Nobel prize winning research on vision

- https://www.youtube.com/watch?v=Mo5yck8OPLw
- Questions:
  - What method(s) was/were used in Hubel and Wiesel's cat experiments? (think about content from Chap 6)

Sensation & Perception: The Visual System

Chapter 7

Sensation vs Perception

Sensation Perception

Figure 7.1 Sensation refers to the ability to detect stimuli, while perception is concerned with interpretation of those stimuli.

Contents

The Eye

- Eye evolved to capture photons
- Photons = elementary particle of light
- Photons behave as both particles and waves, but neuroscientists mostly focus on wave-like properties
- Humans detect a very narrow range of frequencies (~400 nm - ~700 nm)

Wavelengths & perceived colors

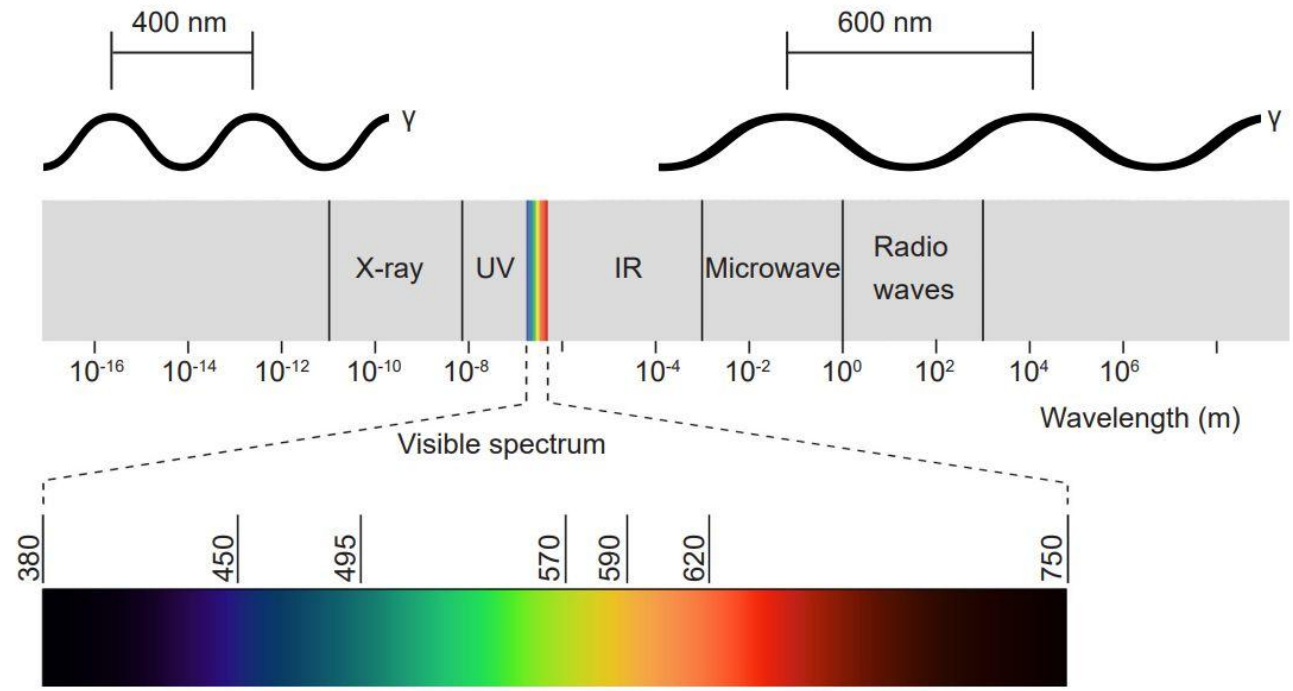
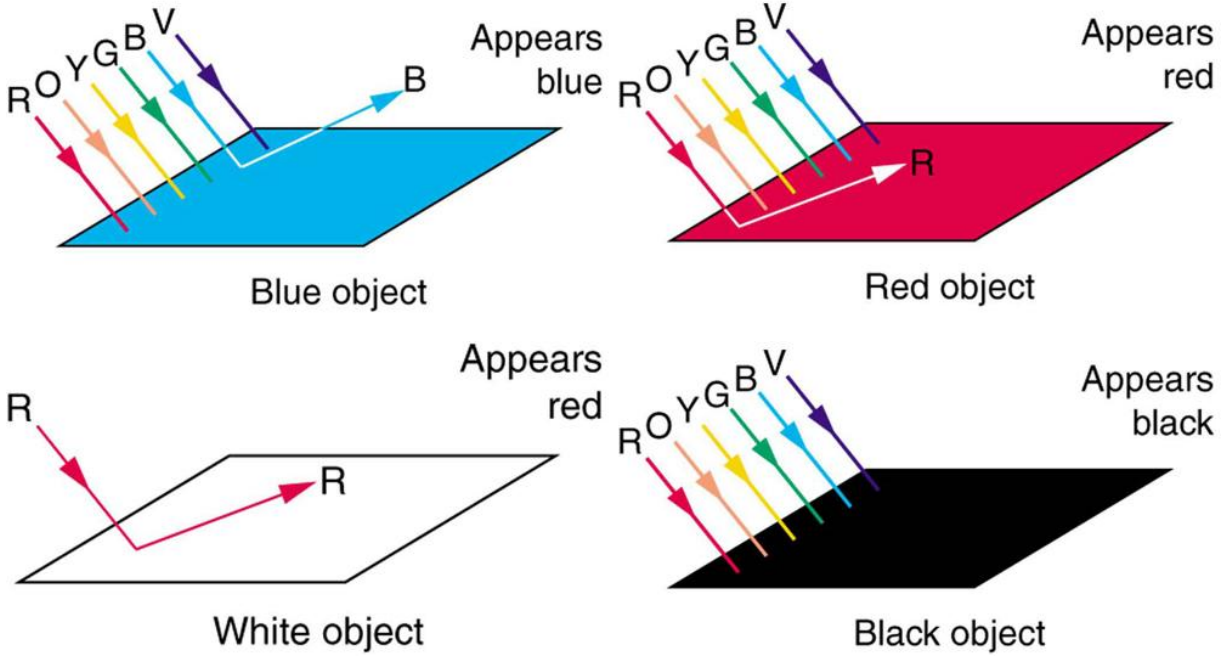


