Theory of Covert Search in Noise Backgrounds Correctly Predicts Asymmetrical Spatial Distributions of Misses and False Alarms

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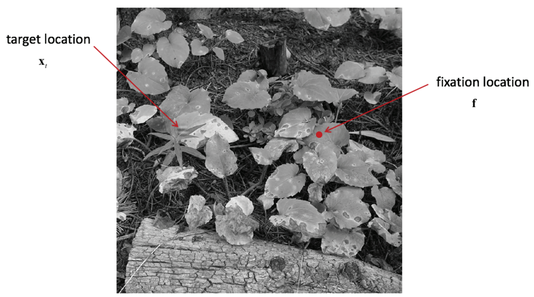
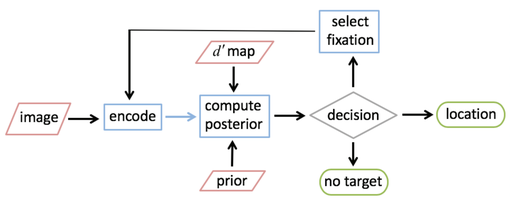
TEXAS

Background and Motivation



Generic Framework



Covert Search Theory

$$R(\mathbf{x}) \sim \begin{cases} \mathcal{N}\left[d'(\mathbf{x})\rho_{TT}(\mathbf{x}-\mathbf{x}_T),1\right] & \textit{present} \\ \mathcal{N}[0,1] & \textit{absent} \end{cases}$$ normalized template response map

$$d'(\mathbf{x}) \propto A(\mathbf{x})\left[a\frac{\|T_\lambda(\mathbf{x})\|}{L(\mathbf{x})C(\mathbf{x})S(\mathbf{x})}F(\mathbf{x})\right]^\beta$$ d' map with no location uncertainty

$$l(\mathbf{x}) = d'(\mathbf{x})R(\mathbf{x}) - 0.5d'^2(\mathbf{x})$$ log likelihood ratio

$$\max_{\mathbf{x}}\left[l(\mathbf{x}) + \ln prior(\mathbf{x})\right] > \gamma$$ present/absent decision rule

$$\hat{\mathbf{x}} = \arg\max_{\mathbf{x}}\left[l(\mathbf{x}) + \ln prior(\mathbf{x})\right]$$ location if present

Current Goal:
Test of Covert Theory in Noise Backgrounds

$$d'(\mathbf{x}) \propto \left[\frac{a}{\sigma}F(\mathbf{x})\right]^\beta$$ white noise backgrounds and no covert attenuation: $A(\mathbf{x}) = 1$

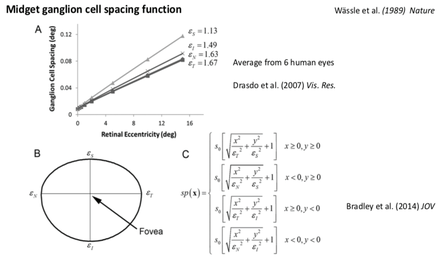
$U(\mathbf{x})$ intrinsic location uncertainty map

$prior(\mathbf{x})$ prior probability over location

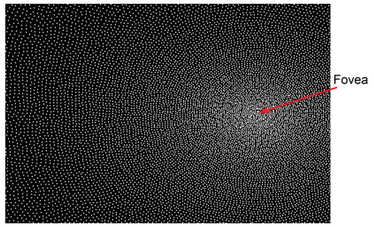
Visual Field Detectability

Ganglion Cells: Critical Visual Information Bottleneck

Midget ganglion cell spacing function



Detectability Falls Inversely with GC Spacing



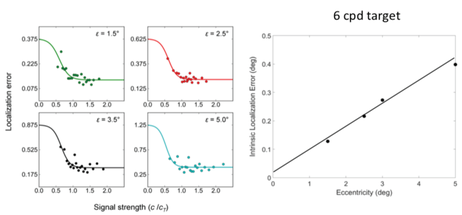
Foveation factor

$$F(\mathbf{x}) = \frac{1+k_{sp}sp(0)}{1+k_{sp}sp(\mathbf{x})}$$ k_{sp} = target dependent constant

Rovamo et al. (1978) *Nature*
Bradley et al. (2014) *JOV*

Uncertainty

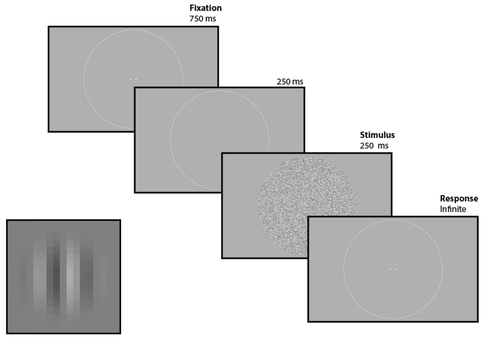
Intrinsic position uncertainty increases in proportion GC spacing



$$u(\mathbf{x}) = k_u sp(\mathbf{x})$$ k_u = target dependent constant

Michel & Geisler (2011) *JOV*

Detection/Search Experiments



Target: 6 cpd raised cosine sine wave stimulus.

