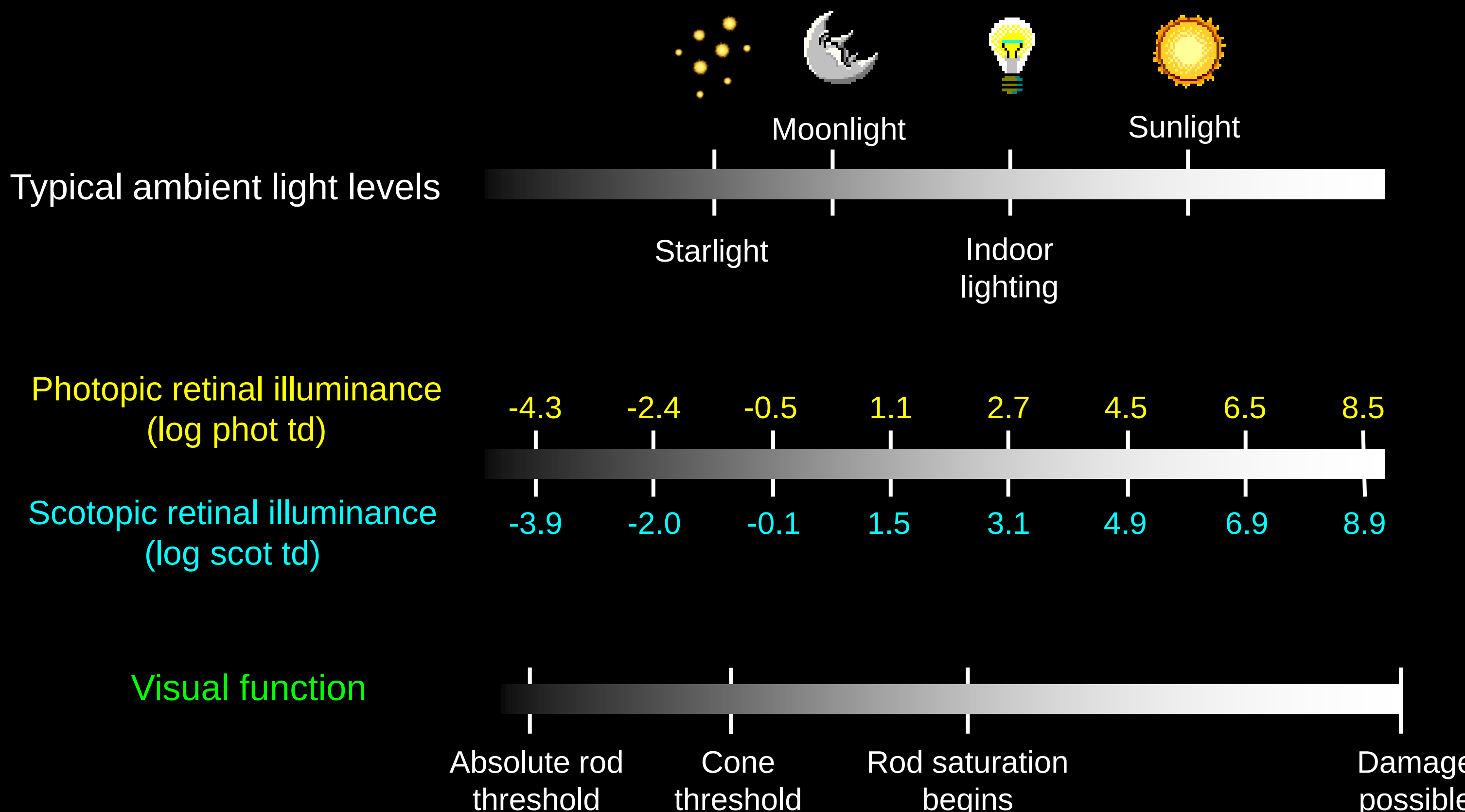
Visual psychophysics, sensitivity regulation and adaptation



NEUR 3045
Visual Neuroscience

Andrew Stockman

Psychophysical measures of adaptation mechanisms

What is visual psychophysics?

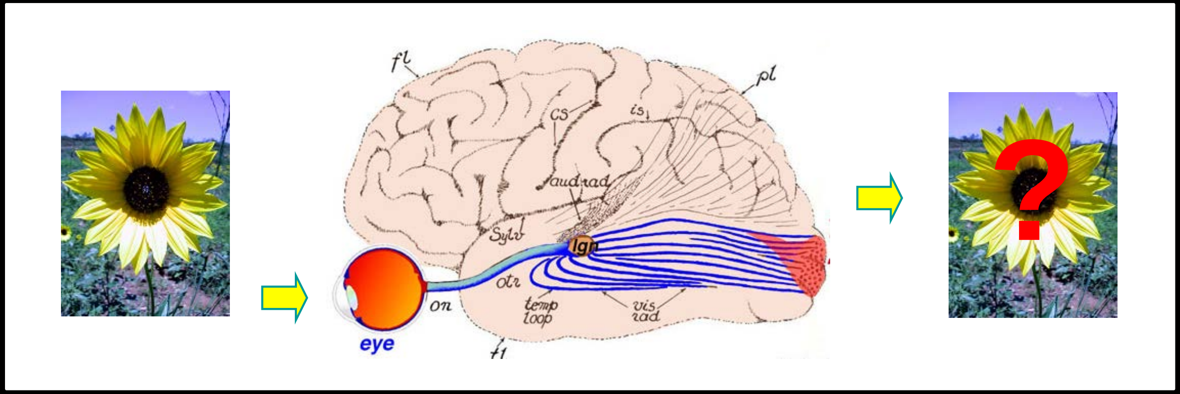
Psychophysicists study human vision by measuring an observer's performance on carefully chosen perceptual tasks.

By manipulating the properties of simple visual stimuli, and measuring the effect of that manipulation on an observer's performance we can infer the way the visual system processes particular properties of a stimulus.

INPUT

PROCESSING

OUTPUT



STIMULUS

VISUAL SYSTEM

PERCEPTION

How do we process visual information?

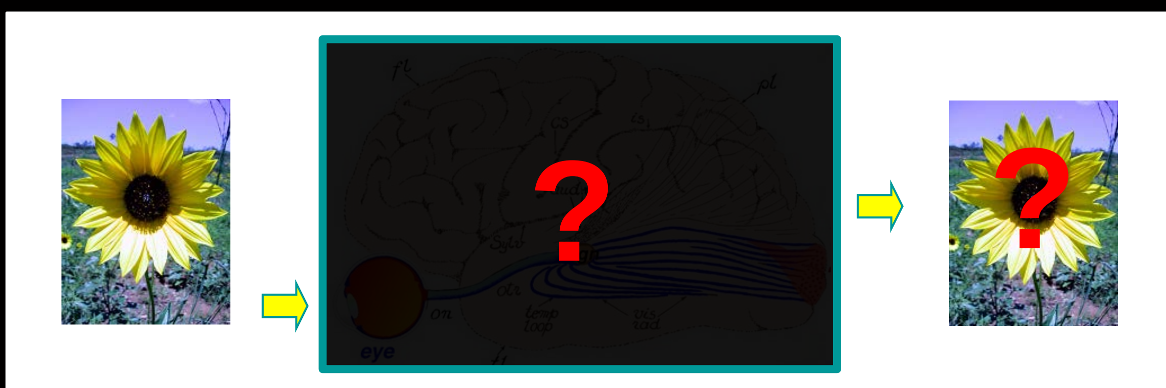
What is visual psychophysics?

In psychophysics, we try to infer what is going on inside the visual system just from studying the input and output.

So, to the psychophysicist the visual system is much like a “BLACK BOX”.

We can learn a surprising amount about the black box and how it works from psychophysical measurements.

INPUT PROCESSING OUTPUT

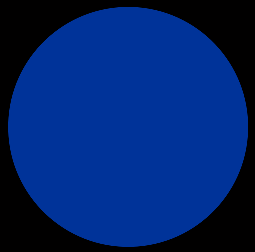


How do we process visual information?

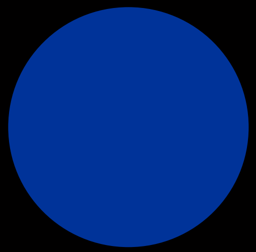
STIMULUS VISUAL SYSTEM PERCEPTION

Psychophysical tasks that can provide useful information:

DETECTION TASKS



Is a circle present?



Is the circle flickering or steady?

Is the pattern (grating) visible?

In general, simple tasks are used.

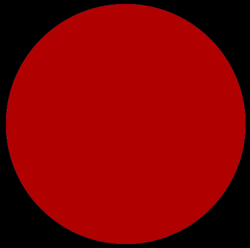
Can you think of other tasks?

Which other tasks provide useful information?

DISCRIMINATION OR MATCHING

Are the two halves the same or different?

REACTION TIME



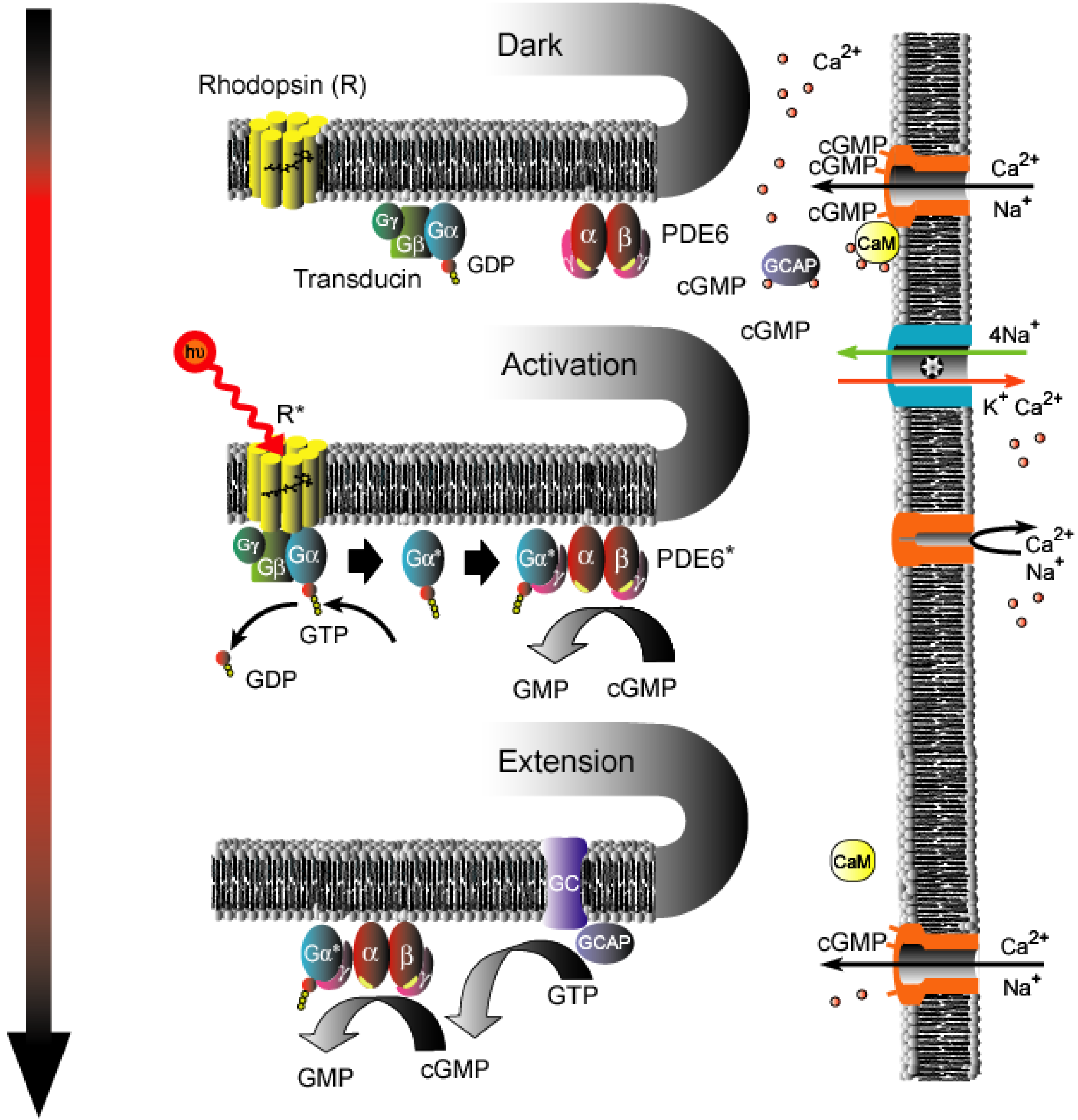
Respond to the appearance of a circle as quickly as you can.

Psychophysics *versus* physiology and anatomy

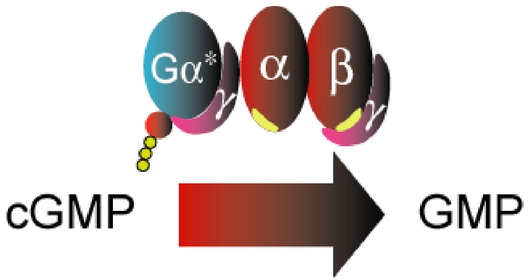
- What sort of things can psychophysics tell us that physiology and anatomy cannot?
- And *vice versa*?
- Can the different approaches be complementary?

As an example, let's link psychophysical measures with the mechanisms of light adaptation at the molecular level (covered in the phototransduction lecture)…

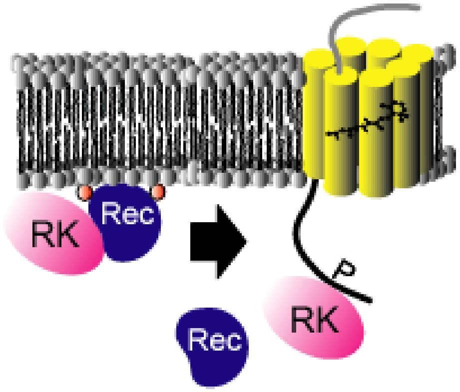
Phototransduction



Mechanisms that shorten the visual integration time

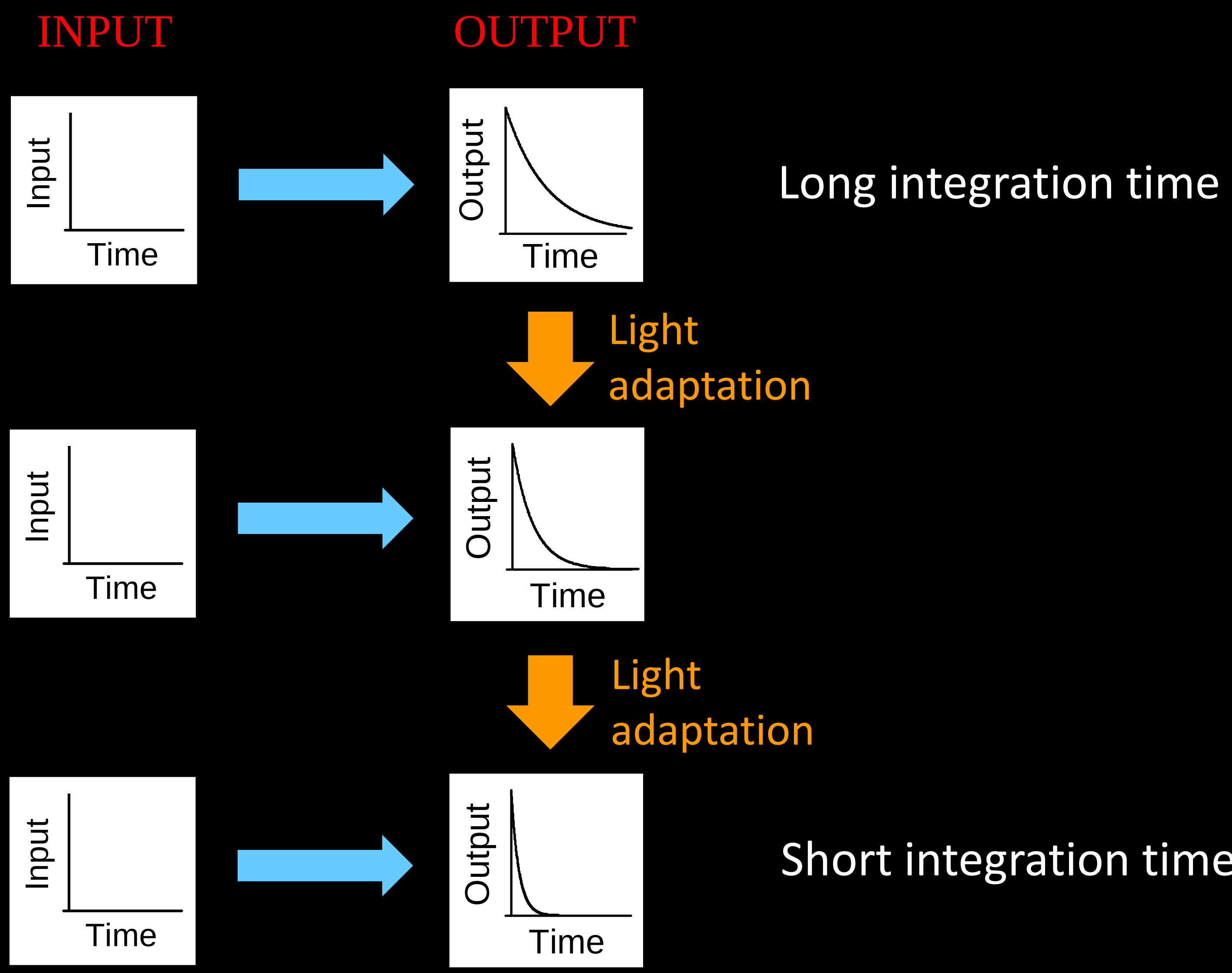


[G*α-PDE6*] dependent Increased rate of hydrolysis of cGMP to GMP



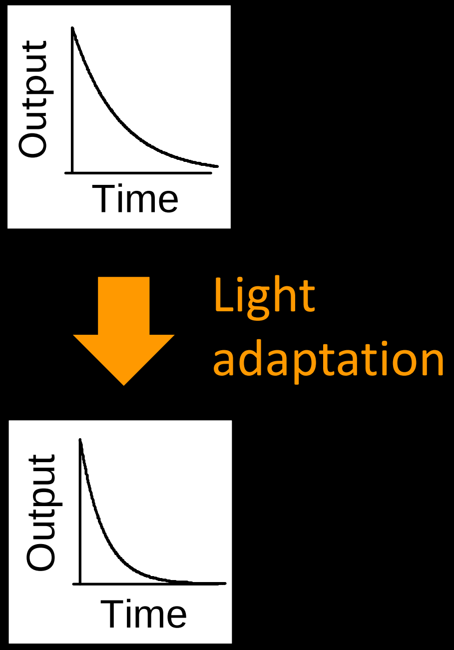
[Ca^{2+}] dependent activity of Rec.

Shortening the integration time of the system...

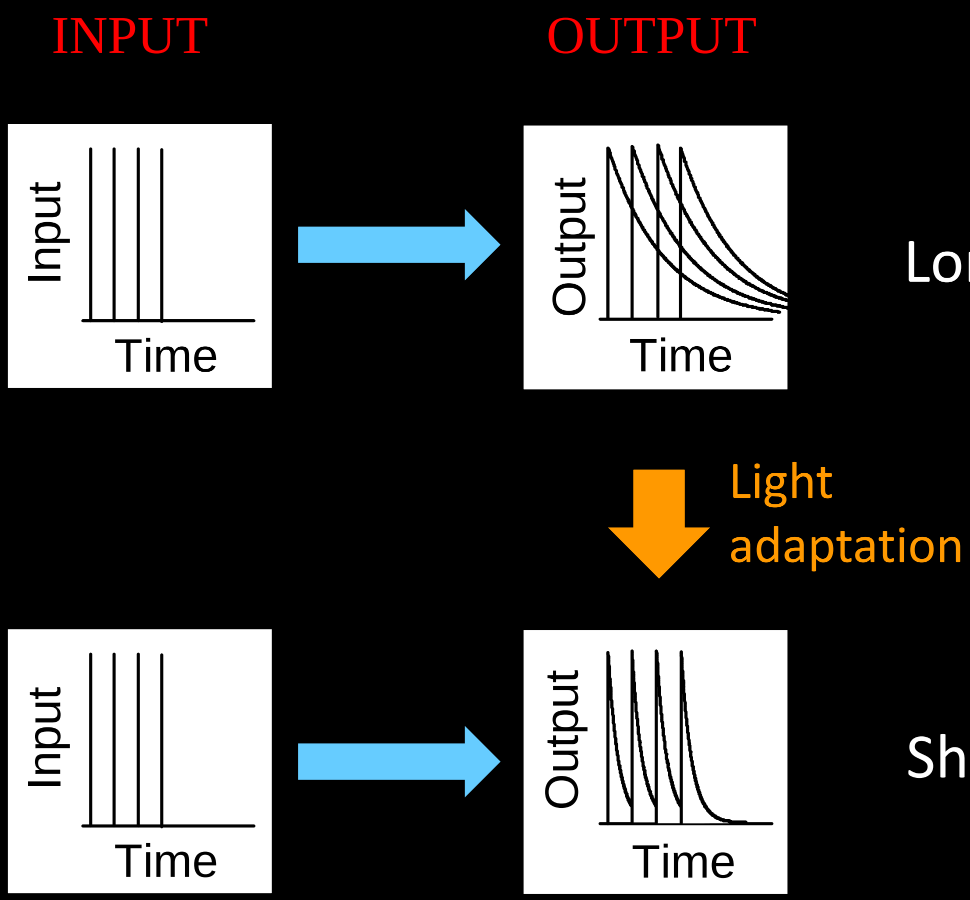


What are the effects on visual performance of shortening the integration time?

And how might we measure those effects psychophysically?



Shortening the integration time of the system will alter the sensitivity of an observer for seeing higher rates of flicker...



Long integration time

Short integration time

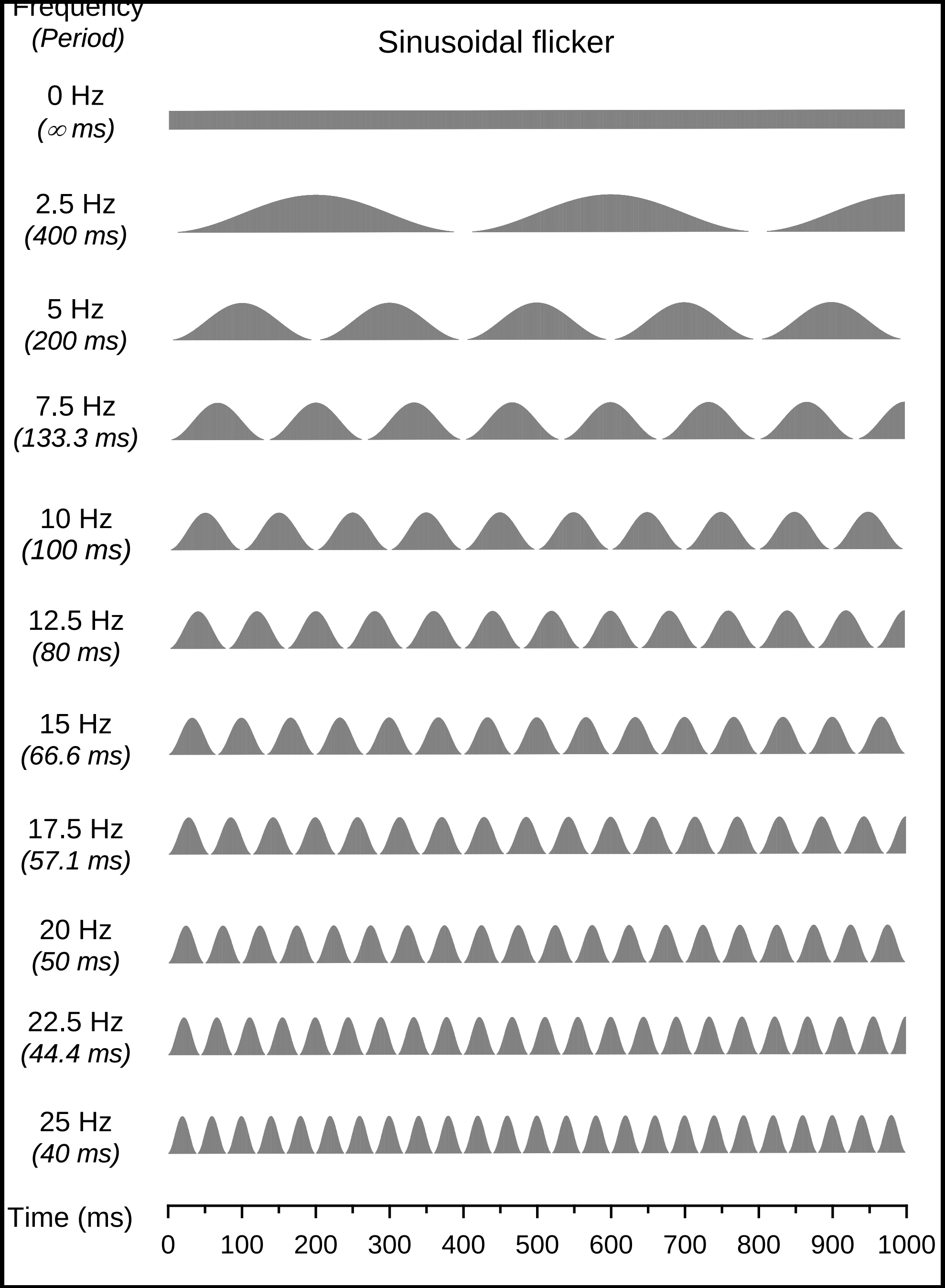
The effects can be seen in...

