Modelling chromatic discrimination of chromatically variegated stimuli

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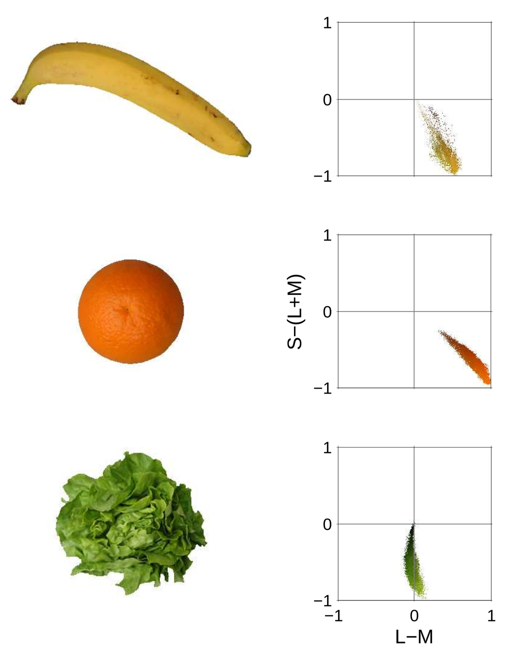
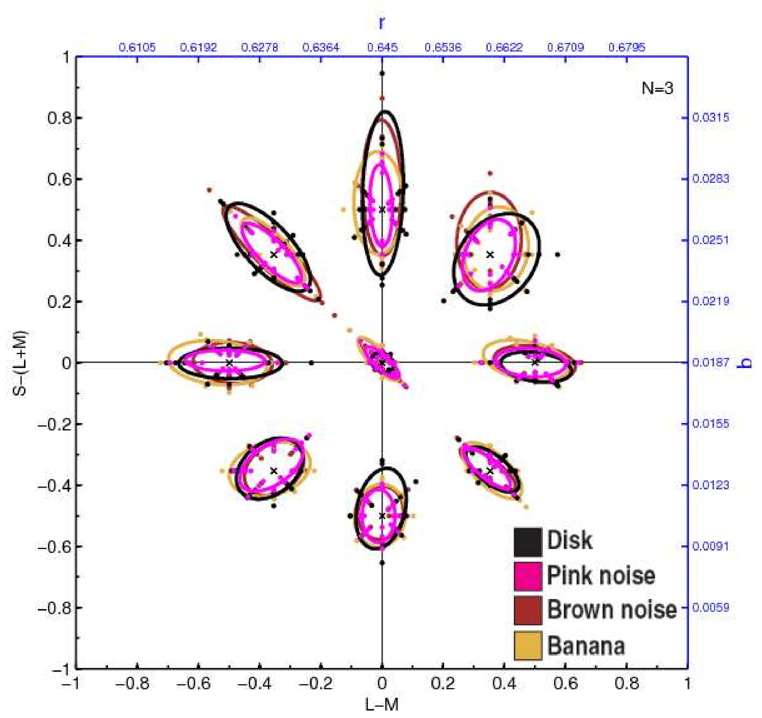
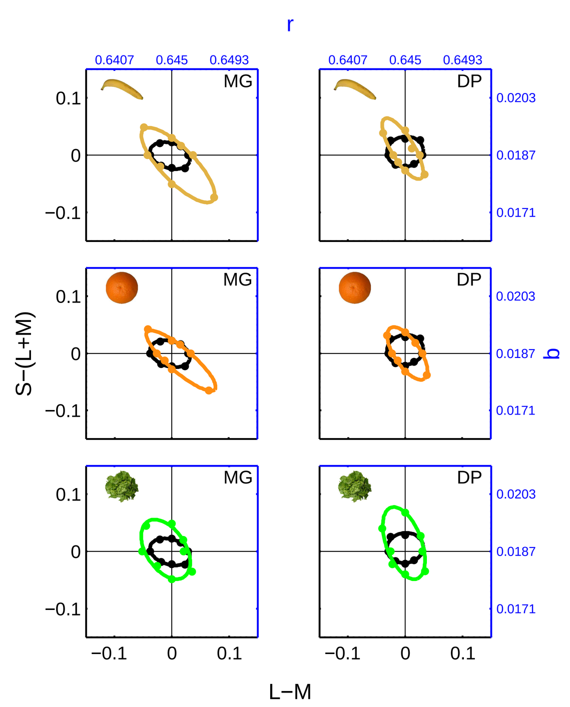
Introduction

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.

