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
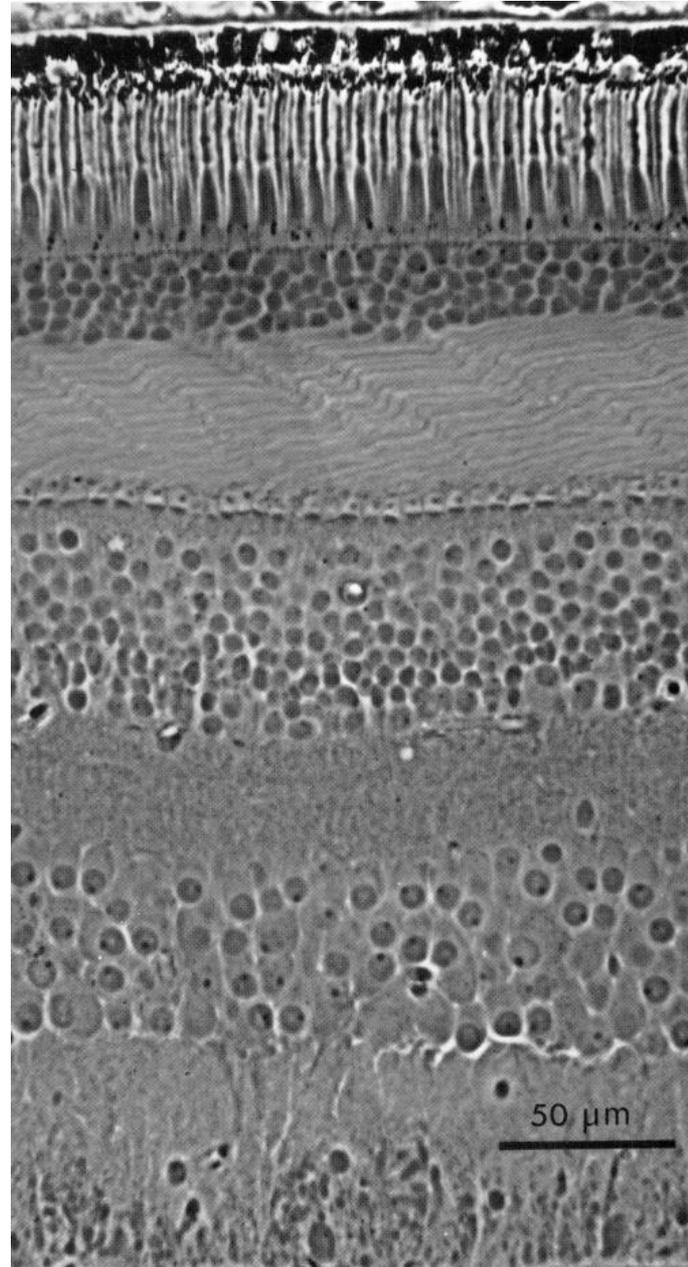
A section through the human retina

Receptors: rods and cones

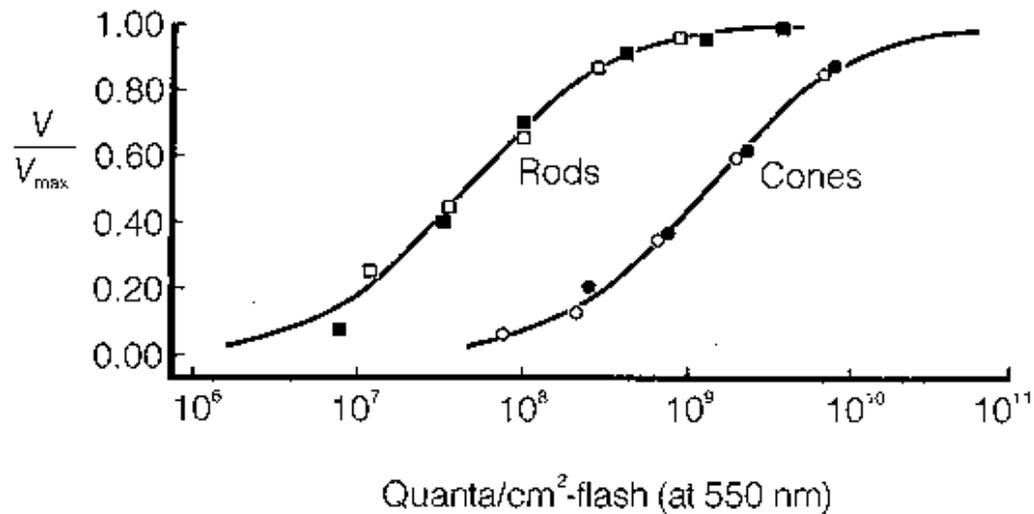Bipolar and Horizontal cells

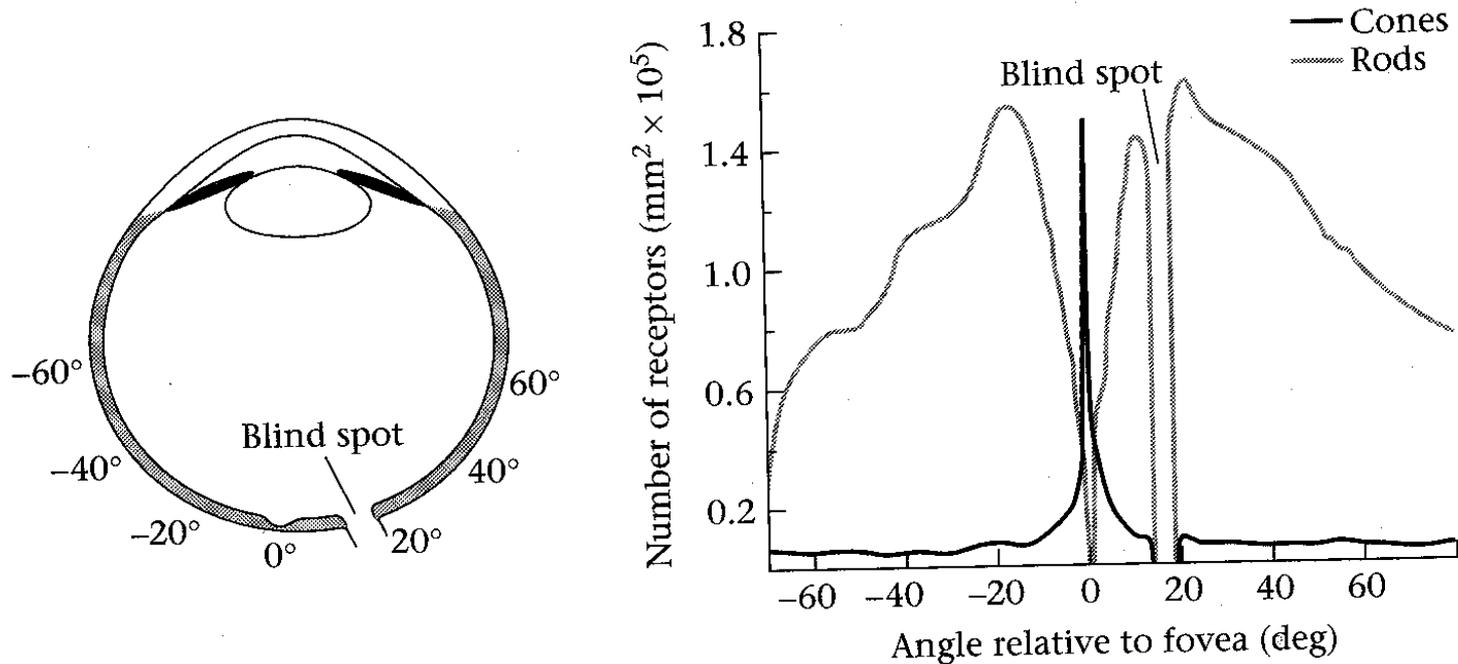Amacrine cells

Ganglion cells

Optic nerve

50 µm

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

Phototransduction in rods and cones

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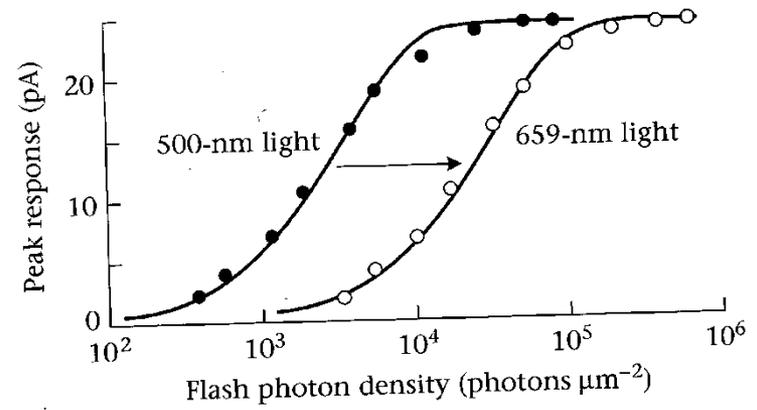
Cones: Vision in stronger light (e.g. day) .
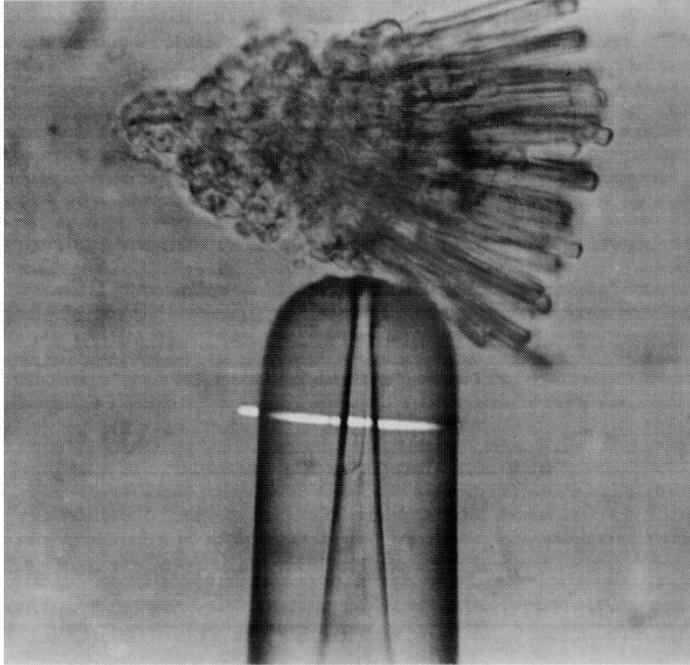

