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Why efficiency, unlike sensitivity, is highly conserved across eccentricity and size

Originally: Crowding area sets a lower bound on the neural noise that limits letter identification

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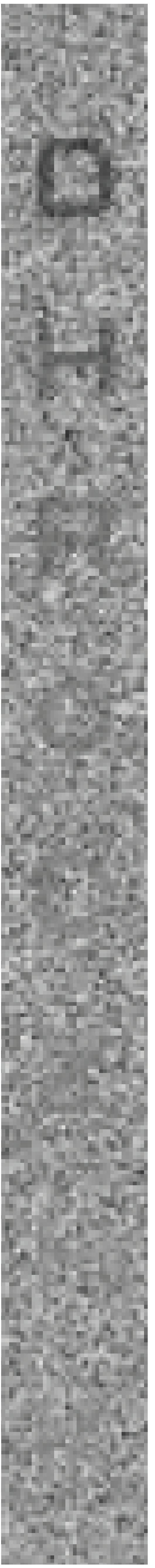
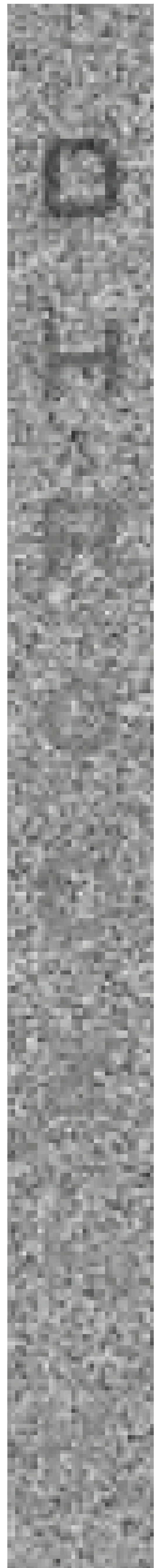




Letter idenditication in noise

Visual sensitivity is the reciprocal of threshold contrast. Contrast threshold for letters (and everything else) depends strongly on size and eccentricity. However, threshold on a white noise background depends only weakly on letter size and eccentricity. Here we decompose sensitivity into efficiency and equivalent input noise (Pelli and Farell, 1999).

Efficiency η is the fraction of the contrast energy used by the human observer that would be required by the optimal algorithm (ideal observer),

$$\eta = \frac{E_{ideal}}{E - E_0} \qquad (1)$$

where E and E_{ideal} are the human and ideal thresholds in noise N, and E_0 is human threshold in zero noise.

Equivalent input noise N_{eq} is the amount of display noise that would be required to account for the measured threshold *without noise*, assuming the efficiency measured at high noise.