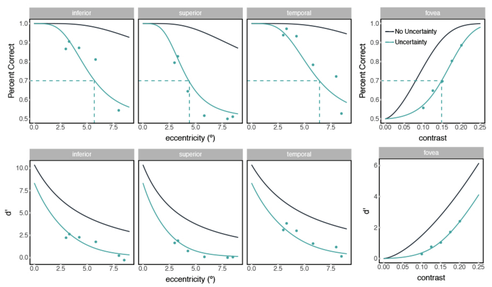
Foveal Task: 5 levels of contrast (blocked). Yes/No Task. Fixed noise (20% RMS).

Peripheral Task: 5 levels of eccentricity (blocked). Yes/No. Fixed noise (20% RMS), fixed signal (amplitude 35%).

Search Task: Polar sampling. Fixed signal, fixed noise.

Detection Results

Psychometric Functions
Detection. White Noise. 6-cpd Target



Identification Performance With Intrinsic Uncertainty

$$d'_u(\mathbf{x}|\mathbf{f}) = \ln\left(\frac{\exp\left[d'(\mathbf{x}|\mathbf{f})\right] + u(\mathbf{x}-\mathbf{f};k_u)}{1+u(\mathbf{x}-\mathbf{f};k_u)}\right)$$ closed-form approximation

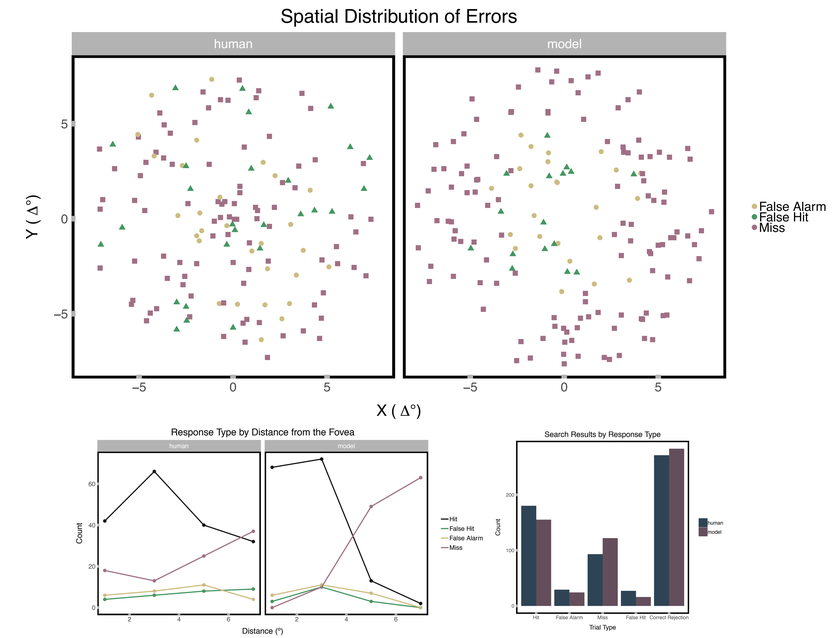
Geisler (2018) *JOV*

$$d'(\mathrm{x}\,|\,\mathrm{f}) = \left(\frac{ak_e(\mathrm{x}\text{-}\mathrm{f})}{\sigma_b}\right)^\beta \qquad k_e(\mathrm{x}\text{-}\mathrm{f}) = \frac{k_0\left(1+k_{sp}sp(0)\right)}{1+k_{sp}sp(\mathrm{x}\text{ - }\mathrm{f})}$$

Unknowns to estimate from preliminary measurements:

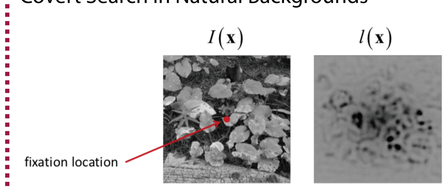
k_0, k_{sp}, β, k_u $\quad k_0 = 3.2 \quad k_{sp} = 1.07 \quad \beta = 1.56$

Covert Search Results



Future Directions and Conclusions

Covert Search in Natural Backgrounds



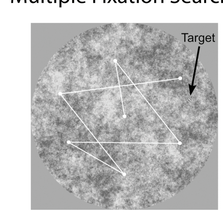
target amplitude — foveation factor

$$d'(\mathbf{x}|\mathbf{f}) = \left[k_0 a(\mathbf{x})\frac{\|T_\lambda(\mathbf{x})\|}{L(\mathbf{x})C(\mathbf{x})S(\mathbf{x})}F(\mathbf{x}-\mathbf{f};k_{sp})\right]^\beta$$

masking factors

$\mathbf{f}$ = fixation location

Multiple Fixation Search



- **Covert search in noise backgrounds is approximated by an optimal search strategy.**
- **Absence of errors in the fovea differs from human spatial distribution of errors.**
- **Retinal factors and uncertainty alone may not explain human covert search.**