Color vision and adaptation

Central questions about color vision and adaptation:

1. What are the basic facts and laws of color vision?
2. What are the major theories of color vision?
3. How is color processed in the retina and the LGN?
4. How is color processed in the cortex?
5. What is the nature of color blindness?
6. How is adaptation achieved in the visual system?
7. What are afterimages?

Color vision

Basic facts and rules of color vision

1. There are three qualities of color: hue, brightness, saturation

2. There is a clear distinction between the physical and psychological attributes of color: wavelength vs. color, luminance vs. brightness.

3. Peak sensitivity of human photoreceptors:

   S = **420**nm, M = **530**nm, L = **560**nm, Rods = **500**nm

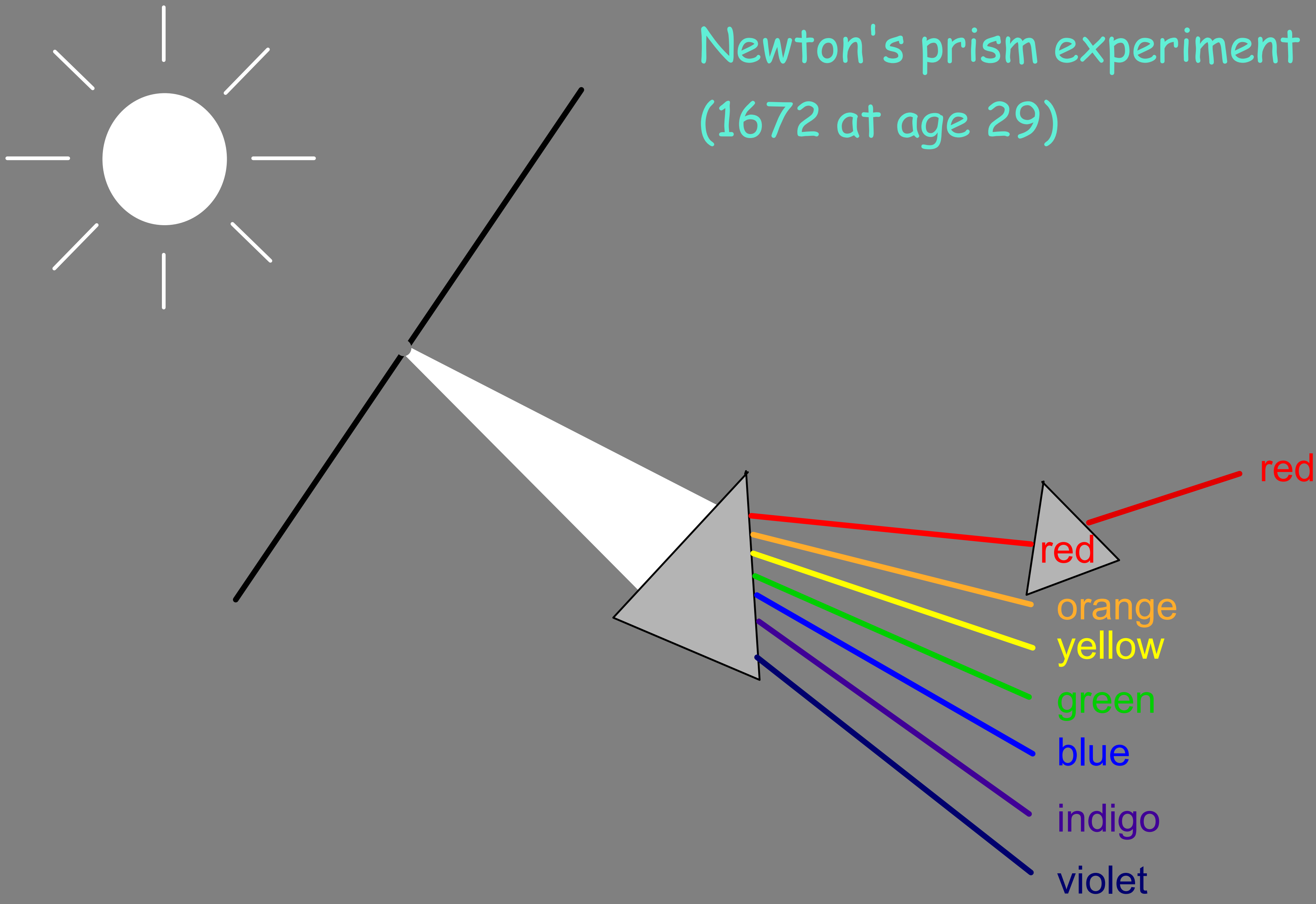
4. Grassman's laws:
   1. Every color has a complimentary which when mixed properly yields gray.
   2. Mixture of non-complimentary colors yields intermediates.

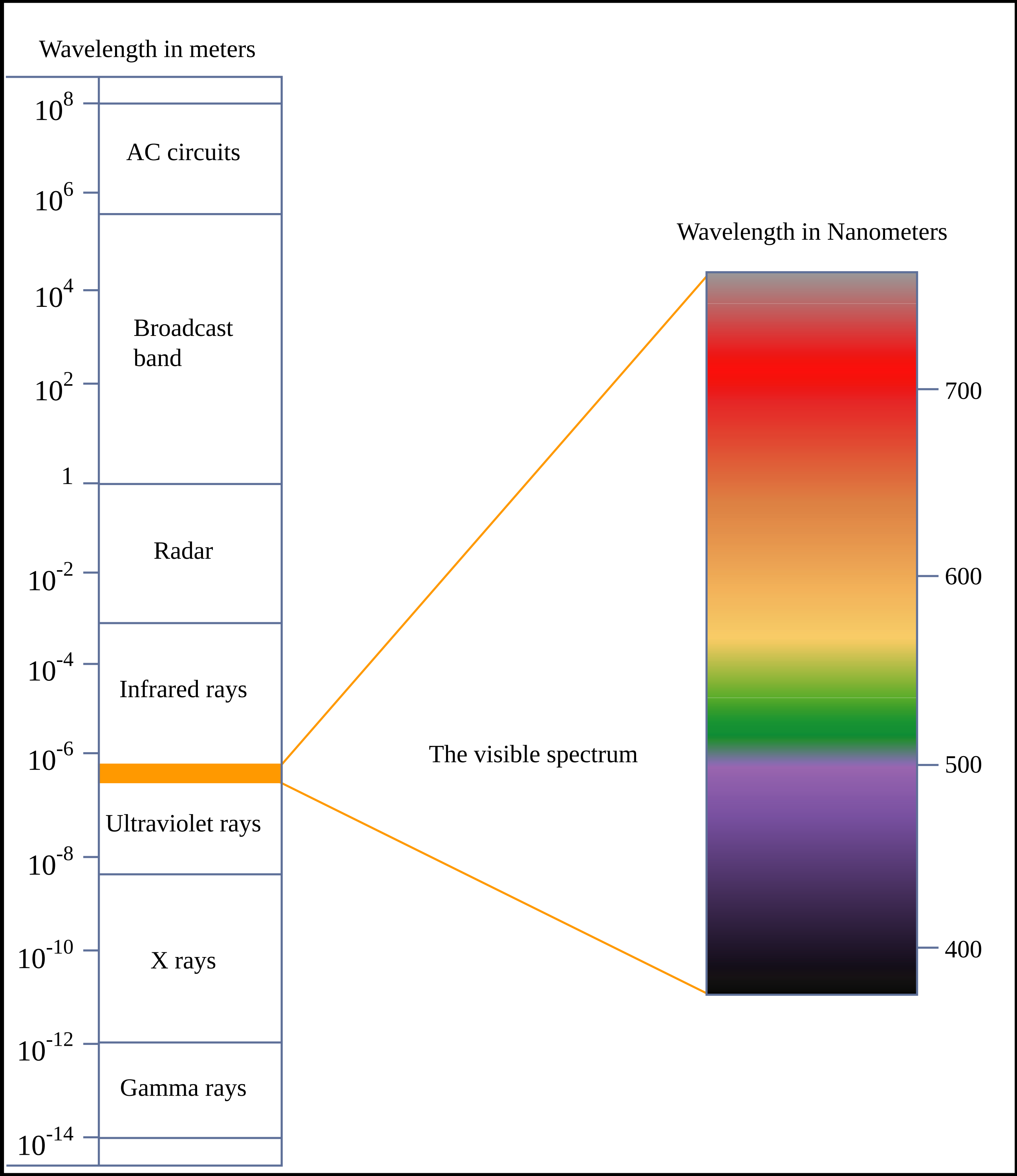
5. Abney's law:

   The luminance of a mixture of differently colored lights is equal to the sum of the luminances of the components.

Newton's prism experiment

(1672 at age 29)





red
orange
yellow
green
blue
indigo
violet

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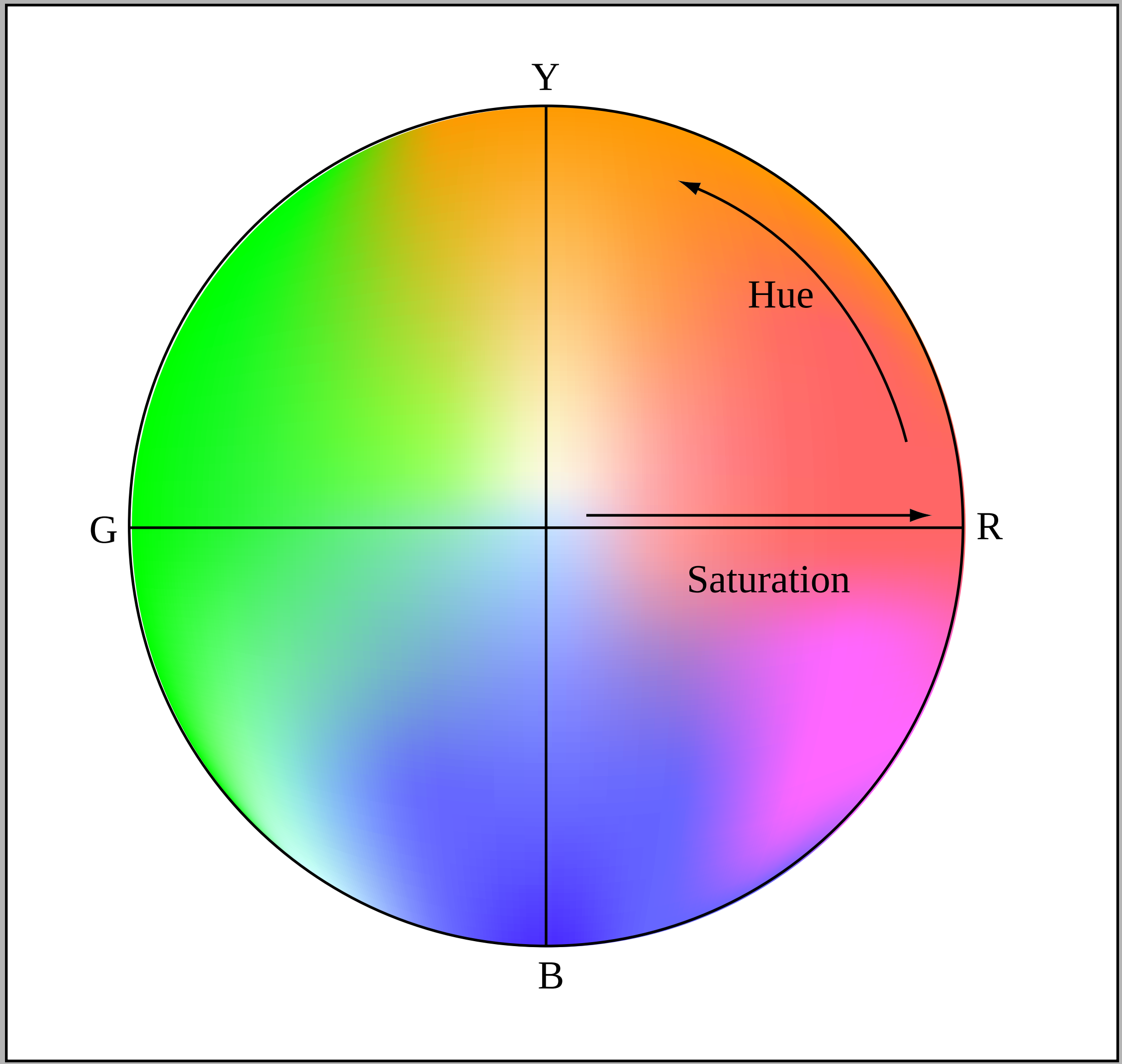
Please see lecture video or the C.I.E. chromaticity diagram from 1931.

The color circle



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The color circle

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Please see lecture video or Figure 3 of Derrington, Andrew M., John Krauskopf, et al. "Chromatic Mechanisms in Lateral Geniculate Nucleus of Macaque." *The Journal of Physiology* 357, no. 1 (1984): 241-65.

Major theories of color vision

Young-Helmholtz theory

There are three types of broadly tuned color receptors. The color experienced is a product of their relative degree of activation.

Problems: Fails to explain Grassman's laws.

Hering's theory

Theory of color opponency based on the observation that red and green as well as blue and yellow are mutually exclusive. The nervous system probably treats red/green and blue/yellow as antagonistic pairs, with the third pair being black and white.

> Earlier Leonardo da Vinci: "Of different colors equally perfect, that will appear most excellent which is seen near its direct contrary...blue near yellow, green near red: because each color is seen, when opposed to its contrary, than to any other similar to it.

Basic physiology of color processing

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Please see lecture video or Figure 1 of De Monasterio, F. M., E. P. McCrane, et al. "Density Profile of Blue-sensitive Cones Along the Horizontal Meridian of Macaque Retina." *Investigative Ophthalmology & Visual Science* 26, no. 3 (1985): 289-302.

