Lines and dipoles are efficiently detected.

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Abstract (11/28/06)

Watson, Barlow, & Robson (1983) rated patterns by contrast energy threshold and found a 7 cpd Gabor to be best. Watson (2000) plotted the contrast energy thresholds for the 43 Modelfest stimuli and found a Gaussian spot with a standard deviation (SD) of 2.1 arc min was best. When he compensated for contrast sensitivity, the best spot was the smallest one (SD = 1.05 min) and the overall best stimulus was the "one octave" (window SD = 2.1 min) 16 cpd Gabor. When he accounted for spatial summation in addition to contrast sensitivity, the spots and the Gabors were similar in performance and the best stimulus (but not significantly different) was the long (window SD = 30 min), narrow (1 pixel = 0.5 min) line.

Using Modelfest-like methods, we have measured the detectability of lines as a function of length (2, 6, 18, 54 min) and width (0.5, 1, 2 min) and also have compared the detectability of lines (8 x 0.5 min) with that of dipoles (2 adjacent 8 x 0.5 min lines of equal and opposite contrast). We found that short lines can have contrast energy thresholds as low as those of spots, and that when contrast sensitivity is taken into account, dipole thresholds can be as low as those of lines.

We also found that the introduction of fixation marks close to the small patterns could lower the thresholds as much as 3 dB, suggesting that spatial uncertainty may have played an important role in the detection of small patterns in the Modelfest experiments.

Introduction (9/08/08)

"What does the eye see best?" is the title of the 1983 Nature article by Watson, Barlow, & Robson. "Best" meant detected most efficiently relative to the ideal observer limited only by quantum noise. They showed that the best pattern is then the one with the lowest contrast energy threshold.

The contrast energy of a discrete space-time contrast signal c(x, y, t) is

$$E = dx\ dy\ dt\ \Sigma\ c(x, y, t)^2$$

where dx is the pixel width, dy is the pixel height, and dt is the pixel duration. We use a decibel scale for contrast energy using the lowest threshold from the Watson, Barlow, and Robson study as the zero point.

$$dBB = 10 \log_{10} (E/E_0)$$

$$E_0 = 10^{-6} \text{ deg}^2 \text{ sec}$$

Watson, Barlow, & Robson measured contrast energy thresholds for Gabors varying in spatial and temporal frequency, f_X and f_T, and horizontal and vertical and temporal standard deviations, s_X, s_Y, and s_T, and squares varying in size. The best stimulus was a Gabor whose contrast over space (x, y) and time (t) was

$$\sin[\ 2\ pi\ (\ f_X\ x + f_T\ t)]\ \exp[\ -\ 0.5\ ((x/s_X)^2 + (y/s_Y)^2 + (t/s_T)^2\ )\ ]$$

with

f_X = 7 cycles/ deg, $s_X = s_Y$ = 1/7 deg, f_T = 4 cycles/ sec, and s_T = 1/16 sec.

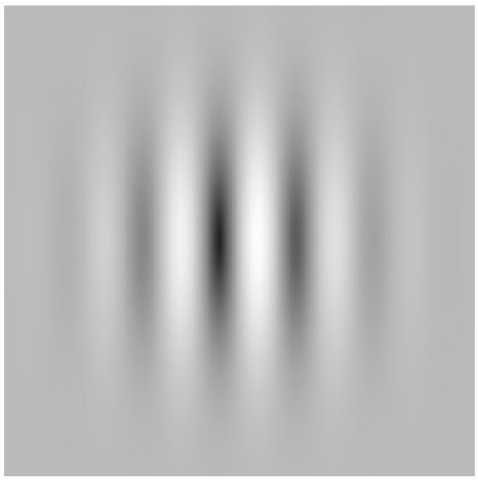

Figure 1.

Figure 1 illustrates the shape of such a pattern. Watson, Barlow, & Robson speculated that the best stimulus had the shape of the detecting template, "… the detector spatial weighting function deduced here resembles the receptive field profiles of many cortical neurones. … Thus patterns like that … may be among the elementary features of visual perception."

Modelfest

The Modelfest foveal pattern detection study began in 1996. There are now contrast thresholds for 16 observers from multiple labs on 43 stimulus patterns, 23 of which are simple Gabor patterns. The stimuli and data are available on the web (Anonymous, 1999).

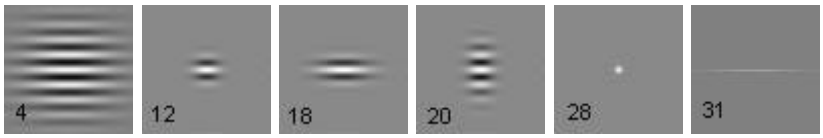

Figure 2.

Figure 2 shows six of the patterns: four of the 4 cpd Gabors, a Gaussian and a line. Some methods were standardized. CRT displays were used with a 60 Hz frame rate, 30 cd/m^2 mean luminance, 256 x 256 pixel stimulus field, 0.5 min pixels, and fixation marks at the outside corners. Two-interval forced choice was the trial method.