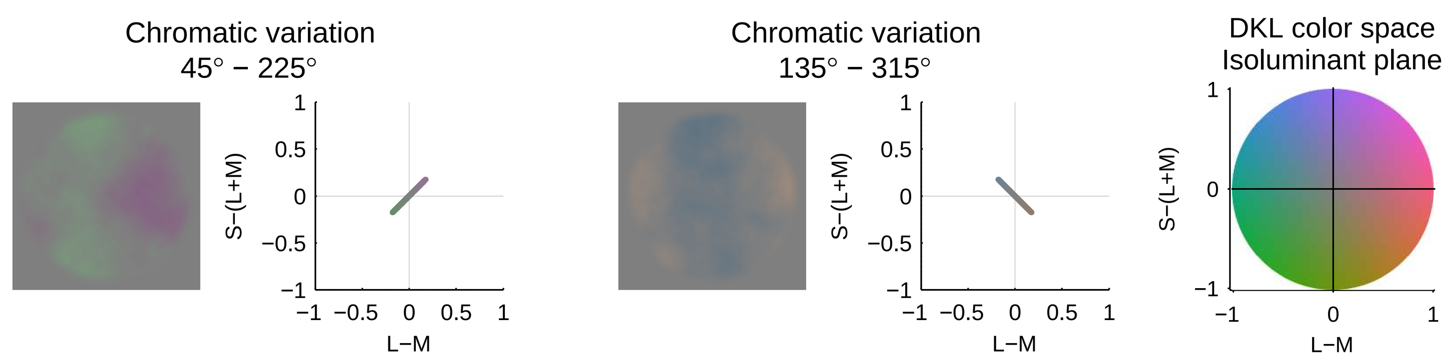






Methods

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.



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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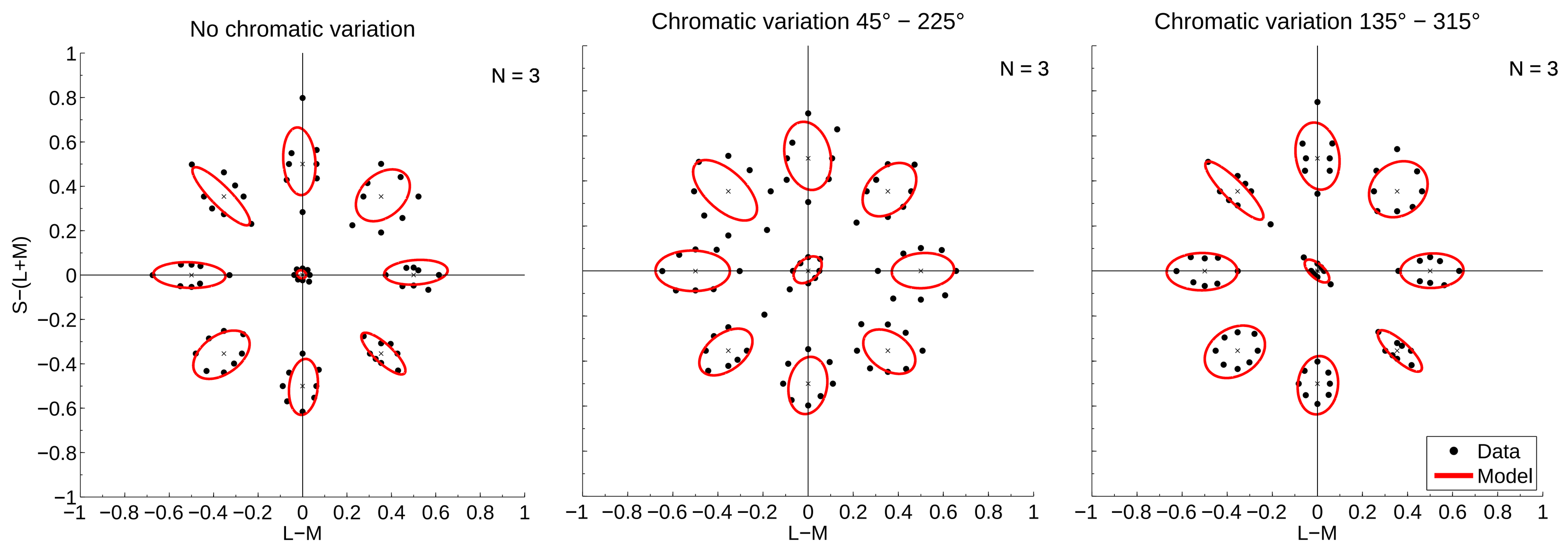
Results