Labeled blue cones

contain calcium-binding protein calbindin-D28k

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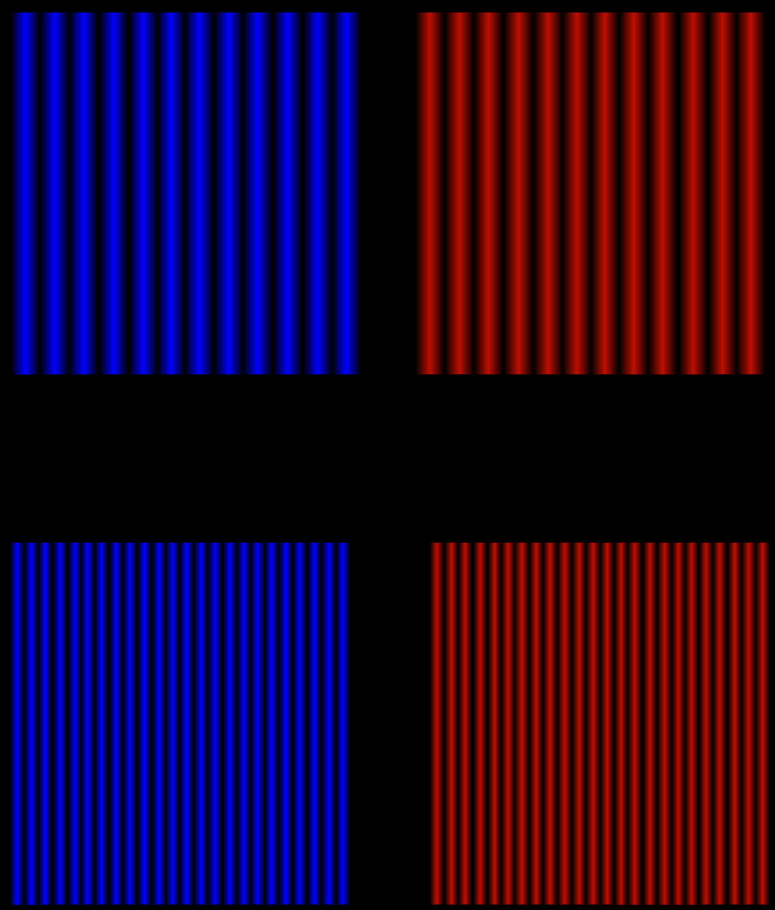
Please refer to lecture video.

Since only one out of eight cones is blue, the spatial resolution of the blue cones is lower



The absorbtion spectra of photorecptors

The absorbtion spectra of photorecptors

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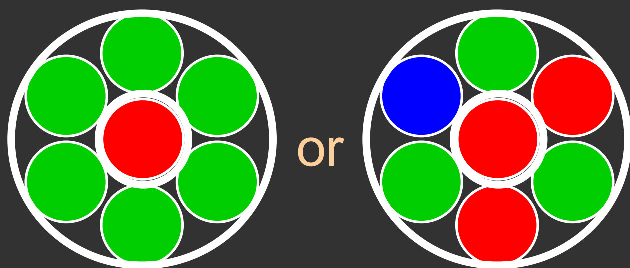
Please see lecture video or Figure 2 of Dartnall, H. J. A., J. K. Bowmaker, et al. "Human Visual Pigments: Microspectrophotometric Results from the Eyes of Seven Persons." *Proceedings of the Royal Society of London. Series B. Biological Sciences* 220, no 1218 (1983): 115-30.