Modelfest Contrast Energy Thresholds

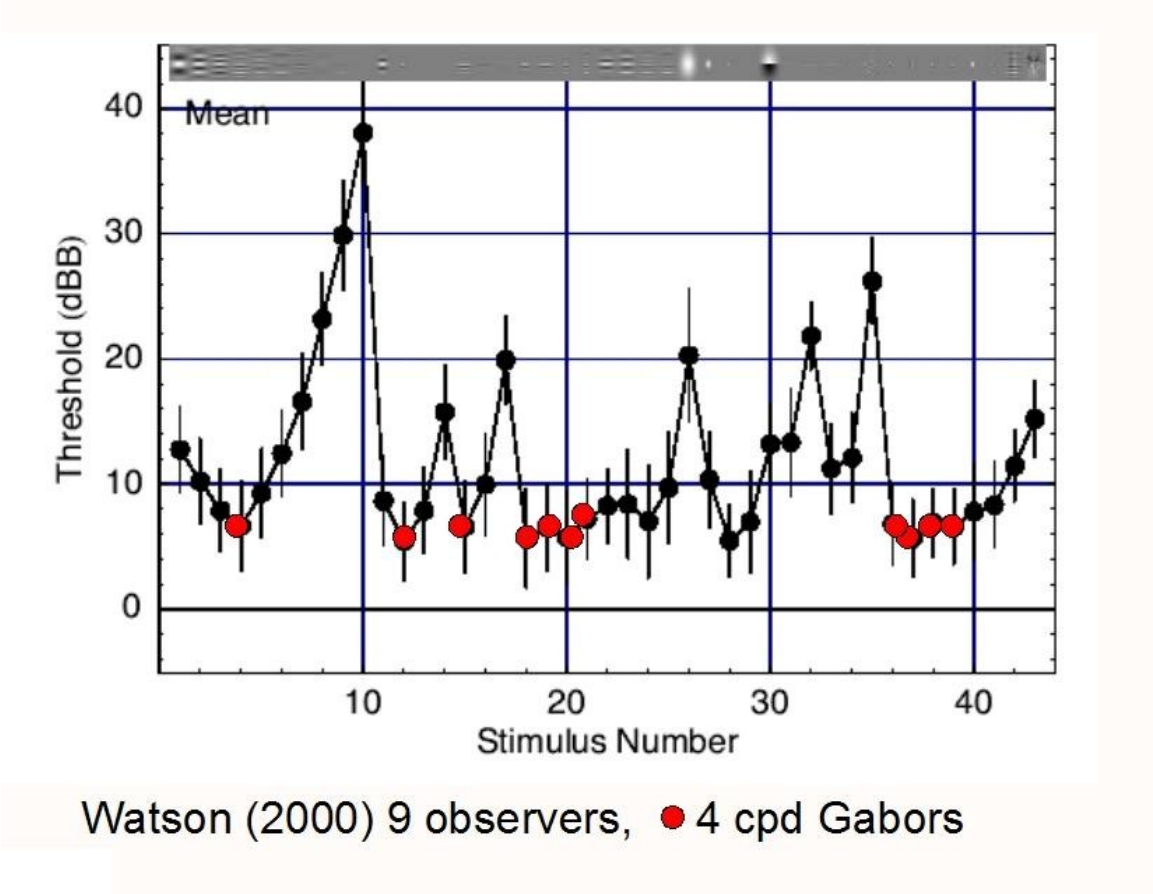

Figure 3

Figure 3 shows the contrast energy thresholds for the first nine Modelfest observers (Watson, 2000). A small horizontally compressed image is shown above each threshold. All the 4 cpd Gabor pattern thresholds are shown in red. However, the best pattern (though not significantly) is stimulus number 28, the second smallest Gaussian spot.

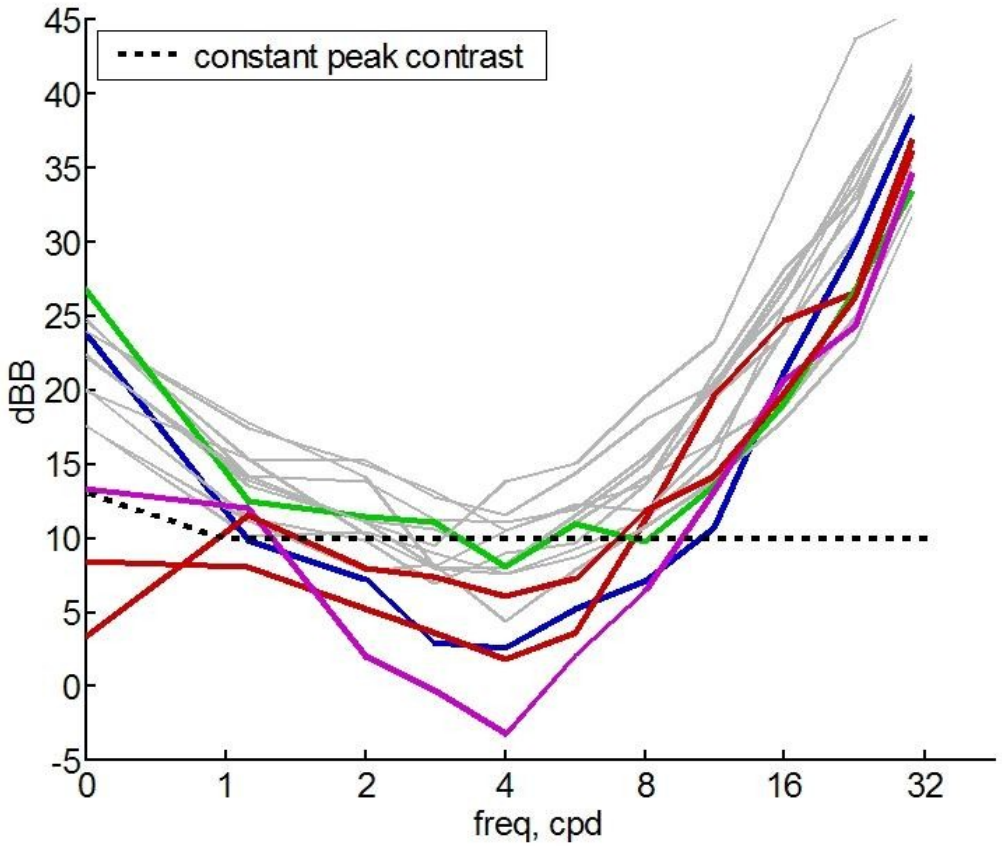

Figure 4.