Model predictions

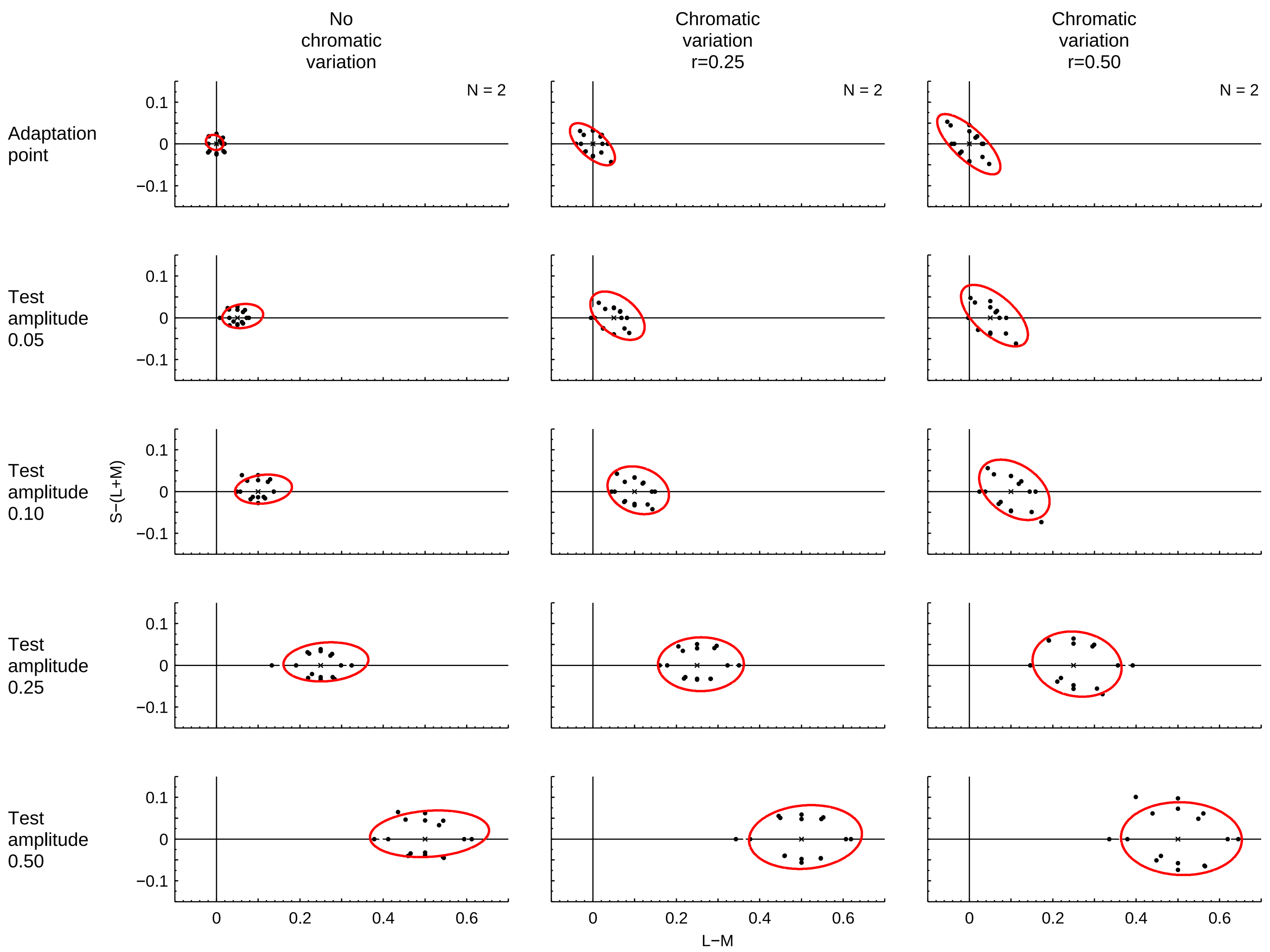
Discrimination at the adaptation point and away from the adaptation point

A model with eight mechanisms ($\mu_i = 0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°$) provides a good fit to the data.



Variation of test amplitude

Discrimination ellipses at five test amplitudes for test direction 0°: Chromatic variation was along the second diagonal (135°–315°). The amplitude of the chromatic distribution was either 0.25 or 0.5.



Evaluation of the model

We also fitted a model with four mechanisms to the data. A model with four mechanisms requires the mechanisms to be more narrowly tuned than expected from a linear combination of cone inputs whereas the model with eight mechanisms has broadly tuned mechanisms along the cardinal directions and more narrowly tuned mechanisms along the intermediate directions.

	g	p	k_0	k_{45}	k_{90}	k_{135}	k_{180}	k_{225}	k_{270}	k_{315}	s_0	s_{45}	s_{90}	s_{135}	s_{180}	s_{225}	s_{270}	s_{315}
$M = 4$	22.1300	0.5511	1.7750	-	1.0000	-	1.7199	-	2.8290	-	22.0503	-	17.7178	-	16.2256	-	28.5516	-
$M = 8$	18.5955	0.5573	1.0000	1.1327	1.0000	1.4305	1.0000	1.0000	1.1669	1.7928	9.2724	23.2260	9.2696	11.6397	7.0733	19.6941	17.8133	20.6046

We computed Akaike's information criterion (AIC_c) for the models with four and eight mechanisms. The AIC_c value is lower for the model with eight mechanisms which indicates that this model provides a better fit to the data despite the larger number of parameters.