Quanta/cm²-flash (at 550 nm)
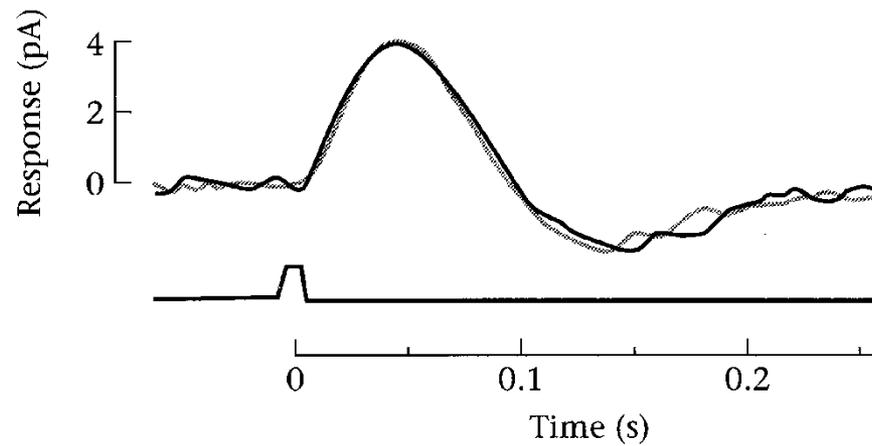
Distribution of rods and cones:

a view from the side

Wandell, 1995 (Fig 3.1)

Response of a cone to light of two different wavelengths

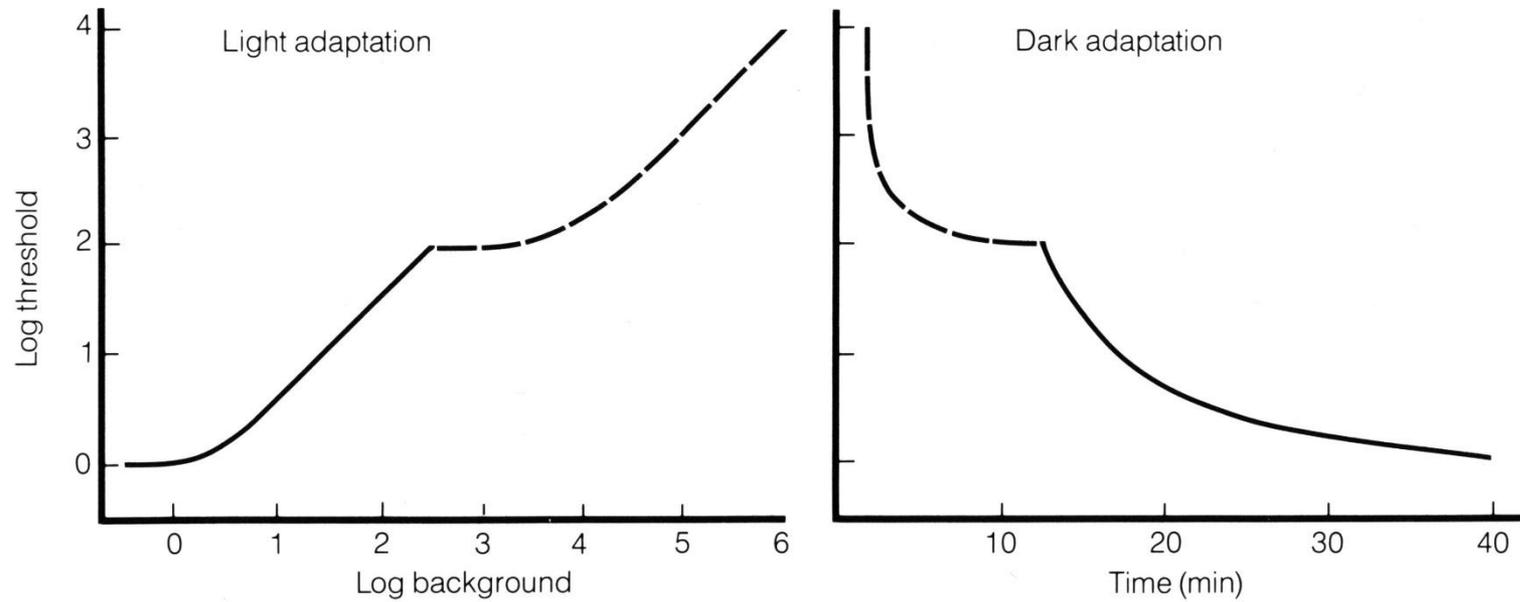Wandell, 1995 (Figs 4.15-4.16)

Principle of univariance

500 nm

659 nm

Response (pA)

30

20

10

0

Stimulus

0   0.1   0.2   0.3   0.4

0   0.1   0.2   0.3   0.4

Time (s)

Response (pA)

