Institute of Neuroinformatics
UNI/ETH Zurich

Biological and Computational Vision

Lecture 2

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www.ini.unizh.ch/~kiper/comp_vis/index.html

A section through the human retina

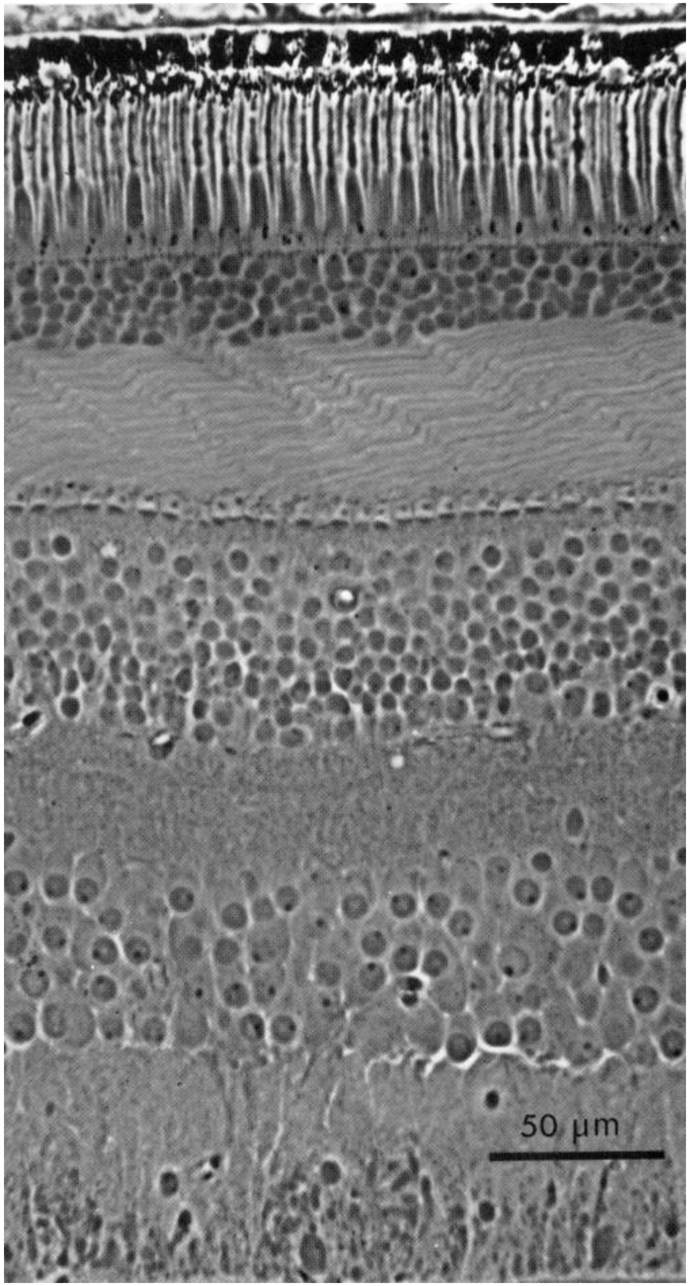
Receptors: rods and cones

Bipolar and Horizontal cells

Amacrine cells

Ganglion cells

Optic nerve

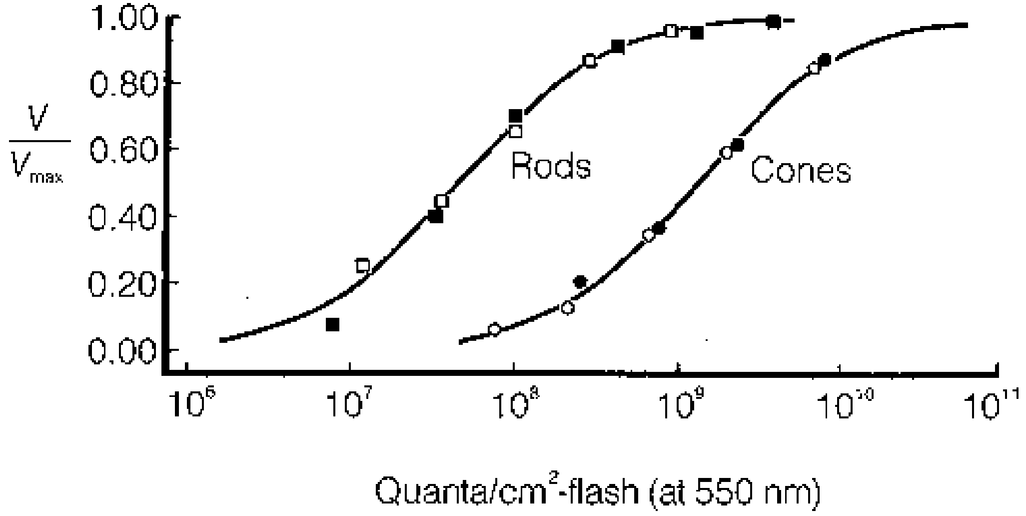


Dowling, 1987 (Fig 2.1)
Boycott and Dowling (1969)

Phototransduction in rods and cones

Rods: Vision in low light (e.g. night).

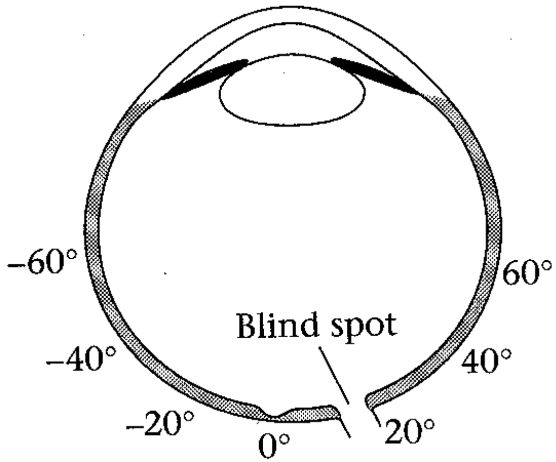
Cones: Vision in stronger light (e.g. day) .

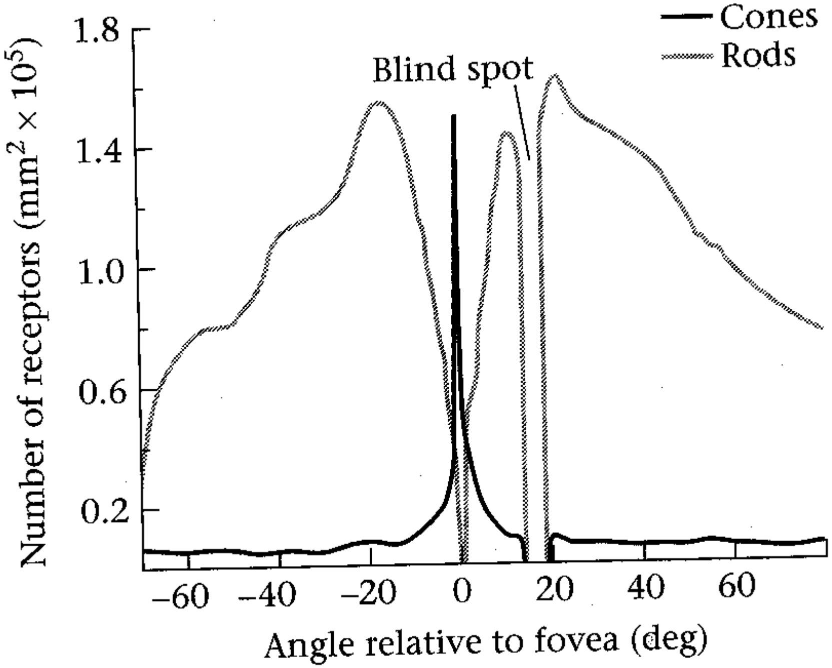


Dowling, 1987 (Fig 4.3b)

Distribution of rods and cones:

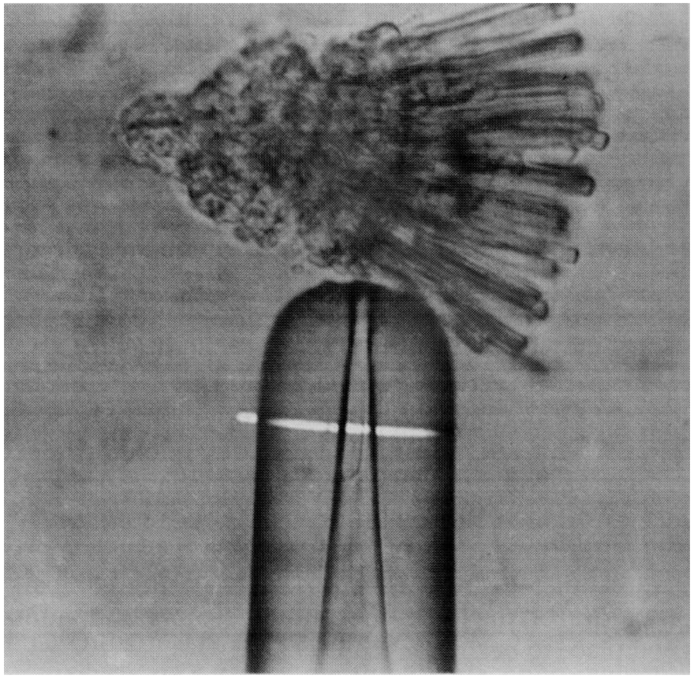
a view from the side

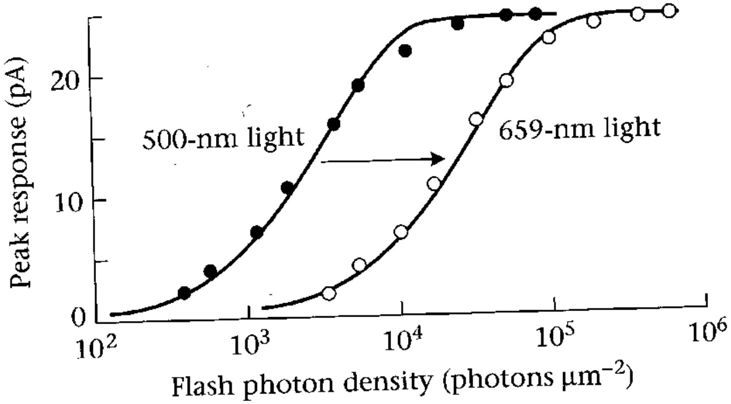




Wandell, 1995 (Fig 3.1)

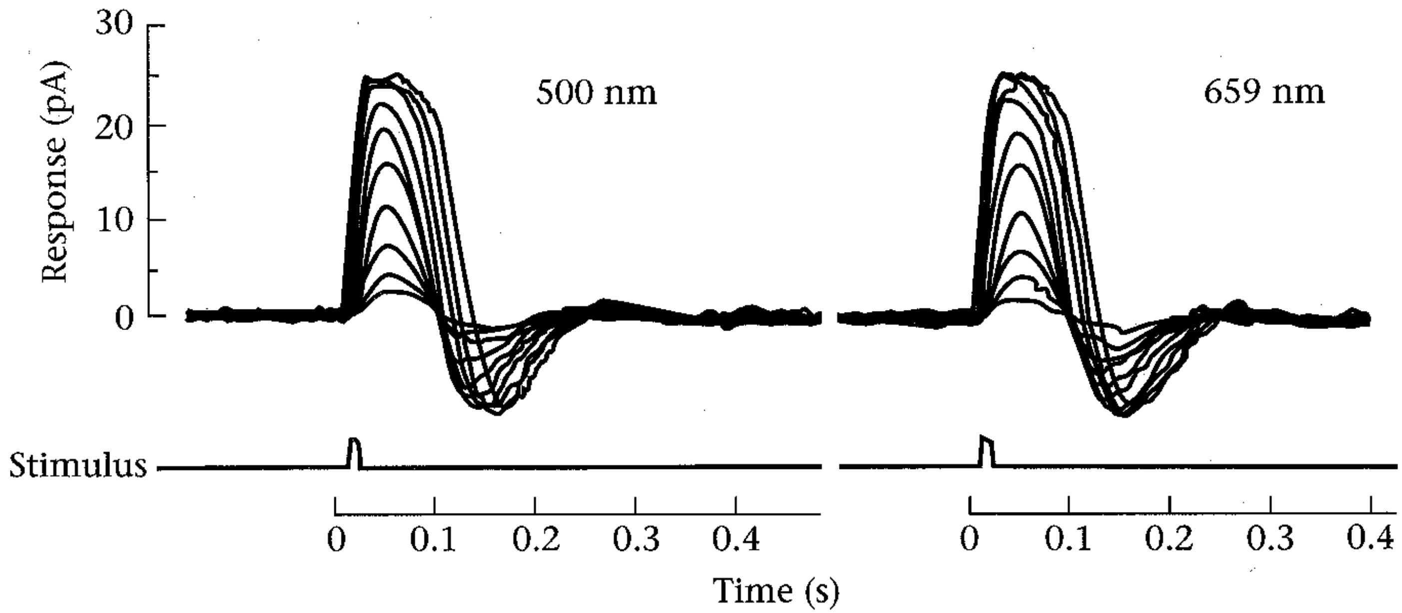
Response of a cone to light of two different wavelengths