Cone temporal (or flicker) modulation sensitivity measurements

Flickering stimuli

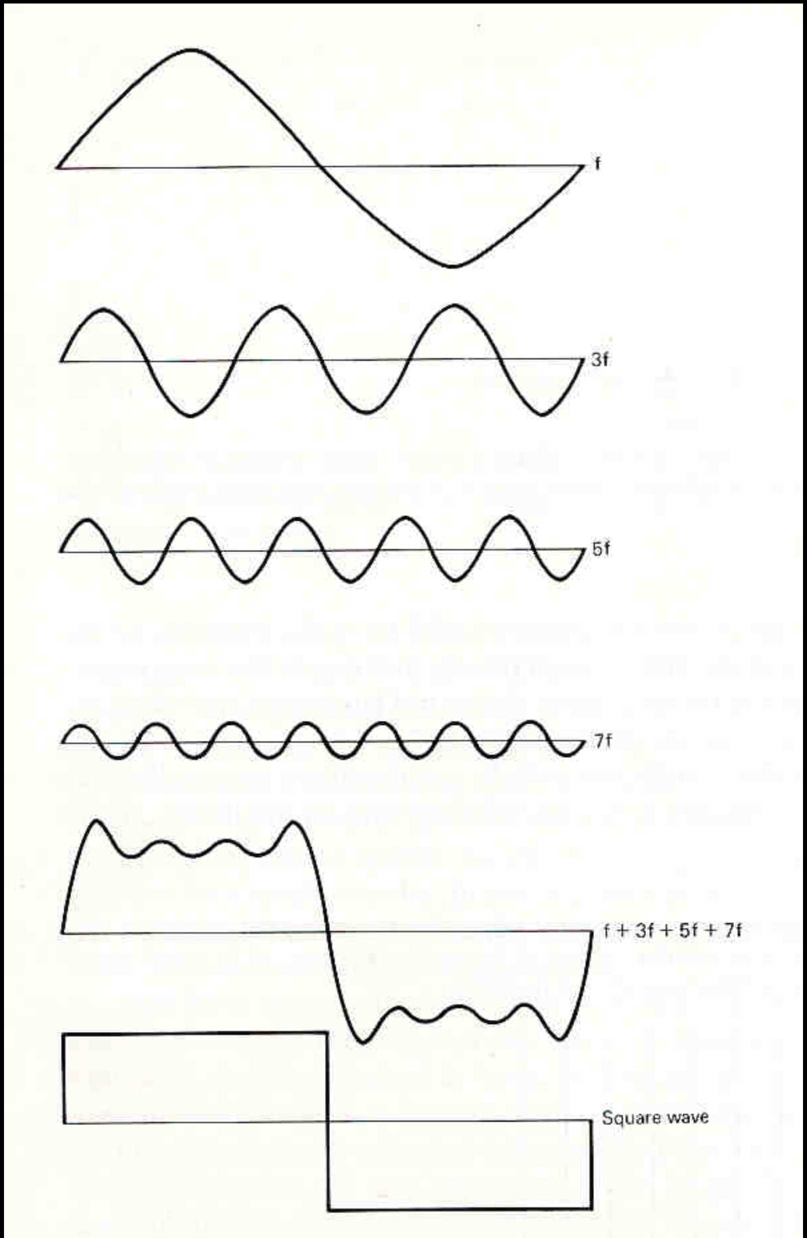
Sinusoidal flickering stimuli are inherently simple.

In the Physiological Optics lecture we were considered about sinusoidal variation over space rather than time.

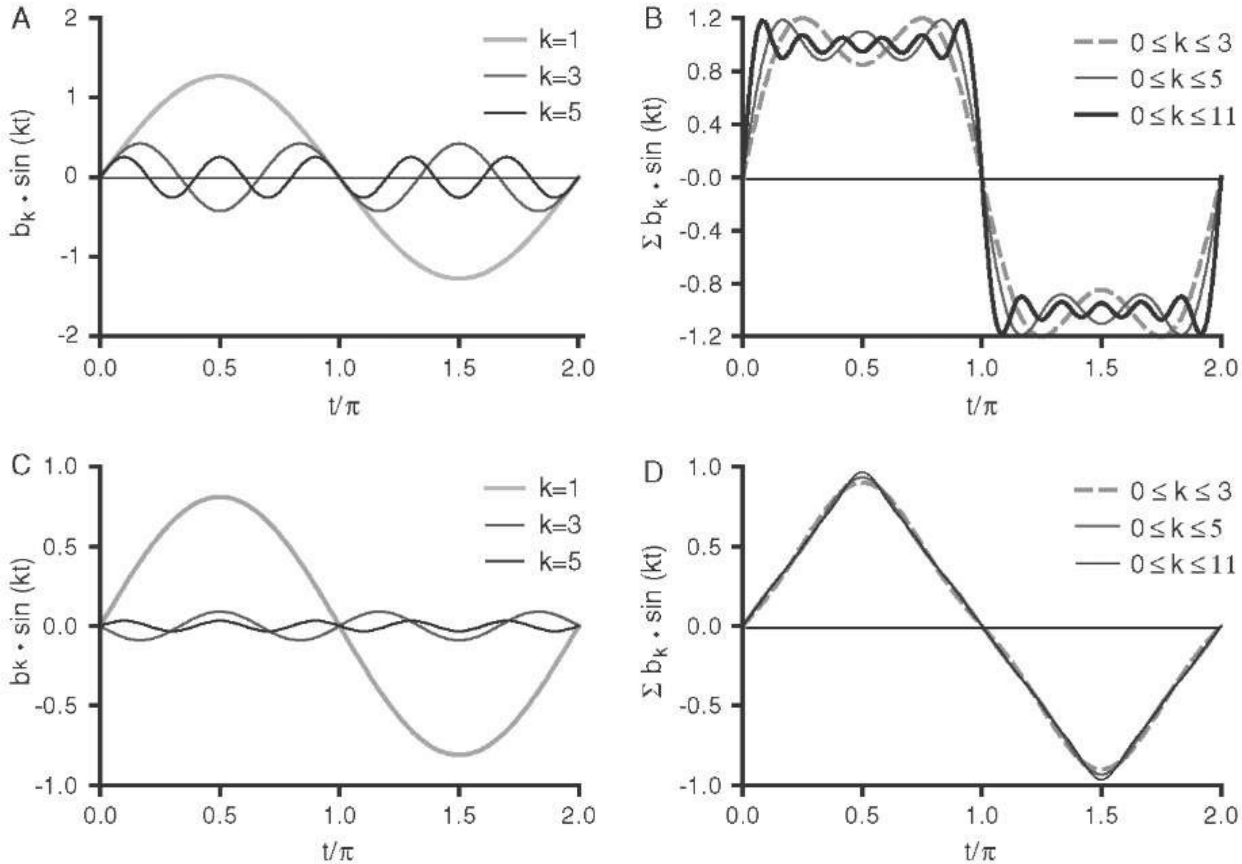


Sinusoids of different frequencies, amplitudes and phases can be summed to produce other waveforms…

This is a powerful way of simplifying the stimuli that are used to study vision – if we can understand how simple sinusoids are processed, we may be able to predict how more complex stimuli will be processed, without measuring all the possible complex stimuli.



Harmonics of a square and triangle wave



Square

Triangle

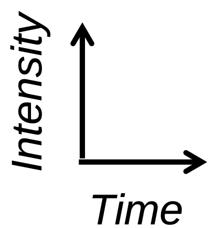
Cone temporal (or flicker) modulation sensitivity measurements..

How do we measure them psychophysically?

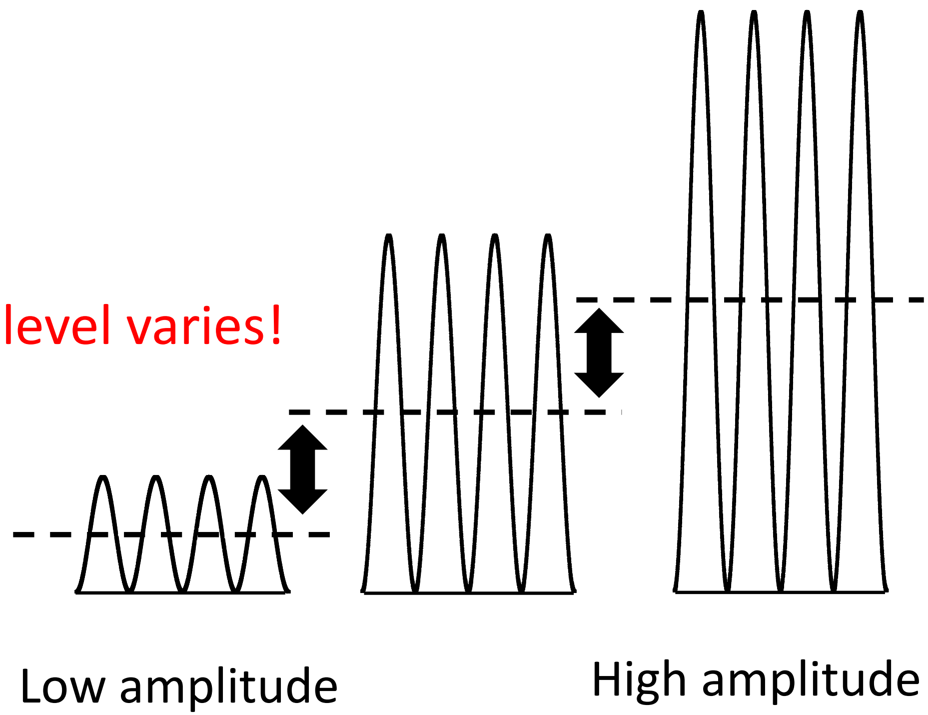
Cone temporal (or flicker) modulation sensitivity measurements.

We can’t vary amplitude to find threshold.

Why not?



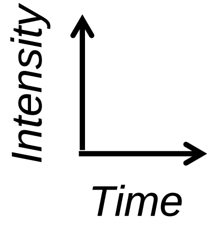
The mean level varies!

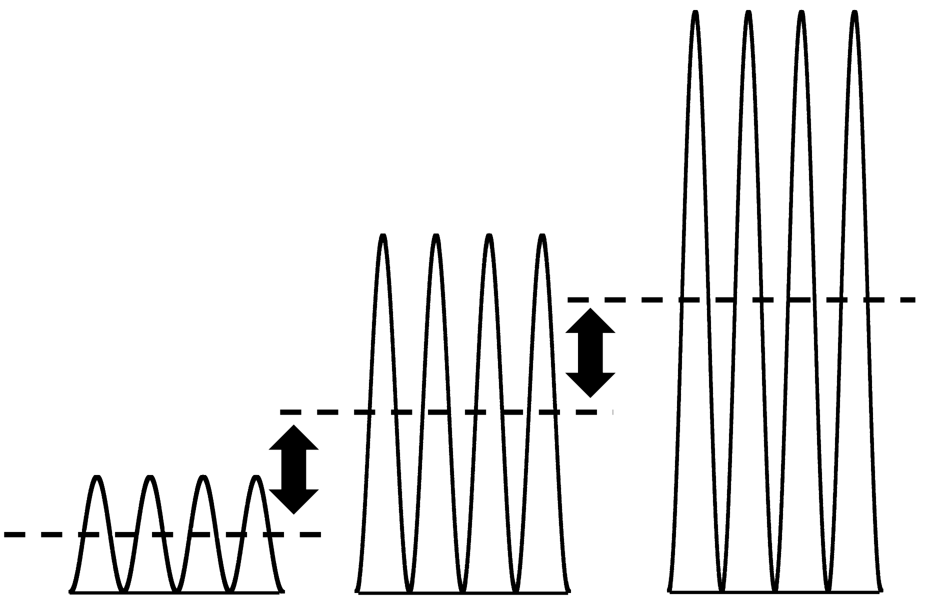


Cone temporal (or flicker) modulation sensitivity measurements.

We can't vary amplitude to find threshold.

Why not?

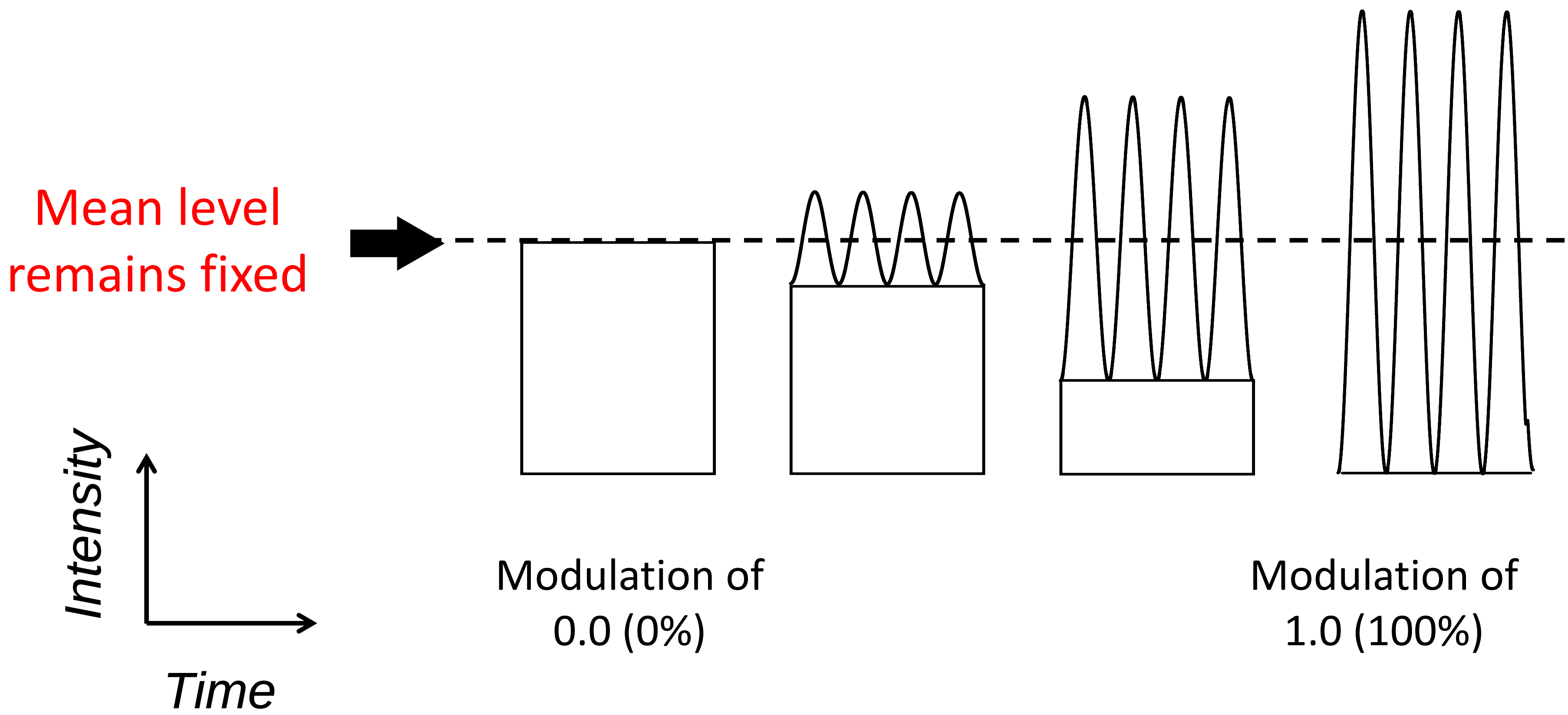




We need instead to measure the sensitivity for flicker but must leave the mean adaptive state of the eye unchanged.

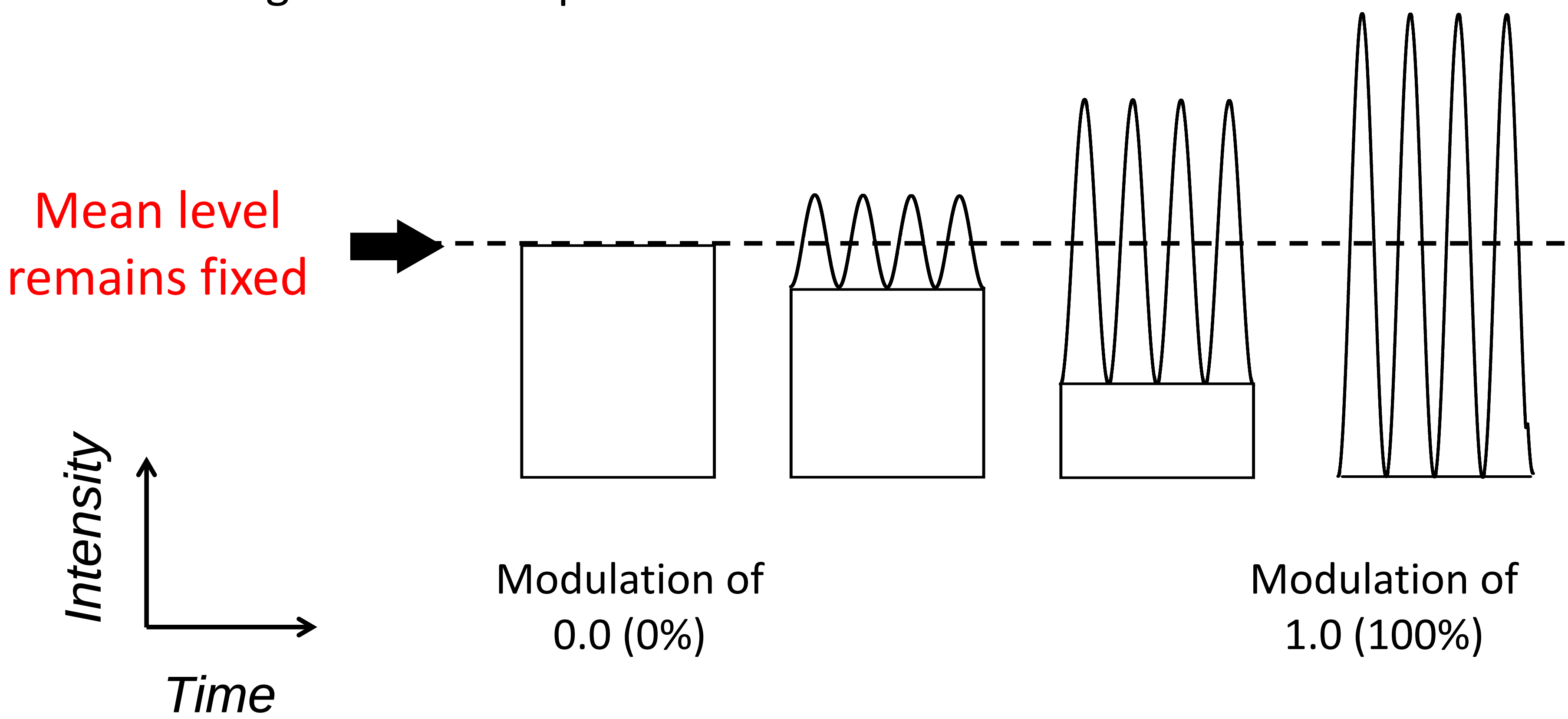
Cone temporal (or flicker) modulation sensitivity measurements.

Instead of varying flicker amplitude, the flicker "modulation" is varied…



Cone temporal (or flicker) modulation sensitivity measurements.