$$N_{eq} = \frac{E_0}{E - E_0} N \qquad (2)$$

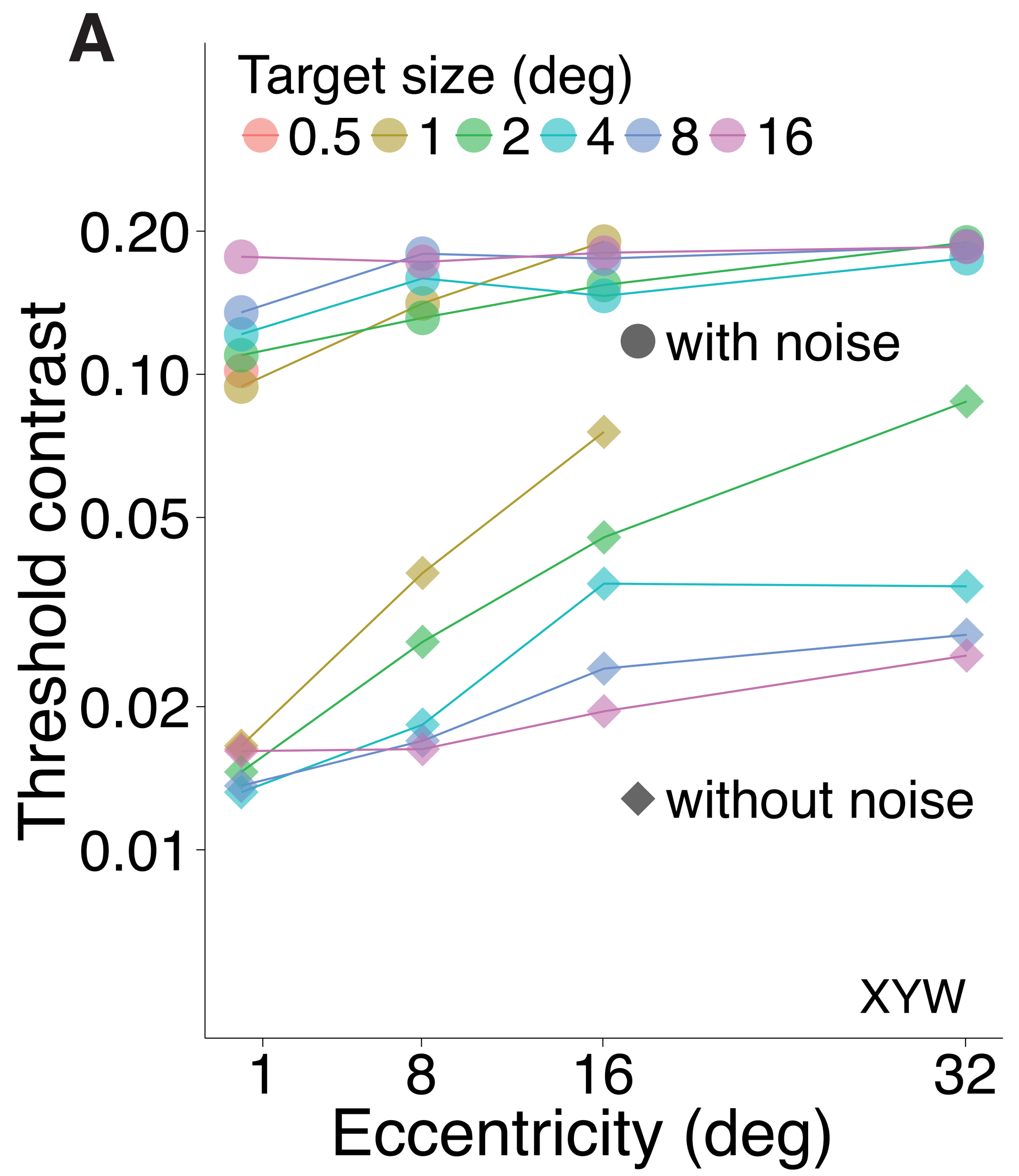
Efficiency is highly conserved: only weakly dependent on letter size and, surprisingly, eccentricity. This predicts, and we confirm, that, contrary to what one might expect from crowding, the integration area for a letter in noise is matched to the letter size, independent of eccentricity.

