Modeling the effect of chromatic distributions and pedestal contrast on chromatic discrimination

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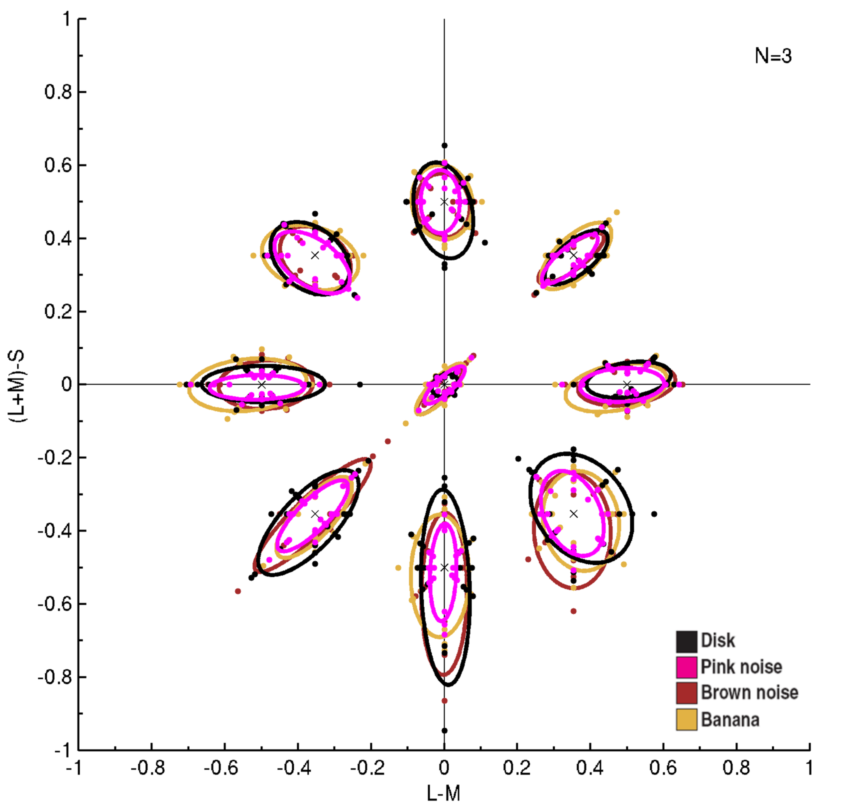
Introduction

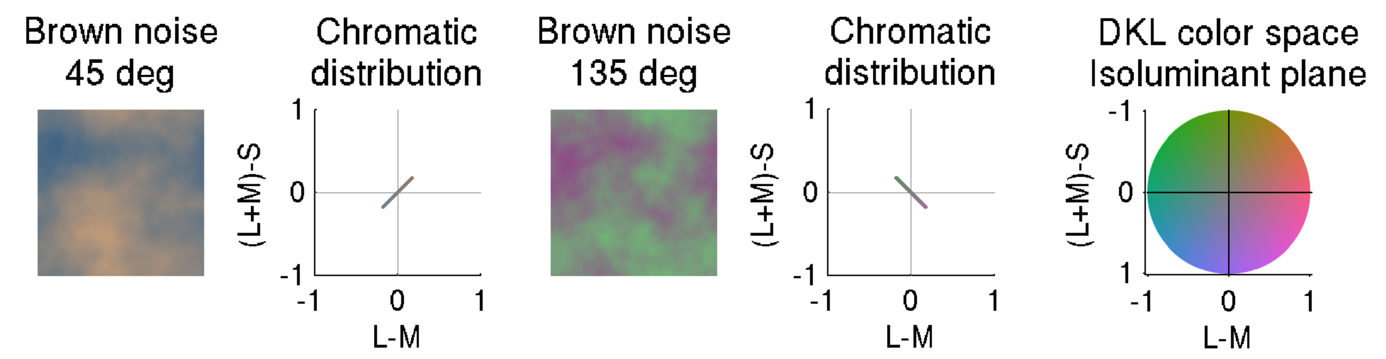
We present an approach to modeling chromatic discrimination thresholds using a discrimination model with multiple differently tuned chromatic mechanisms. The model is based on the input from the cone opponent mechanisms as represented by the cardinal axes of the DKL color space.

Previously [1], we have measured chromatic discrimination thresholds for homogeneously colored stimuli, photographs of natural objects and chromatically variegated stimuli at various positions in DKL color space. We found that at the adaptation point thresholds for the chromatically variegated stimuli were elongated into the direction of their chromatic distribution. Away from the adaptation point threshold ellipses for all types of stimuli were similarly elongated in the direction of the contrast axis. The data indicate that there are more than four cardinal color mechanisms. Furthermore these mechanisms seem to differ in their sensitivities.



