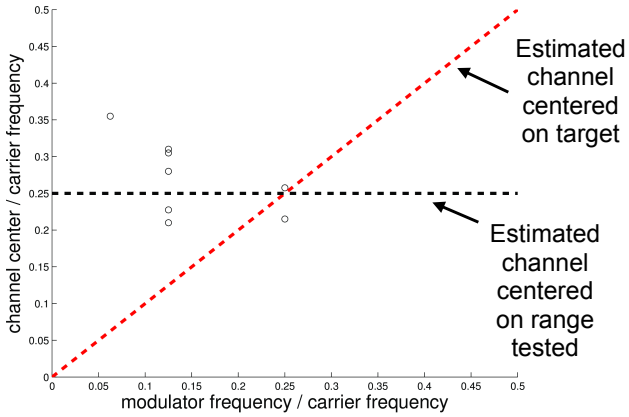
Therefore: 2nd-order (modulation) sensitivity should be low-pass!

0.5 cpd modulator



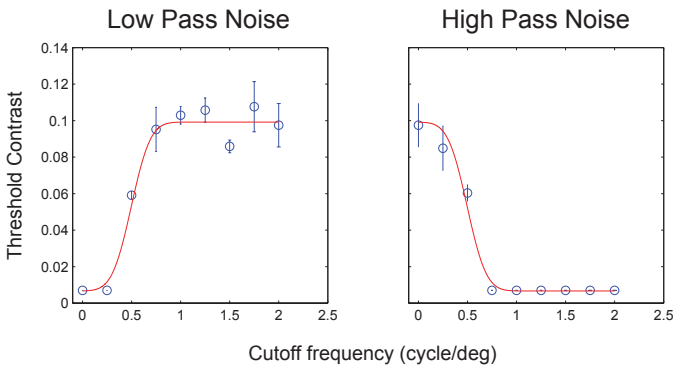
Therefore: a flat (all-pass) filter fits the results as well as or better than a band-pass filter.

Channel centers don't scale with modulator



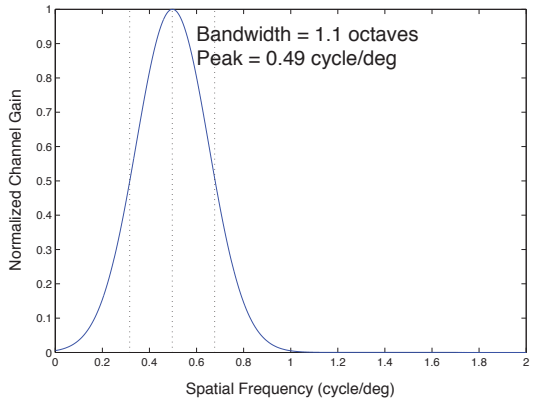
Not a result of nonlinearities in FRF

Analysis of FRF-simulated data



Not a result of nonlinearities in FRF

Analysis of FRF-simulated data

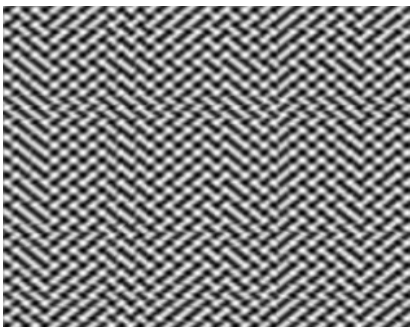


Elaborated FRF-like model consistent with all the data

1. Calculate local energy of each carrier (F_1R) using a quadrature pair of filters for each.
2. At each pixel, estimate likelihood ratio at that pixel of the two possible carriers present there based on responses in a neighborhood.
3. Assign each pixel to the more likely carrier, resulting in a binary image.
4. Apply matched filters for the two possible (V/H) modulators.

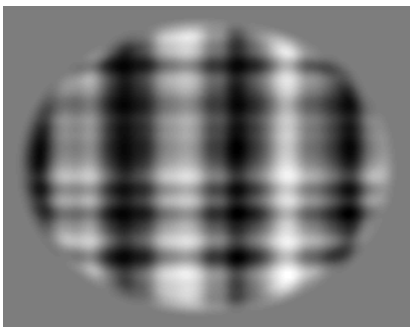
Elaborated FRF-like model consistent with all the data

Near-threshold stimulus:



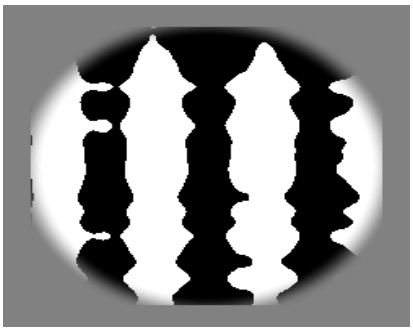
Elaborated FRF-like model consistent with all the data

