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

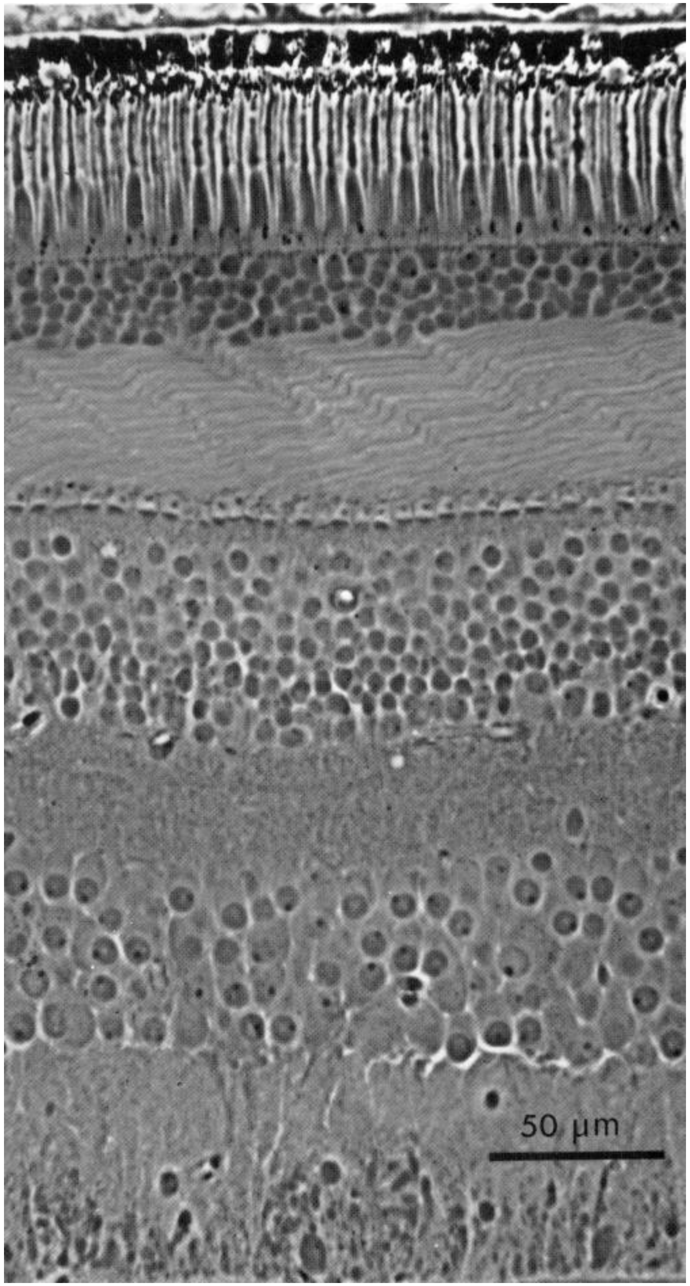
Receptors: rods and cones

Bipolar and Horizontal cells

Amacrine cells

Ganglion cells

Optic nerve

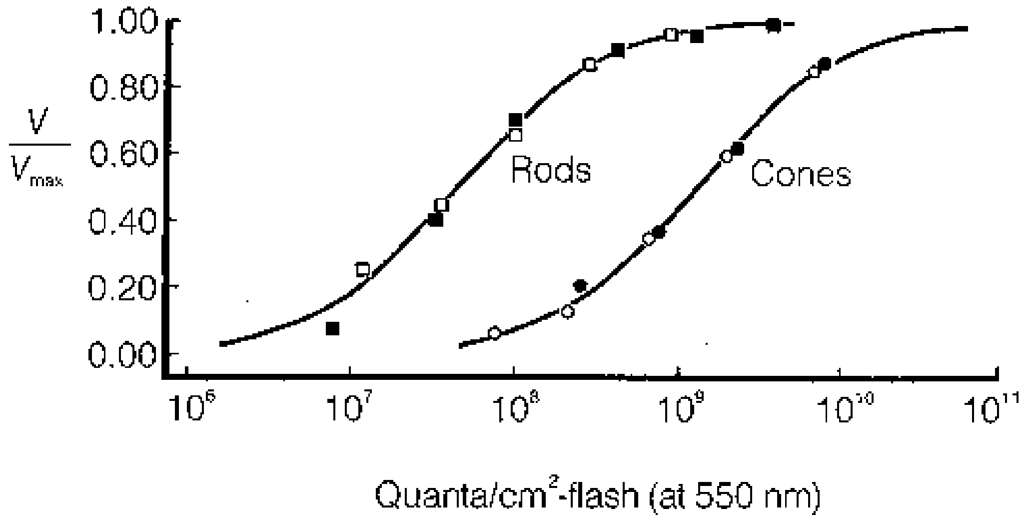


Dowling, 1987 (Fig 2.1)
Boycott and Dowling (1969)

Phototransduction in rods and cones

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

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

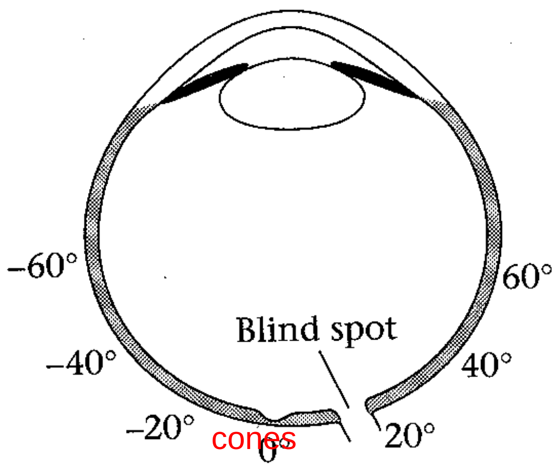


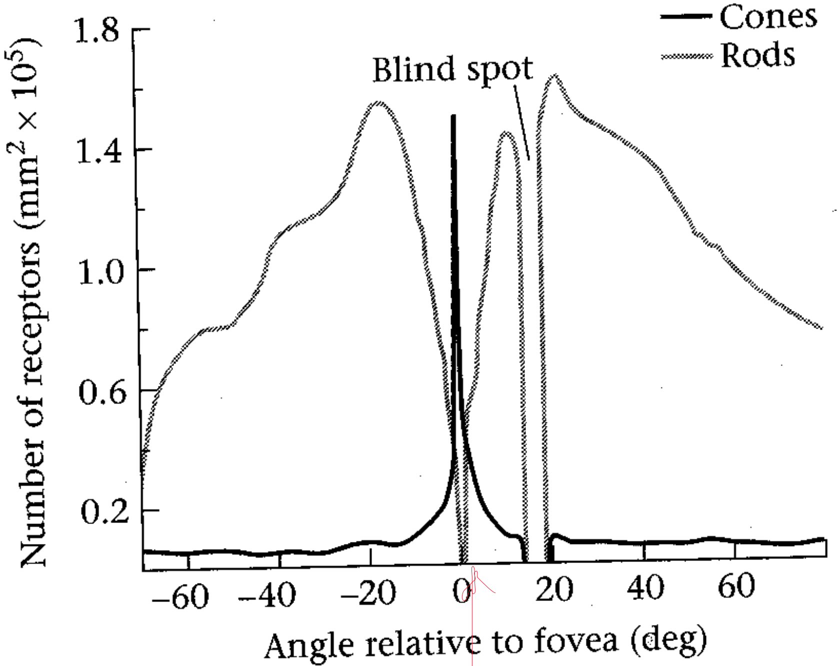
Dowling, 1987 (Fig 4.3b)

Distribution of rods and cones:

a view from the side

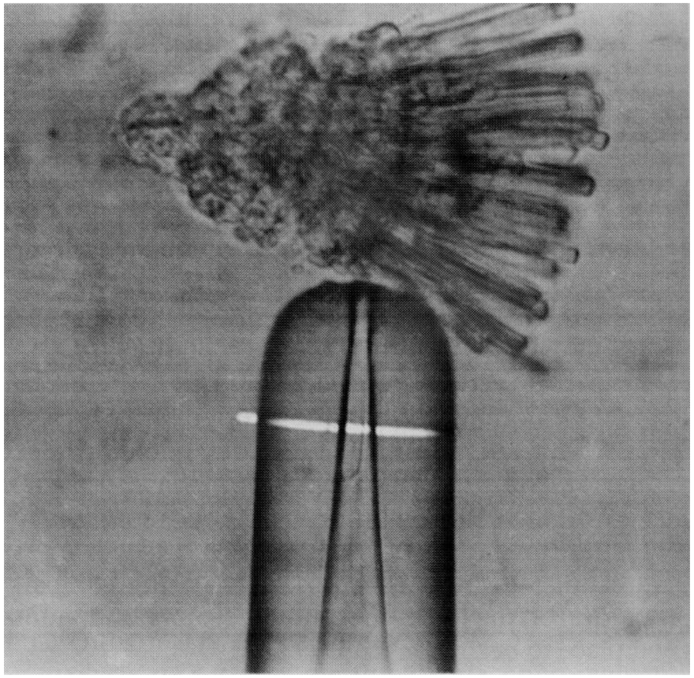
distribution of cones and rods are not homogoneously distributed

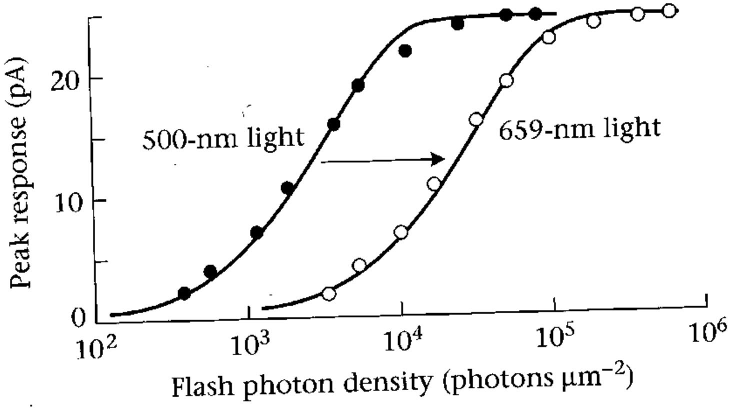




Wandell, 1995 (Fig 3.1)

Response of a cone to light of two different wavelengths





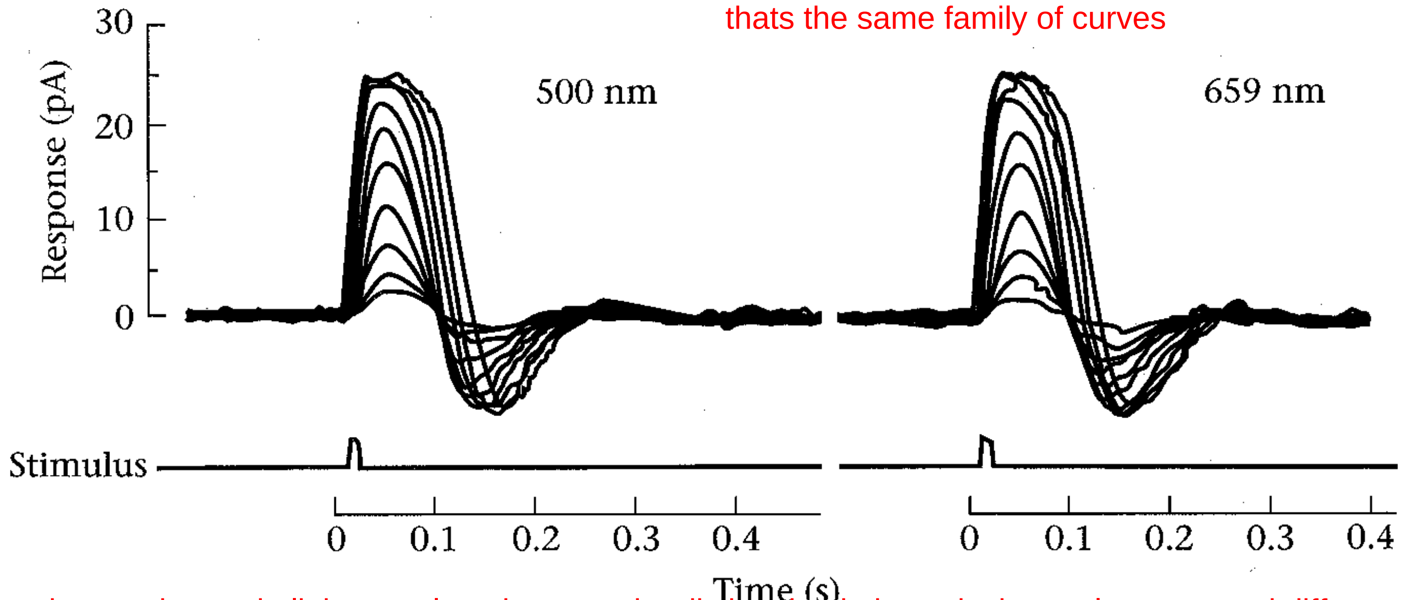
response is wavelength depended

Wandell, 1995 (Figs 4.15-4.16)