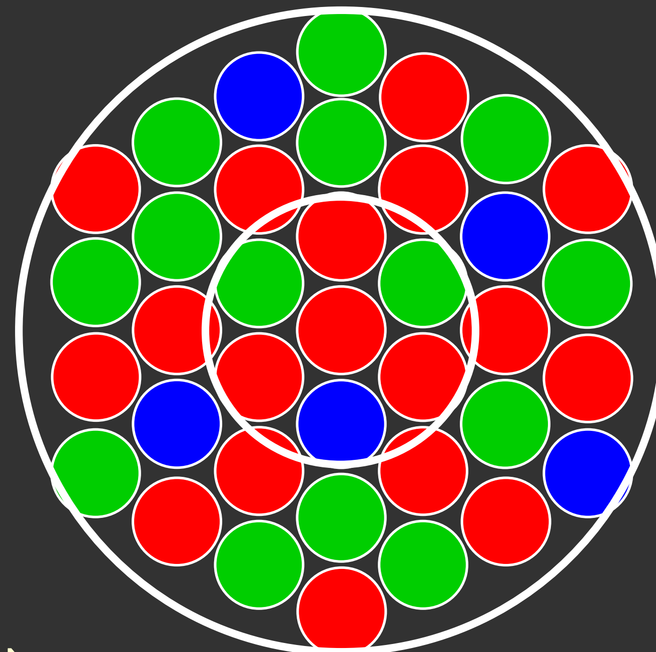
Microspectrophotometry

How much light of various wavelengths is absorbed by single cones and rods

MIDGET SYSTEM

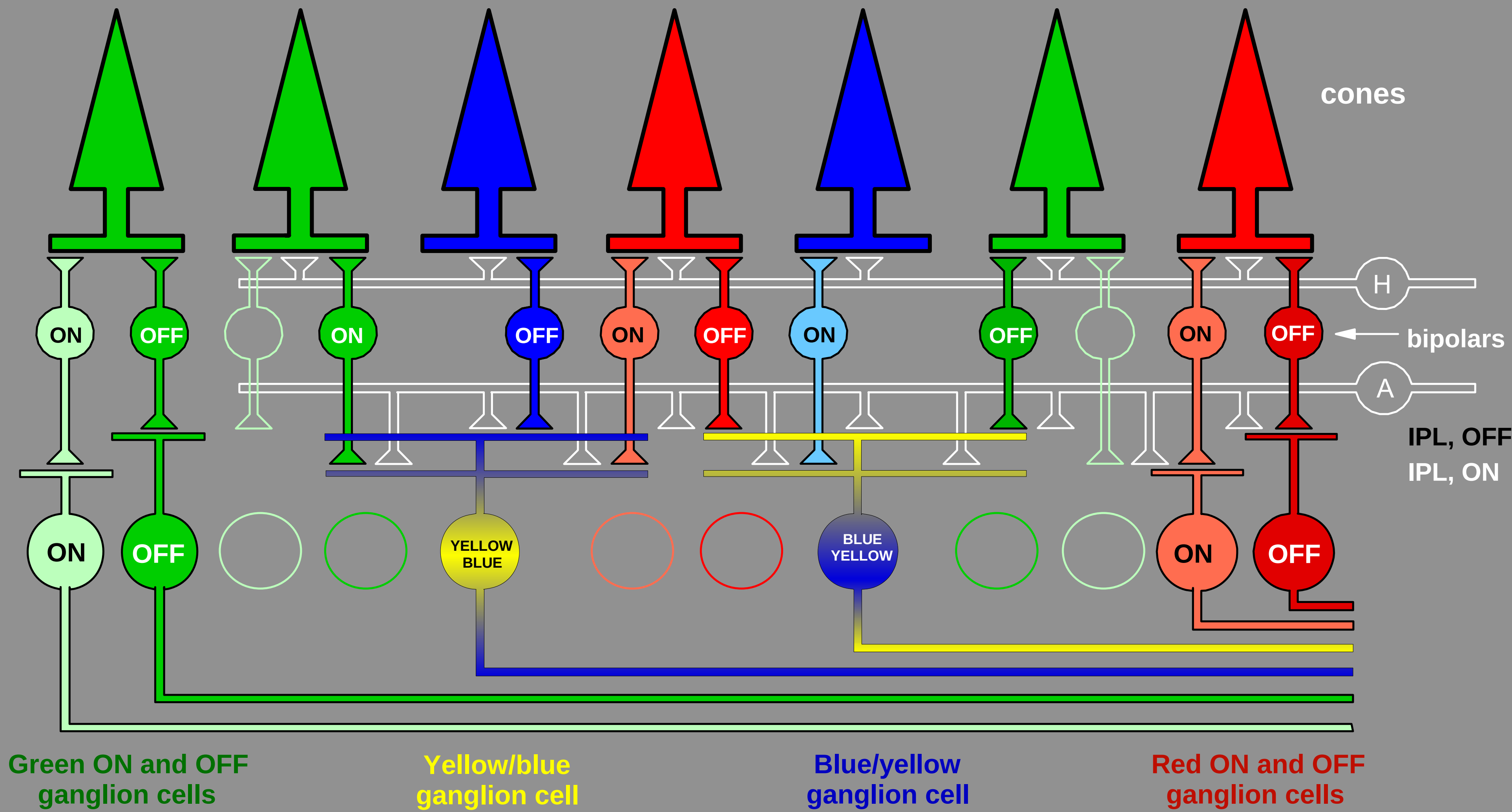
PARASOL SYSTEM





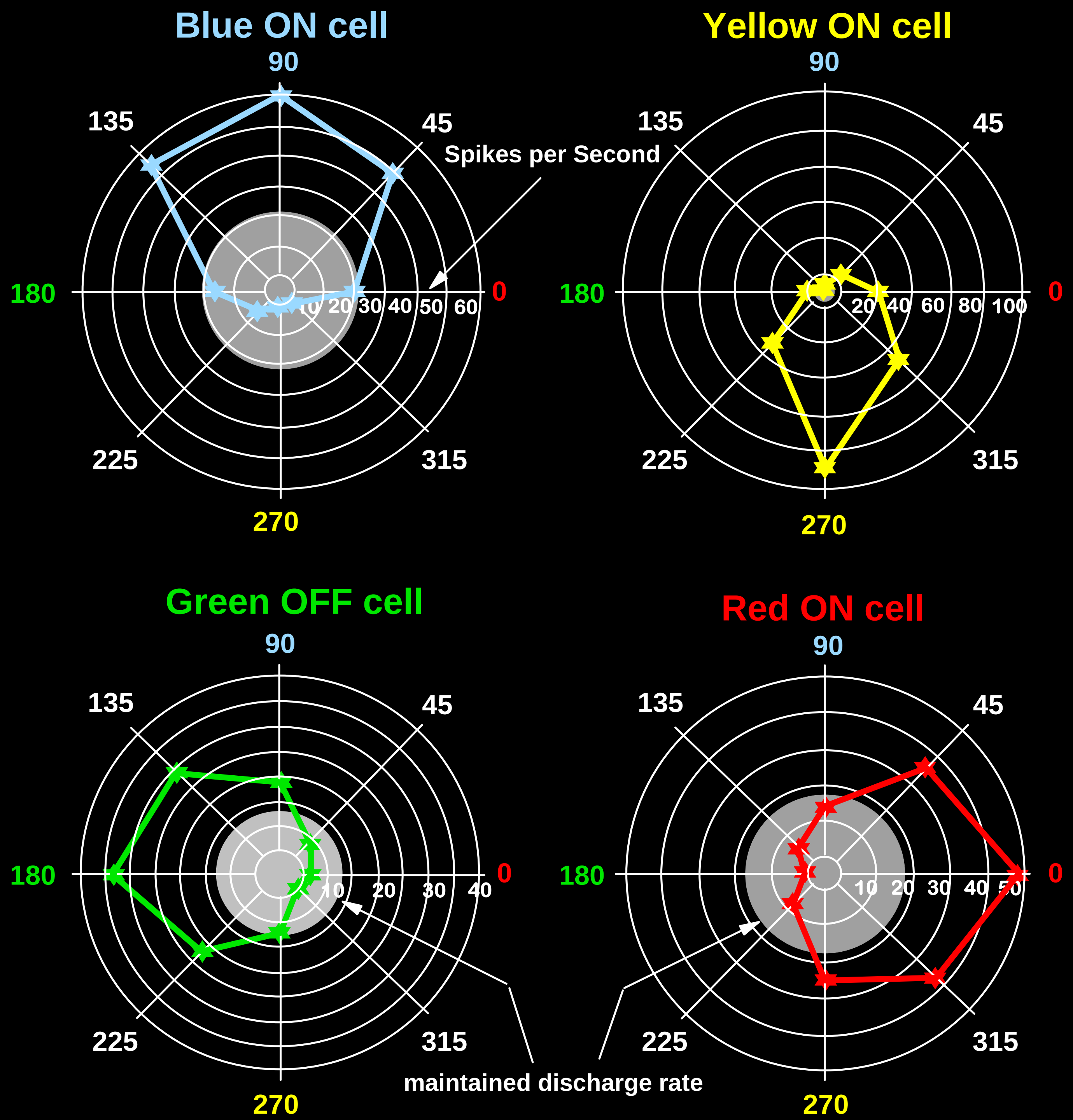
Neuronal response profile

Midget and blue/yellow systems



Color selectivity in the LGN

Response to Different Wavelength Compositions in LGN



Major classes of midget cells in primate retina

Red ON

Red OFF

Green ON

Green OFF

Blue ON

Yellow ON

The effects of lesions on color vision

Coronal section of monkey LGN

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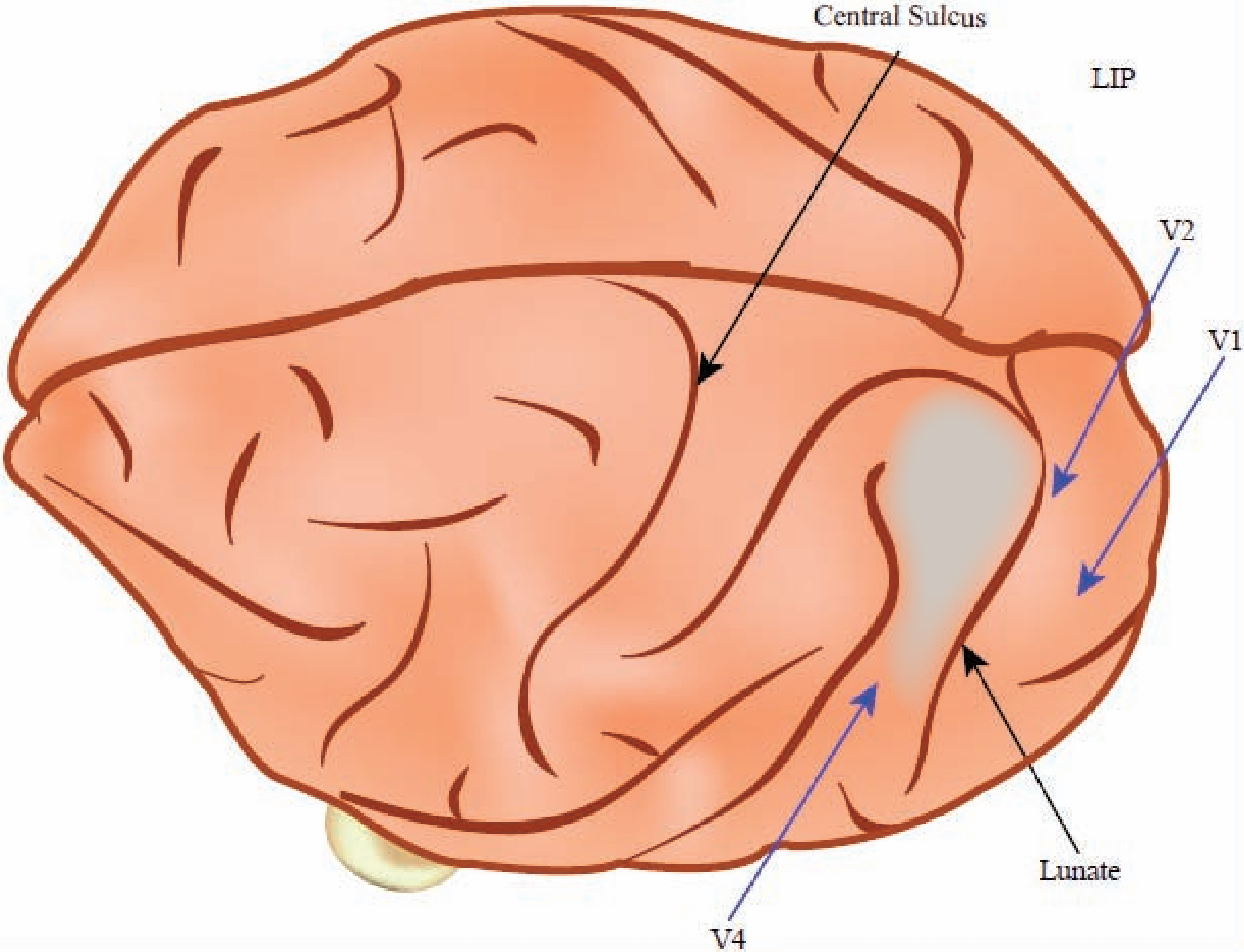
Please refer to lecture video or Figure 4a of Schiller, Peter H., and Edward J. Tehovnik. "Visual Prosthesis." *Perception* 37, no. 10 (2008): 1529.



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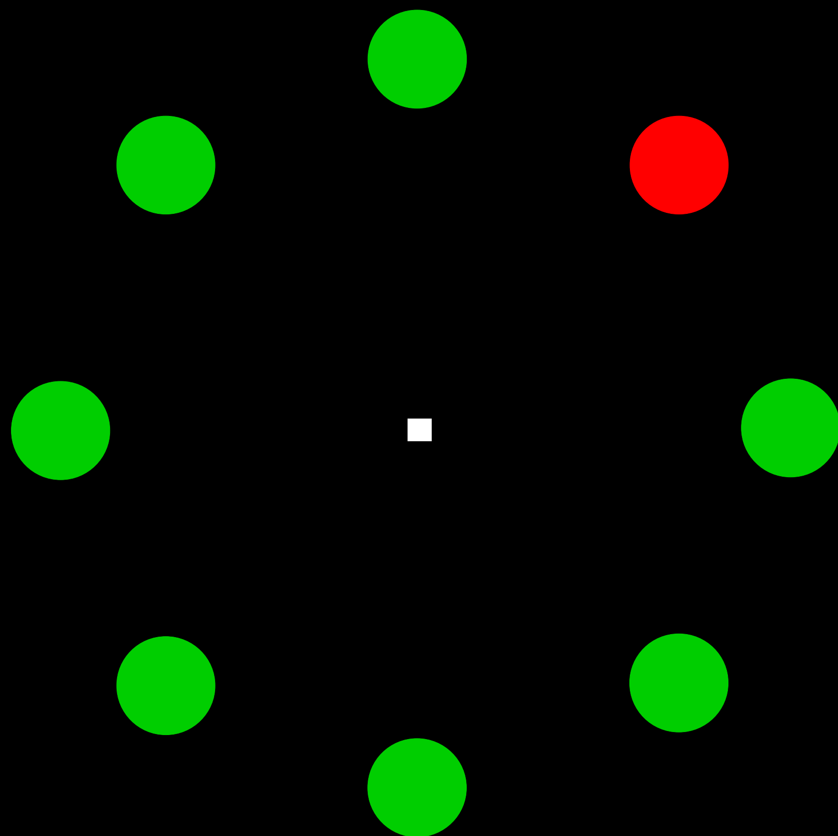
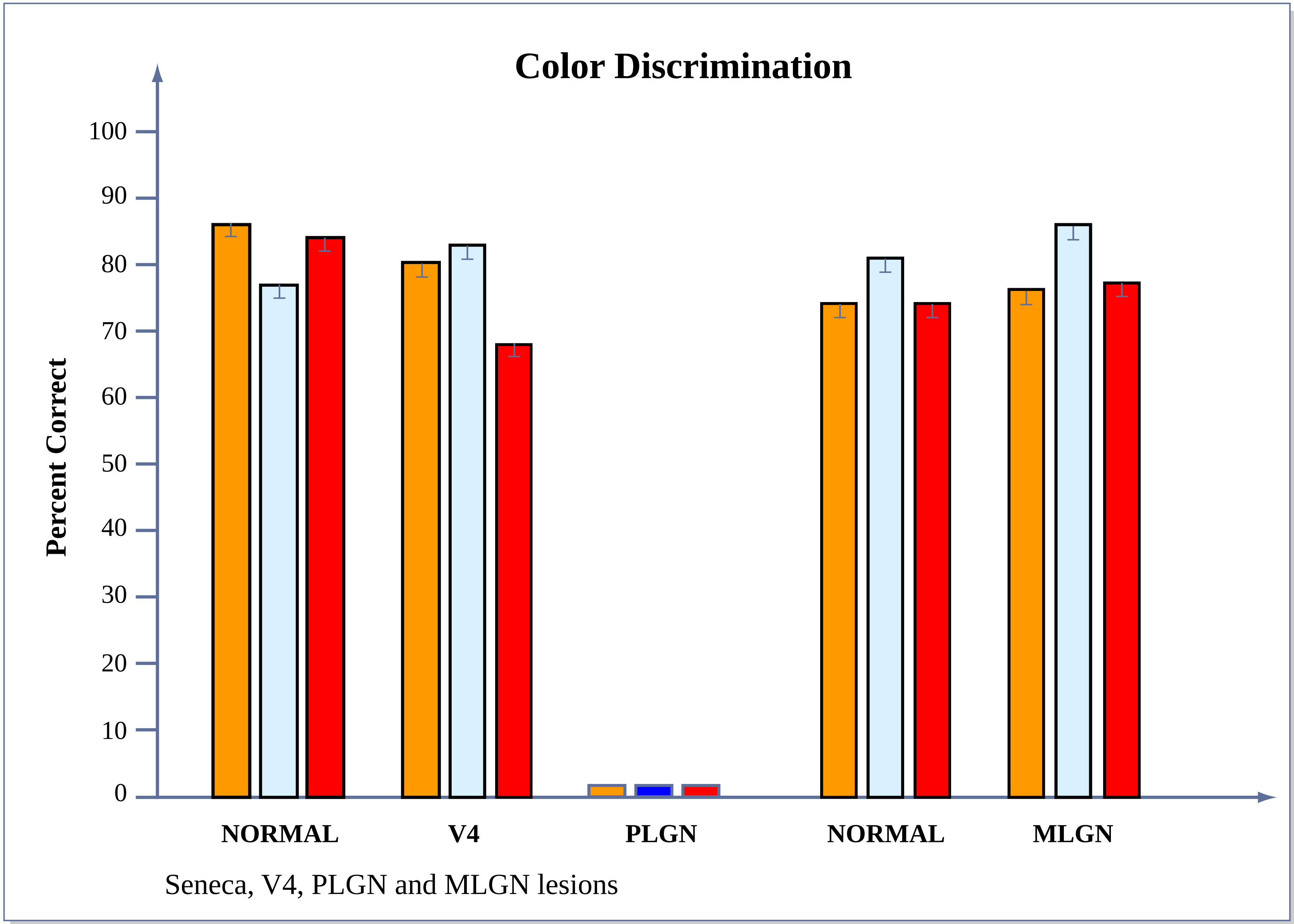
Color discrimination





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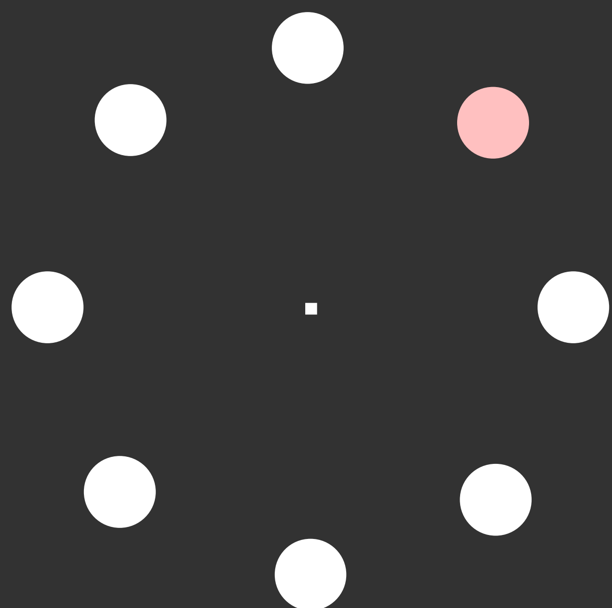
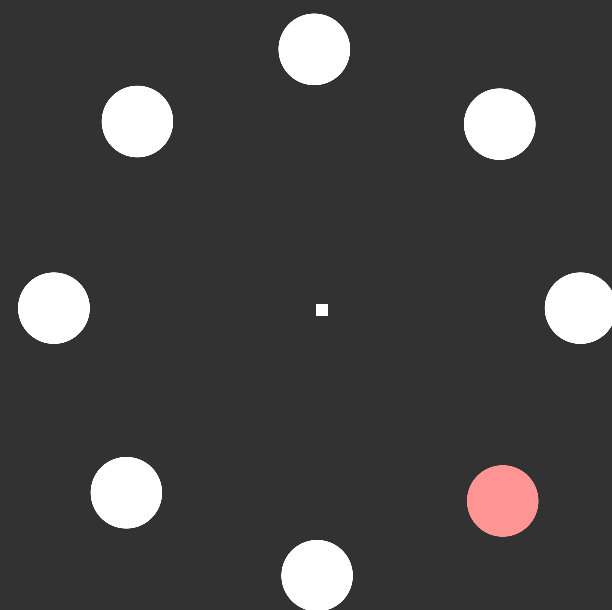
Color discrimination with varied color saturation

Low saturation



Higher saturation



Color saturation discrimination

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Please refer to lecture video or Schiller, Peter H. "The Effects of V4 and Middle Temporal (MT) Area Lesions on Visual Performance in the Rhesus Monkey." *Visual Neuroscience* 10, no. 4 (1993): 717-46.