4

2

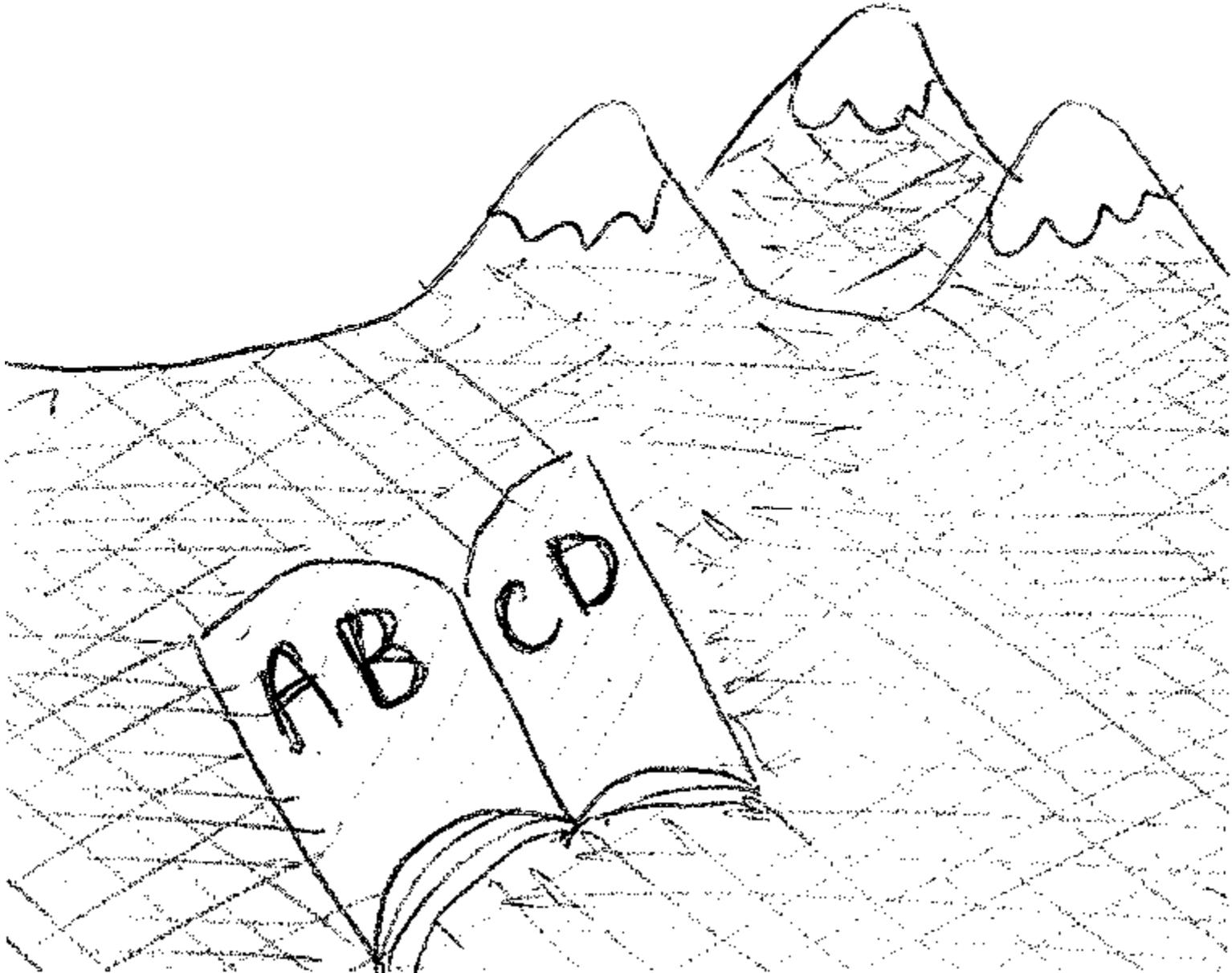0

0   0.1   0.2

Time (s)
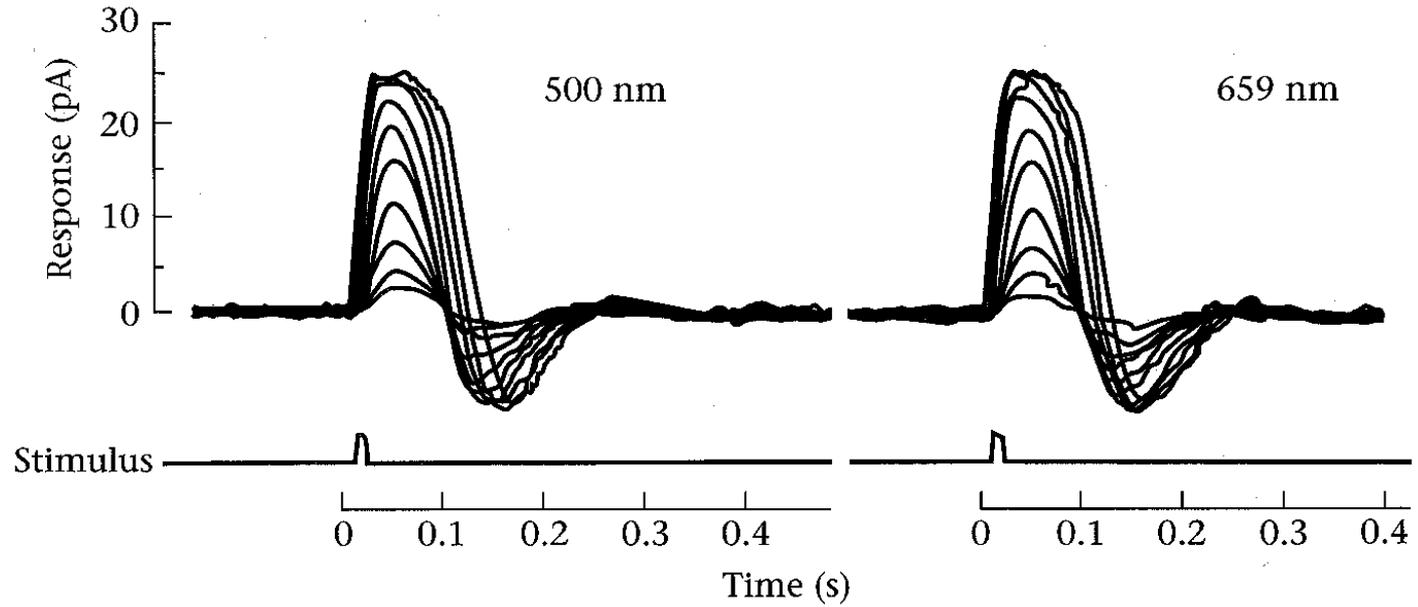
Light adaptation

Human light and dark adaptation
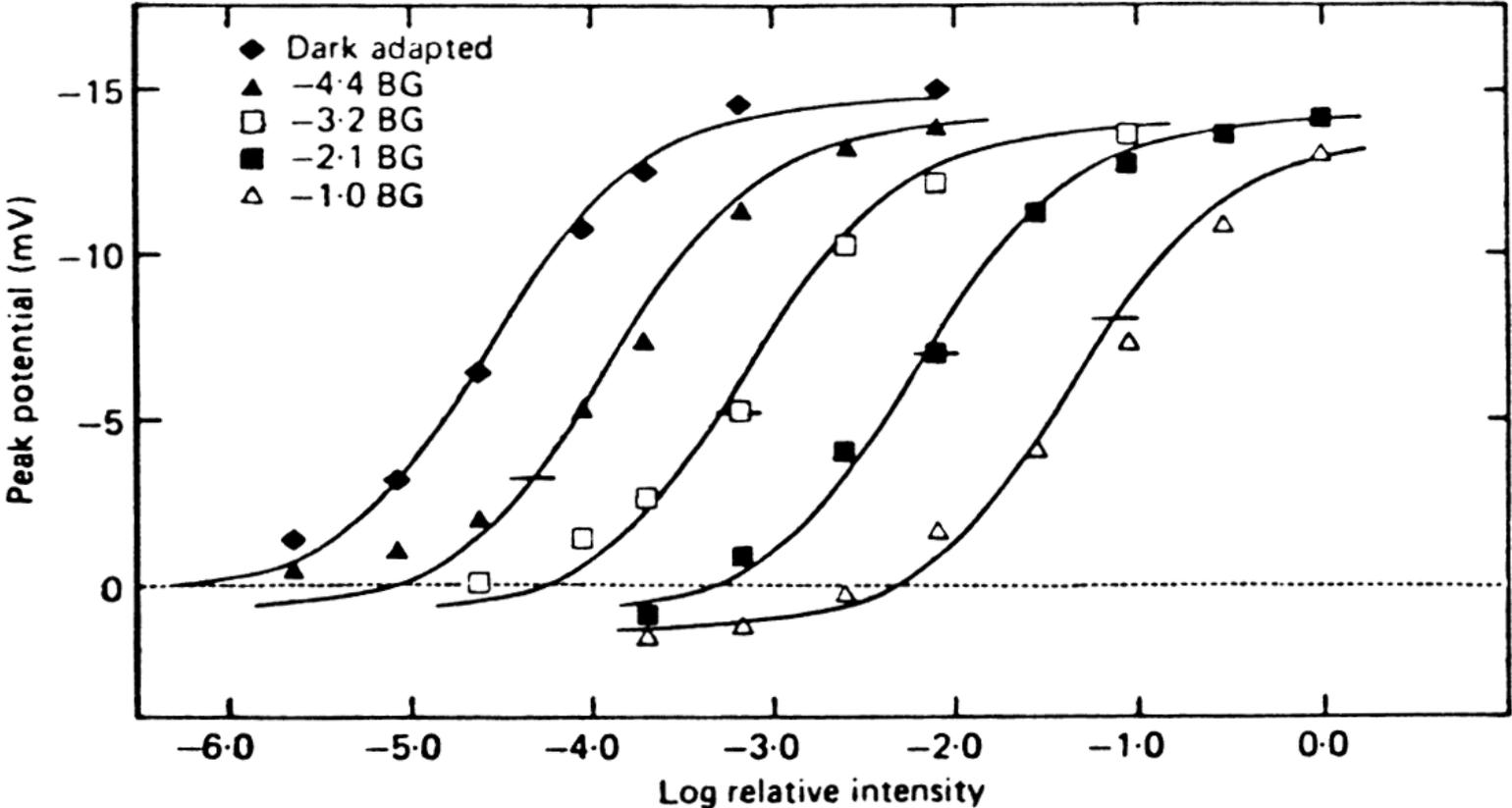
The Jungfrau viewed from Wengen

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

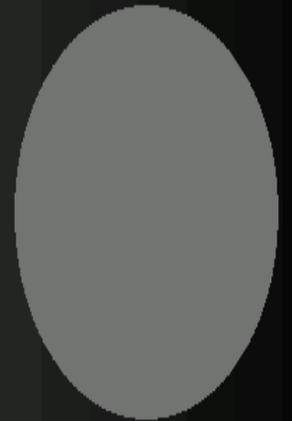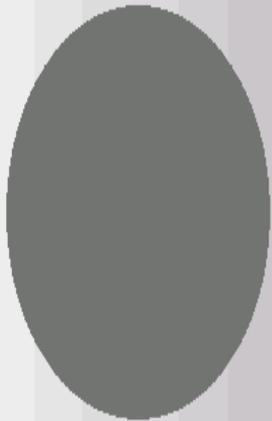|	Reflectance	Intensity I at noon (1000000 W)	Intensity I at dusk (1000 W)	Local contrast c at noon (1000000 W)	Local contrast c at dusk (1000 W)
Snow	90%	900000 W	900W	1.25	1.25
Grass	40%	400000 W	400 W	0	0
Paper	80%	800000 W	800 W	1	1
Ink	10%	100000 W	100 W	-0.75	-0.75
Mean	40%	400000 W	400 W	0	0

Intensity I is reflectance*illuminance.

Local contrast is c = (I-Imean)/Imean.
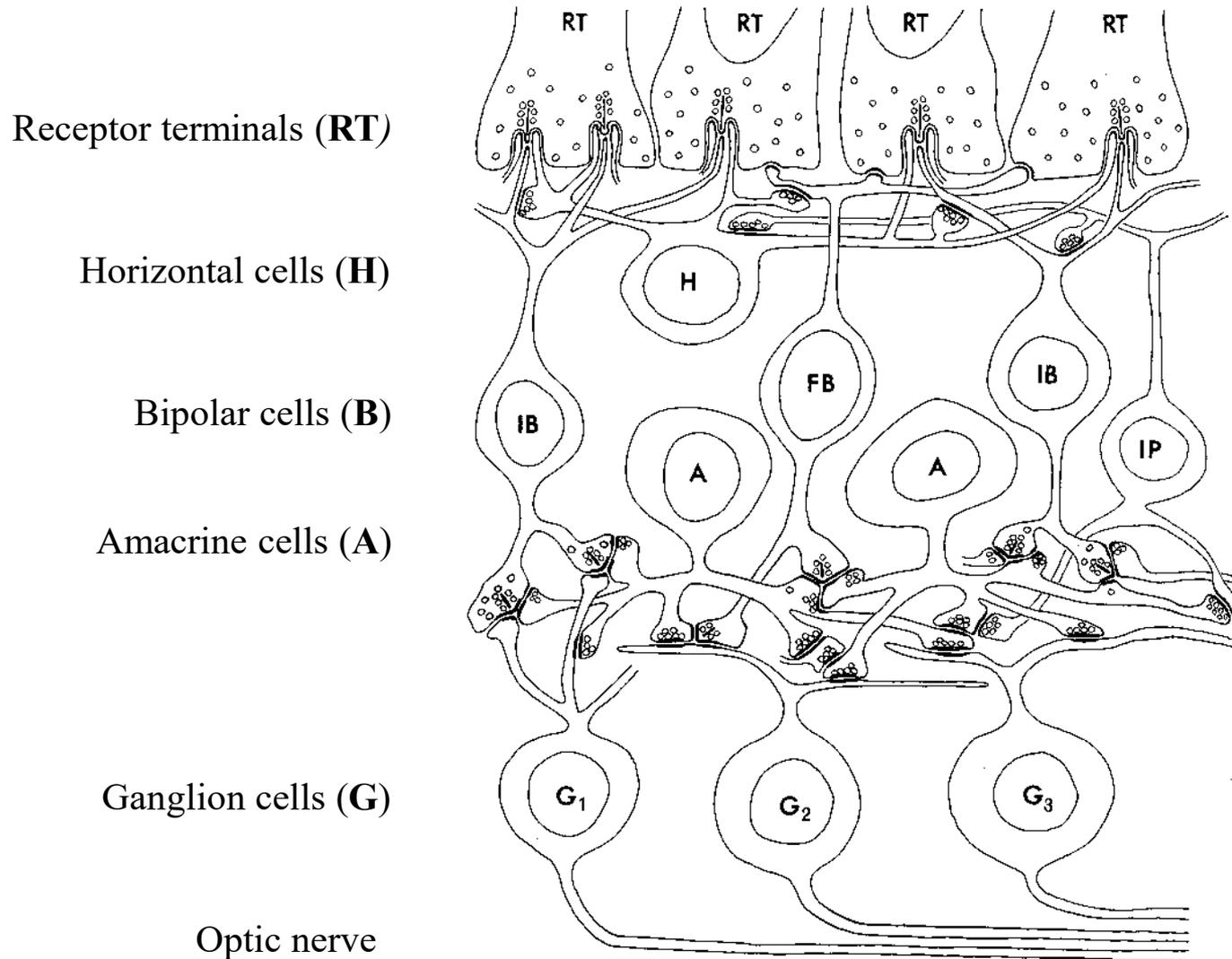
Cone responses adapt to background illumination

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

Concentric receptive fields
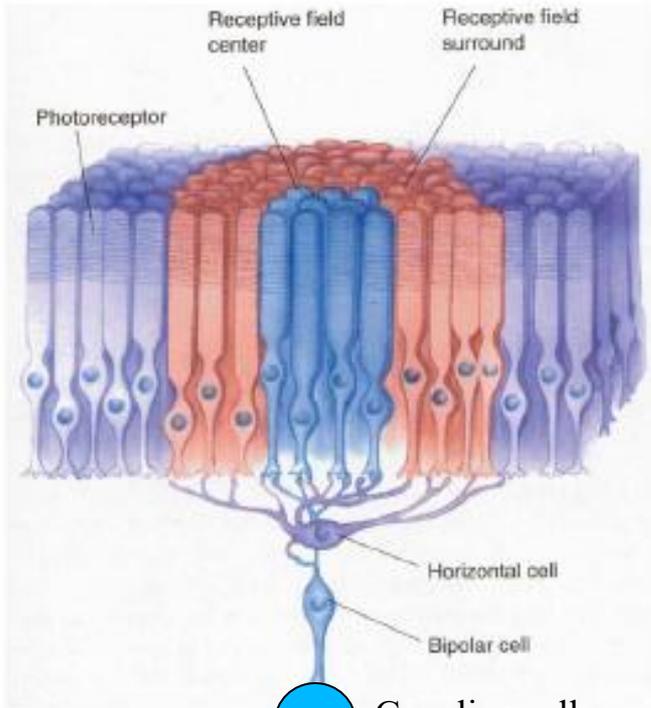
Ganglion cell
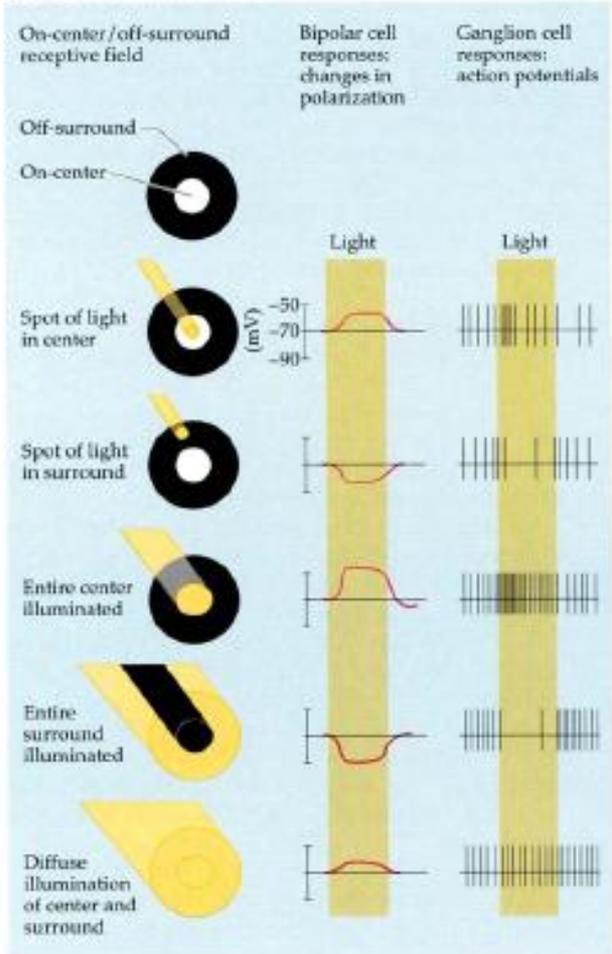
Ganglion cells adapt to the mean light intensity