The observer varies the target modulation to find the threshold for detecting flicker. As modulation is varied, the time-averaged mean adaptation level remains constant



Classic data from Kelly (1961) and DeLange (1958):

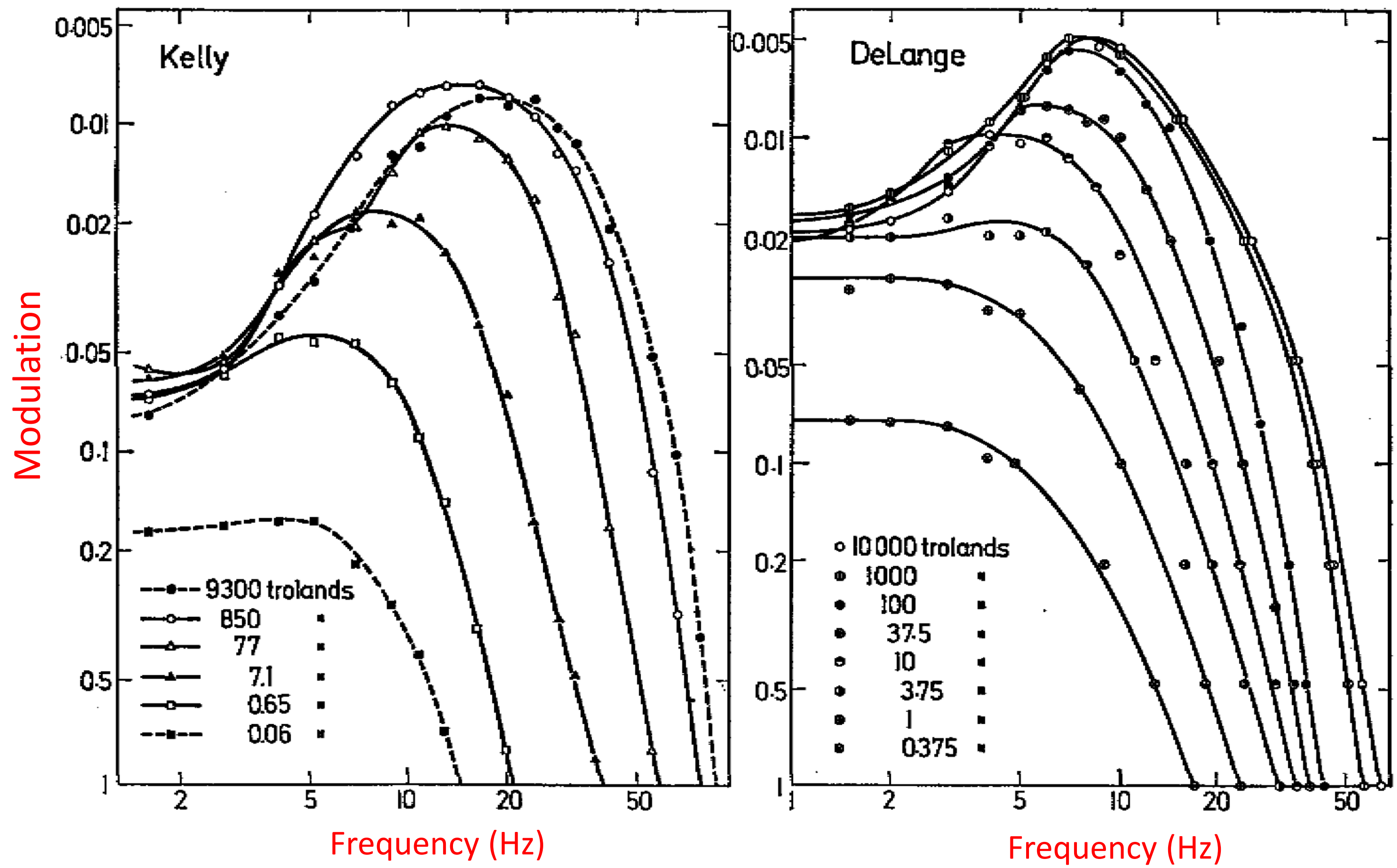


Fig. 9. Photopic modulation sensitivity data. The curves on the left were obtained with a large flickering field; those on the right with a small flickering spot on a steady surround (KELLY, 1961 a; DELANGE, 1958 a)

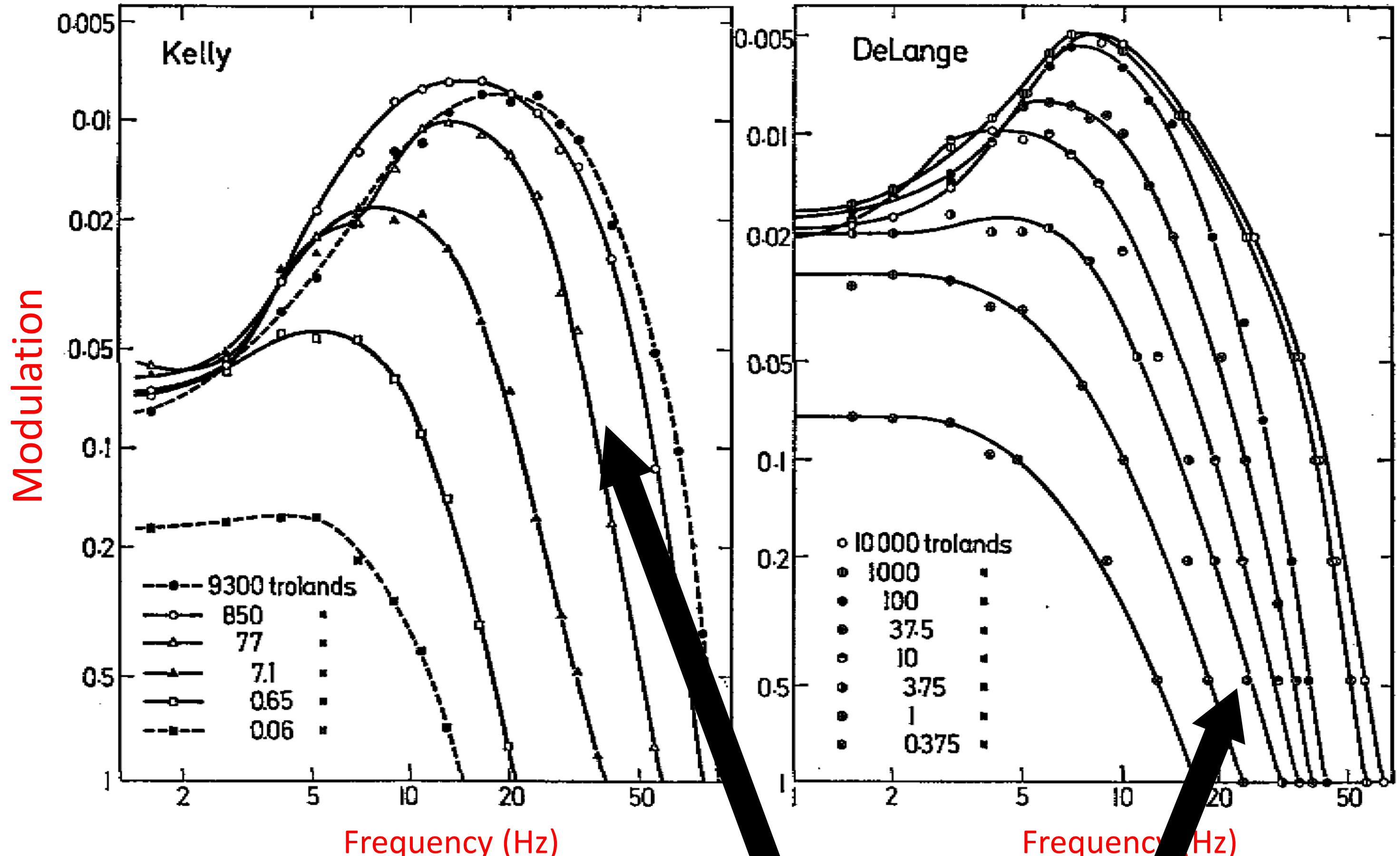


Fig. 9. Photopic modulation sensitivity data. The curves on the left were obtained with a large flickering field; those on the right with a small flickering spot on a steady surround (KELLY, 1961 a; DELANGE, 1958 a)

Improvements in sensitivity at moderate and higher frequencies

Psychophysical experiments can provide important insights into many properties of vision and visual perception.

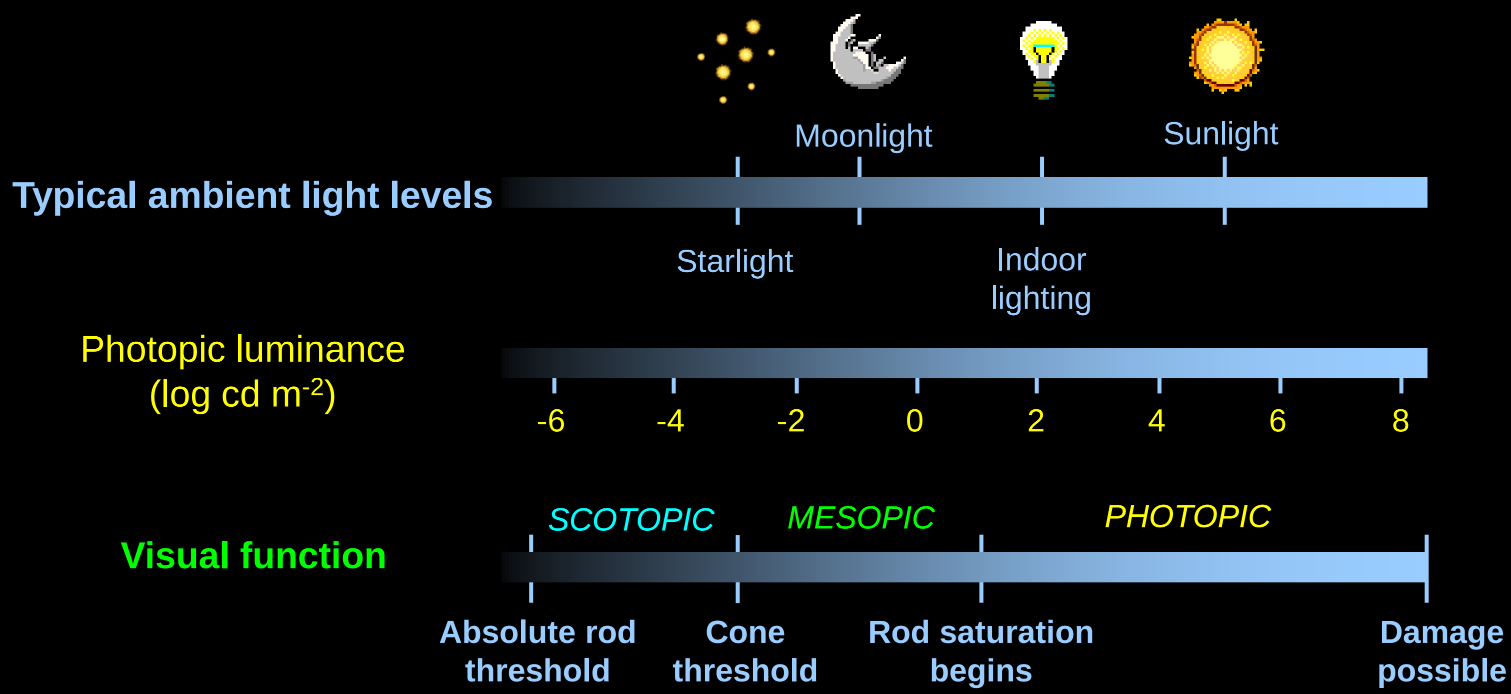
OUTLINE

Sensitivity regulation and visual adaptation

- Light adaptation
- Contrast adaptation
- Adaptation to features of a stimulus

LIGHT ADAPTATION

Light adaptation: What's the problem?



The stimulus…

11 log units, a factor of 100000000000

A typical neuron's response…

2 or 3 log units, a factor of 100 or 1000

Given that a typical neuron can only operate over a range of $<10^3$, how does the visual system maintain itself in a useful operating range despite the $>10^{11}$ change in illumination from starlight to bright sunlight?

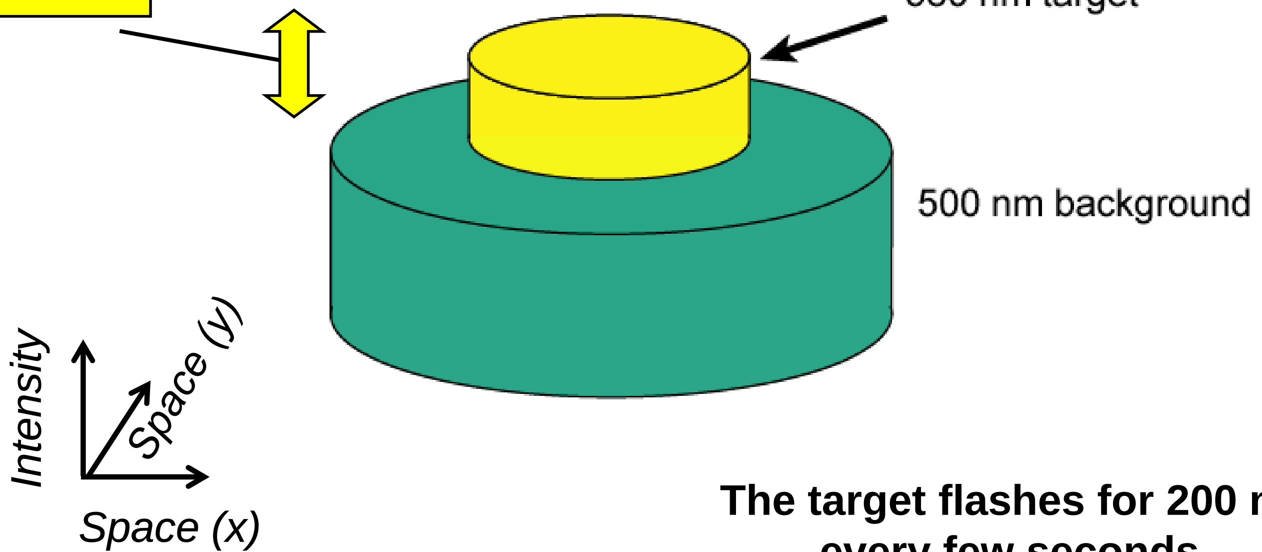
Suggestions, please…

Light adaptation: How is it done?

1. Multiple systems with different sensitivities (rods and cones)

Measuring light adaptation psychophysically: rod and cones

The subject's task is to adjust the intensity of the target flash, so that the flash is just visible (i.e., the subject sets threshold).



The target flashes for 200 ms every few seconds.

Two systems

Rod and cone threshold-versus-intensity or tvi curves

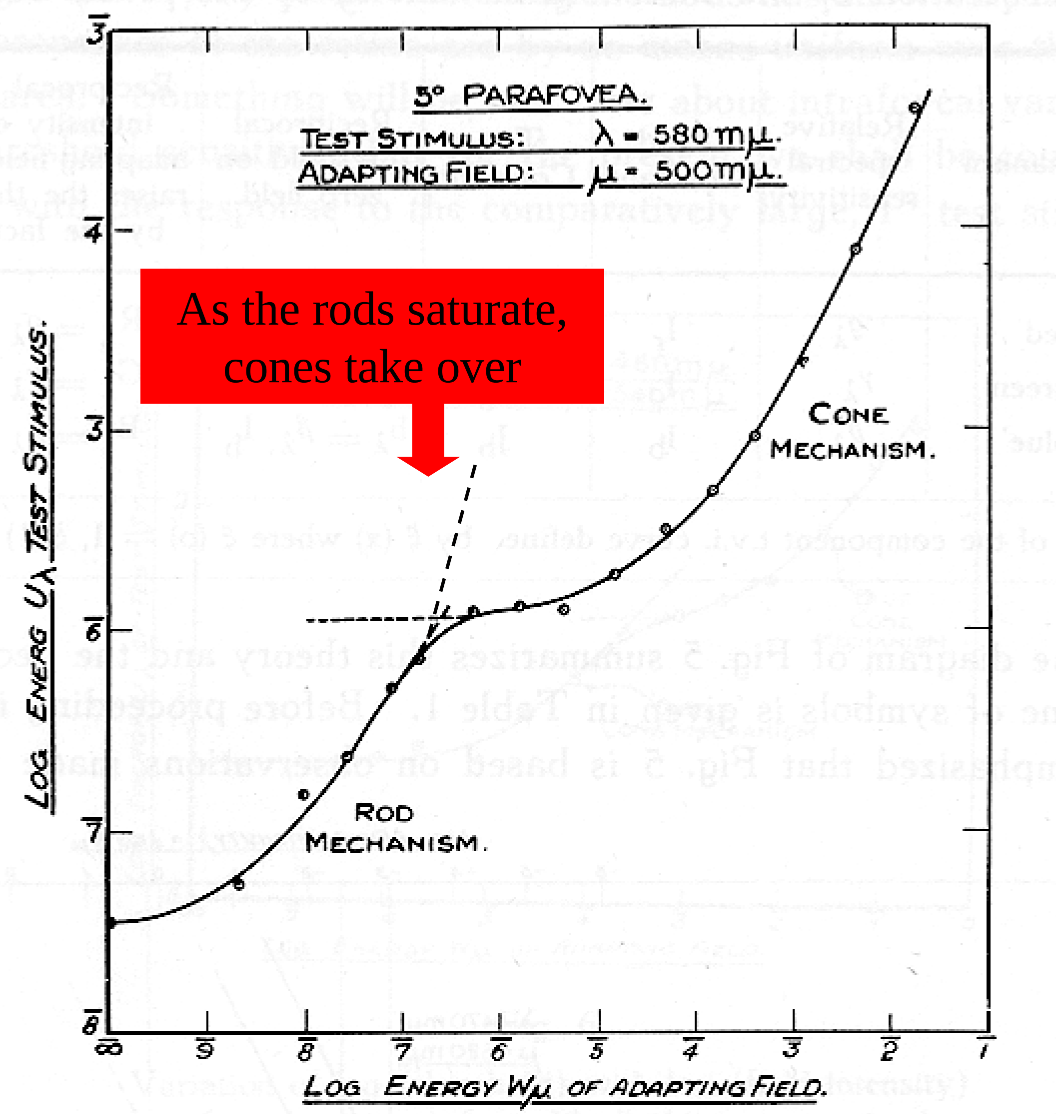
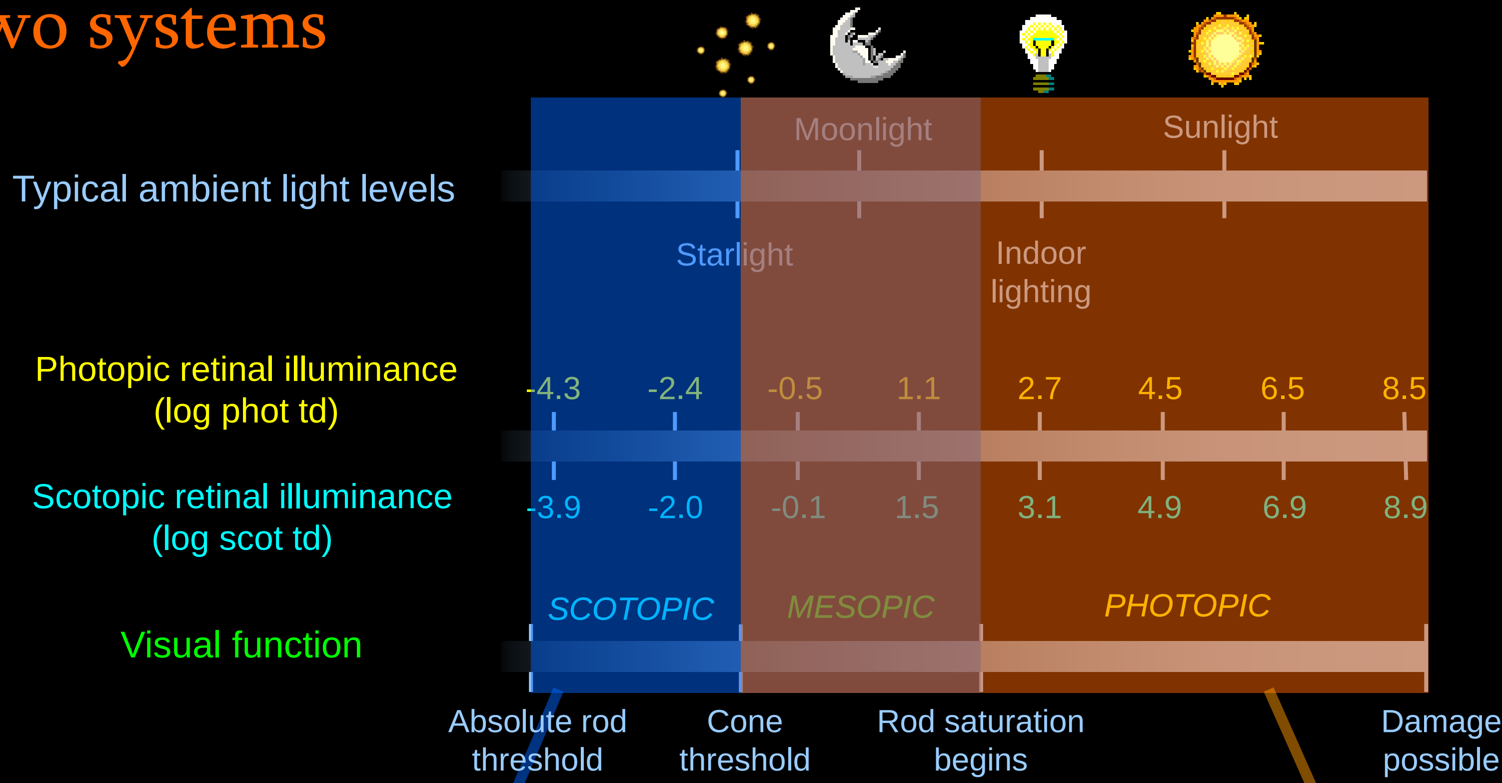


Fig. 4.

Variation of log (threshold) with log (field intensity) for a 1° flashing test stimulus of yellow light (exposure time 0.063 sec.) on a blue-green field: 5°- parafoveal vision. (Stiles, 1939)

Two systems



Rod levels
(below rod saturation)
where rod vision
functions alone.
A range of c. $10^{6.5}$

Cone levels
(above cone threshold)
where cone vision
functions alone.
A range of c. 10^{10}

Notes on “threshold” and “sensitivity”

- The lower the threshold, the higher the sensitivity
- The lower the sensitivity, the higher the threshold
- Threshold = 1 / sensitivity
- Both are often plotted in log coordinates

Light adaptation: How is it achieved?

1. Multiple systems with different sensitivities (rods and cones)

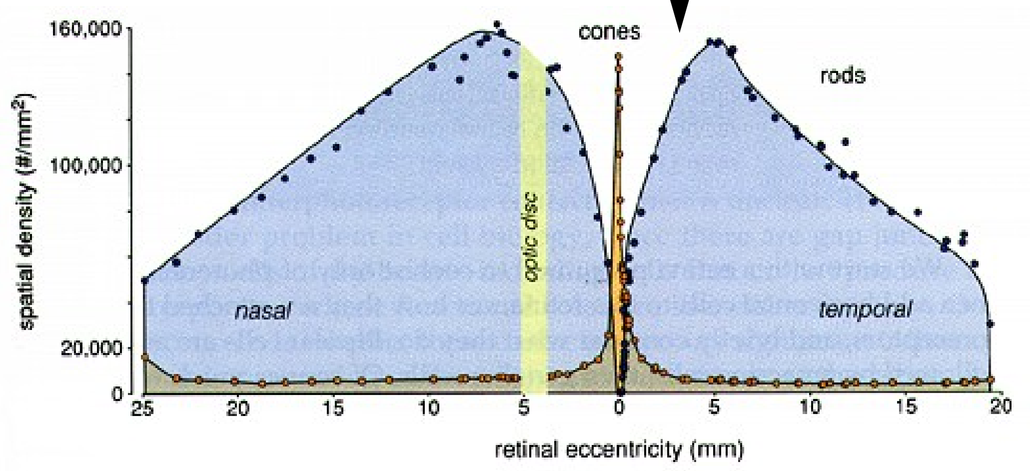
2. Desensitization (e.g., gain change, bleaching, response compression)

A simple case: Measuring light adaptation in rods alone

First, choose an area of retina that favours the rods…

Then choose stimulus wave-lengths that favour rod sensitivity over cones…

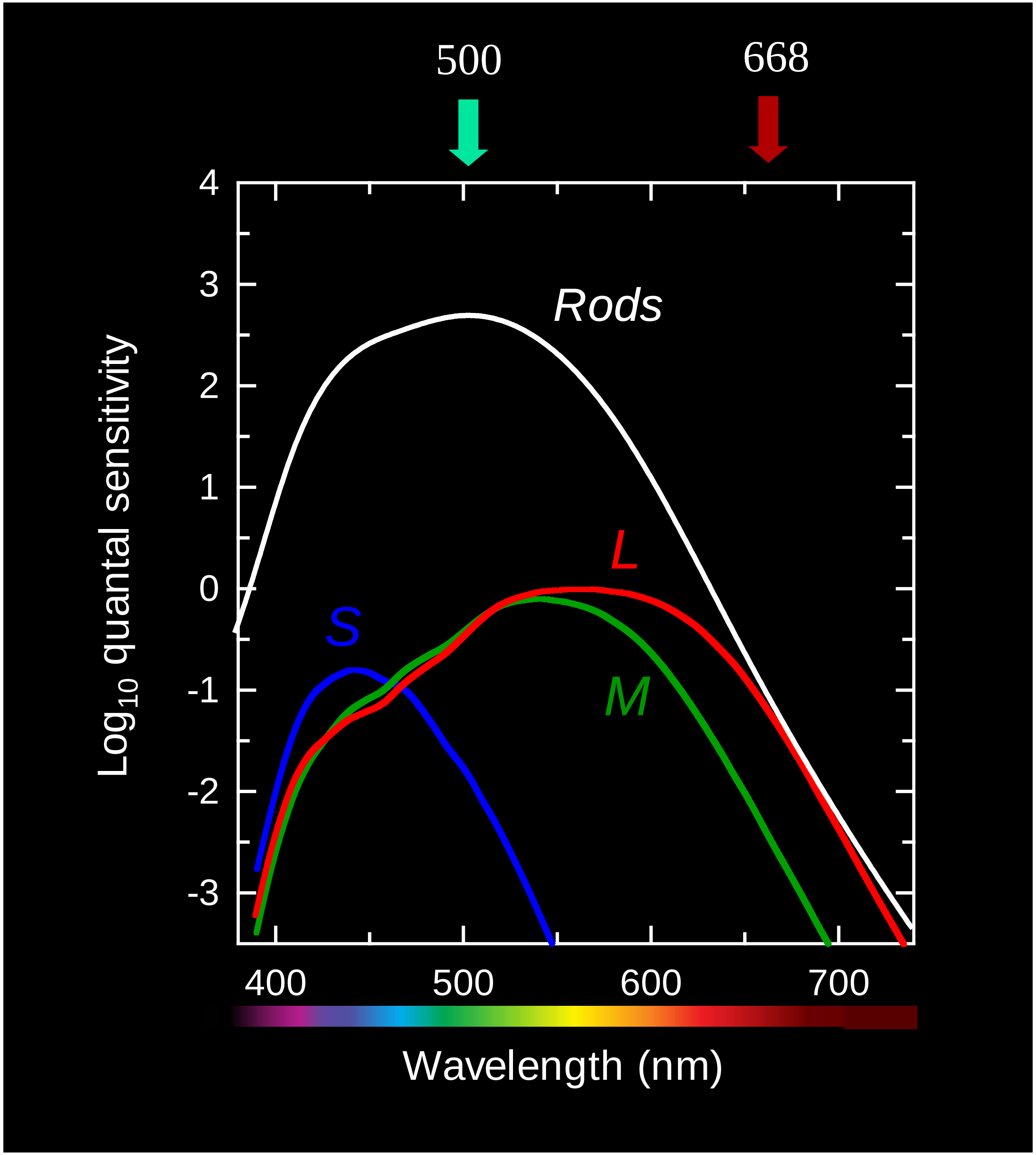
3 mm (10 deg)



after Østerberg, 1935; as modified by Rodieck, 1988

First, choose an area of retina that favours the rods…

Then choose stimulus wave-lengths that favour rod sensitivity over cones…



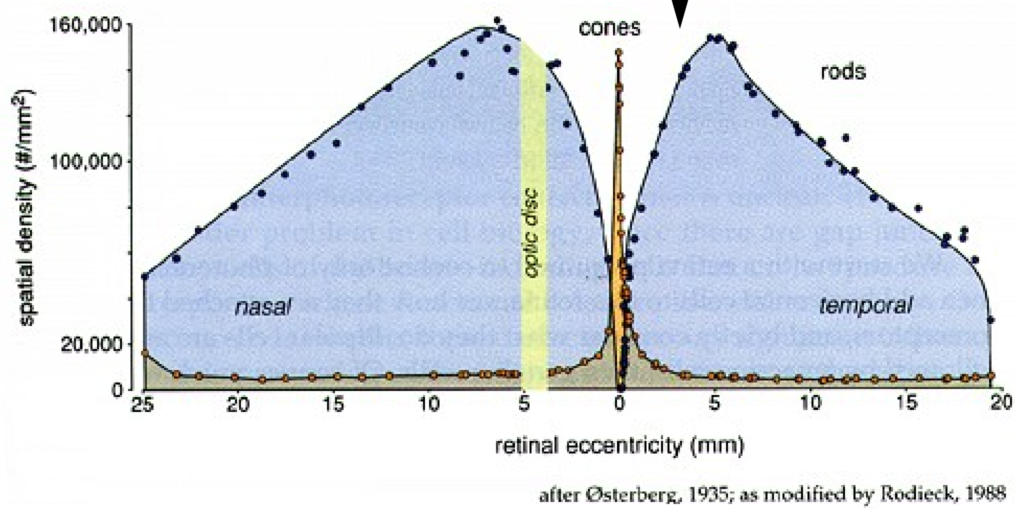
A simple case: Measuring light adaptation in rods alone