Methods

Psychophysical measurements In a 4AFC experiment four isoluminant stimuli were presented for 500 ms in a 2-by-2 arrangement. One of the four stimuli (comparison stimulus) differed in chromaticity. The observers' task was to indicate the position of the comparison stimulus. For nine test locations, discrimination thresholds were measured along eight comparison directions relative to the mean chromaticity of the test stimuli. Discrimination thresholds were determined along each of the eight comparison directions by using an adaptive staircase method. The stimuli were either homogeneously colored or their chromaticities varied along a line in DKL color space.



Model The model assumes in addition to the four cardinal mechanisms of the DKL color space higher level mechanisms along intermediate chromatic directions. The number of mechanisms is $M = 8$. Each mechanism has a preferred chromatic direction μ_i to which its sensitivity is maximal. The response of a mechanism to an image of size N is computed by projecting the chromatic coordinates r_j and θ_j of each pixel j of the image onto the mechanism i. The sensitivity profile of each mechanism is determined by the tuning width k_i and the parameter sc_i.

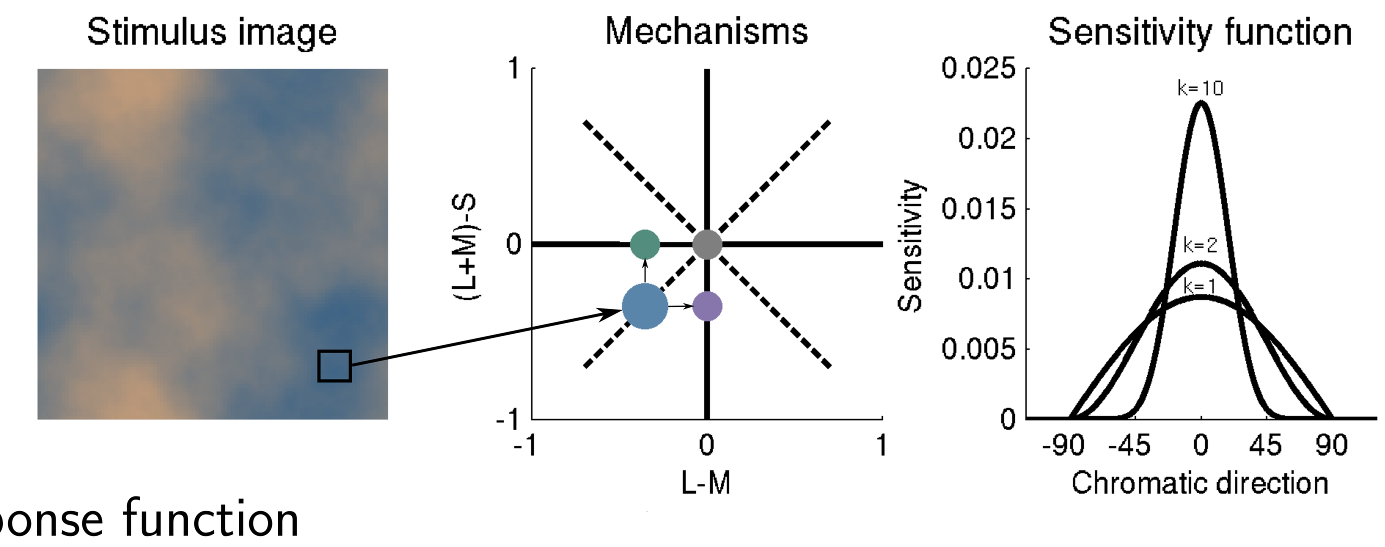
1. Excitatory stage

Sensitivity S_i of mechanism i to chromatic direction θ:

$$S_i(\theta) = sc_i * [cos^{k_i}(\theta - \mu_i)]^+ \quad \text{with } \mu_i = [0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°]$$

The excitatory response E_i of mechanism i to the image is given by:

$$E_i = \frac{1}{N} * (\sum_{j=1}^{N} r_j S_i(\theta_j))$$



2. Response function

$$R_i = g * E_i^p + Z$$

3. Decision variable

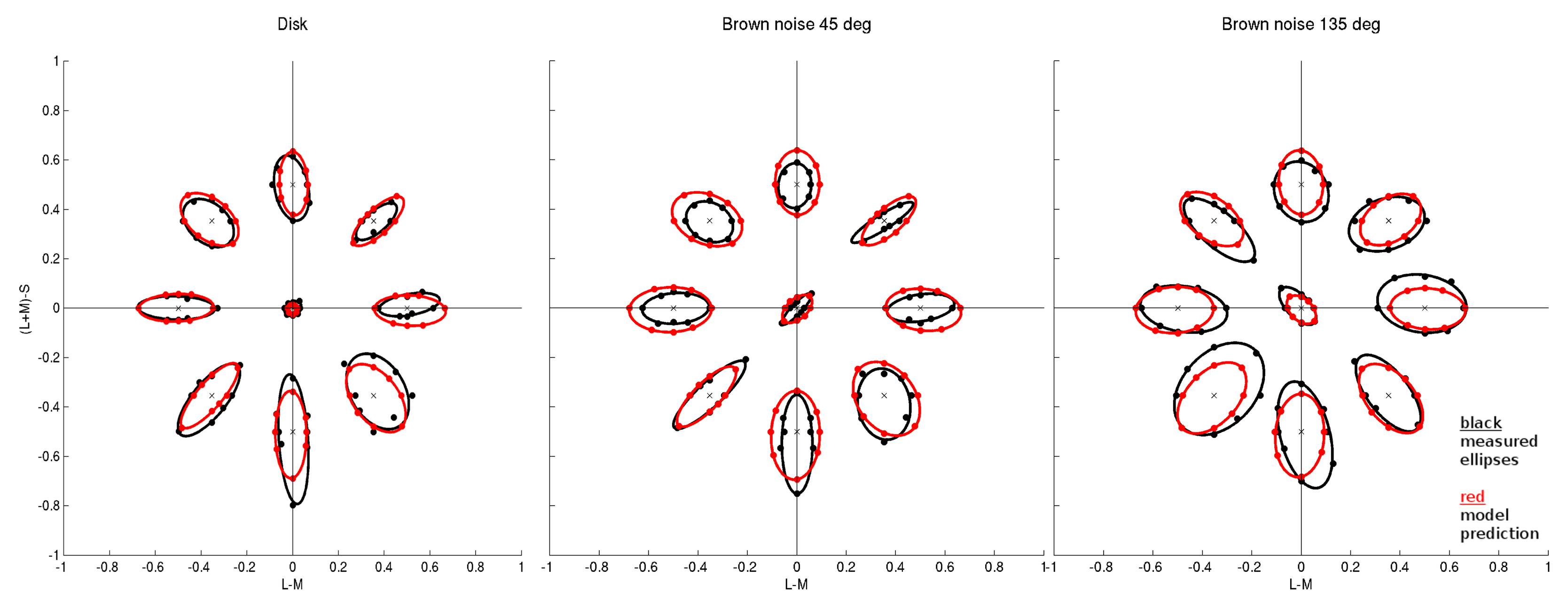
The decision variable D is computed using the responses to the comparison image R_{C_i} and the responses to the test image R_{T_i}. Threshold is reached when $D = 1$.

$$D = (\sum_{i=1}^{M} |R_{C_i} - R_{T_i}|^2)^{\frac{1}{2}}$$

Results

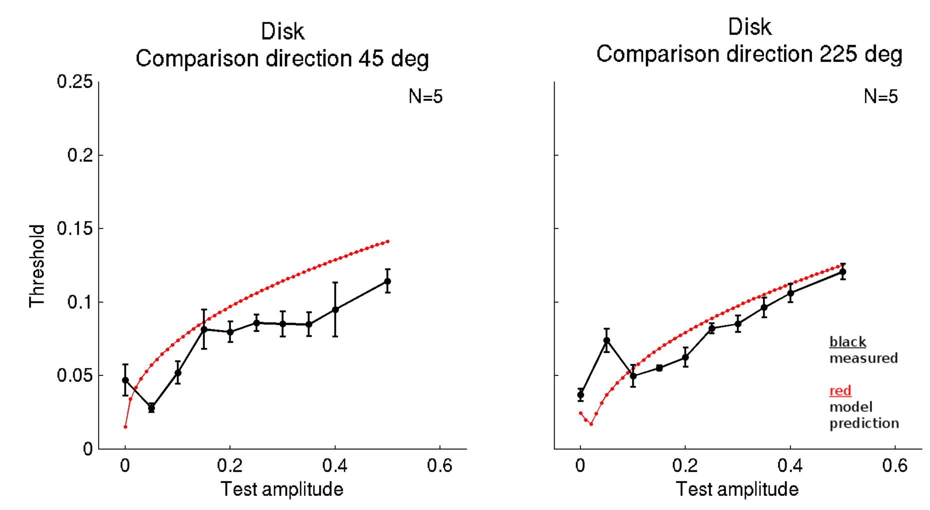
Psychophysical data and model predictions

We fitted the model simultaneously to the discrimination data for the disk and the chromatically variegated stimuli averaged across subjects.