Perception at isoluminance

At isoluminance vision is compromised

DEPTH
FORM
TEXTURE
MOTION

DEPTH
FORM
TEXTURE
MOTION

DEPTH
FORM
TEXTURE
MOTION

Texture, Motion and Stereo

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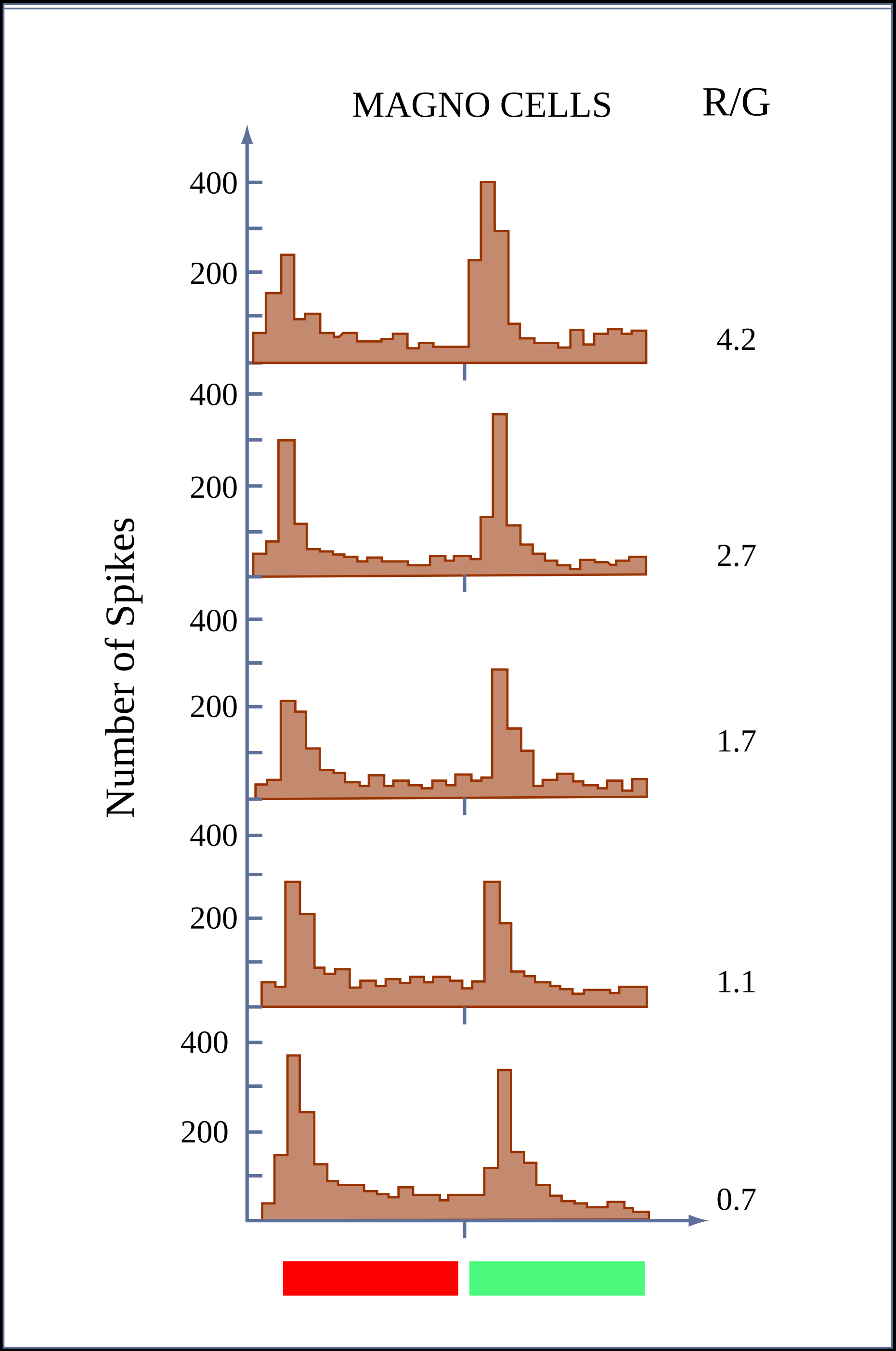
Please refer to lecture video or Figure 3, 4 of Schiller, Peter H., Nikos K. Logothetis, et al. "Parallel Pathways in the Visual System: Their Role in Perception at Isoluminance." *Neuropsychologia* 29, no. 6 (1991): 443-41.

Neuronal responses at isoluminance

The response of a group of magnocellular LGN cells to color exchange



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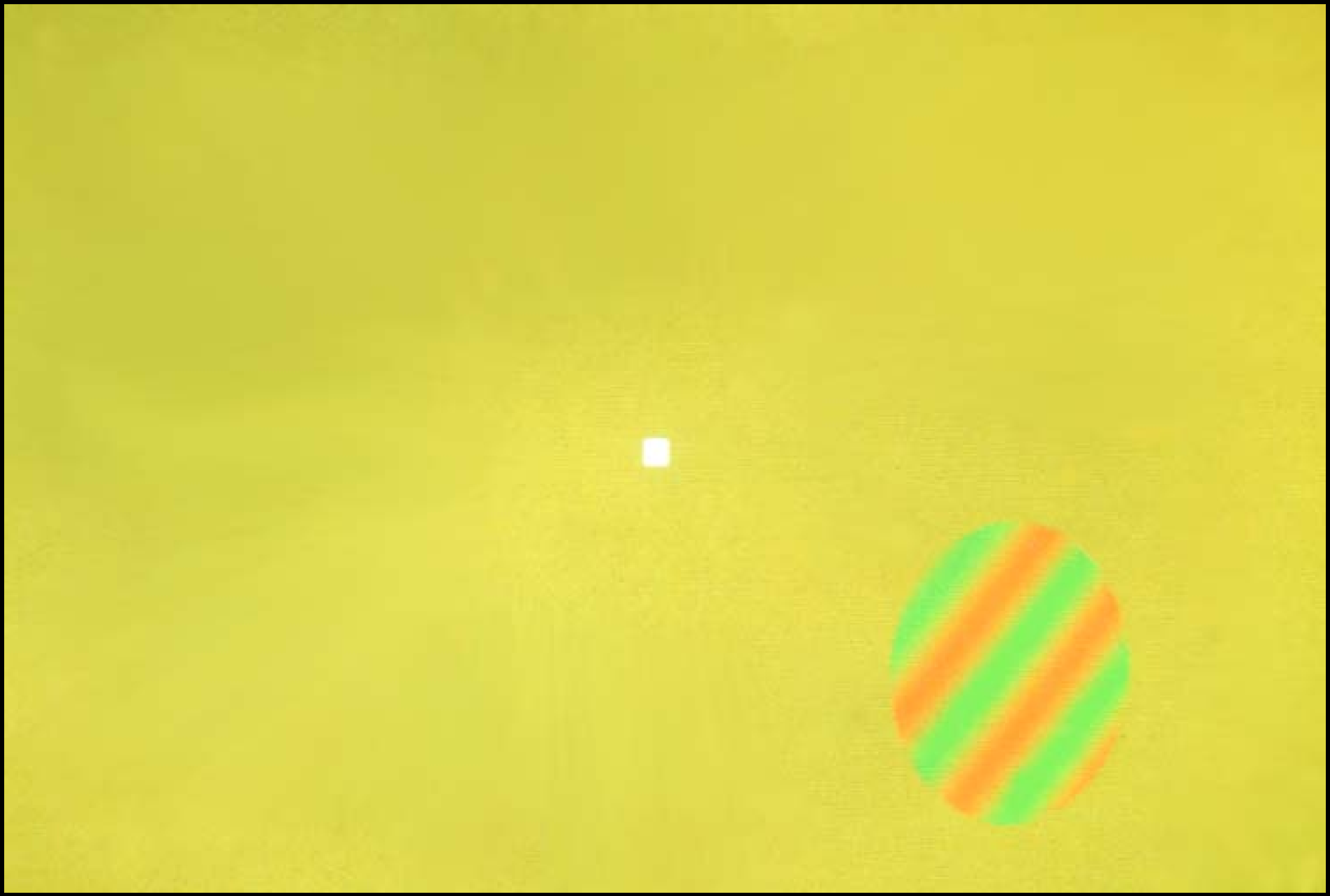
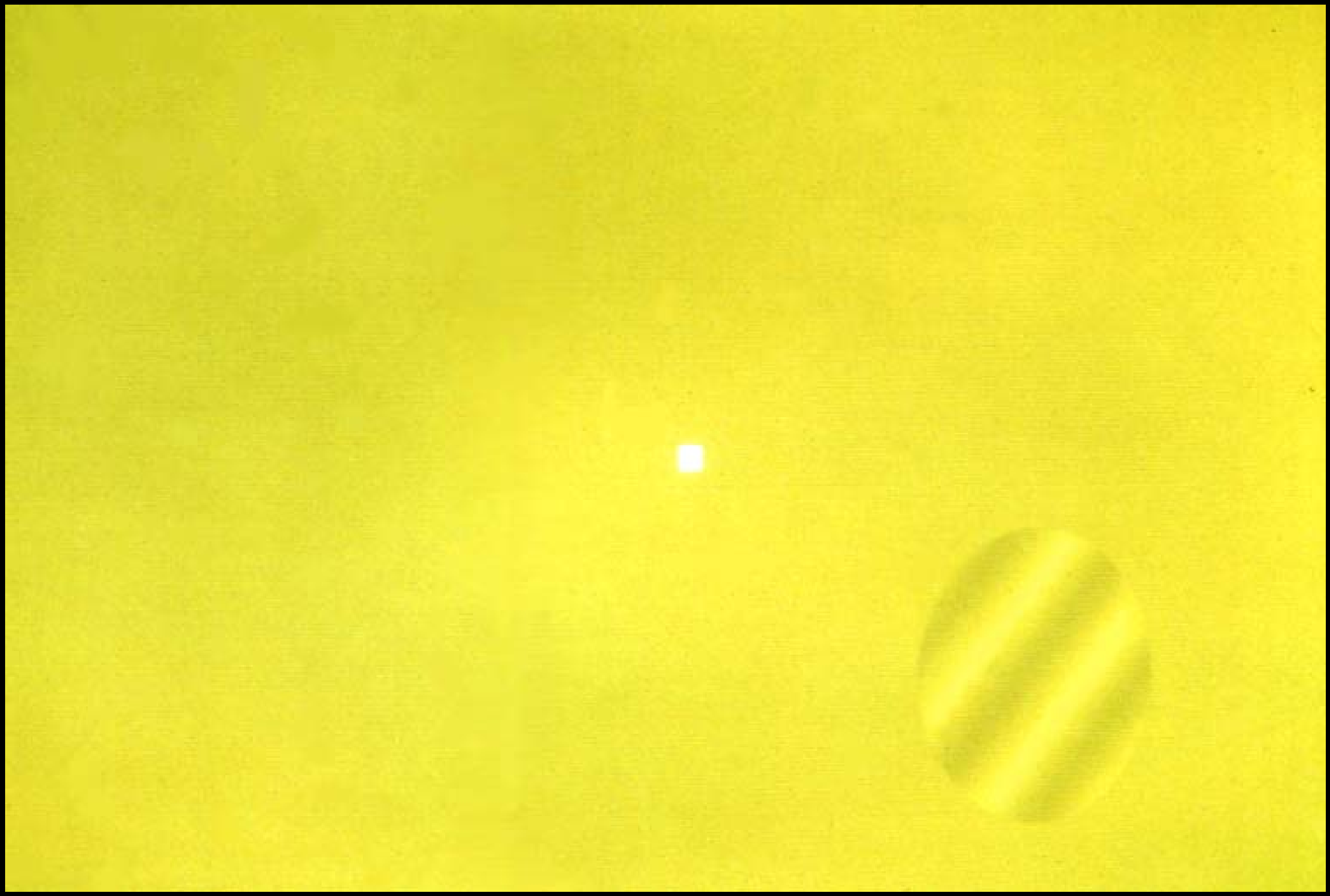
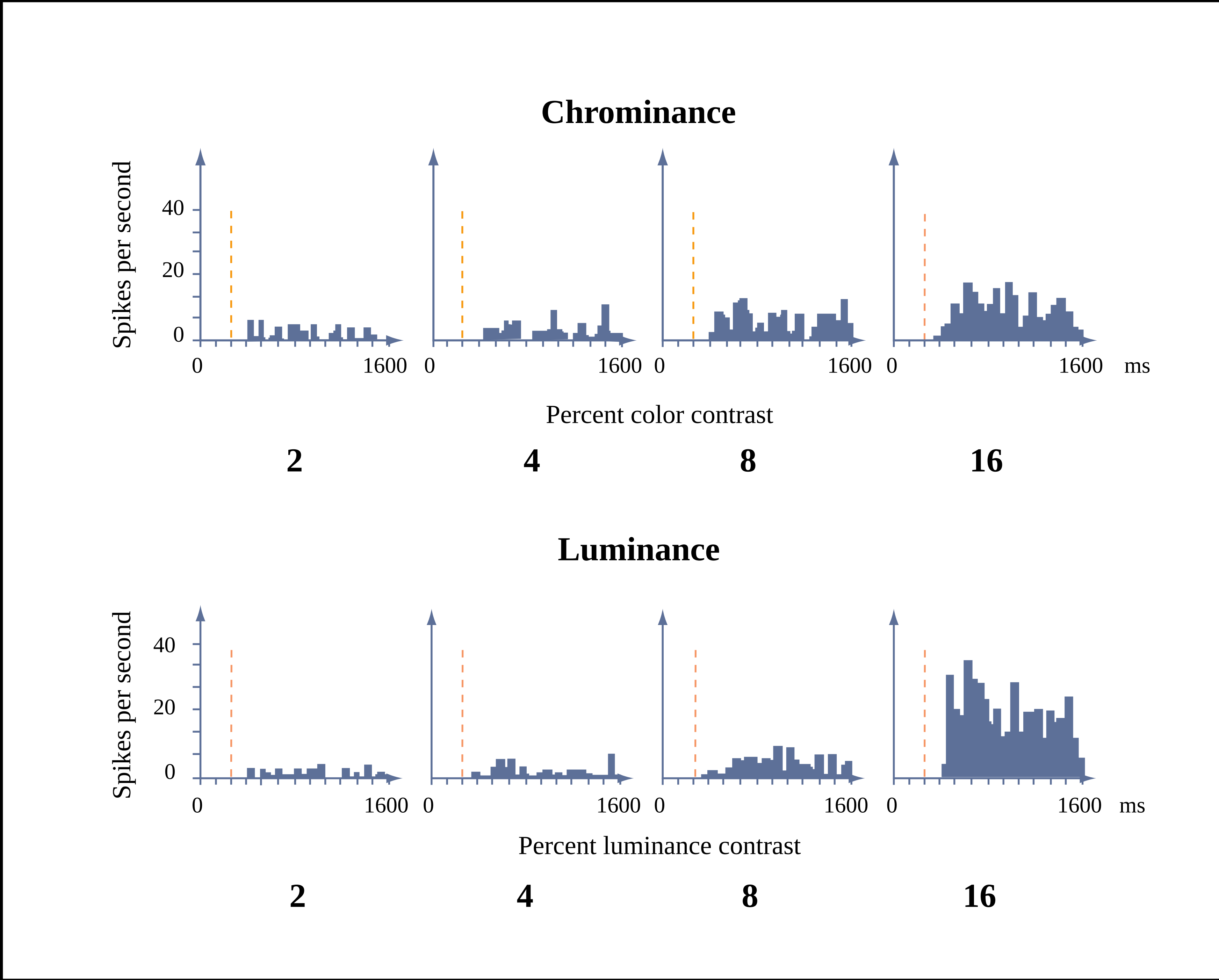
Isoluminant color grating