Figure 4 shows the large size Gabor pattern contrast energy thresholds as a function of spatial frequency for all of the 16 current observers individually. The first anomaly I noticed in the data is the lowest threshold for the Gaussian blob on the left. At first I assumed it was some kind of recording error, but now I think it is most likely the result of an artifact of the method used to extend the dynamic range, in this case Morphonome (Tyler et al., 1992;). Note that the other red observer and the magenta observer are detecting the Gaussian blob at a lower peak amplitude than the 1.2 cpd Gabor. Also the blue and magenta observer curves appear to be stretched downward in the center more than the others. The blue observer is BRB from the Watson lab. There the dynamic range extension was done using the Pelli mixer, using a calibration method that assumed the DAC bit voltages were related by perfect powers of 2.

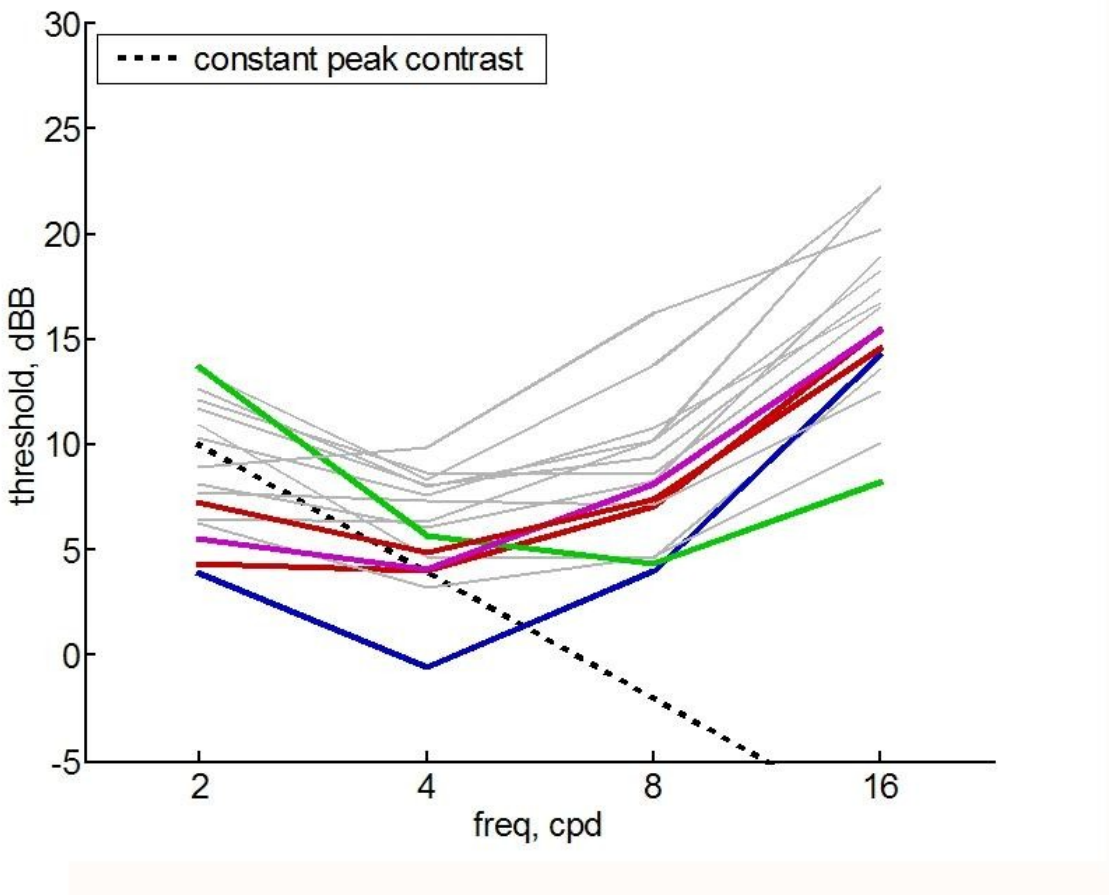

Figure 5.

Figure 5 shows the same observer thresholds for the constant bandwidth Gabor patterns as a function of spatial frequency. Again the red, magenta, and blue data appear to be anomalous. The green observer is also atypical, but just because she appears to have a higher spatial frequency response than the others.

