BANDWIDTH AFFECTS VISUAL LATERAL INTERACTIONS

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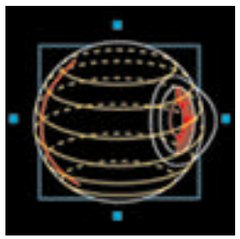
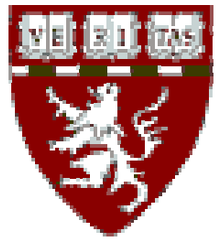




Abstract

Purpose: Usually a co-local, high-contrast mask increases contrast threshold (inhibition). Interestingly, often a laterally displaced mask (flanker) will facilitate contrast detection (Polat & Sagi, 1993, 1994). When spatial scaling of these flanker effects was evaluated, stimulus bandwidth was confounded with spatial frequency (λ^{-1}). Under conditions where at lower spatial frequencies, the size (standard deviation, σ) of the Gabor patch was smaller ($\sigma < \lambda$) than at higher spatial frequencies ($\sigma = \lambda$), the effect appeared scale invariant. **Methods:** Contrast threshold of a Gabor patch was measured with and without flanking Gabor patches equidistant above and below. Three subjects were involved in a series of experiments in which the distance between the patches, λ and σ were varied independently. **Results:** We replicated the original results for all conditions. However, when Gabor size was fixed ($\sigma = \lambda$), facilitation changed with spatial frequency (range 2 to 13 cycles/deg.). When Gabor size was varied ($\sigma = 0.5\lambda$ to 2λ), the combination of larger patch sizes and lower spatial frequencies usually caused inhibition. Narrow flankers (wide bandwidth) produced more facilitation than wider flankers (narrow bandwidth) and these effects varied with the size of the grating (λ). **Conclusions:** We were unable to find any conditions that demonstrated spatial scaling. The size, both λ and σ, of both stimulus and flankers, influenced facilitation. These results need to be reconciled with current models of lateral interactions and have implications for image enhancement.

Introduction

Lateral interactions:

- Usually a co-local, high-contrast mask inhibits contrast detection.
- A laterally-displaced, high-contrast mask (flanker) may facilitate contrast detection (Polat & Sagi, 1993, 1994).

Spatial scaling of lateral interactions:

- Polat & Sagi demonstrated spatial scaling with Gabor patches – lateral interactions independent of wavelength (λ), if distances scaled in λ.
- However, bandwidth was confounded with spatial frequency (λ^{-1}). [At lower spatial frequencies, the standard deviation (σ) of the Gabor patch was smaller ($\sigma < \lambda$) than at higher spatial frequencies ($\sigma = \lambda$).]

We critically evaluated the reported spatial scaling.

General Methods

- Measured contrast threshold of a Gabor patch with and without flanking Gabor patches. Gratings were vertical (usually).
- Parameters chosen to replicate Polat & Sagi (1993, 1994).
- Masks (40% contrast) equidistant above and below test patch (usually); test-mask distance = center to center.
- Each Gabor patch, $G(x,y) = \cos\left[\frac{2\pi}{\lambda}\left[(x-x_0)\cos\theta + (y-y_0)\sin\theta\right]\right] e^{-\frac{(x-x_0)^2+(y-y_0)^2}{\sigma^2}}$

  where λ is grating wavelength and σ is standard deviation of the Gaussian envelope. λ and σ were varied independently.
- VisionWorks™ system & Nanao™ EIZO® monitor [120 Hz, 1024 × 600 pixels, 23.4 × 40 cm, 12-bit, average luminance 37 cd/m^2].

- Five subjects (three naïve).
- Temporal 2AFC, 3/1 staircase with unequal step size. Initial contrast 25%.
- One staircase was either 4 × (2 practice + 10 experimental reversals) OR (2 practice + 40 reversals). Each data point is average of 3 to 6 staircases.

Figure 1. Temporal 2AFC.