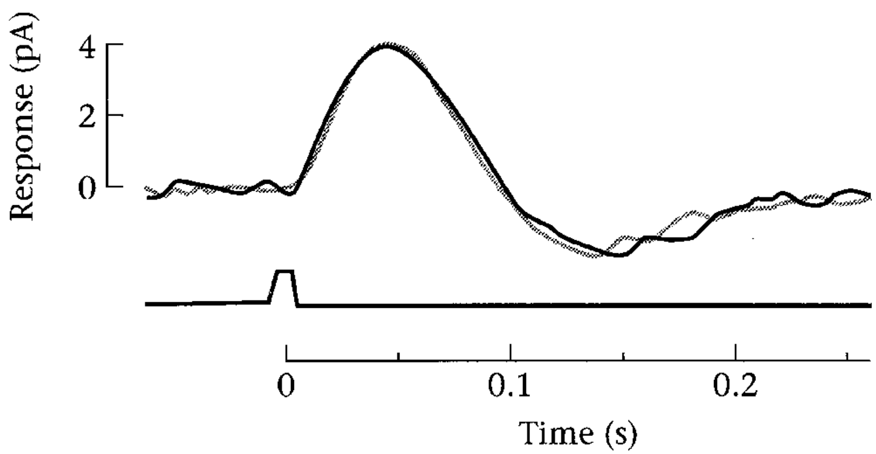
intensity or wavelength can change to change the curve

Principle of univariance

thats the same family of curves



change in light intensity or vchange in light wavelength cannot be distinguised. the rods themselves respond differently to different wavelengths

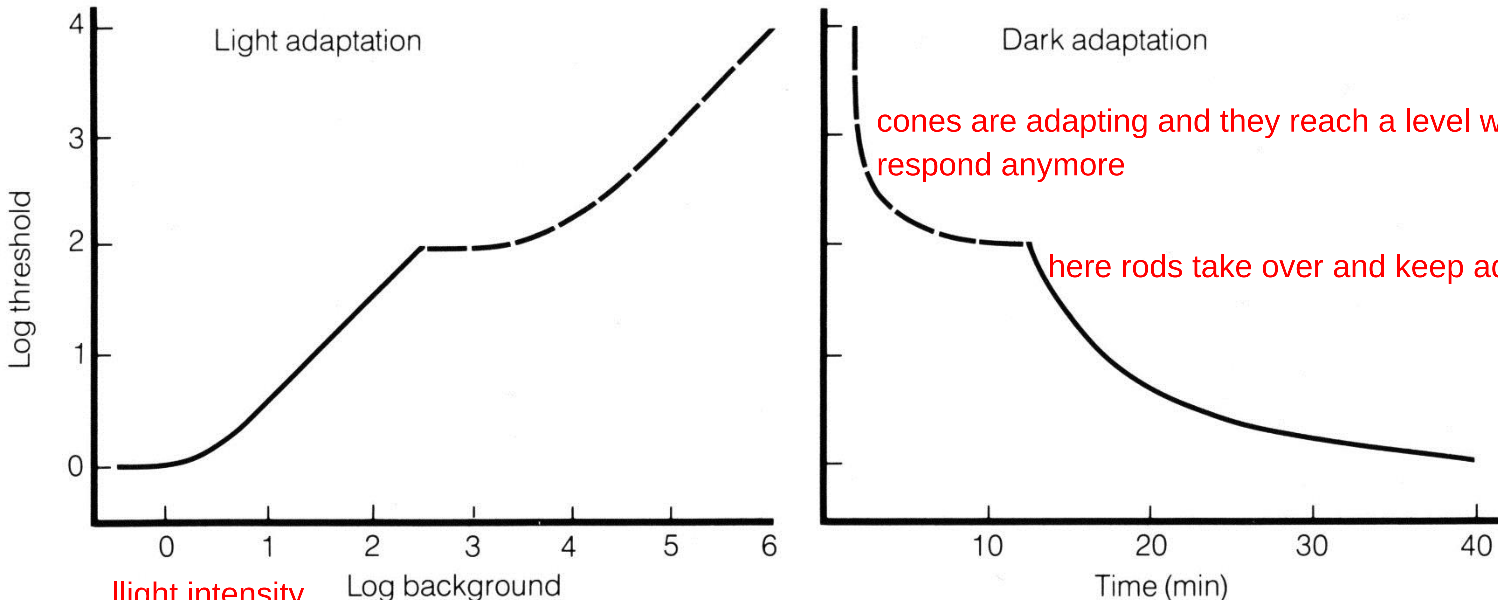


Wandell, 1995 (Figs 4.17-4.18)

Light adaptation

retina responsible for light adaptation starts at the level of photoreceptors and conintous in the pahway, all of these cells are capable of light adaptation

Human light and dark adaptation



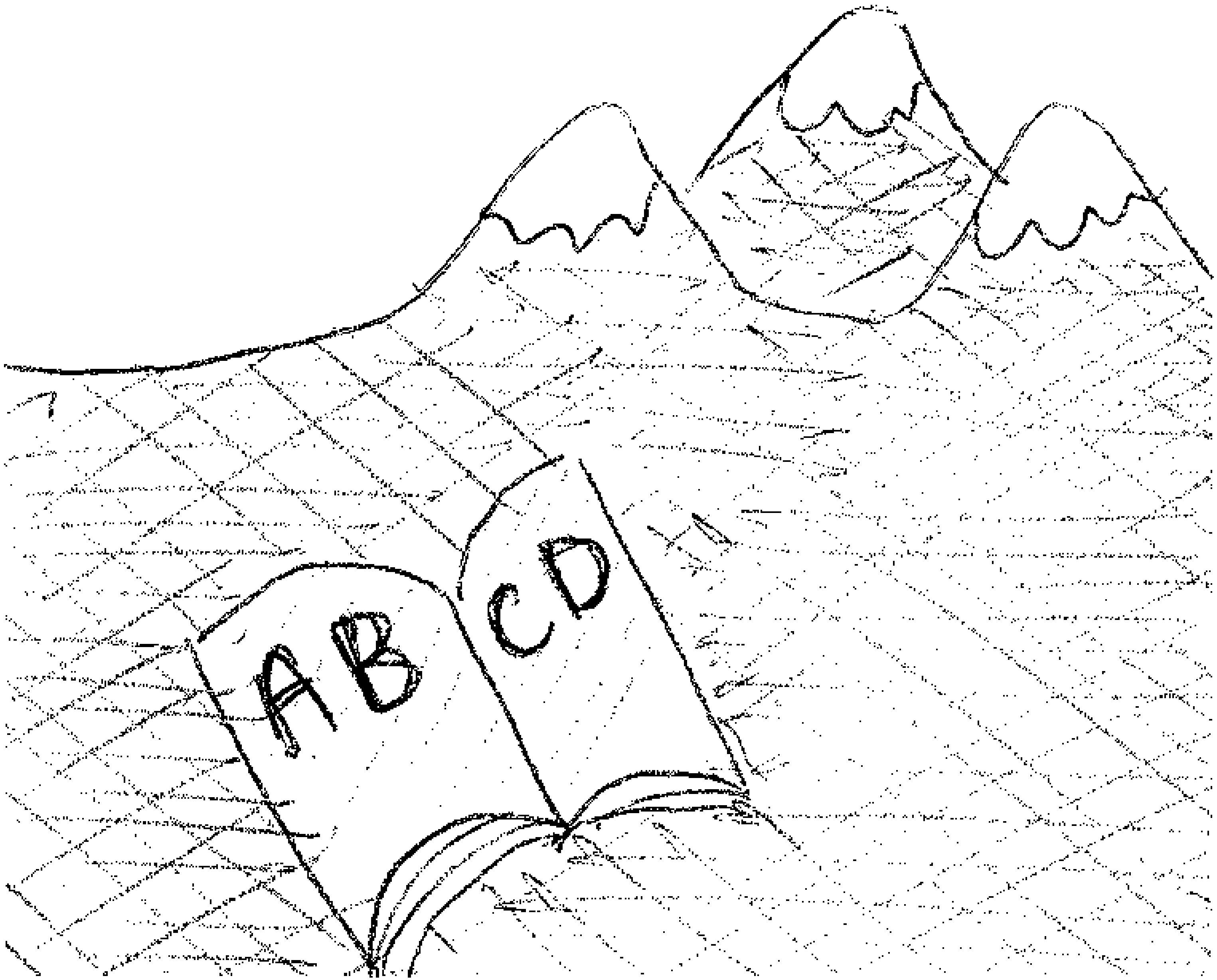
cones are adapting and they reach a level where they cannot respond anymore

here rods take over and keep adapting

llight intensity

after 40 mins, ppl become very sensitive in dark environment
5-7 absorbed photons are enough to have vision
1 photon is enough to activate a photoreceptor. we have extremely sensitive retinas due to the sensitivity of the rods

The Jungfrau viewed from Wengen



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

retina doesnt care about changes in intensity, vision does not depend so much on light availibility (recogntion of objects happens at most levels of light intensity), but local contrast is a lot more important and it's what our retina signals to brain7
RF of ganglion cells makes that kind of signalling
what does the retina do: gets rid of changes in illumination (not completely ofc)

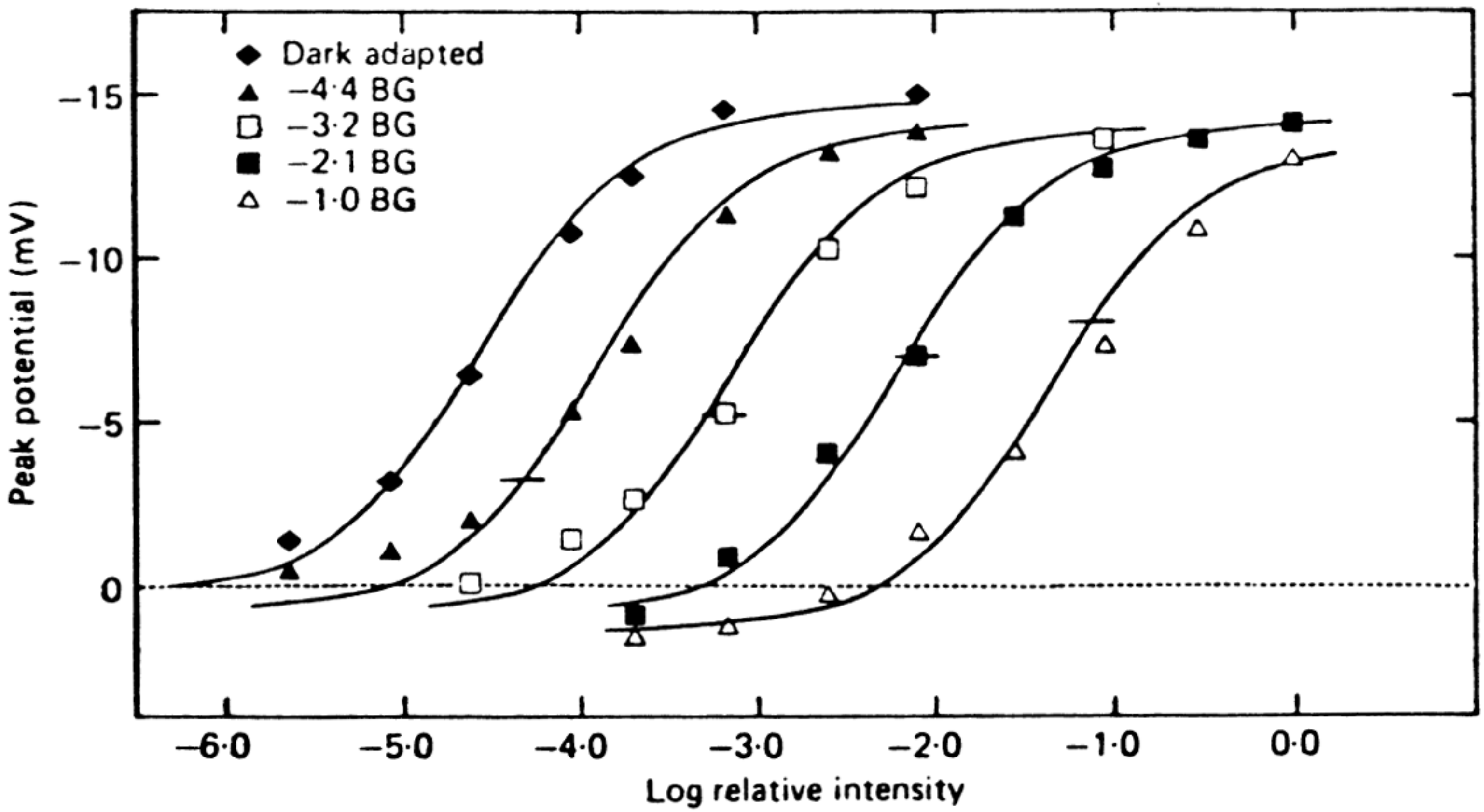
	Reflectance of surface	Intensity *I* at noon (1000000 W)	Intensity *I* at dusk (1000 W)	Local contrast *c* at noon (1000000 W)	Local contrast *c* at dusk (1000 W)
Snow	90%	900000 W	900W	1.25	1.25
Grass	40%	400000 W	400 W	0	0
Paper	80%	800000 W	800 W	1	1
Ink	10%	100000 W	100 W	-0.75	-0.75
Mean	40%	400000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

*Intensity I is reflectance*illuminance.*

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

BG := background

Cone responses adapt to background illumination



Norman & Perlmann (1979)

Light adaptation is somewhat local in space

these eclipses are the same light intensities
the retina though computes the contrasts, so they are perceived differently (distrinction in brightness)
light intensity does not completely determine our perception. brightness is a psychological term and cannot be measure:
only can be measured how it appears to a human observer. light has no brightness so to say, as brightness depends on human perceptiopn and does not so depend on wavelength of light, just like color.