Luminance grating



Responses of an MT cell to luminance and chrominance differences



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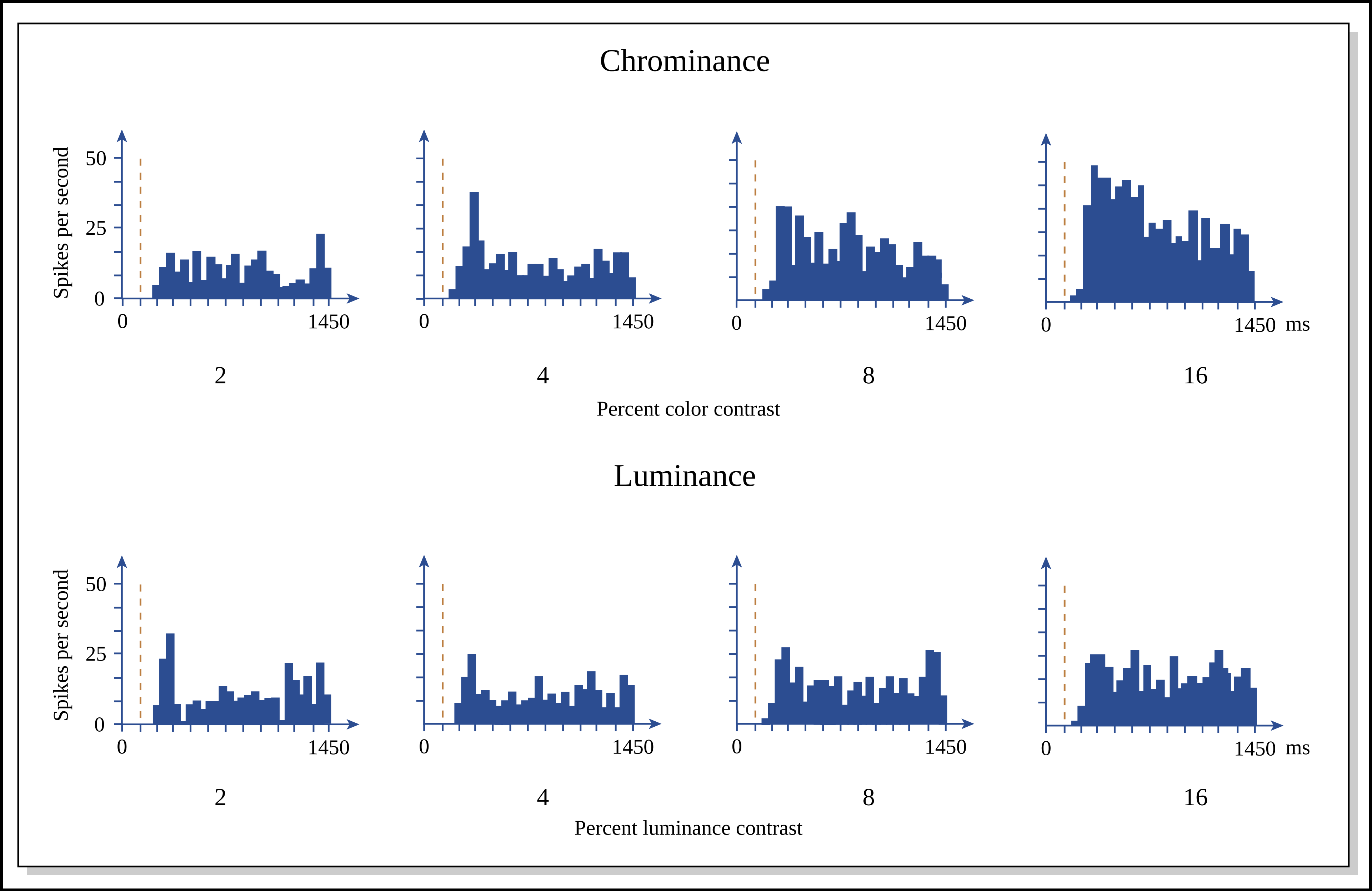
Responses of an MT cell to luminance and chrominance differences



Color blindness and tests for it

Color blindness

1. **Incidence:**

   males: 8/100 in whites, 5/100 in asians, 3/100 in africans

   females: frequency 10 times less

2. **Types:**

   protanopes: lack L cones

   deuteranopes: lack M cones

   tritanopes: lack S cones

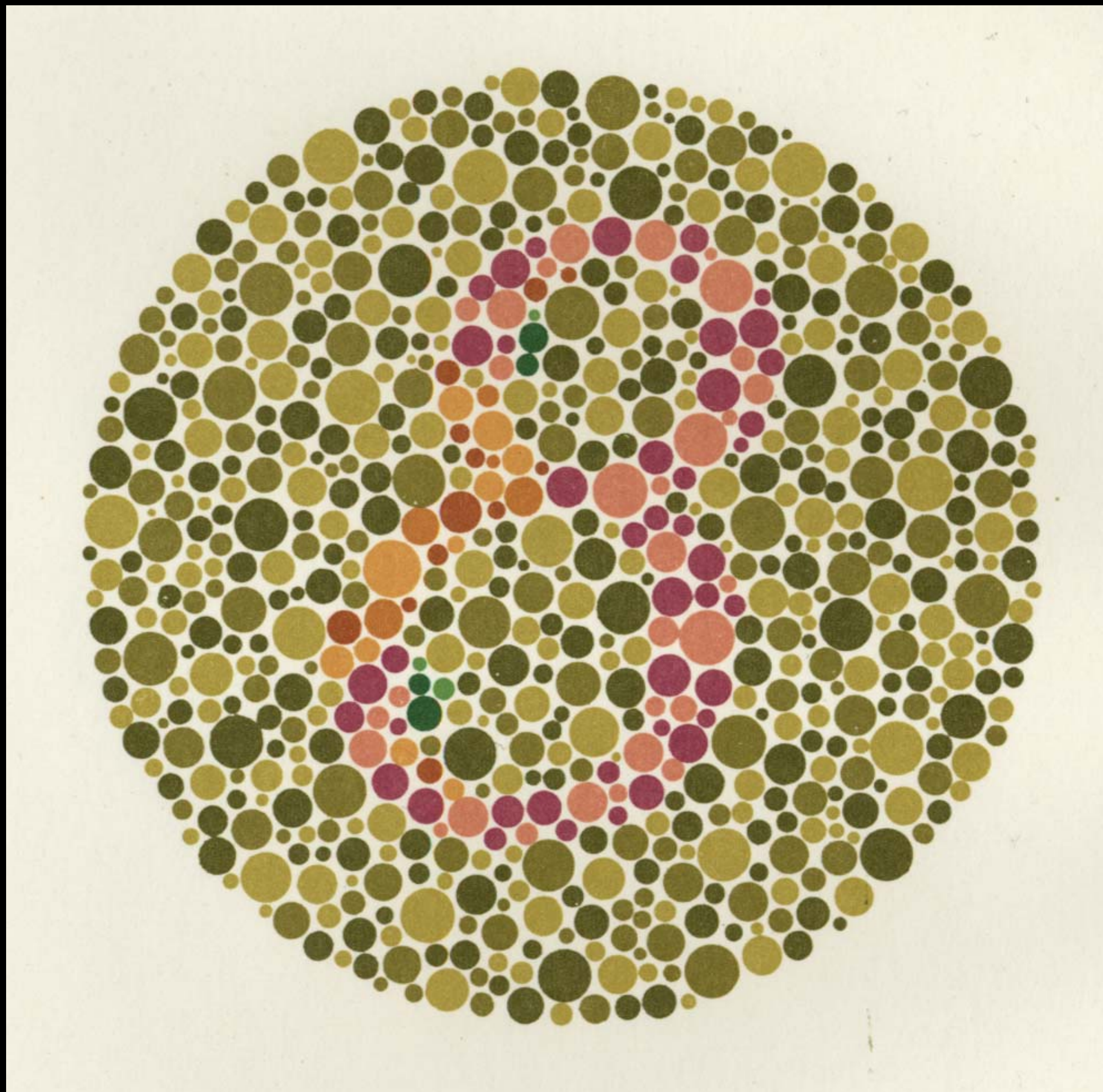
3. **Color tests:**

   Ishihara plates

   Farnsworth-Munsell Hue Test

   Dynamic computer test (City University Dynamic Color Vision Test)

Ishihara plate #2. Do you see an 8 or a 3?