Sakmann and Creutzfeldt (1969)
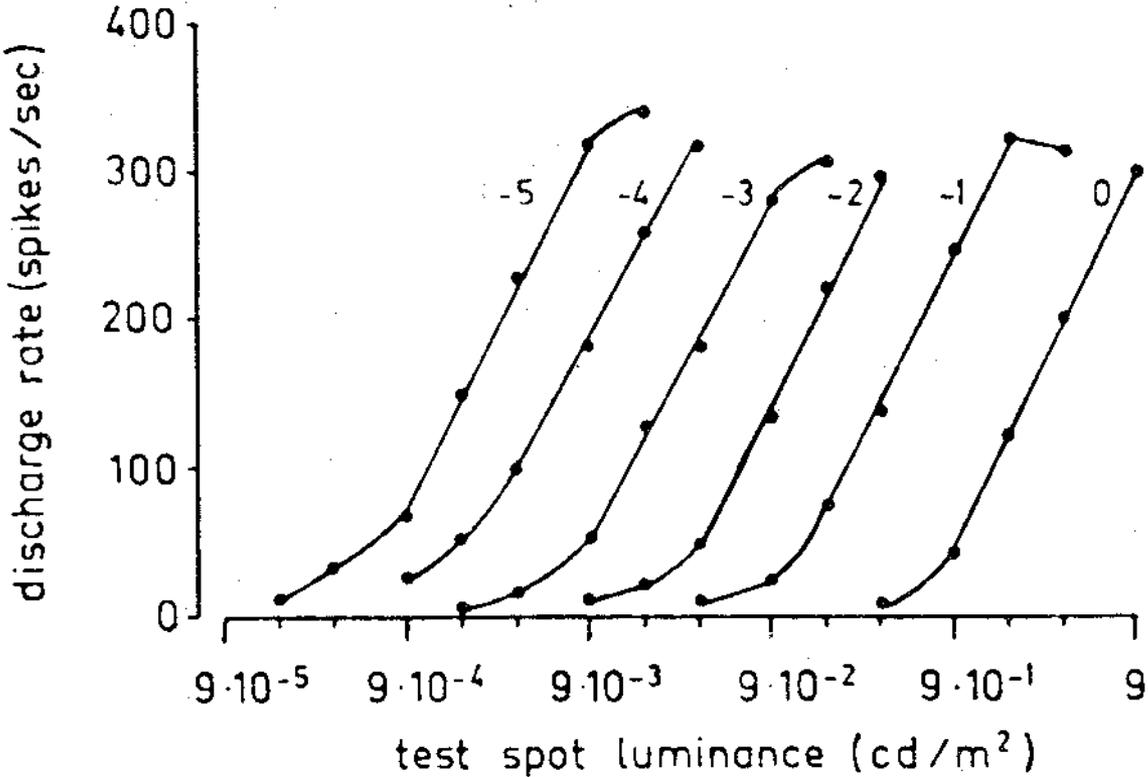
Ganglion cells have center-surround receptive fields
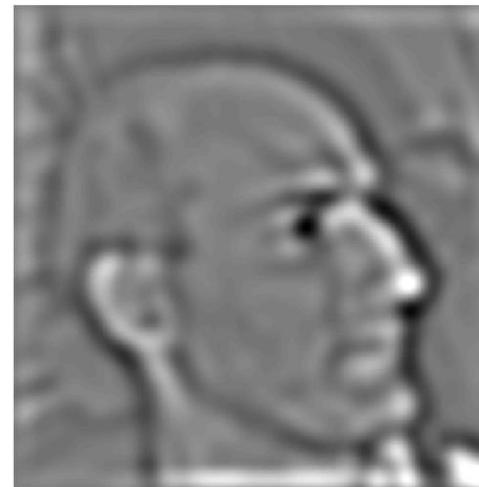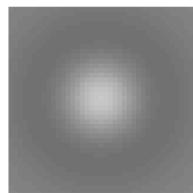

Dowling, 1987 (Fig 2.13)
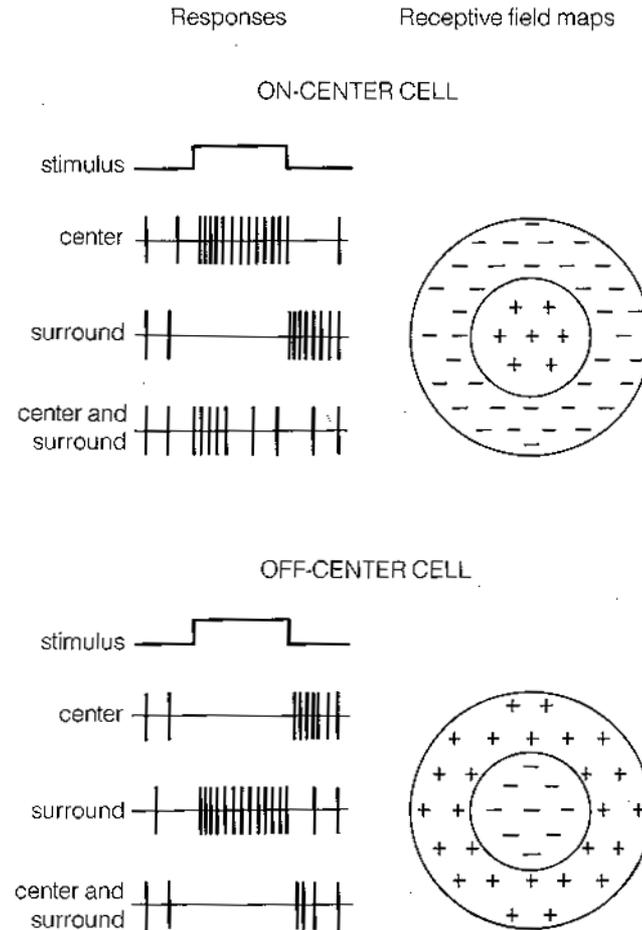
Examples of responses of an ON-center cell
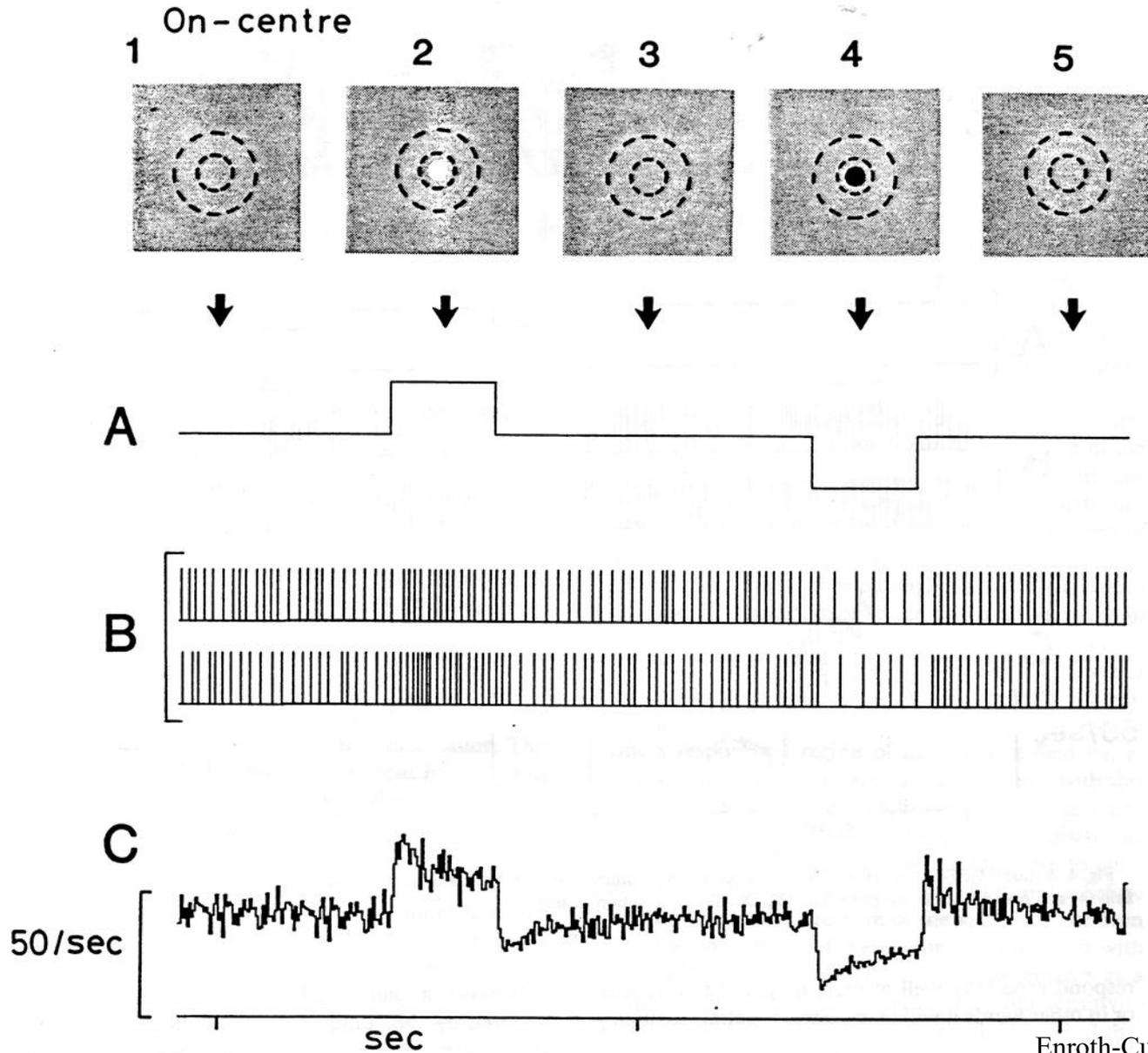
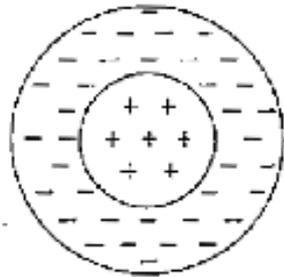# Examples of responses of an OFF-center cell
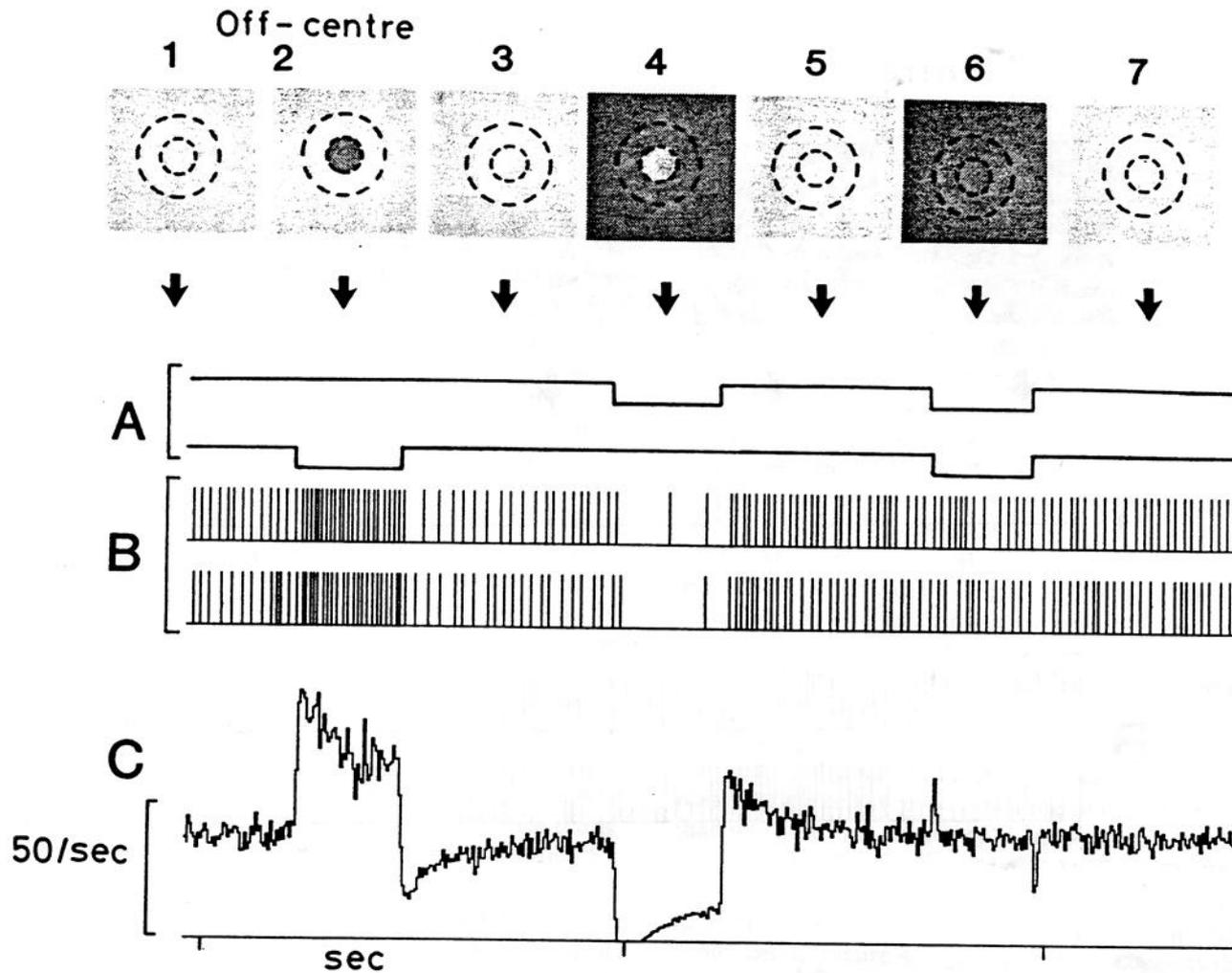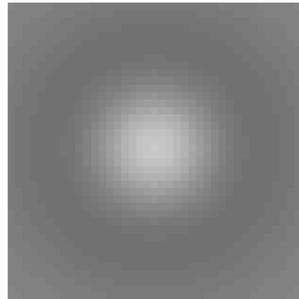
Center-surround receptive fields enhance edges