Ganglion cells

Basic retinal circuitry

Receptor terminals (**RT**)

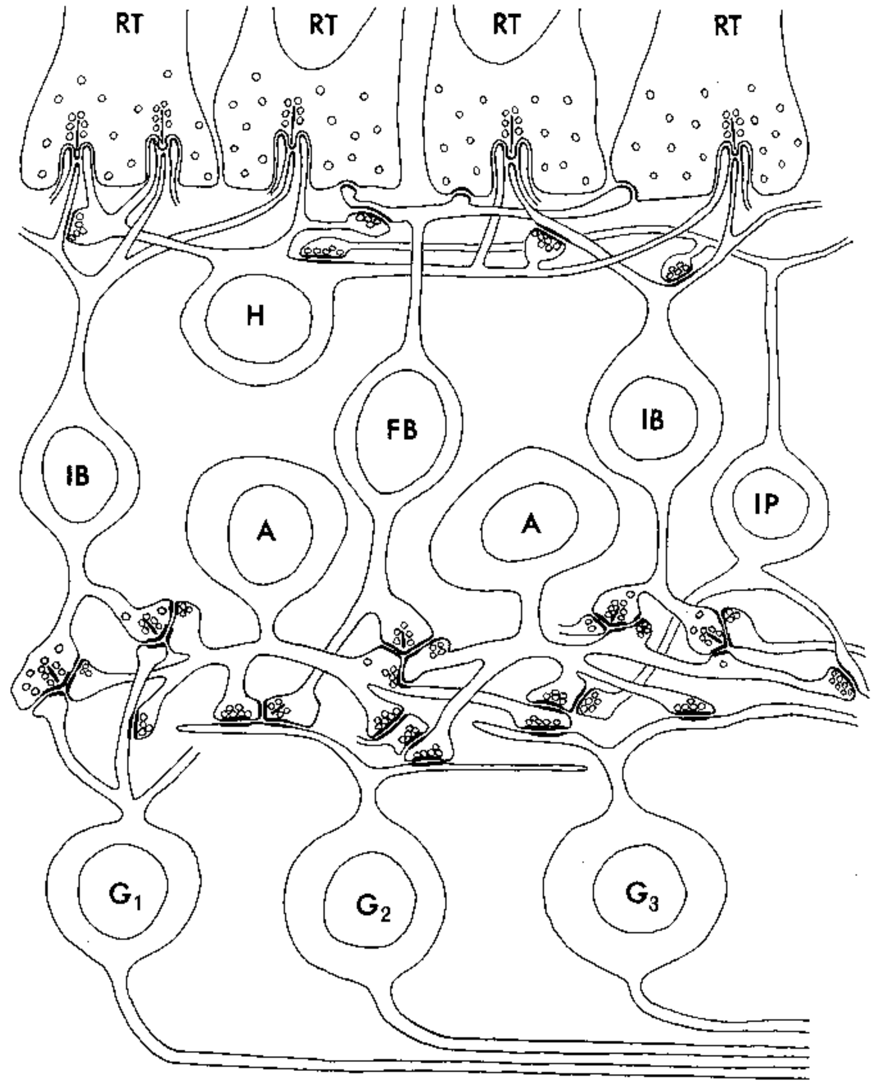
Horizontal cells (**H**)

Bipolar cells (**B**)

Amacrine cells (**A**)

Ganglion cells (**G**)

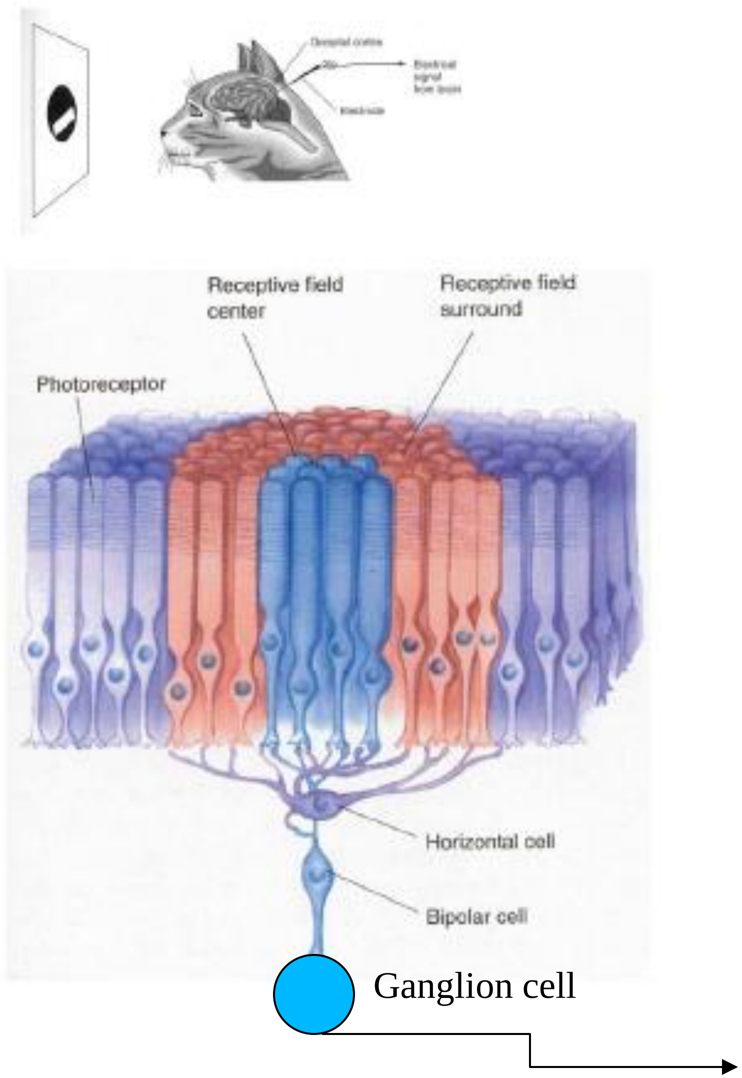
Optic nerve

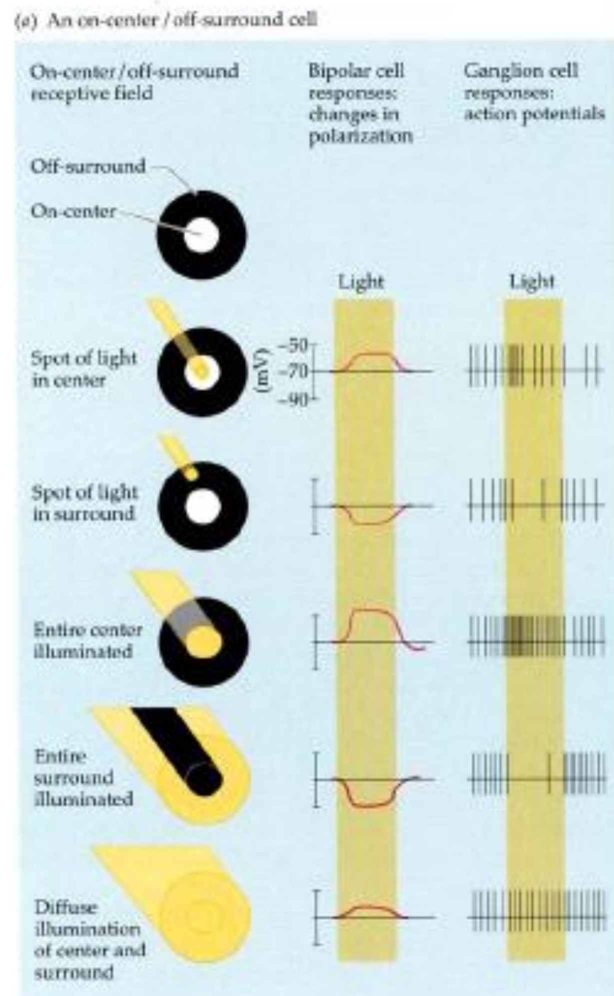


Dowling, 1987 (Fig 3.17)

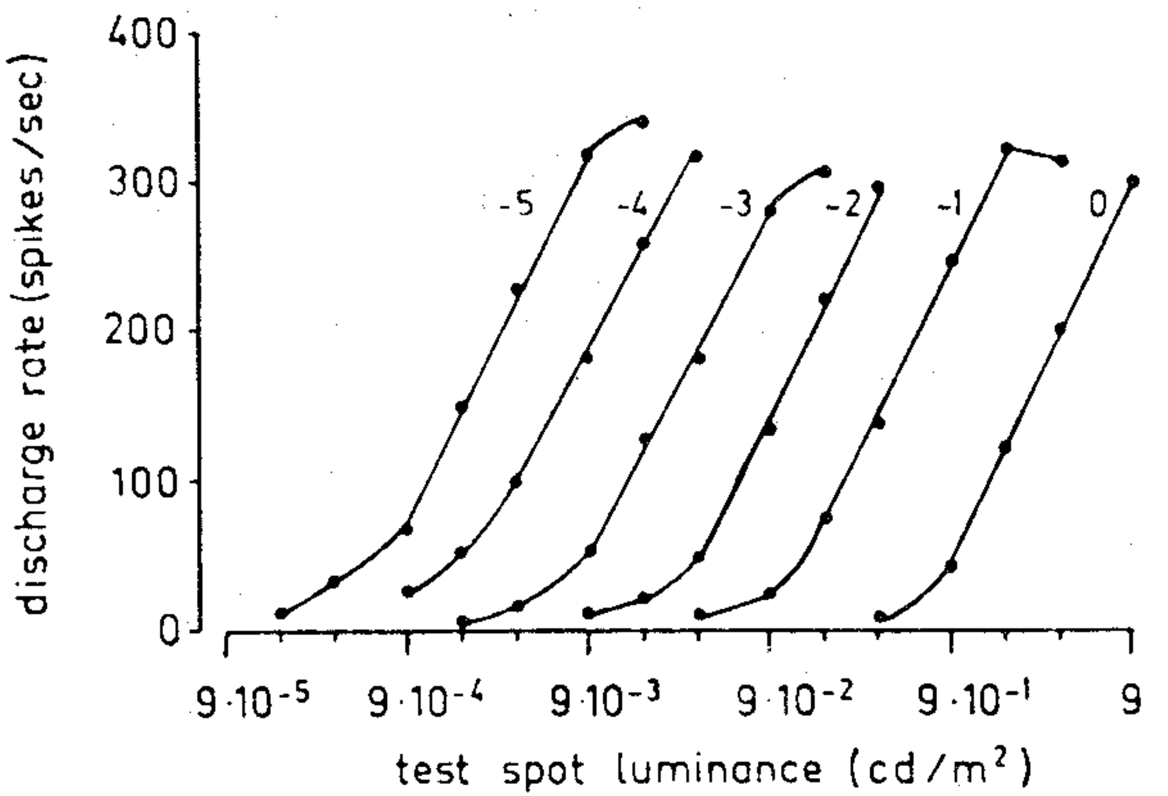
RF in cortical cells look also differnet than when compared to ganglion cells or photoreceptor cells