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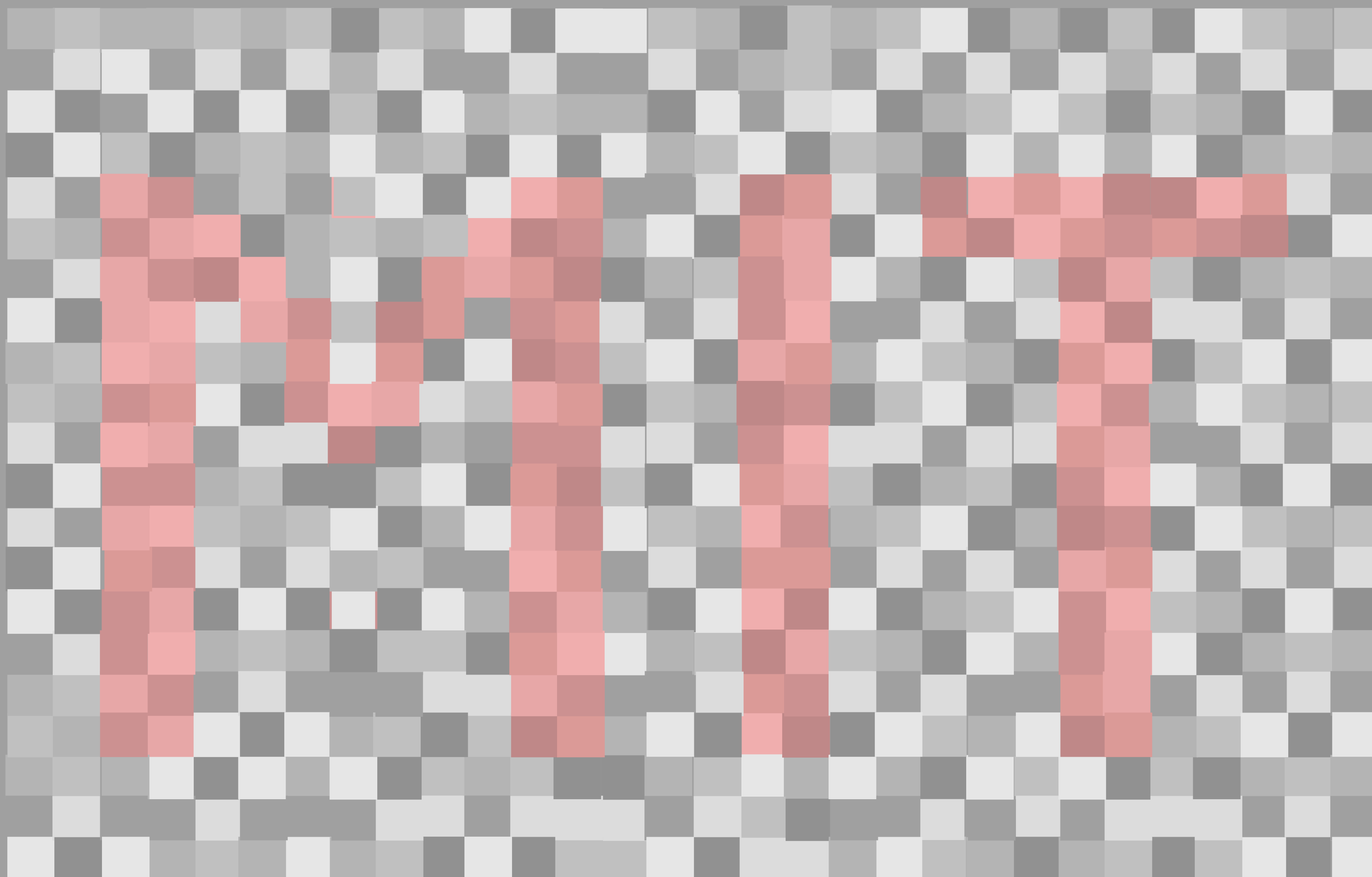
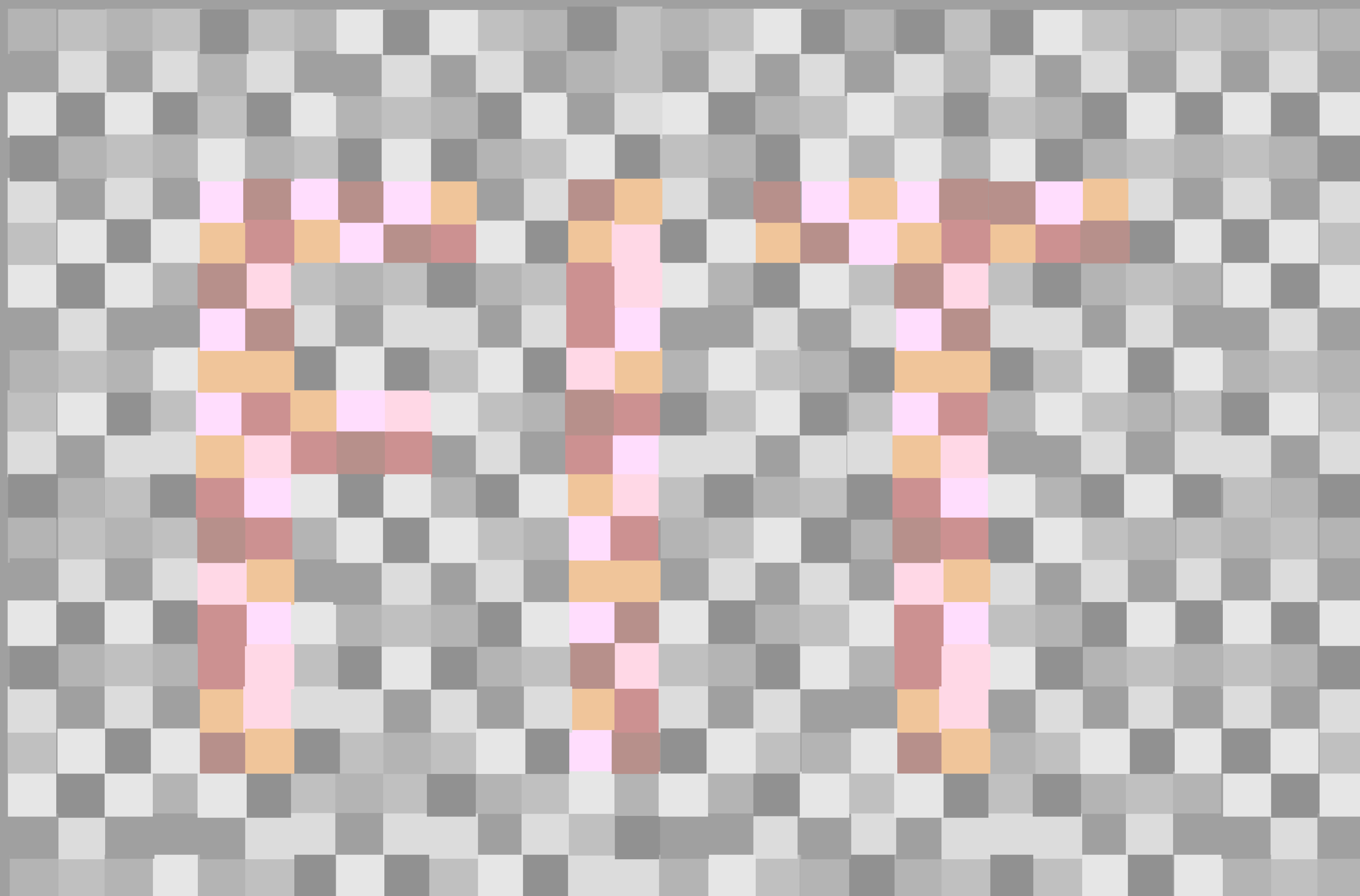
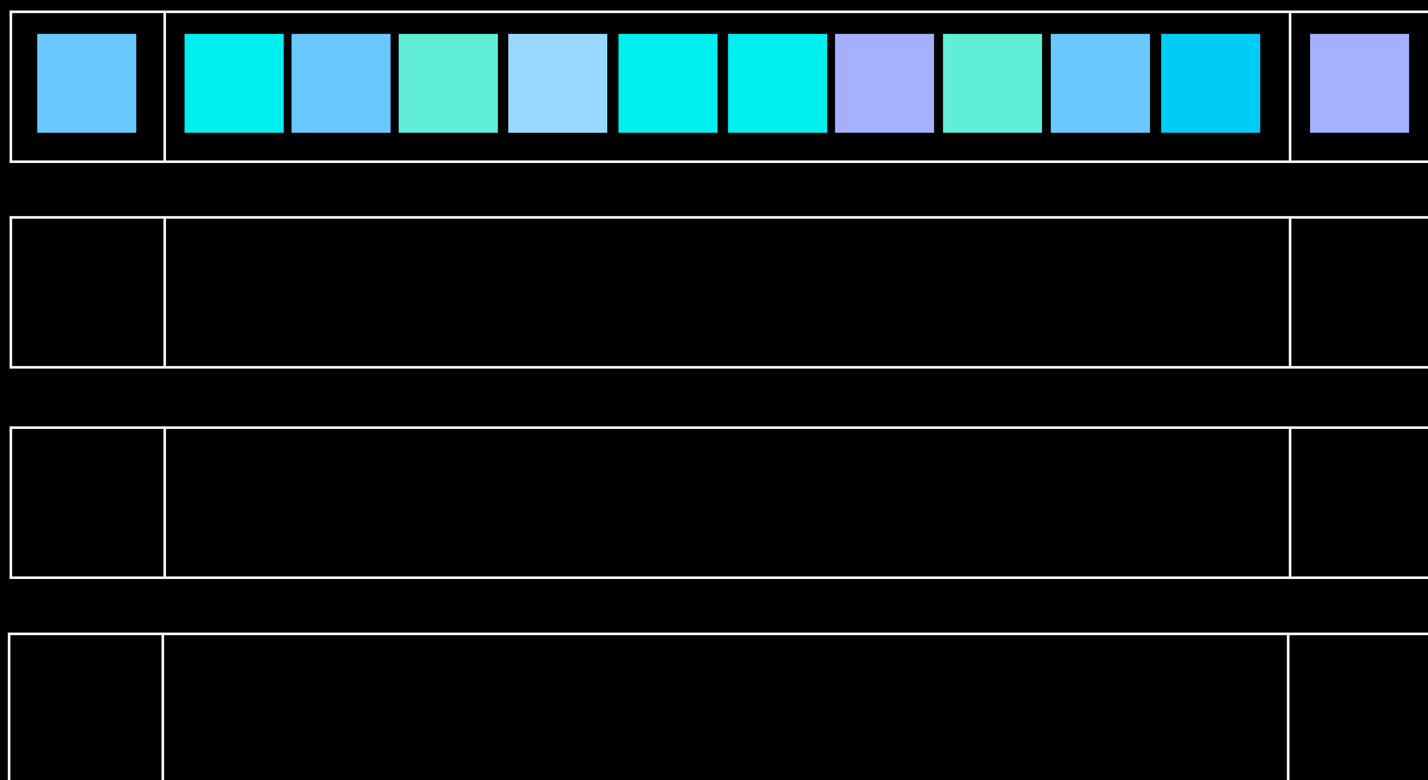
Please refer to lecture video or adapted from Figure 1 from Barbur, J. L., A. J. Harlow, et al. "Insights into the Different Exploits of Colour in the Visual Cortex." *Proceedings of the Royal Society of London. Series B: Biological Sciences* 258, no. 1353 (1994): 327-34.


