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Updating the Standard Spatial Observer for contrast detection

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Summary

Watson and Ahumada (2005) constructed a Standard Spatial Observer (SSO) model for foveal luminance contrast signal detection based on the Modelfest data (Watson, 1999). Here we propose two changes to the model, dropping the oblique effect from the CSF and using the cone density data of Curcio *et al.* (1990) to estimate the variation of sensitivity with eccentricity. Dropping the complex images, and using medians to exclude outlier data points, the SSO model now accounts for essentially all the predictable variance in the data, with an RMS prediction error of only 0.67 dB.

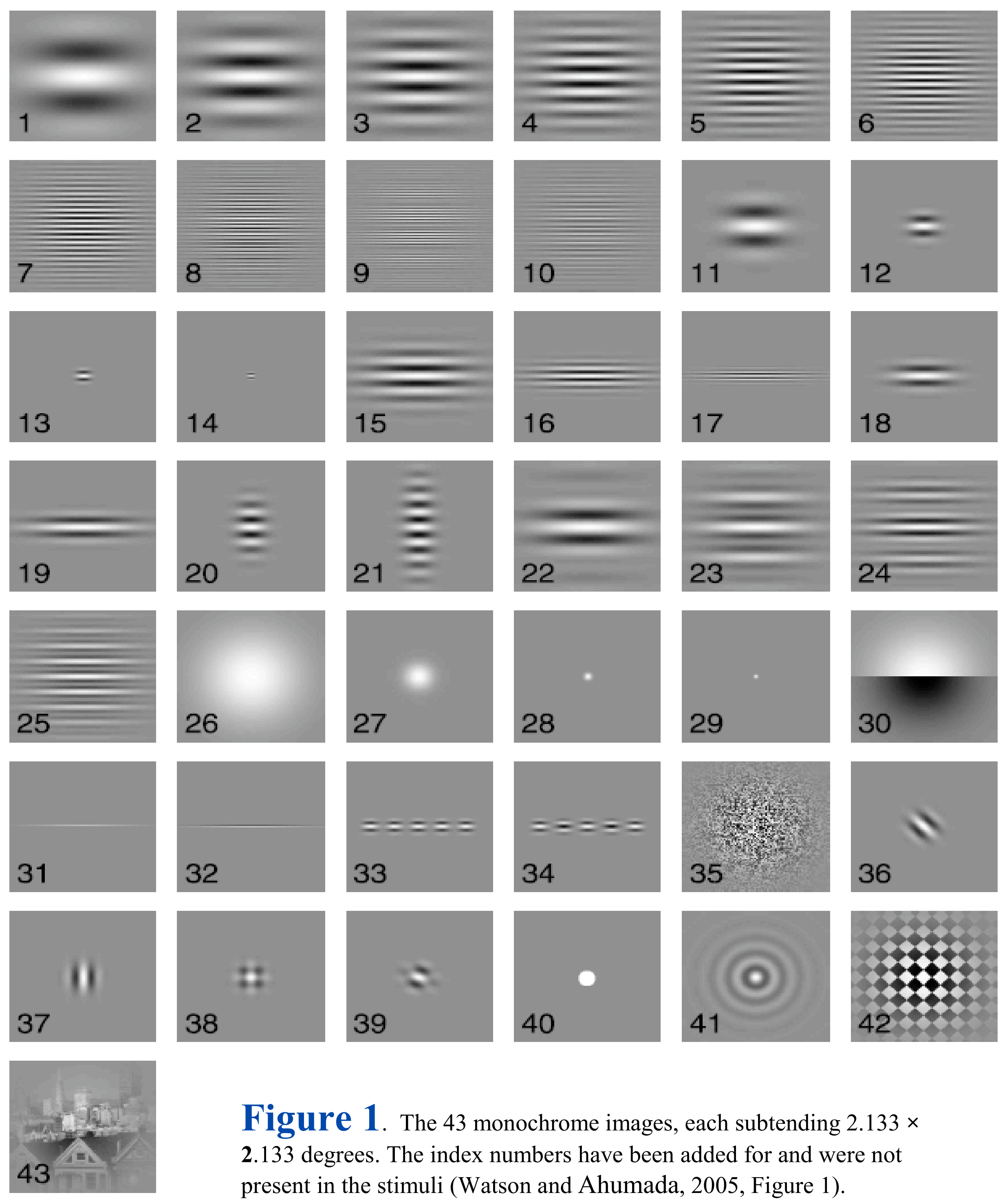

Figure 1. The 43 monochrome images, each subtending 2.133 × 2.133 degrees. The index numbers have been added for and were not present in the stimuli (Watson and Ahumada, 2005, Figure 1).