First, choose an area of retina that favours the rods…

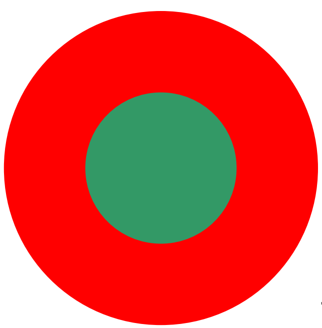
Then choose stimulus wave-lengths that favour rod sensitivity over cones…

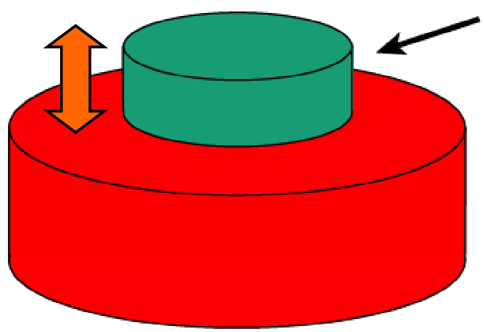
The observer's task is to adjust the intensity of the target flash, so that the flash is just visible (i.e., the subject sets threshold).

3 mm (10 deg)



10° eccentric fixation

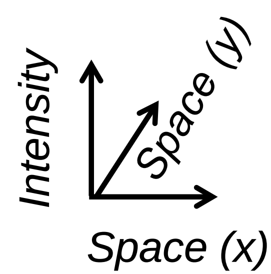




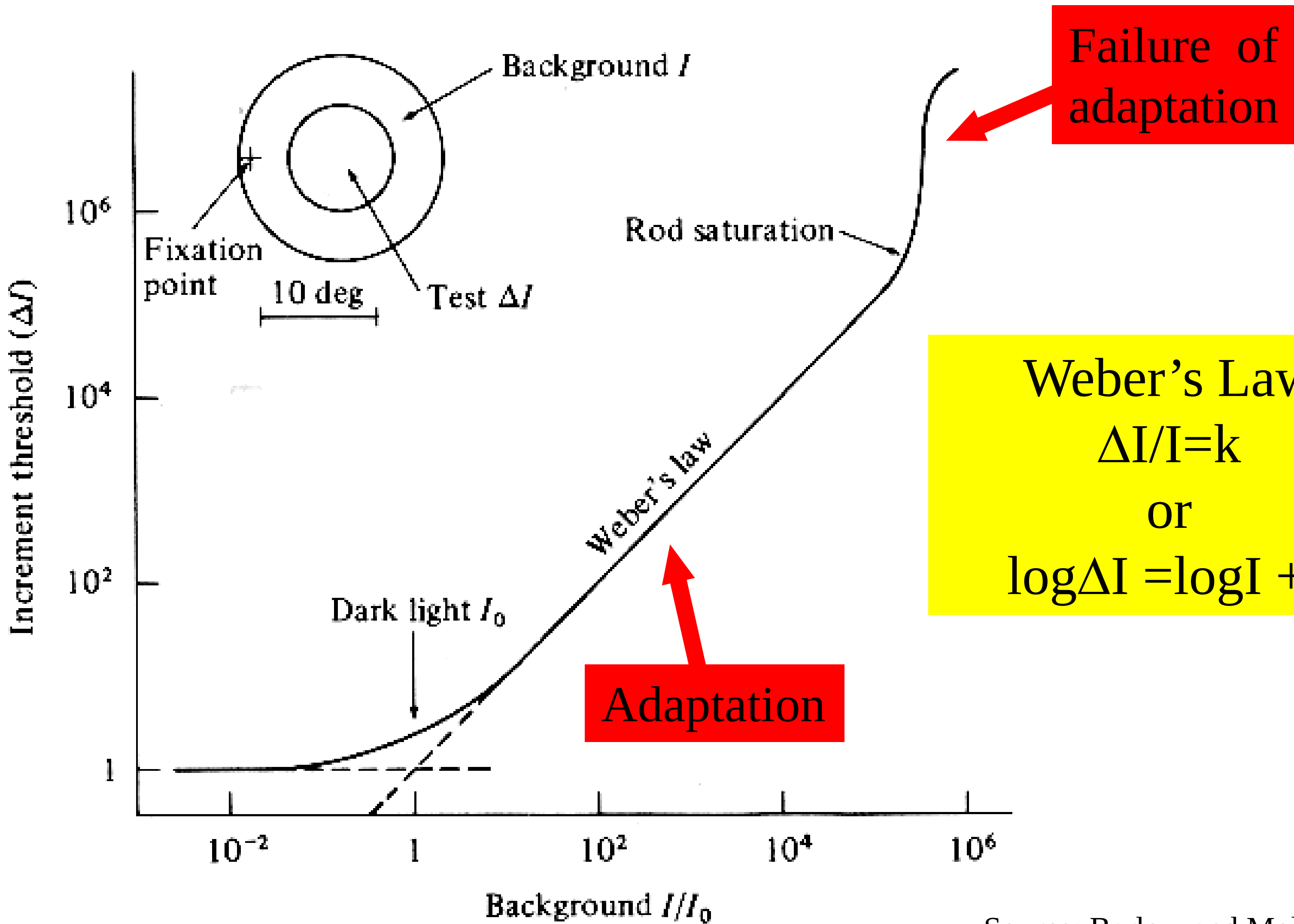
Rod-detected green (e.g., 500-nm) flashed target

Red (e.g., 668-nm) background to suppress the cones

The target flashes for 200 ms every few seconds.



Rod threshold versus intensity (tvi) curves



Weber's Law

$\Delta I/I=k$

or

$\log\Delta I = \log I + c$

Source: Barlow and Mollon, 1982

What are the advantages of a system that follows Weber's Law?

Weber's Law

$\Delta I/I=k$

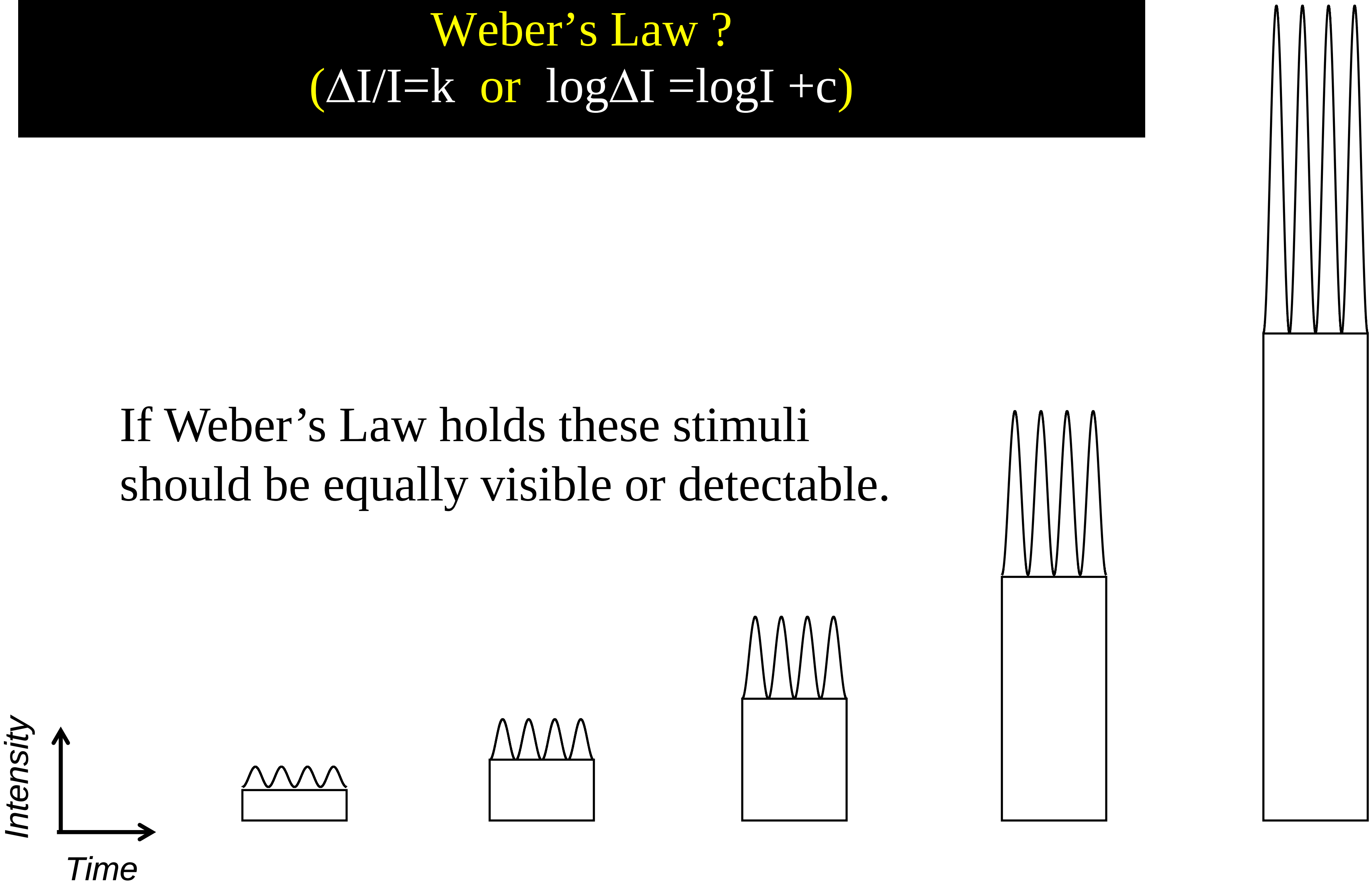
or

$\log\Delta I = \log I + c$

What happens to contrast as adaptation changes?

What are the advantages of a system that follows Weber's Law ?
($\Delta I/I=k$ or $\log\Delta I = \log I + c$)

If Weber's Law holds these stimuli should be equally visible or detectable.



Things of the same contrast ($\Delta I/I$) look the same!

Weber's Law

$\Delta I / I = k$

or

$\log \Delta I = \log I + c$

How can Weber's Law be implemented?

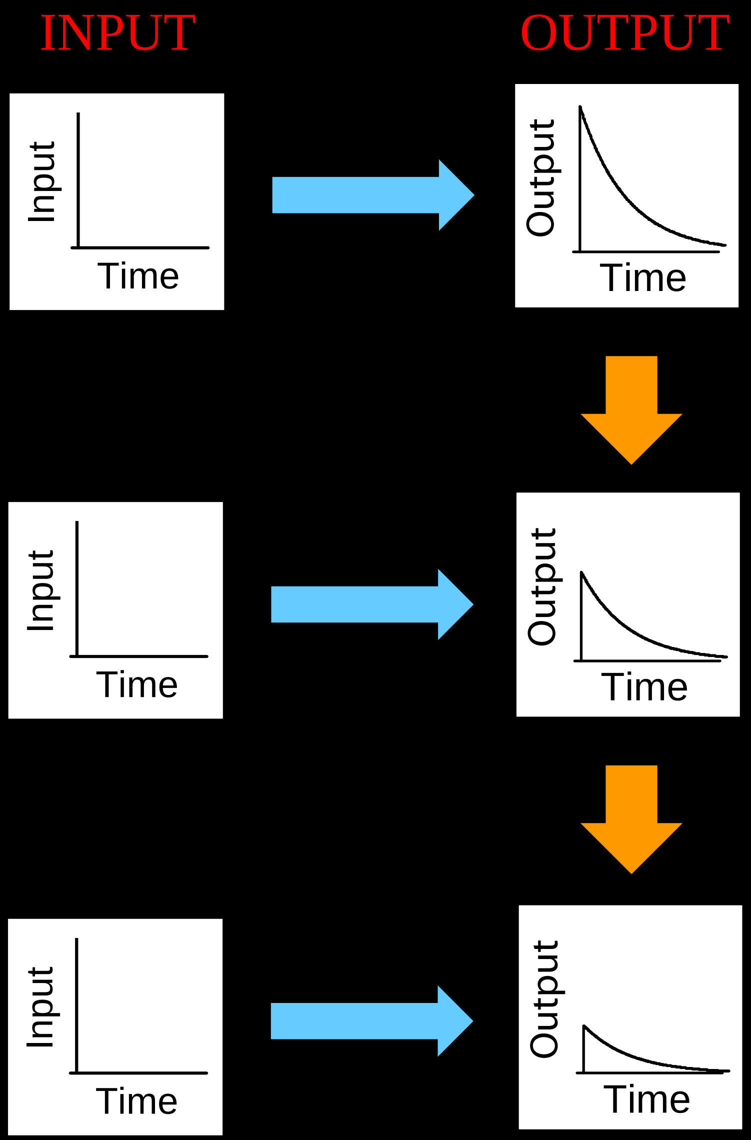
Weber's Law

$\Delta I / I = k$

or

$\log \Delta I = \log I + c$

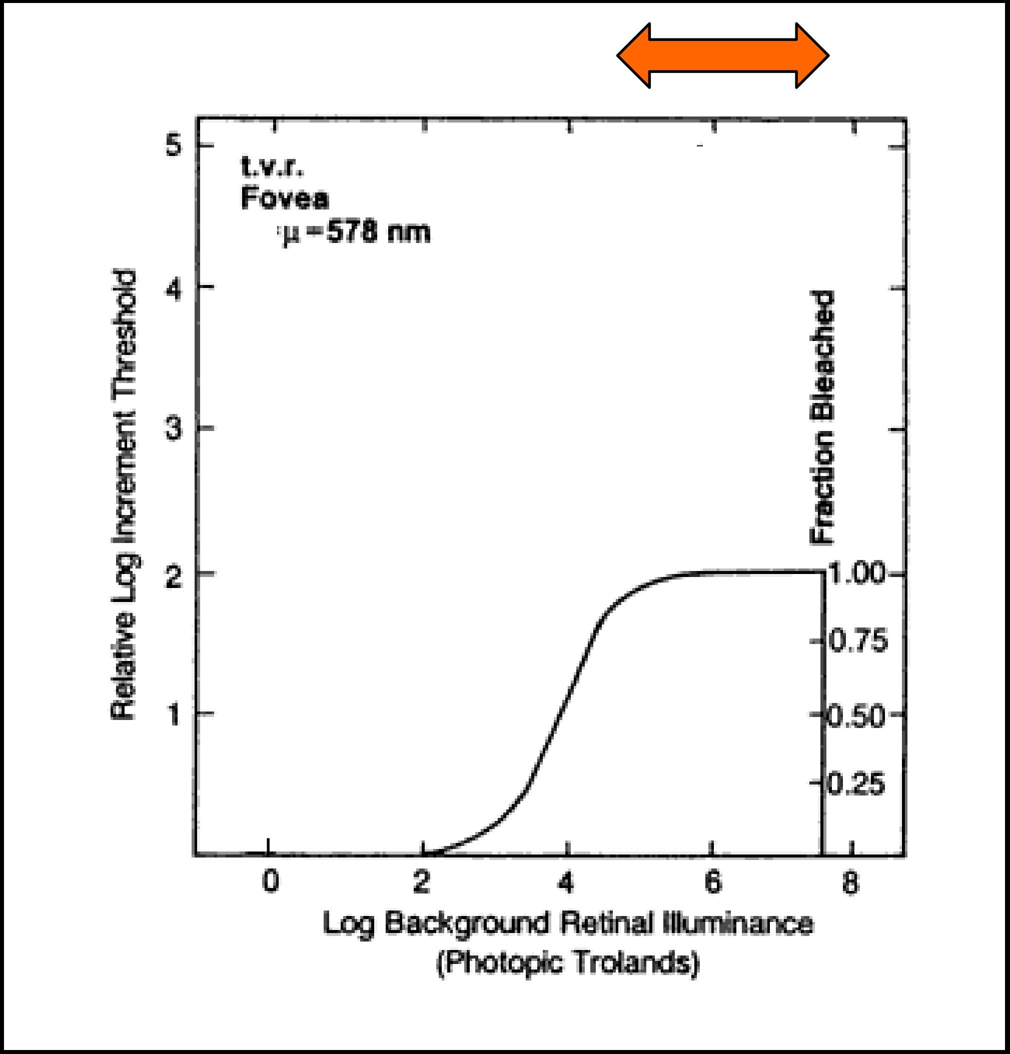
Several mechanisms, singly or in combination, can give rise to Weber's Law…



The change in the gain of the system...

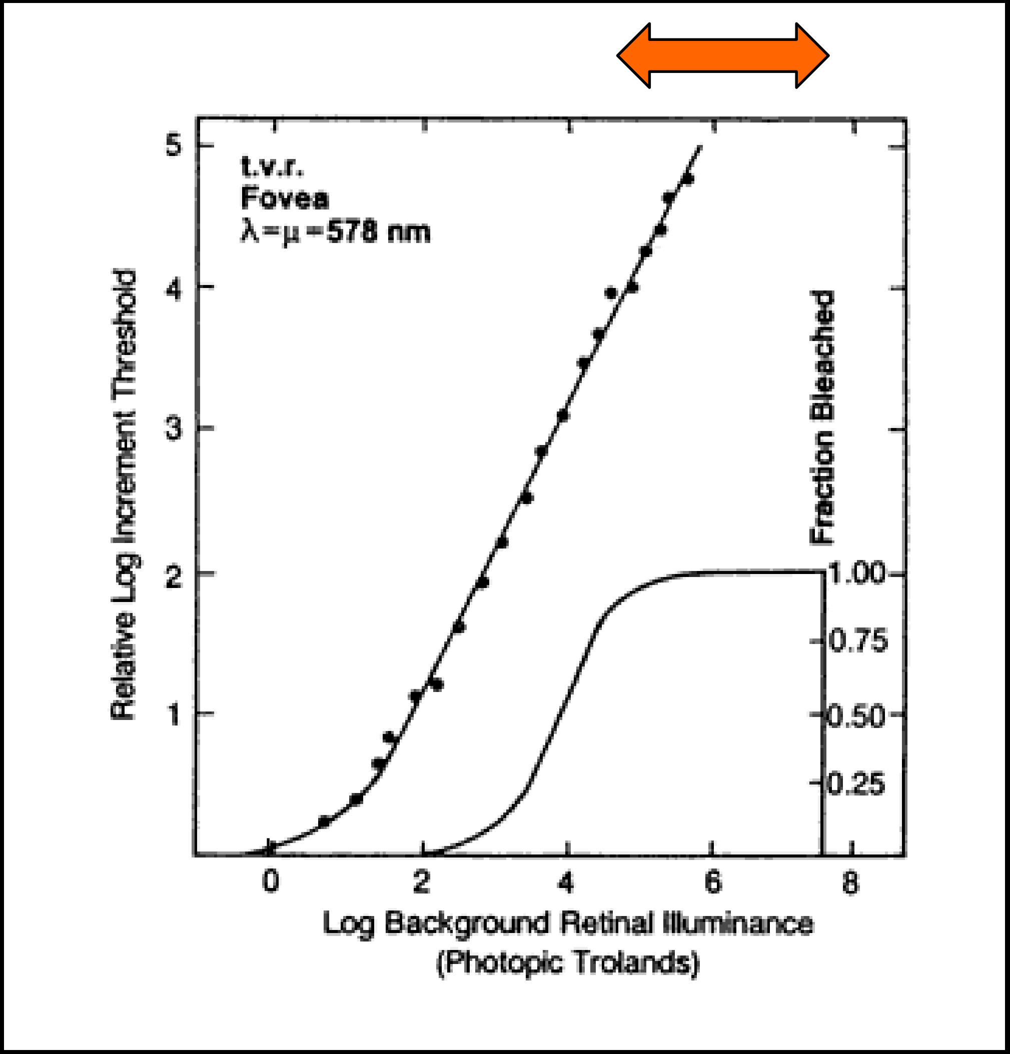
could be adjusted to maintain Weber's Law at *all* frequencies

Photopigment bleaching



At cone bleaching levels…

Jay Enoch

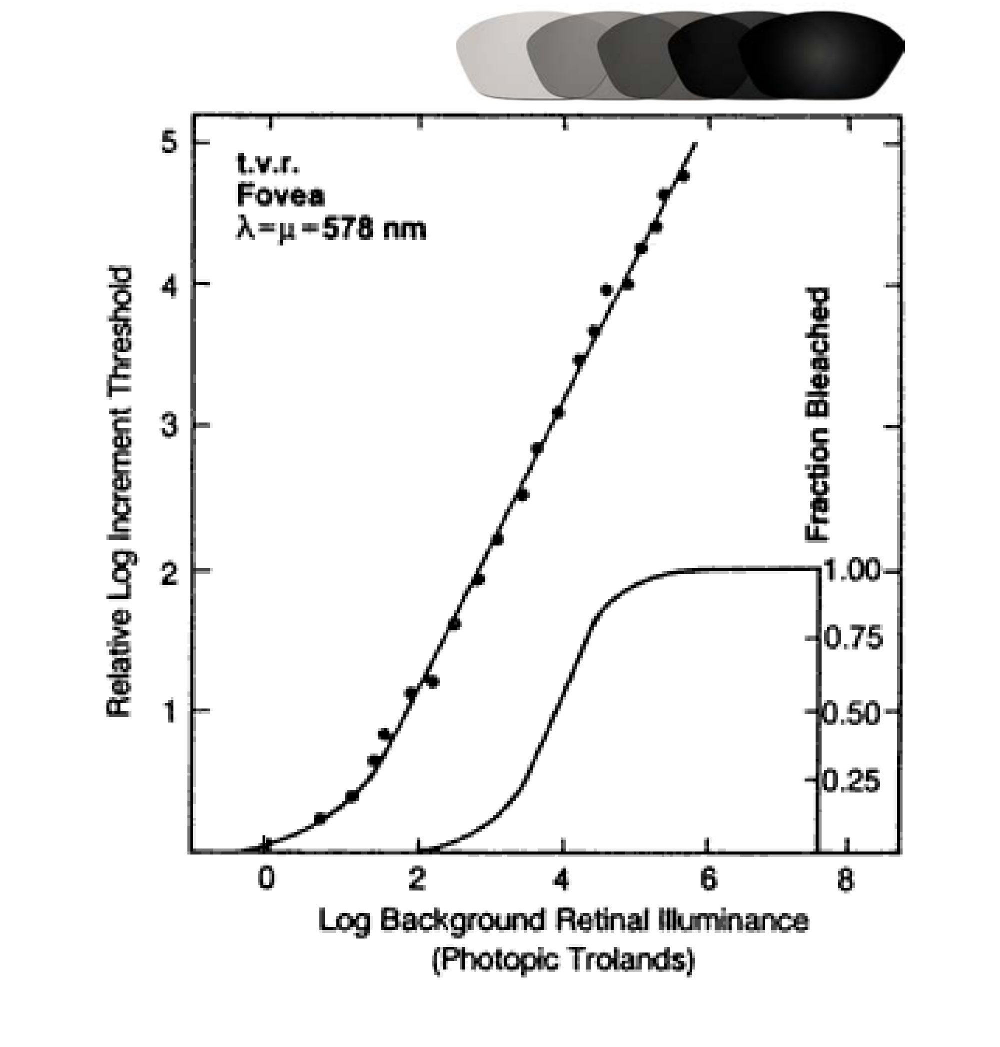


At cone bleaching levels…

Weber’s law continues to hold.