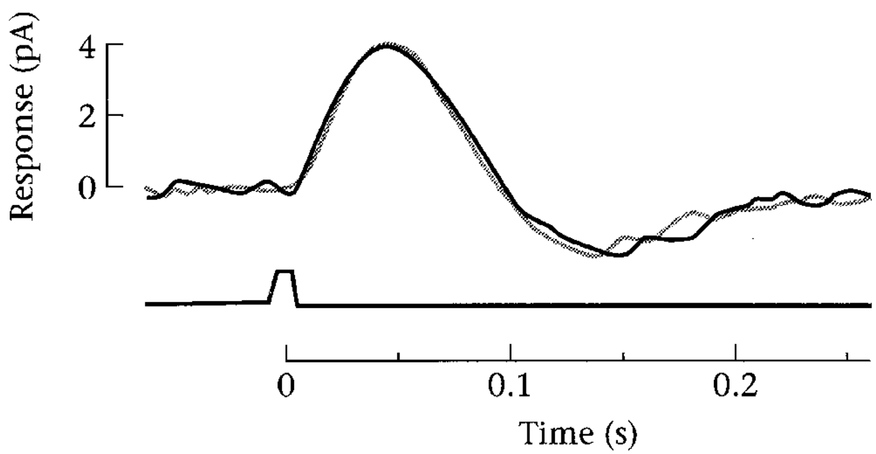




Wandell, 1995 (Figs 4.15-4.16)

Principle of univariance

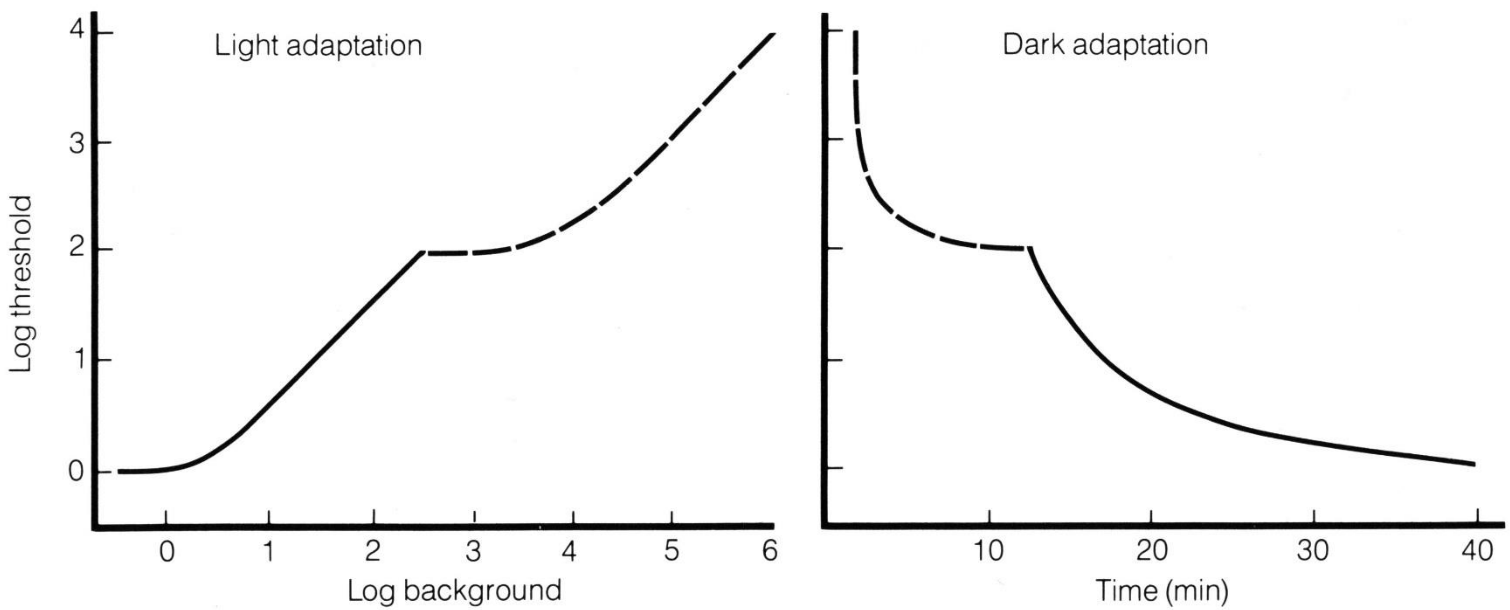




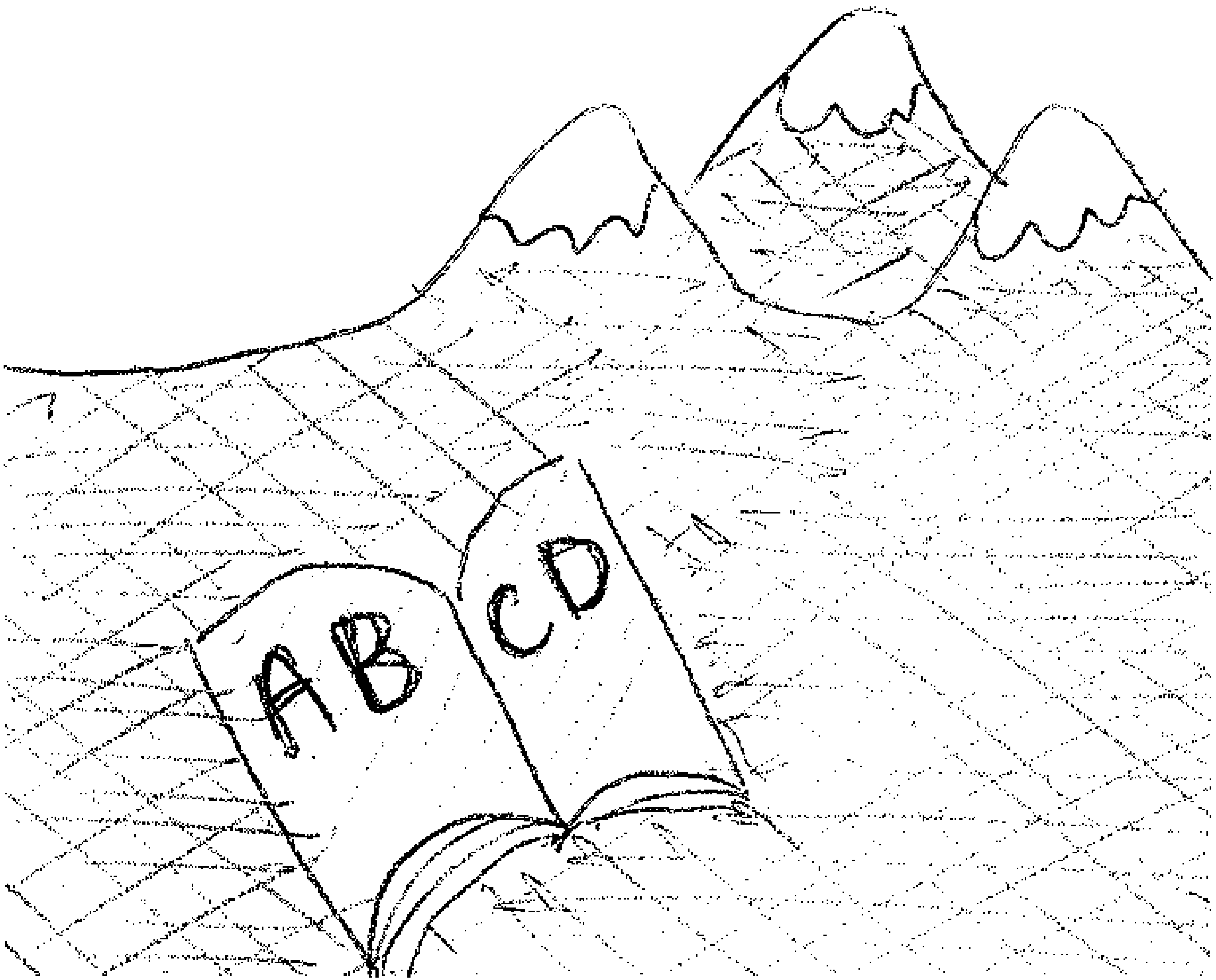
Wandell, 1995 (Figs 4.17-4.18)

Light adaptation

Human light and dark adaptation



The Jungfrau viewed from Wengen



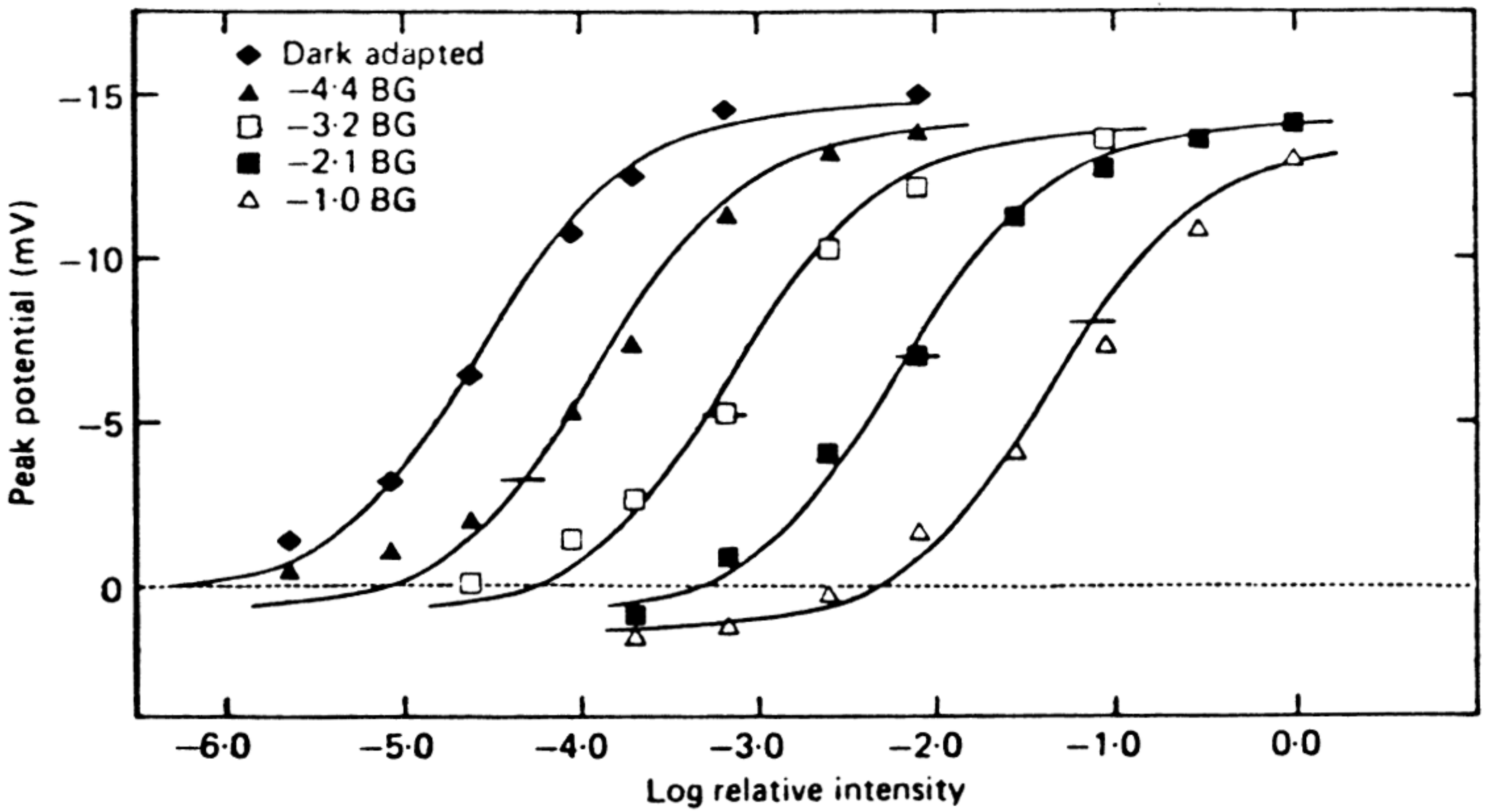
We care for surface reflectance, not light intensity. Contrast is proportional to reflectance.