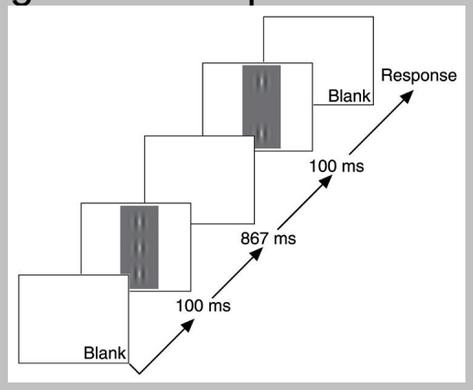
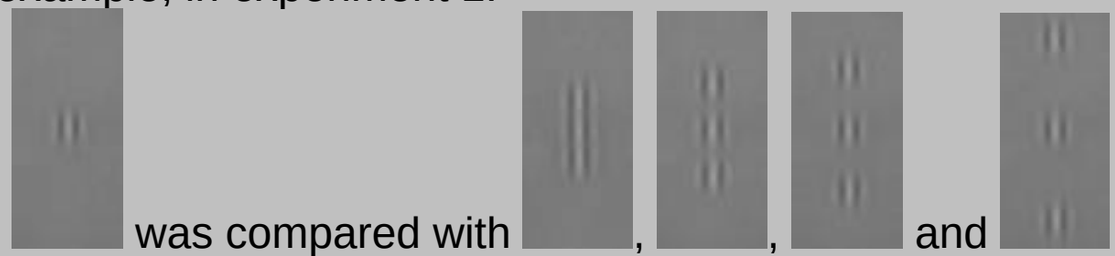


Figure 2. Contrast sensitivity of a ‘standard’ (without masks) was compared with masked conditions. For example, in experiment 1:

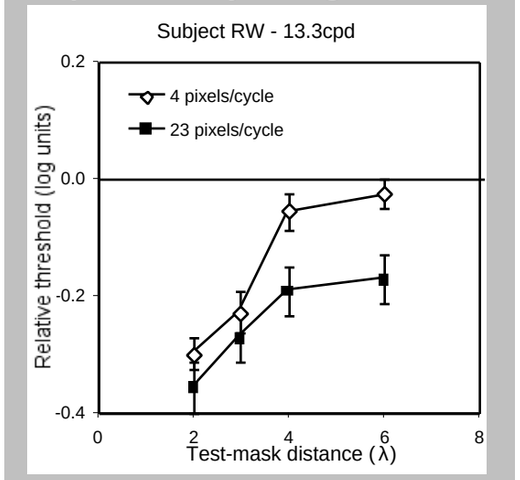


Preliminary Experiments

Experimental conditions were altered due to display system non-linearities.

- Polat and Sagi tested 13.3 to 3.3 cpd (56 Hz, 512 x 512 pixel, 9.6° × 9.6°). Hence, at 13.3 cpd, there were only 4 pixels/cycle.
- We replicated their lateral interactions with 4 pixels/cycle.
- However, the measured lateral interactions varied with the number of pixels/cycle (figure 3).
- Also, the relative orientation between grating and raster changed the lateral interactions (figure 4).

Figure 3. More facilitation was found with 23 pixels/cycle than 4 pixels/cycle (used by Polat & Sagi, 1993, 1994). See figure 5 for explanatory diagram.



· This suggests an inability to accurately represent gratings of high contrast and high frequency across the raster (Klein et al., 1996; Pelli, 1997).

Figure 4. When there were only 4 pixels/cycle, the lateral interactions were influenced by the relative orientation of the grating and the raster. When there were 23 pixels/cycle, there was no difference between the "across" and "along" conditions (though there was a small difference between vertical and horizontal gratings).