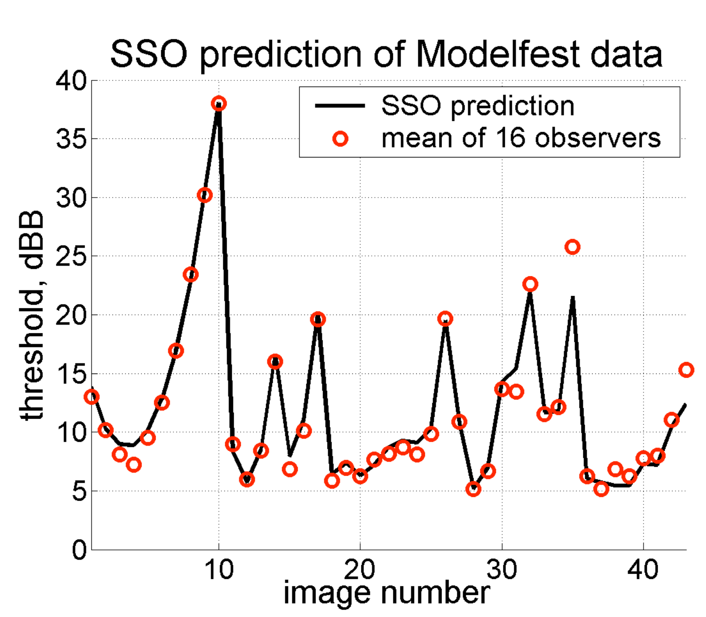

Figure 2. Average Modelfest observer thresholds (red circles) and best SSO model (black line). The vertical axis is in units of dBB, a logarithmic measure of the contrast energy of the stimulus, normalized by a nominal minimum threshold of 10^{-6} deg^2 sec (Watson, 2000; Watson *et al*., 1997). Note the poor fit for images 35 and 43.

Introduction

The ModelFest data (Watson, 1999) were used by Watson and Ahumada (2005) to construct a Standard Spatial Observer (SSO) model for small target contrast detection. Figure 1 shows the images and Figure 2 shows the fit of the model. Their SSO model has three steps:
(1) filtering by a contrast sensitivity function (CSF) including an oblique effect;
(2) windowing by a spatial Gaussian, representing the higher sensitivity of the central fovea;
(3) summation over space with an exponent.

Table 1 shows the best fitting parameters for four of the CSFs they tried. The best fit they obtained was an RMS error of 1.13 dB (taking into account the number of parameters estimated). They also tested individual components of the model. Both the oblique effect and the spatial sensitivity window were shown to contribute significantly. The standard error of the observer means based on the observer × image interaction error was 0.60 dB, indicating that significant improvement in the model was still possible.

	CSF parameters							
	fit, dB	fc, cpd	p	fs, cpd	a	σ, deg	β	gain
HPmH	1.13	4.17	0.78	1.36	0.85	0.63	2.41	372
	1.21	4.35	0.79	1.45	0.85	0.37	2	500
HPmG	1.14	5.35	0.86	1.98	0.80	0.63	2.41	280
	1.23	6.07	0.92	1.95	0.79	0.37	2	360
	1.16	7.52		1.9	0.82	0.71	2.47	360
DoG	1.27	7.64		1.98	0.82	0.36	2	504
	1.92	15.4		1.35	0.76	0.35	1.996	273
	1.90	15.4		1.34	0.76	0.34	2	272

Table 1

Parameter estimates and fits (normalized by the number of estimated parameters) to the means over 16 observers of the means of 4 thresholds for each observer over the 43 images. The CSFs are HPmH, the exponentiated hyperbolic secant minus a hyperbolic secant; HPmG, the exponentiated hyperbolic secant minus a Gaussian; EmG an exponential minus a Gaussian; and DoG, a Gaussian minus a Gaussian. The parameters: fc is the center frequency parameter, p is the exponent in the center response for the exponentiated hyperbolic secant, fs is the surround frequency parameter, a is the surround weight, σ is the standard deviation of the eccentricity sensitivity Gaussian window function, and β is the spatial summation exponent. The second line for each CSF has the summation exponent forced to 2.

