Parafoveal Target Detectability
Predicted by Local Luminance and Contrast Gain Control

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Abstract

Observer performance for target detection was measured for four backgrounds in the fovea and in the parafovea (4 deg eccentric). Parameters were estimated for a single channel image discrimination model with local luminance adaptation and local contrast gain control. The estimates of the sizes of the pooling regions for local luminance and local contrast did not differ with eccentricity.

Introduction

This project is part of a program to develop image discrimination models for the prediction of the detectability of objects in a range of backgrounds. We wanted to see whether simple models could predict parafoveal object detection as well as they have predicted detection in foveal vision (Ahumada, Watson, and Rohaly (1995); Rohaly, Ahumada, and Watson (1995); Ahumada (1996); Ahumada and Beard (1996); Ahumada and Beard (1997a,d); Rohaly, Ahumada, and Watson (1997)).

In the earlier work, the single channel model used a contrast sensitivity filter after computing contrast based on the global image average luminance. Also the contrast gain was adjusted based on the global image root mean square (RMS) contrast. We wanted to make our simplified models more general by local computation of luminance and contrast gain control.

The Experiment

Methods

Stimuli. The target image shown in Figure 1 (0.78 x 0.17 deg) was made by subtracting the simulated airport runway scene background image (2.7 deg square) from the same scene containing an obstructing aircraft.

Procedure. Target visibility contrast thresholds were measured in a factorial design with two factors, eccentricity and background. The there were three viewing conditions, illustrated in Figure 2. In condition 0, the observers were asked to fixate the target location, centered between the marks at the side of the image (Figure 2a). In condition 4, the observers were asked to fixate the cross 4 deg above the target location (Figure 2b), and in condition 4M3, they were given the same instructions, but they were seated only one third as far from the screen (Figure 2c). The four backgrounds are shown in Figure 3. All contained the same fixed-pattern white noise sample with an RMS contrast of 20%. The four backgrounds will be referred to as: uniform (Figure 3a), box (Figure 3b), flanks in box (Figure 3c), and runway scene (Figure 3d).

Three experienced observers responded to 3 repetitions of 60 2IFC trials in each condition and 75% correct thresholds were estimated by maximum likelihood probit analysis.

Results Figure 4 shows the signal contrast energy thresholds for each of the subjects, each viewing condition and each background. The error bars are 95% confidence intervals for the observer's mean based on his/her pooled repetition variance. In each background, foveal viewing led to lower thresholds than eccentric viewing for the same size target, and magnification of the target led to even worse performance, except for two observers in the runway background condition. The magnification factor of three was chosen as the value which should approximately keep the contrast threshold constant in a uniform background for 4 deg. The contrast threshold is 10 $\log_{10} 9 = 9.5$ dB lower than the contrast energy condition for the magnified condition, so the expected difference was accurately reproduced by two of the three observers.

The Model

Algorithm

For both the background and the target plus background image, the following computations are performed.

Blur. The image I is convolved with a low pass Gaussian filter F_B,

$$B[x,y] = I[x,y] * F_B[x,y] .$$

Local luminance. The blurred image B is convolved with a low pass Gaussian filter F_L,

$$L[x,y] = B[x,y] * F_L[x,y] .$$

Temporal averaging. The local background luminance is averaged with the constant between-trial background luminance L_0,

$$L[x,y] = p\, L[x,y] + (1-p) L_0 .$$

Local contrast. The contrast image is computed from the local luminance,

$$C[x,y] = \frac{B[x,y] - L[x,y]}{L[x,y]} .$$

Local RMS contrast. Squared contrast image values are convolved with a Gaussian low pass filter F_E,

$$\bar{C}[x,y] = (C[x,y]^2) * F_E[x,y] .$$

Local contrast gain adjustment. The masked visible contrast image is computed using a standard divisive inhibition formula.

$$G[x,y] = \frac{C[x,y]}{(1 + (g_G \, \bar{C}[x,y])^2)^{0.5}} .$$

Summation of differences. The distance between the masked visibility images is based on a Minkowski metric with an exponent of 4, corresponding to probability summation over space.

$$d' = g_c \left(\sum_{x,y} (G_1[x,y] - G_2[x,y])^4\right)^{0.25} .$$

Parameter Estimation

Parameters for the model were estimated by least squares fit to the mean subject thresholds for each of the four backgrounds and three viewing conditions. Table 1 shows the parameter estimates.

Table 1 - Model Parameter Estimates

		0	4	deg
s_B	blur spread	0.6*	1.9	arc min
s_L	local luminance spread	9	10	arc min
p	adaptation speed weight	0.68	0.83	
s_C	local contrast spread	25	23	arc min
g_G	contrast gain gain	7	6	
g_c	contrast sensitivity gain	10.5	2.0	

* minimum from pixel size

The parameters that change with eccentricity, change in the expected direction. The initial blur is worse in the parfovea, the overall contrast sensitivity is lower there, and the adaptation is faster there. Less expected are the similarities in the luminance pooling areas, the contrast energy pooling areas, and the masking gain parameters. One might have expected the pooling areas to increase as the cone density decreases, for a constant number of cones in the pooling area. By maintaining constant values for these parameters, the system would increase the correlation between the signals resulting from images translating to different eccentricities.

Results

The predicted thresholds of the model for these parameters are plotted along with the data in Figure 3. For these parameters, the model could "pass" as another observer. It behaved similarly to at least one observer in every background. There is only one condition where the model predictions differ from the majority behavior. The model does not predict the poor performance of two of the three observers detecting the unmagnified target in the parafovea with the runway scene background.

Conclusions

A model with local contrast and local contrast energy masking is able to account for the variations of signal detection in a range of backgrounds in the fovea and parafovea. The parameters estimated from this data need to be checked on a wider range of targets and backgrounds. The parameters suggest that where possible, the system tries to keep the images translation invariant, rather than trying to keep them similar under "cortical magnification."