Jay Enoch

Bleaching can be thought of as putting on dark glasses of increasing density.

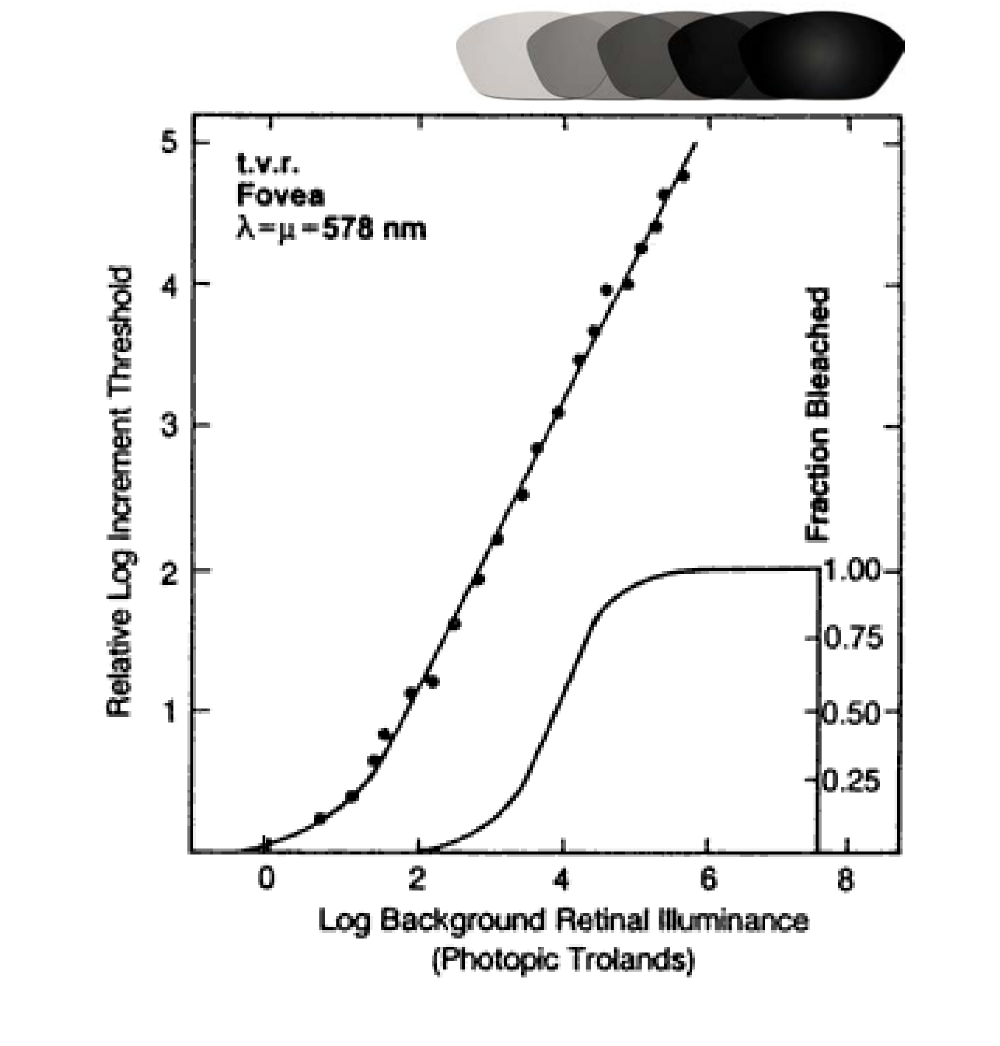


At cone bleaching levels…

Weber's law continues to hold.

Jay Enoch

Bleaching can be thought of as putting on dark glasses of increasing density.



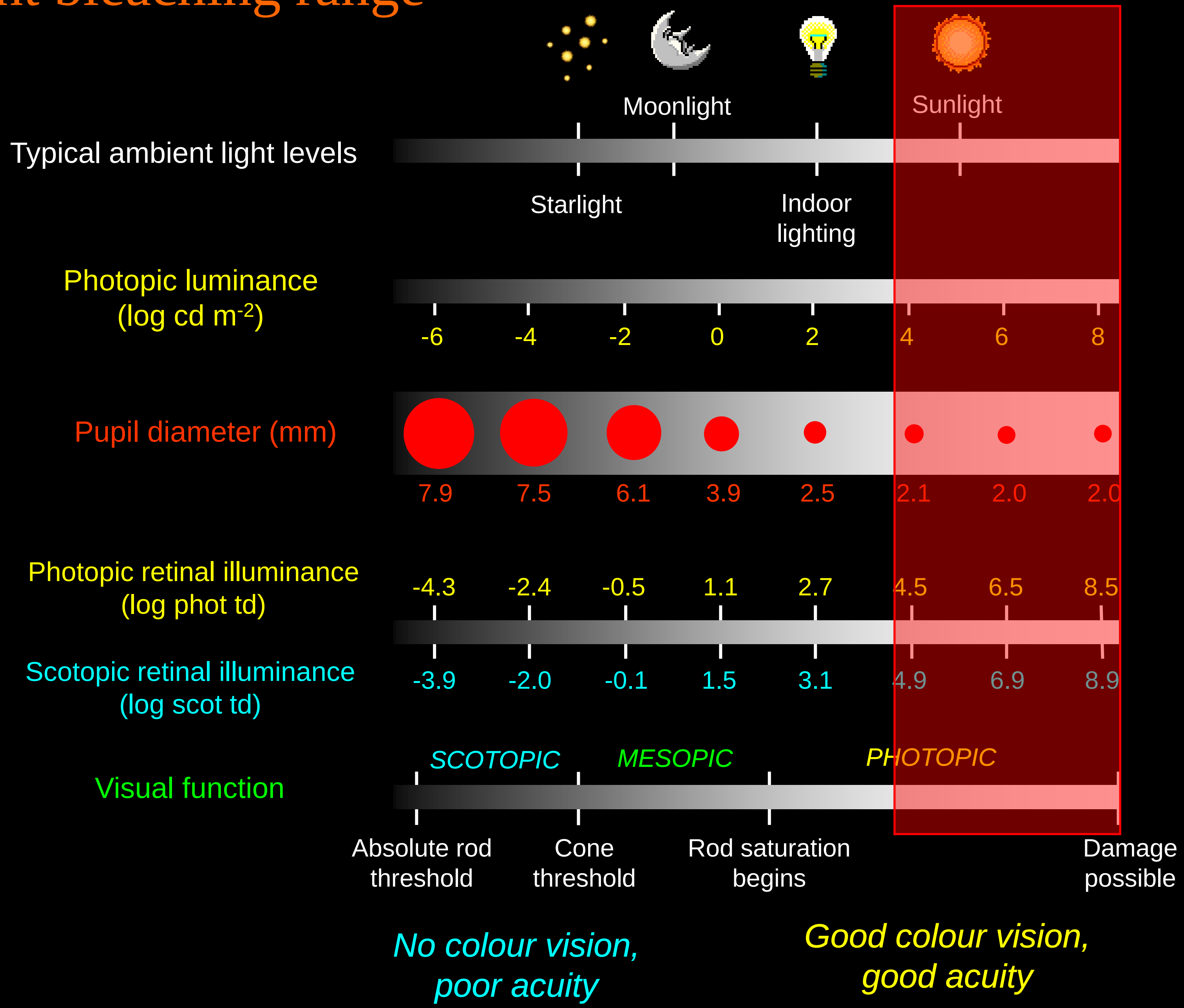
At cone bleaching levels…

Weber's law continues to hold.

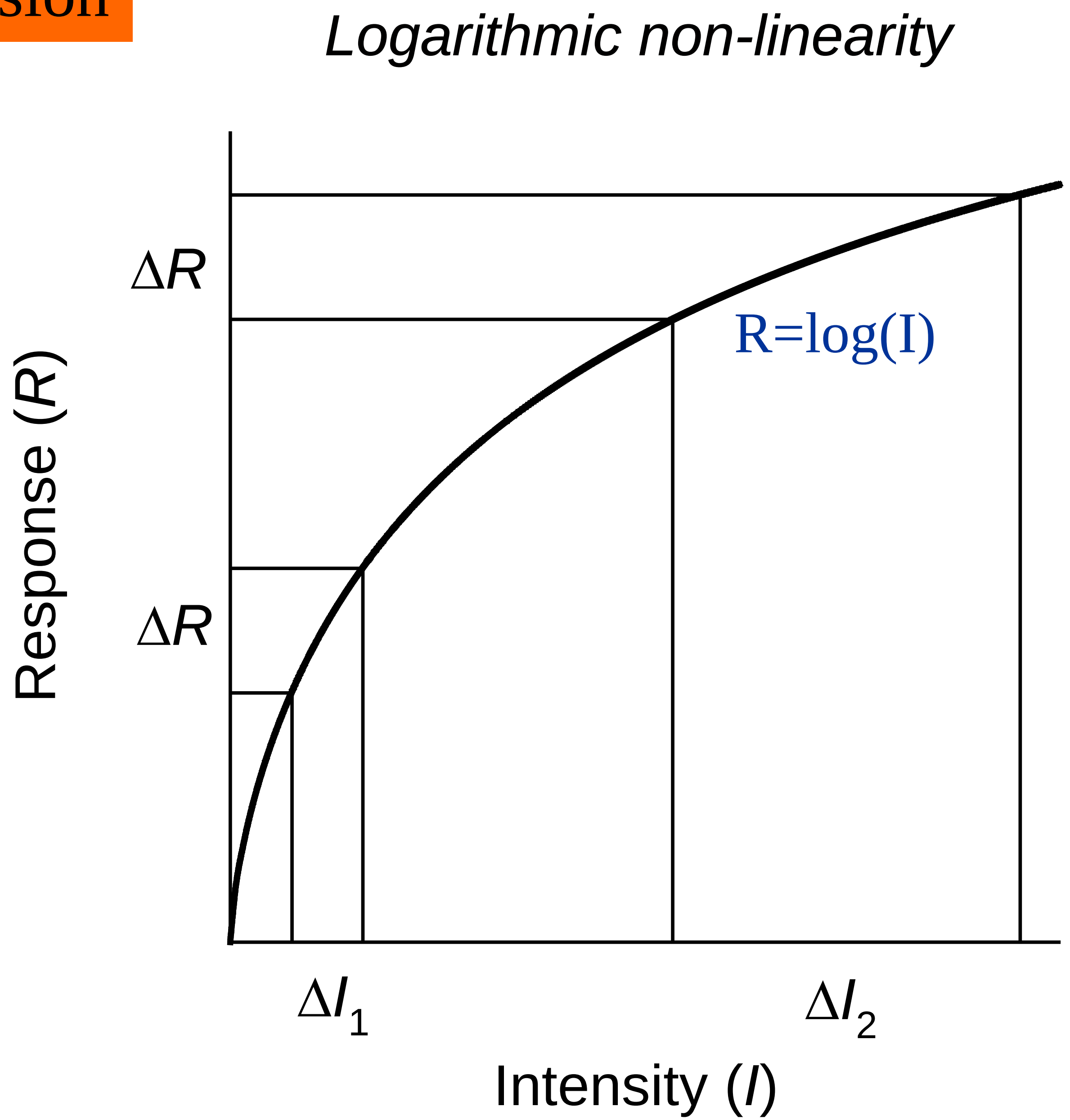
Photopigment bleaching stops the cones from saturating.

Jay Enoch

Important bleaching range



Response compression

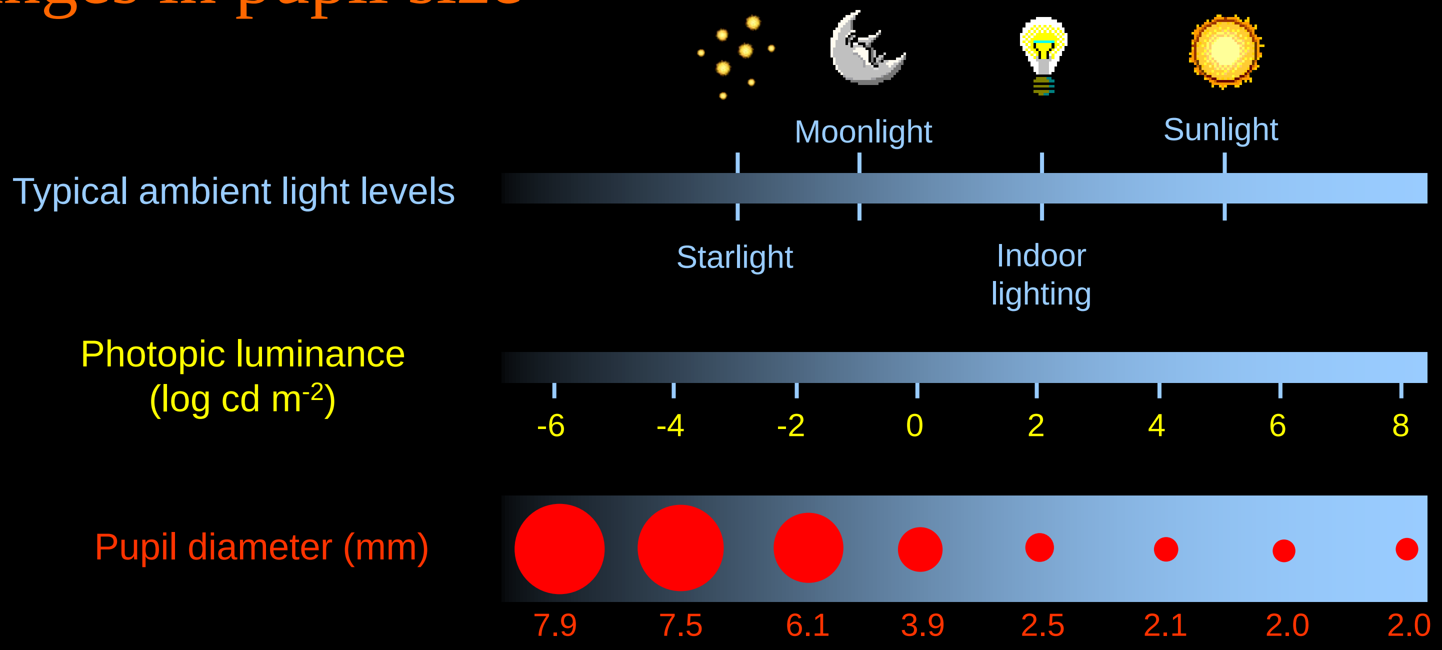


Assume that the ΔR required for detection is the same for all I.

Light adaptation: How is it achieved?

1. Multiple systems with different sensitivities (rods and cones)
2. Desensitization (e.g., gain change, bleaching, response compression)
3. Change in pupil size

Changes in pupil size



What is the effect of changing the pupil diameter from 7.9 mm to 2 mm on the light entering the eye?

Area = πr^2

So the area changes from about

$3.45 \times 3.45 \times 3.14 = 37.39$ sq mm

to

$1 \times 1 \times 3.14 = 3.14$ sq mm

Which is a factor of c. 10, or 1 log unit.

Light adaptation: How is it achieved?

1. Multiple systems with different sensitivities (rods and cones)
2. Desensitization
3. Changes in pupil size
4. Temporal adaptation (speeding up/ shortening time constants)

Back to: Shortening time constants

- The system sums light over shorter and shorter time periods.
- As a result, the system becomes relatively more sensitive to high temporal frequencies and relatively less sensitive to low temporal frequencies.
- The system also responds more quickly; i.e., becomes less sluggish.

Can changing the integration time also give rise to Weber's Law?

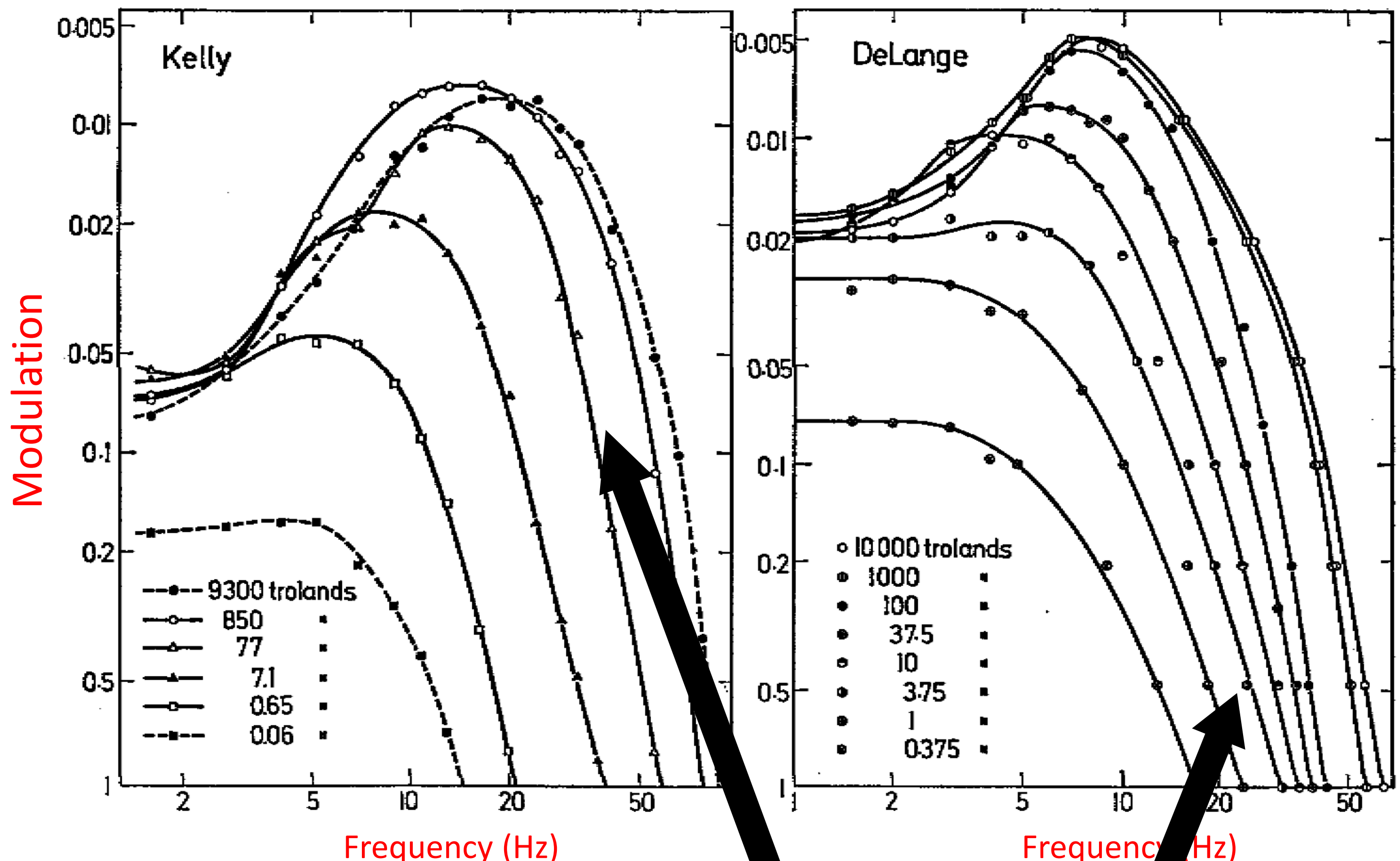


Fig. 9. Photopic modulation sensitivity data. The curves on the left were obtained with a large flickering field; those on the right with a small flickering spot on a steady surround (KELLY, 1961 a; DELANGE, 1958 a)

Improvements in sensitivity at moderate and higher frequencies

Weber's law at low frequencies: $\Delta I/I$ is constant

YES!