	Reflectance	Intensity *I* at noon (1000000 W)	Intensity *I* at dusk (1000 W)	Local contrast *c* at noon (1000000 W)	Local contrast *c* at dusk (1000 W)
Snow	90%	900000 W	900W	1.25	1.25
Grass	40%	400000 W	400 W	0	0
Paper	80%	800000 W	800 W	1	1
Ink	10%	100000 W	100 W	-0.75	-0.75
Mean	40%	400000 W	400 W	0	0

*Intensity I is reflectance*illuminance.*

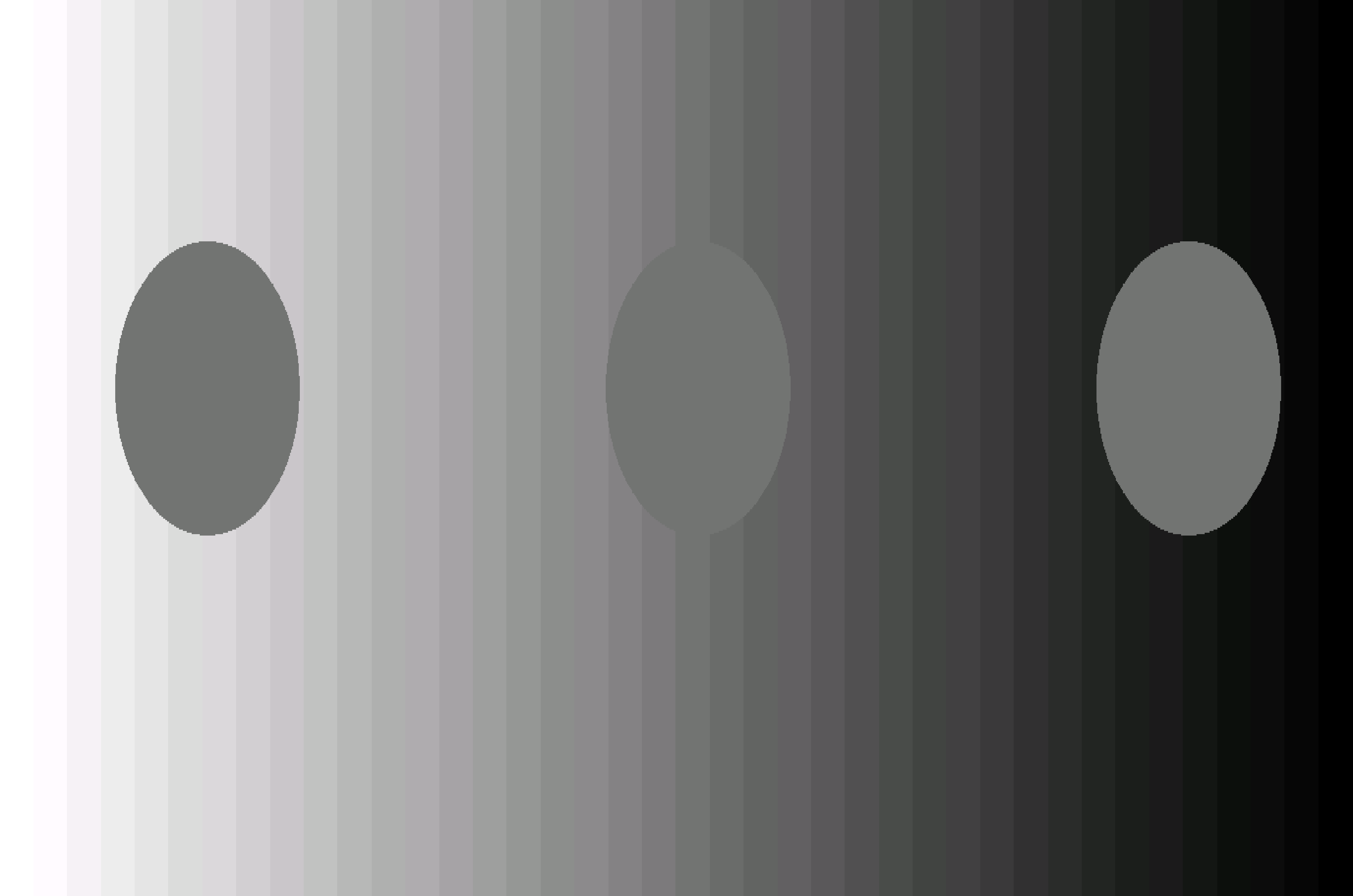
Local contrast is c = (I-Imean)/Imean.

Cone responses adapt to background illumination



Norman & Perlmann (1979)

Light adaptation is somewhat local in space



Ganglion cells

Basic retinal circuitry

Receptor terminals (**RT**)

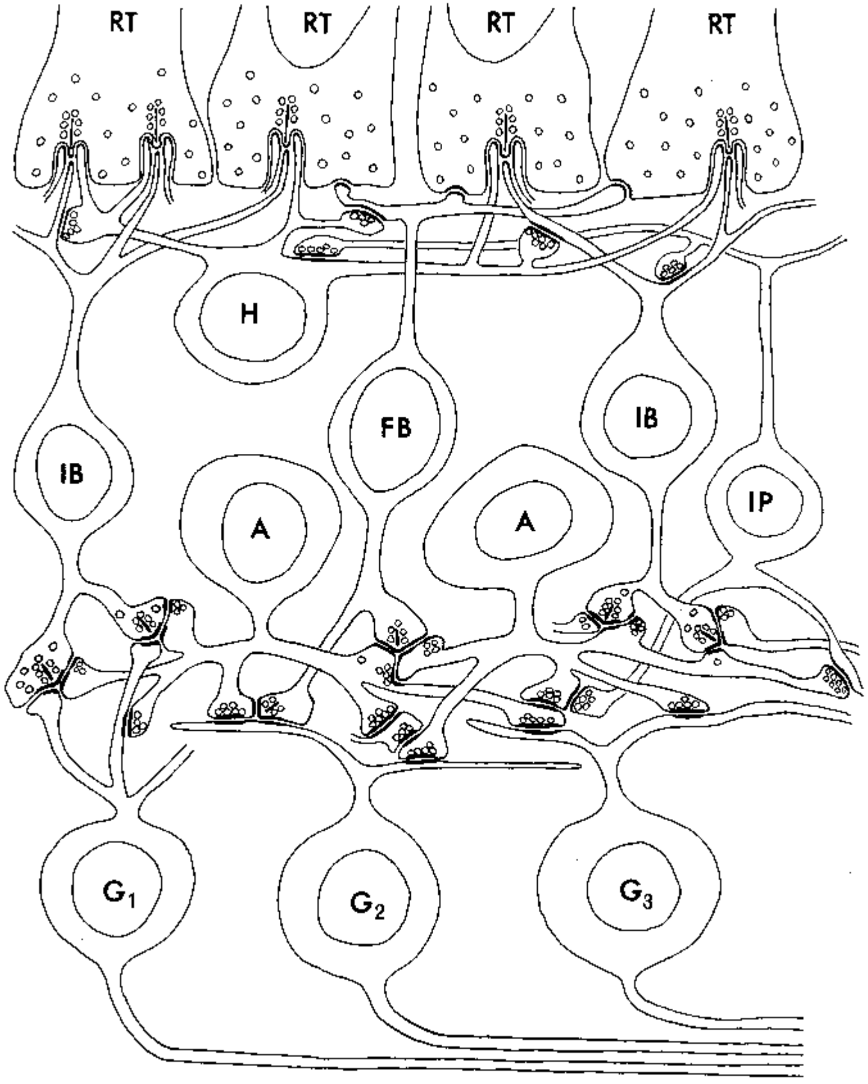
Horizontal cells (**H**)

Bipolar cells (**B**)

Amacrine cells (**A**)

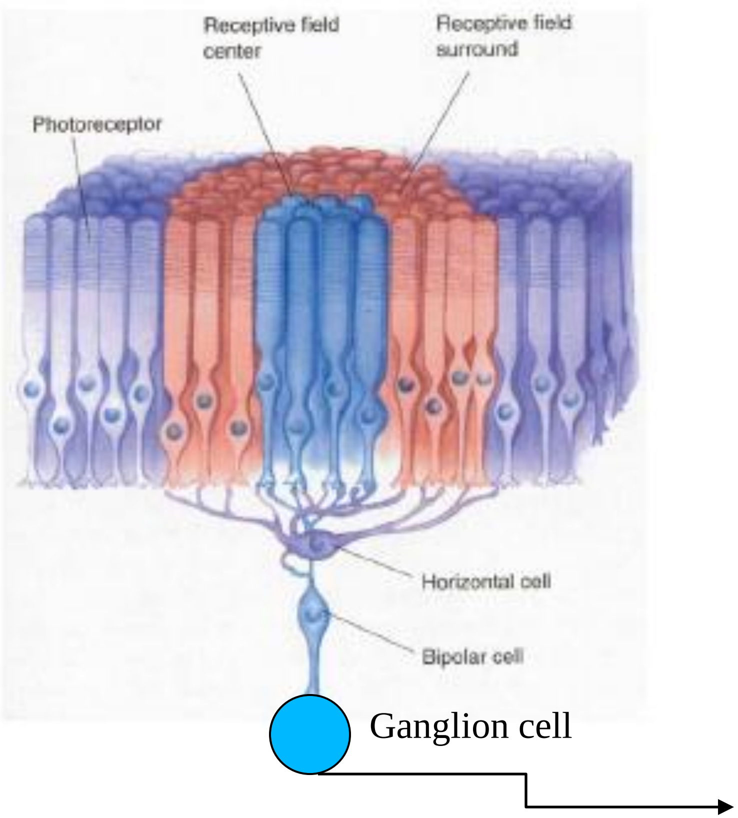
Ganglion cells (**G**)

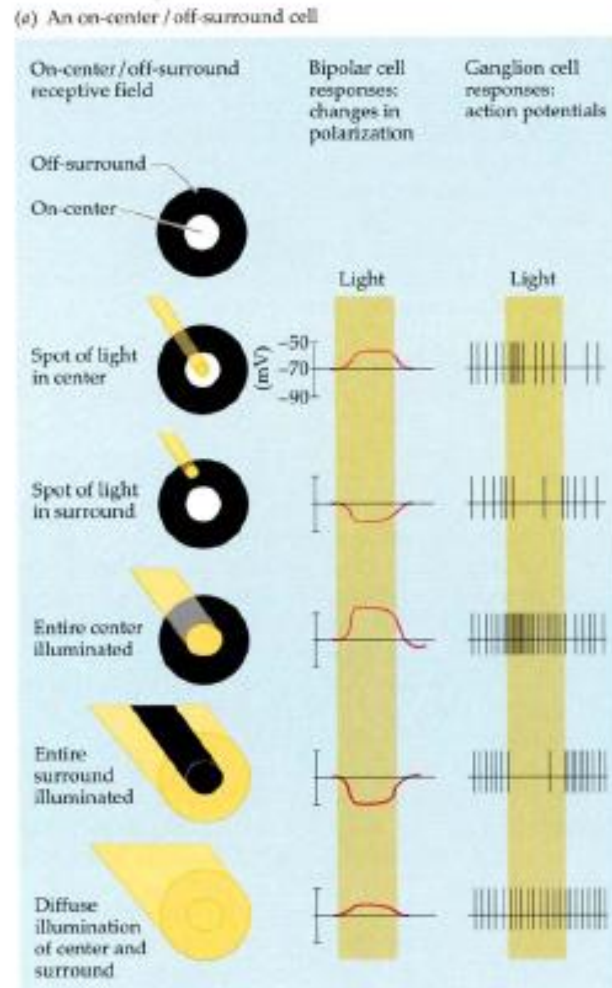
Optic nerve



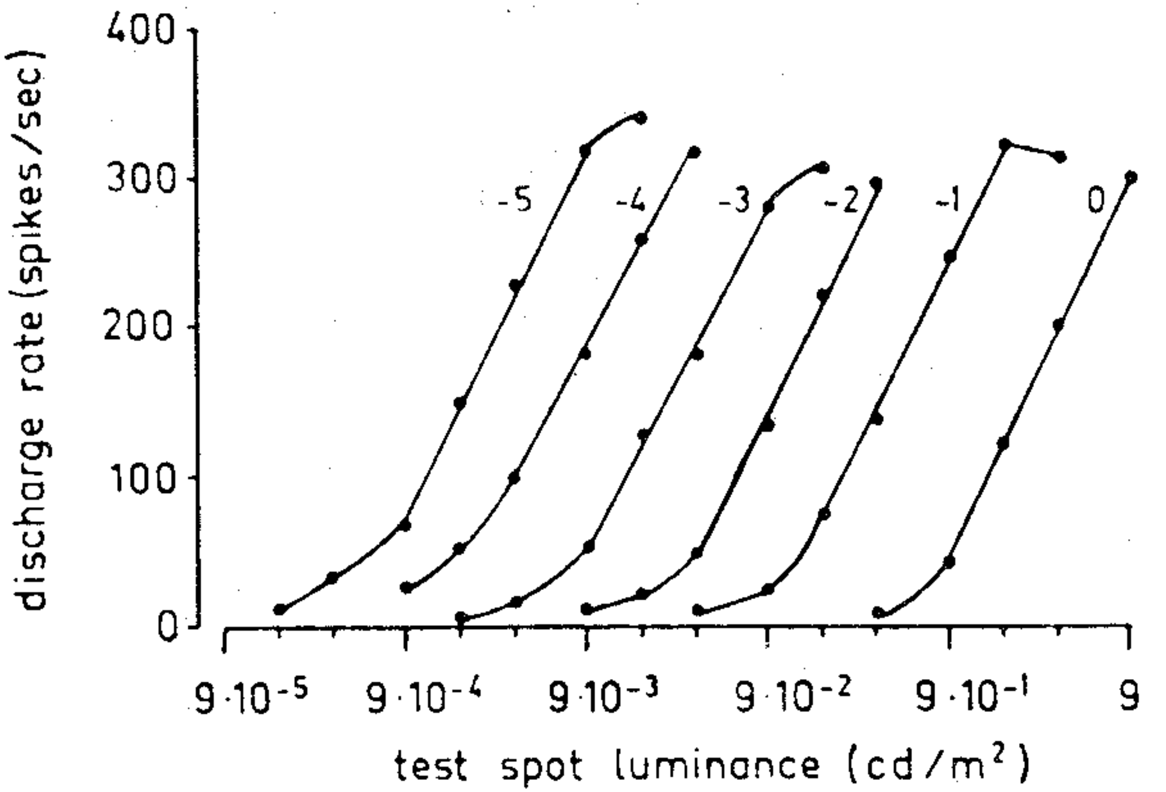
Dowling, 1987 (Fig 3.17)