NIT



Farnsworth - Munsell color test

Arrange in hue order

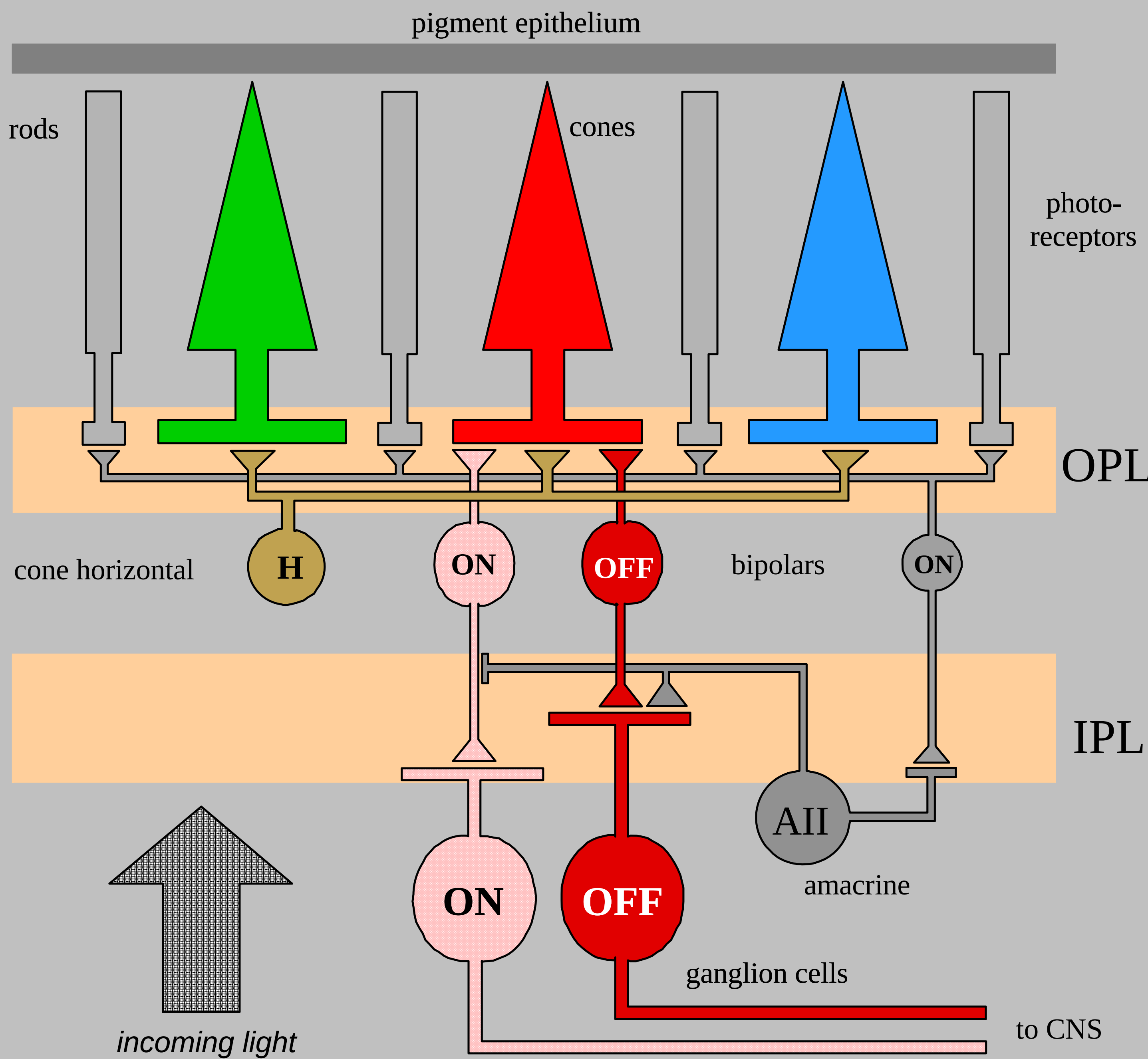


Four rows of 20 each

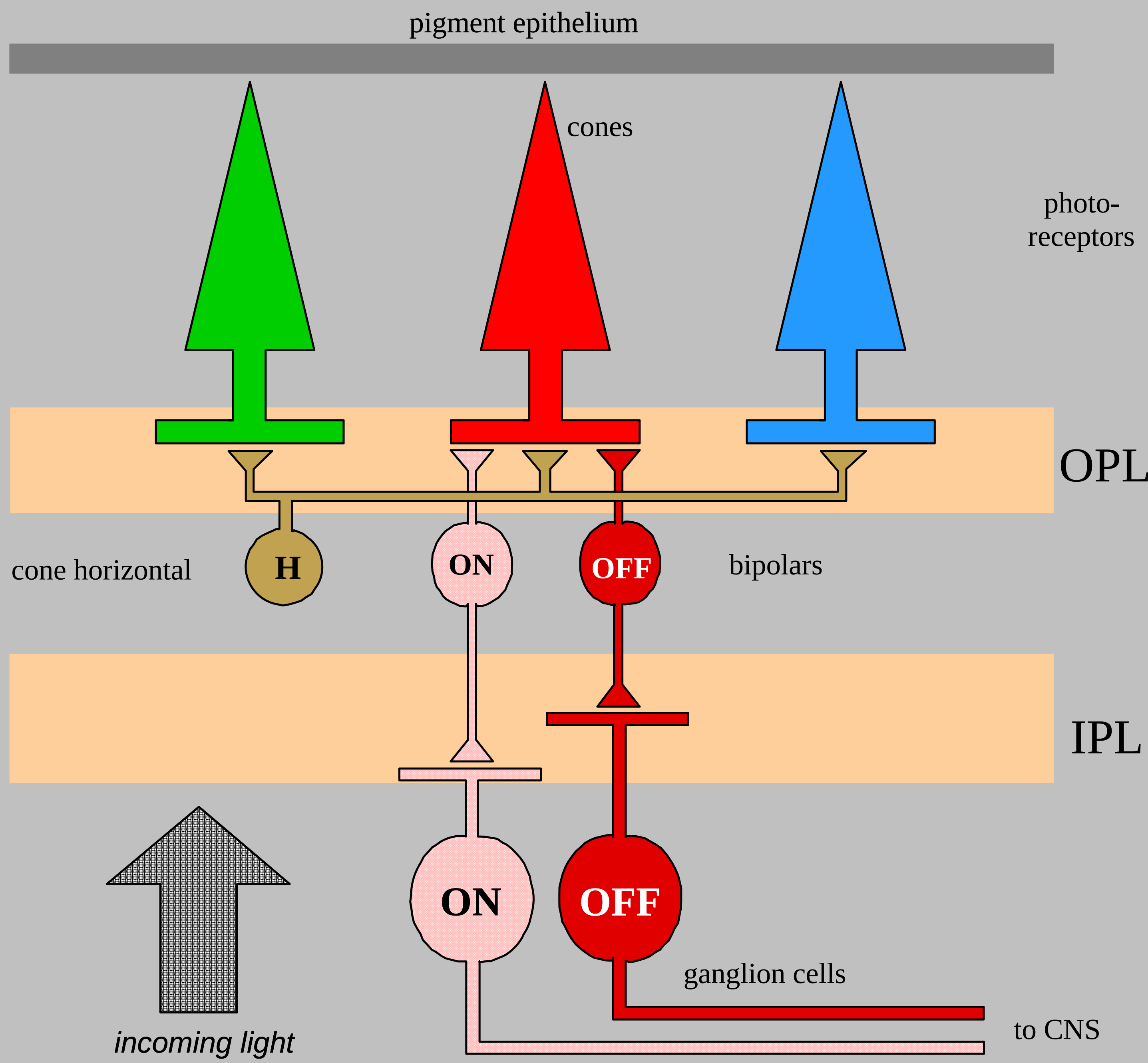
Adaptation

Basic facts about adaptation

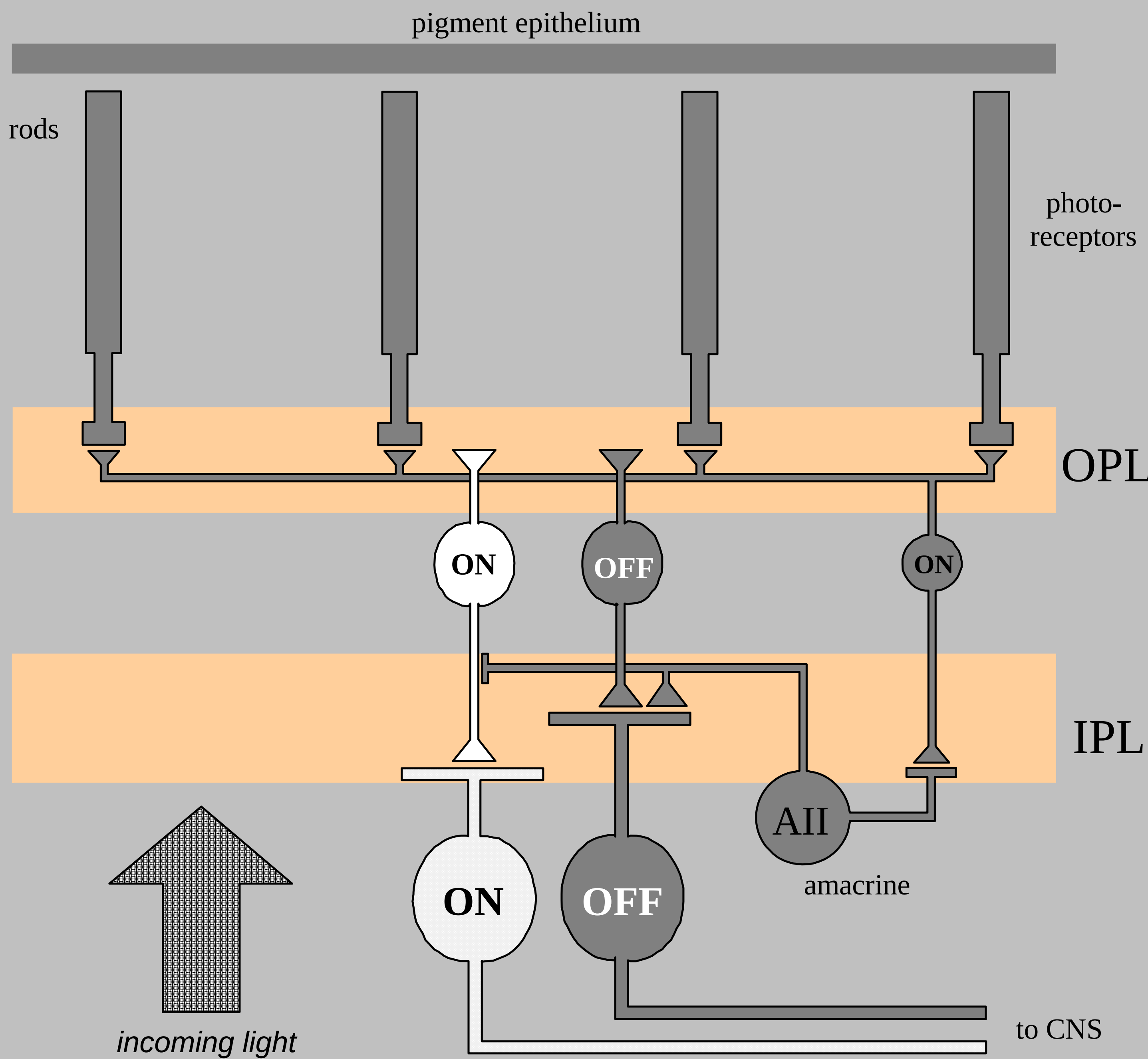
1. Range of illumination is 10 log units. But reflected light yields only a 20 fold change (expressed as percent contrast).
2. The amount of light the pupil admits into the eye varies over a range of 16 to 1. Therefore the pupil makes only a limited contribution to adaptation.
3. Most of light adaptation takes place in the photoreceptors.
4. Any increase in the rate at which quanta are delivered to the eye results in a proportional decrease in the number of pigment molecules available to absorb those quanta .
5. Retinal ganglion cells are sensitive to local contrast differences, not absolute levels of illumination.


pigment epithelium
rods
cones
photo-
receptors
OPL
cone horizontal
H
ON
OFF
bipolars
ON
IPL
AII
amacrine
ON
OFF
ganglion cells
incoming light
to CNS

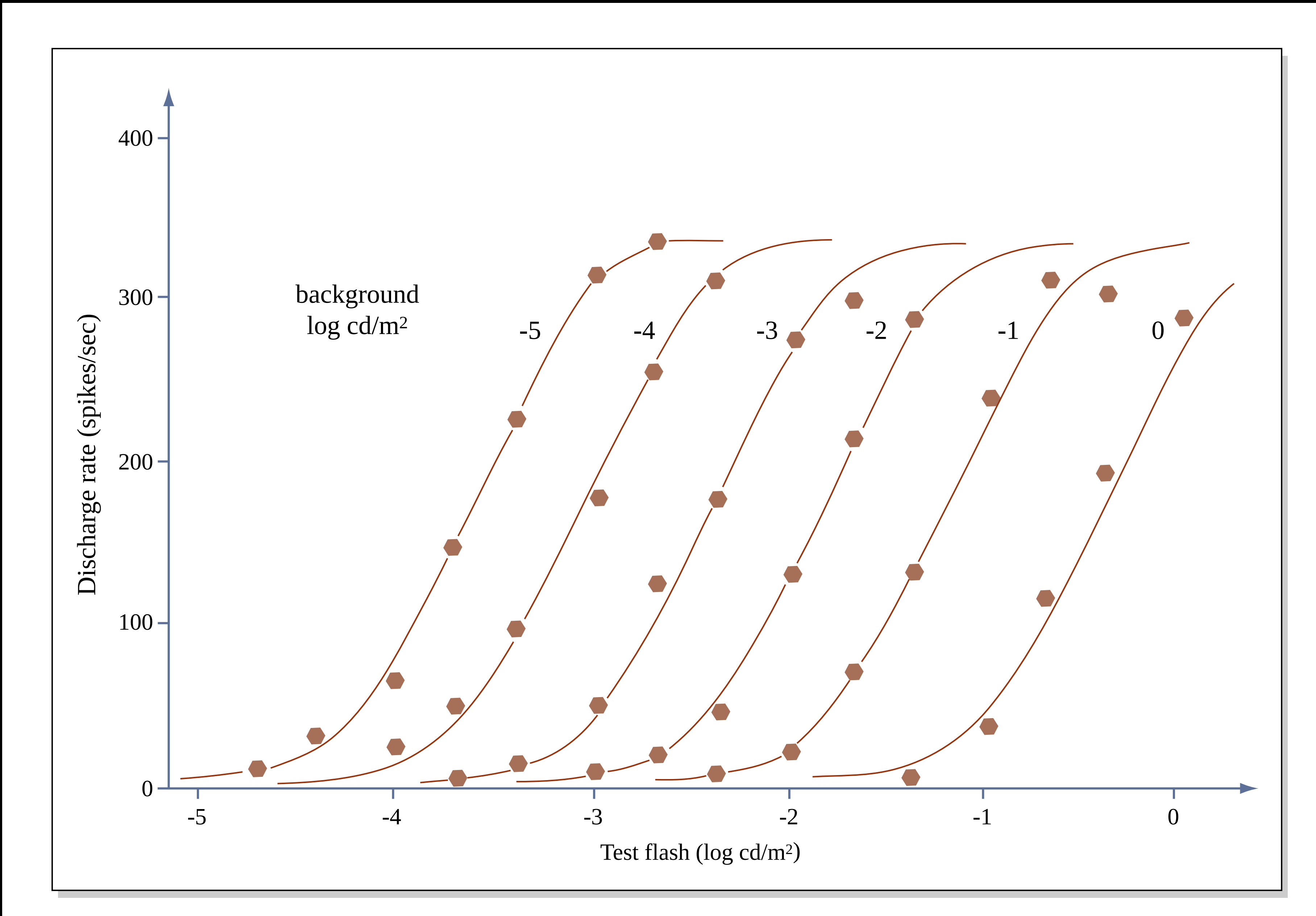
Effective connections under light adapted conditions



Effective connections under dark adapted conditions



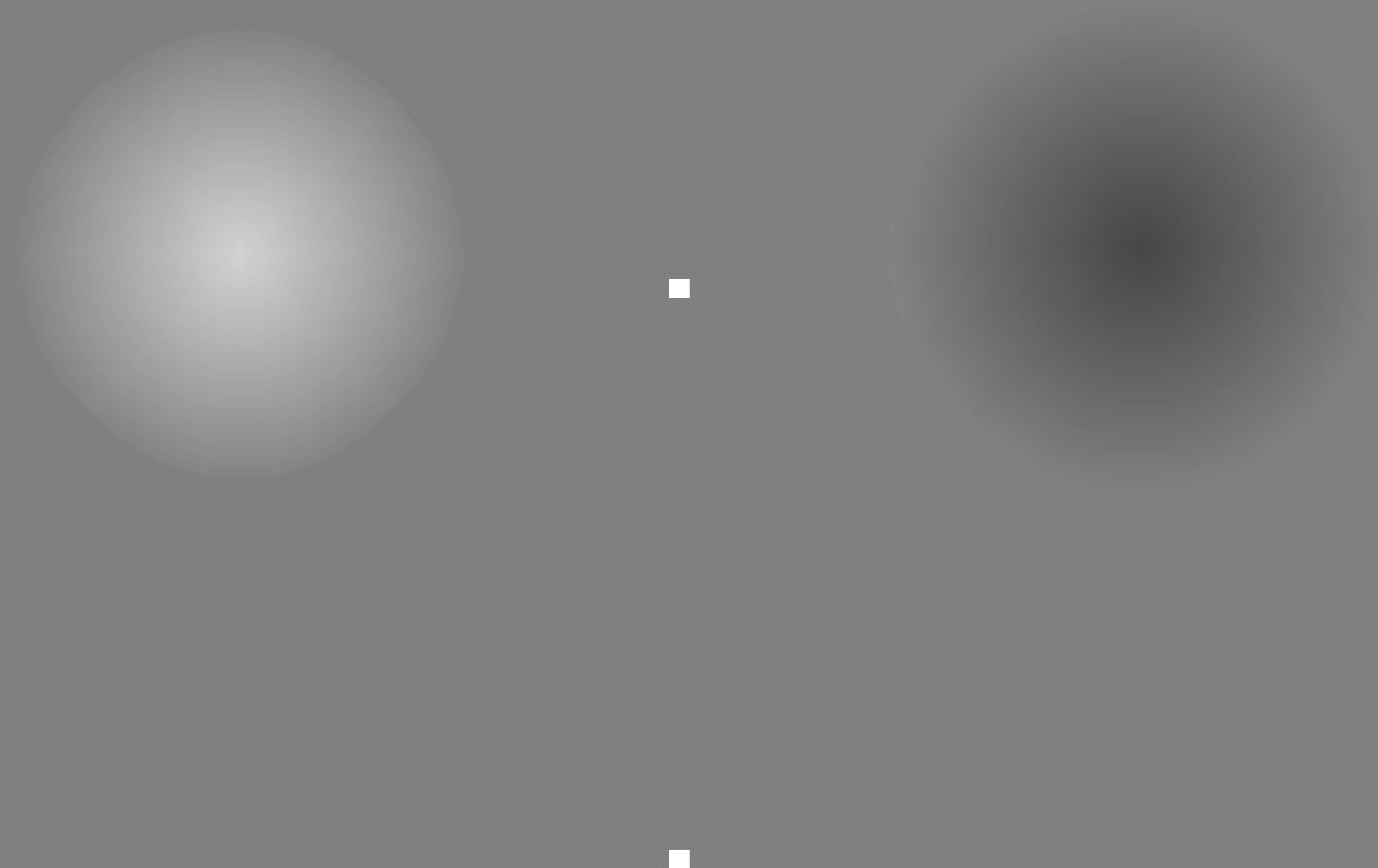
Response of a retinal ganglion cell at various background adaptation levels