Local relative texture energy:

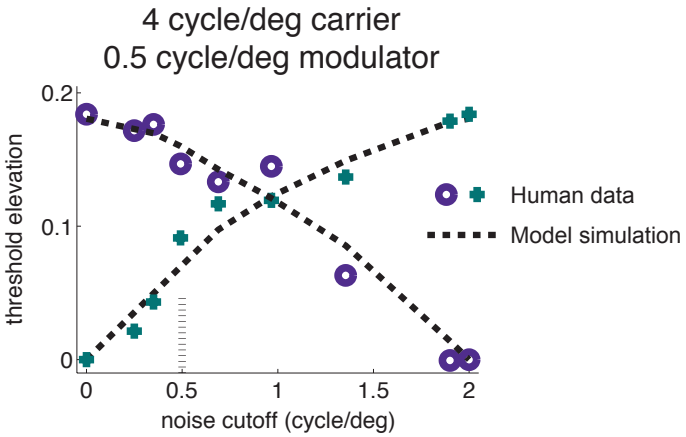


Elaborated FRF-like model consistent with all the data

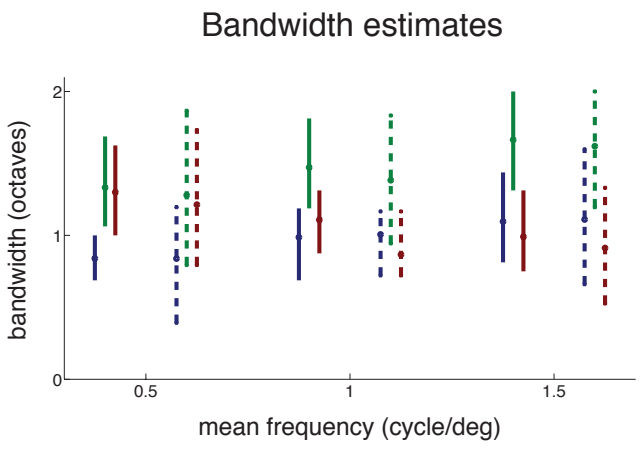
Maximum-likelihood carrier image:



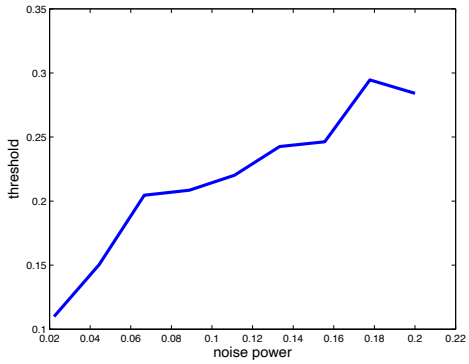
Model results: Critical-band masking



Model results: 2x2 AFC Experiment



Threshold vs. noise

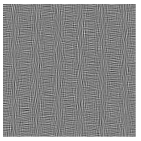


Summary – 2nd-order channel shape

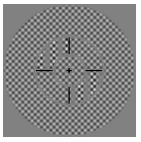
- The flat CSF is inconsistent with the FRF model
- Multiple 2nd-order channels evident by multiple experimental techniques - inconsistent with critical-band masking results
- A modified model resolves these inconstencies:
  - The first F needs to be broadband
  - The R needs to be more severe and adaptive

Outline

- 2nd-order channels: bandwidth



- 2nd-order channels: normalization

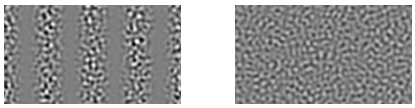


Normalization

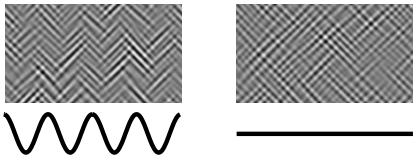
- There is plenty of evidence for 1st-order normalization processes, whereby neural responses are normalized (divided) by pooled responses of neighboring neurons
- Psychophysics: surround suppression
- Physiology: contrast gain control
- Is there 2nd-normalization ($F_1R_1N_1F_2R_2N_2$)? Is FRN a module cascaded in cortex?