Concentric receptive fields



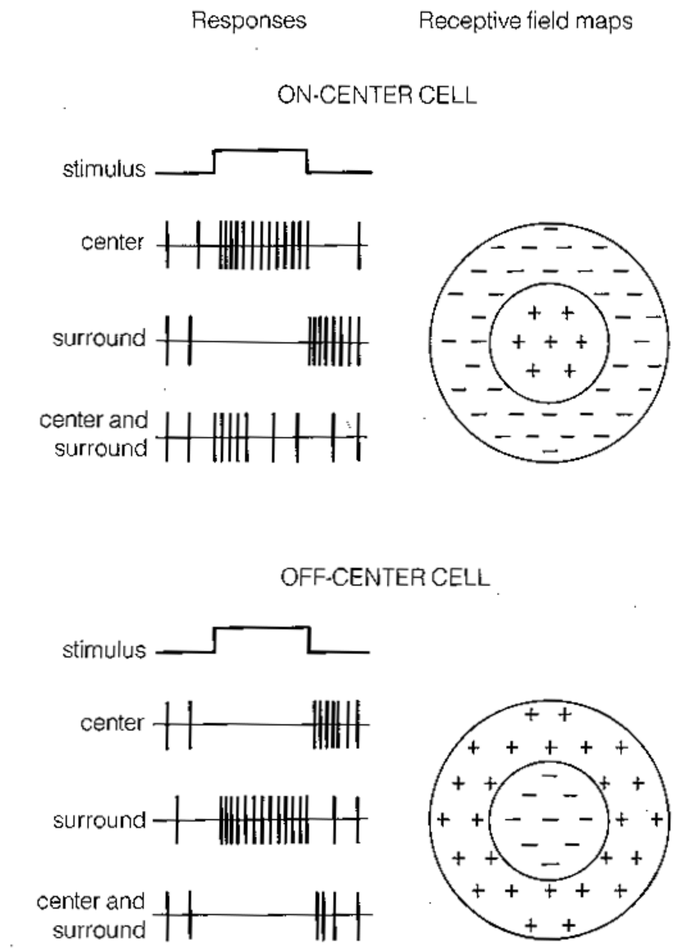


Ganglion cells adapt to the mean light intensity



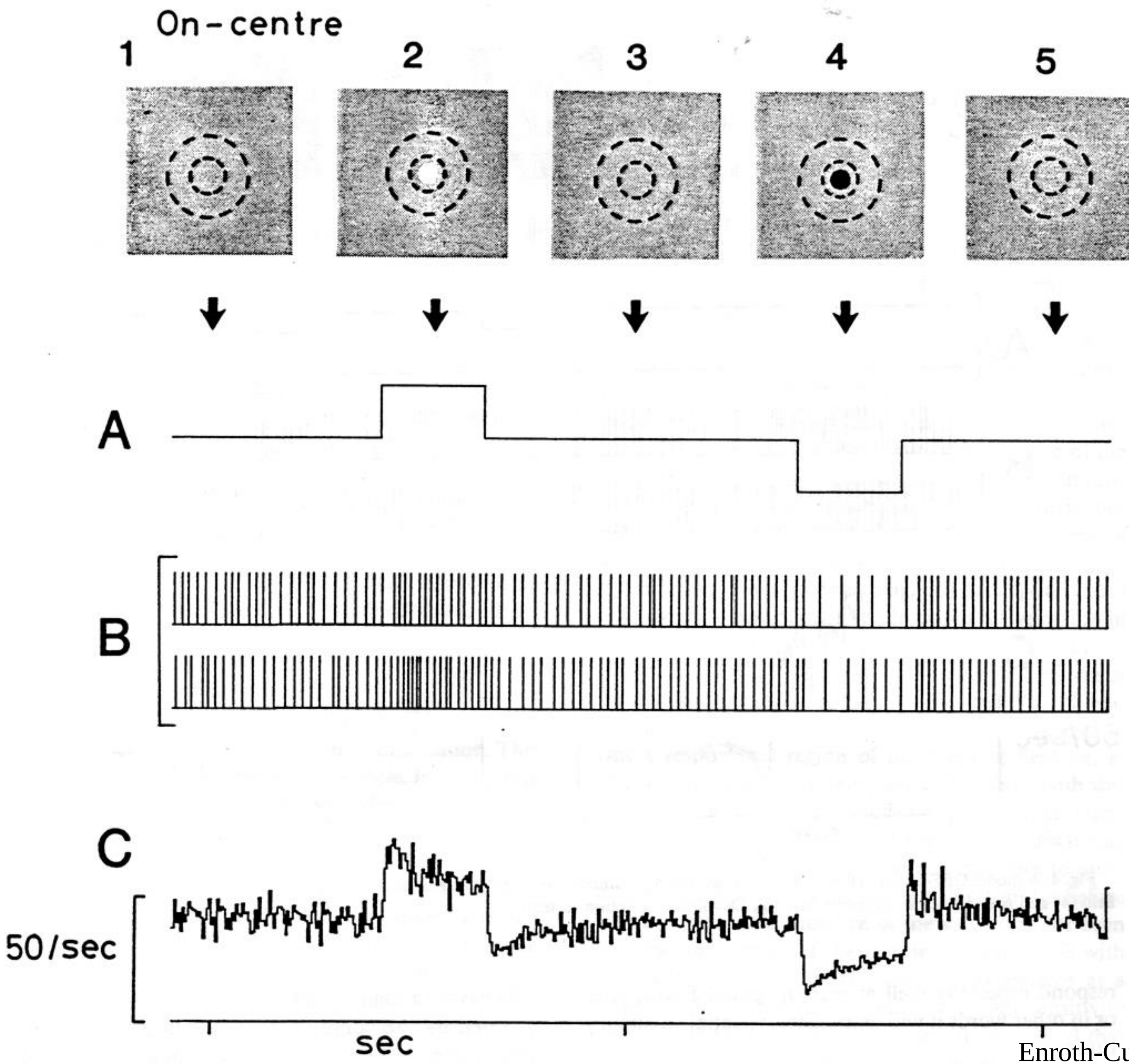
Sakmann and Creutzfeldt (1969)

Ganglion cells have center-surround receptive fields



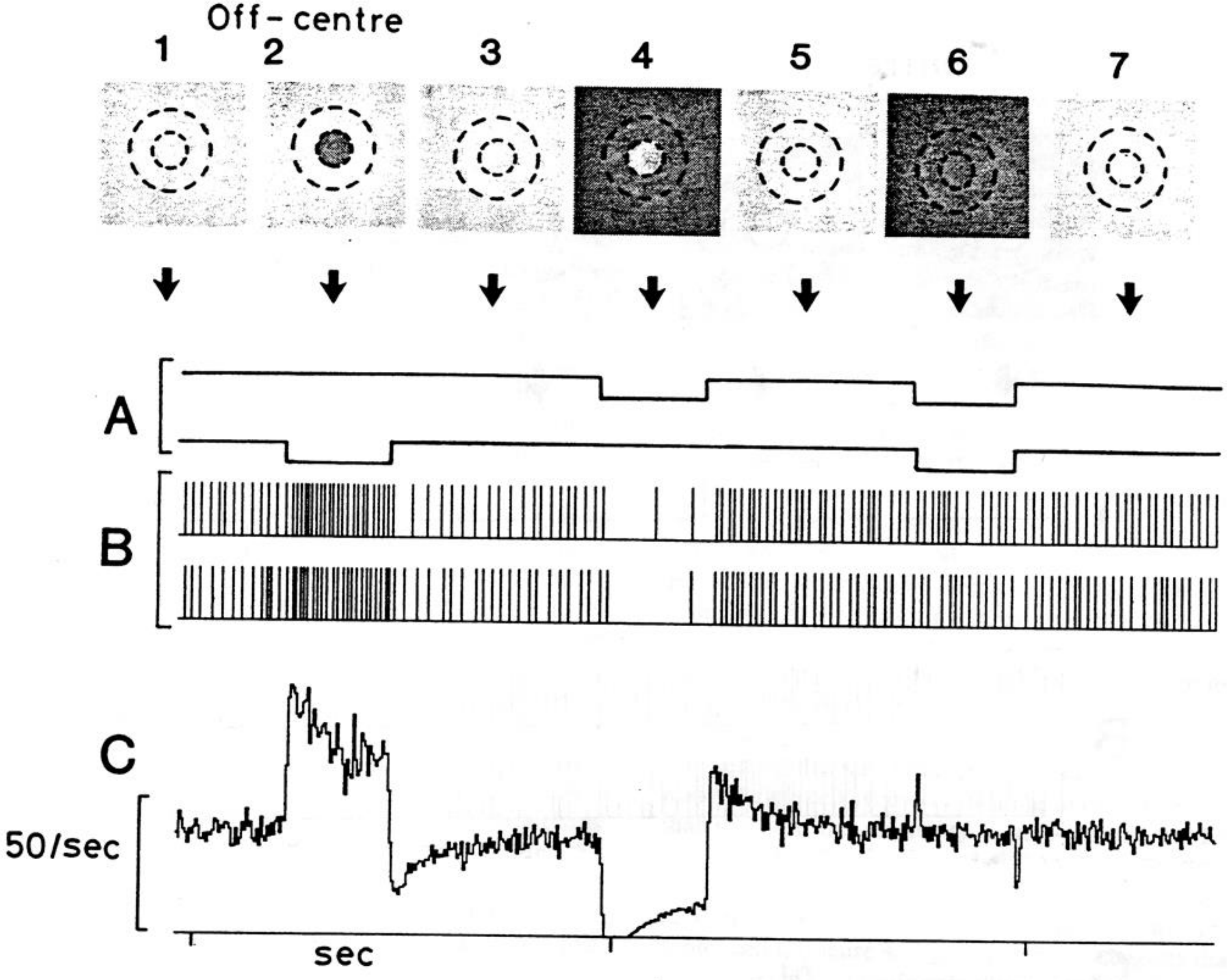
Dowling, 1987 (Fig 2.13)