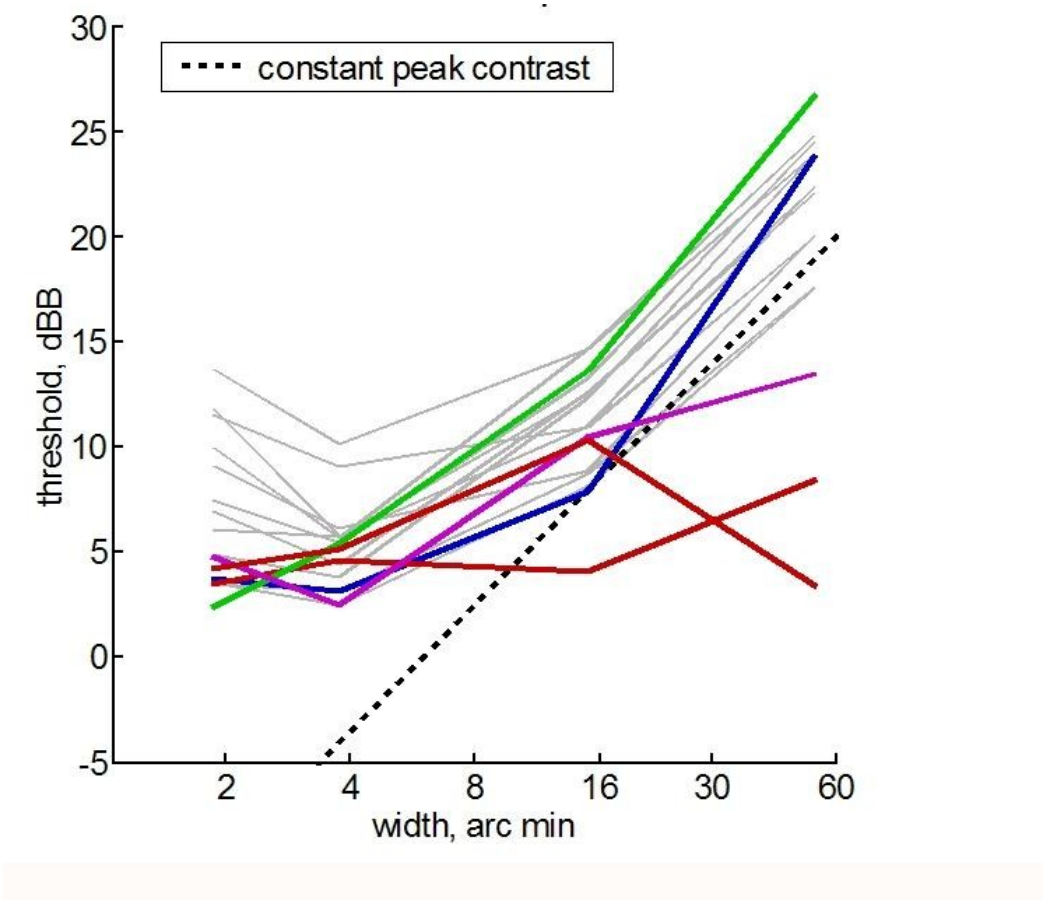

Figure 6.

Figure 6 shows the contrast thresholds for the Gaussian blob stimuli as a function of the width of the blob. The green observer and the two red observers have their best threshold for the smallest spot, but everyone else is best at the 4 arc min width. The green observer result is consistent with the Figure 5 result. The red, magenta, and blue results appear to be distorted.

These graphs suggest that the detailed shape of the CSF estimated for the standard observer (Watson and Ahumada, 200) should be taken with a grain of salt. Also, since no spatial calibration of the displays was provided, the high frequency cutoff of the observers is surely underestimated, especially the green observer. Watson and Ahumada (2008) had to raise the cutoff by a factor of 2 in order to predict acuity data for various aberrations.

Experiments

The line (number 31) is not among the best. A Gaussian blob can be thought of as a short blurred line. Our first experiments were done to see whether shorter, fatter lines might not have even lower contrast energy thresholds.

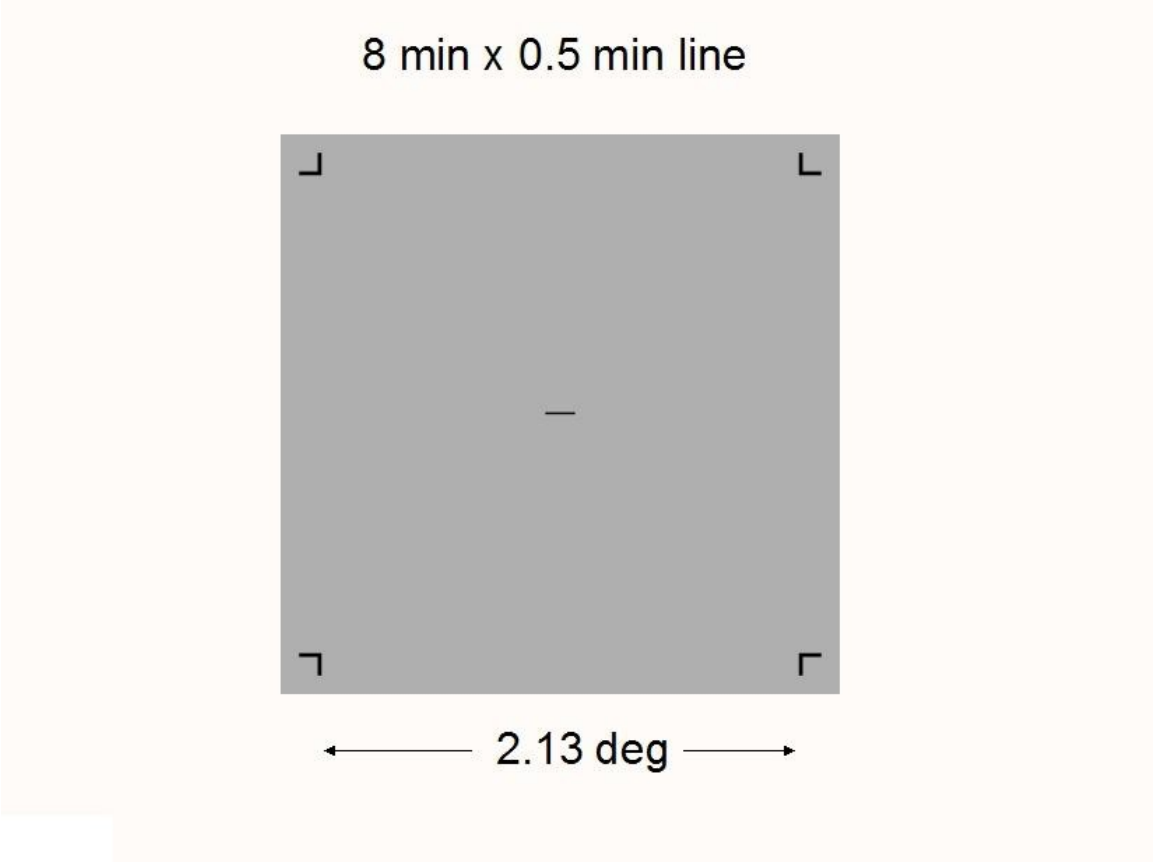

Figure 7.