Concentric receptive fields



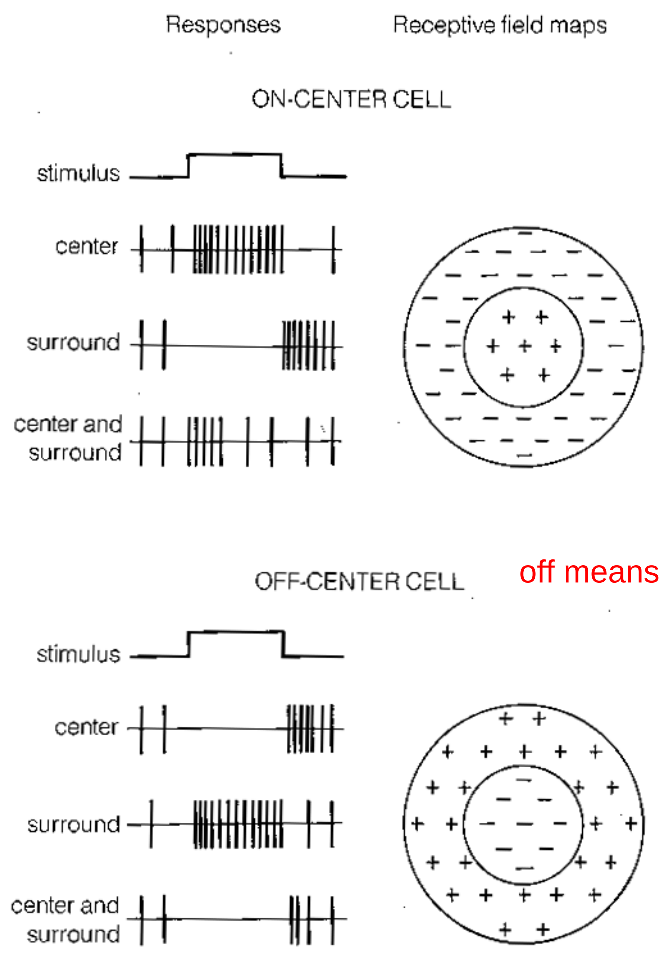


Ganglion cells adapt to the mean light intensity



Sakmann and Creutzfeldt (1969)

Ganglion cells have center-surround receptive fields

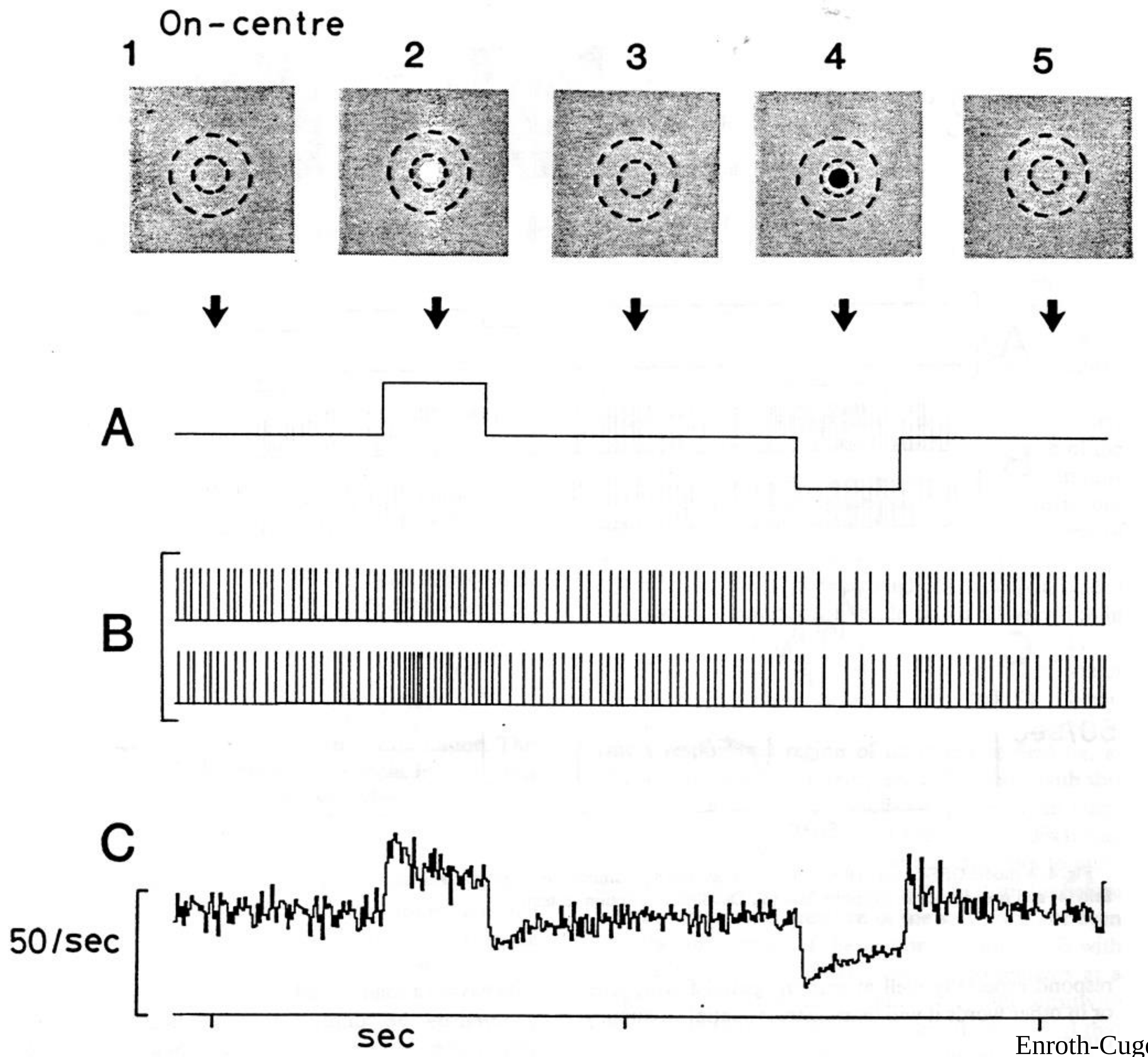


off means: response when light intensity is decreased

Dowling, 1987 (Fig 2.13)

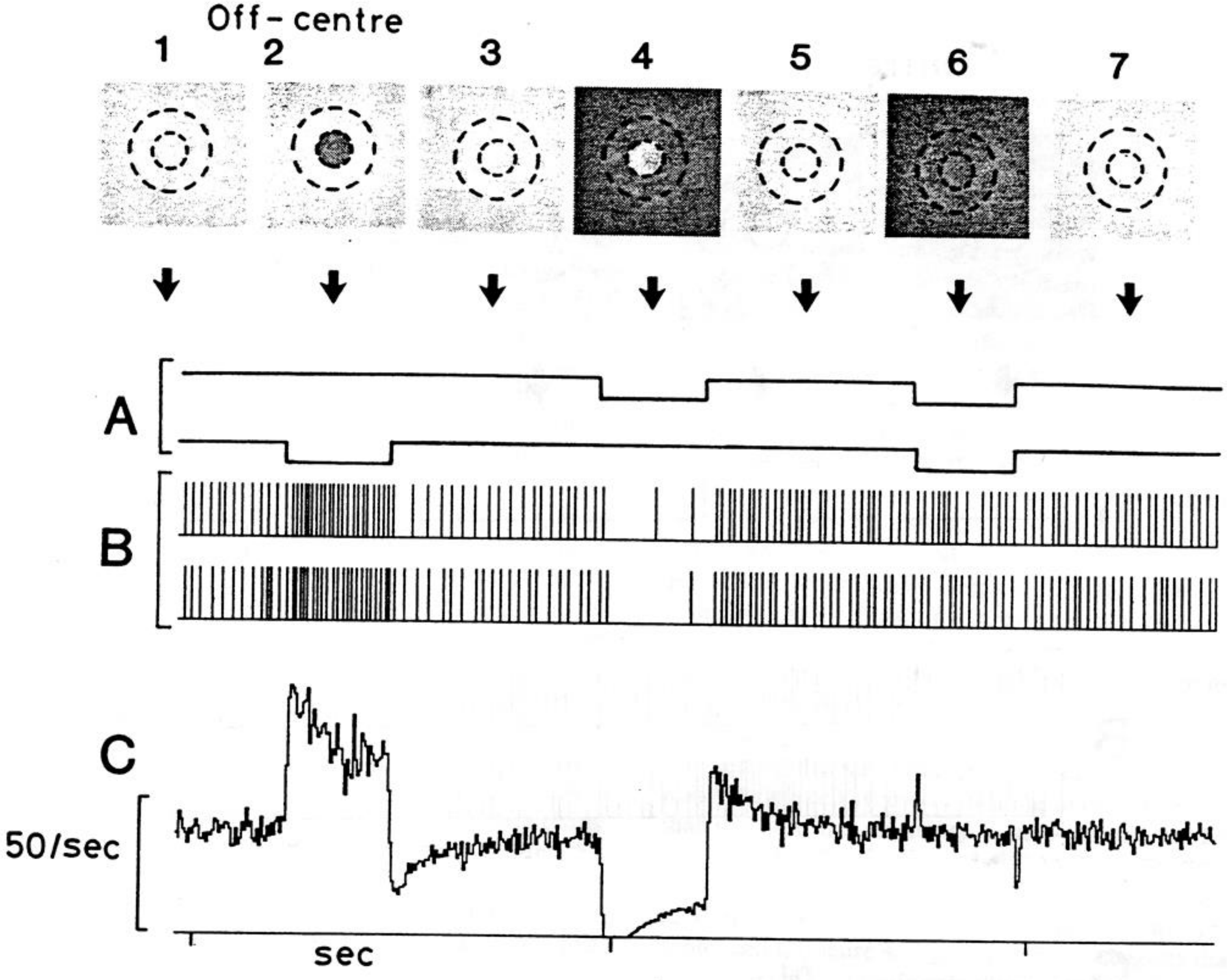
lec: no need to dwell upon this slide for too long

Examples of responses of an ON-center cell



Enroth-Cugell and Robson (1984)

Examples of responses of an OFF-center cell

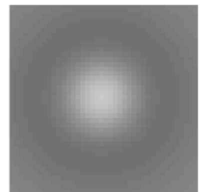


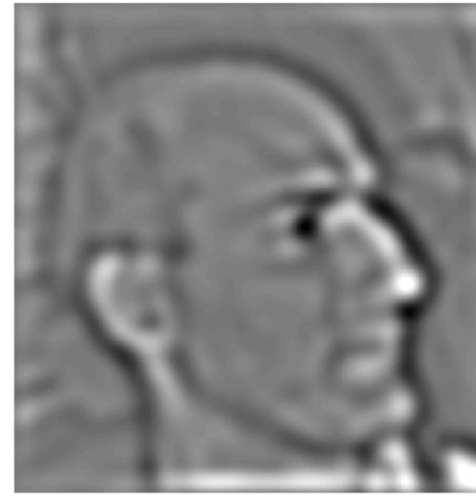
Enroth-Cugell and Robson (1984)

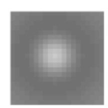
Center-surround receptive fields enhance edges

ON RESP: brighter
OFF RESP: less bright - off center field

think of them as filters







this RF is smaller then the upper one
(it's intended like this)

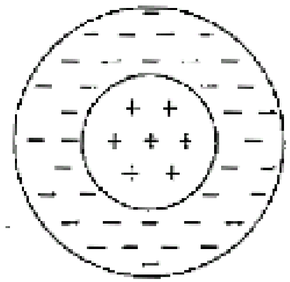
small RF: higher resolution

The linear model

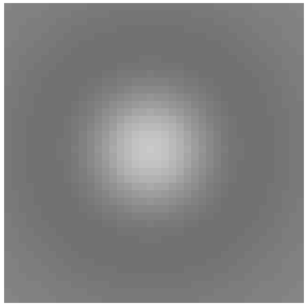
A model of the ganglion cell receptive field

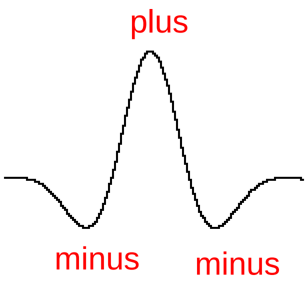
linear model: the filters are linear filters

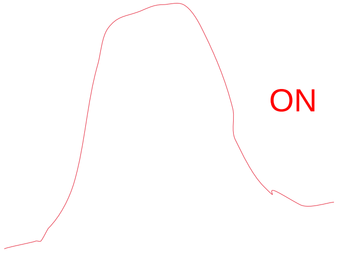
ON-center
receptive field



"Difference of
gaussians" model



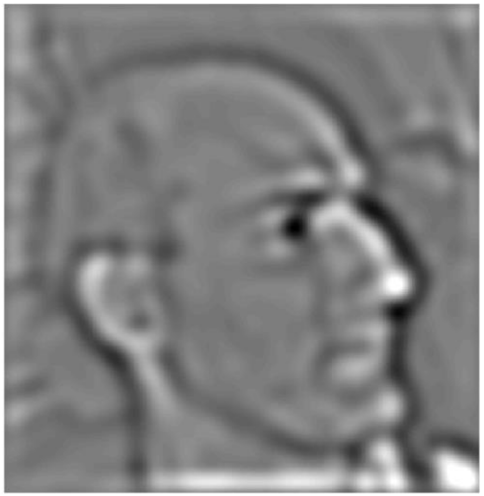




ON

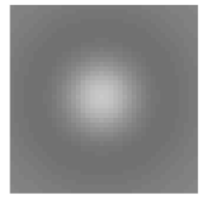
OFF, take difference of these gaussians and you get the upper graph. we cal it the difference of gaussians model

R(x,y)



=

F(u,v)



*

I(x,y)

response = filter * (light) intensity

we can also make predictions with this model to predict how the retina will respond.

for this the operations must all be linear

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

this is a convolution

image made of different pixels. each pixel has a different intensity (number). a filter also has a number of regions (like squares e.g.), with 1 or -1 as its entries to model ON or OFF filters. The filter values are then correspondingly multiplied with the numbers from the pixel pic (basically the signs are changed). then find out the sum: this is the new value of the inner pixel and then move by one row and get the output for the pixel next to it (ignoring edge effects)

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?