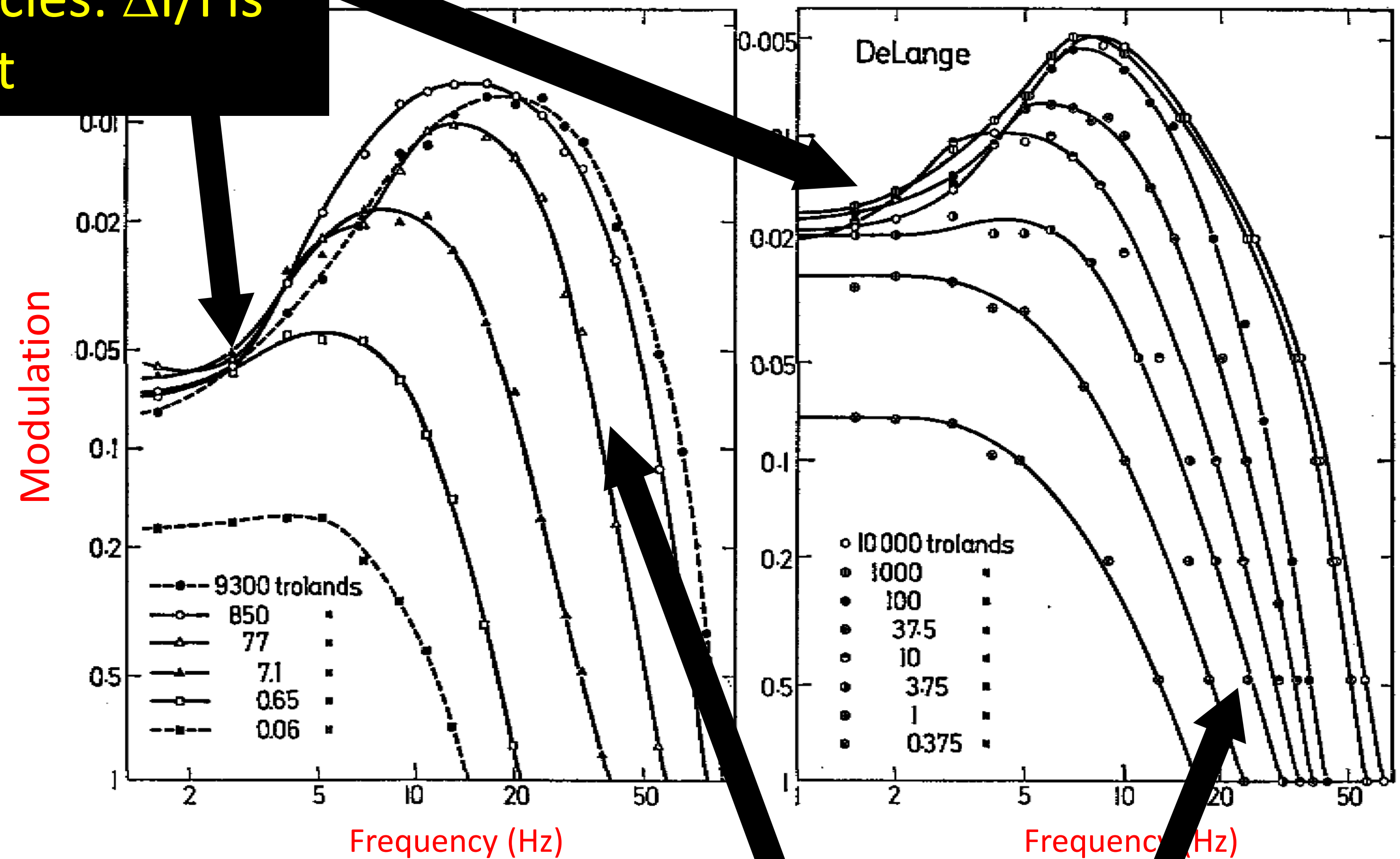


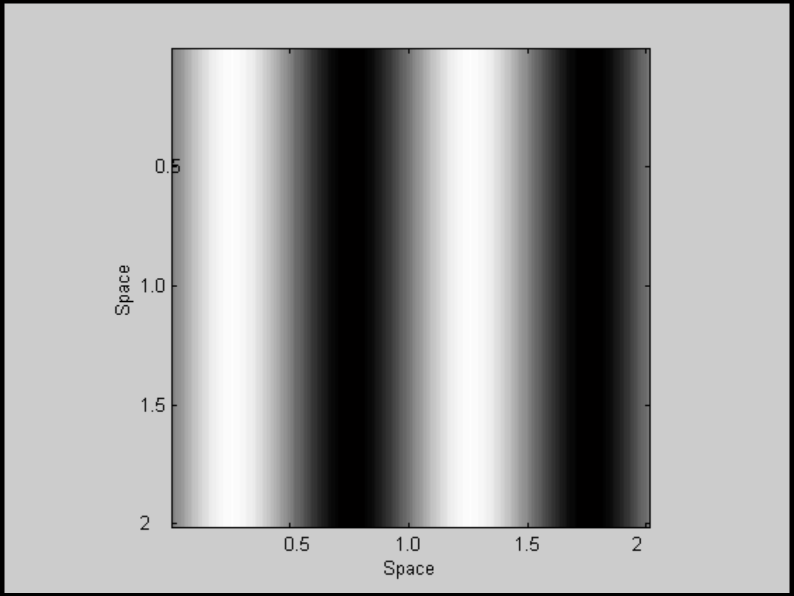
Fig. 9. Photopic modulation sensitivity data. The curves on the left were obtained with a large flickering field; those on the right with a small flickering spot on a steady surround (KELLY, 1961a; DELANGE, 1958a)

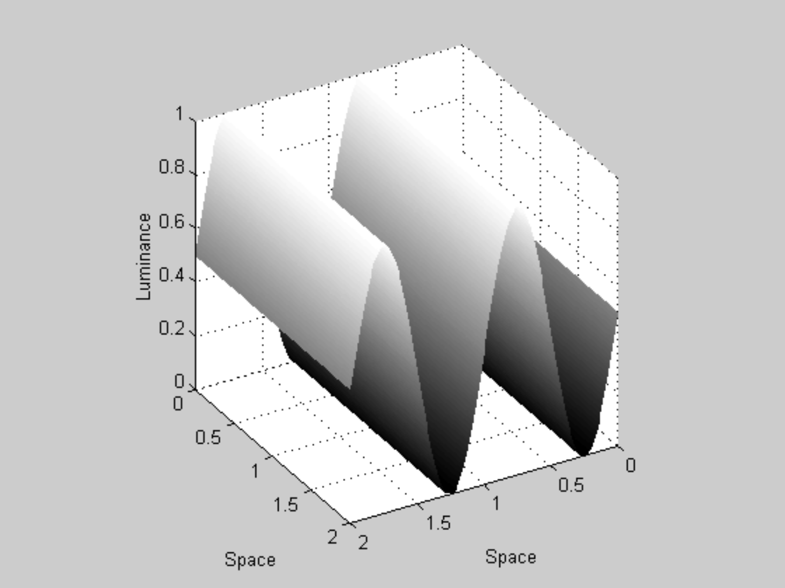
Improvements in sensitivity at moderate and higher frequencies

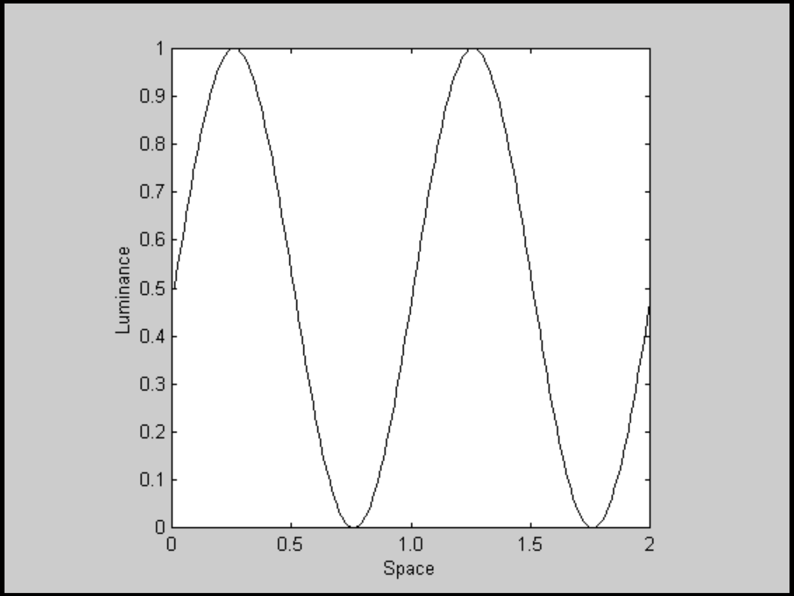
Light adaptation: How is it achieved?

1. Multiple systems with different sensitivities (rods and cones)
2. Desensitization
3. Changes in pupil size
4. Temporal adaptation (shortening time constants)
5. Spatial reorganization (shortening space constants)

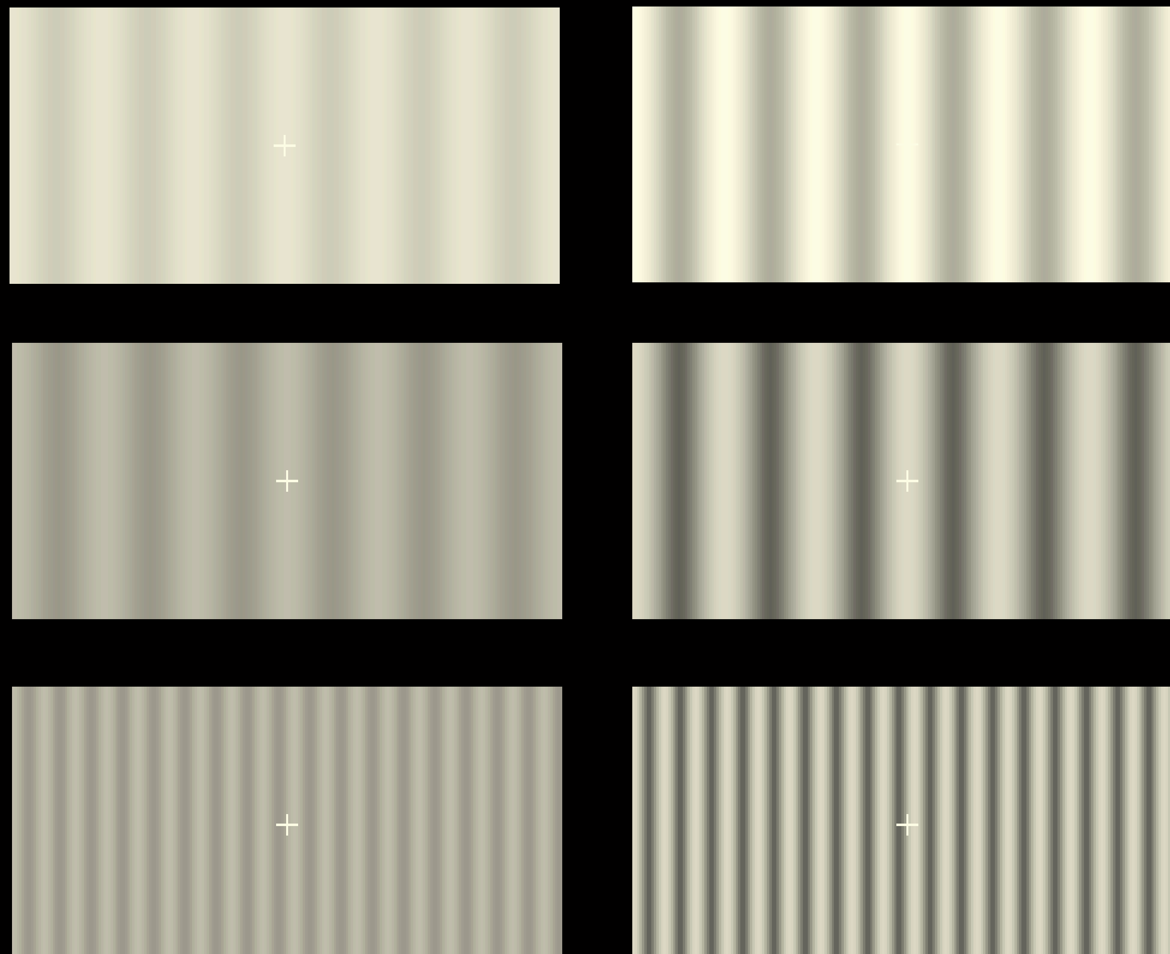
Spatial frequency







Spatial frequency gratings



Lower frequency

Higher frequency

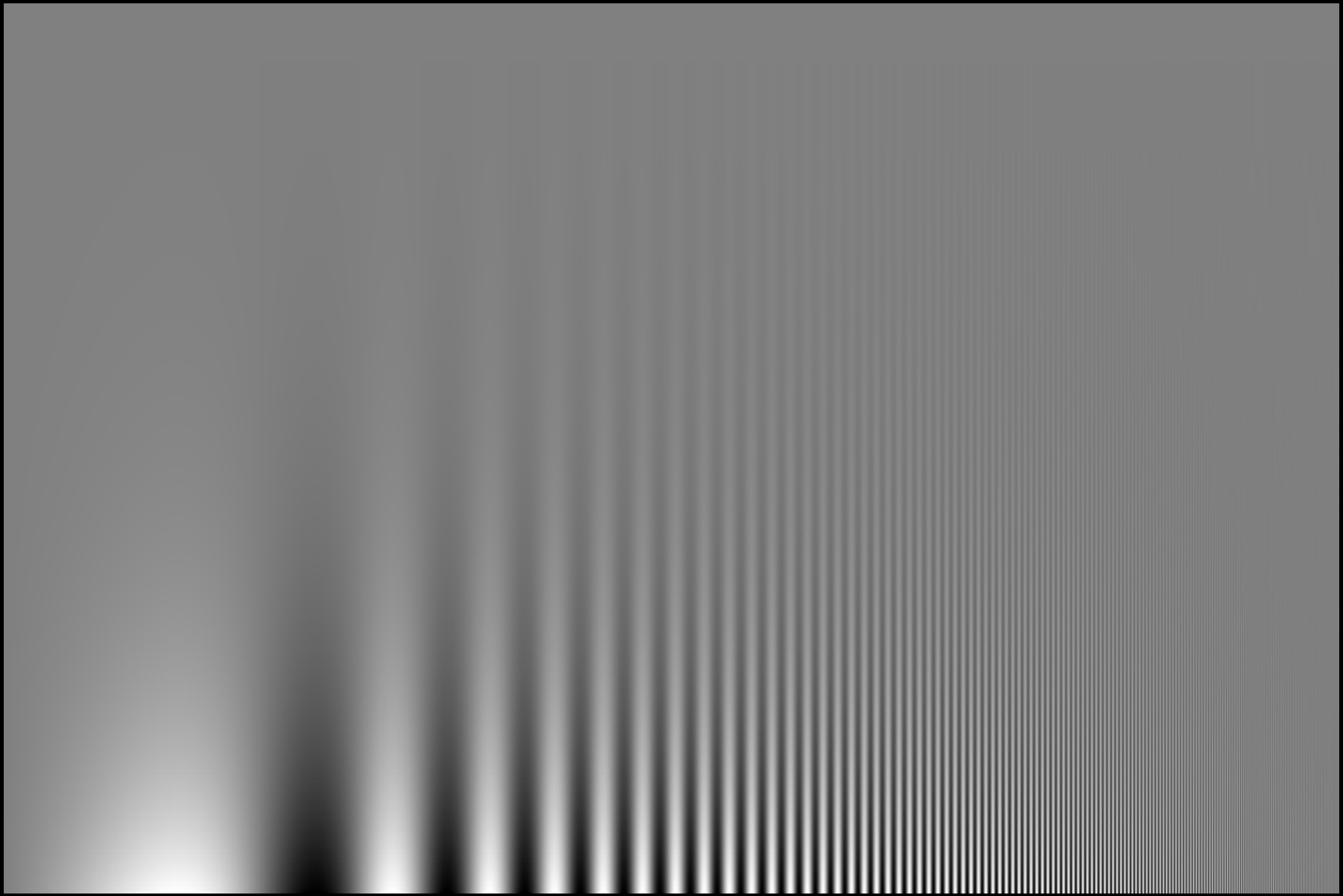
Lower contrast

Higher contrast

Hans Irtel

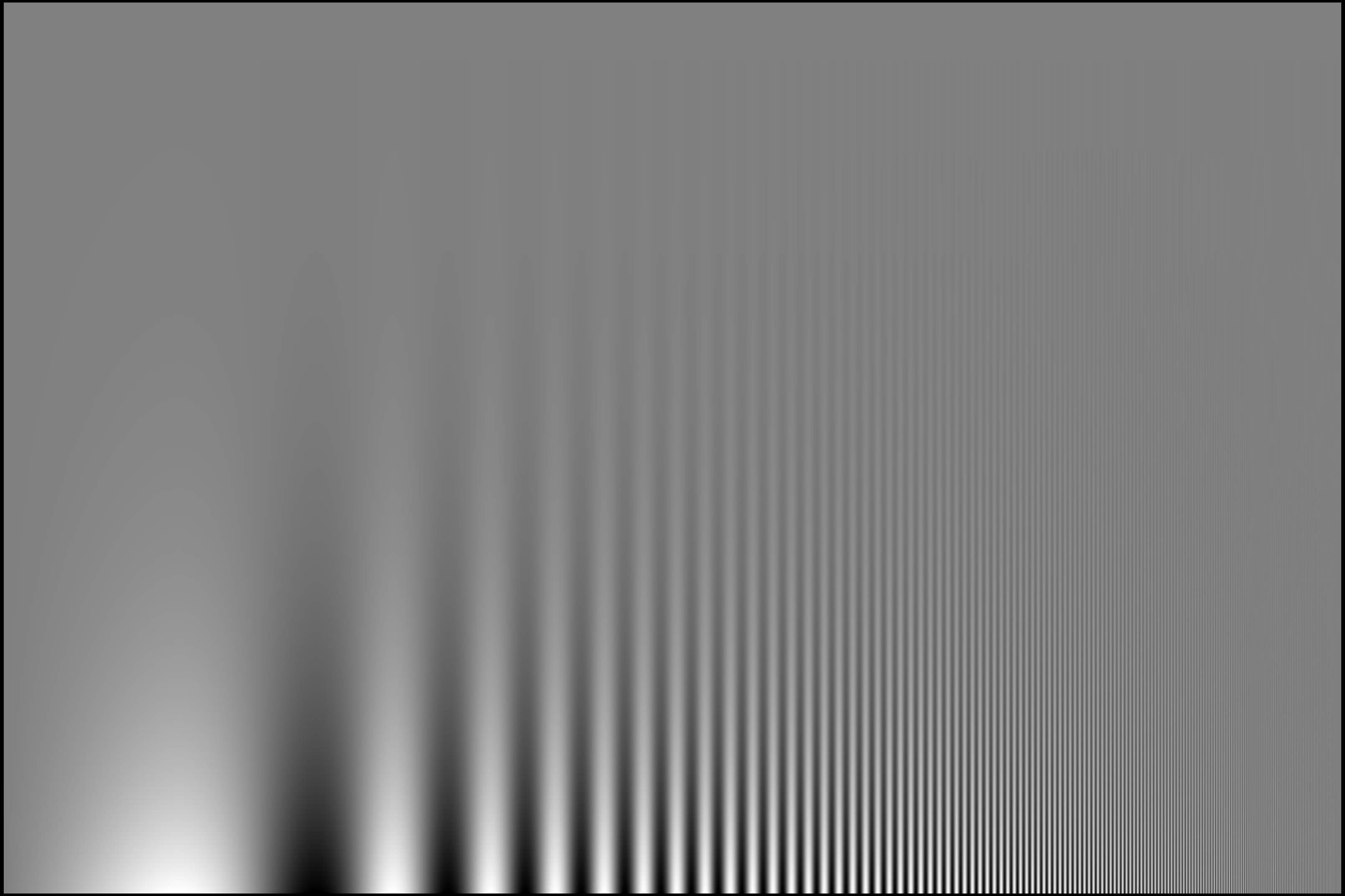
Spatial MTF

Spatial frequency in this image increases in the horizontal direction and modulation depth decreases in the vertical direction.



Spatial MTF

The apparent border between visible and invisible modulation corresponds to your own visual modulation transfer function.



Spatial MTFs

What happens as the visual system light adapts?

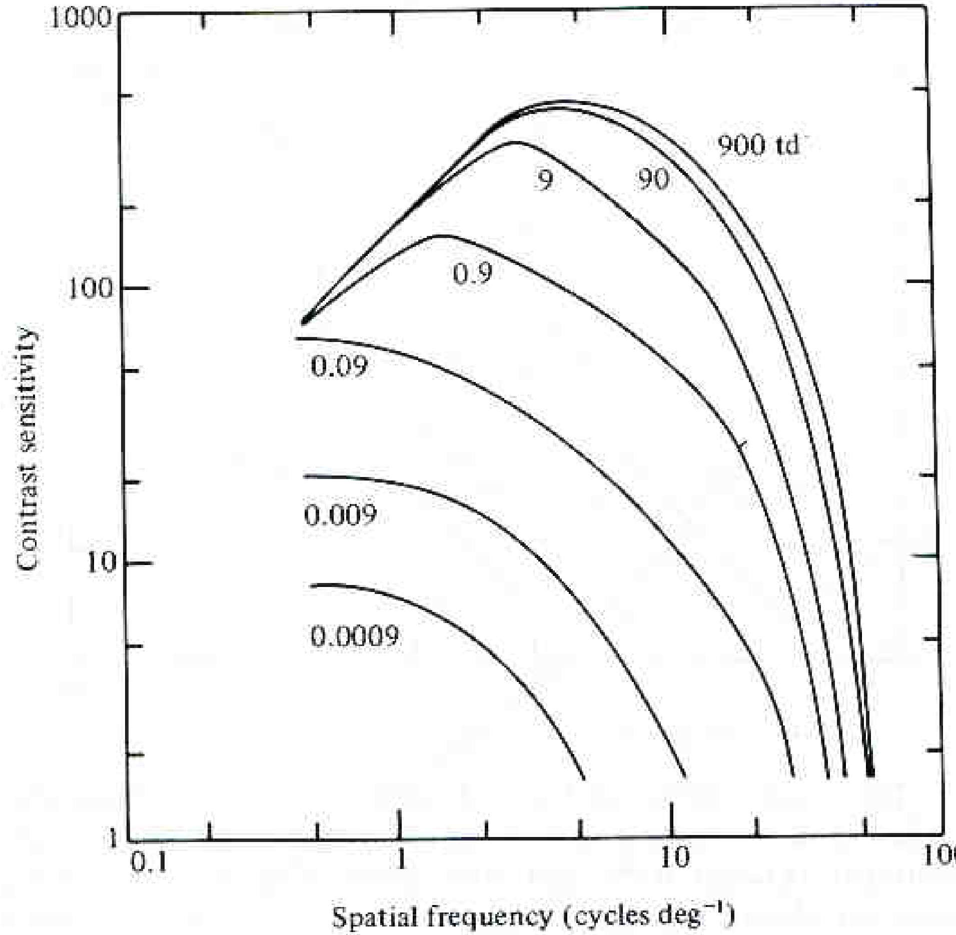
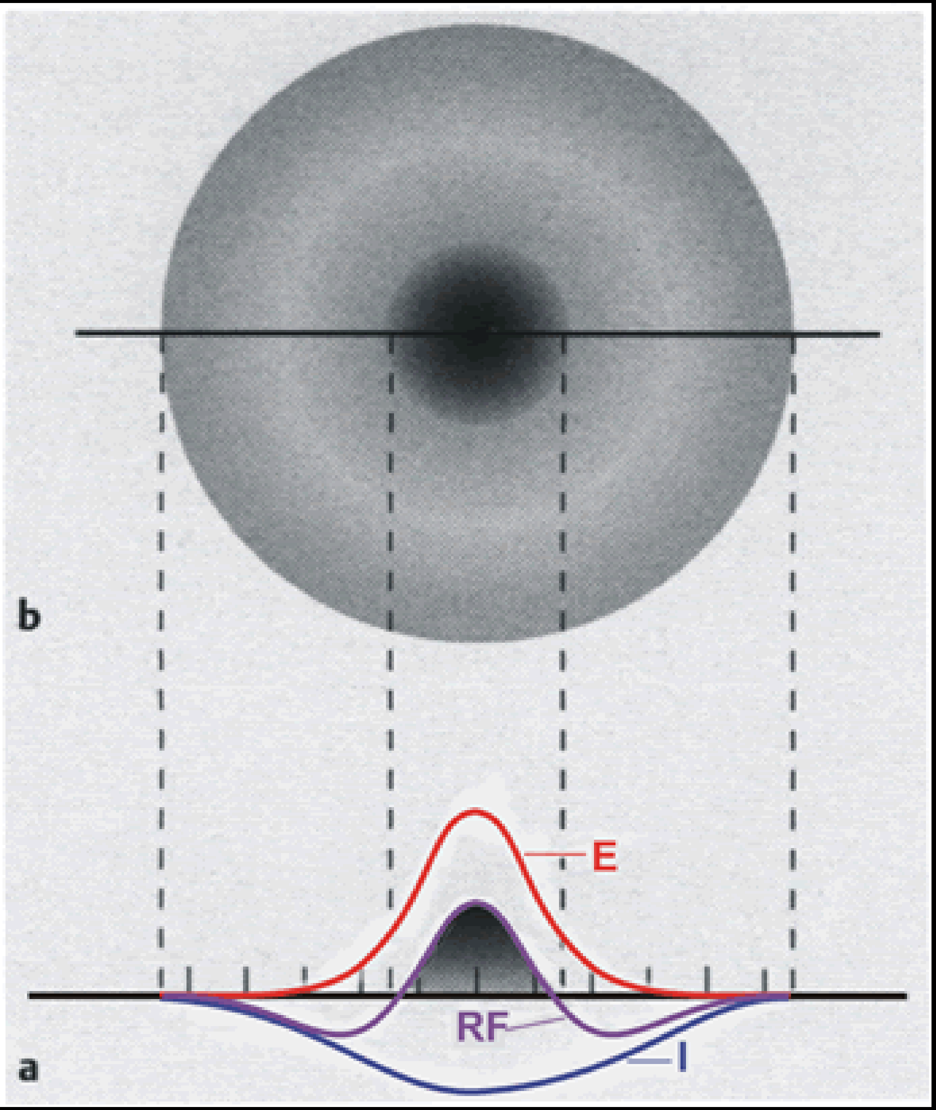


Fig. 8.4. Spatial contrast sensitivity curves at seven different retinal illuminance levels between 0.0009 and 900 trolands. The subject viewed the gratings through a 2 mm diameter artificial pupil. The wavelength of the light was 525 nm. Notice the loss of sensitivity for medium and high frequencies as the retinal illumination is decreased. (Adapted from Van Nes & Bouman, 1967.)