Examples of responses of an ON-center cell



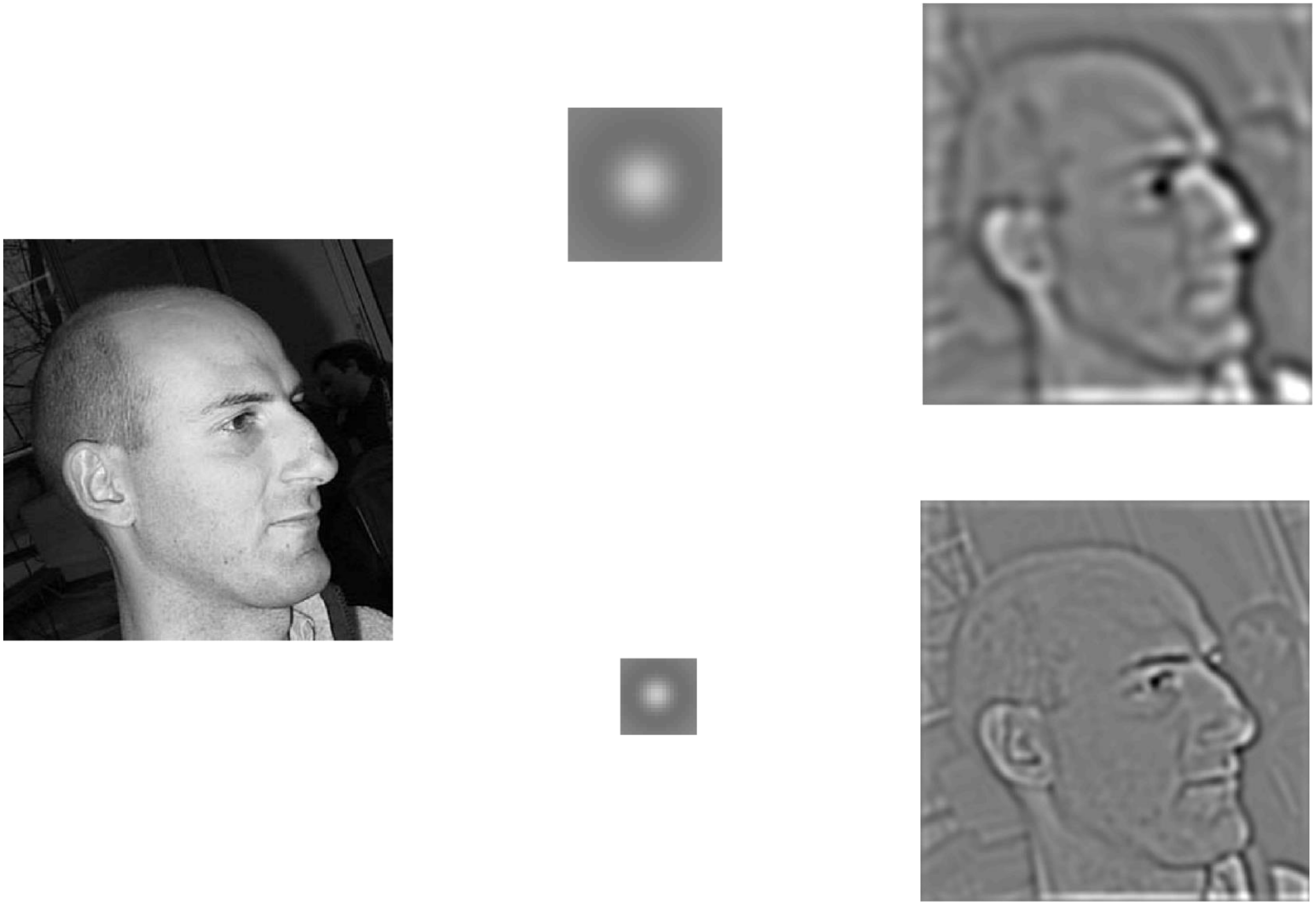
Enroth-Cugell and Robson (1984)

Examples of responses of an OFF-center cell



Enroth-Cugell and Robson (1984)

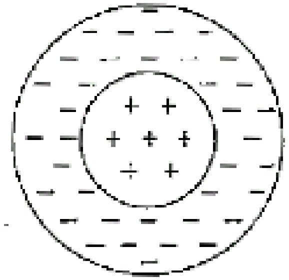
Center-surround receptive fields enhance edges



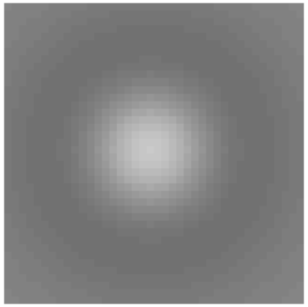
The linear model

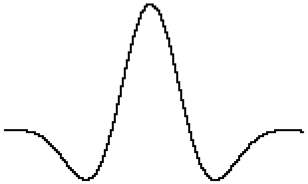
A model of the ganglion cell receptive field

ON-center
receptive field



“Difference of
gaussians” model

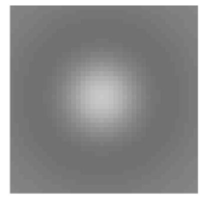




$R(x,y)$

=

$F(u,v)$



*

$I(x,y)$

$$R(x,y) = \iint F(u,v)\, I\,(x+u,\, y+v)\, du\,dv$$

Assumptions implicit in the last 3 slides

•Receptive fields are difference of gaussians

•Responses are a weighted average of the stimulus intensity, where the map of the weights is the receptive field.

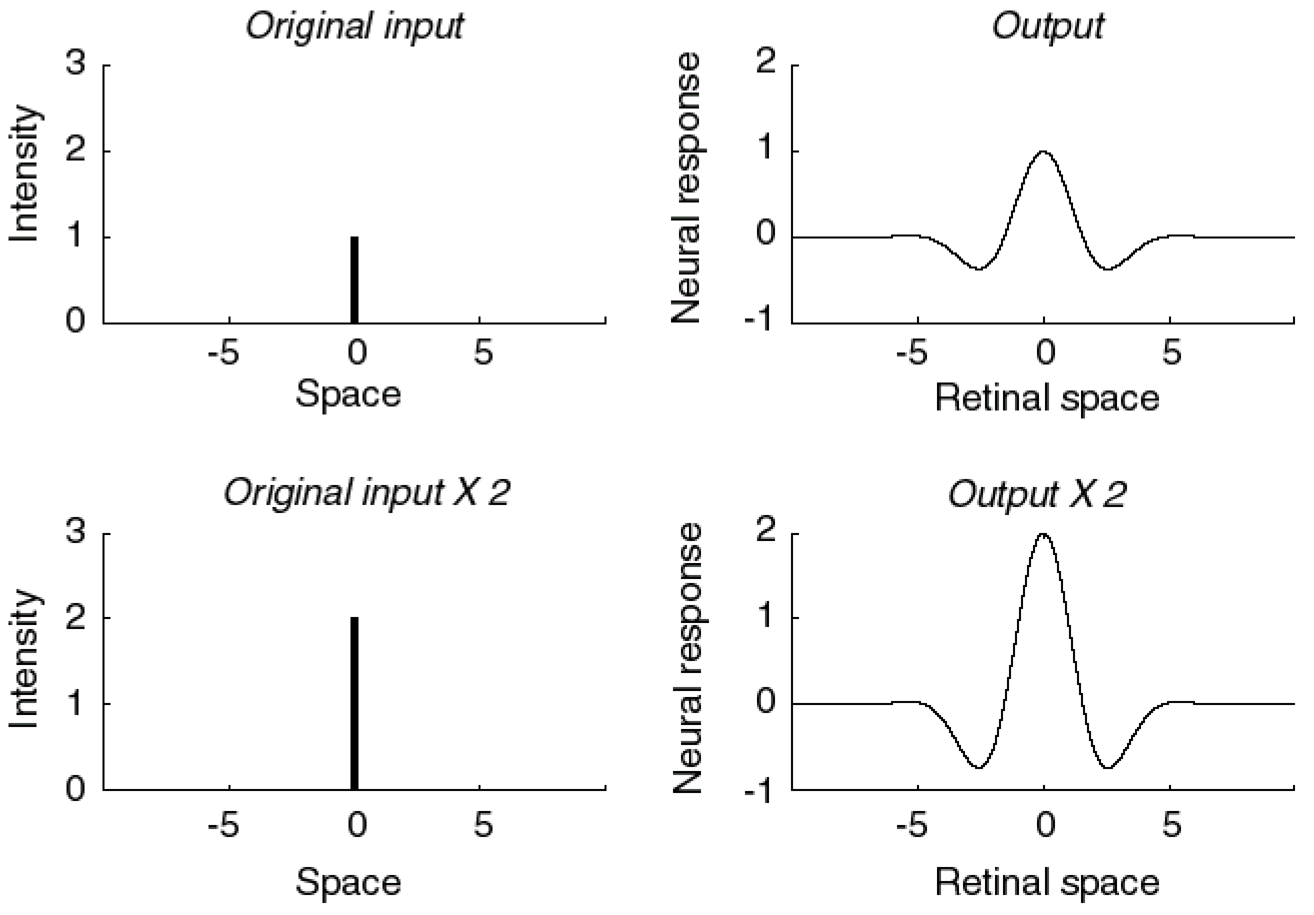
Are these assumptions reasonable?

The second assumption is true if and only if the cell is a linear system.