Data Modifications

Most of the patterns in the Modelfest images can be exactly described with a small number of parameters. Two of them cannot, the noise sample (#35) and the San Francisco scene (#43). Performance for these two stimuli was worse than the SSO model predictions, by 4.2 and 2.9 dB respectively. Instead of contaminating the parameters we remove them and admit that the model cannot accurately predict the detectability of these high entropy stimuli (Watson *et al.*, 1997). Without them, with the same SSO parameters, the normalized RMS error dropped to 0.76 dB, much closer to the predictable error (now 0.61 dB).

We also decided to use the median over observers rather than the mean. Ahumada, Scharff, & Watson (2007) showed that there are serious outliers in the Modelfest data, suggesting that the median may be more accurate than the means. The original SSO parameters predict the median data with an RMS error of 0.74 dB. Re-estimating the parameters without the complex images lowers the fit of the mean data to 0.70 dB and the fit of the median data to 0.63 dB.

The Oblique Effect

Dropping the oblique effect and refitting the median data gives a not significantly worse fit of 0.65 dB. The two stimuli dropped have significant oblique energy, so perhaps the significance of the oblique effect before (Watson and Ahumada, 2005) was the primarily the result of these two stimuli. There are 6 symmetric stimuli (#26-29, 40-41). One might expect if they needed the oblique effect, their thresholds would be under-predicted with the oblique effect removed. They were, but only by a mean amount of 0.2 dB. Also, the two smallest Gaussians, with the most high frequency energy, should have shown the largest effect, but they had better performance than the model predicted. The updated SSO has no oblique effect, as illustrated in Figure 3.

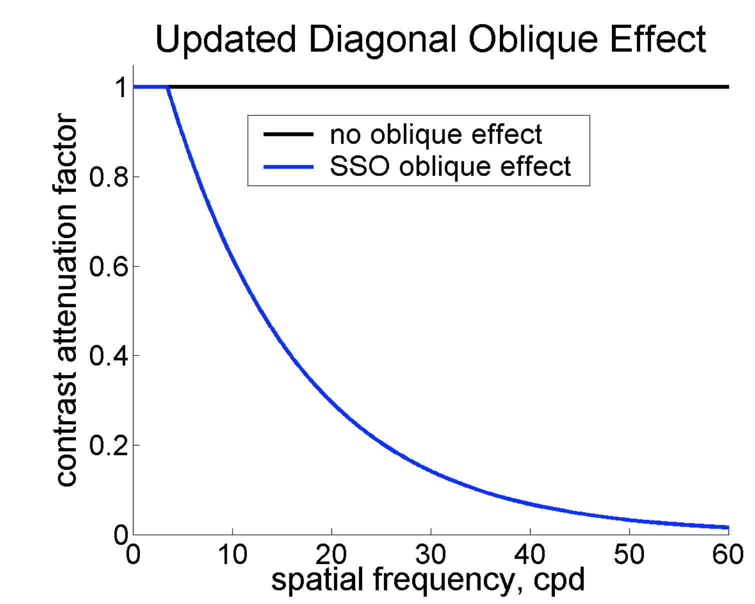

Figure 3. The blue line shows the amount of attenuation for diagonal orientations for the oblique effect used by the original SSO. The updated SSO uses no oblique effect as indicated by the black line.

