A generalized cortical magnification rule predicts low-contrast letter recognition in the visual field

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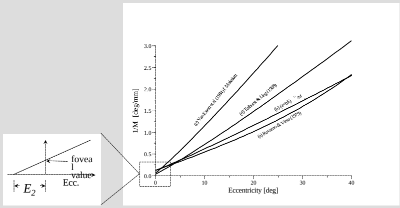
Introduction

Recognizing low-contrast patterns off the point of fixation is more difficult than what would be expected on the basis of retinal receptor density or size of projection onto the primary visual cortex (Strasburger et al. 1994). Nonetheless, estimates of the cortical magnification factor predict, reasonably well, across the visual field both recognition performance for single, high contrast letters and grating detection contrast sensitivity.

After a review of the *M*-scaling concept, a non-linear descriptive model is presented which predicts single-character recognition at arbitrary contrast across the visual field. The model is both simplified relative to the one presented previously, and extended, based on extensive additional data.

The model states a hyperbolic relationship between character size and log recognition contrast at threshold, the asymptotes of which depend linearly on retinal eccentricity. Solved for character size, it represents a generalization of *M* scaling which at high contrast is reduced to conventional *M* scaling. The prediction of percent correct recognition is by the psychometric function.

M scaling approaches



M scaling functions from a number of authors. By definition, only size is considered in the scaling.

(cortical) magnification:

$$M^{-1} = (1+aE)\cdot M_0^{-1}$$

or ...

$$M^{-1} = a(E+E_2)\cdot M_0^{-1}$$

... using Denis Levi's E_2.
Caution: E_2 alone does not predict slope!
(needs foveal value)

Other *M(E)*; less useful:

$$M^{-1} = (1+aE+bE^3)\cdot M_0^{-1}$$

$$M^{-1} = (1+aE)^{1.1}\cdot M_0^{-1}$$

$$M^{-1} = a + b\sin E$$

***M* scaling:**

$$S = (1+aE)\cdot S_0$$

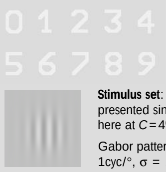
Equations from Strasburger (2002, Chpt. 4)

E_2 Values of Assorted Acuity Measures

Visual Function	*E_2 Value*	*Lit. Source*
Beard et al. (1997)		
Vernier acuity	0.8 ± 0.2	Beard et al.
Drasdo (1991)		
Grating acuity	2.6	Klein & Levi (1987)
Grating acuity	2.7	Virsu et al. (1987)
Landolt-C acuity	1.14	Virsu et al. (1987)
Landolt-C acuity	1.0	Weymouth (1958)
Vernier acuity	0.7	Levi et al. (1985)
Vernier acuity	0.64	Bourdon (1902)
Levi et al. (1985)		
M^{-1}	0.77	Dow et al. (1981)
M^{-1}	0.82	Van Essen et al. (1984)
Grating acuity	3.0	Levi et al. (1985)
Grating acuity	2.2	Levi et al. (1985)
Grating acuity	2.6	Levi et al. (1985)
Vernier acuity	0.77	Levi et al. (1985)
Vernier acuity	0.62	Levi et al. (1985)
Weymouth (1958)		
Grating acuity	≈ 2.5	Wertheim (1894)
Landolt-C acuity (students)	1.0	Weymouth
Landolt-C acuity (subj. K)	2.6	Weymouth
Landolt-C acuity (subj. M)	1.8	Weymouth
Virsu et al. (1987)		
Two-point hyperacuity	≈ Grating acuity	Virsu et al.
Two-point resolution	≈ Grating acuity	Virsu et al.
Snellen E acuity	≈ Grating acuity	Virsu et al.
Landolt-C acuity	factor of 2 difference to grating acuity	Virsu et al.
bisection hyperacuity	factor of 2 difference to grating acuity	Virsu et al.
Anstis (1974)		
Letter acuity	2.3	Anstis

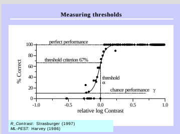
(Anstis reports y = 0.031 + 0.046 E. The E_2 results with an estimated foveal value of 0.1°)

Methods

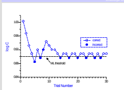


Stimulus set: digits, presented singly, here at $C=4\%$;