The linear model
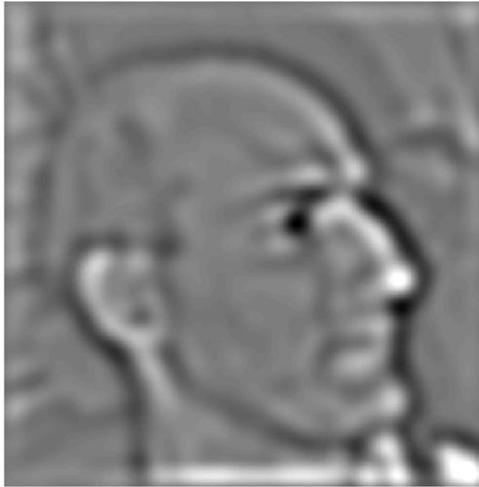
A model of the ganglion cell receptive field

ON-center
receptive field
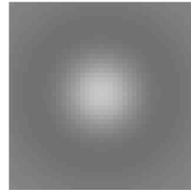
"Difference of
gaussians" model

$$R(x,y) = \iint F(u,v)\, I\,(x{+}u,\ y{+}v)\ dudv$$

Assumptions implicit in the last 3 slides

•Receptive fields are difference of gaussians

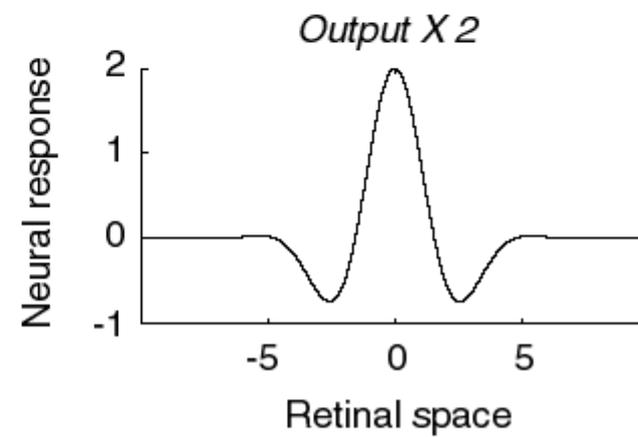•Responses are a weighted average of the stimulus intensity, where the map of the weights is the receptive field.
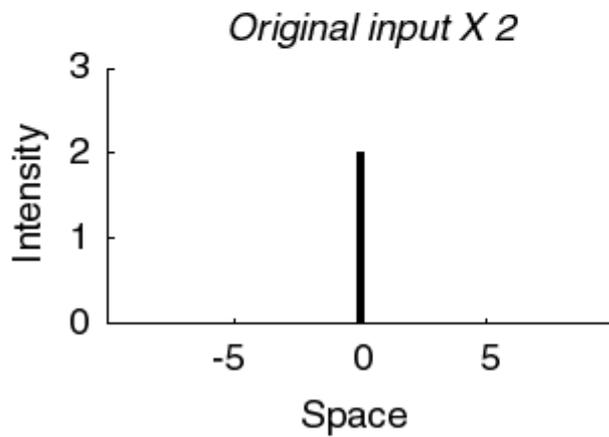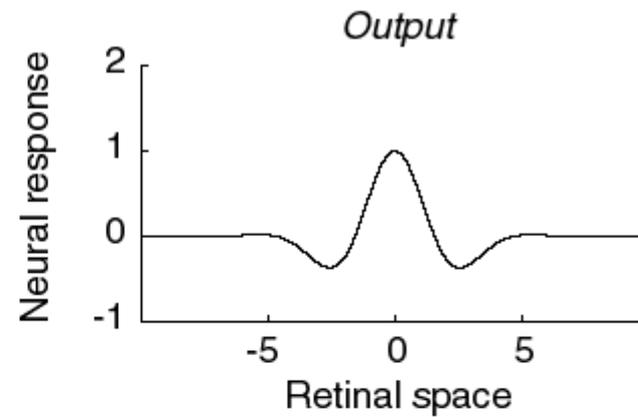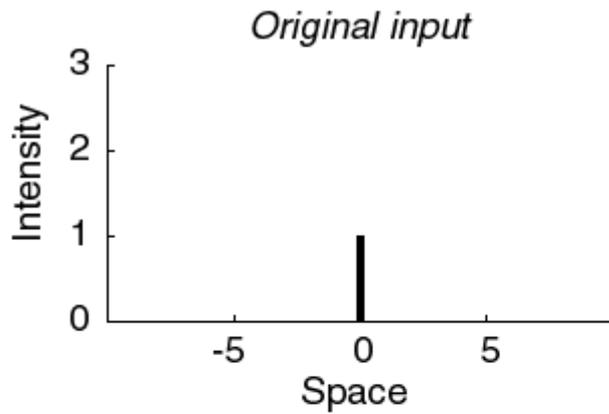
Are these assumptions reasonable?

