Human Orientation Sensitivity During Object Perception

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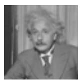
Introduction

Orientation information is crucial for object perception, yet little is known about how it is encoded in complex images. The precision of orientation coding has been traditionally investigated using simple stimuli such as single Gabors. We developed an image manipulation technique that allows us to vary the complexity of an image using multiple Gabors. We also developed a paradigm to assess orientation discrimination thresholds in complex object images. In the present study we ask how well such measures capture the efficiency of coding orientation information during object perception. The relative fit of two models (Hard Threshold and Equivalent Noise) and their ability to explain changes in threshold with the addition of external noise are compared.

Methods

Object patterns were composed by analyzing images with a bank of wavelet filters that define local amplitude, spatial frequency orientation and phase:



Original image

Orientation and spatial frequency selective filters:

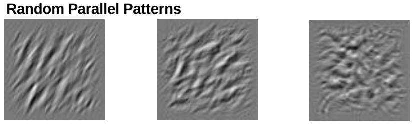
$$F_\theta = \frac{1}{\sqrt{2\pi\sigma_x\sigma_y}} \exp\left[-\frac{x^2}{2\sigma_x^2} - \frac{y^2}{2\sigma_y^2} + i(\varpi x_\theta)\right]$$

Filtered image 175 elements

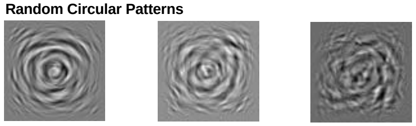
Filtered image 800 elements

SAMPLE STIMULI

Random Parallel Patterns



Random Circular Patterns



Object Patterns

Orientation Noise: σ=1° σ=16° σ=32°

All images composed of 800 Gabor elements: 100, 200, and 500 elements at 2, 4 and 8 c/deg respectively.

Procedure:

1

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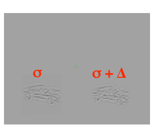
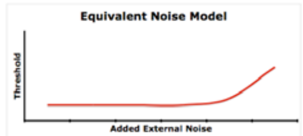


A noiseless source image was viewed, followed by a pedestal image with a fixed amount of orientation noise (σ) and target image containing pedestal noise plus additional noise under control of a staircase procedure (σ+Δ). Subjects indicated whether the target appeared to the left or right of the fixation point.

Variance of orientation noise for the pedestal image was between 1º and 32º in log steps.

Possible Models



$$T_\psi = \sqrt{\frac{\sigma_{ext}^2 + \sigma_{int}^2}{N}}$$

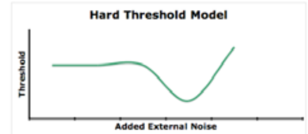
T_ψ = Experimentally observed threshold

N = Sample Size

σ_{ext}^2 = External noise

σ_{int}^2 = Internal noise

- **Estimates thresholds as function of added external noise**
- **Allows estimate of internal noise, sampling efficiency**
- **Steady performance at external noise levels below internal noise, rapid increase in threshold above internal noise.**



$$\Delta\sigma_p = \theta * w + \begin{cases} \theta - \sigma_p & \theta > \sigma_p \\ w * \sigma_p & \theta \le \sigma_p \end{cases}$$

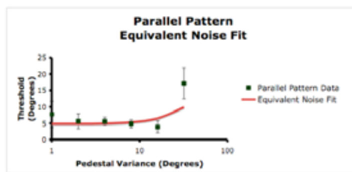
$\Delta\sigma_p$ = Change in pedestal required for discrimination

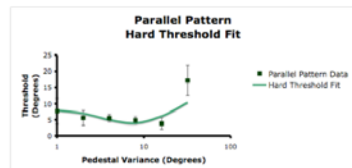
θ = Internal noise

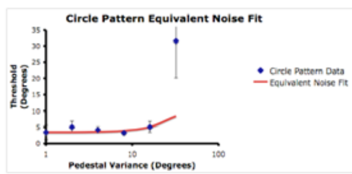
w = Weber fraction

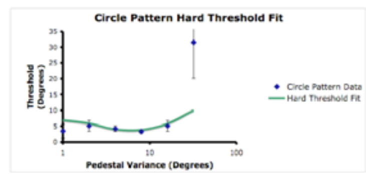
- **Estimates change in pedestal variance required for successful discrimination**
- **Provides a decision model for discrimination based upon difference between internal noise and pedestal noise.**
- **Orientation noise calculated relative to a single primary orientation**

Results with random patterns:





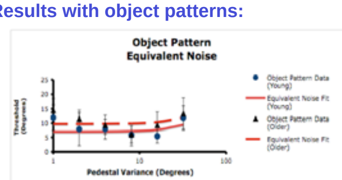


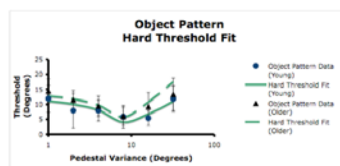


- Steady performance with sharp decline at 32º pedestal variance
- Thresholds elevated relative to those obtained using single gratings (typically <1°)
- No significant difference in goodness of fit between models.

PATTERN TYPE	MODEL	CORRELATION (DATA & FIT)
CIRCLE	Equivalent Noise	0.89
	Hard Threshold	0.72
PARALLEL	Equivalent Noise	0.74
	Hard Threshold	0.73

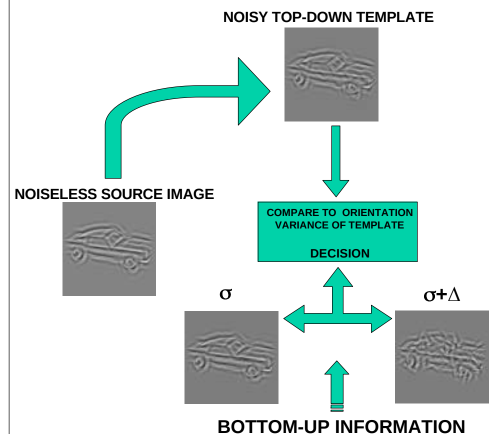
Results with object patterns:





- Discrimination thresholds for object patterns differed significantly from those obtained for parallel random patterns ($F(5,11) = 9.51$, $p<.001$).
- Addition of noise <u>improves</u> thresholds up to a point, with peak in performance between 8º-12º added external noise, followed by rapid increase in threshold at high added noise levels.
- Equivalent Noise Model fails to capture dipper in function. Hard Threshold Model reflects improvement in performance with noise.
- Hard Threshold Model assumes single primary orientation from which noise is calculated. Cannot explain data since circular and object patterns contain all orientations.

Alternative Model



- **Subjects cannot determine directly from source and target image which has more noise. They must refer to memory of source image.**
- **Since images contain all possible orientations, a decision requires a global comparison of orientation variance between image and top-down template.**
- **Optimum of threshold function is near the level of internal orientation noise of top-down template.**
- **A Bayesian framework that incorporates uncertainty of local orientations in the top-down template as a prior presents a viable alternative model.**

Conclusions

- **Orientation discrimination threshold depends on the general internal noise of orientation coding which leads to a paradoxical improvement of threshold at intermediate noise levels.**
- **This effect increases with increasing complexity of the input pattern, suggesting a crucial role for the internal top-down template in discrimination.**
- **A probabilistic framework that encodes prior distribution of orientations and their uncertainty provides an adequate model.**

References:

Regan, D. & Beverly, K. I. (1985). Postadaptation orientation discrimination. *Journal of the Optical Society of America (A), 2*, pp. 147-155.

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