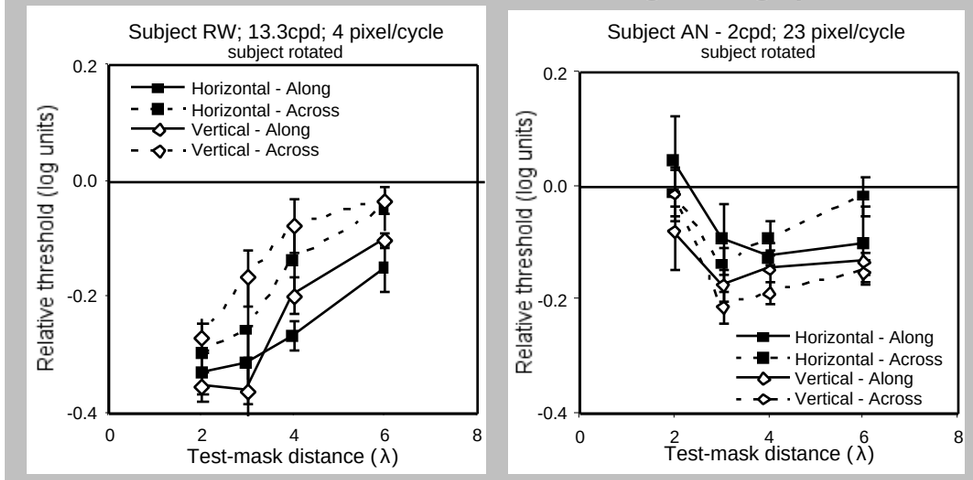
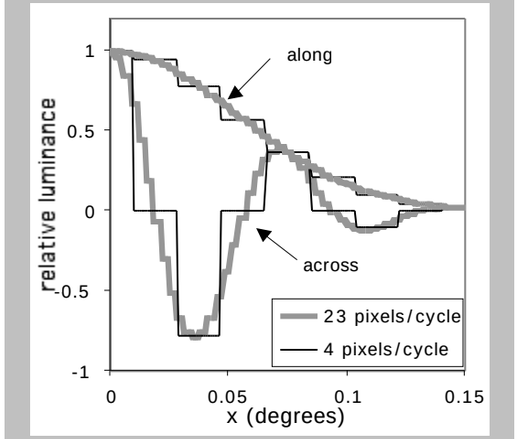


Figure 5. Schematic diagram showing the effect of changing the number of pixels used to represent the target (in this case, a 13.3 cpd Gabor with σ = λ)



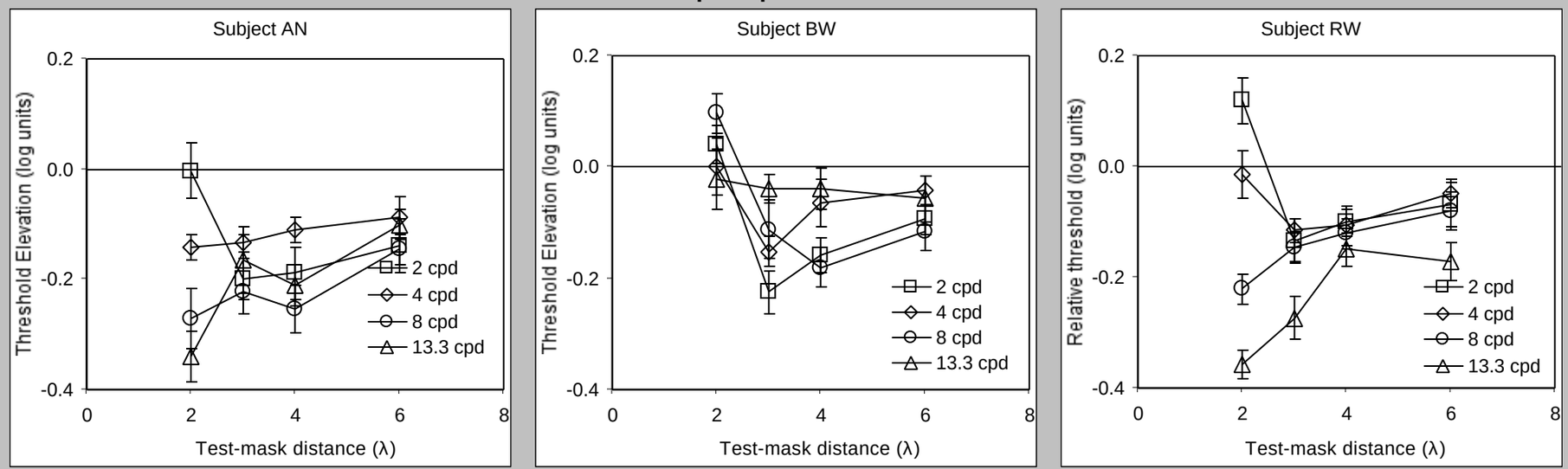
Therefore, we varied viewing distance to alter the spatial frequency of the gratings