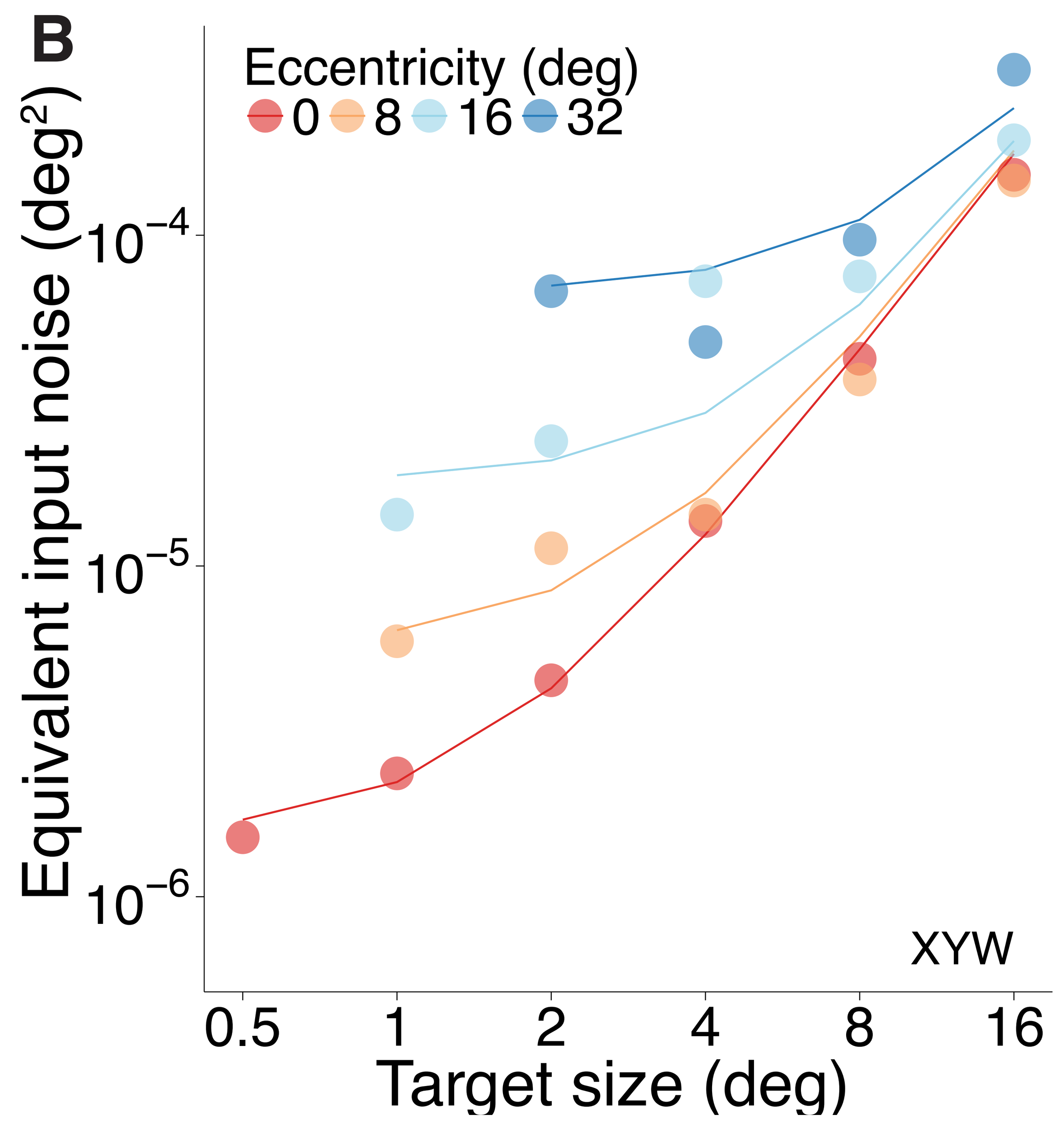
Equivalent input noise is the sum of two components, one dependent on letter size (and consistent with scale-invariant processing in the cortex) and another dependent on eccentricity (possibly reflecting ganglion cell noise).