Model

We fitted a chromatic discrimination model simultaneously to the discrimination data for the disk and the chromatically variegated stimuli averaged across subjects. Each of the M mechanisms has a preferred chromatic direction μ_i to which its sensitivity is maximal. The excitatory response E_i of mechanism i to an image is computed by projecting the chromatic coordinates r_j and θ_j of each pixel j of the image onto the mechanism. The sensitivity profile of each mechanism is determined by the tuning width k_i and the sensitivity parameter s_i.

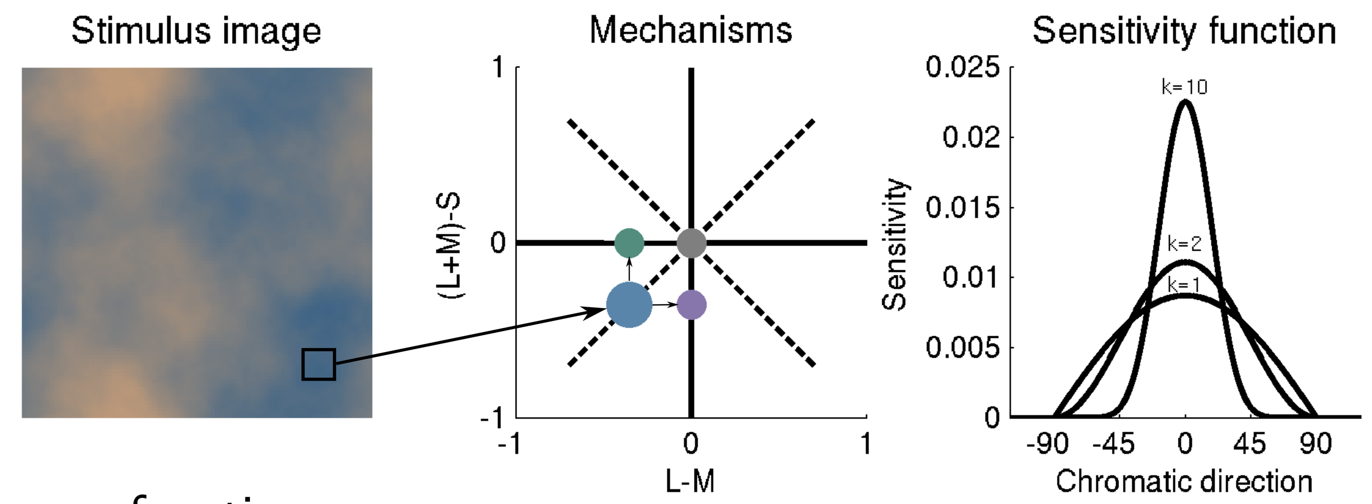
1. Excitatory stage

Sensitivity S_i of mechanism i to chromatic direction θ:

$$S_i(\theta) = s_i[\cos^{k_i}(\theta - \mu_i)]^+$$

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

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



2. Response function

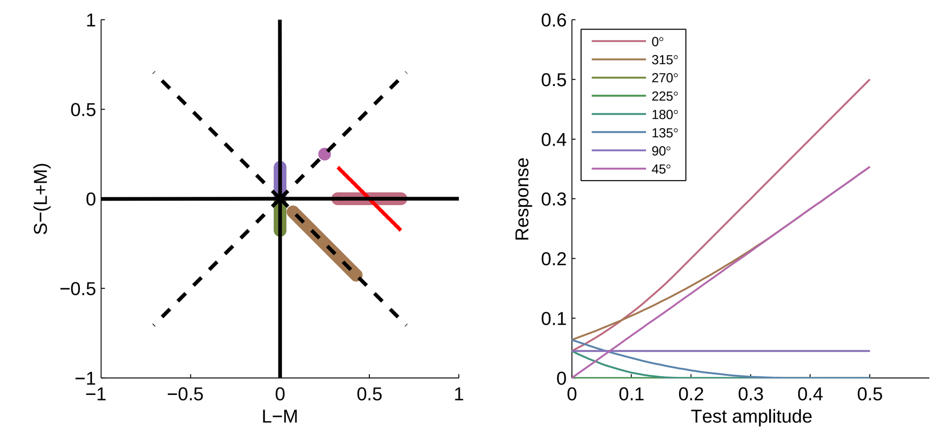
$$R_i = gE_i^p$$

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 $D = 1$.

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

Sketch of mechanism responses for test direction 0°



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 eight chromatic mechanisms provides a reasonable prediction of the discrimination data.