The after-effects of adaptation

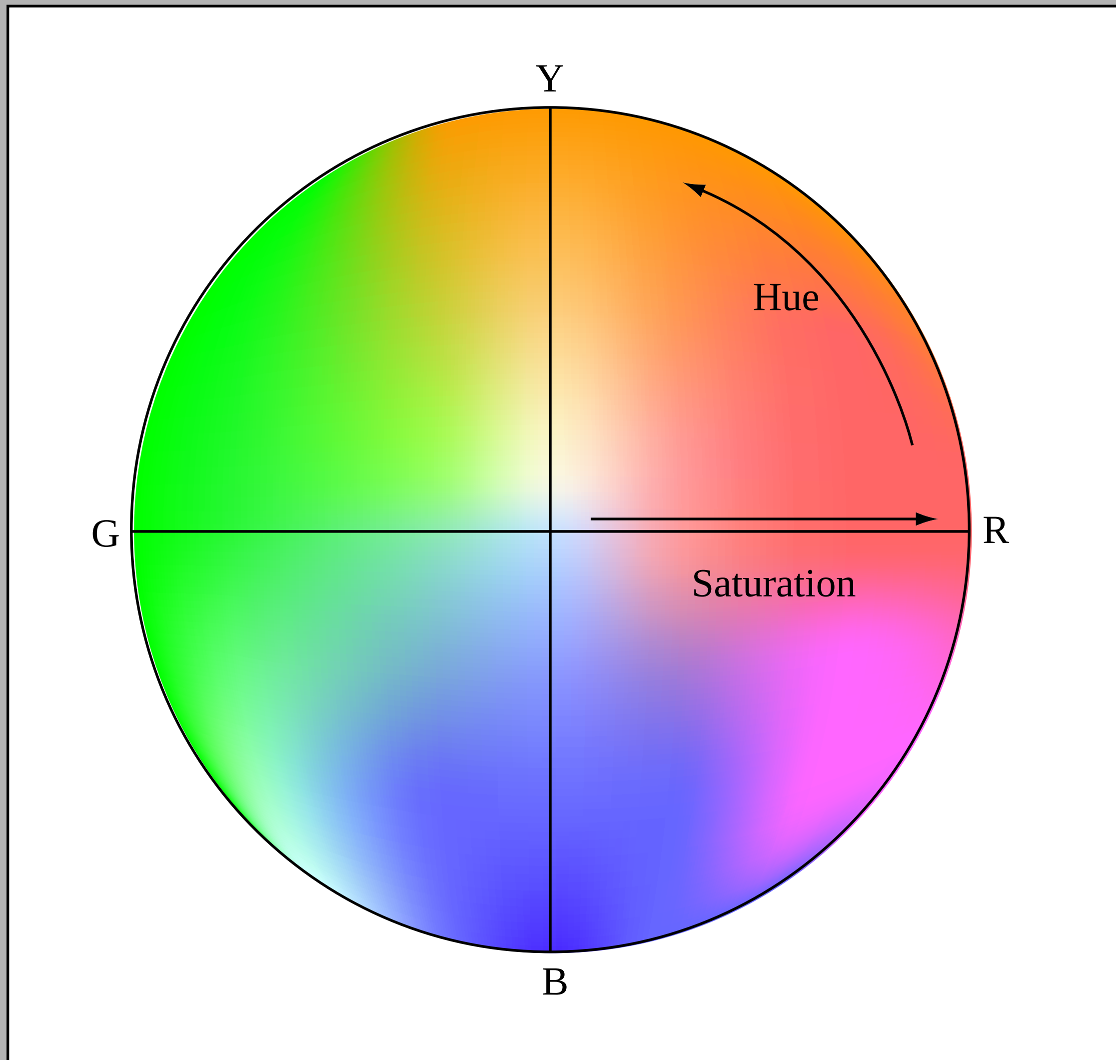
stabilized images

afterimages



PERCEPTION AND SYSTEM RESPONSE BEFORE AND AFTER ADAPTATION

Please refer to lecture video or Schiller, Peter H., and Robert P. Dolan. "Visual Aftereffects and the Consequences of Visual System Lesions on their Perception in the Rhesus Monkey." *Visual Neuroscience* 11 no. 4 (1994): 643-65.



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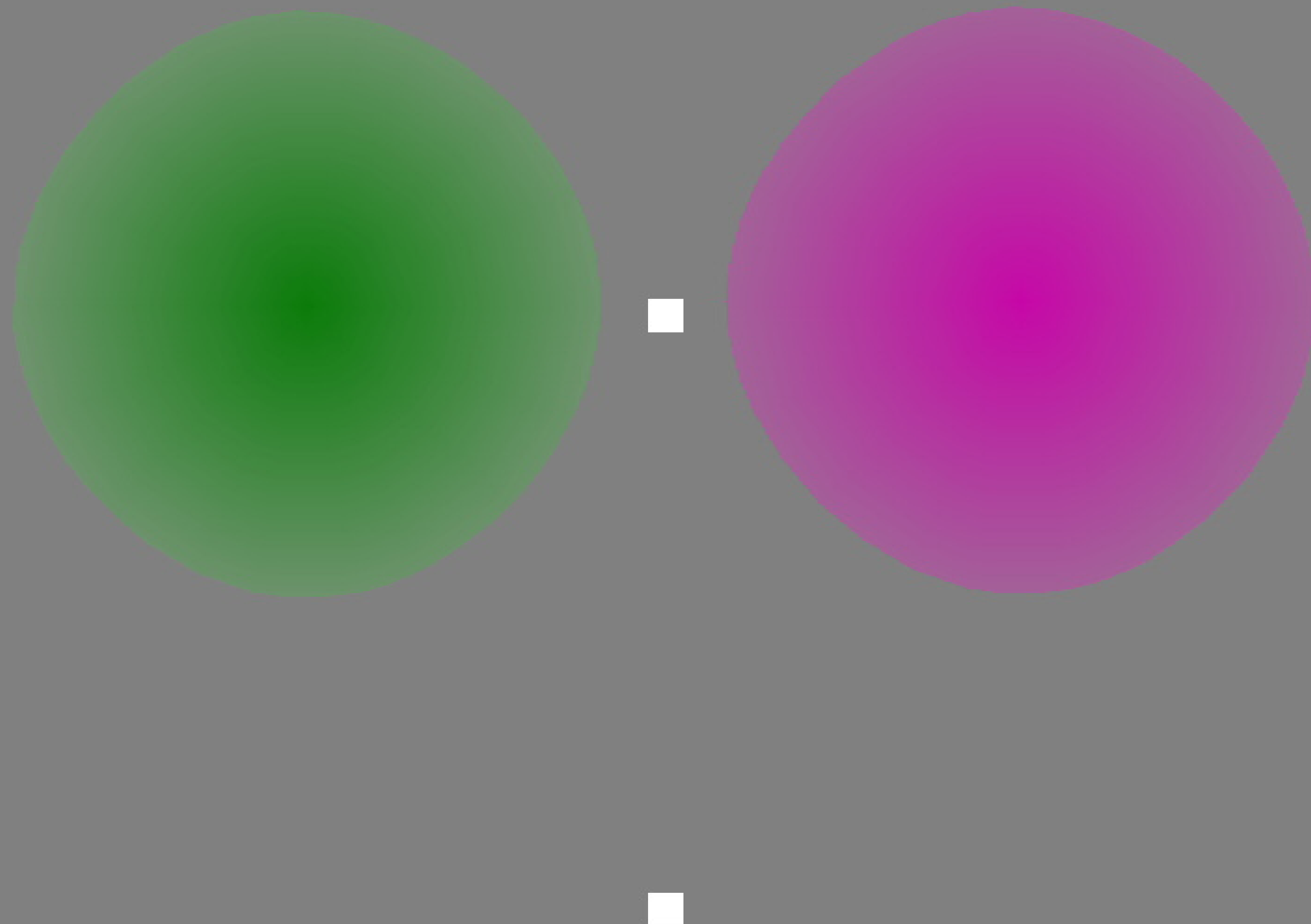
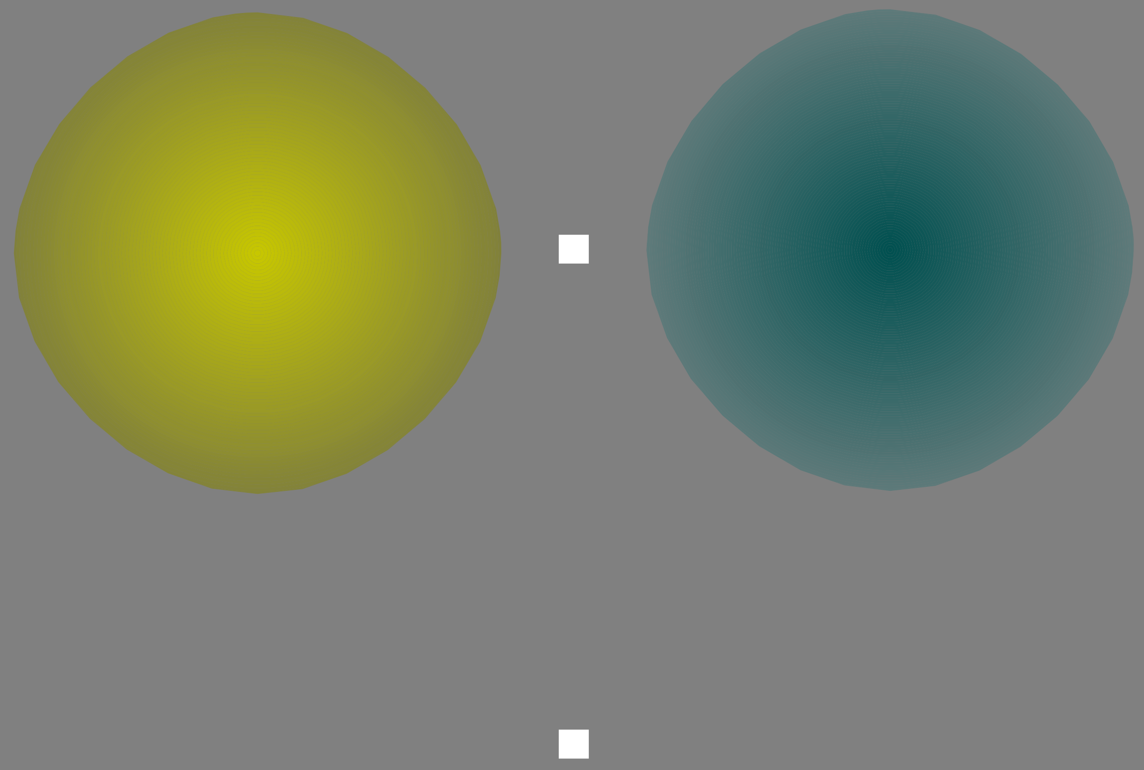
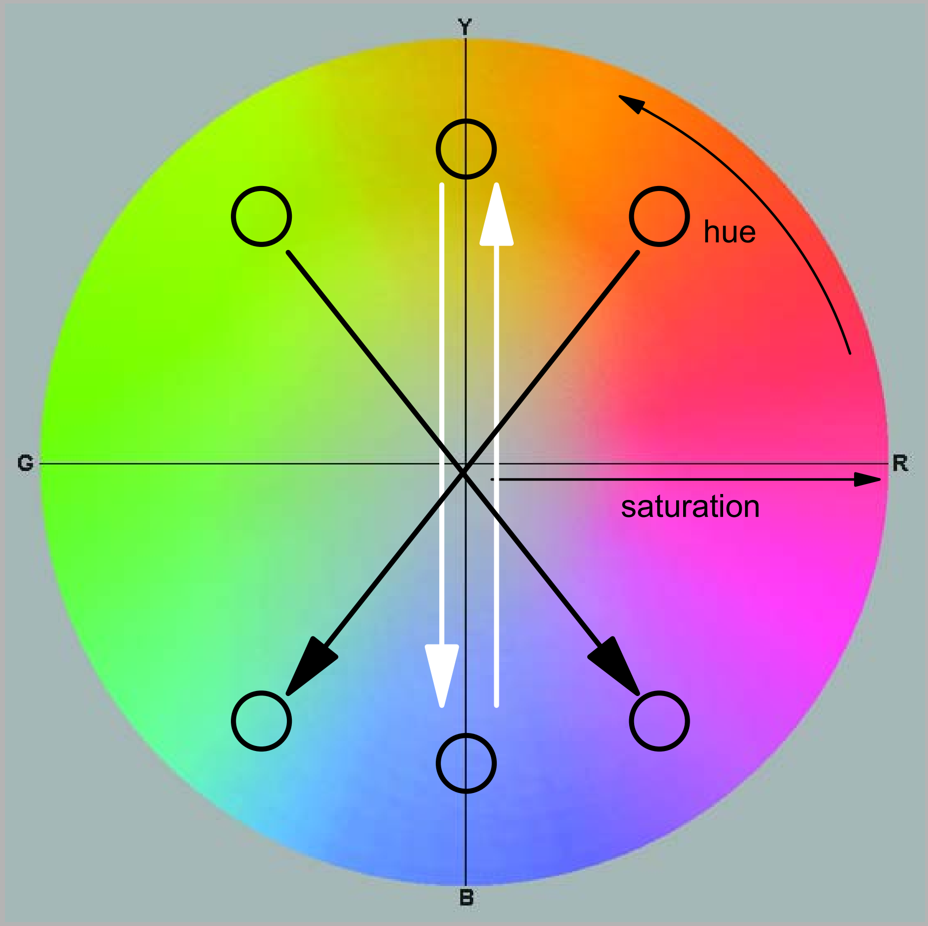
G/R



off axis




Y
hue
G
R
saturation
B

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Please refer to lecture video or see John Sadowski's big Spanish castle illusion.

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Please refer to lecture video or see John Sadowski's big Spanish castle illusion.

Summary:

1. There are three qualities of color: hue, brightness, and saturation.
2. The basic rules of color vision are explained by the color circle.
3. The three cone photoreceptors are broadly tuned.
4. Color-opponent midget RGCs form two cardinal axes, red/green and blue/yellow.
5. The midget system is essential for color discrimination.
6. The parasol cells can perceive stimuli made visible by chromiance but cannot ascertain color attributes.
7. Color is processed in many cortical areas; lesion to any single extrastriate structure fails to eliminate the processing of chrominance information.
8. Perception at isoluminance is compromised for all categories of vision.
9. The most significant aspects of luminance adaptation occur in the photoreceptors.
10. Afterimages are a product of photoreceptor adaptation and their subsequent response to incoming light.

9.04 Sensory Systems
Fall 2013