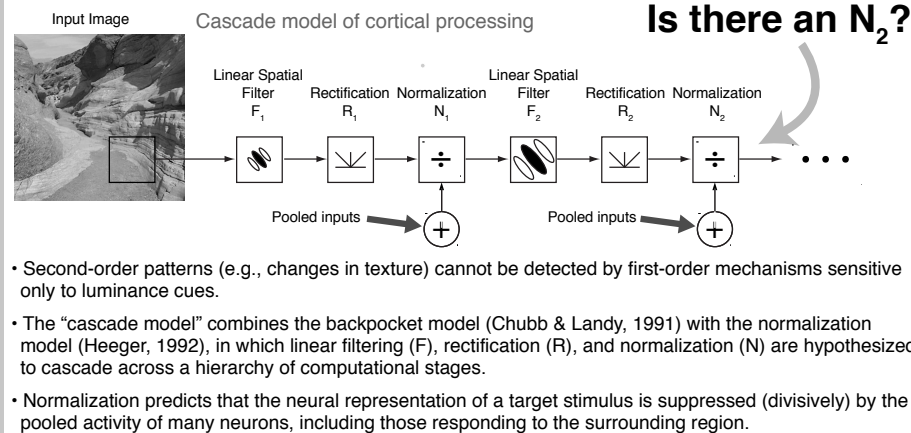# Psychophysical Evidence for Normalization in Second-Order Mechanisms

Helena X. Wang, Michael S. Landy, and David J. Heeger
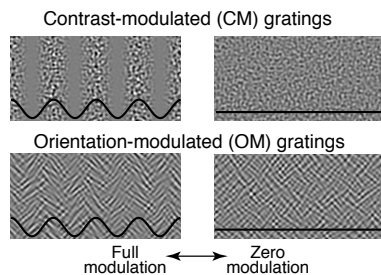
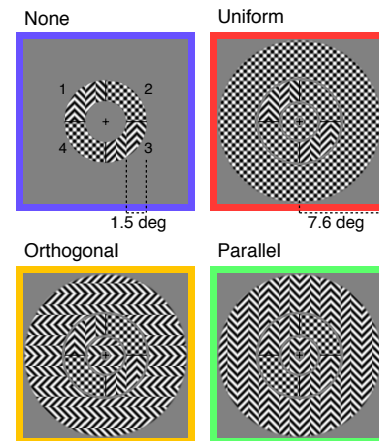Center for Neural Science & Dept. of Psychology, New York University

Background

Input Image

Cascade model of cortical processing

Is there an N_2?

Linear Spatial Filter F_1 — Rectification R_1 — Normalization N_1 — Linear Spatial Filter F_2 — Rectification R_2 — Normalization N_2 · · ·

Pooled inputs — (+)   Pooled inputs — (+)

- Second-order patterns (e.g., changes in texture) cannot be detected by first-order mechanisms sensitive only to luminance cues.

- The "cascade model" combines the backpocket model (Chubb & Landy, 1991) with the normalization model (Heeger, 1992), in which linear filtering (F), rectification (R), and normalization (N) are hypothesized to cascade across a hierarchy of computational stages.

- Normalization predicts that the neural representation of a target stimulus is suppressed (divisively) by the pooled activity of many neurons, including those responding to the surrounding region.

Stimuli

Contrast-modulated (CM) gratings

Orientation-modulated (OM) gratings

Full modulation ←→ Zero modulation

- Modulator: 1.5 cyc/deg sine wave (vertical or horizontal)
- Carrier:
  - OM: isotropic bandpass noise (center SF: 8 cyc/deg)
  - CM: modulation between 45° and 135° bandpass noise
- Task: 2AFC detection. Was modulation in quadrants 1/3 or 2/4?
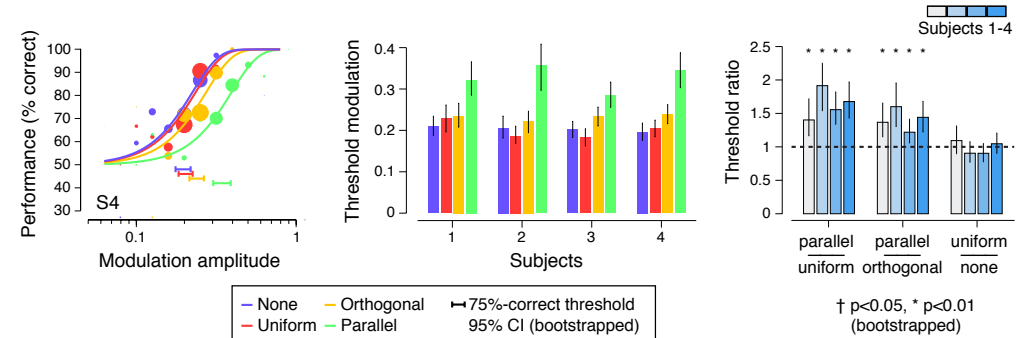- Staircase procedure, surround conditions interleaved
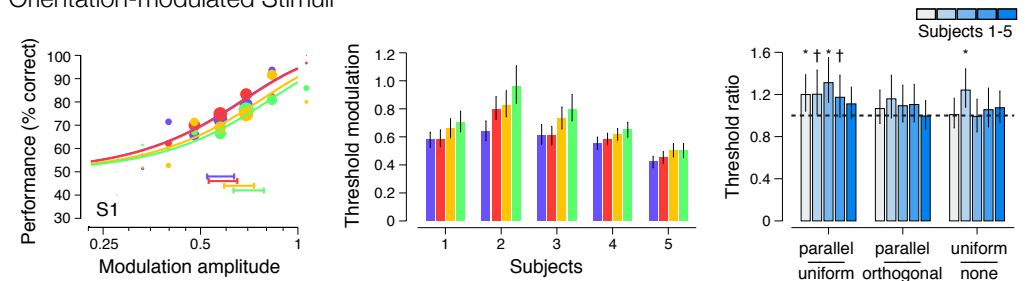
Surround Conditions

None   Uniform

1.5 deg   7.6 deg

Orthogonal   Parallel

Cartoon stimuli

Results

Contrast-modulated Stimuli

Subjects 1-4

Performance (% correct) vs Modulation amplitude — S4

Threshold modulation vs Subjects (1, 2, 3, 4)

Threshold ratio — parallel uniform / parallel orthogonal / uniform none
* * * *

— None — Orthogonal ⊢⊣ 75%-correct threshold
— Uniform — Parallel   95% CI (bootstrapped)

† p<0.05, * p<0.01 (bootstrapped)

Orientation-modulated Stimuli

Subjects 1-5

Performance (% correct) vs Modulation amplitude — S1

Threshold modulation vs Subjects (1, 2, 3, 4, 5)

Threshold ratio — parallel uniform / parallel orthogonal / uniform none
* † * †   *

Summary

- Higher thresholds for second-order target stimuli in the presence of full-modulation surround.

  ⇒ **Second-order surround suppression**

- Suppression was orientation-specific for CM stimuli but not for OM stimuli.

- First-order suppression was negligible ("none" versus "uniform").

  ⇒ No confound between first- and second-order suppression

- Supports the cascade model of cortical computation.

References

Chubb C, Landy MS. (1991). In *Computational Models of Visual Processing* (MS Landy & JA Movshon, eds.). pp. 291-301.

Heeger DJ. (2002). *Vis. Neurosci.* 9: 181.

Landy MS, Graham N. (2004). In *The Visual Neurosciences* (LM Chalupa & JS Werner, eds.). pp. 1106-1118.

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