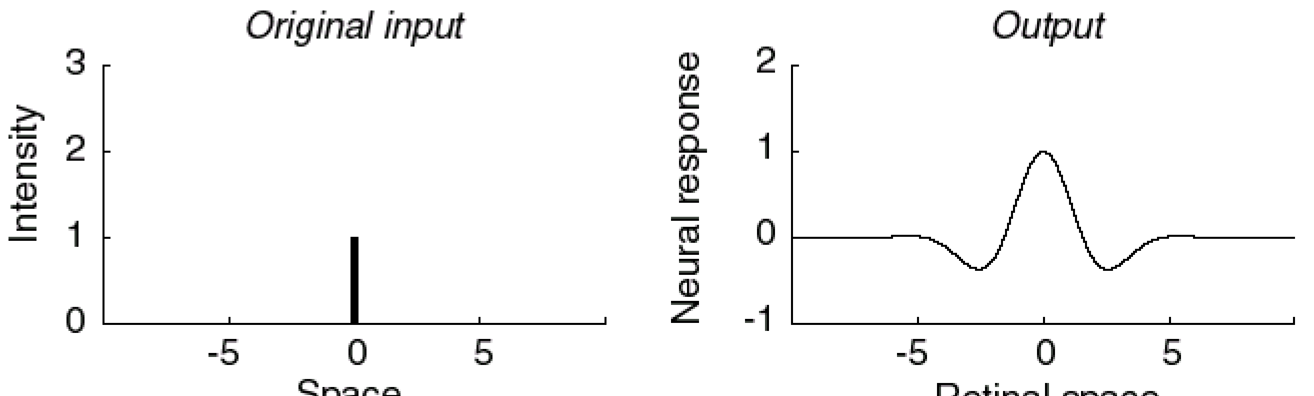
the ganglion cells are in extreme cases not linear systems and all other cells, they saturate.
normally in the range they work, they can be sometimes be modeled as linear systems.

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

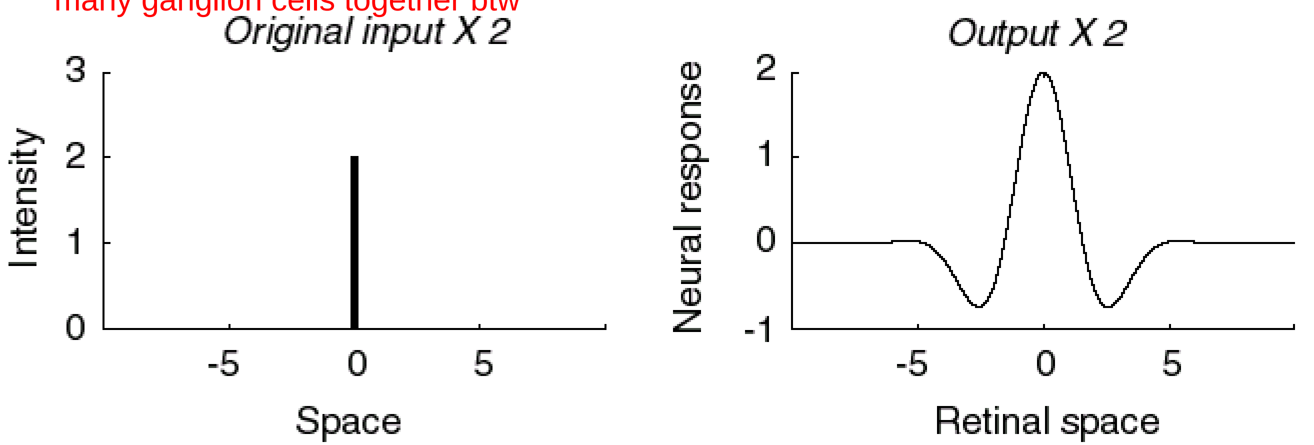
Linear systems $L(x)$ obey

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

Homogeneity

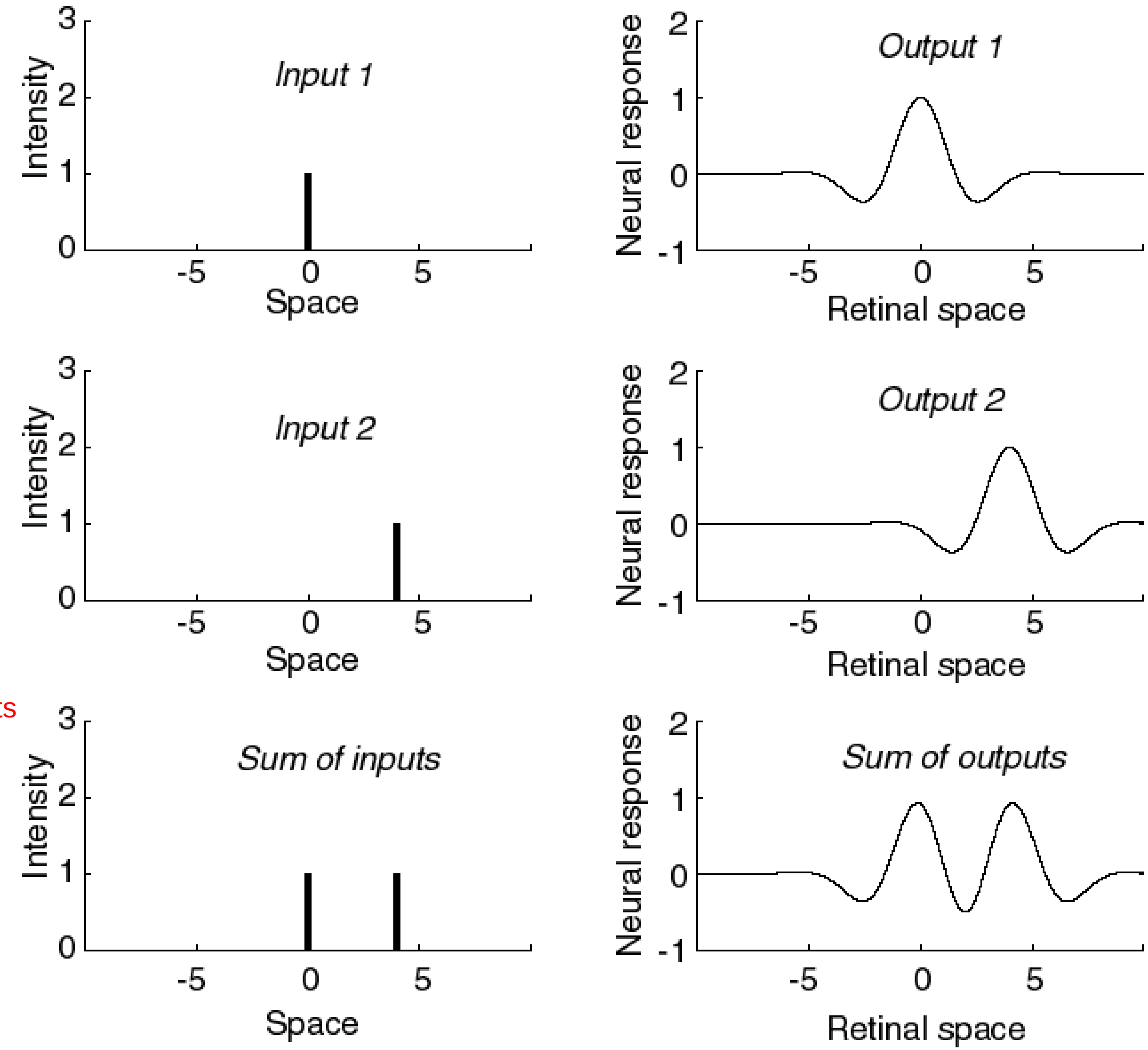


this'd be just a bright spot creating the mexican hat curve resposne. this is the response of many ganglion cells together btw



Superposition

same with two inputs



sine wave gradients used to characterize RF of neurons

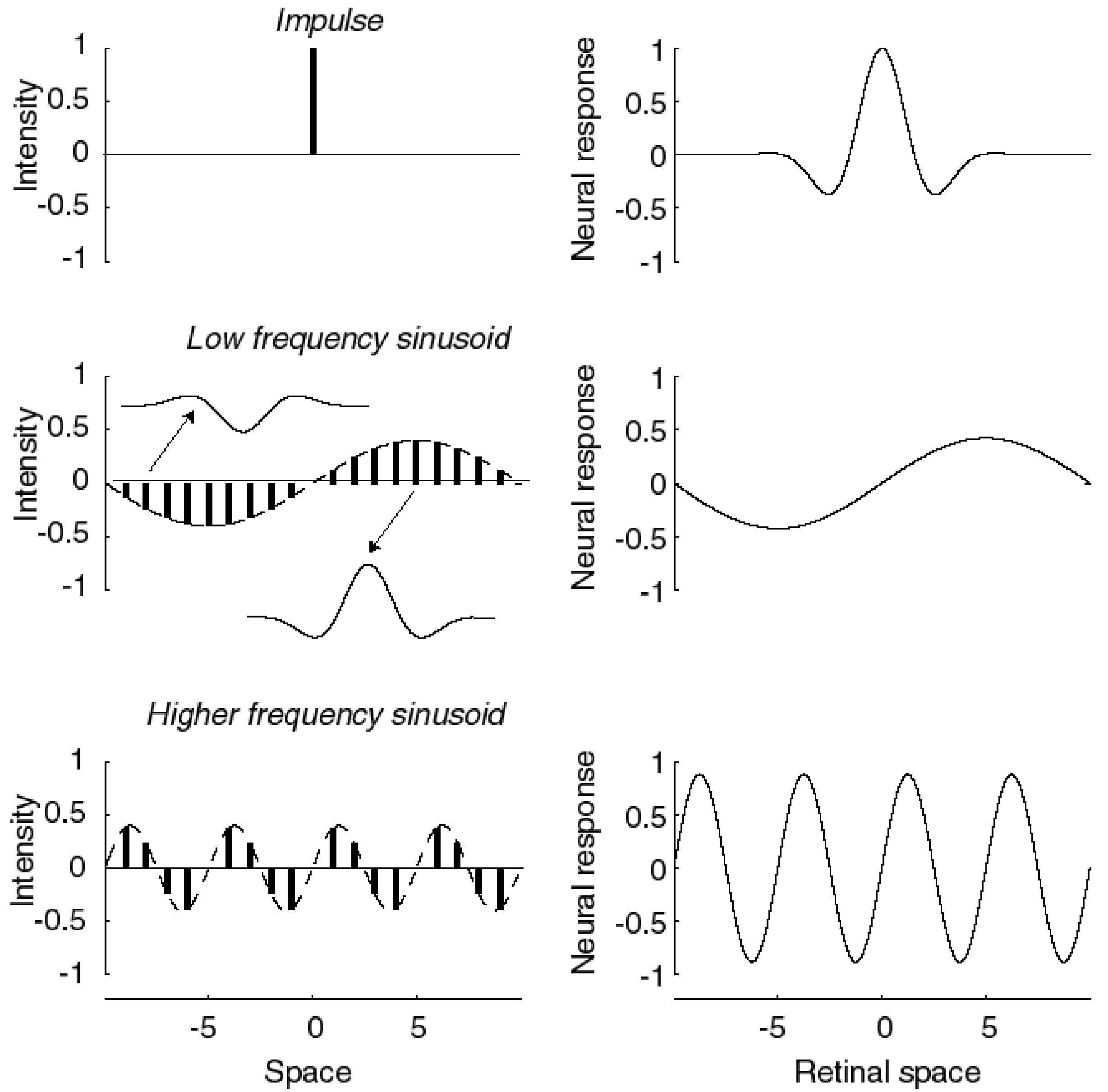
Linearity is often checked by using sinusoidal stimuli, because for a linear system:

1) The responses to sinusoids are sinusoids.

