Spatial-Temporal Visible Contrast Energy Predictions of Detection Thresholds

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Ahumada and Watson (2013) used visible contrast energy to predict vision thresholds for visual images . For low contrast images, their local luminance based visible contrast image $v(x, y)$ can be computed from the contrast image $c(x, y)$ using an "optical" low pass filter $M_0(f_x, f_y)$ and an "inhibitory surround" low pass filter $M_1(f_x, f_y)$,

$$v(x, y) = FFT^{-1}(M_0(f_x, f_y)\ (1 - a\ M_1(f_x, f_y)\ )\ FFT(c(x, y)), \quad (1)$$

Barten (1994) added temporal low pass filters $H_0(f_t)$ and $H_1(f_t)$ to form a visible contrast "movie" $v(x, y, t)$ as

$$v(x, y, t) = FFT^{-1}(M_0(f_x, f_y)\ H_0(f_t)\ (1 - M_1(f_x, f_y)\ H_1(f_t))\ FFT(c(x, y, t)), \quad (2)$$

If $v(x, y, t)$ is masked by white noise, the detection performance of an ideal observer is a function only of the noise level and the signal energy, $Ev = \int\int\int v(x, y, z)^2\, dx\, dy\, dt = \|v(x, y, z)\|$. Letting $V(f_x, f_y, f_t)$=FFT(v(x, y, t), the final inverse need not be computed since $Ev = \|V(f_x, f_y, f_t)\| = \int\int\int |V(f_x, f_y, f_t)|^2\, df_x\, df_y\, df_t$ if the FFT is appropriately normalized.

$$Ev = \|M_0(f_x, f_y)\ H_0(f_t)\ (1 - M_1(f_x, f_y)\ H_1(f_t))\ C(f_x, f_y, f_t)\ \|, \quad (3)$$

where $C(f_x, f_y, f_t)$=FFT(c(x, y, t). When the image sequence is space-time separable, $C(f_x, f_y, f_t) = C_{XY}(f_x, f_y)\ C_T(f_t)$, and, dropping the f's for clarity,

$$Ev = \|(M_0\ C_{XY})\ (H_0\ C_T) - (M_0\ M_1\ C_{XY})\ (H_0\ H_1\ C_T)\|, \quad (4)$$

When $\|M_1\ C_{XY}\| << 1$,the inhibitory response is negligible, and

$$Ev = \|M_0\ C_{XY}\|\ \|H_0\ C_T\|. \quad (5)$$

Using Gaussian spatial filters $M=\exp(-(f_x^2 + f_y^2)/f^2)$and Gamma temporal filters, $H=1/(1+i2\pi\tau f_t)^n$, we predicted the contrast energy threshold data of Carney et al. (2013) for

$c_{XY}(x,y) = \exp(-(x^2 + y^2)/(2\ (0.5\ deg)^2) \cos(2\ \pi\ f_Y\ y)$, f_Y = 0, 4, 11.3;

$c_T(t) = c_0(t) = \exp(-t^2/(2\ (0.25\ sec)^2)$ and

$c_T(t) = c_0(t) \sin(2\ \pi\ f_T\ t)$, f_T = 1, 2, 4, 8, 15, 25 Hz.

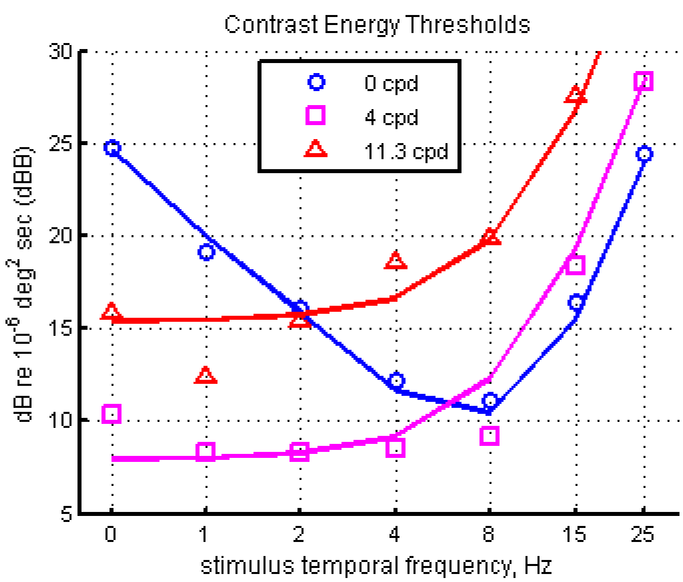

Figure 1. Data from Carney et al. (2013) [symbols] and model predictions [lines].

The model parameters were $[f_0, f_1]$ = [11.4, 0.88] cpd, $[\tau_0, \tau_1]$ = [12.5, 12.5] msec, $[n_0, n_1]$ = [3, 2]. The ideal observer noise spectral density estimate is 4.3 dBB. The RMS model fit is 1.6 dB with 20 - 6 df (n_1 was not allowed to vary). Additivity in log sensitivity is predicted to hold for f_Y = 4 and 11.3. The RMS error for 4 and 11.3 cpd additivity is 1.9 dB with 5 df.

References

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