Figure 7 shows an example stimulus pattern. The experiments were done using Modelfest-consistent methods. The long distance from the corner markers to the stimuli suggested that small stimuli might have their contrast thresholds reduced by spatial uncertainty (Cohn and Lasley, 1974).

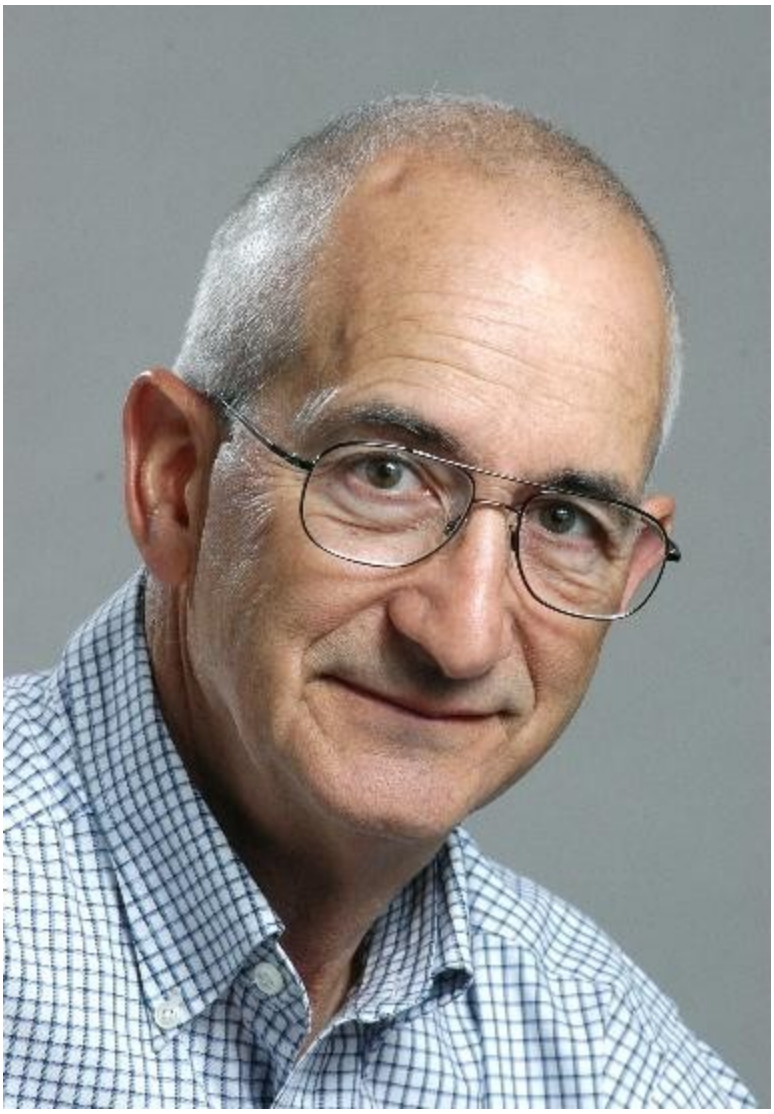

Figure 8. Ted Cohn, 1941-2006.

Line Length Experiment

Line lengths: 2, 6, 18, 54 arc min
Line width: 0.5 arc min
Fixation markers:
    Far image corners only (12 Ss);
    Far vs. near (and far) corner markers (1 Ss)
Trials blocked by stimulus (block order randomized)
2-interval forced-choice staircase method
Stimulus duration: 0.250 seconds
3-6 thresholds per stimulus (varied by participant)
Fixation corners constantly present