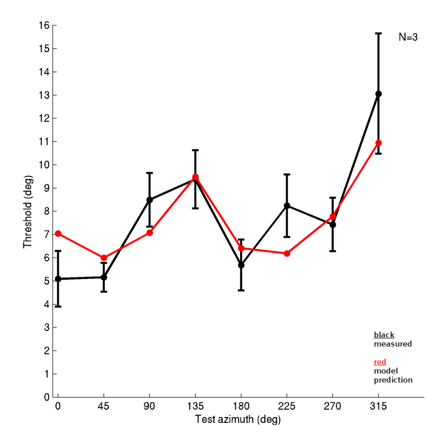
Threshold versus Contrast function

We measured thresholds at various distances from the adaptation point for one test direction. The model prediction of the TvC curves based on the fit to the discrimination data shown above is close to the measured data. The deviations from the data indicate that the response function needs to be modified by including an inhibitory term which would allow to model the saturation of the response at high contrast levels and the dipper at subthreshold levels.



Approximation of hue discrimination thresholds

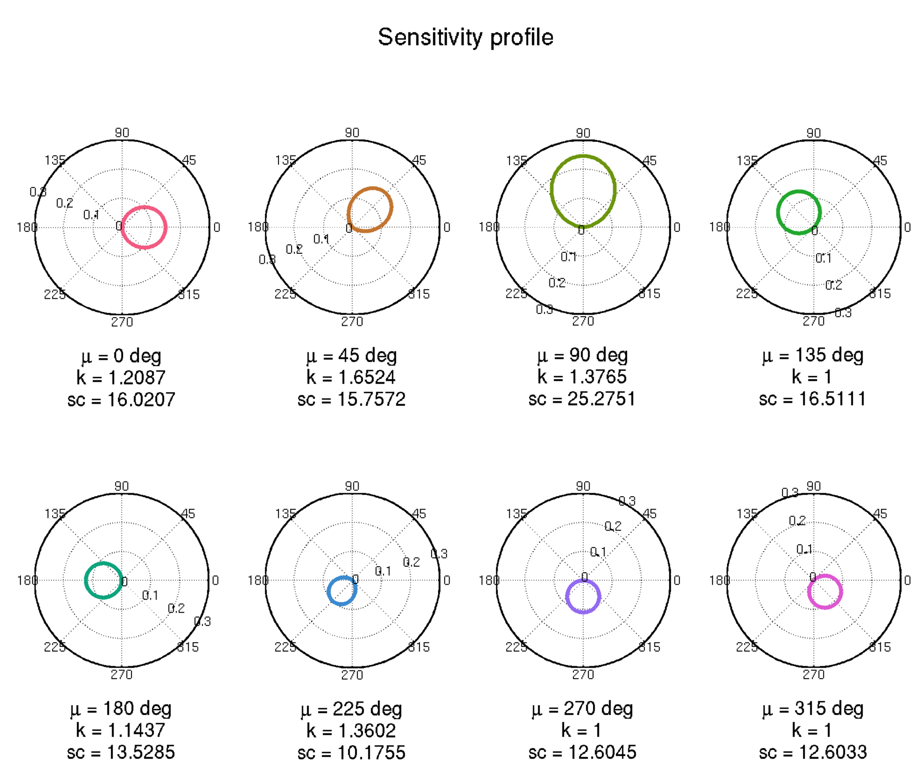
The length of the minor axis of the discrimination ellipses which is approximately a tangent to the hue circle gives an estimate of hue discrimination thresholds. In accordance with previous results hue discrimination thresholds are highest in the second (135 deg) and fourth quadrant (315 deg).



Model parameter

Fitted response function: $R_i = 17.1182 * E_i^{0.5504} + 8.9221$

All mechanisms are broadly tuned. The tuning width k of the mechanisms varies between 1 and 1.6. The mechanisms along the first diagonal are the most narrowly tuned. This corresponds to the narrow ellipses at the test locations 45 deg and 225 deg. The mechanisms at 135 deg and 315 deg are the most broadly tuned which is in accordance with the more circular discrimination ellipses at these test locations. The finding that the thresholds in the lower two quadrants of the DKL color space (180 deg–270 deg) are higher than the thresholds in the upper two quadrants is reflected by the lower values of the parameter sc which scales the sensitivity function.



Conclusions

- Discrimination thresholds at the adaptation point and away from the adaptation point are influenced by both the chromatic distribution of the input signals and the pedestal.
- The data suggest that discrimination is governed by more than four cardinal mechanisms.
- A discrimination model assuming 8 chromatic mechanisms provides a reasonable prediction of the discrimination data.

References

[1] Hansen, T., Giesel, M., & Gegenfurtner, K.R. (2008). Chromatic discrimination of natural objects. *Journal of Vision*, 8(1):2, 1–19.

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