Experiment 1 – Effect of spatial frequency

Question: Is there spatial scaling? **Answer:** No (see figure 6).

- If so, then predict same lateral interactions at 2, 4, 8 and 13.3 cpd.
- For all spatial frequencies, $\sigma = \lambda$.

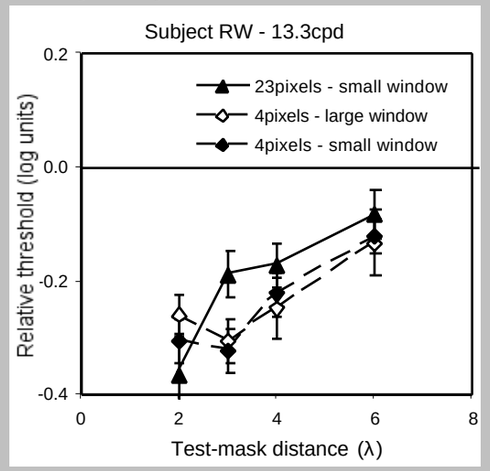
Figure 6. Spatial scaling did not occur: note the differences between spatial frequencies, particularly at 2λ. We suspect that the lack of facilitation at 8 and 13 cpd for subject BW was because the masks were too close to her peripheral threshold.



Question: As viewing distance changed with spatial frequency (see preliminary experiments), did the size of the "window" (visible area of the monitor) influence measured lateral interactions?

Answer: No (see figure 7).

Figure 7. There was no difference in the lateral interactions when the size of the window visible at the shorter viewing distance (4 pixel/cycle) was altered to match the window apparent at the longer viewing distance (23 pixel/cycle).

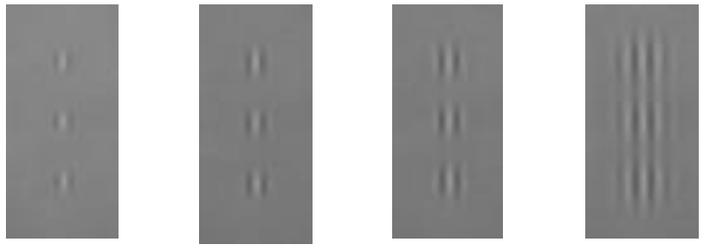


Lateral interactions: At higher spatial frequencies greater facilitation at short test-mask distances.

Experiment 2 – Effect of patch size (bandwidth)

Question: Is there spatial scaling? **Answer:** No (see figure 8).

- If so, then predict same lateral interactions when Gabor size (σ) is altered.
- σ = 0.5λ, 0.75λ, λ, and 1.5λ.



- λ = 2 and 8 cpd.

Question: Could spatial scaling be related to patch size (σ)?

Answer: No (see figure 9).

Figure 8. Lateral interactions changed as patch size was altered. This effect changed with spatial frequency. Note the difference in the y-axis from previous figures.