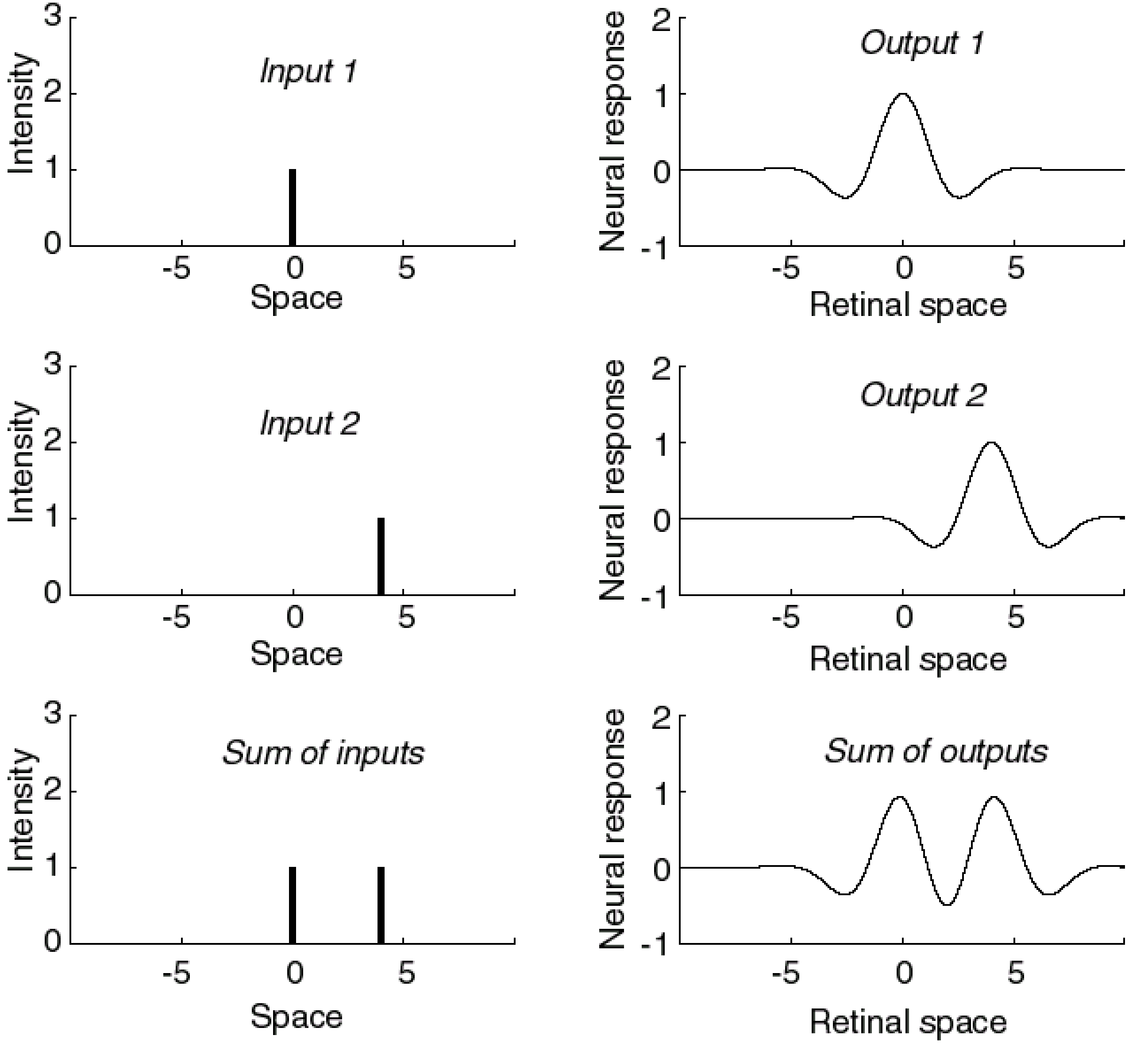
Linear systems $L(x)$ obey

- homogeneity: $L(a\,x) = a\,L(x)$
- superposition: $L(x+y) = L(x) + L(y)$

Homogeneity



Superposition



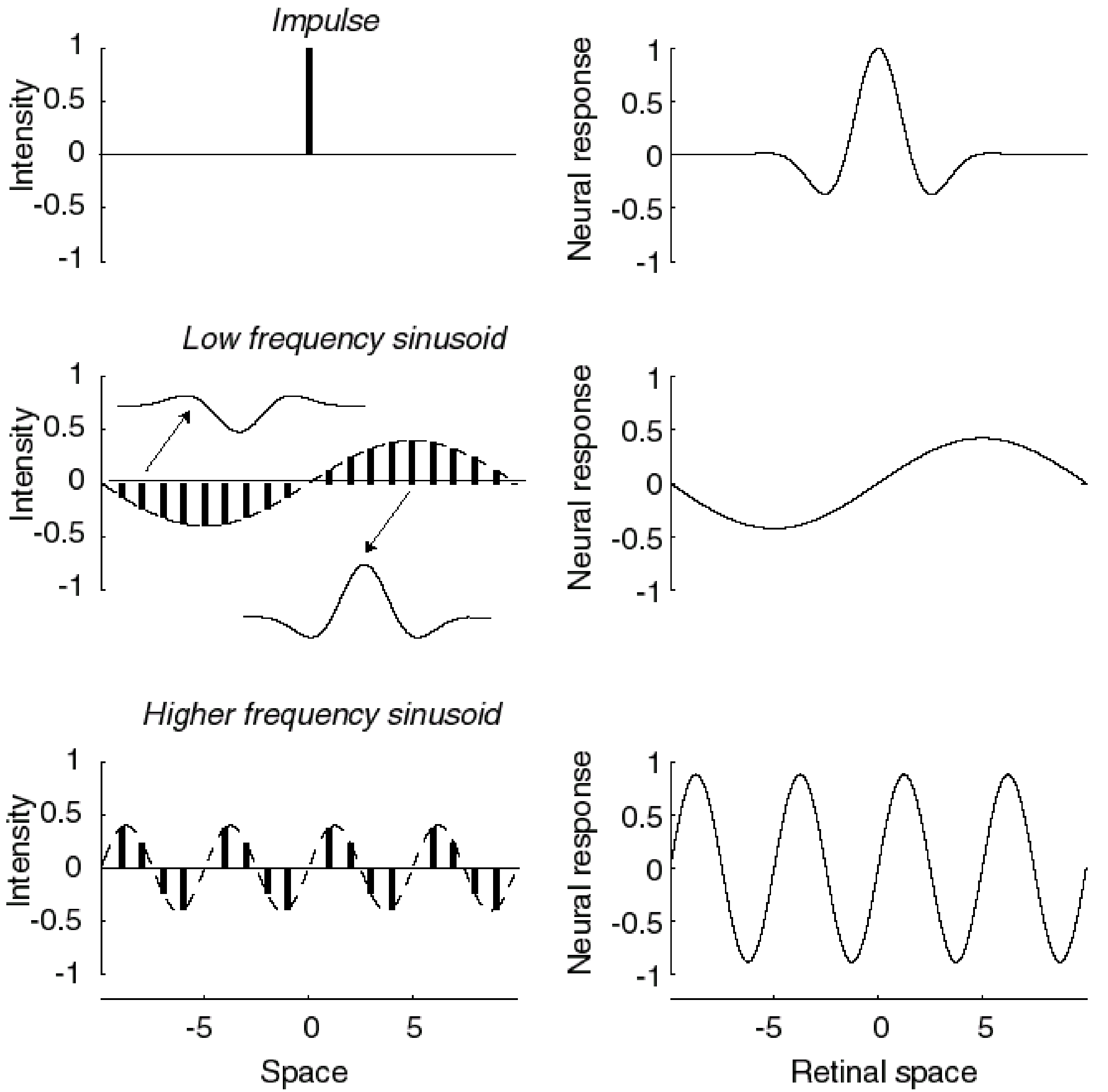
Linearity is often checked by using sinusoidal stimuli, because for a linear system:

1) The responses to sinusoids are sinusoids.

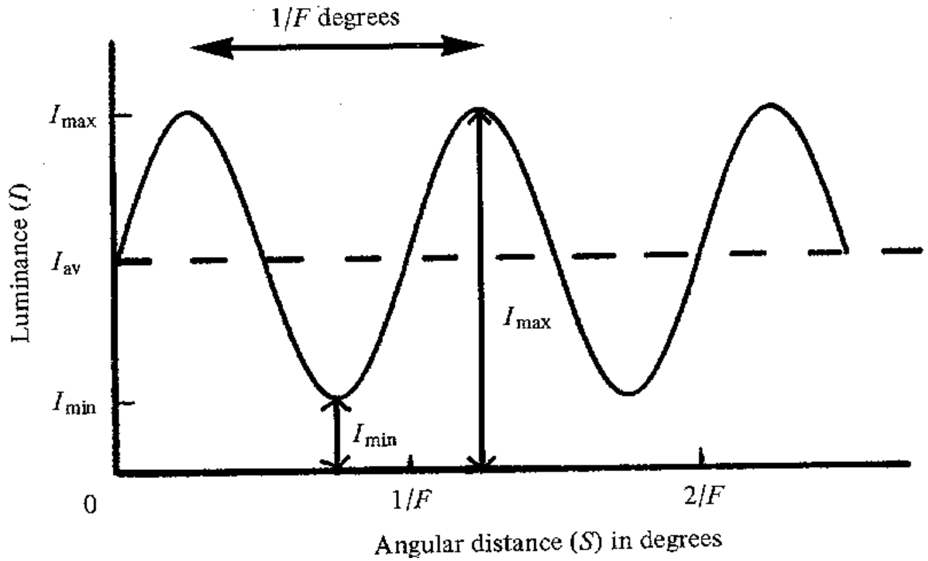
2) The dependence of response on stimulus frequency can be predicted from the shape of the receptive field.

(so if any of these two are false, the system is not linear)

Responses of a linear system to sinusoids

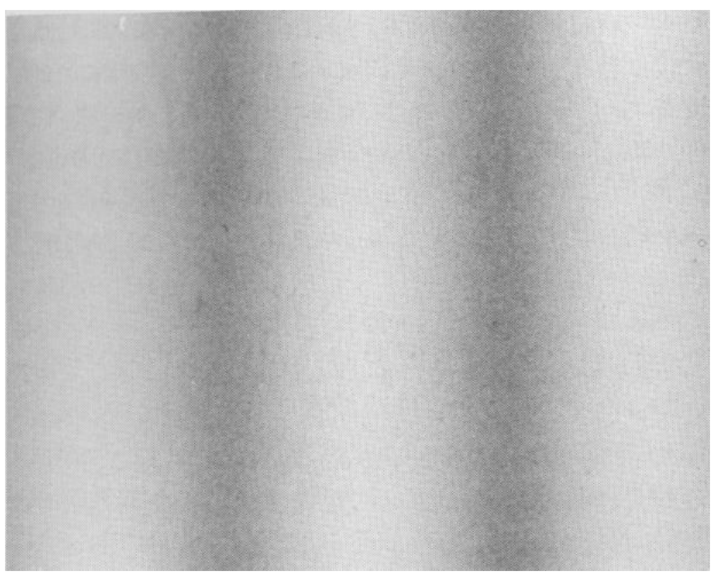


A sinusoid in 2-D: a sinusoidal grating



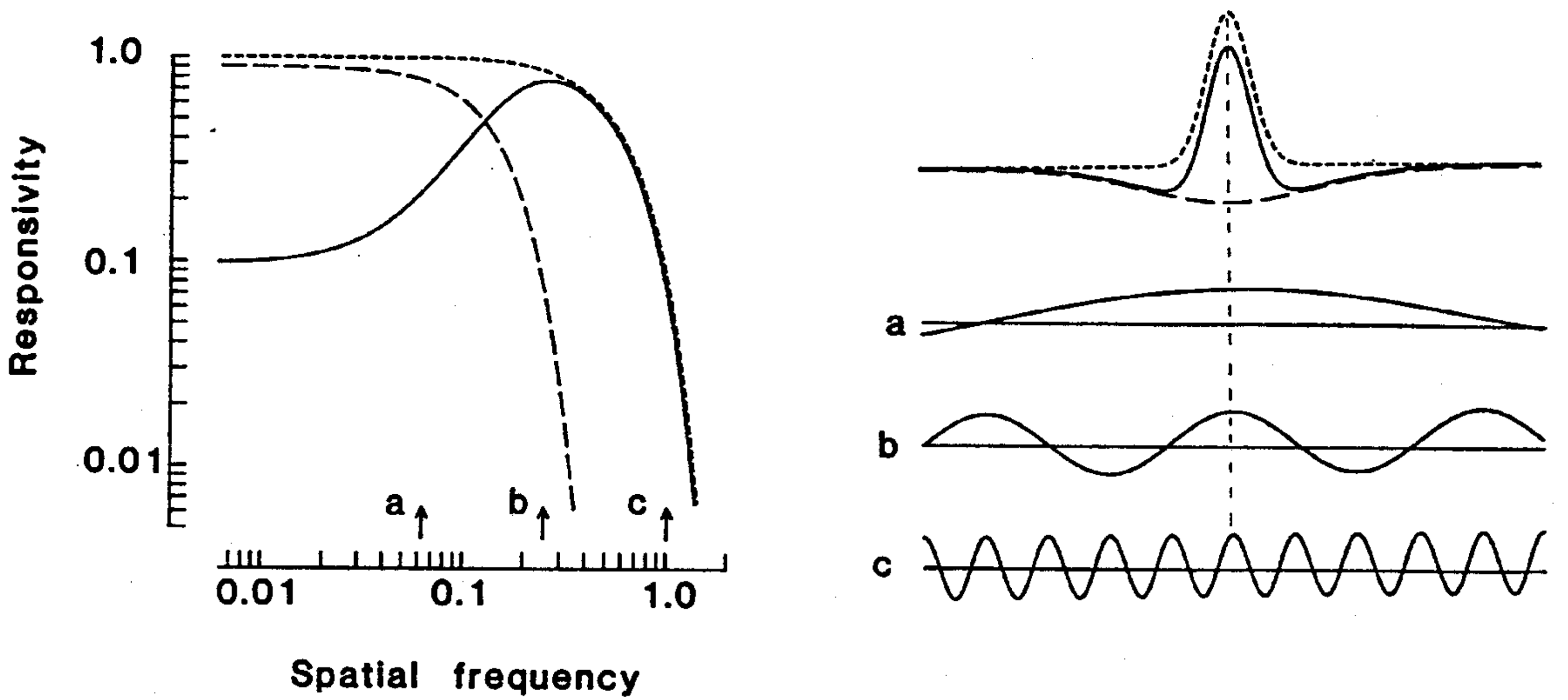
$$\text{Contrast} = C = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

$$I = I_{av}\, C \sin 2\pi\, FS$$



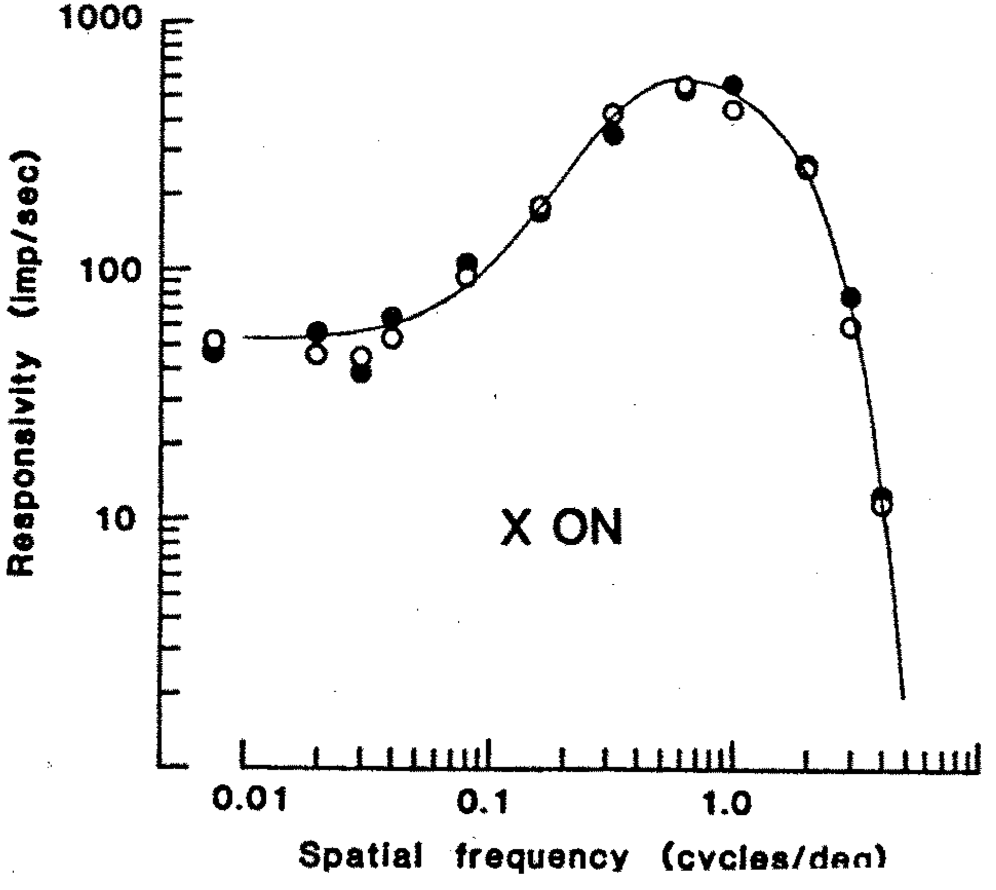
Barlow and Mollon, 1982 (Fig 1.3)

Predictions of the linear model with a "difference of gaussians" receptive field



Enroth-Cugell and Robson (1984)

