Modeling visual sensitivity to spatial correlations in multiple gray-level textures

Jonathan D. Victor[1], Lilah Evans[2], Mary M. Conte[1]

[1]Feil Family Brain and Mind Research Institute, Weill Cornell Medical College, New York, NY; [2]Howard University, Washington, D.C.

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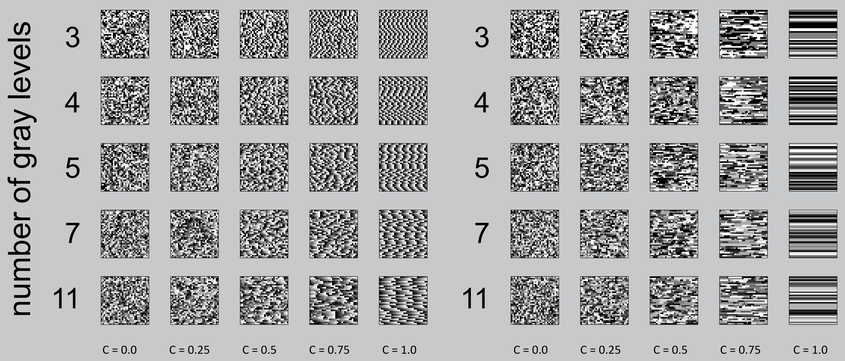
Motivation

Image statistics have enormous variety. However, most studies focus either on statistics that consider multiple gray levels but ignore spatial correlations, or statistics that consider spatial correlations but ignore gray levels. Recently, we proposed a model for sensitivity to image statistics that involve both spatial correlations and multiple gray levels. The model combines the impact functions of Silva & Chubb (2014), which are determined from measured sensitivity to textures with multiple gray levels without spatial correlation, and the quadratic form of Victor et al., (2015), which is determined from measured sensitivity to black-and-white textures with spatial correlations. The model has no free parameters. Here, we test the model's predictions of sensitivity to image statistics that entail spatial correlations and up to 11 gray levels.

Stimulus Domain



Texture patches illustrating the "stepped gradient" and "streak" image statistics. Each is defined by correlations between horizontally adjacent checks. For "**stepped gradients**", check luminance tends to increase gradually or decrease abruptly in one direction. For "**streaks**", check luminance between horizontally adjacent checks tends to match. In all cases, C = 0 corresponds to the random texture, and C = 1 corresponds to maximal correlation strength.

Methods

Subjects

N = 5
VA: 20/20

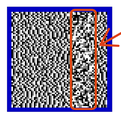
Conditions

4-AFC Design
320 trials per block
12 blocks per condition
19,200 - 30,720
trials per subject
126,720 total trials

Stimuli

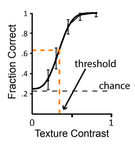
Contrast: 1.0
Check size: 14 min
Display size: 14.8 deg^2
Binocular viewing at 1 m
Duration: 120 ms followed by a 300 ms mask
Target: 16 x 64 pixels on a 64 x 64 array
Practice: 1-3 hours per subject
Feedback: during practice only

Task



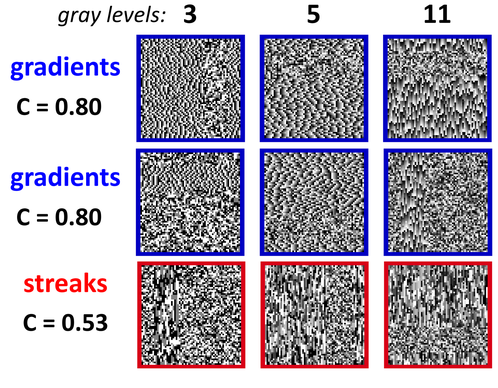
Subjects perform a 4-AFC segmentation task. In a typical stimulus, a target stripe, either textured or random, is embedded in one of four positions.

Psychometric Curve



Weibull functions are fitted to the psychometric curve of fraction correct measured at each value of texture contrast (C). The threshold is taken as the texture contrast required to achieve a fraction correct of 0.625.