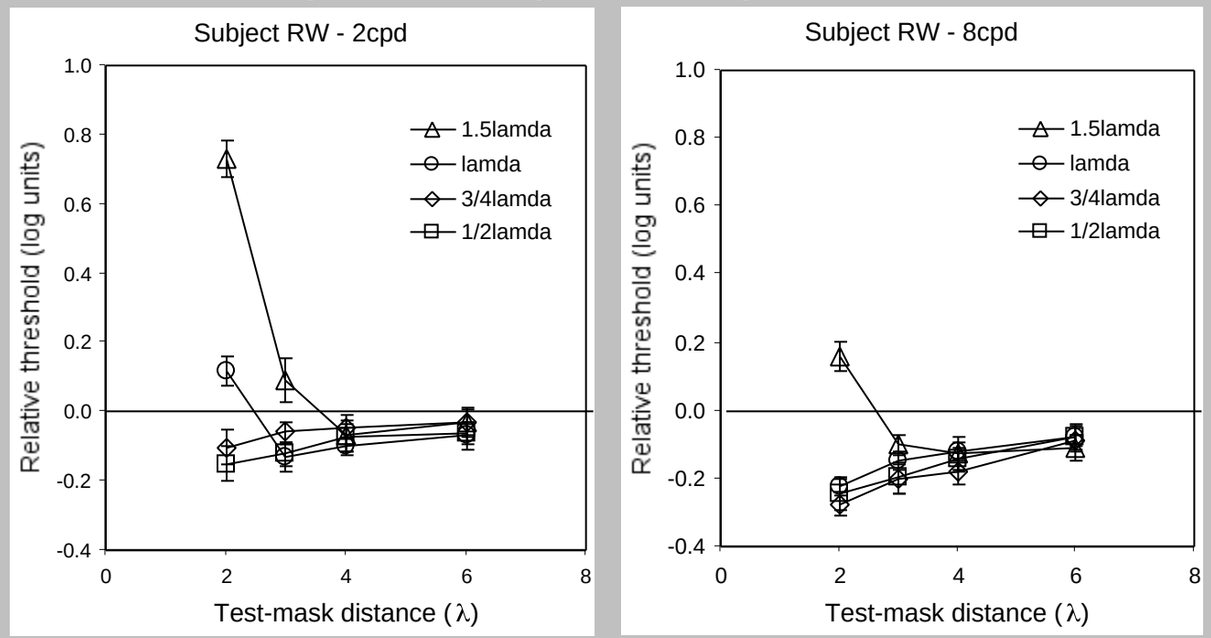
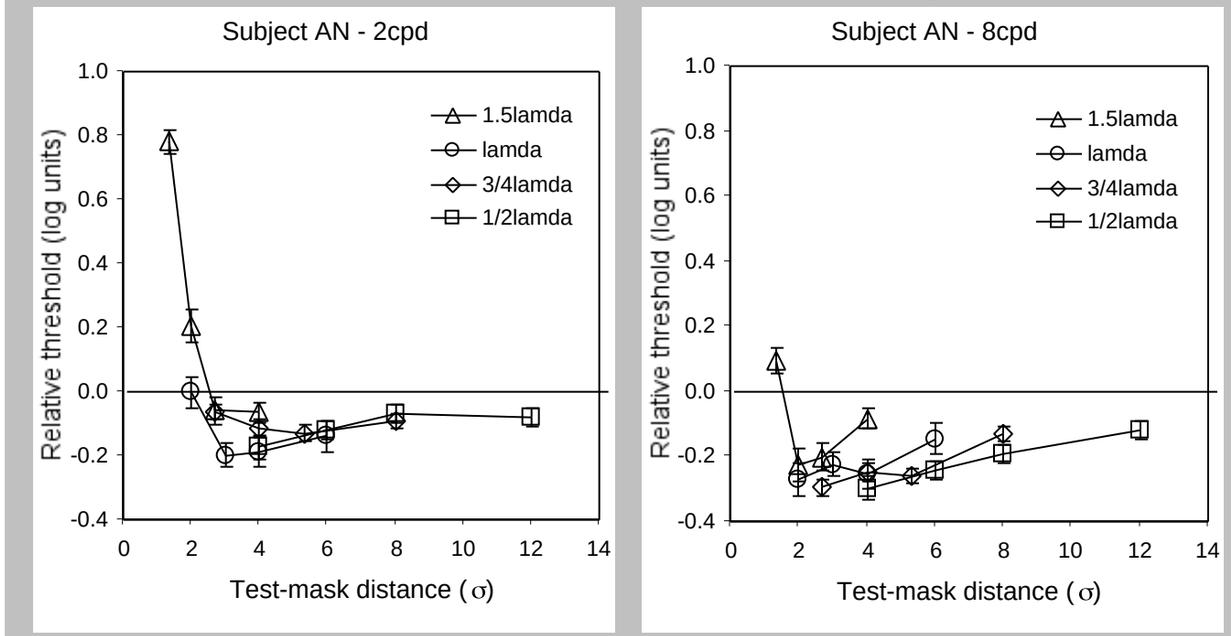