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

Linear systems L(x) obey

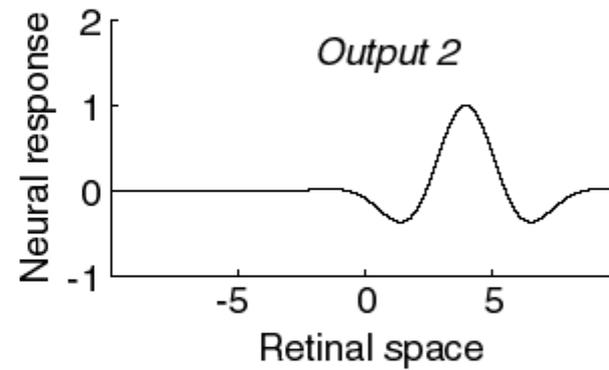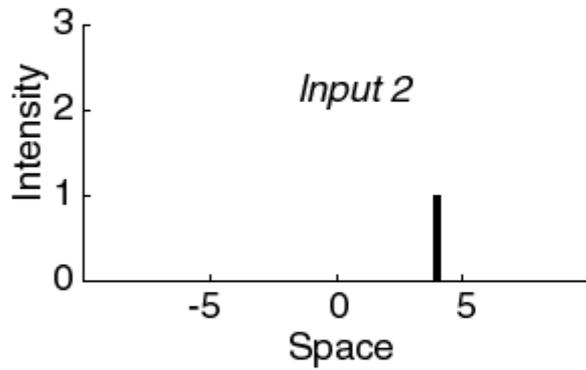- homogeneity: $L(a\,x) = a\,L(x)$

- superposition: $L(x+y) = L(x) + L(y)$

Homogeneity

Original input

Output

Original input X 2

Output X 2

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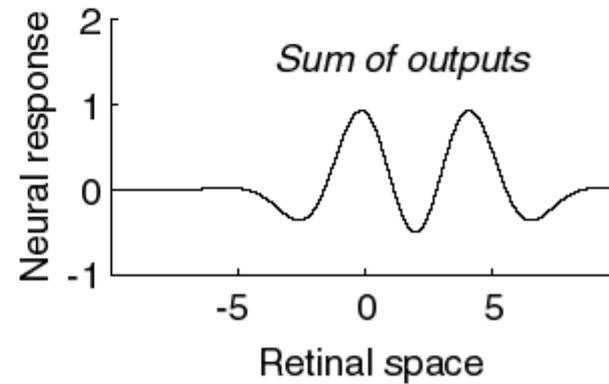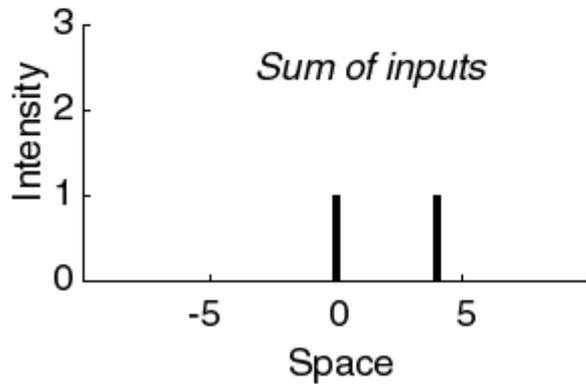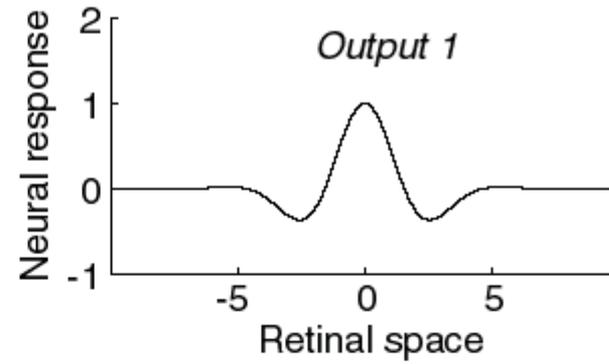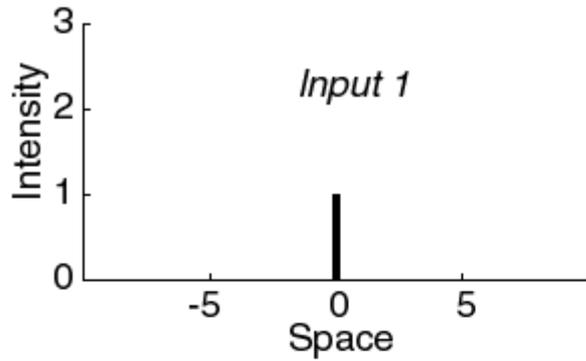
Linearity is often checked by using sinusoidal stimuli, because for a linear system:

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

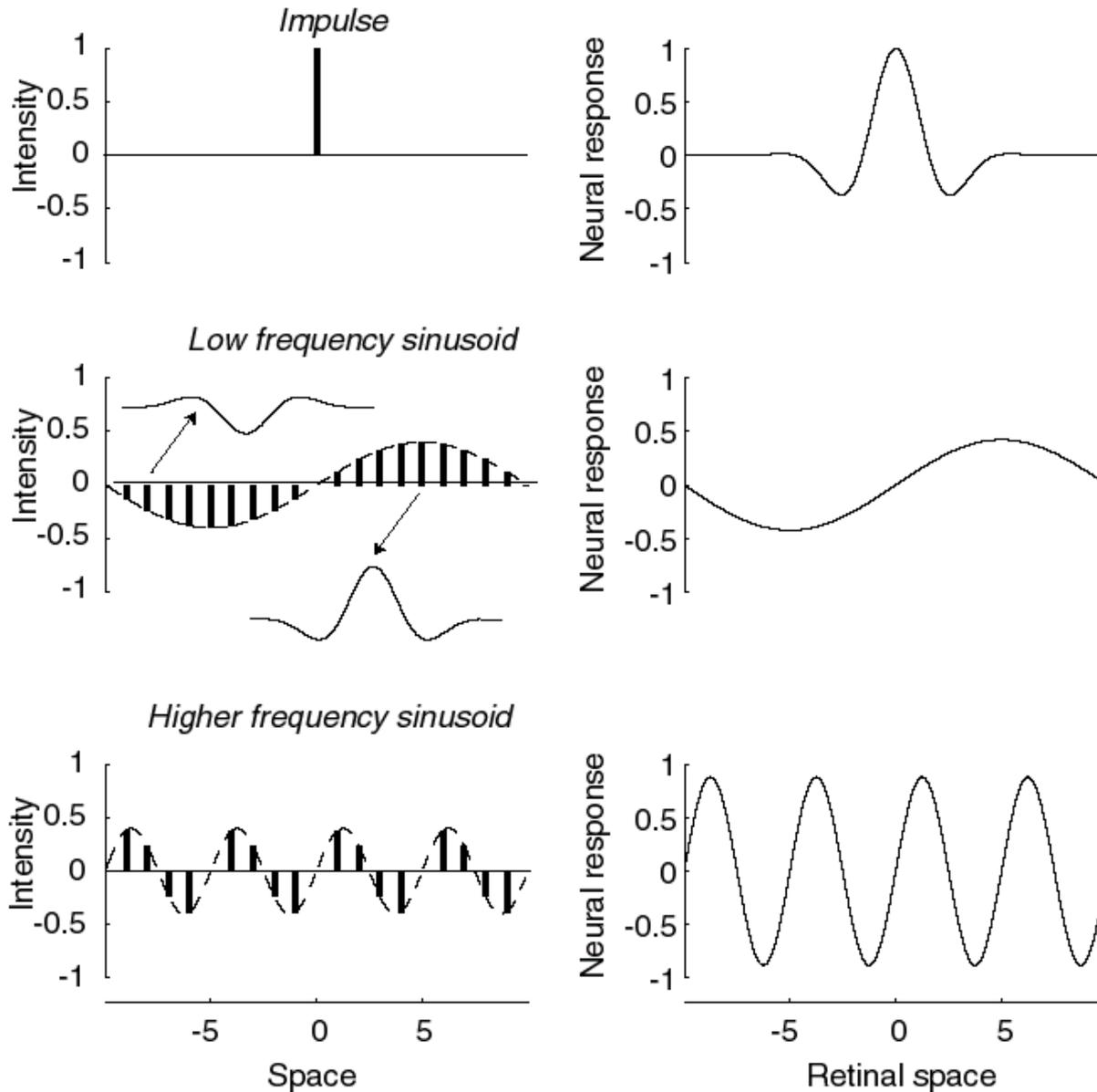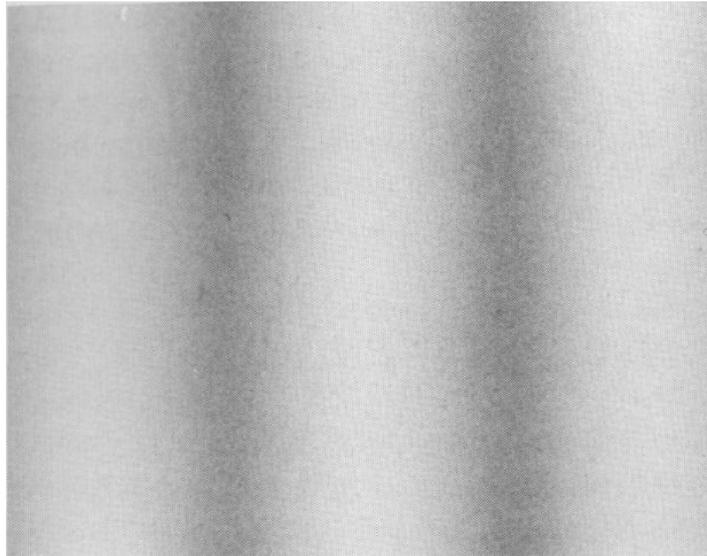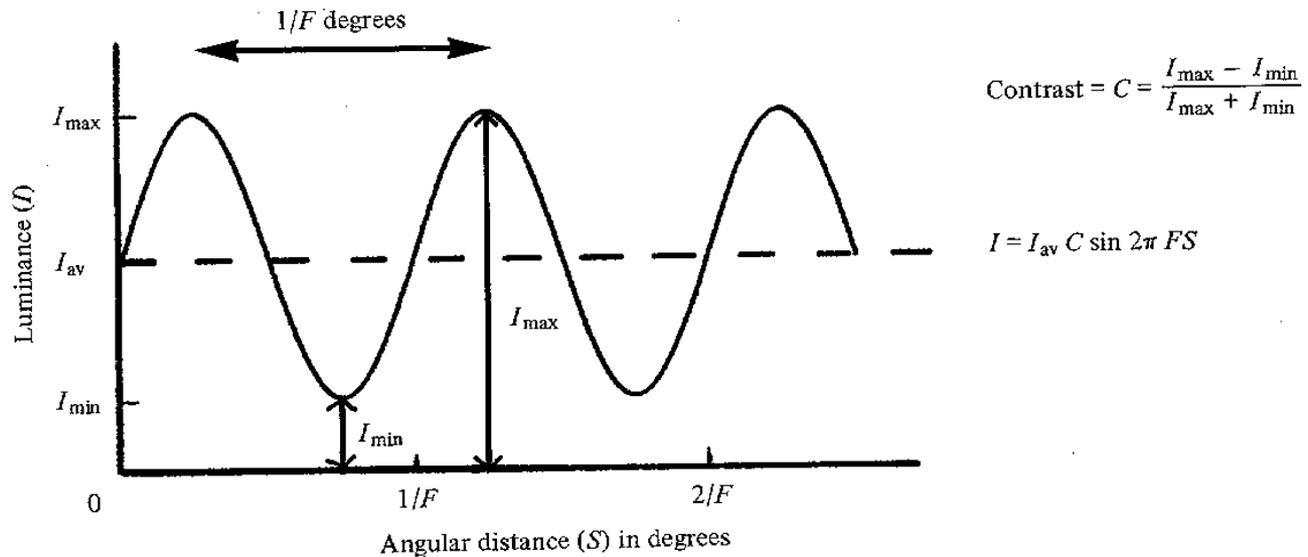# A sinusoid in 2-D: a sinusoidal grating

