# Noise unveils spatial frequency and orientation selectivity during visual search


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## Introduction

Spatial frequency and orientation are features whose significance in visual selectivity is supported by physiological and psychophysical evidence. In this study, a fast classification images framework (Tavassoli *et al.*, in press) distinguishing foveal and non-foveal search processes was employed to examine the strategies of 3 human observers (AJS, AT, and IVDL) in 8 separate visual search experiments using Gabor targets.

## Methods

Eye movements were recorded during every trial as observers searched for one target (Fig. 1a & 1b) randomly embedded in one tile of a grid of 49 $1/f$ noise tiles. Each observer performed 700 trials for each target condition and was instructed to maintain fixation to select the target candidate.

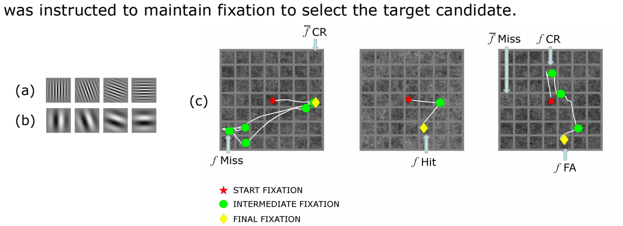



**Figure 1.** Gabor targets at 0, 20, 70 and 90 deg at (a) 8 cpd, and (b) 2 cpd. Examples of stimuli are shown with scan paths in (c).

A variant of signal detection theory (Tables 1a & 1b) was used to classify noise tiles. Noise tiles were then averaged within each class, both in space and Fourier (amplitude) domain, then combined across classes (Table 1c):

(a)

| ALL TILES | | | |
|---|---|---|---|
| **Target?** | **Attracted?** | **Class** | **Max Number of Tiles Possible per Trial** |
| PRESENT | YES | $\bar{f}_{Hit}$ | 1 |
| PRESENT | NO | $\bar{f}_{Miss}$ | 1 |
| ABSENT | YES | $\bar{f}_{FA}$ | 48 |
| ABSENT | NO | $\bar{f}_{CR}$ | 48 |

(b)

| ALL FIXATED TILES | | | |
|---|---|---|---|
| **Target?** | **Observer's Decision?** | **Class** | **Max Number of Tiles Possible per Trial** |
| PRESENT | MAINTAIN FIXATION | $f_{Hit}$ | 1 |
| PRESENT | CONTINUE SEARCH | $f_{Miss}$ | 1 |
| ABSENT | MAINTAIN FIXATION | $f_{FA}$ | 1 |
| ABSENT | CONTINUE SEARCH | $f_{CR}$ | (Num of Fixated Tiles -1) |

(c)

| | Signal Absent Trials | Signal Present Trials |
|---|---|---|
| ***Foveal*** | $f_{AI} = f_{FA} - f_{CR}$ | $f_{AI} = f_{Hit} - f_{Miss}$ |
| ***Non-Foveal*** | $\bar{f}_{AI} = \bar{f}_{FA} - \bar{f}_{CR}$ | $\bar{f}_{AI} = \bar{f}_{Hit} - \bar{f}_{Miss}$ |

**Table 1.** Categorization of the tiles into (a) non-foveal and (b) foveal classes. Combination of averages across classes is shown in (c).

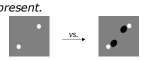
## Results

We have made several interesting findings, examples of which are indicated with the corresponding colors in Figs. 2 & 3:

### Complementary Spectral Components

*Observers' Fourier (amplitude) average images, in the signal absent cases, contain both reductions and increases in frequency components, suggesting a differing strategy from an ideal observer where only increases in frequencies close to the target's would be present.*

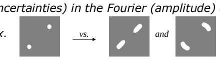
*Ex.*




### Frequency and Orientation Uncertainties

*We have observed large radial smearing (corresponding to frequency uncertainties) and rotational smearing (corresponding to orientation uncertainties) in the Fourier (amplitude) domain.*

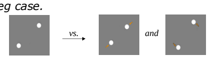
*Ex.*




### Frequency and Orientation Offsets

*We have found lower central frequencies and shifts away from the sought orientations, especially in the 8 c/deg case.*