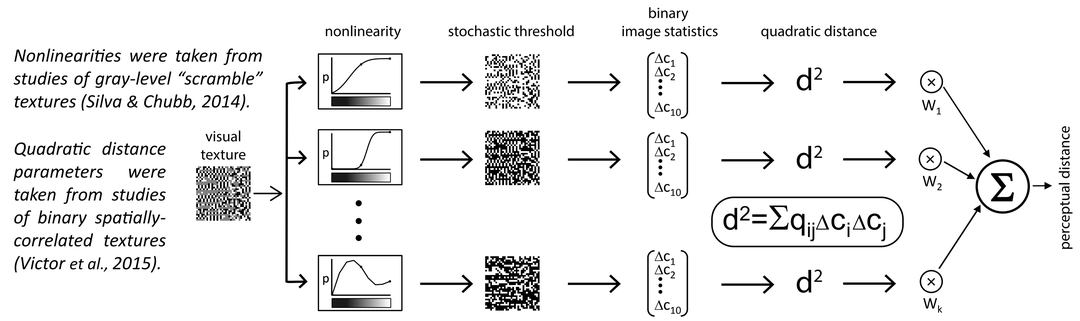
Sample Stimuli



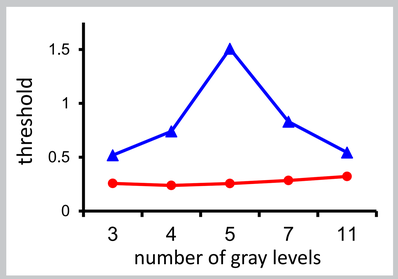
A Model Framework

Nonlinearities were taken from studies of gray-level "scramble" textures (Silva & Chubb, 2014).

Quadratic distance parameters were taken from studies of binary spatially-correlated textures (Victor et al., 2015).



Each channel transforms the gray-level image into a binary image via a stochastic threshold, in which the probability of assignment to black or white depends nonlinearly on the input gray-level value. The 2x2 block statistics of these internal representations are computed, yielding 10-element parameter vectors (Δc_1, …, Δc_{10}). A quadratic form is applied to this vector, and the weighted sum across channels is the predicted perceptual distance from randomness.

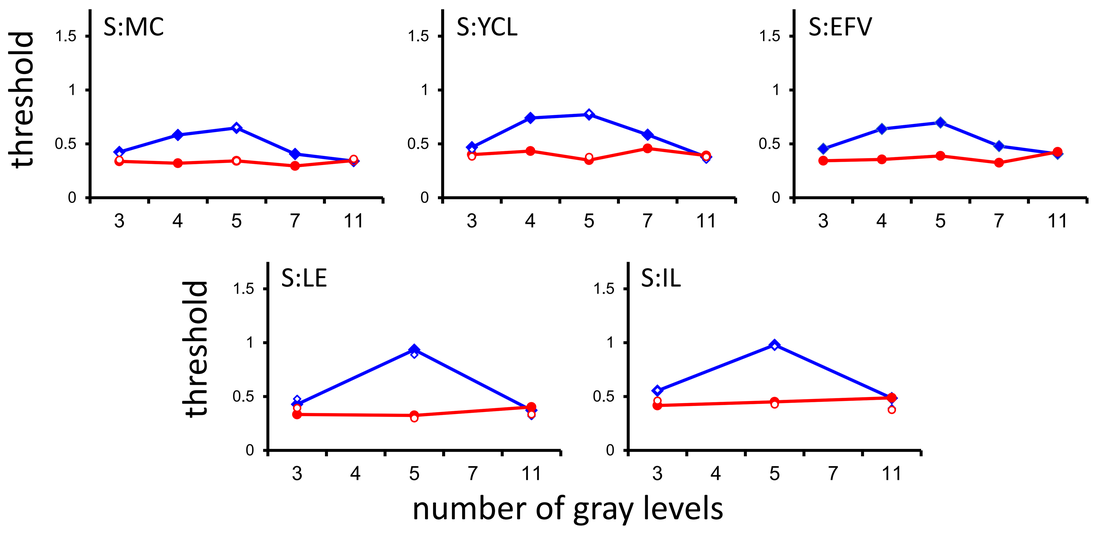


The model makes two key predictions:

- For **stepped gradients**, threshold is maximal for 5 gray levels, and substantially lower for 3 or 11 gray levels.
- For **streaks**, threshold is approximately independent of the number of gray levels.

There are no free parameters underlying these predictions; the model is fully constrained by data from binary textures and Chubb scrambles.

Results



Psychophysical thresholds for stepped gradients and streaks, as a function of number of gray levels, for N=5 subjects. For stepped gradients, all subjects had the highest threshold for 5 gray levels, and lowest thresholds for 3 and 11 gray levels. For streaks, thresholds were lower than for stepped gradients, and approximately independent of the number of gray levels. Note that in four of the five subjects, replications (open symbols) were carried out in separate sessions, and in most cases, the data points overlap.

Summary and Conclusions

- We constructed a model for sensitivity to local image statistics that involve multiple gray levels and spatial correlations.
- The model was completely determined by two complementary sets of psychophysical measurements. One set considered multiple gray levels but not spatial correlations; one set considered spatial correlations but only black-and-white elements.
- The model predicted the main features of experimentally-measured psychophysical thresholds for two kinds of image statistics, gradients and streaks, that had spatial correlations *and* up to 11 gray levels.

References

Silva, A.E. and Chubb, C. (2014). The 3-dimensional, 4-channel model of human visual sensitivity to grayscale scrambles. Vision Research **101**, 94-107.

Victor, J.D., Thengone, D.J., Rizvi, S.M., and Conte, M.M. (2015). A perceptual space of local image statistics. Vision Research **117**, 117-135.

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