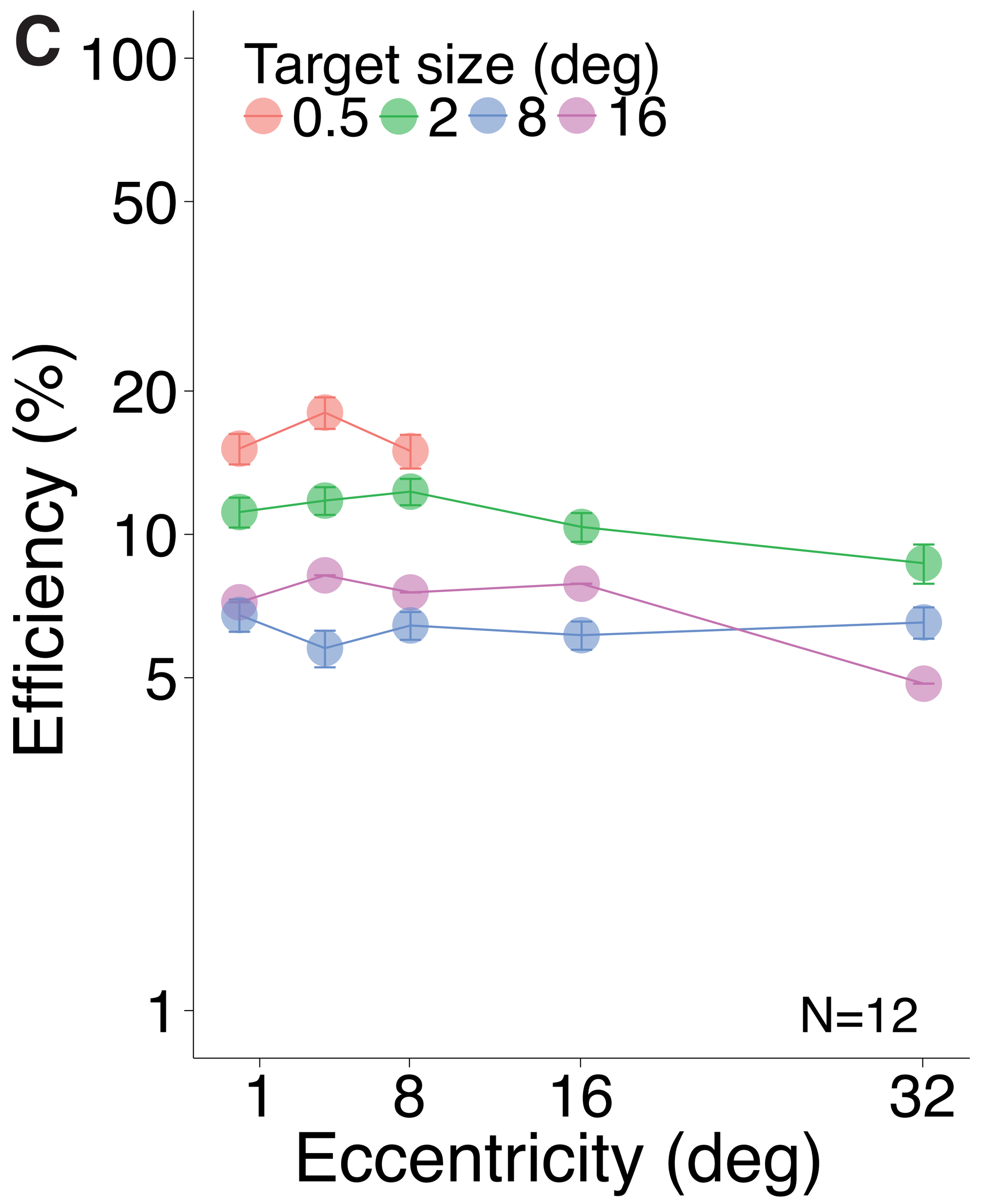
Methods

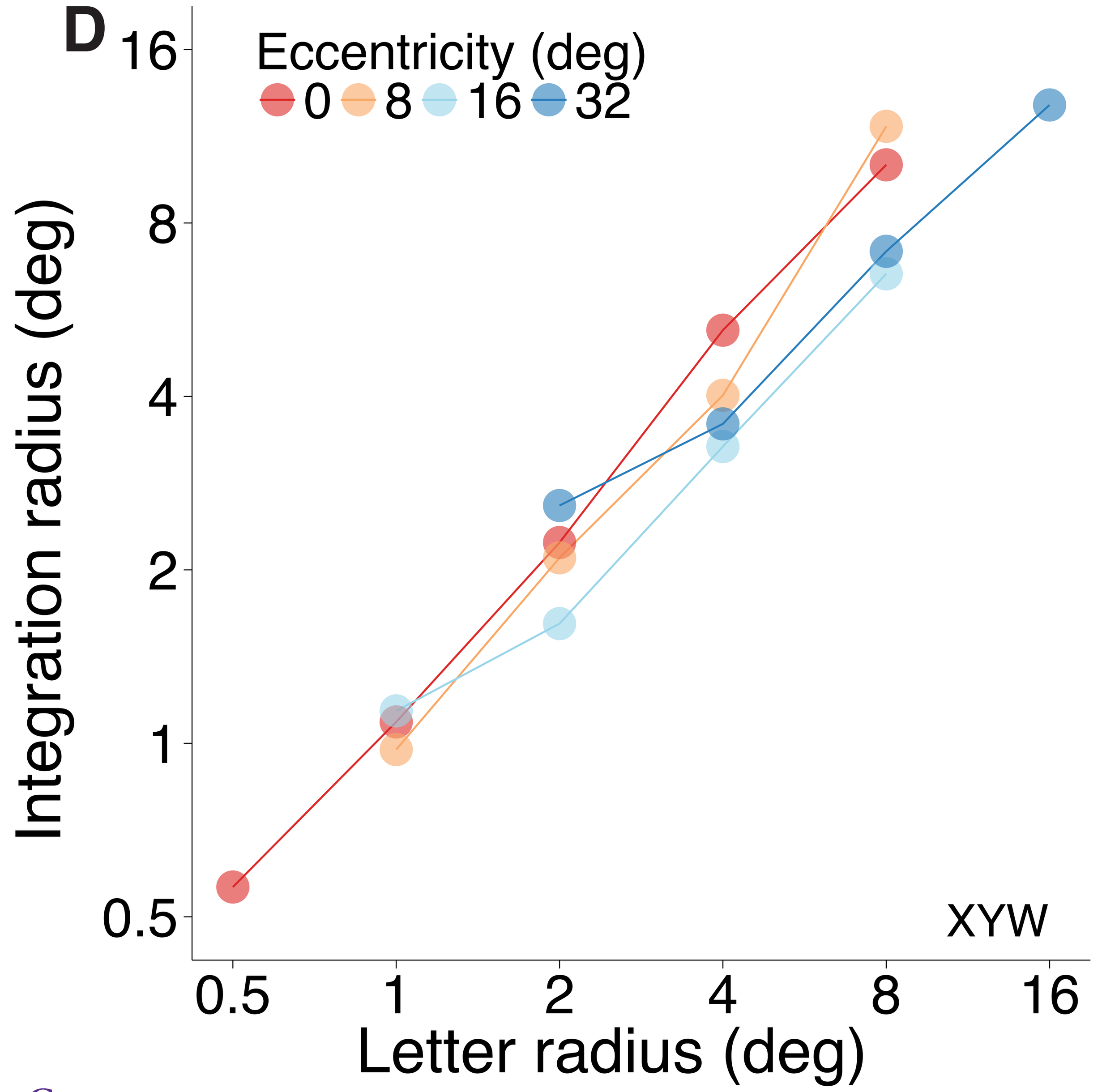
We presented letters **DHKNORSVZ** (in Sloan font) of *sizes 0.5°, 1°, 2°, 4°, 8°, 16°* and *32°* at *eccentricities 0°, 8°, 16°* and *32°* visual angles with and without visual noise. The noise was fullfield white noise whose check size was 1/20 of letter size.

We used a 10 bit per channel display to measure thresholds without noise.









$$N_{eq} = 2.7\times10^{-6}\left(H_{letter}^{\ 2} + 0.024\left(\varphi + 0.05\right)^2 + 0.56\right) \qquad (3)$$

Theory

N_{eq} proportional to signal area H^2.

Finding that efficiency depends only weakly on size is suggestive of scale-invariant computation. Pelli and Raghavan (2016) showed that supposing that the cortical computation, including noise, is scale invariant predicts that the equivalent input noise scales as well. Scaling an image of white noise by a factor of M horizontally and vertically will increase its power spectral density by a factor of M^2. This predicts that the equivalent input noise of any scale-invariant cortical computation will scale with letter area H^2. They reported that component in foveal measurements of equivalent input noise. We confirm that, and extend results to many *eccentricities*.

N_{eq} proportional to *eccentricity*^{2}.

We find a new component of equivalent input noise that is proportional to squared eccentricity. This might be ganglion cell noise, since the area occupied by a fixed number of ganglion cells increases as the square of eccentricity.

D. We tested identification performance by systematically controlling the noise radius in addition to eccentricity and target size. We softened the noise edge using a Gaussian envelope. We found that the radius of the noise integration region trackes letter radius, but not eccentricity. This indicates that the effect of noise not only restricted to overlap masking, but extends beyond the edge, and is not effected by eccentricity.

Citation

Yiltiz, H. & Pelli, D. G. (2016) Crowding area sets a lower bound on the neural noise that limits letter identification. 16th Annual Meeting of the Vision Sciences Society (VSS 2016), May 13-18, 2016 in St. Pete Beach, Florida. https://psych.nyu.edu/pelli/posters.html • http://hyiltiz.com/en/publication/

Rerefences

1. Pelli, D. G. & Farell, B. (1999) Why use noise? Journal of the Optical Society of America A, 16, 647-653.
2. Pelli, D. G., and Raghavan, M. (2016) Photon and cortical noises limit what we see. Computational and Systems Neuroscience (Cosyne) 2016, February 25 - 28, 2016 in Salt Lake City.

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