*Ex.*




### Phase Uncertainty

*We find a similar result as previous parafoveal yes-no detection studies (Ahumada & Beard, 1999; Solomon, 2002), where no spatial template appears for the target-absent trials for the higher frequency Gabor targets.*

### Differences Between Non-Foveal and Foveal Classes

*Lower accuracy in both frequency and orientation in the periphery, with the tightening of these properties as target candidates were foveated.*

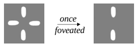
### Inter-Observer Differences

*An example is that AJS seems to have a systematic orientation bias, shown by an overestimation of orientations in the periphery, as compared to the other two observers.*

### An Unusual Outcome

*All three observers had significant horizontal frequency components in the non-foveal Fourier (amplitude) average images for the 90 deg, 8 cpd Gabor search task, although only vertical frequency components should have been present. The horizontal components vanished once tiles were foveated. This effect is also present for the 70 deg case, though slightly weaker.*

*Ex.*



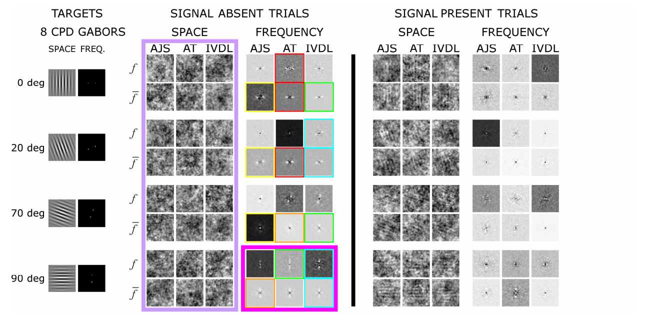




**Figure 2.** Space and frequency domain average images for 8 cpd trials for each of the 3 observers and 4 target orientation conditions (0, 20, 70 and 90 deg).

## Results *Continued*

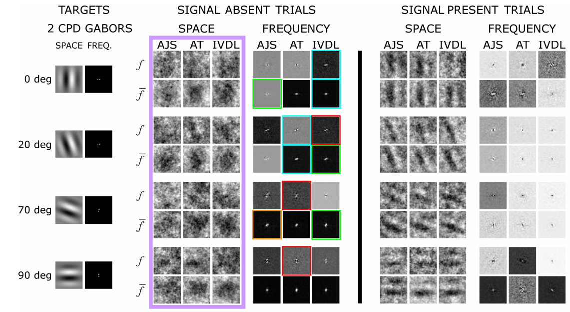



**Figure 3.** Space and frequency domain noise images for 2 cpd trials for each of the 3 observers and 4 target orientation conditions (0, 20, 70 and 90 deg).

Frequency and orientation offsets were quantified by fitting Fourier amplitude of Gabors to the data, where frequency, bandwidth, and orientation were varied to obtain the best fit. Examples are shown in Fig. 4.

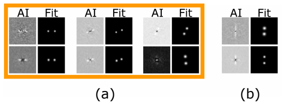



**Figure 4.** Frequency domain average images (AI) and their fits are shown in (a). A less suitable fit is shown in (b).

## Conclusions

Our data are consistent with earlier parafoveal studies, but provided additional insight into observers' dynamic decision-making, highlighting different search strategies that predominate at different target frequencies and orientations. Our novel classification images extension allowed differences between foveal and parafoveal processes to be probed. This experiment yielded interesting orthogonal confusion effect in the 90 deg, 8 cpd target case that warrants further study.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### Citations


Tavassoli, A., van der Linde, I., Bovik, A.C., and Cormack, L.K. An efficient technique for revealing visual search strategies with classification images. *Perception & Psychophysics*. (In press)

Ahumada, A.J. Jr. and Beard, B.L. (1999). Classification Images for Detection. *IOVS 40* (4, ARVO Supplement), S572 (abstract).

Solomon, J. A. (2002). Noise reveals visual mechanisms of detection and discrimination. *Journal of Vision*, 2(1), p. 105-120.