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

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

Barlow and Mollon, 1982 (Fig 1.3)

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

Responsivity

1.0

0.1

0.01

a   b   c

0.01   0.1   1.0

Spatial frequency

a

b

c

Enroth-Cugell and Robson (1984)
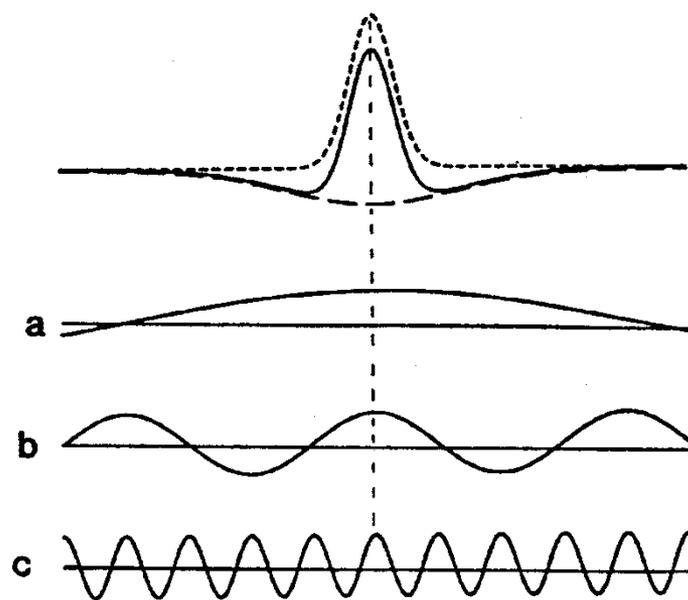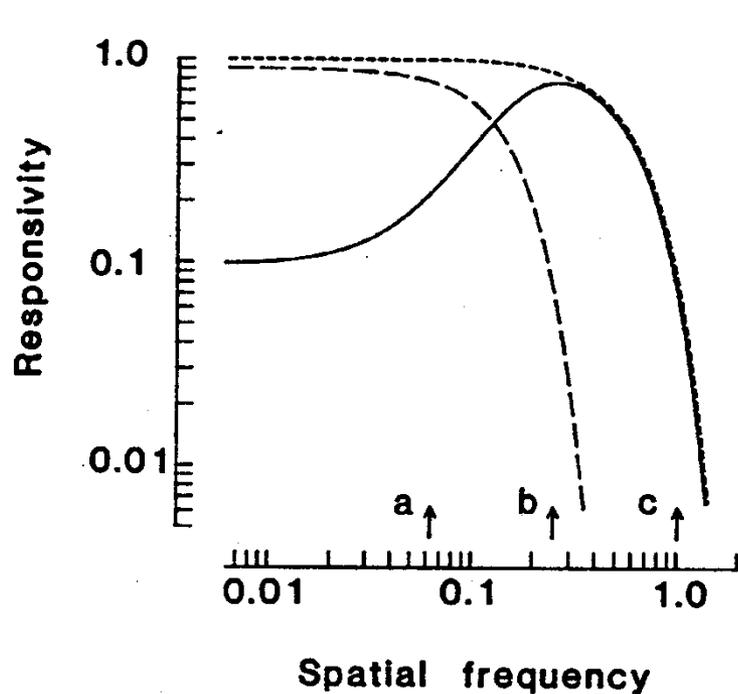
Fitting the model to the data

Enroth-Cugell et al. (1983)
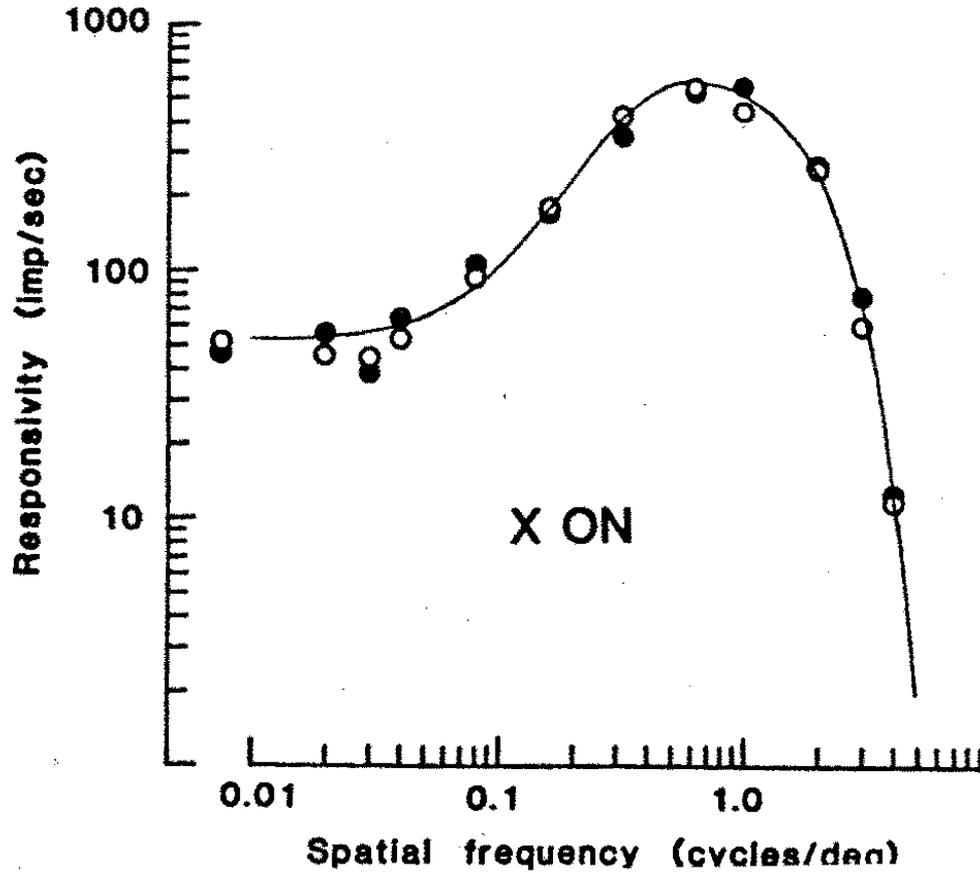
The fits are good: the responses to sinusoids are predictable by a linear model with a "difference of gaussians" receptive field.
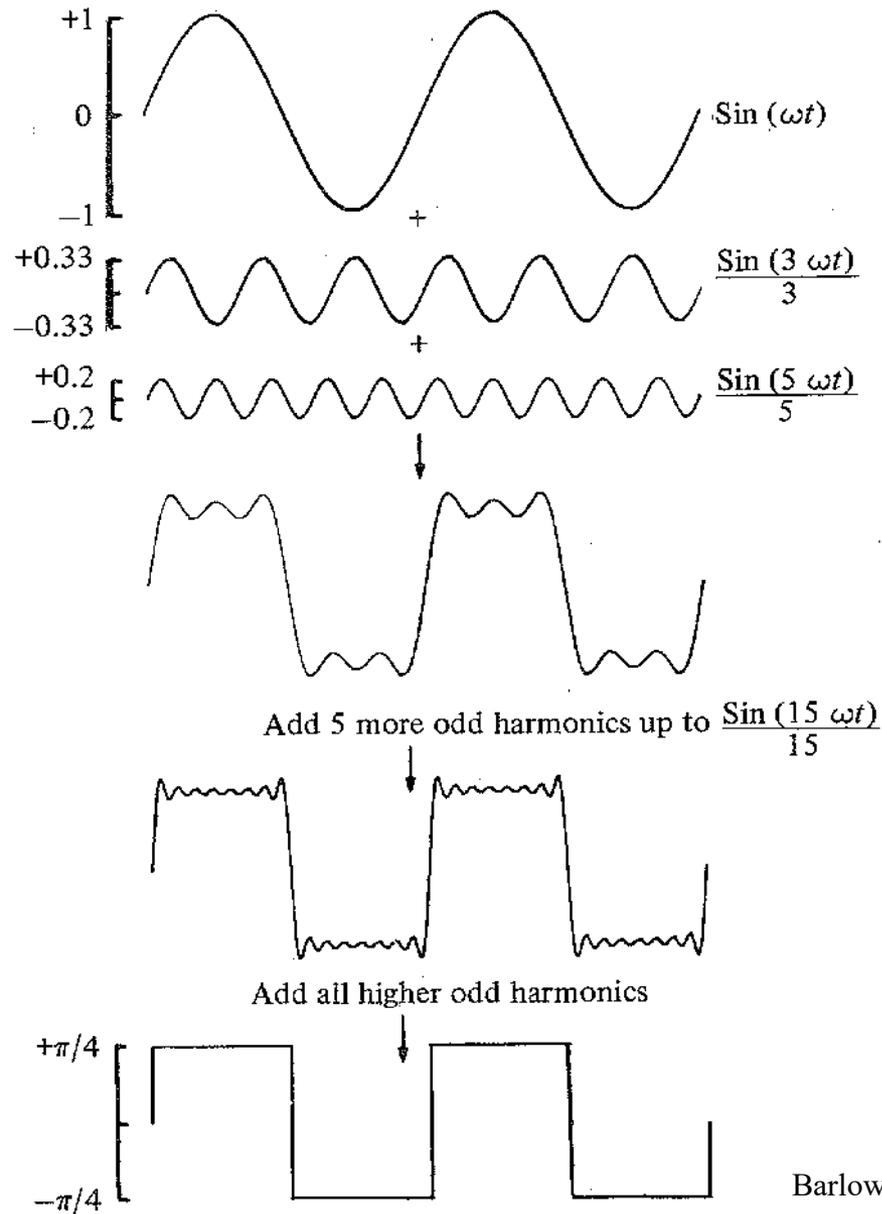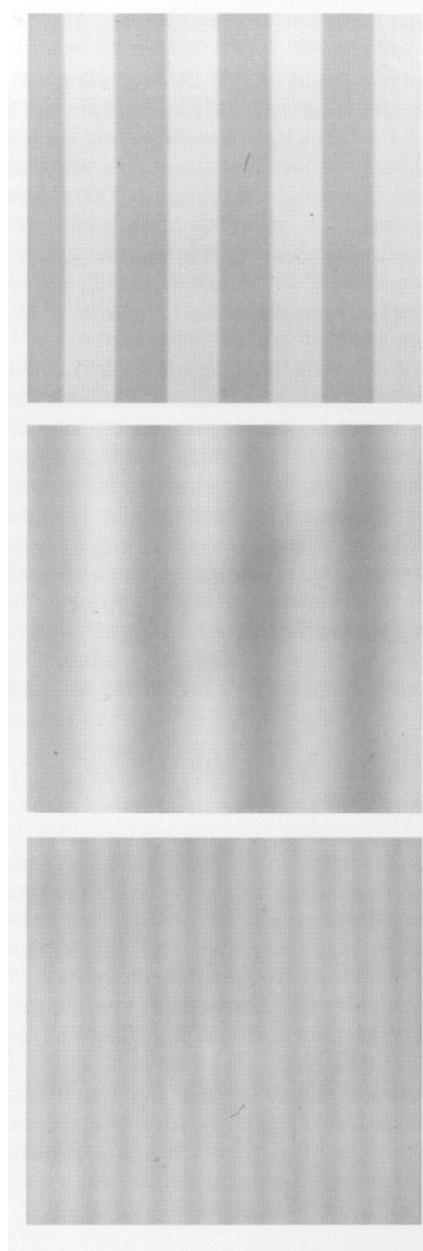
Let's try another test of linearity. If it succeeds as well, we'll be happy with the model.