Line Stimuli

Near fixation markers condition

8 min x 0.5 min line

Line Width, Near and Far Markers

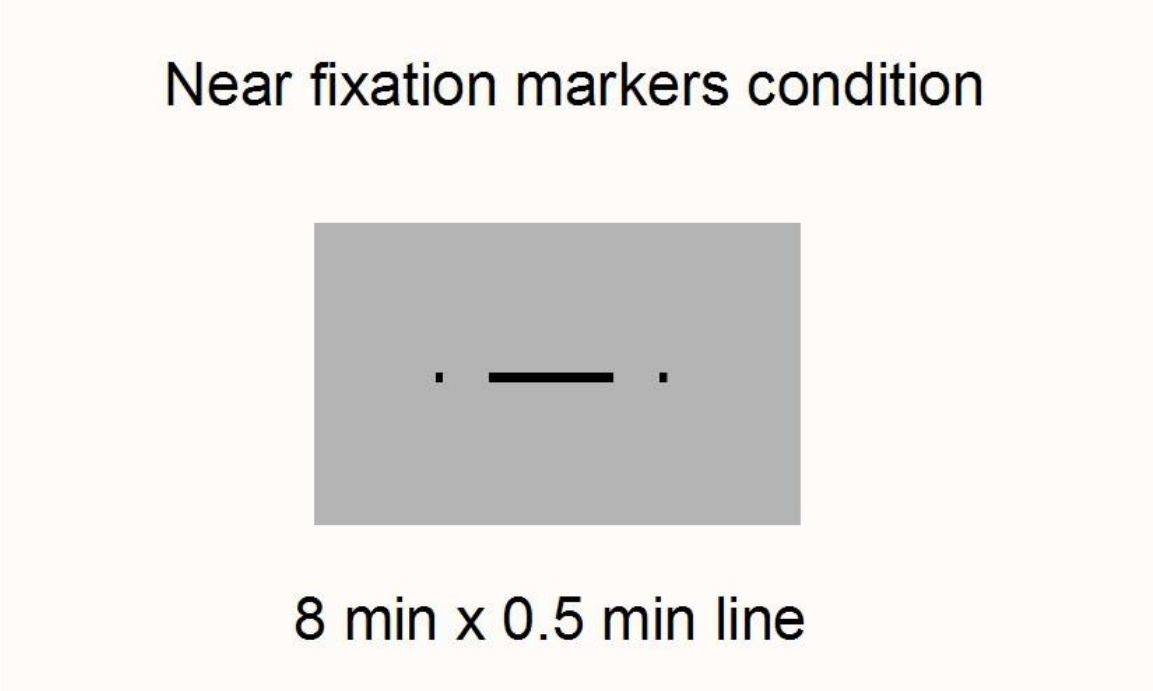

Figure 9.

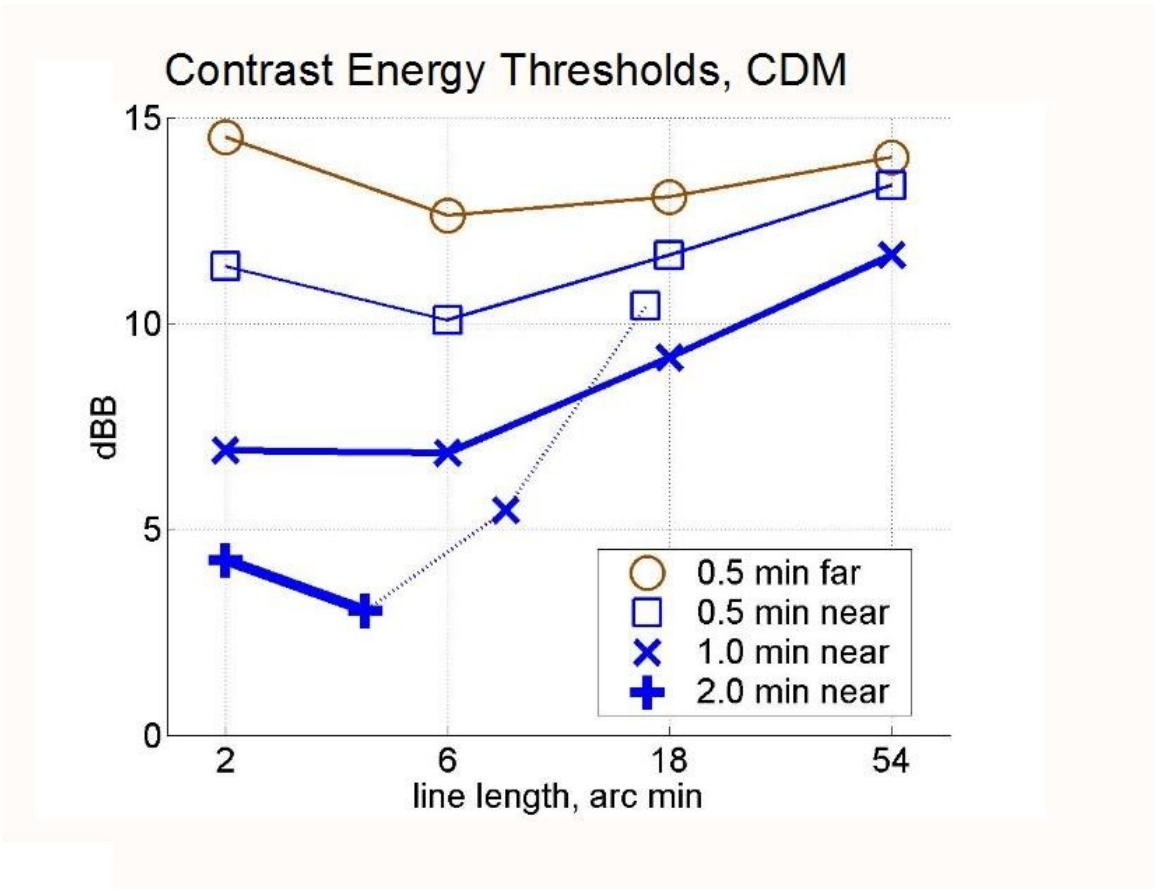

Figure 10.

Example spot image

Spot Thresholds (Raw)

