Nonlinear transformation from threshold to suprathreshold texture similarity judgments

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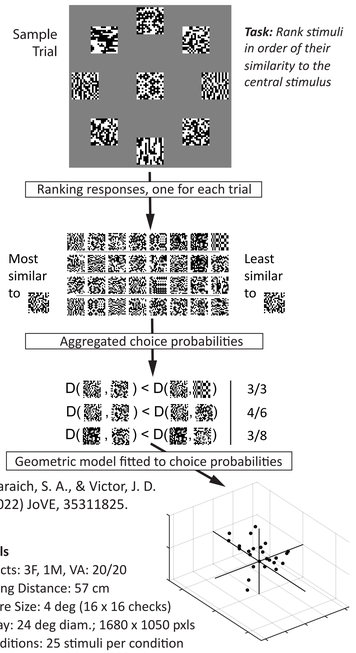
VSS 2024

Introduction

Suprathreshold similarity judgments can depart substantially from predictions based on thresholds. However, it is unclear whether the shift from threshold to suprathreshold judgments is merely one of channel-specific gain changes or something more complex. To address this, we compare suprathreshold similarity judgments and thresholds in a well-characterized multidimensional domain of visual textures.

Methods

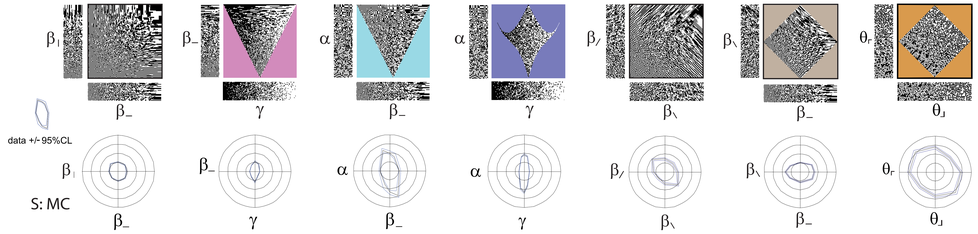


Waraich, S. A., & Victor, J. D. (2022) JoVE, 35311825.

Details
Subjects: 3F, 1M, VA: 20/20
Viewing Distance: 57 cm
Texture Size: 4 deg (16 x 16 checks)
Display: 24 deg diam.; 1680 x 1050 pxls
8 conditions: 25 stimuli per condition
10 sessions/condition: 1000 trials
28,000 pairwise comparisons per condition per subject
Data fit to models of 1 to 7 dimensions

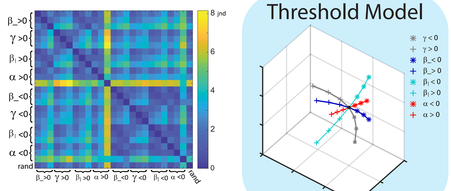
Support: NIH EY7977

Texture discrimination thresholds



Previously (Victor and Conte 2015), thresholds for distinguishing structured from random textures were determined via a texture-segmentation task. Results are shown here for several coordinate planes. Isodiscrimination contours are approximately elliptical, indicating a Euclidean distance in which subthreshold signals are combined quadratically. Similar isodiscrimination ellipses were found for measurements centered at other points in the space.

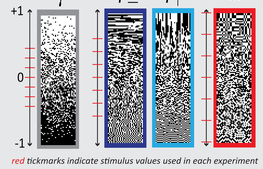
Based on these measurements, perceptual distances for the current stimuli were calculated (heatmap). These distances were used to construct a model for the perceptual space via multidimensional scaling, the "threshold model".



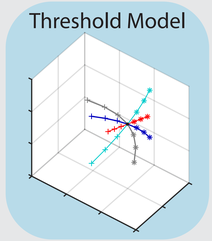
1 grid spacing = 2 jnd

Perceptual spaces for suprathreshold similarity

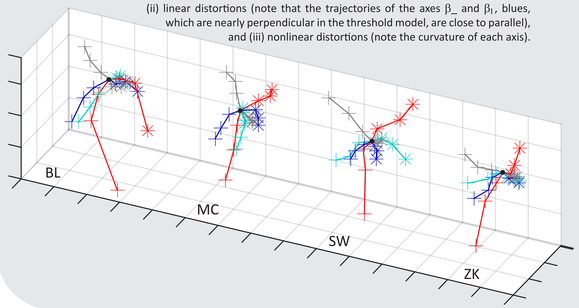
We collected suprathreshold similarity judgments for textures based on several combinations of image statistics. In each case, we constructed a perceptual space that accounted for the judgments. While there was good agreement across subjects, there were major deviations between the geometry of this space and the geometry predicted from threshold measurements.

