Figure-ground separation depends on texture differences and texture composition

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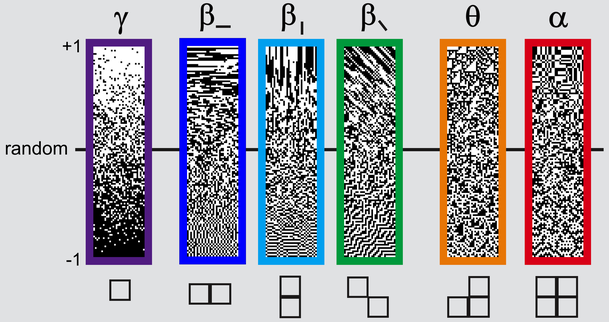
143.03
SFN 2019

Support: NIH EY7977

Motivation

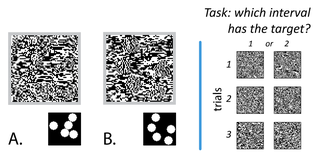
Separating figure from ground is a crucial step in early visual processing. In complex, textured images, local analysis of image statistics provide several kinds of cues: the statistics within the figure, the statistics within the ground, and the differences between them. Here, we attempt to separate these roles.

Methods



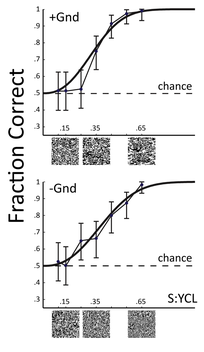
Local image statistics. Each strip shows the textures generated by varying an image statistic over its range, from -1 to +1. The first-order statistic determines the fraction of white vs. black checks. Second-order statistics determine correlations between pairs of checks that are adjacent horizontally, vertically, or diagonally. Third- and fourth-order statistics determine the parity of checks in regions containing 3 and 4 checks, respectively. In all cases, the random texture corresponds to a correlation of 0. Image statistics can be varied individually (as shown here) or in combination (see lower right).

Sample Trials and Task



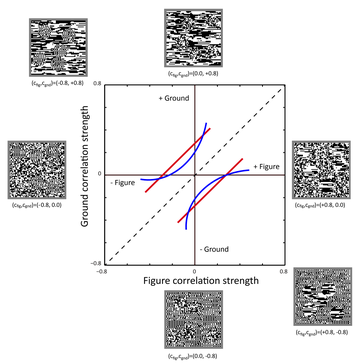
Before each block, subjects were shown samples of the targets with cartoons illustrating the size and location of circles. These examples are drawn from two blocks that probe the $\beta_{\_}$ plane.
A: circles are defined by positive horizontal correlation; background is random. **B:** circles are defined by negative horizontal correlation; background by positive horizontal correlation.

Weibull Functions



Example psychometric functions along the $\beta_{\_}$ axis (560 trials per curve, 80 trials per data point). **Upper panel:** positive correlation in ground; **lower panel:** negative correlation in ground. Smooth curves are Weibull function fits to fraction correct data; error bars indicate 95% confidence limits via bootstrap. Threshold is taken as the texture contrast at which fraction correct is 0.75. S: YCL.

Possible Outcomes



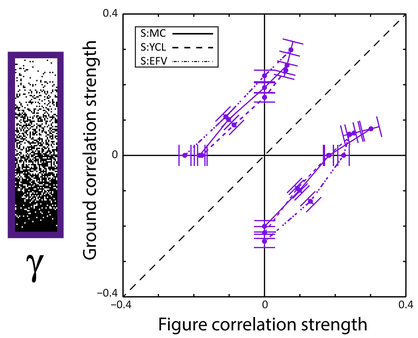
The locus of thresholds indicates how figure and ground statistics combine to determine the threshold for figure-ground separation. Parallel lines at a slope of 45 deg indicate that threshold is determined by texture contrast, i.e., a figure-ground difference. Hyperbolic loci suggest that threshold is determined by a quadratic discriminant.

Details

3F subjects	Contrast: 1.0; Check size: 9.8 min
2-AFC design	Luminance: 81 cd/m^2; Display size: 10.5 deg^2
140 trials/block	Target structure: 5 circles randomly-positioned
32 blocks/cond.	and equal to 25% of stimulus area
98,560 total trials	Duration: 500 ms intervals followed
Practice: 1 hr/subject	by 500 ms mask
Feedback: practice only	Binocular viewing at 1 m

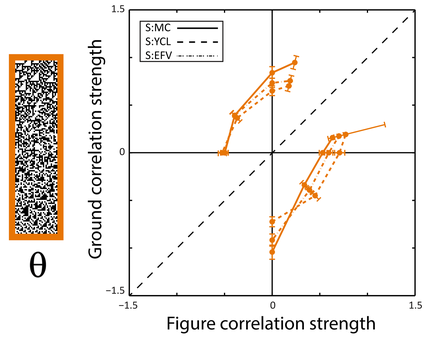
Results

1st-order statistics

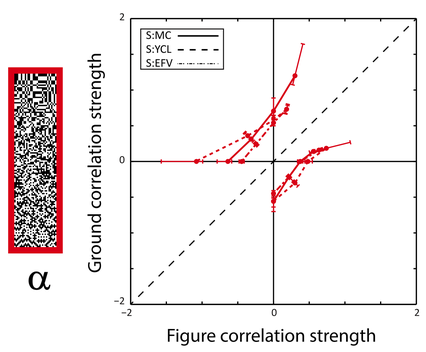


For first-order statistics, thresholds for figure-ground separation were closely approximated by two parallel lines at a slope of 45 deg. This indicates that thresholds depended only on the absolute value of the difference between figure and ground, and not on the sign of the statistic in either region.