Fitting the model to the data

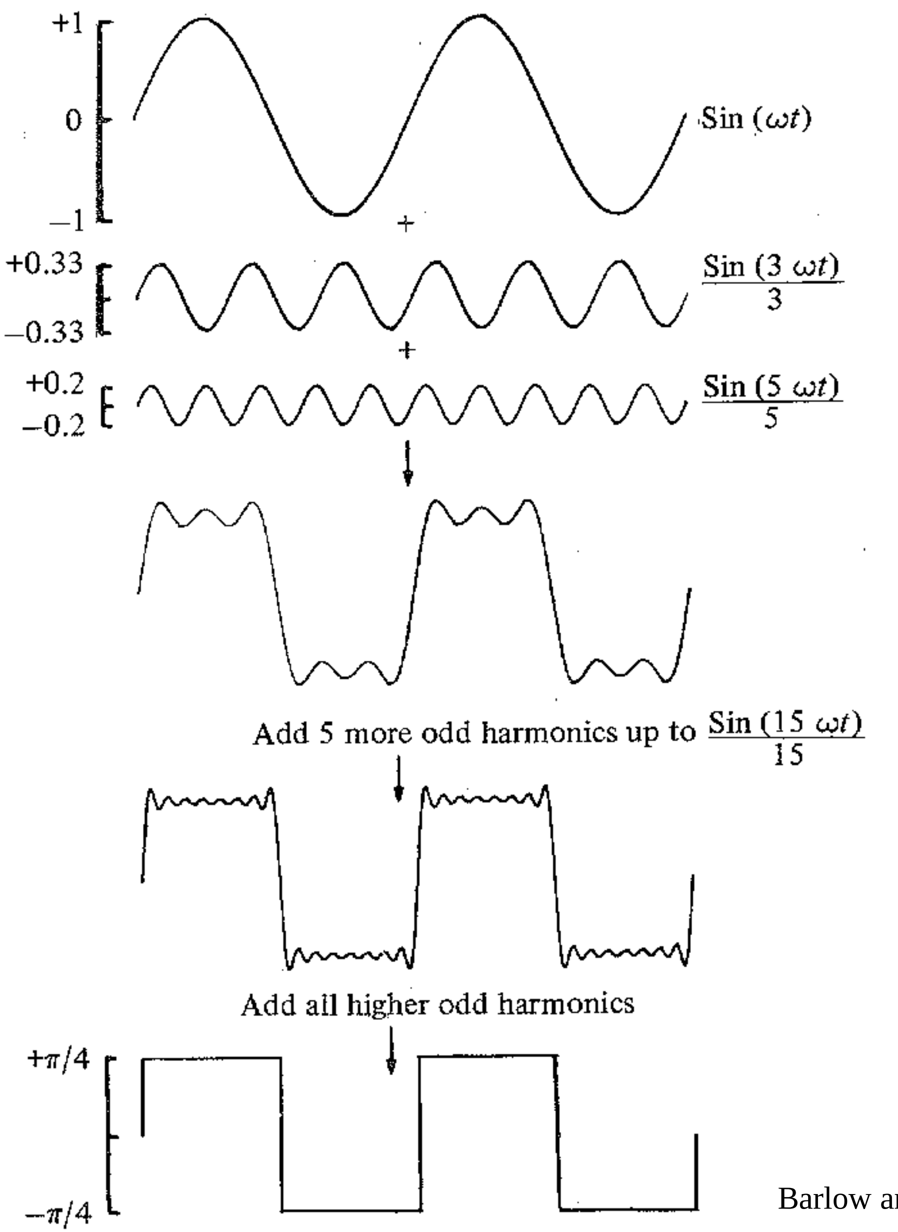


Enroth-Cugell et al. (1983)

The fits are good: the responses to sinusoids are predictable by a linear model with a “difference of gaussians” receptive field.

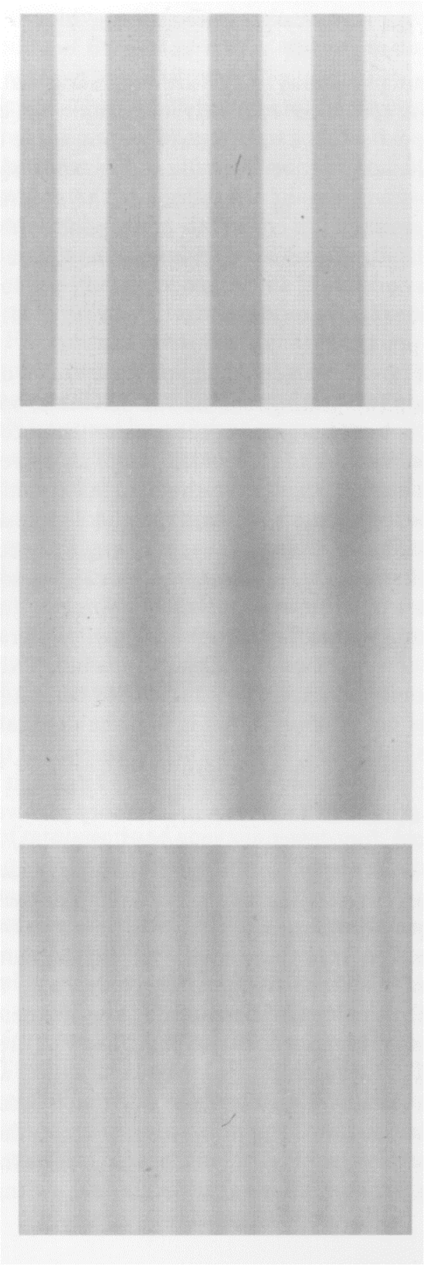
Let’s try another test of linearity. If it succeeds as well, we’ll be happy with the model.

Making a square wave with sinusoids



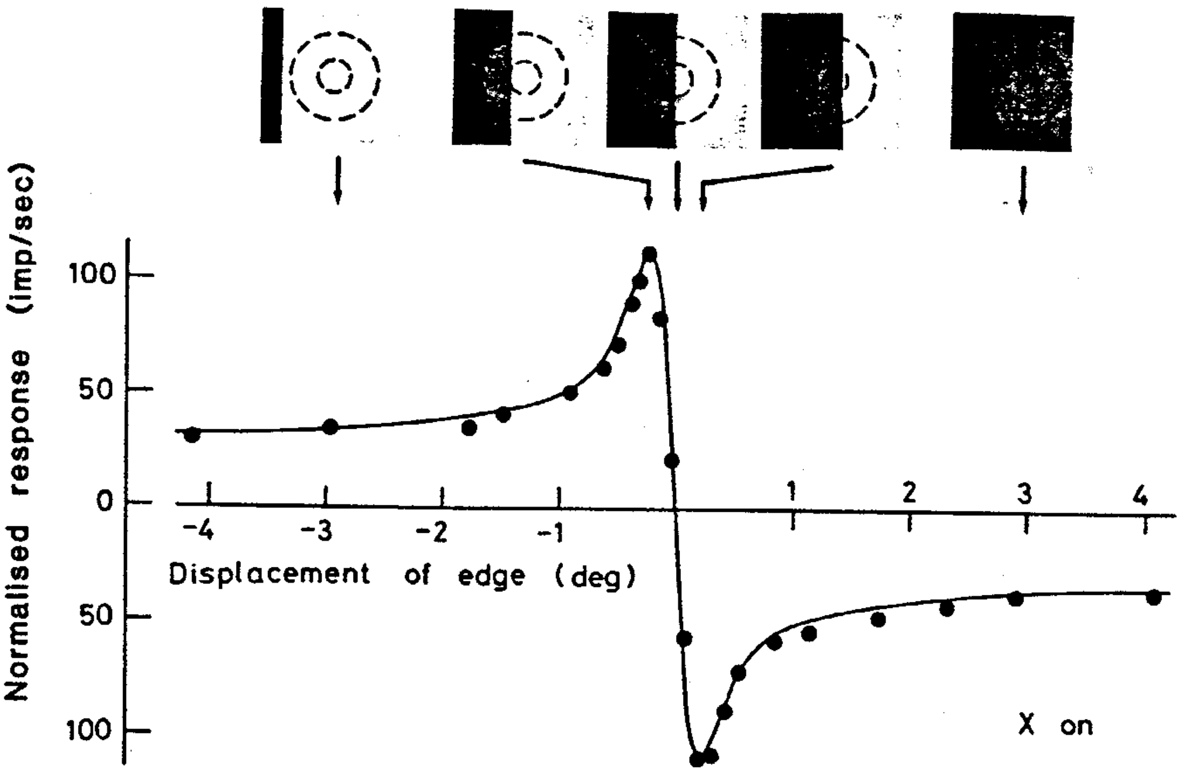
Barlow and Mollon, 1982 (Fig 1.2)

Square waves in 2-D



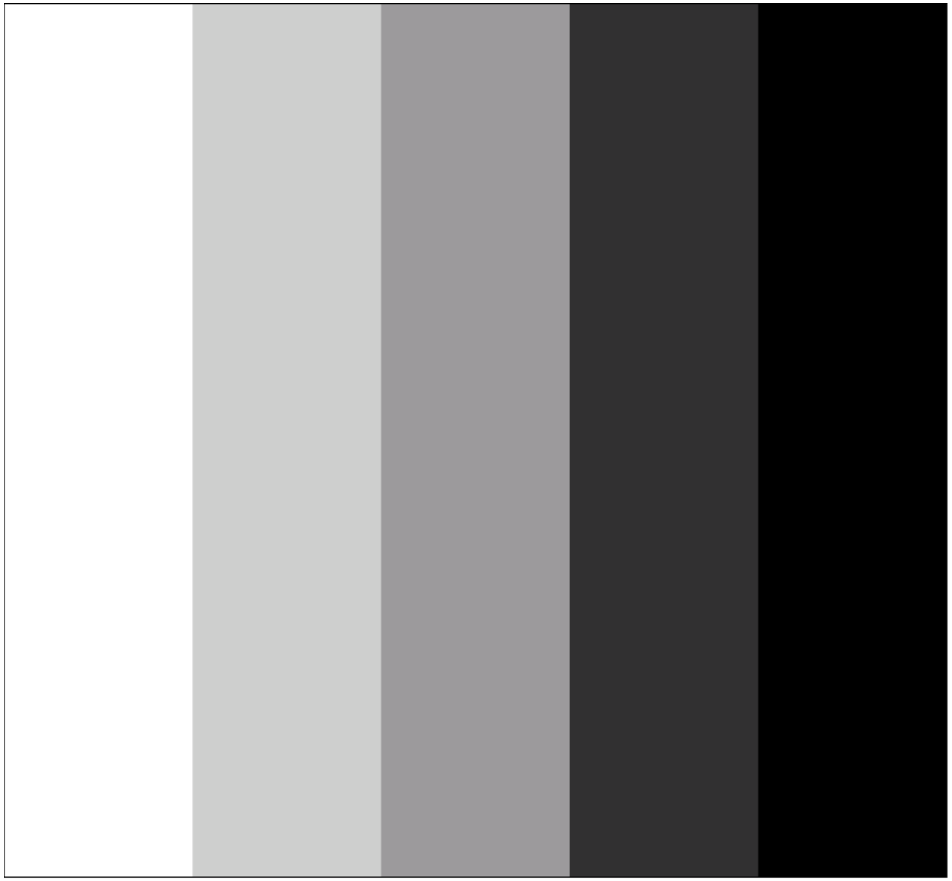
Barlow and Mollon, 1982 (Fig 8.7)

Responses of a ganglion cell to edges



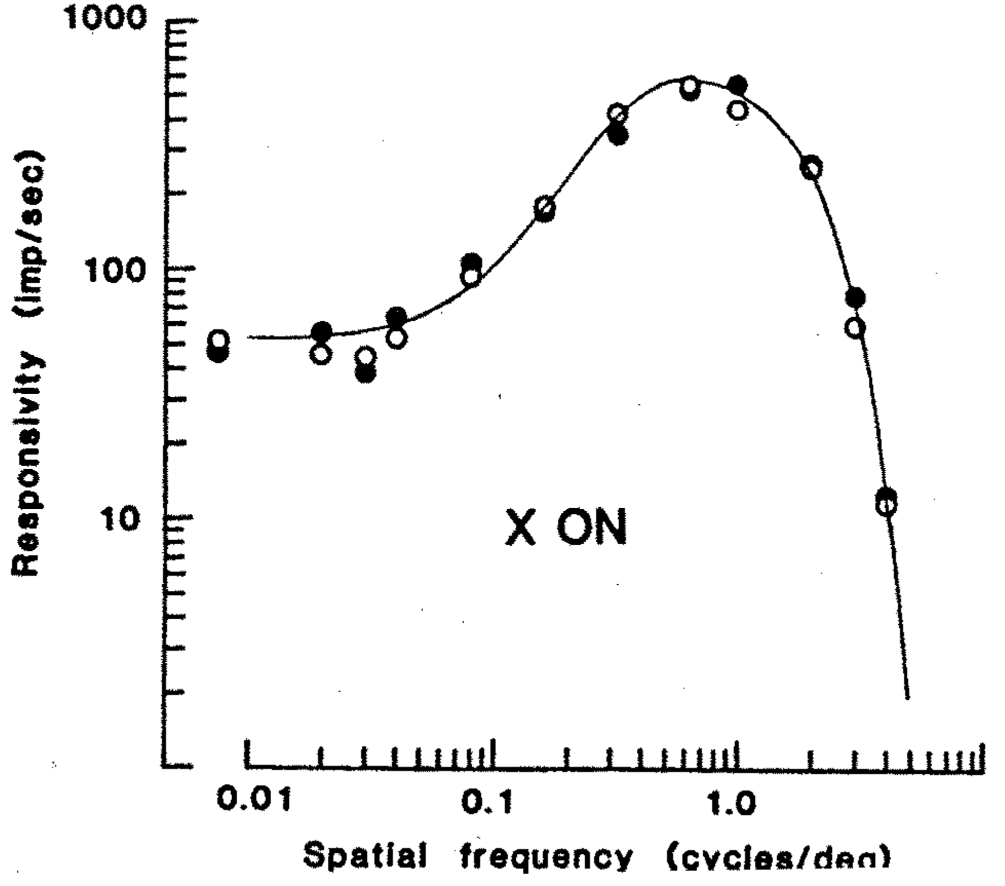
Enroth-Cugell and Robson (1984)