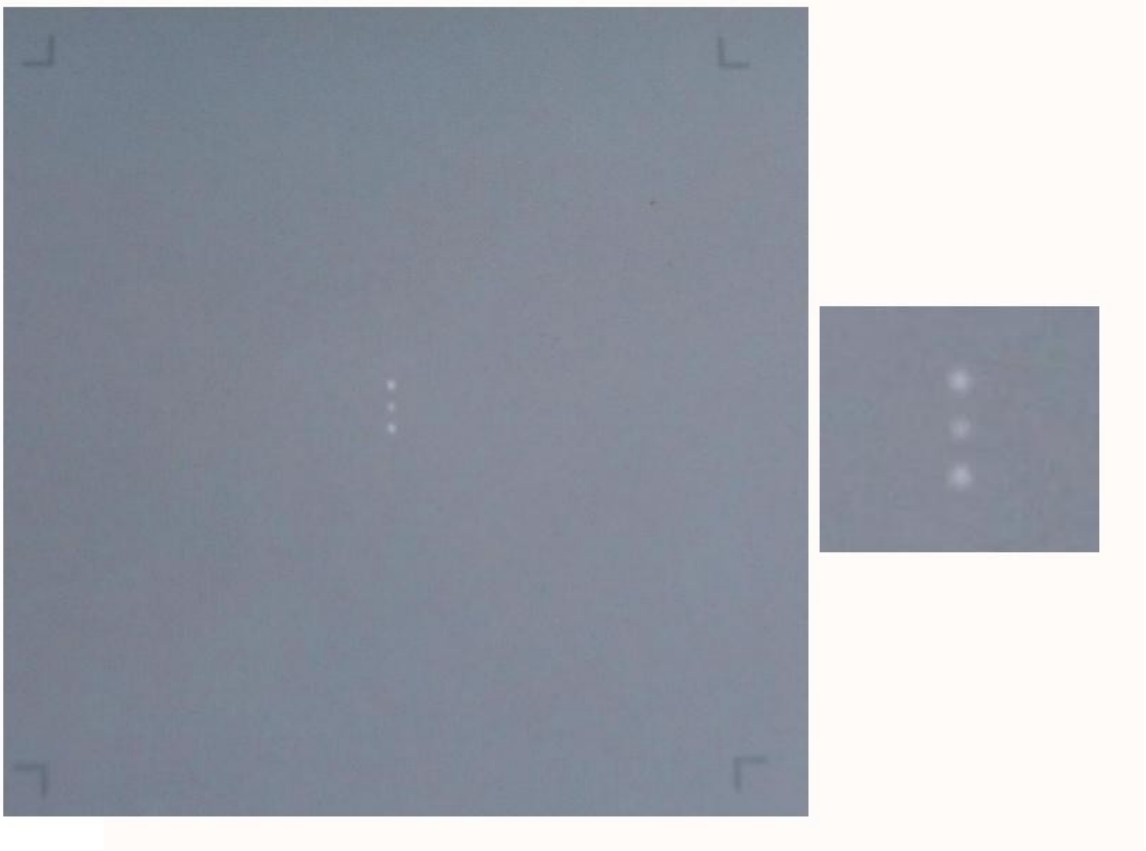

Figure 11.

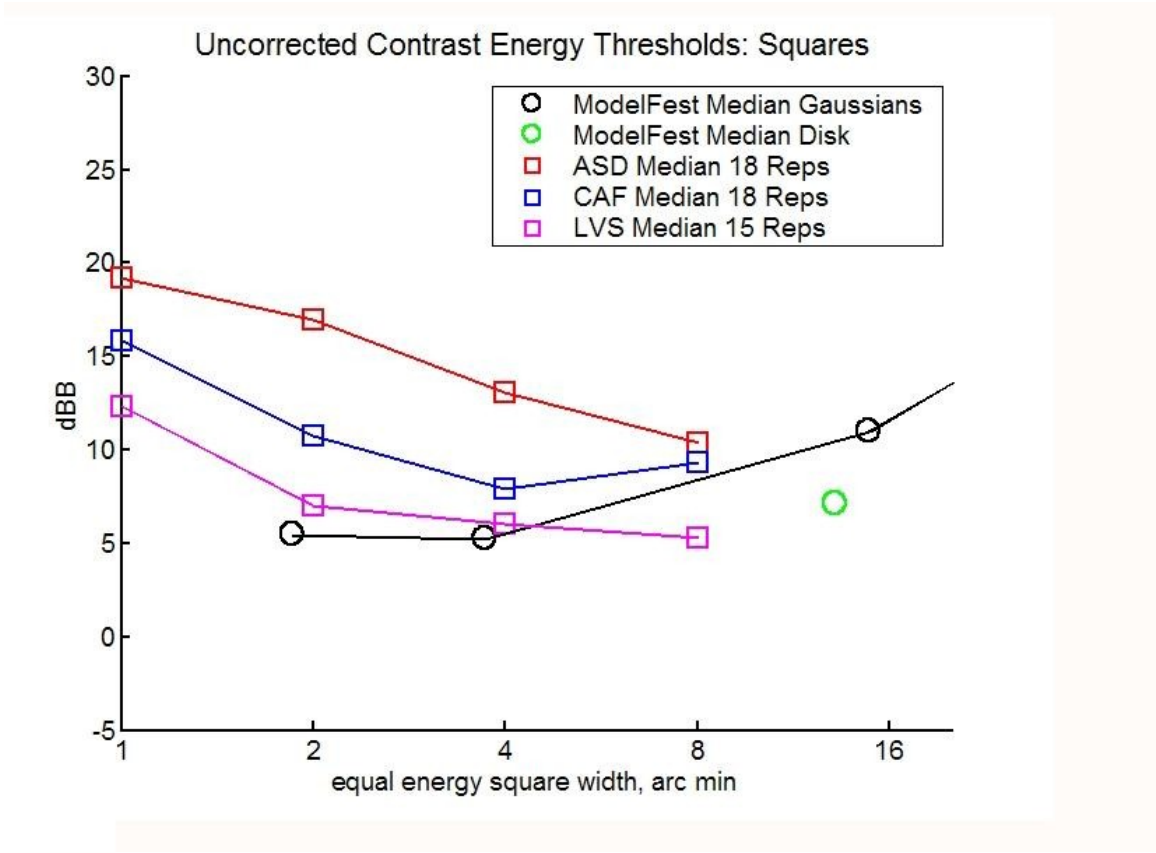
Uncorrected Contrast Energy Thresholds: Squares
ModelFest Median Gaussians
ModelFest Median Disk
ASD Median 18 Reps
CAF Median 18 Reps
LVS Median 15 Reps
dBB
30
25
20
15
10
5
0
-5
1
2
4
8
16
equal energy square width, arc min

Figure 12.