Second order stimuli

Contrast modulated

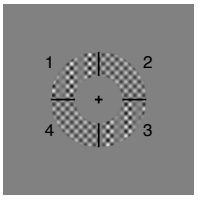


Orientation modulated

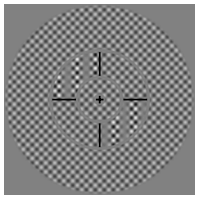


Experimental protocol

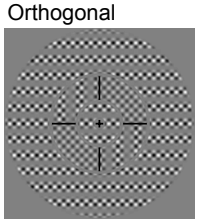
None



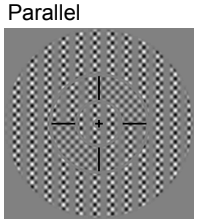
Uniform



Orthogonal



Parallel

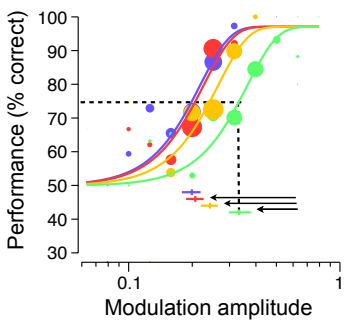


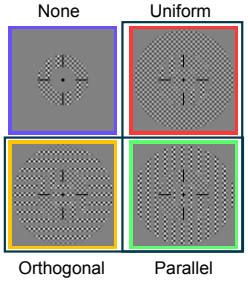
- Modulator: 1.5 cyc/deg sine wave (vert/horz)
- Carrier: bandpass noise
- Staircase procedure, surround conditions interleaved

Cartoon stimuli

2nd-order suppression: Contrast-modulated

Example subject

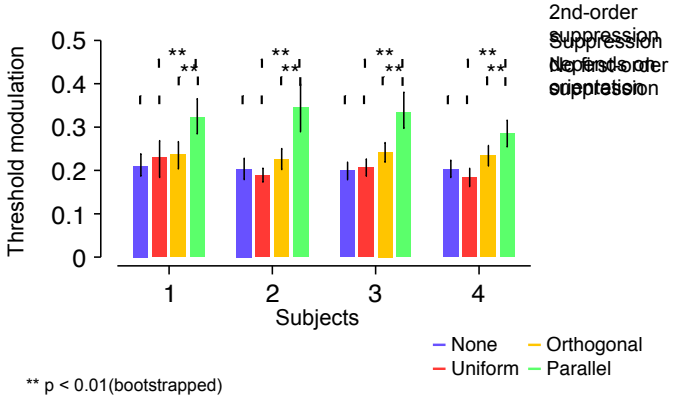




▪ 75%-correct threshold
↤↦95% CI (bootstrapped)

Wang, Heeger & Landy, *Vis Res*, in press

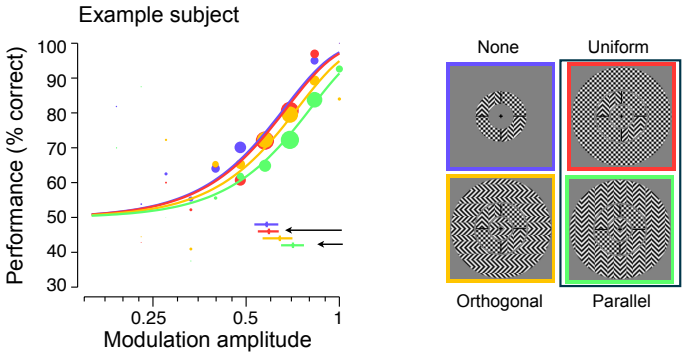
2nd-order suppression: Contrast-modulated



** p < 0.01(bootstrapped)

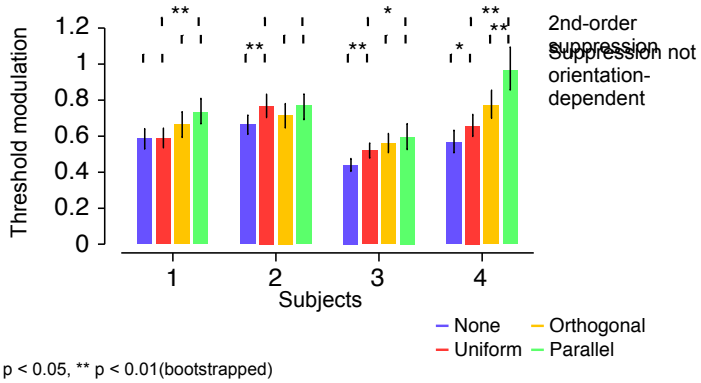
Wang, Heeger & Landy, *Vis Res*, in press

2nd-order suppression: Orientation-modulated



Wang, Heeger & Landy, *Vis Res*, in press

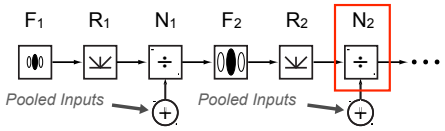
2nd-order suppression: Orientation-modulated



* p < 0.05, ** p < 0.01(bootstrapped)

Wang, Heeger & Landy, *Vis Res*, in press

2nd-order surround suppression



Does it exist? YES

Is it orientation selective?  YES  NO

Support for the cascade model

Acknowledgments

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