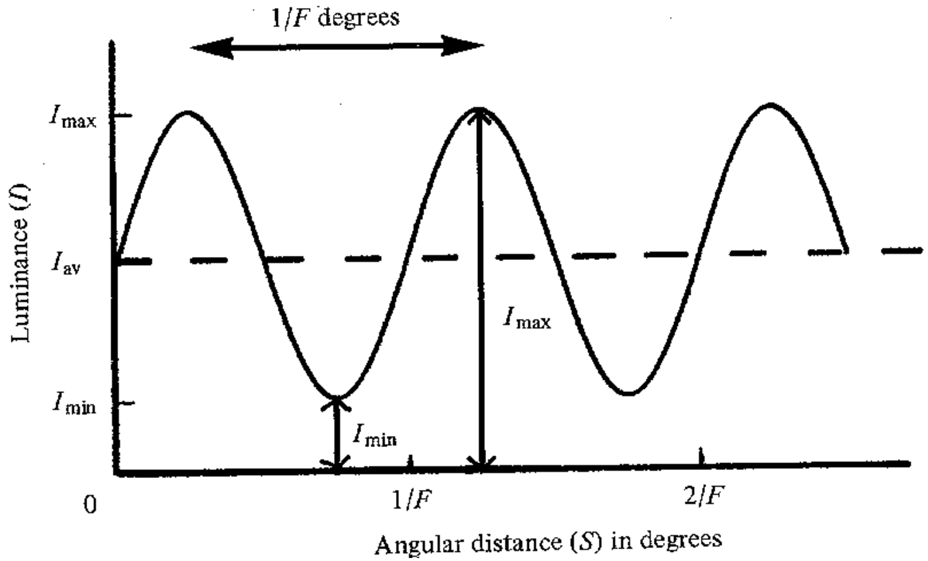
2) The dependence of response on stimulus frequency can be predicted from the shape of the receptive field.

(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



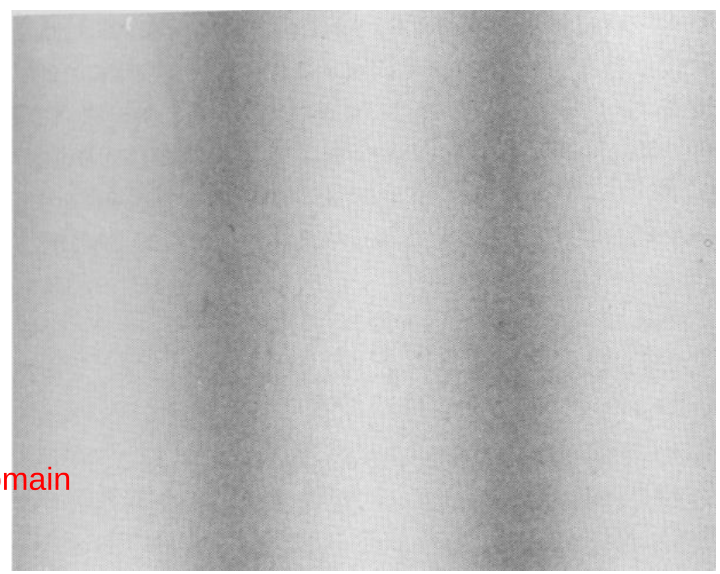
$$\text{Contrast} = C = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

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

that's a sinusoid
with varying intensity of light

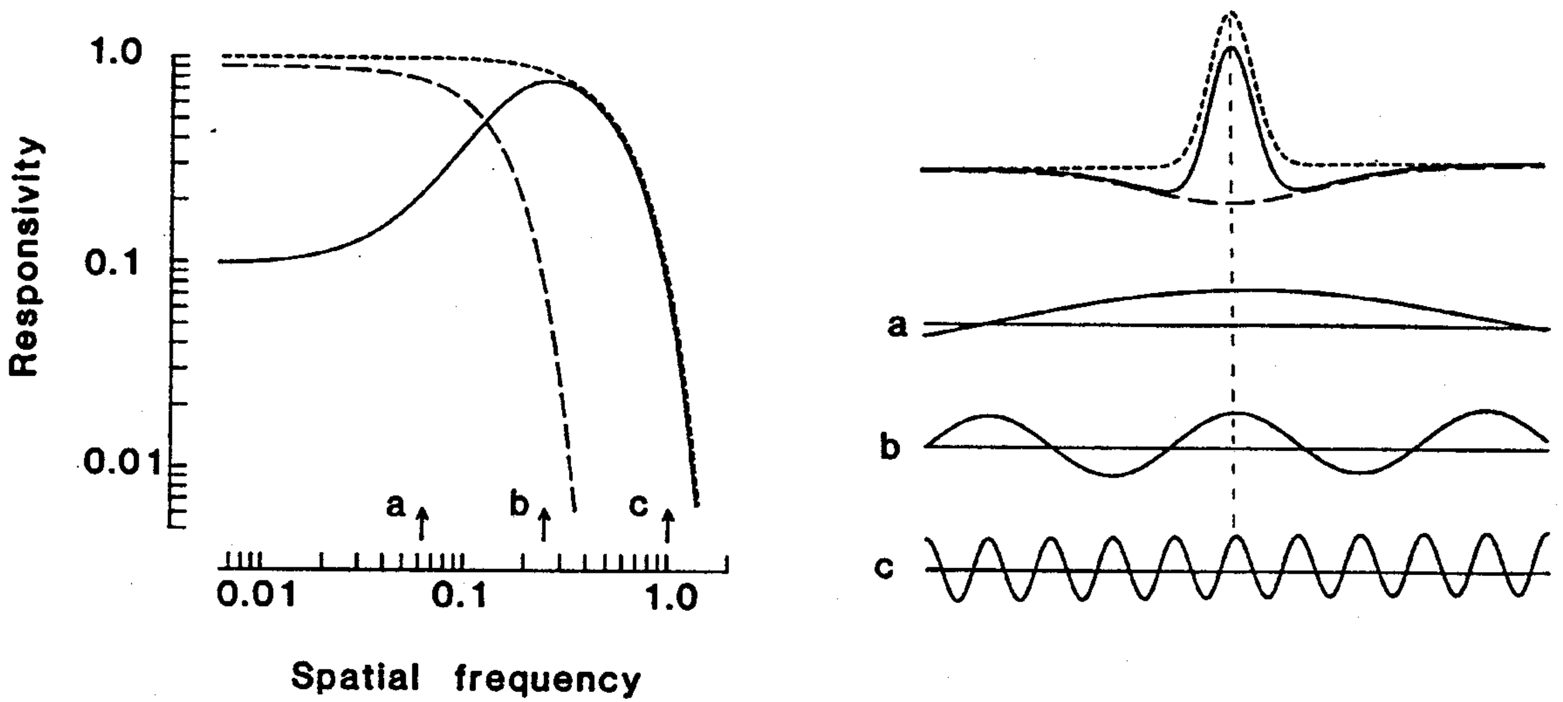
this is a sinusoid in the
spatial domain

experiments are often done
in the temporal and spatial domain
by moving such a picture too



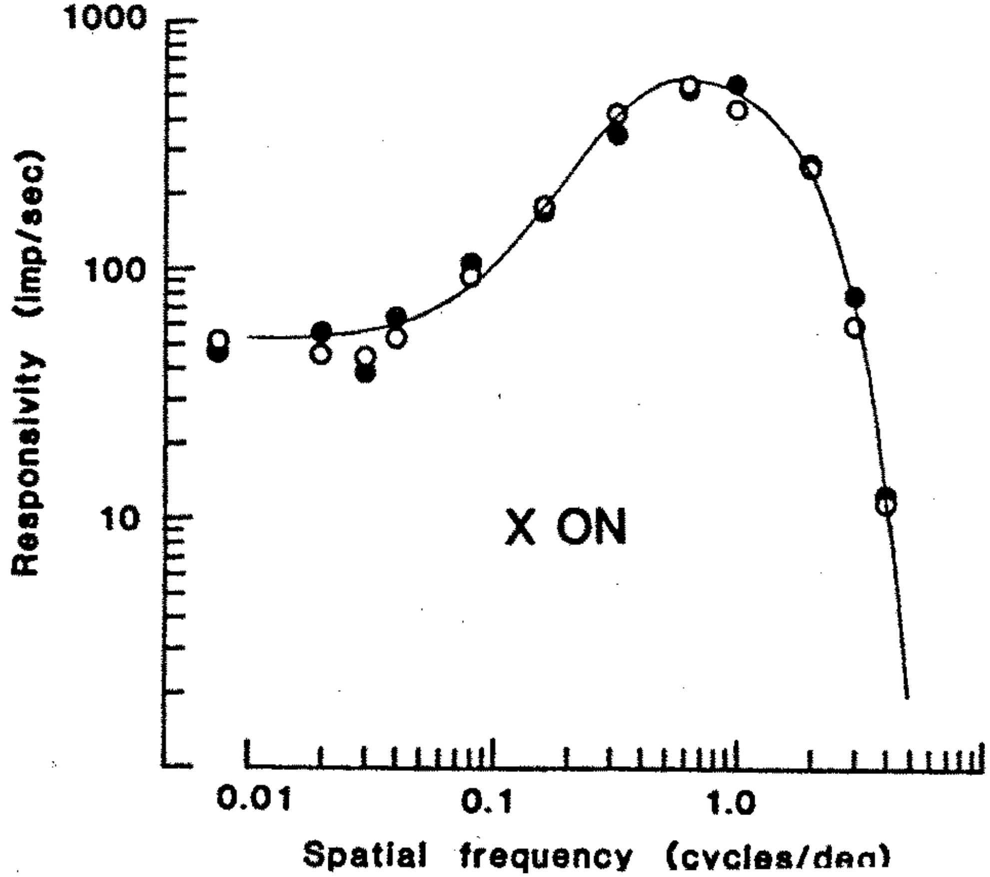
Barlow and Mollon, 1982 (Fig 1.3)

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



Enroth-Cugell and Robson (1984)

Fitting the model to the data

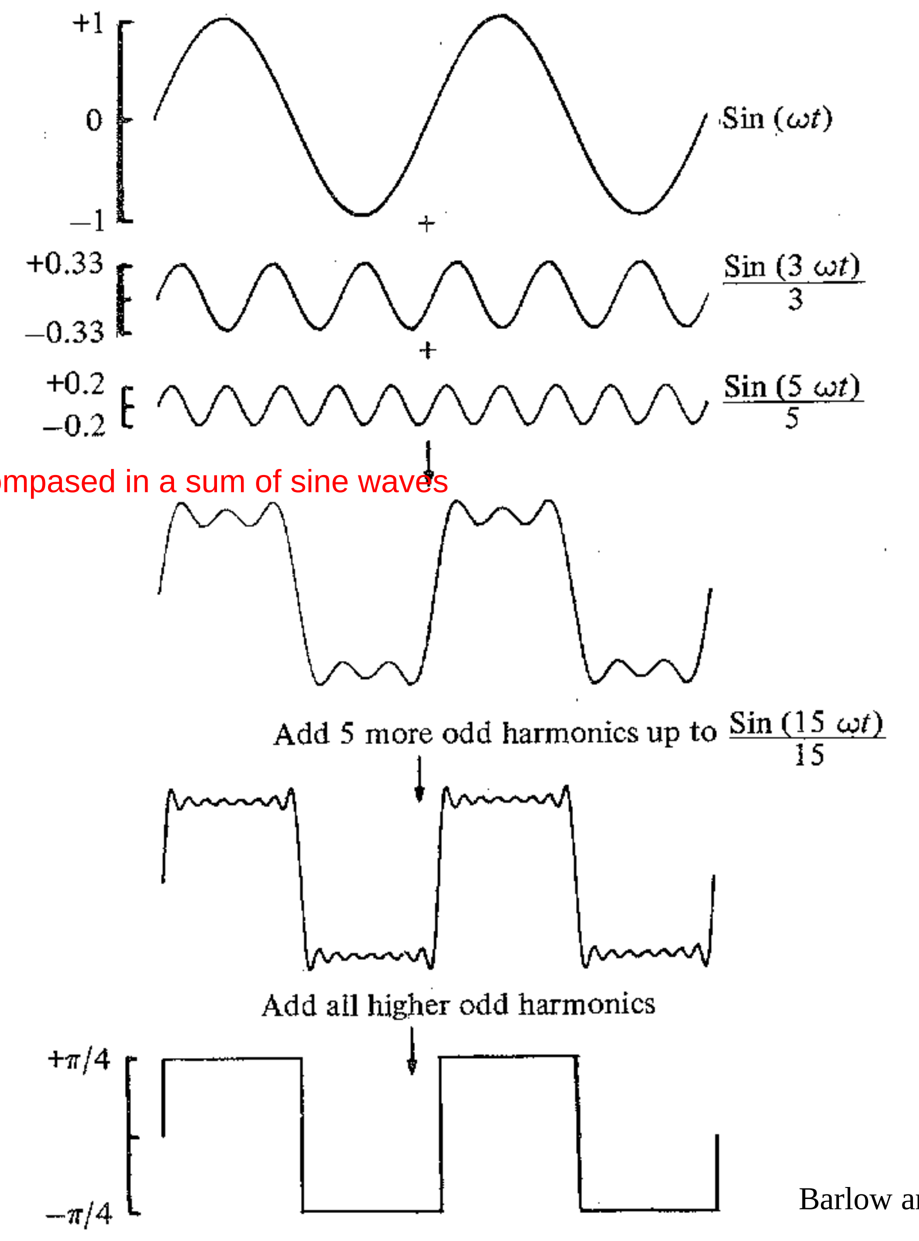


Enroth-Cugell et al. (1983)

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.