Making a square wave with sinusoids

$\mathrm{Sin}\,(\omega t)$

$\dfrac{\mathrm{Sin}\,(3\,\omega t)}{3}$

$\dfrac{\mathrm{Sin}\,(5\,\omega t)}{5}$

Add 5 more odd harmonics up to $\dfrac{\mathrm{Sin}\,(15\,\omega t)}{15}$

Add all higher odd harmonics

Barlow and Mollon, 1982 (Fig 1.2)
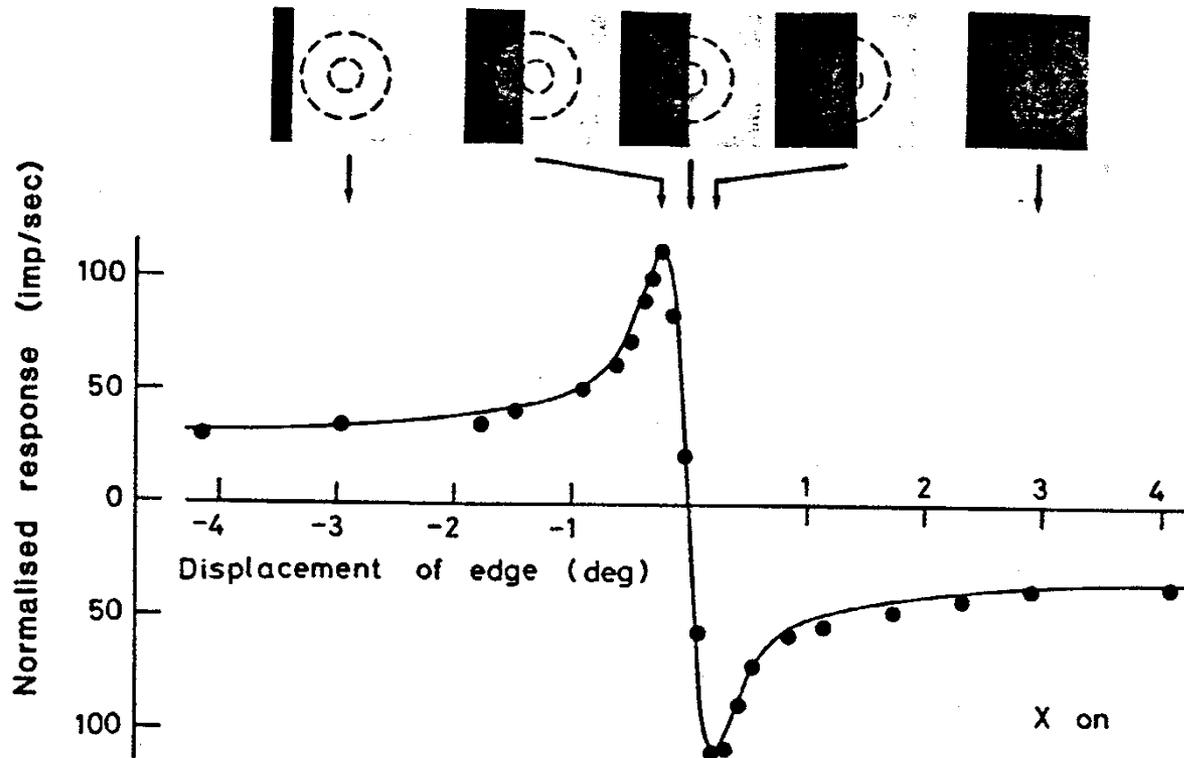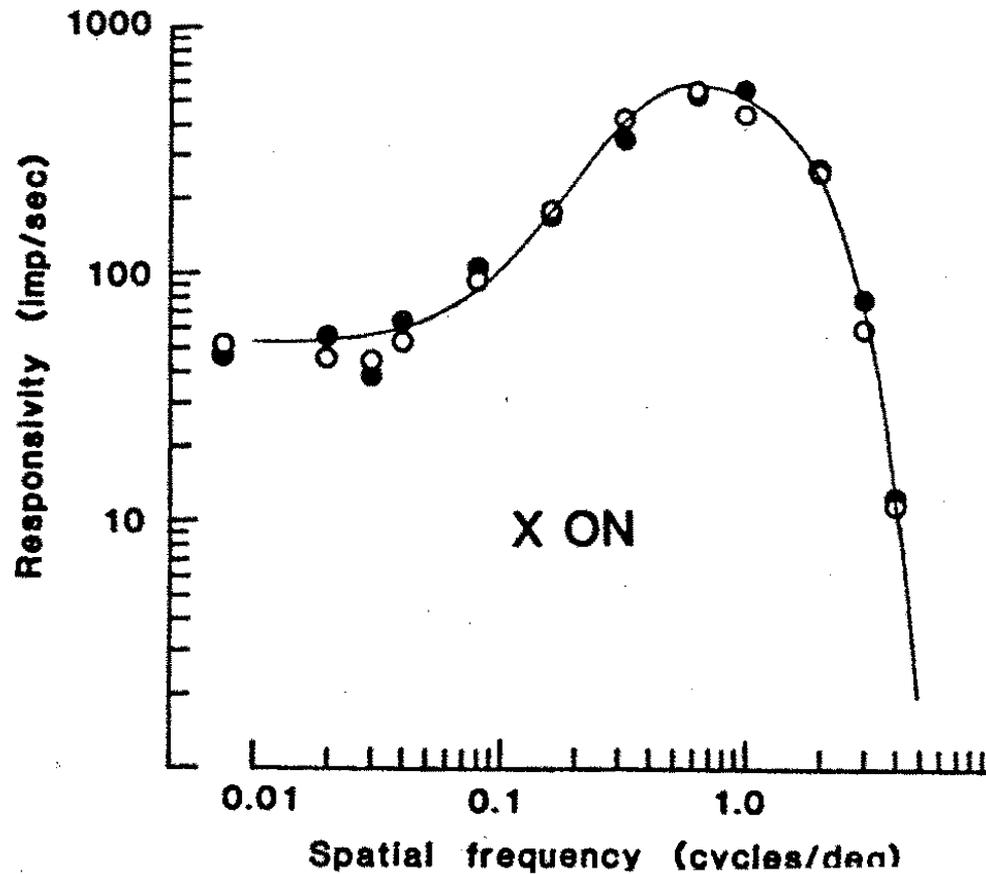
Square waves in 2-D

Responses of a ganglion cell to edges

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
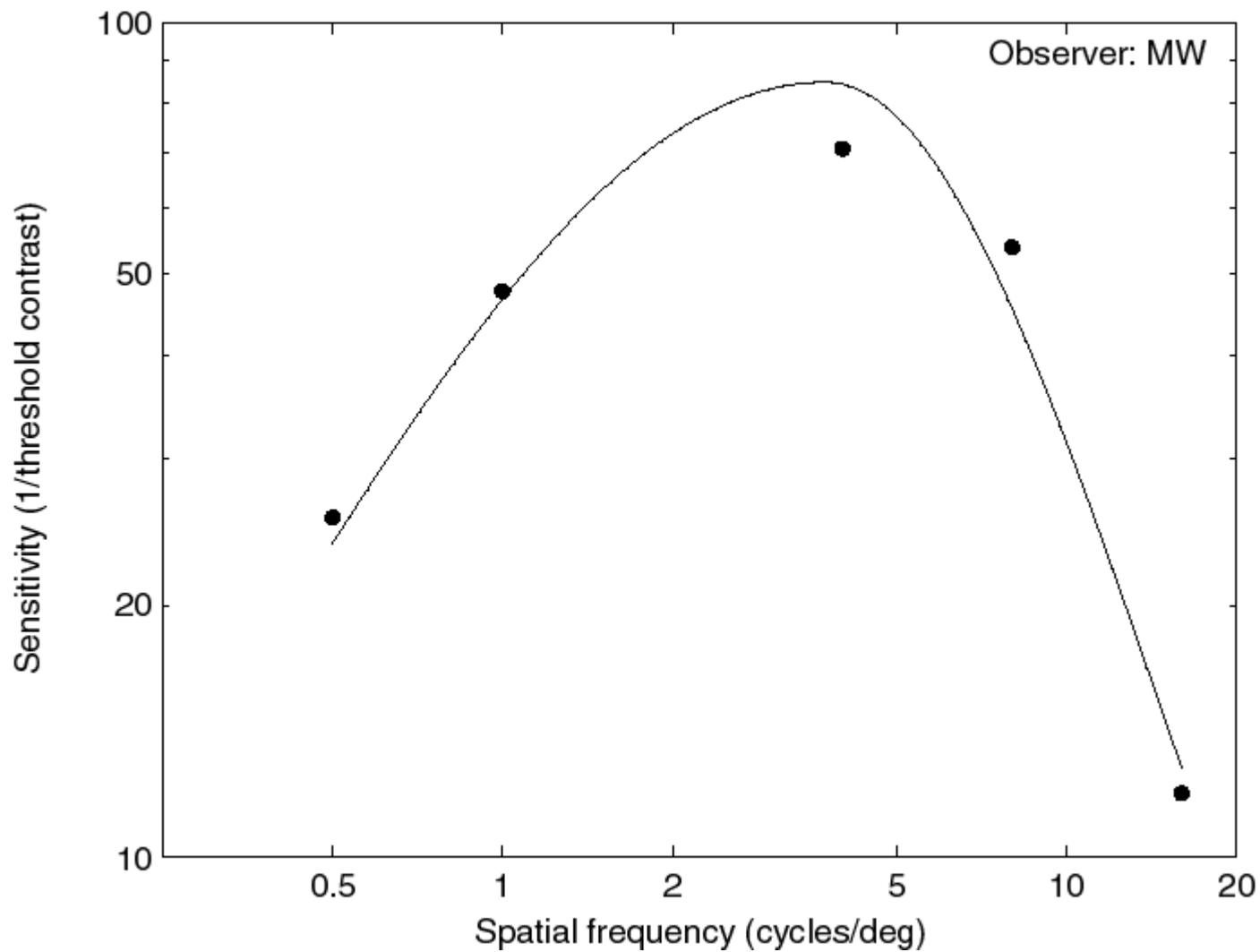
Contrast sensitivity varies with spatial frequency

One interpretation of the contrast sensitivity curve