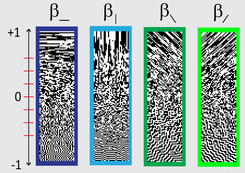


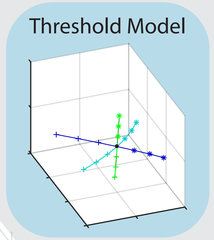
red tickmarks indicate stimulus values used in each experiment

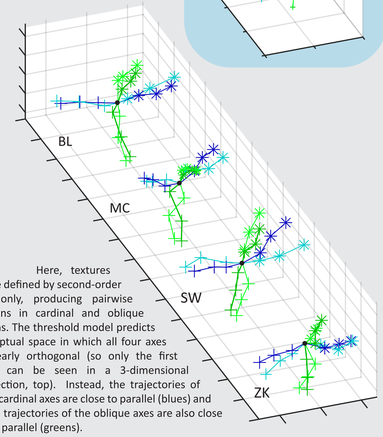


In this experiment, the suprathreshold space deviated from the threshold model in three ways: (i) selective gain changes (note the expansion of the trajectory), (ii) linear distortions (note that the trajectories of the axes β_- and $\beta_|$, blues, which are nearly perpendicular in the threshold model, are close to parallel), and (iii) nonlinear distortions (note the curvature of each axis).

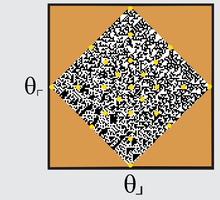


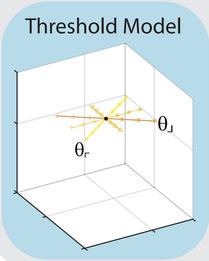


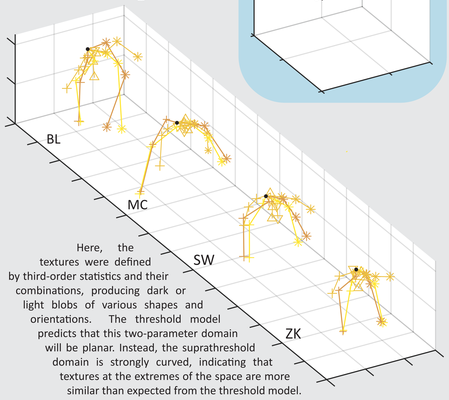




Here, textures were defined by second-order statistics only, producing pairwise correlations in cardinal and oblique directions. The threshold model predicts a perceptual space in which all four axes are nearly orthogonal (so only the first three can be seen in a 3-dimensional projection, top). Instead, the trajectories of the cardinal axes are close to parallel (blues) and the trajectories of the oblique axes are also close to parallel (greens).







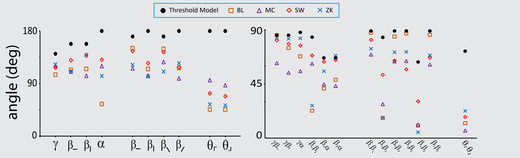
Here, the textures were defined by third-order statistics and their combinations, producing dark or light blobs of various shapes and orientations. The threshold model predicts that this two-parameter domain will be planar. Instead, the suprathreshold domain is strongly curved, indicating that textures at the extremes of the space are more similar than expected from the threshold model.

1 grid spacing corresponds to d'=2 for judgments of similarity

Conclusions

- Suprathreshold similarity judgments of visual textures can be captured by a perceptual space.
- The space is highly consistent across subjects.
- The geometry of this space differs markedly from the predictions of threshold measurements:
  - Direction-specific gain changes
  - Linear distortions, producing changes in angles
  - Nonlinear distortions, producing curvature
- Some of these changes likely reflect the functional consequences of canonical neural transformations, such as contrast normalization and rectification.

Deviations of the suprathreshold perceptual space from the threshold model

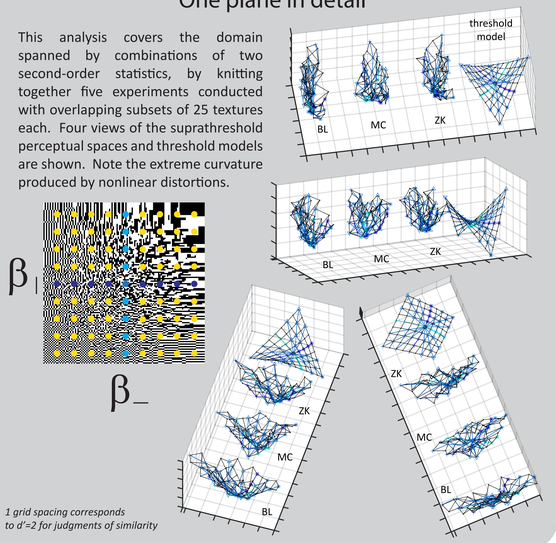


Along each axis: threshold model predicts that positive and negative rays diverge by ~180 deg; a much smaller angle was observed.

Angles between pairs of axes: threshold model predicts ~90 deg; a much smaller angle was observed, especially for the second-order statistics.

One plane in detail

This analysis covers the domain spanned by combinations of two second-order statistics, by knitting together five experiments conducted with overlapping subsets of 25 textures each. Four views of the suprathreshold perceptual spaces and threshold models are shown. Note the extreme curvature produced by nonlinear distortions.



1 grid spacing corresponds to d'=2 for judgments of similarity