Figure 7.2 Photons (γ) oscillate at different frequencies. If the oscillation repeats every 400 nanometers, we perceive that color as violet (top left), but if it oscillates at 600 nm, we perceive those wavelengths as orange (top right). Humans are only able to detect a narrow range of particles within the electromagnetic spectrum, between 400 and 700 nanometers (bottom).

Three conditions of seeing light

1. Photons must be present
2. Photons must reflect off objects in surrounding world
    1. Reflected wavelengths determine the colours we perceive
3. Photons need to reach the back of the eyeball



Parts of the eye

- Cornea – anterior part of eye;
- Pupil – hole in iris (coloured portion of eye)
  - Pupillary dilator muscle – causes dilation
  - Pupillary sphincter – causes constriction
- Lens – biconvex
  - Accommodation
    - Controlled by ciliary muscle

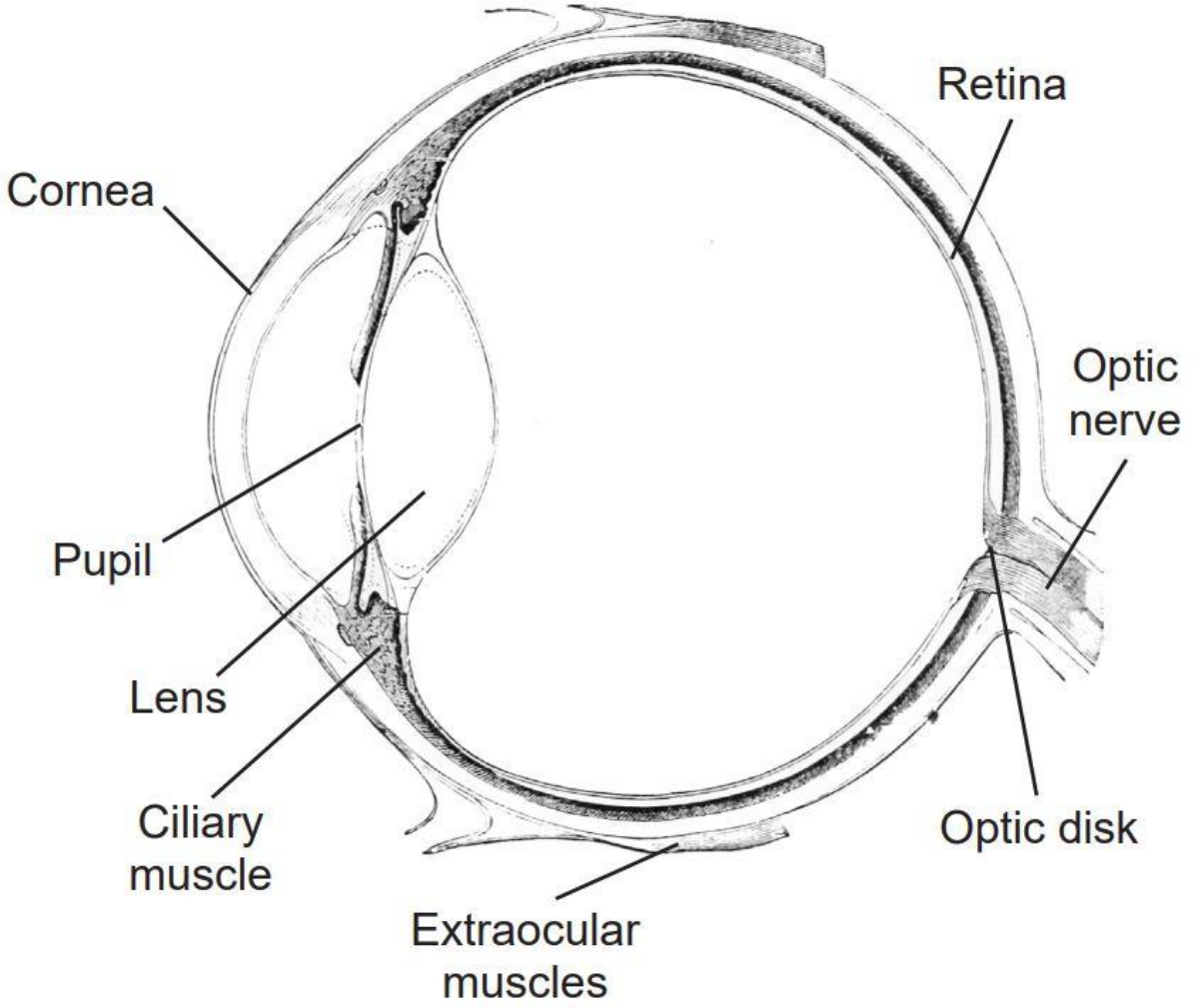


Figure 7.3 Anatomy of the eyeball.

More details on parts of the eye

- Cornea – anterior part of eye; refracts or bends incoming light rays to converge them on retina
- Pupil – diameter changes based on ambient light conditions
    - Mydriasis – pupil dilates, or gets bigger, in dark
    - Miosis – pupils constrict, or get smaller, in well-lit conditions
    - Pupillary dilator muscle – causes dilation (mydriasis)
    - Pupillary sphincter – causes constriction (miosis)
- Lens – also refracts so rays converge on back of eye; biconvex
    - Accommodation
        - Thicker when focused on close objects
        - Thinner/flat when focused on objects in distance
        - Controlled by ciliary muscle

Question

- Pupillary dilator muscle – causes dilation
- Pupillary sphincter – causes constriction

- Which muscle is innervated by the sympathetic nervous system? The sympathetic nervous system? The autonomic nervous system? How can you remember?