Gabor patterns 1cyc/°, σ = 1.5°



Terms



A typical run

Contrast thresholds for the *recognition* of characters and discrimination of Gabor patterns were obtained by a maximum-likelihood adaptive procedure (R_Contrast, Strasburger 1997, Harvey 1997) as the point of inflection on a Weibull function.
Binocular viewing, 100 ms presentation time, backgd. lum. $L_b \approx 60$ cd/m^{-1};
$C = (L_p - L_b)/(L_p + L_b)$; contrast threshold confidence interval 0.13 log units
Each threshold two runs of ≈ 30 trials.
Size/contrast trade-off at varying eccentricity: 6 sjs; 55,000 responses.
Constant size at all meridians: 17 subjects; 160,000 responses.
Psychometric function at all eccentricities: 2 sjs; 24,000 responses.

References

Harvey L O Jr (1997). Efficient estimation of sensory thresholds with *ML-PEST*. *Spatial Vision 11*(1), 121-128.
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Strasburger H (2001). Invariance of the psychometric function for letter recognition across the visual field. *Perception & Psychophysics 63*, 1356-1376.
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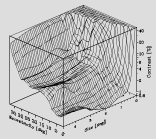
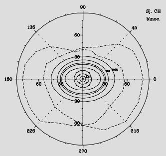
Strasburger H, Rentschler I & Harvey L O Jr (1994). Cortical magnification theory fails to predict visual recognition. *European Journal of Neuroscience 6*, 1583-1588.
Strasburger H (2002). *Indirektes Sehen. Formerkennung im zentralen und peripheren Gesichtsfeld.* Hogrefe: Göttingen, Bern, Toronto, Seattle.

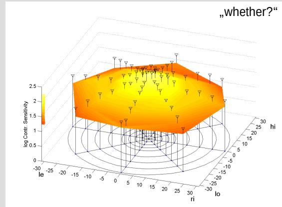
Data



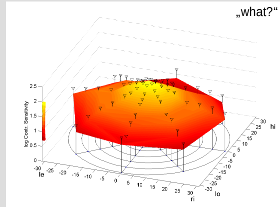
Size/contrast trade off
violation of M-scaling concept
(Strasburger et al. 1994)



Recognition vs. Detection
low-contrast recognition. at fovea only
(Strasburger & Rentschler 1996)



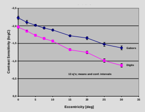
Gabor discrimination (constant size)
(1c/°, s = 1.5°) (Strasburger 2002)



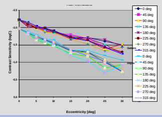
Character recognition (constant size)
(size 2.4°) (Strasburger 2002)

Constant large size, details. Characters: 2.4°, Gabors 1 c/°

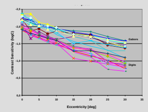
All meridians



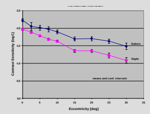
Half meridians



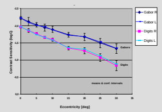
Subjects



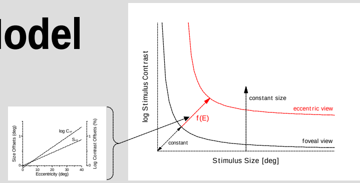
Hor. meridian



Right/left field



Model

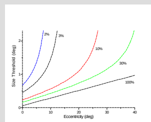


Size/contrast threshold trade-off at ecc. *E*

$$(\log C - \log C_{off})(S - S_{off}) = 0.25$$

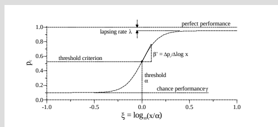
$$S_{off} = 0.022\,E$$

$$\log C_{off} = -2.07 + 0.0345\,E$$



Generalized size scaling

$$S = 0.022\,E + \frac{0.25}{\log C + 2.07 - 0.0345\,E}$$



Proportion of correct answers

$$P(c) = g + (1-g)(1+e^{-bx})^{-1} \quad \text{with} \quad x = \log_e(c/a)$$

$$b = 9.5 = const. \cong 4.8 \;\; \Delta p_c / \log_{10} c$$

α = C = contrast threshold

Conclusions

With the provided empirical parameters, based on ¼ million subject responses, the model predicts contrast and size thresholds for recognition, and the proportion of correct recognition, for singly presented characters of any contrast, of any size and at any position in the visual field.