The Eccentricity Sensitivity Window

The SSO used Gaussian window functions ranging in standard deviation from 0.35 to 0.72 deg, predicting negligible sensitivity in the parafovea. One way of predicting the variation with sensitivity is to assume that the internal noise is primarily contributed by the cones and that each cone contributes the same level of noise. The contrast sensitivity will then be proportional to the square root of the cone density or directly proportional to the estimated Nyquist frequency. We fit the human cone density measurements of Curcio, *et al.* (1990) with a function which is Gaussian at the center, but asymptotically becomes an exponential, using an exponential, $Bx = \exp(-x/xb)$), to blend from one to the other. The normalized Nyquist window function is

$$Nx = 1 / \{1+g\,[1-\exp(-[x / (xe+[xg-xe]\,Bx)]^{1+Bx})]\}.$$

asymptoting at

$$1/(1 + g), \text{ when } x >> xe.$$

The parameters found were $xg = 3.84$ deg, $xe = 5.72$ deg, $xb = 0.186$ deg, and $g = 4.09$. This windowing function has no parameters estimated from the Modelfest data, maintains peripheral sensitivity, and fits the Modelfest data as well as the Gaussian window (the RMS error increases only by 0.01 dB). Figure 4 shows this updated window along with the smallest and largest windows used by Watson and Ahumada (2005) and the intermediate window for the best-fitting CSF.

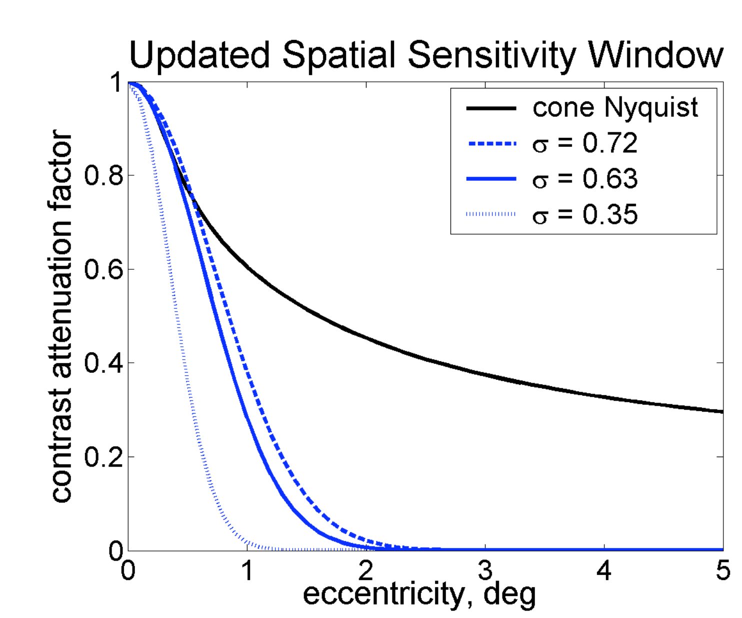

Figure 4. The black line shows the updated sensitivity window based on the cone density Nyquist frequency. Initially it closely follows the solid blue line, which is the window for the Watson and Ahumada (2005) best-fitting CSF. The dashed and dotted blue lines show the largest and smallest windows they fit to various CSFs.

Results

Table 2 shows the updated parameter estimates and normalized fits without the oblique effect and with the cone density based spatial sensitivity window. As compared with Table 1, the fits with variable summation exponents are much better, primarily because images 35 and 43 were dropped from the analysis. Forcing the summation exponent to 2 results in poorer fits than before because the spatial sensitive window could not compensate for the summation exponent change. The DoG CSF now behaves more like the others: the estimate for a is the same and the estimate for beta is also similar.

Without the oblique effect and with a spatial window that does not go to zero, this version of the Spatial Standard Observer model can account for most of the predictable variation in the 16 observer by 41 image ModelFest data.

	CSF parameters						
	fit, dB	fc, cpd	p	fs, cpd	a	β	gain
HPmH	0.67	5.27	0.86	1.09	0.86	2.54	265
	154	6.01	0.95	1.10	0.88	2	286
HPmG	0.71	5.92	0.91	1.68	0.83	2.55	236
	156	6.68	1.00	1.67	0.86	2	259
EmG	0.78	7.65		1.73	0.85	2.47	320
	1.65	6.68		1.67	0.86	2	259
DoG	1.69	15.4		1.14	0.83	2.44	181
	2.06	15.4		1.25	0.85	2	209

Table 2

Updated parameter estimates and normalized fits as in Table 1 for the medians over 16 observers of the medians of 4 thresholds for each observer of 41 images.

References

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Acknowledgments

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