Shortening space constants

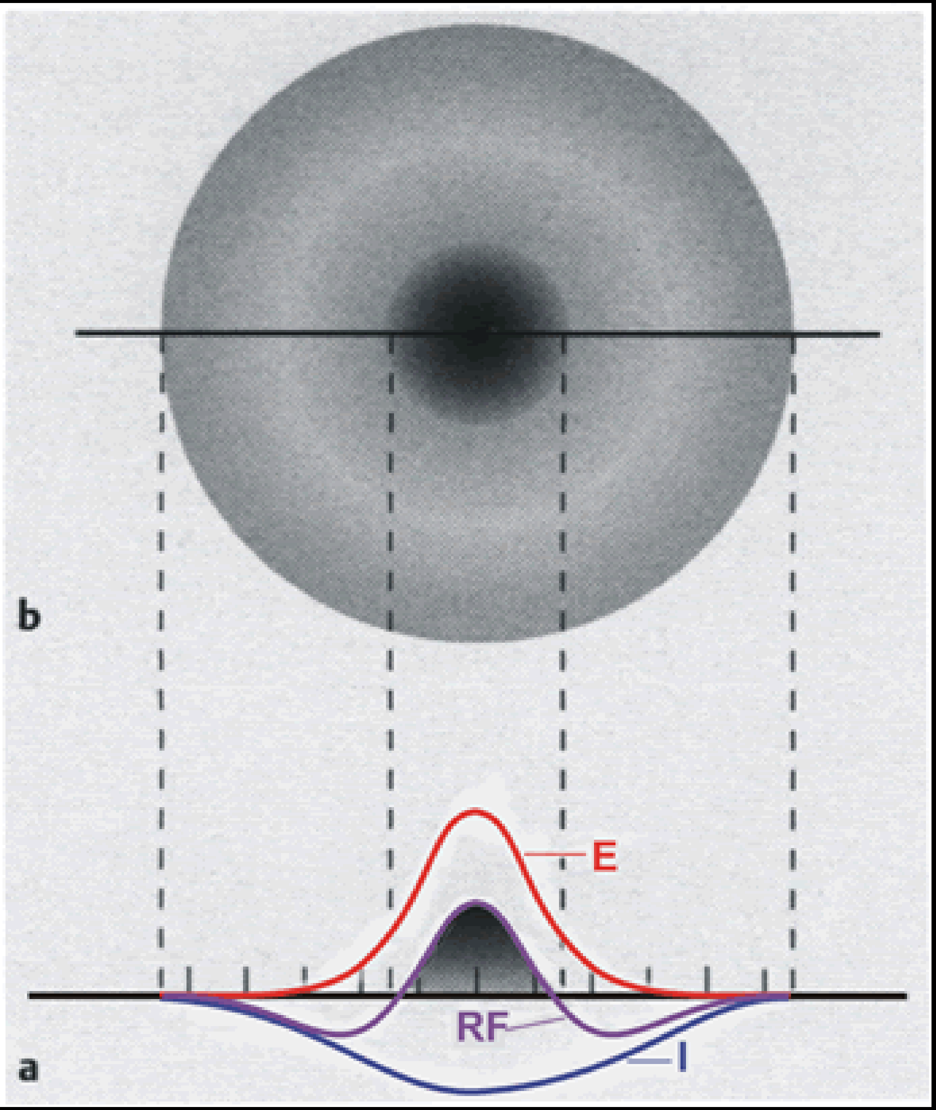
- The system sums light over smaller and smaller areas.
- As a result, the system becomes relatively more sensitive to high spatial frequencies and relatively less sensitive to low spatial frequencies.

Possible mechanisms?



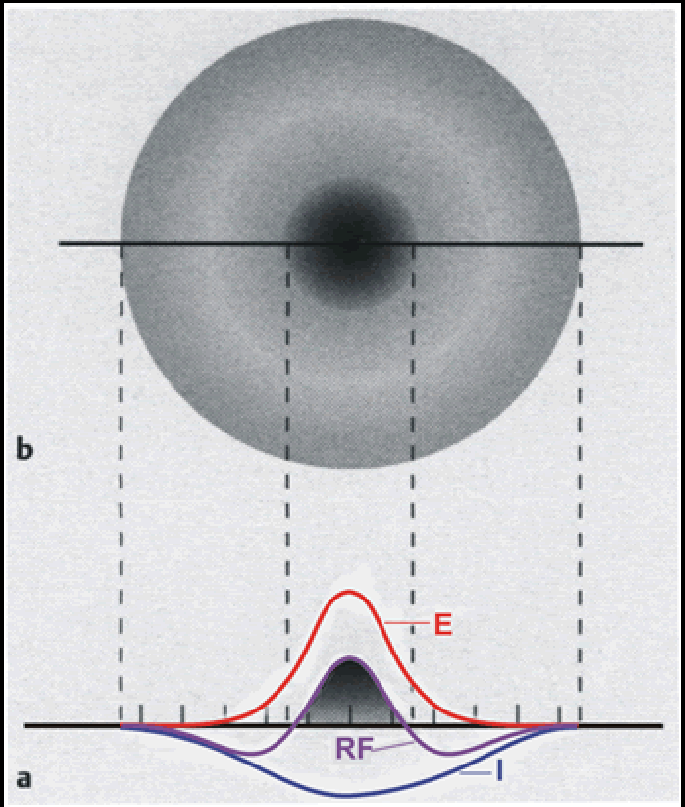
Surround inhibition increasing at higher light levels

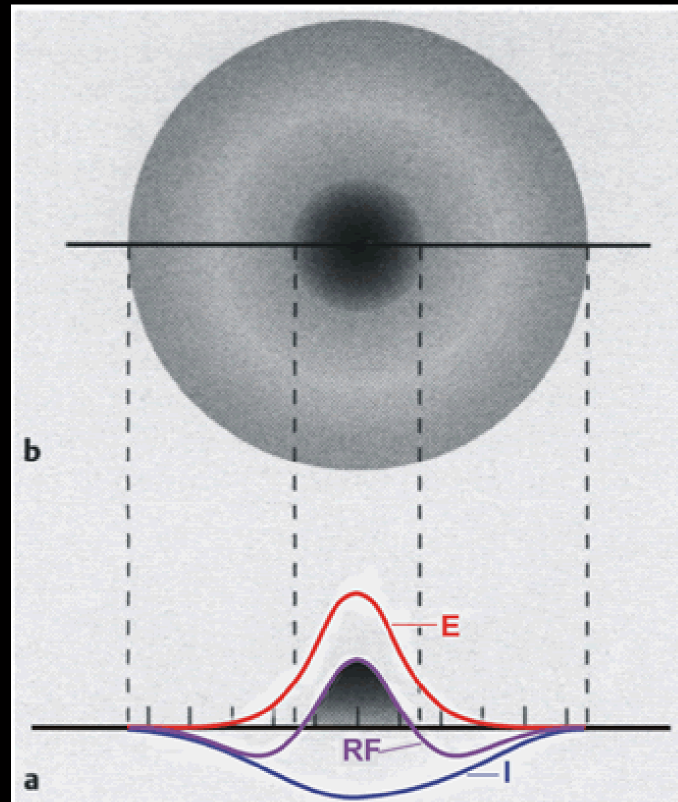
Holk Cruise

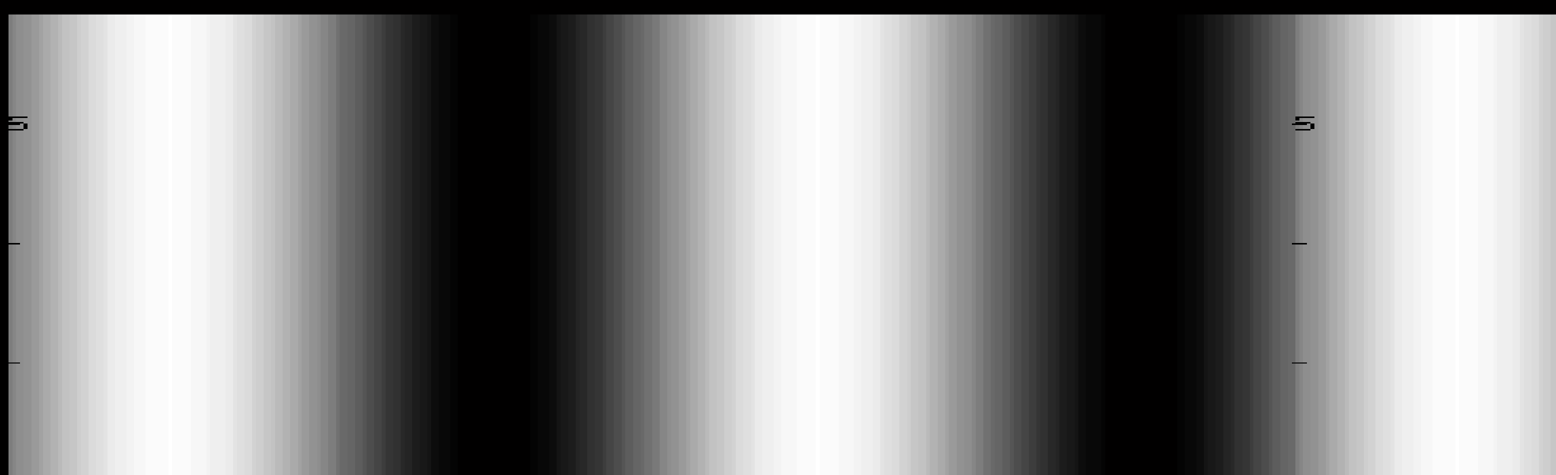


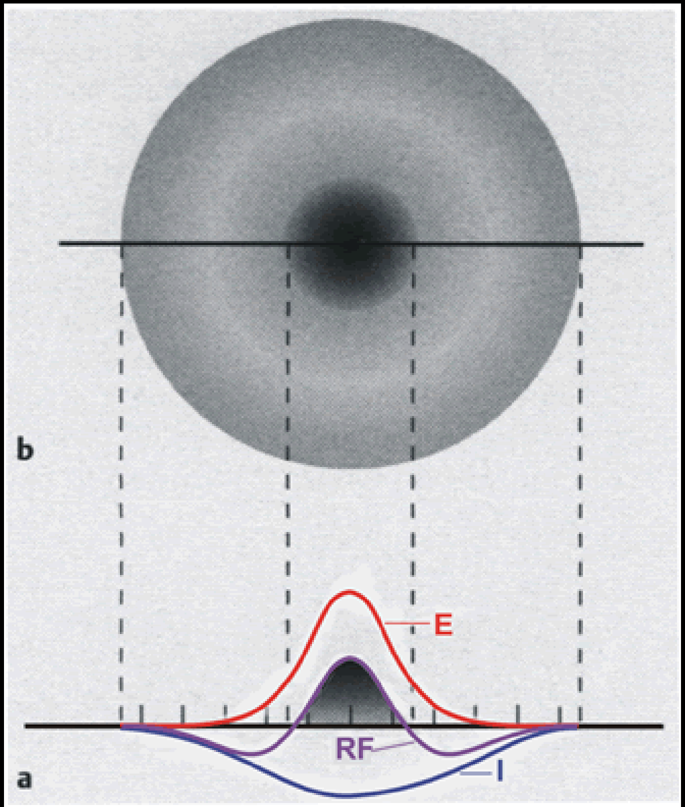
How will this give rise to a band-pass spatial contrast sensitivity function?

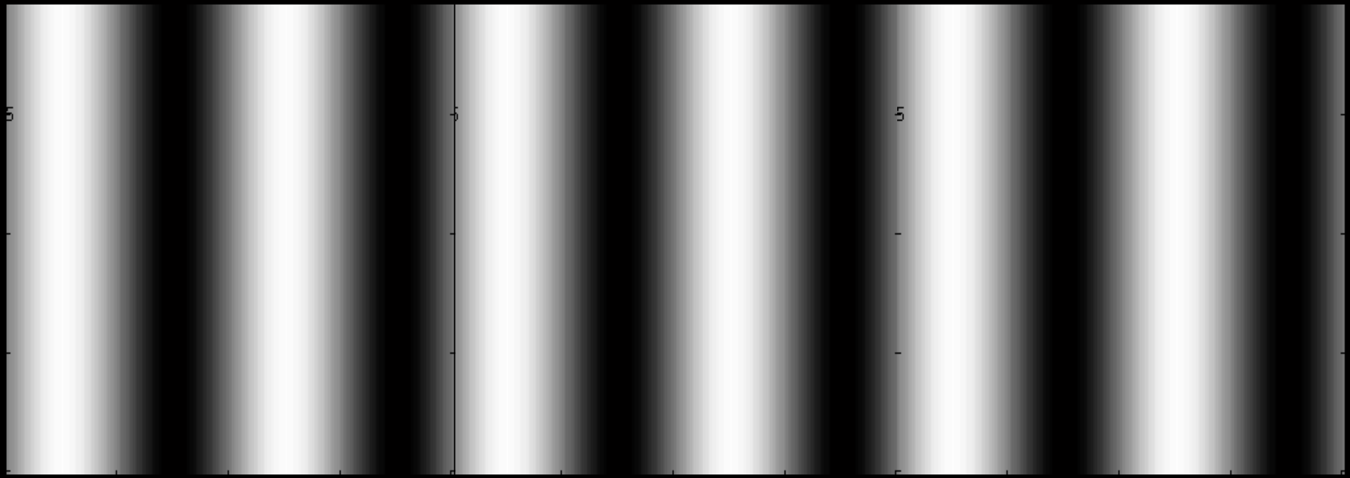
Holk Cruise

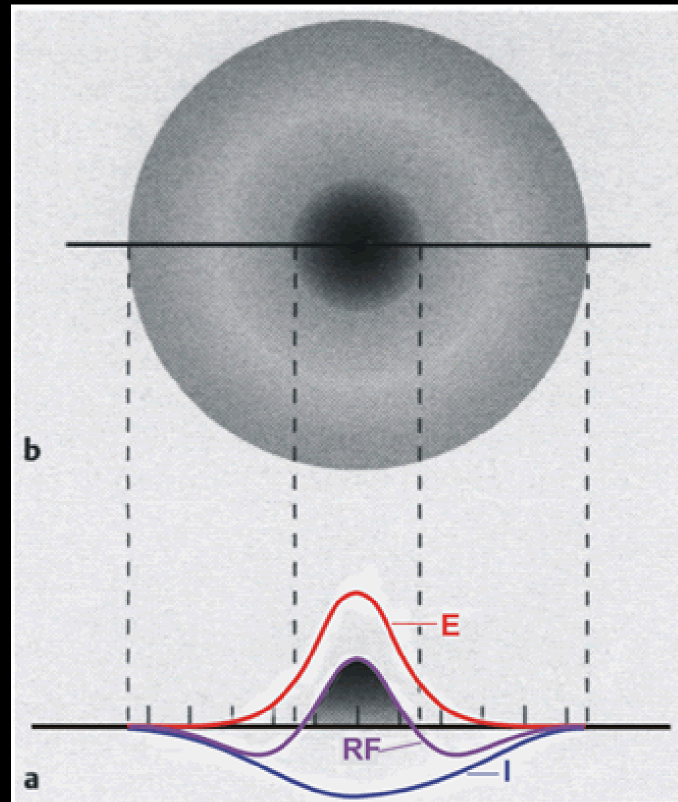

b
E
RF
I
a

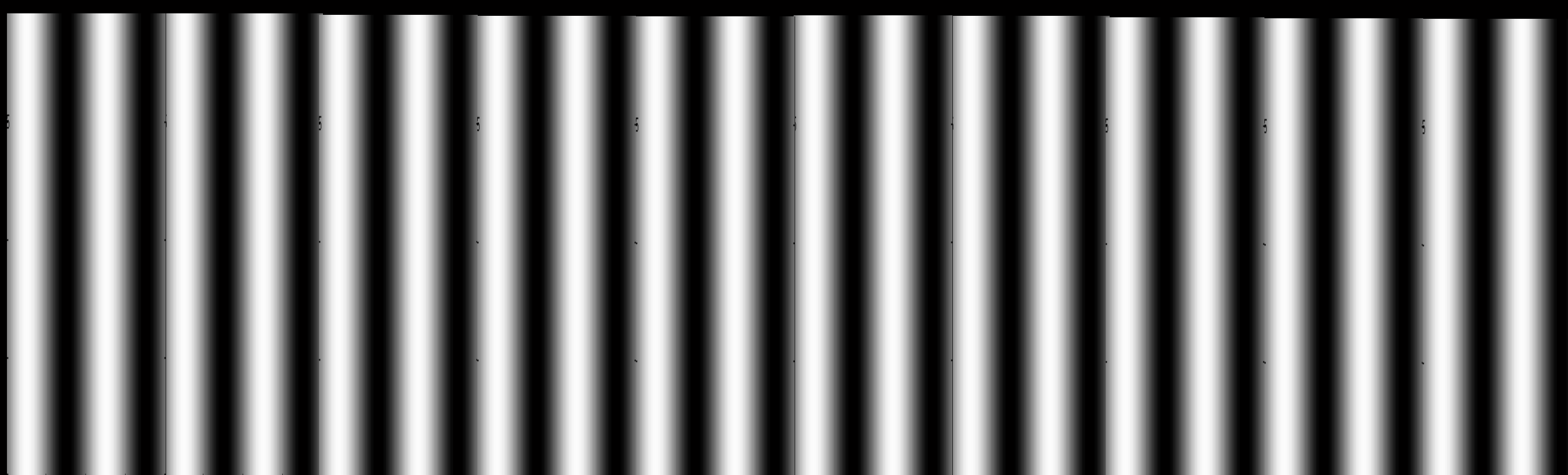

b
E
RF
I
a

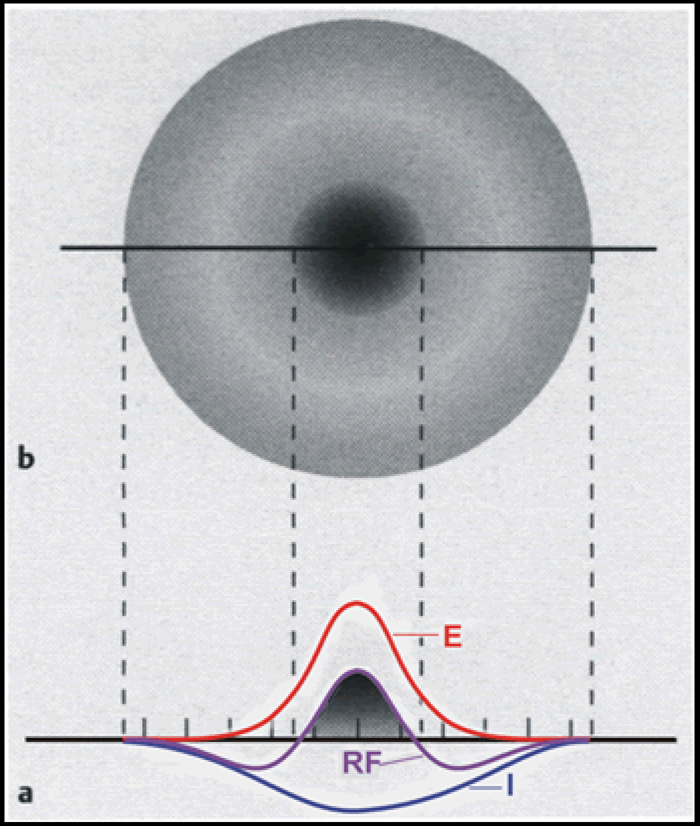


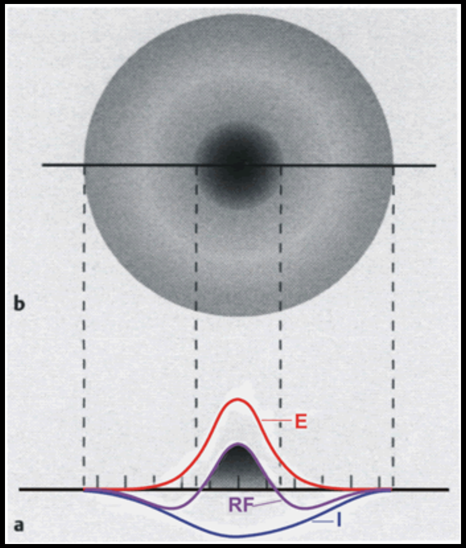

b
E
RF
I
a

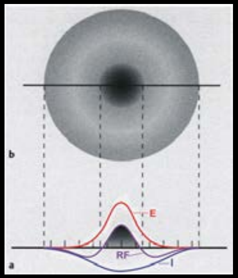



b
E
RF
I
a









The space constant will also decline if cells with smaller receptive fields become more effective as the light level increases.

Light adaptation: How is it achieved?

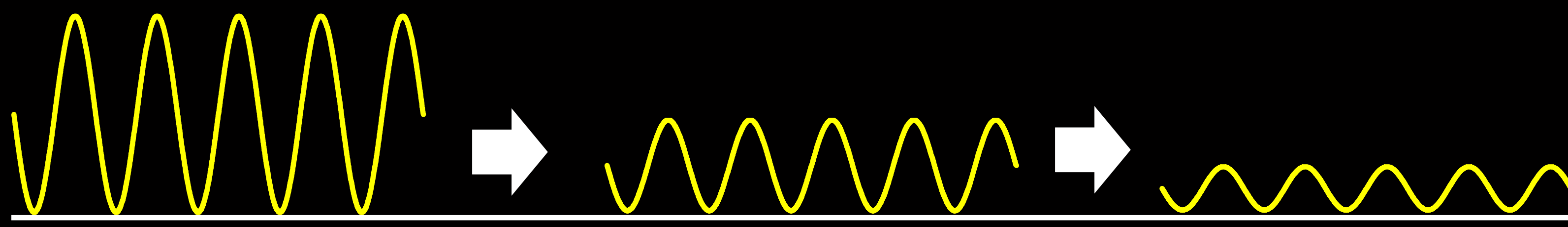
1. Multiple systems with different sensitivities (rods and cones)
2. Desensitization
3. Changes in pupil size
4. Temporal adaptation (shortening time constants)
5. Spatial reorganization (shortening space constants)