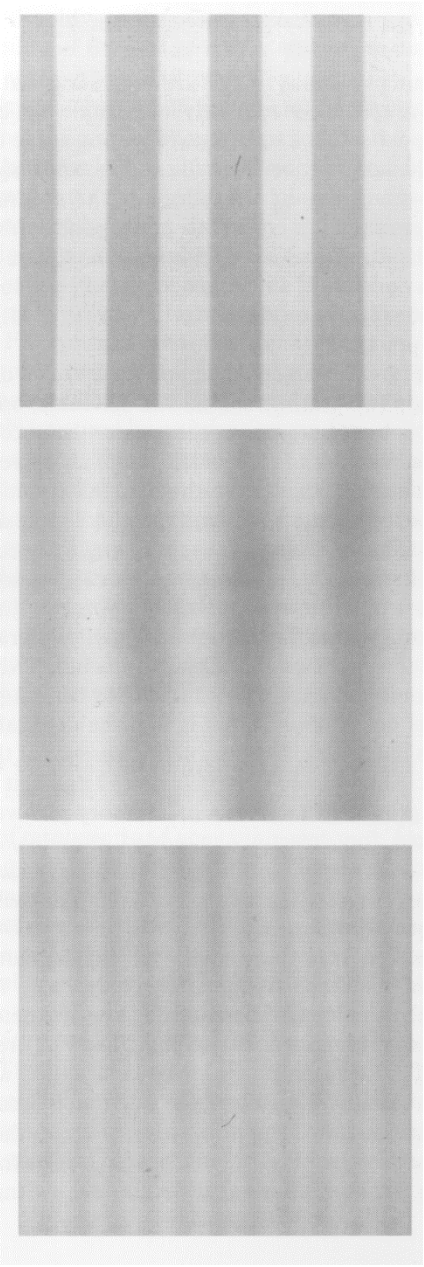
Making a square wave with sinusoids



any image (signal) can be decompased in a sum of sine waves

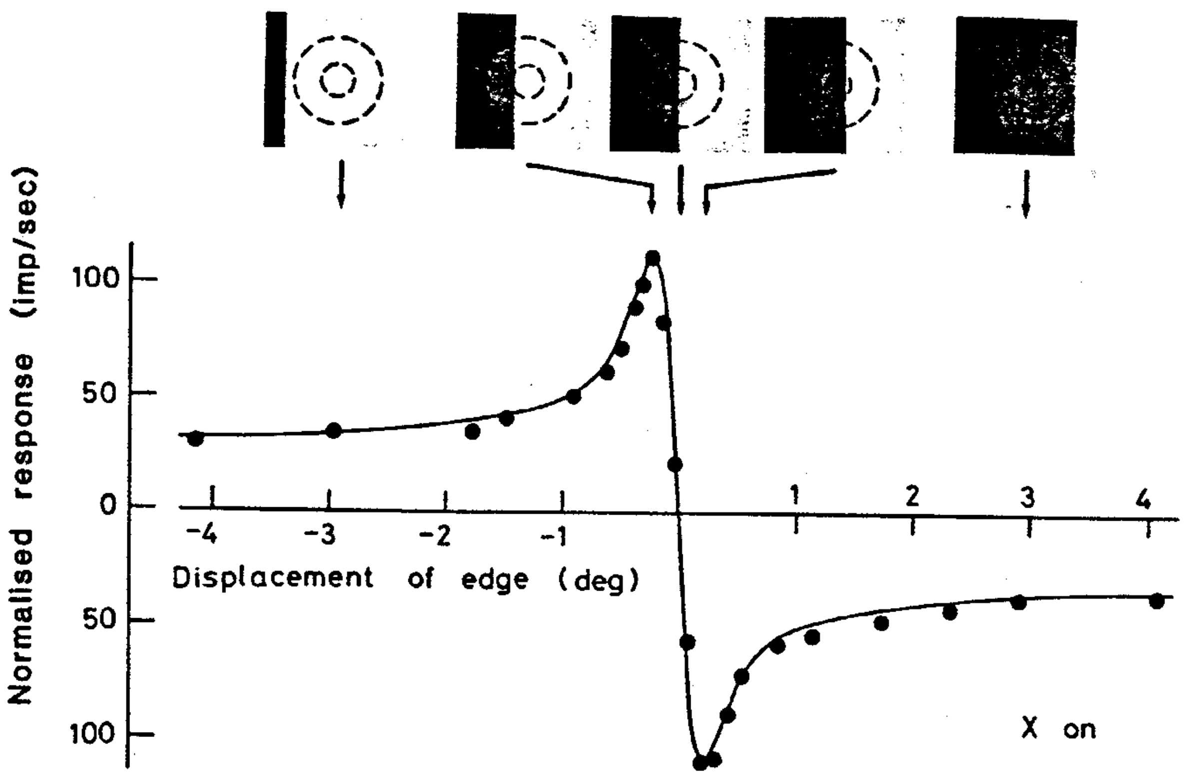
Barlow and Mollon, 1982 (Fig 1.2)

Square waves in 2-D



Barlow and Mollon, 1982 (Fig 8.7)

Responses of a ganglion cell to edges



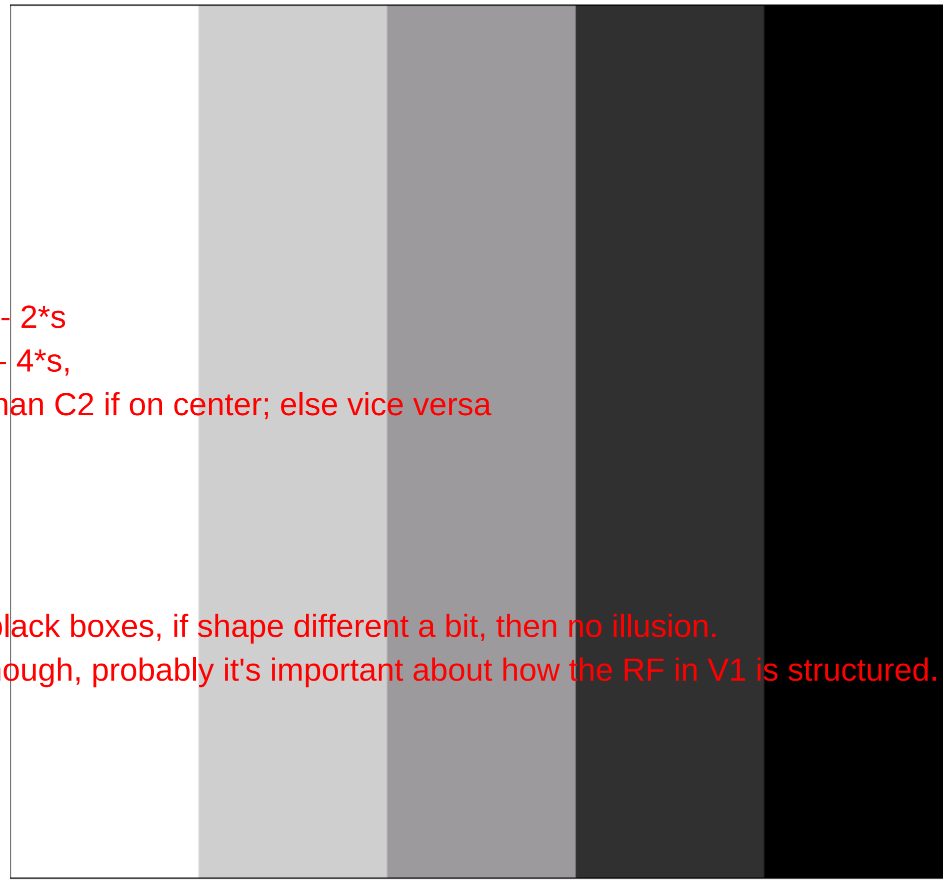
response is not a sqaure with edges, but with these cufrves

Enroth-Cugell and Robson (1984)

Chevreuil illusion - Mach bands

illusion: at the edges, there is a really small band which is slightly darker (see last slide). it's when you look at edges and the seem to have some "aura"

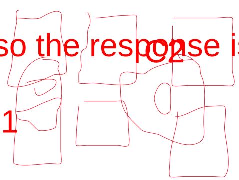
brain knows if signal is received from on or off center cell (not understood yet)



box should be fully black. it is: C1 - 2*s

C2 - 4*s,

so the response is greater of C1 than C2 if on center; else vice versa



C2

C1

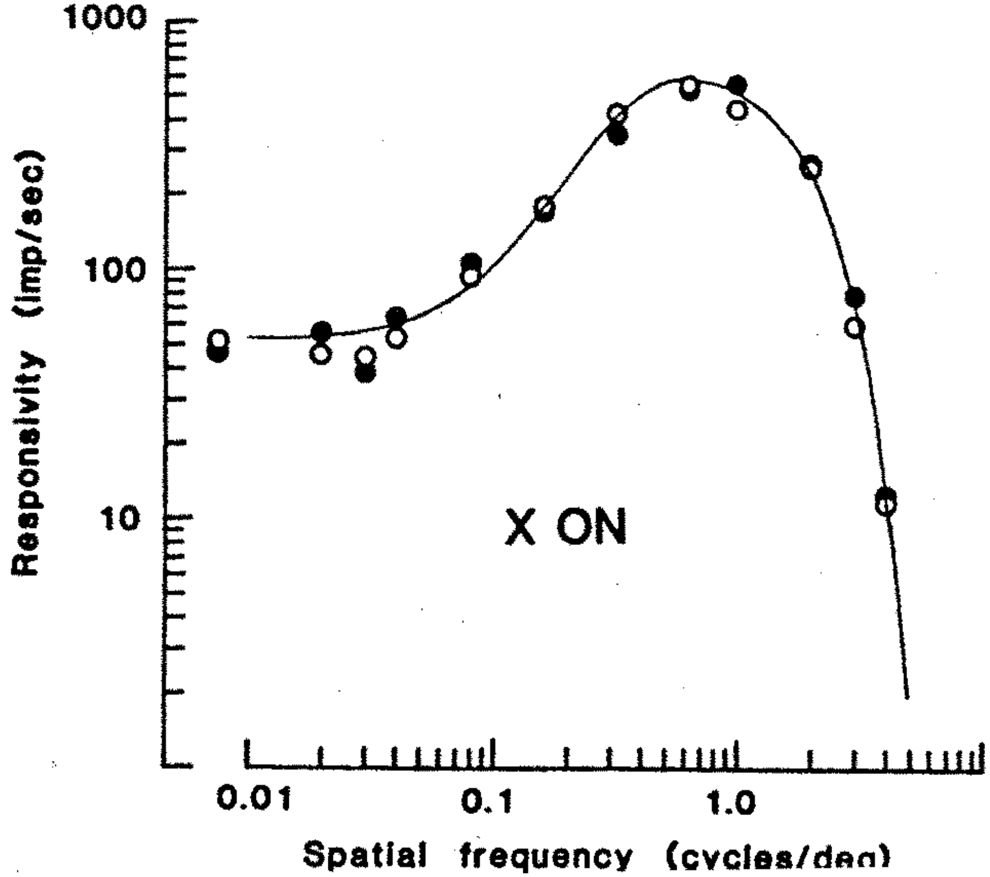
this only works if they are perfect black boxes, if shape different a bit, then no illusion.