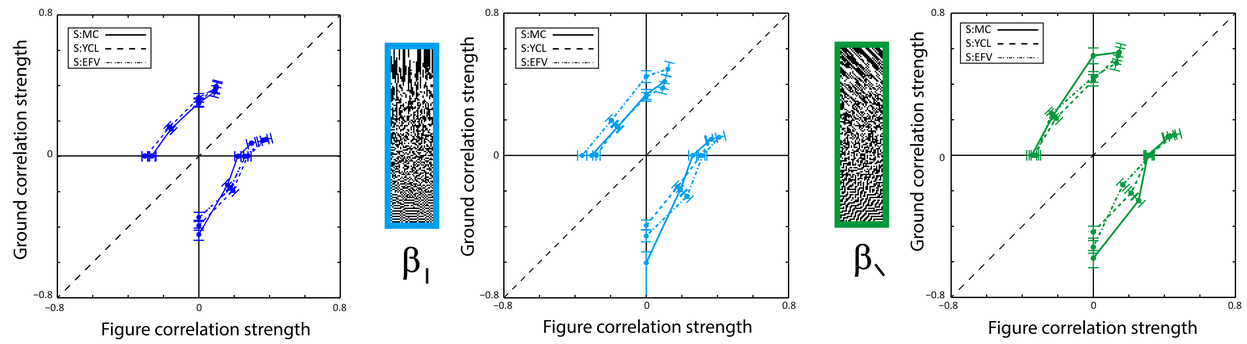
3rd- and 4th-order statistics



For third-order (*above*) and fourth-order (*below*) statistics, the deviations are more pronounced, and the threshold loci show some evidence of curvature. A hyperbolic threshold locus suggests that the figure-ground computation is based on a quadratic discriminant, rather than a texture difference.



2nd-order statistics



For second-order statistics (above), thresholds for figure-ground separation deviated somewhat from two parallel lines. The threshold for negative correlations in the ground was larger than thresholds for positive correlations in the ground, or for negative correlations in the figure.

Summary: Individual statistics

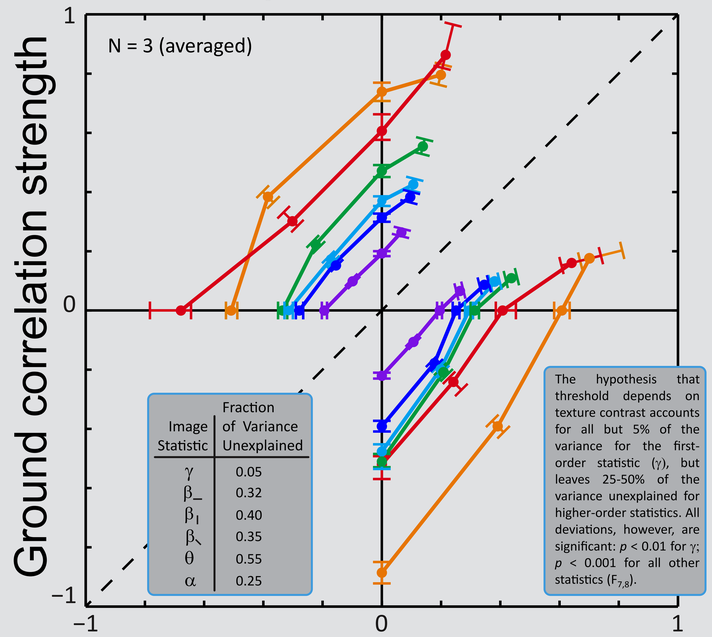
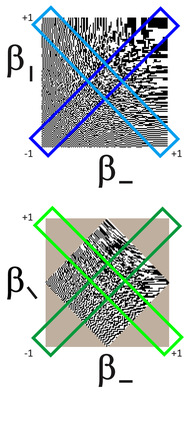


Image Statistic	Fraction of Variance Unexplained
γ	0.05
$\beta_{\_}$	0.32
$\beta_{\|}$	0.40
$\beta_{\backslash}$	0.35
θ	0.55
α	0.25

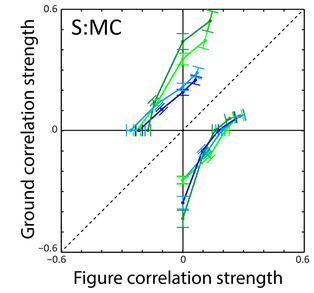
The hypothesis that threshold depends on texture contrast accounts for all but 5% of the variance for the first-order statistic (γ), but leaves 25-50% of the variance unexplained for higher-order statistics. All deviations, however, are significant: $p < 0.01$ for γ; $p < 0.001$ for all other statistics ($F_{7,8}$).

For each kind of statistic (color-coded to adjacent plots), loci are approximately parallel lines, indicating that thresholds are primarily driven by the figure-ground difference. Deviations are more prominent for higher-order statistics. Results are averaged across three subjects; error bars are 95% confidence limits.

Pairwise combinations



For some pairwise combinations of second-order statistics, there are large differences in thresholds when the correlations are present in the figure, vs. in the ground.



Conclusions

- To a first approximation, figure-ground thresholds were determined by the difference between value of an image statistic in figure vs. ground.
- For image statistics beyond first-order, and especially for combinations of second-order statistics, consistent deviations were found: unequal sensitivities to positive vs. negative correlations, and unequal sensitivities to statistics in figure vs. ground.