Other forms of adaptation…

CONTRAST ADAPTATION

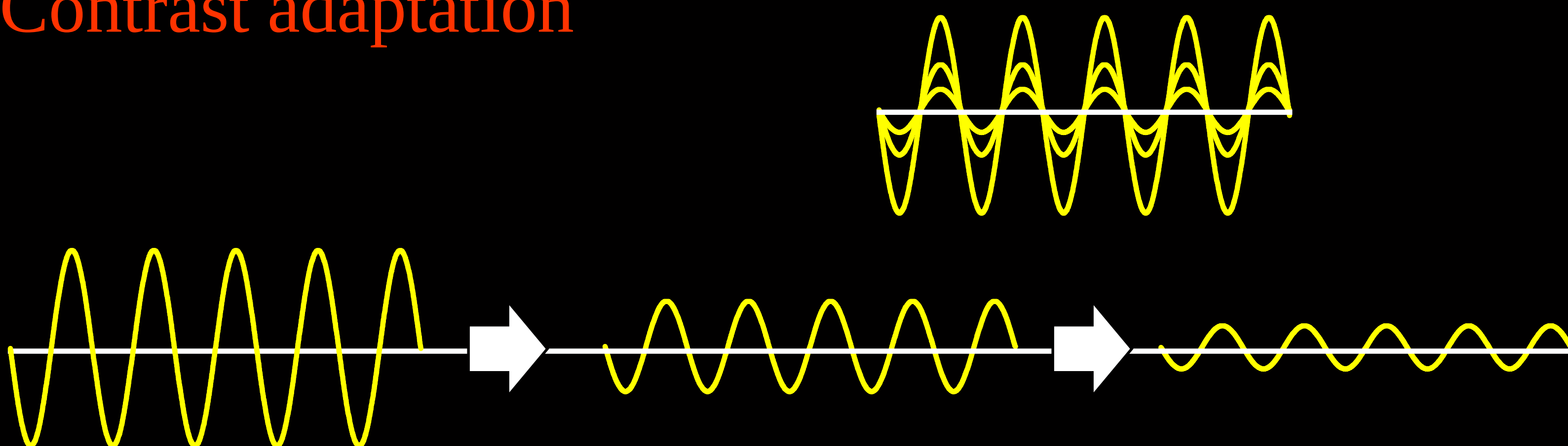
Simple light adaptation

Adaptation to increasingly intense steady lights



Contrast adaptation

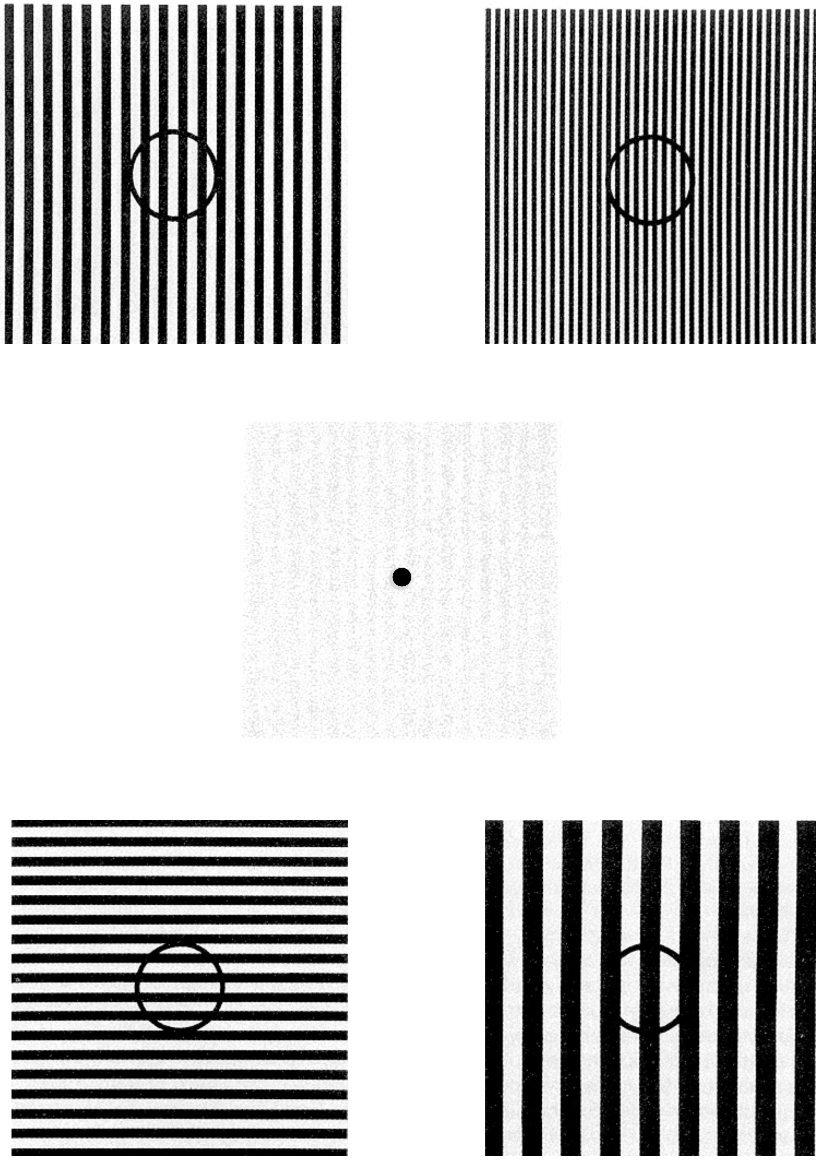
Adaptation to lights of increasing contrast



Credit: Michael Bach

Credit: Michael Bach

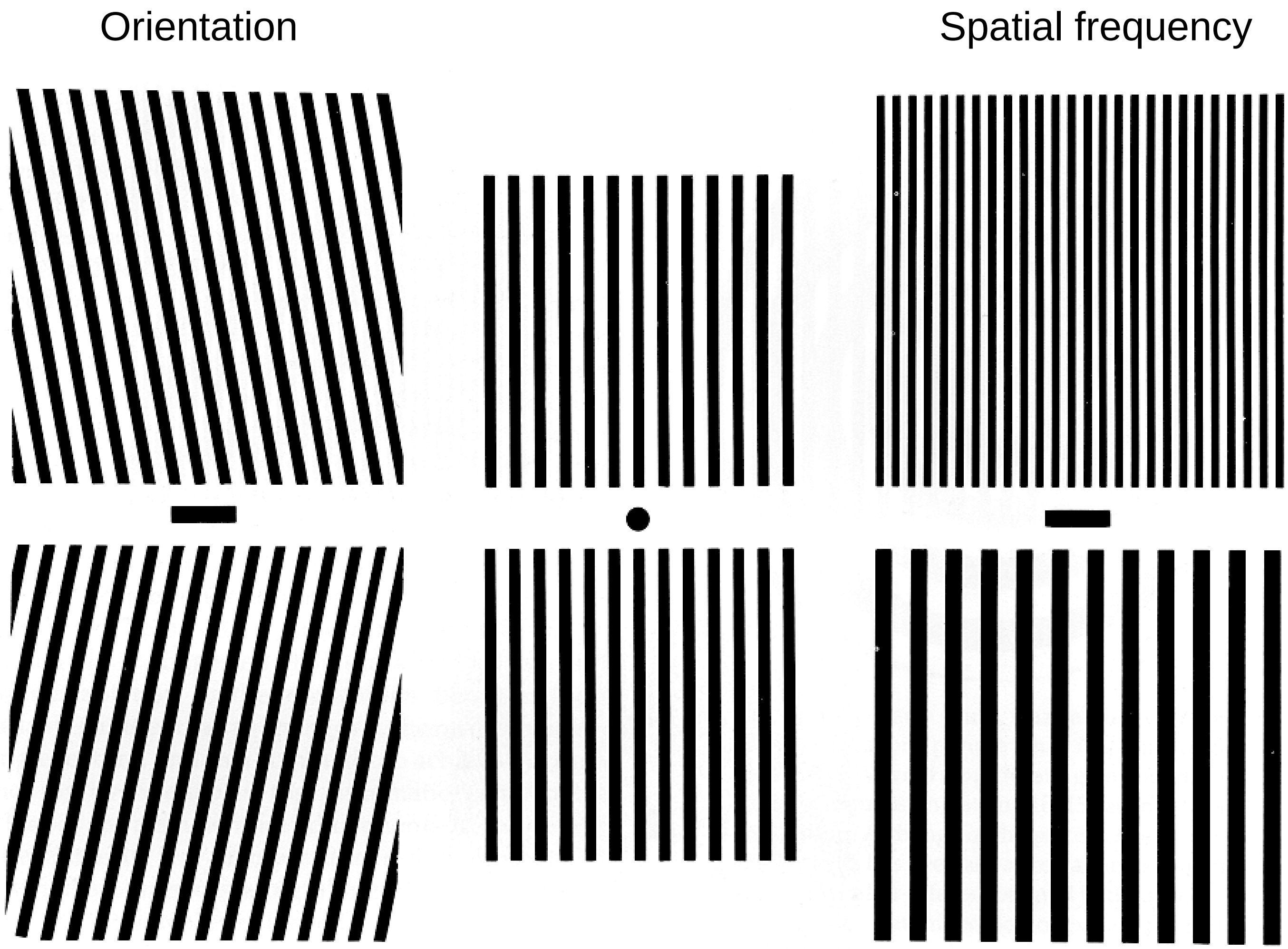
Contrast adaptation



Source: Horace Barlow

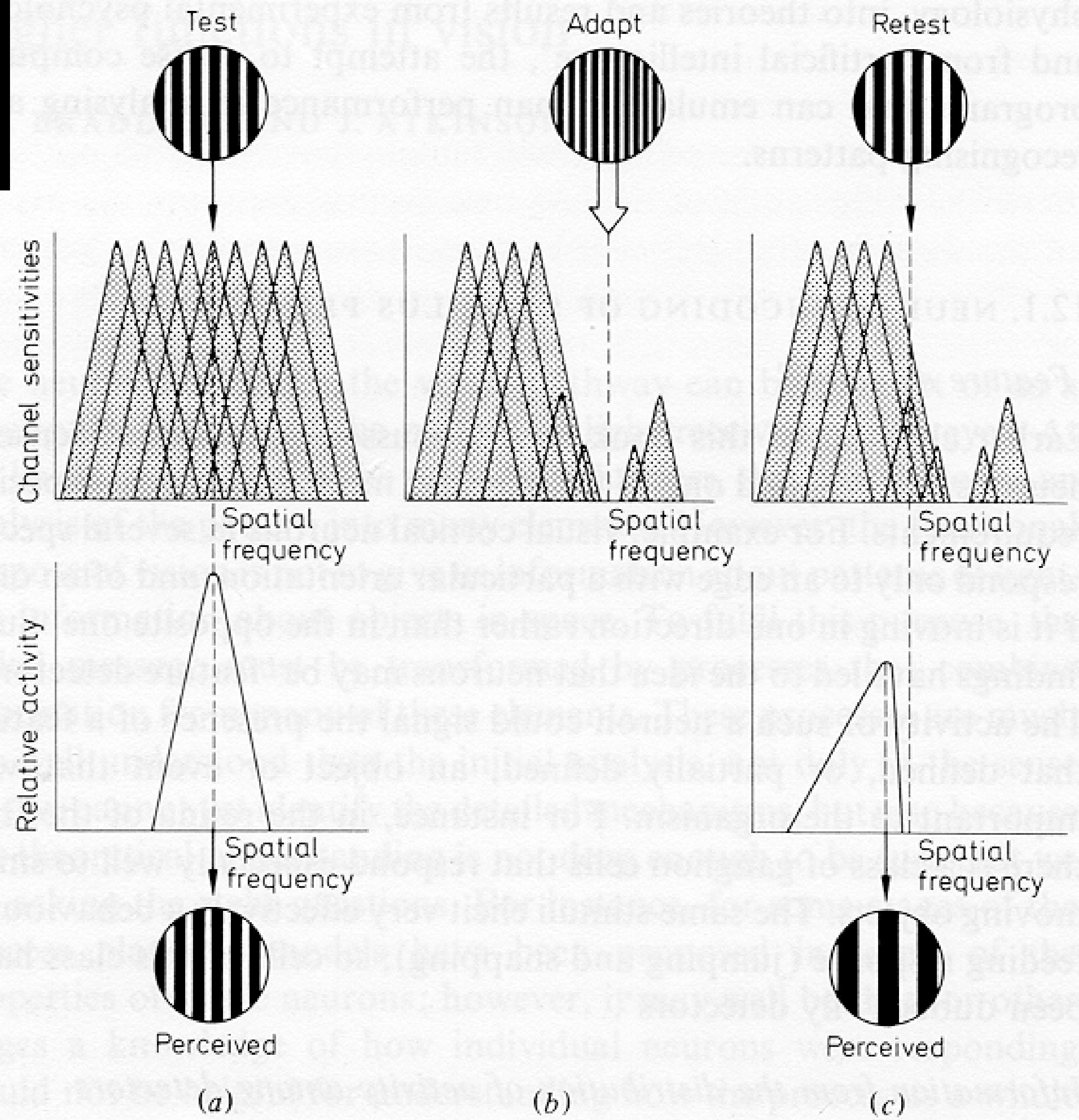
ADAPTATION TO FEATURES OF A STIMULUS

Orientation and spatial frequency selective adaptation



Source: Barlow and Mollon, 1982

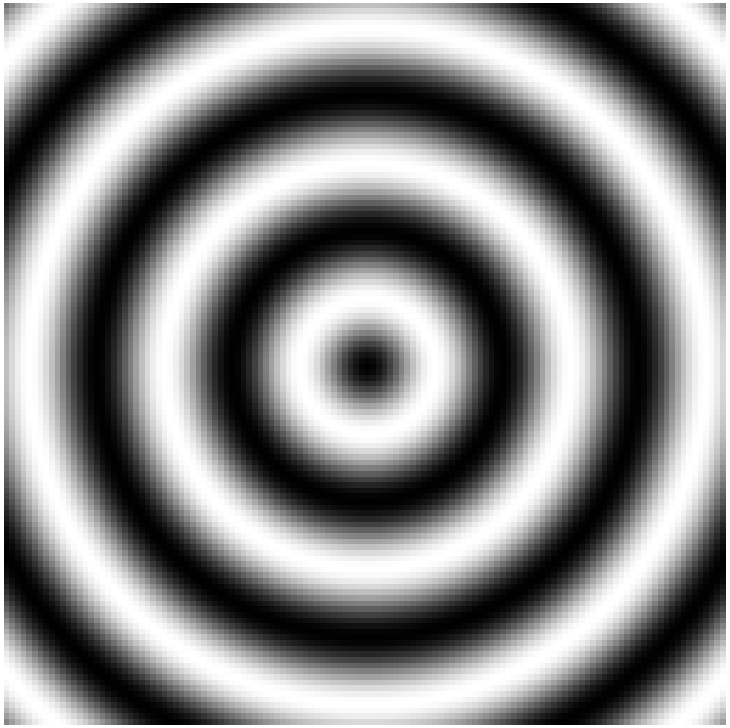
Spatial frequency adaptation explained?

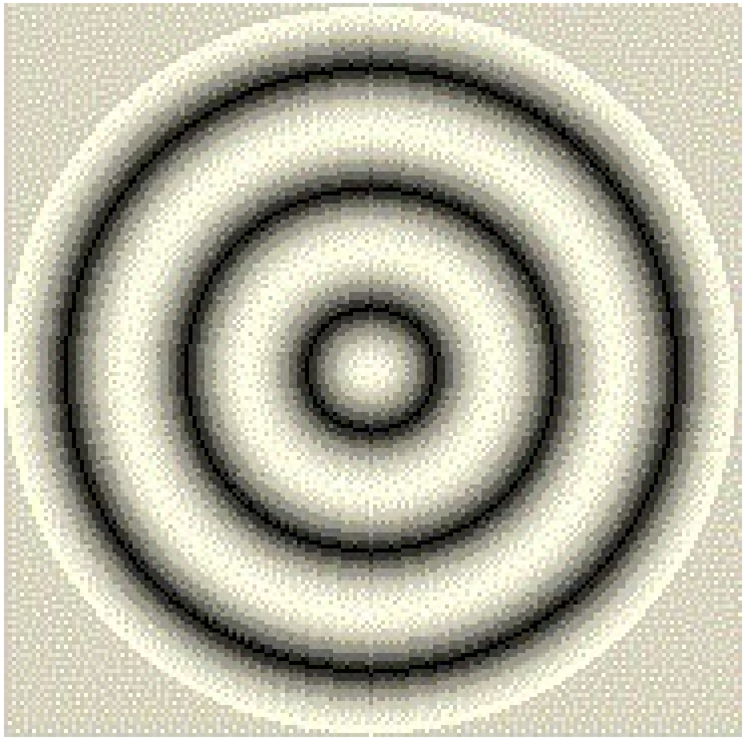


Source: Barlow and Mollon, 1982

Motion after-effect

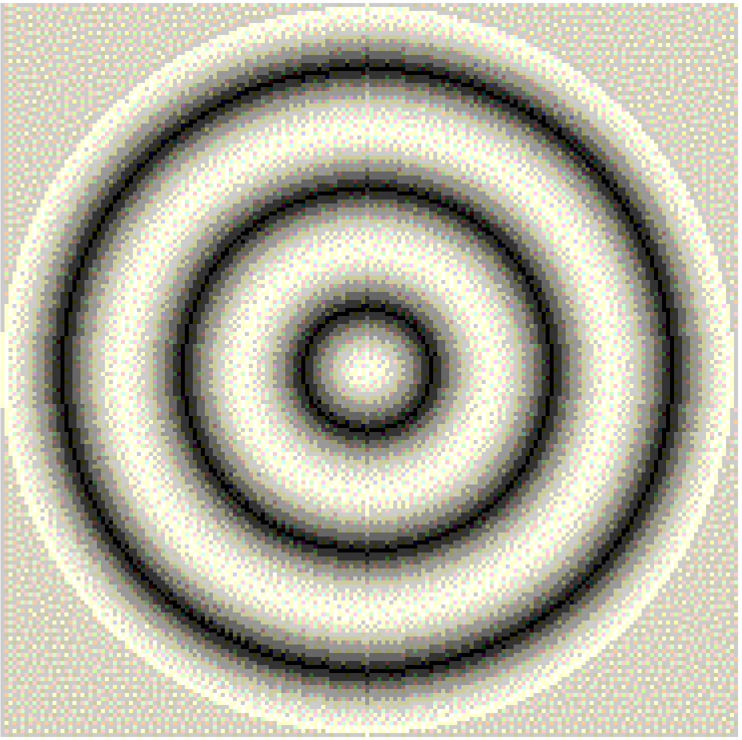
Motion



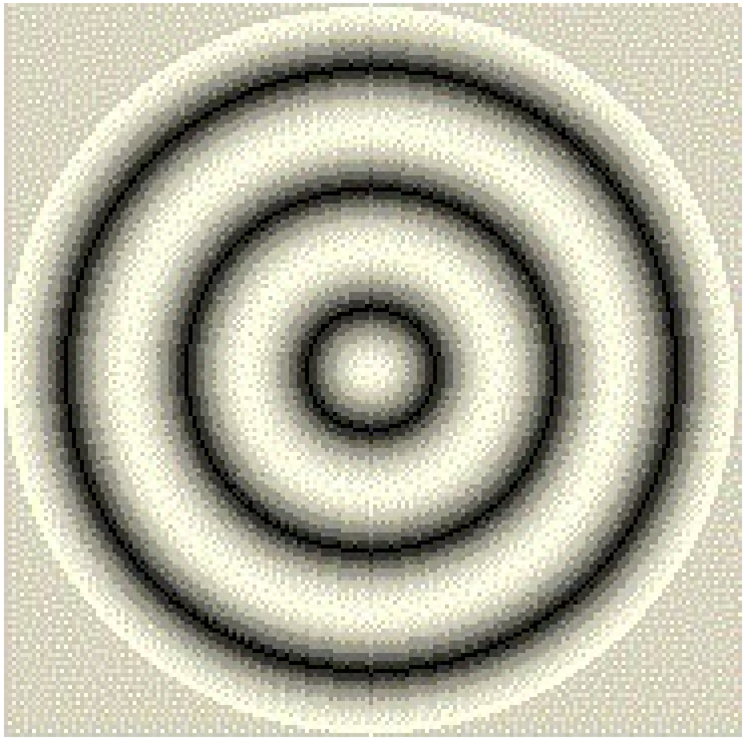


Source: Hans Irtel

Motion



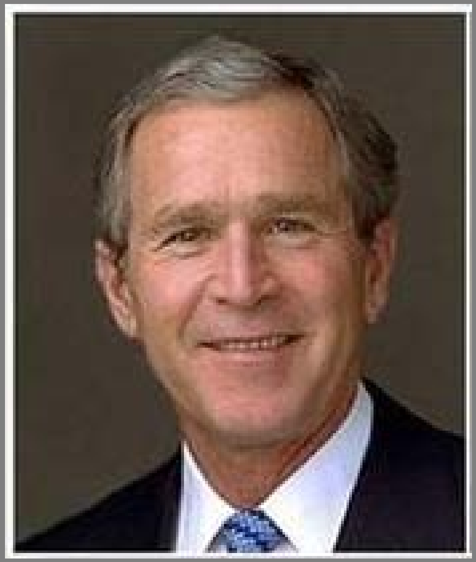
Source: Hans Irtel

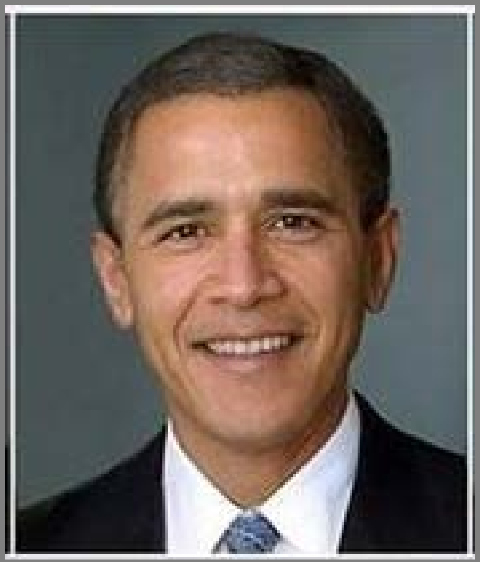


Source: Hans Irtel

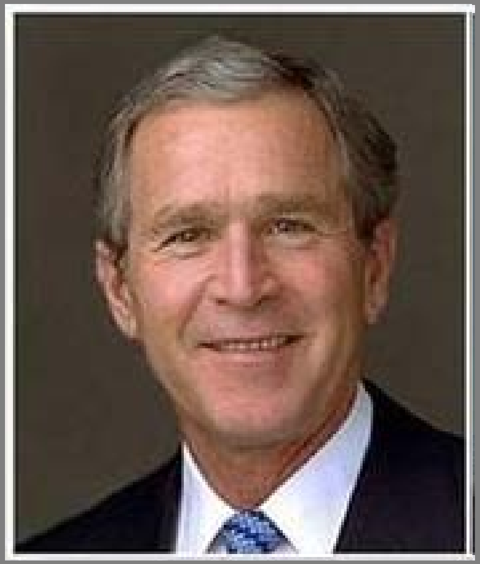
Face after-effects

Face after-effects





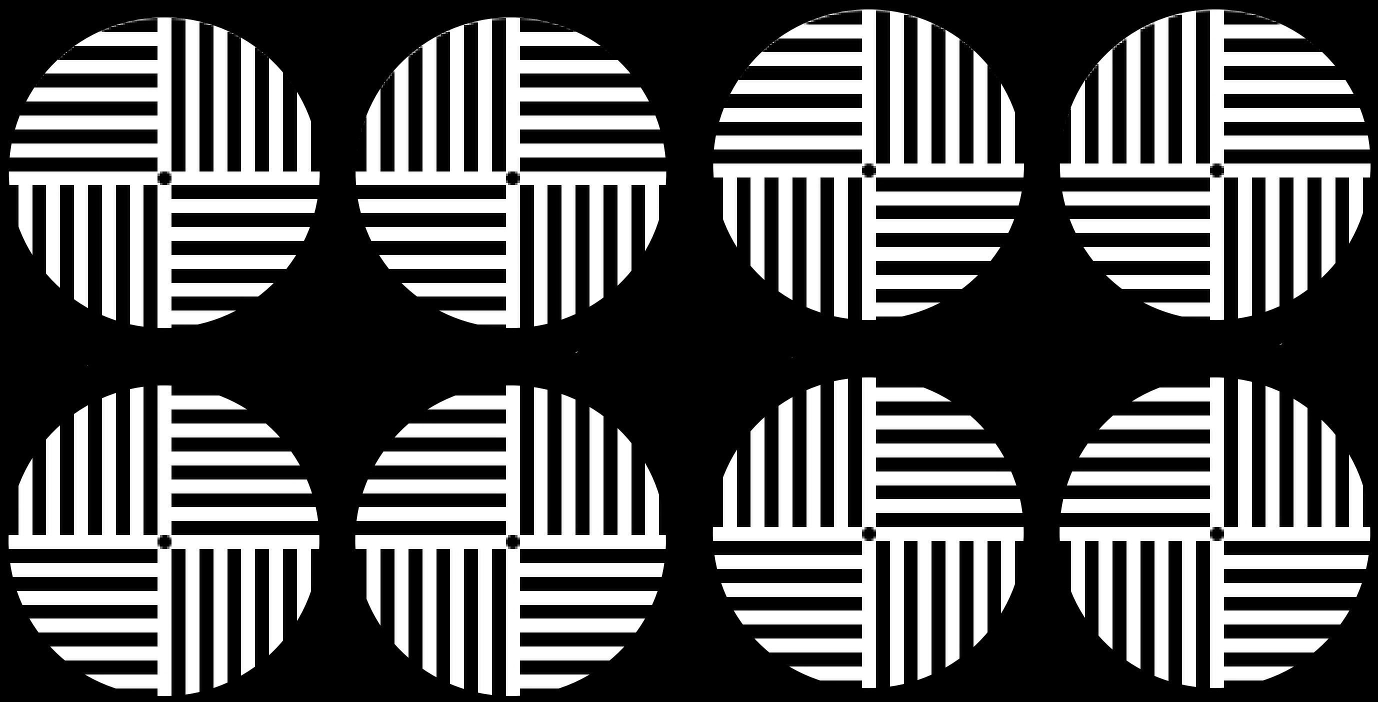
Face after-effects



Face after-effects

Face after-effects

McCollough effect test pattern



Version by Akiyoshi Kitaoka

McCollough effect test pattern