Chevreuil illusion - Mach bands



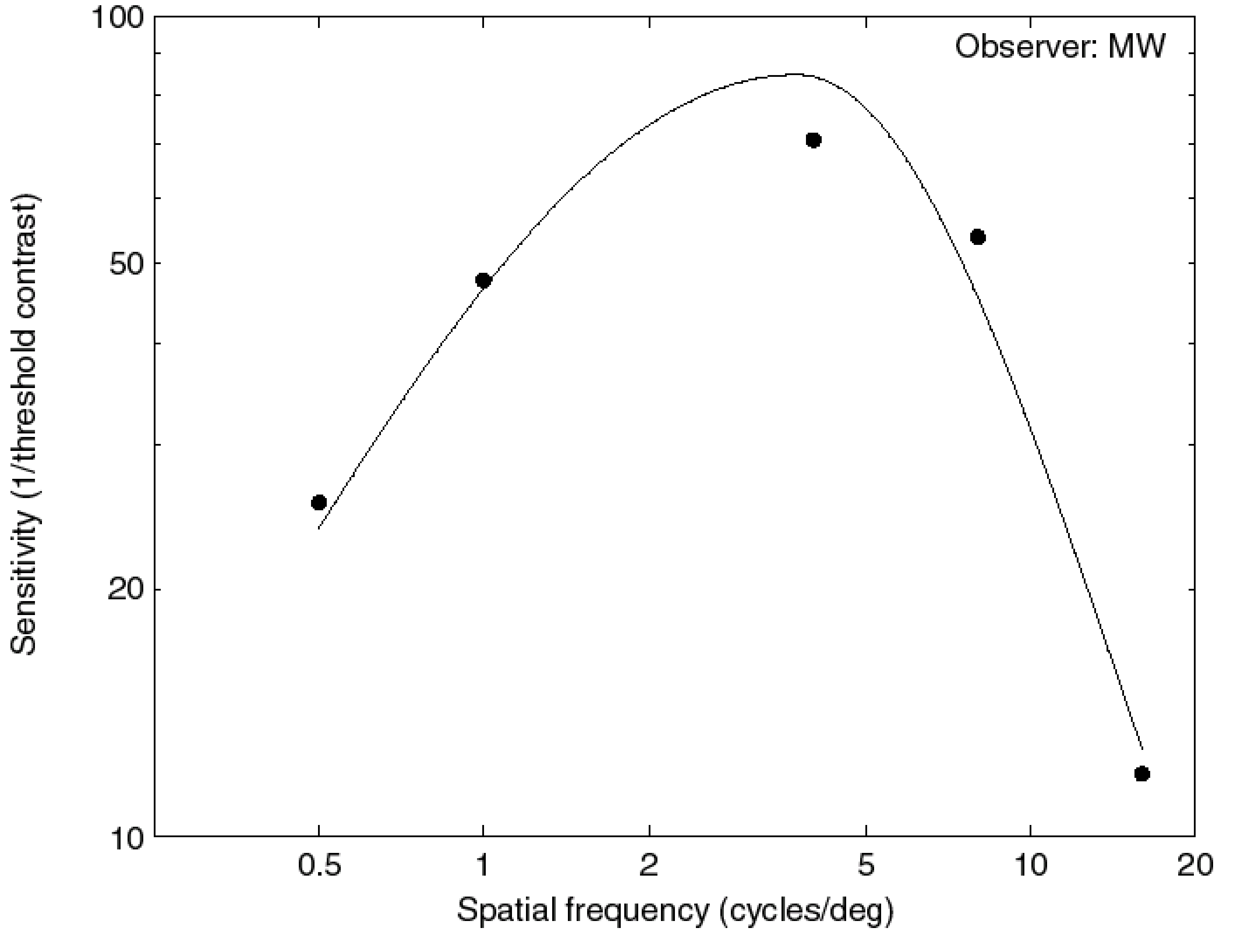
Sensitivity for different spatial frequencies

Spatial frequency tuning of a ganglion cell

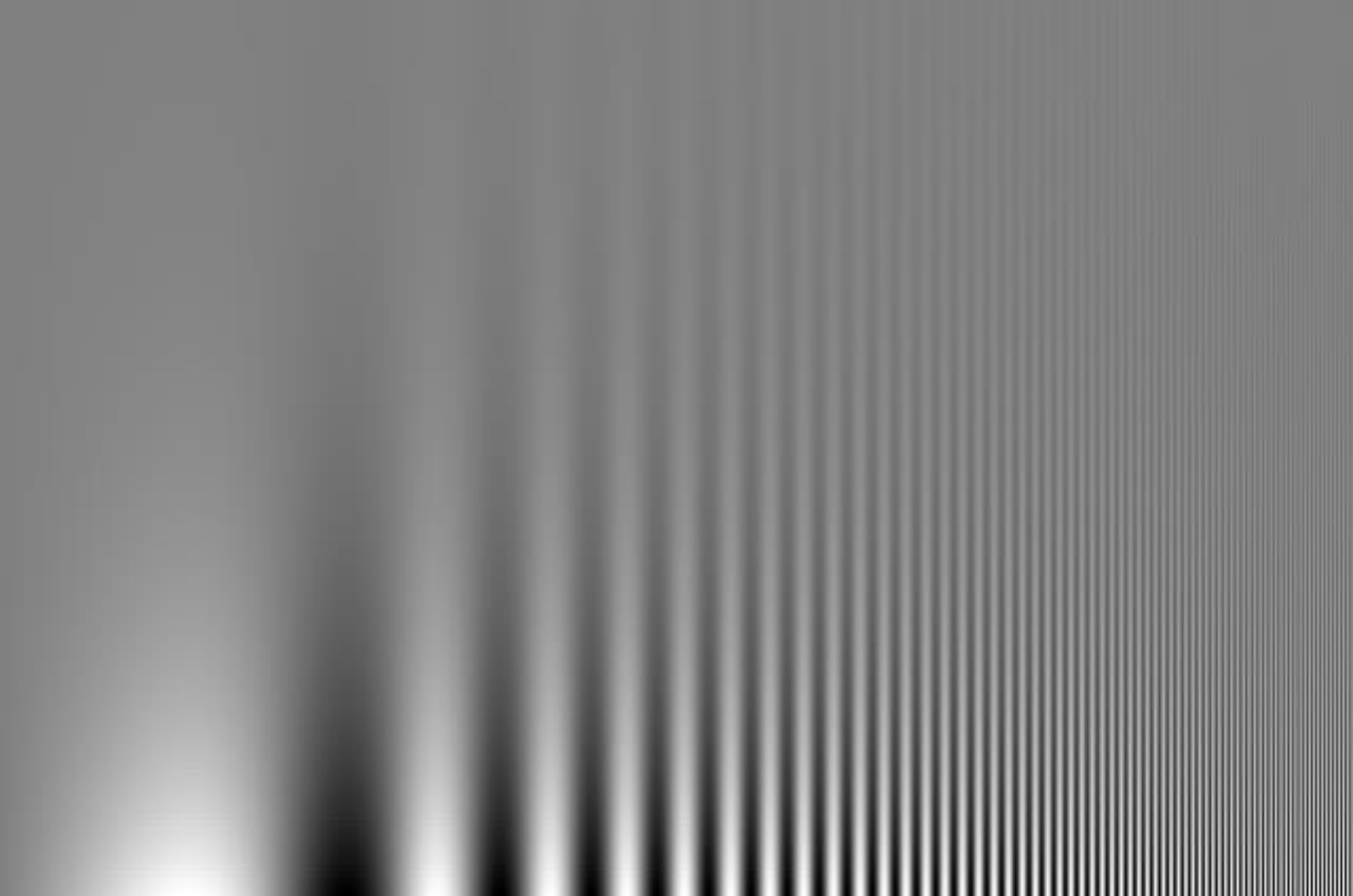


Enroth-Cugell et al. (1983)

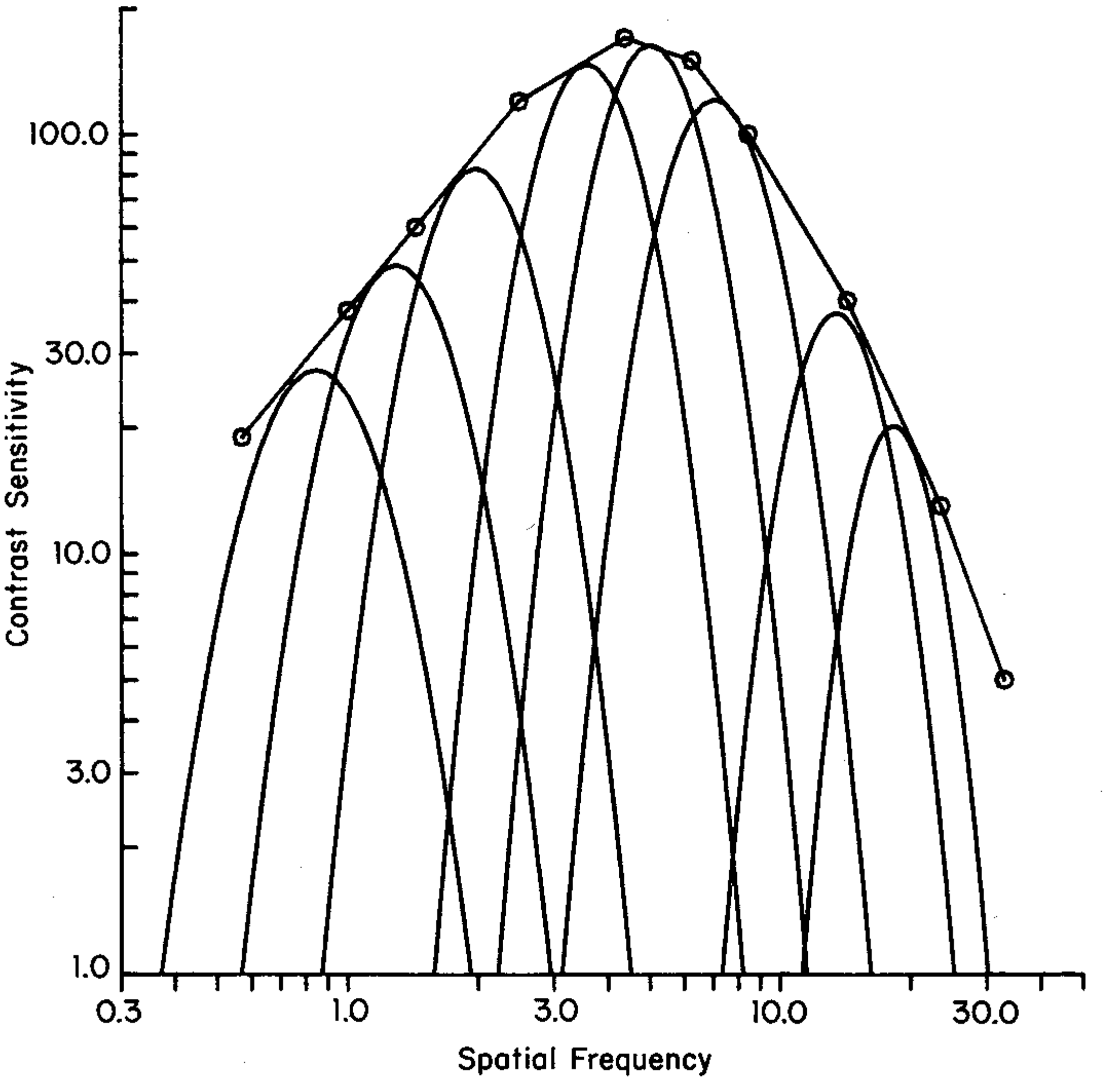
Spatial frequency sensitivity curve of a whole brain



Contrast sensitivity varies with spatial frequency



One interpretation of the contrast sensitivity curve



De Valois & De Valois (1990)