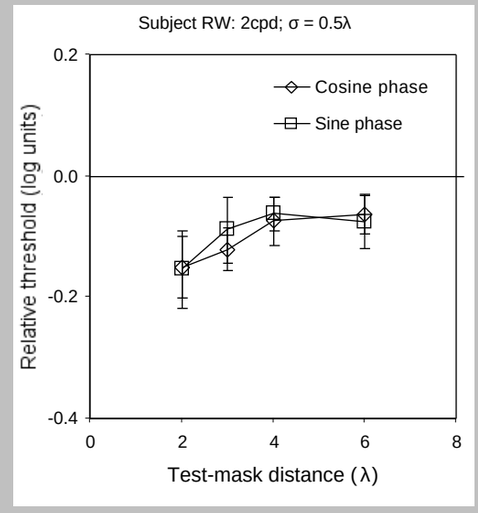
Figure 9. Though at 2 cpd there is the appearance of spatial scaling, when the test-mask distance was scaled relative to the patch size (σ) rather than the wavelength (as in figure 8), this was not apparent at 8 cpd. Note the change in x-axis.



Question: Luminance artifact?

Answer: No (see figure 10).

Figure 10. No difference between sine and cosine phase for small patches (σ =0.5λ).

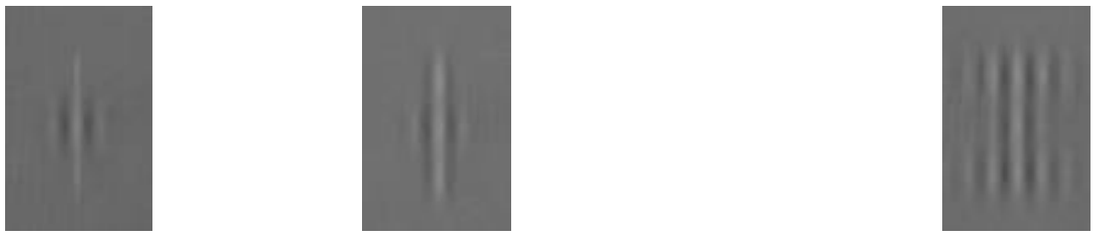


Lateral interactions: Less facilitation with large patches.