it's not the complete explanation though, probably it's important about how the RF in V1 is structured. also the size of grid is important

hermanns grid explanation: (standard): the reason why we see the dark spots at the intersection in the periphery when we fixate a spot, is that RF of cells overlap with 4 squares (OFF parts) and intersection will be on ON. the response of the cell which is in the middle of the street is higher, so the intersections are perceived as darker, so there is darkness interpreted. at the FP, it is too small, so no effect so to say. since the brain knows the quality of the input (what kind of cell is signalling), then all is the way it should be since the brain knows

Sensitivity for different spatial frequencies

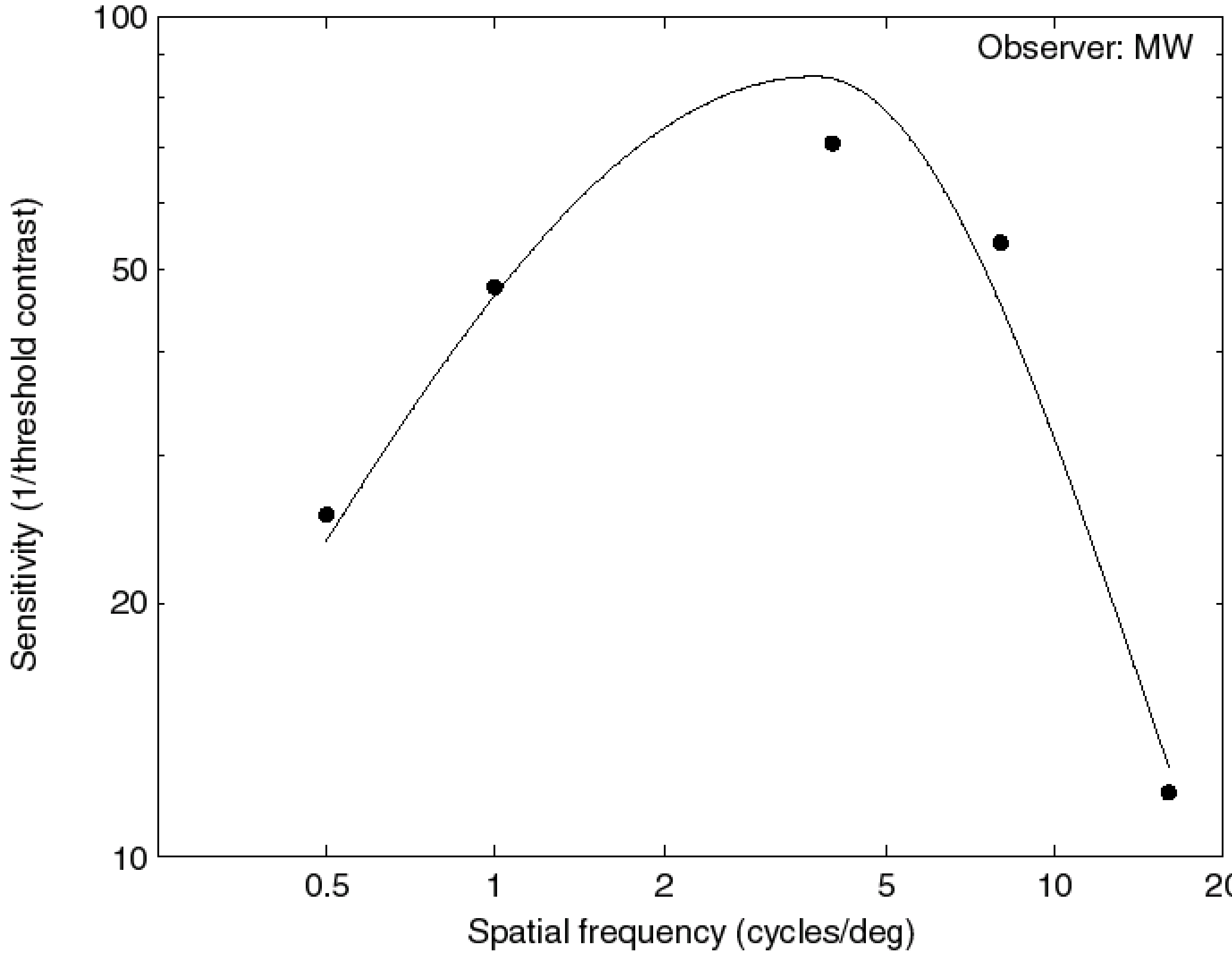
Spatial frequency tuning of a ganglion cell



Enroth-Cugell et al. (1983)

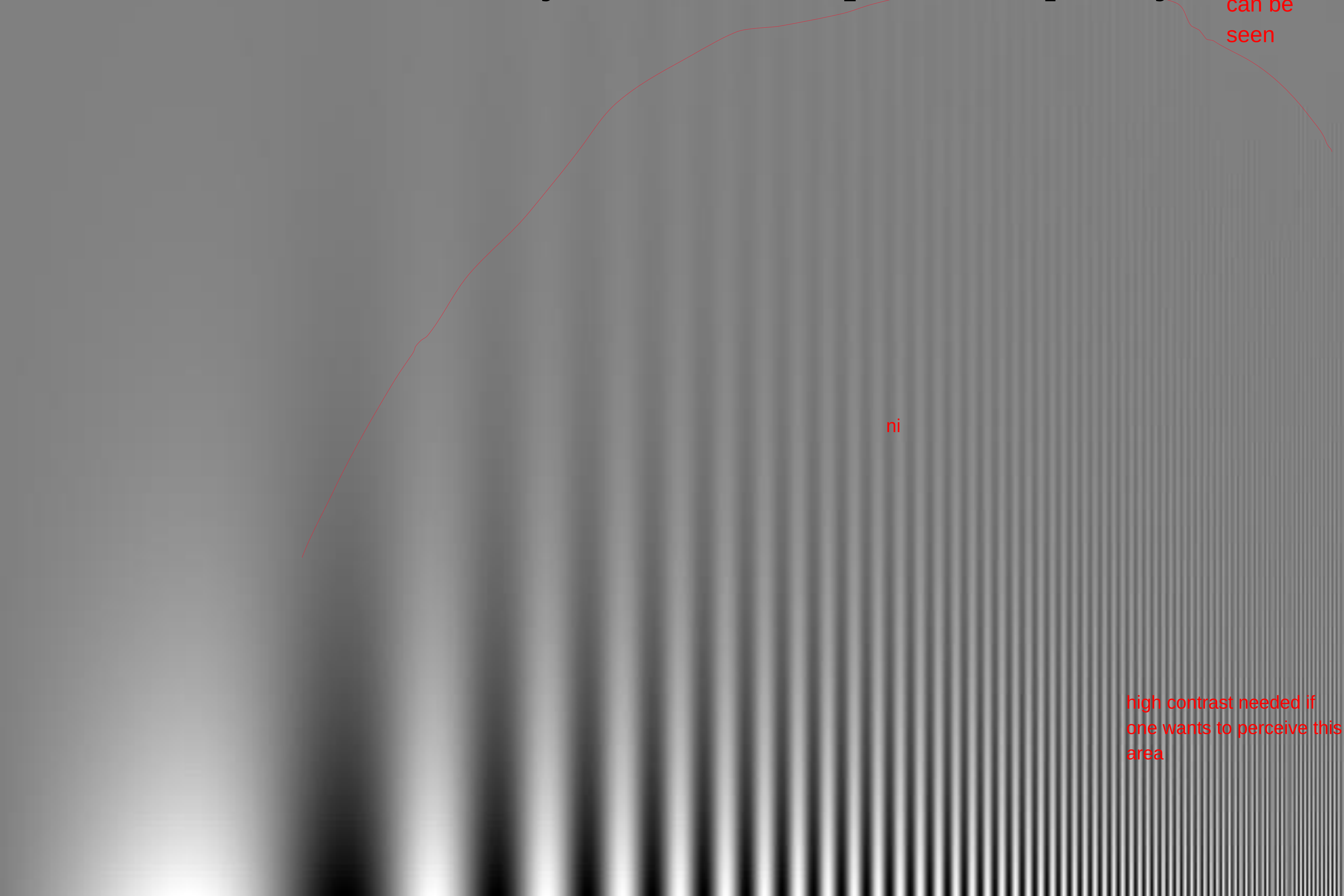
Spatial frequency sensitivity curve of a whole brain

sensiivity = 1/threshold



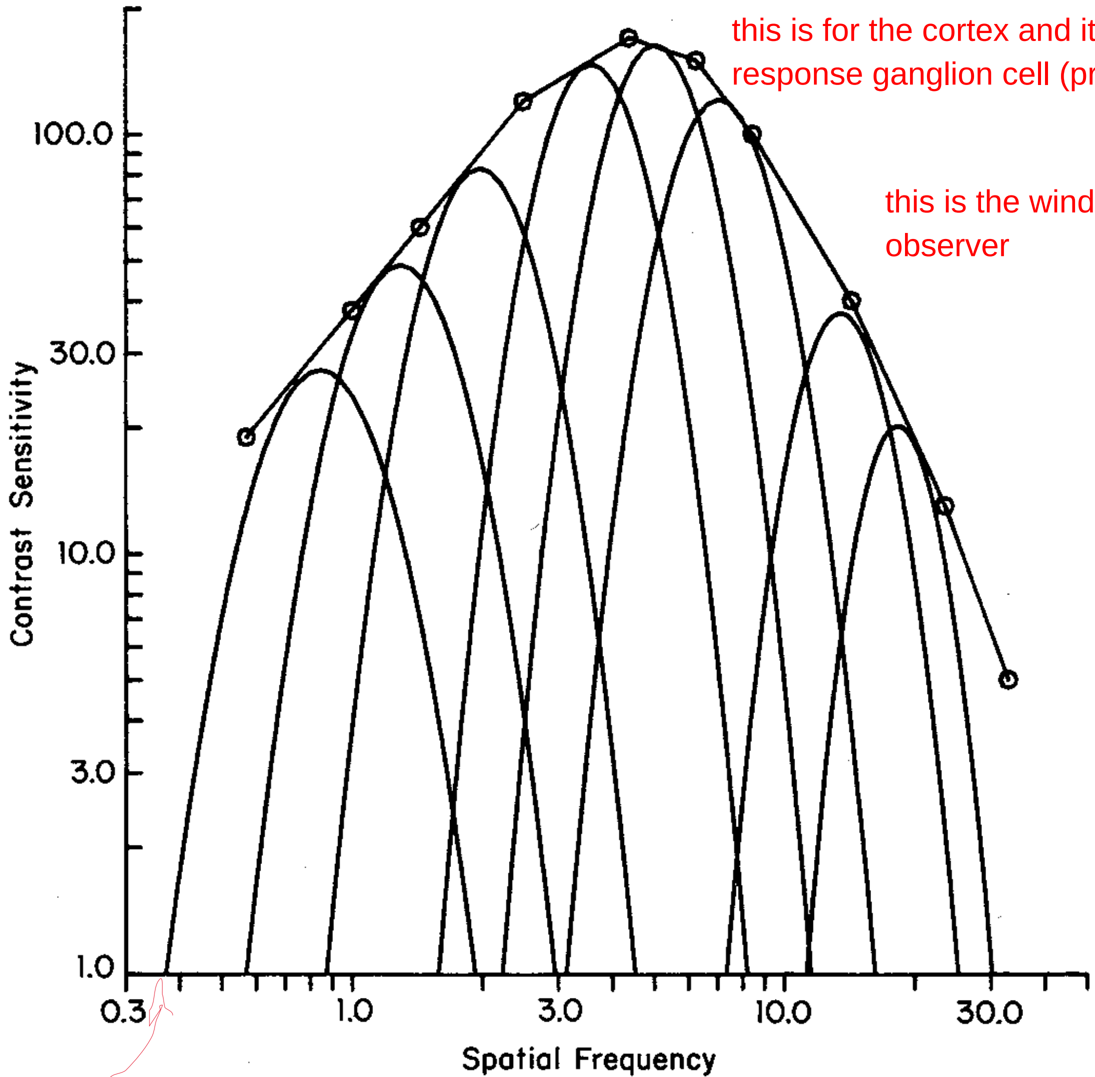
need very high contrast to see the wave for the last point (see next slide)

Contrast sensitivity varies with spatial frequency



his slide is more of a teaser

One interpretation of the contrast sensitivity curve



this is for the cortex and it is very different to the response ganglion cell (previous few slides)

this is the window visibility of a human observer

response of one cortical cell

De Valois & De Valois (1990)