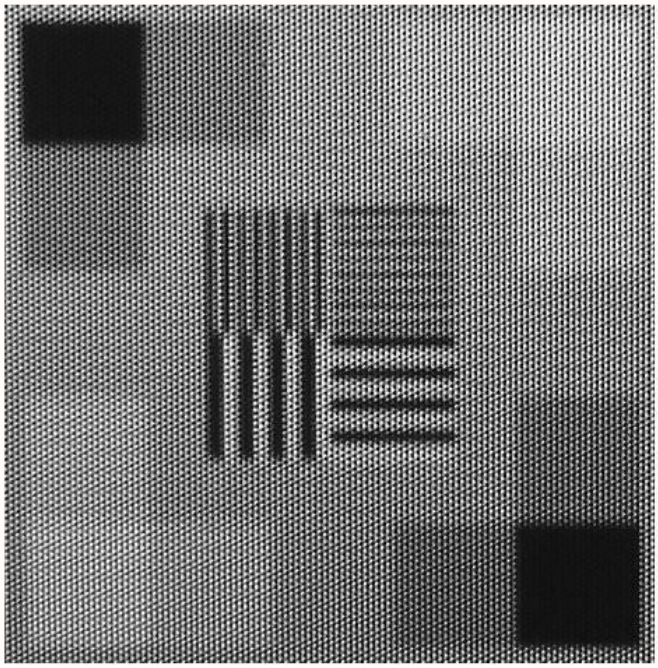

Figure 13.

Calibration Image

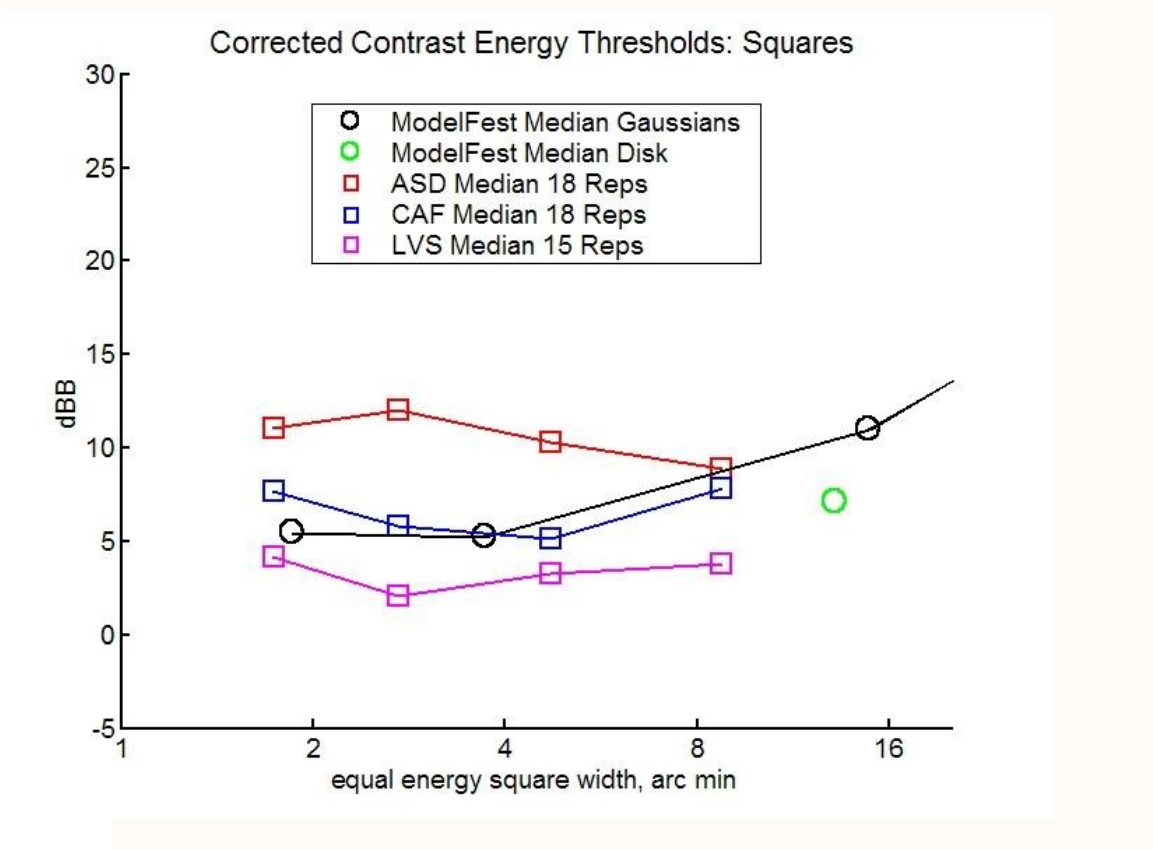

Figure 14.

Spot Thresholds

Conclusions

Modelfest

1) Data show contamination from attempts to extend dynamic range (possibly minimal in median data).
2) High spatial frequency responses must have been affected by that of the monitors.
3) Trial-by-trial data would have allowed the estimation of psychometric slopes, which vary with uncertainty.
4) It would have been nice to know the ages of the observers.

Incidental Surprises

1) Contrast energy is not a sensible measure for wideband stimuli without a high pass filter. For the same reasons that in audition dBSPL is usually limited to 20 KHz, dBB should be limited to something like 60 cpd.
2) Some Macs have an inverse gamma (0.66) inserted after the Digital-to-Analog converters.

Experimental Results

1) Spots and lines can be as visible as multi-cycle Gabor patterns of the same contrast energy.
2) Small pattern thresholds are affected by position uncertainty.
3) Which visual images are best detected may not be a sensitive indicator of underlying mechanisms.

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