Experiment 3 – Effect of flanker bandwidth

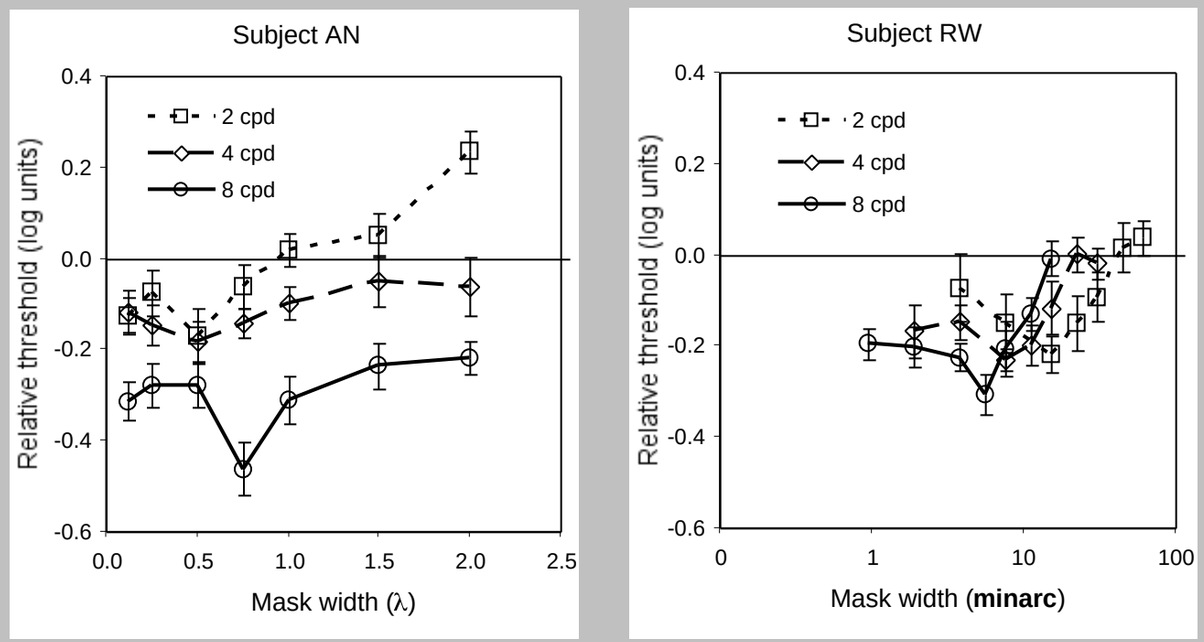
Question: Two possible conclusions from experiment 2:

- lateral interactions change with patch bandwidth; OR
- effects due to overlap of the mask and test patch.
- Fixed mask patch height ($\sigma_y = \lambda$); fixed test-mask distance (2λ).
- $\sigma_x = 0.125\lambda,\ 0.25\lambda, 0.5\lambda, 0.75\lambda, \lambda, 1.5\lambda, 2\lambda$



Answer: Lateral interactions changed with mask bandwidth (σ_x) (see figure 11). Effects altered with wavelength.

Figure 11. Lateral interactions changed as mask patch width was altered. This effect changed with spatial frequency. Note the difference in the y-axis from previous figures. Note that the two figures have different x-axis units.



Question: Spatial scaling for absolute distance?

Answer: No (see figure 11).

The future: What is the impact of test-mask overlap? We will address this question by fixing mask width (σ_x) and systematically altering mask height (σ_y)

Lateral interactions: More facilitation with narrow masks.

Conclusions

- Replicated Polat & Sagi's (1993, 1994) results for all their conditions.
- Lateral interactions varied with:
    1. Wavelength [from 2 to 13 cpd, when Gabor size was fixed ($\sigma = \lambda$)];
    2. Gabor size [from $\sigma = 0.5\lambda$ to 2λ, at 2 and 8 cpd]; and
    3. Mask Gabor width [from $\sigma_x = \lambda/8$ to 2λ , when test-mask distance was fixed (2λ), at 2, 4 and 8 cpd].
- Hence, no spatial scaling.

- Summary of lateral interactions:
    1. Higher spatial frequencies produced greater facilitation at short test-mask distances (i.e. 2λ);
    2. Larger patches (narrow bandwidth) produced less facilitation; and
    3. Narrow masks (wide bandwidth) produced more facilitation than wide masks (narrow bandwidth).

- Results need to be reconciled with current models of lateral interactions and have implications for image enhancement.

Acknowledgements

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References

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Comments