Blurry vision and refraction

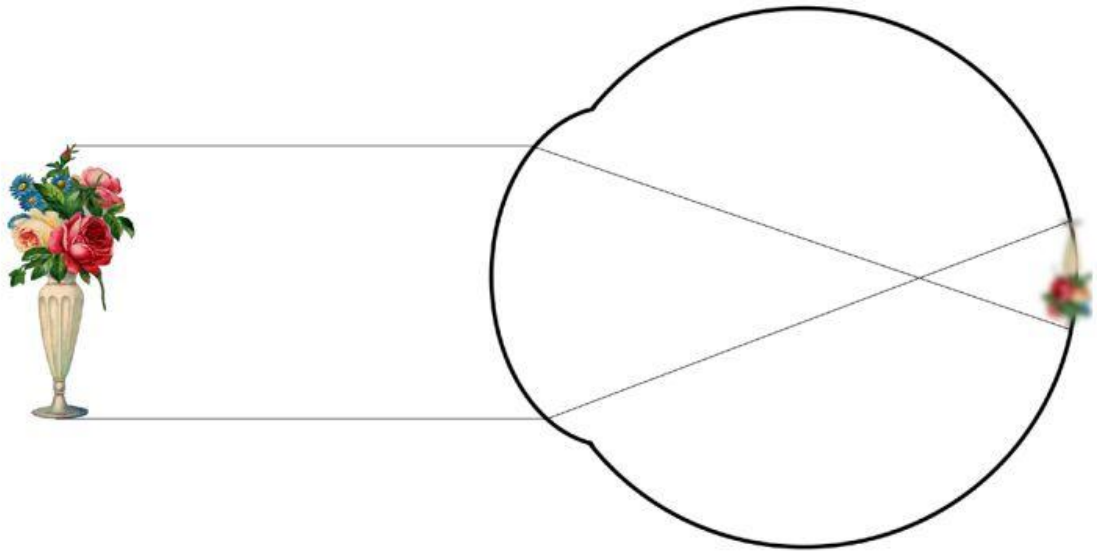


Figure 7.4 If the light refracts incorrectly, the image does not focus on the retina and our field of view will be blurry.

Lens and focus

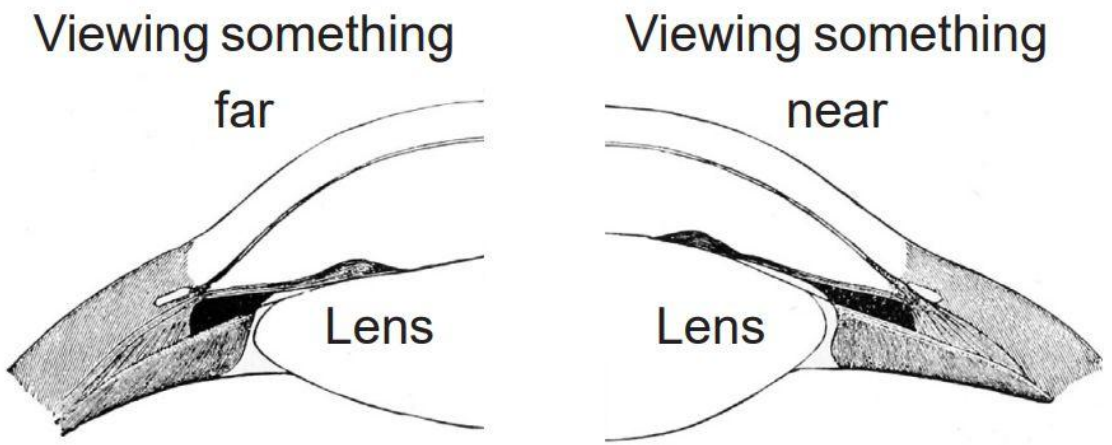
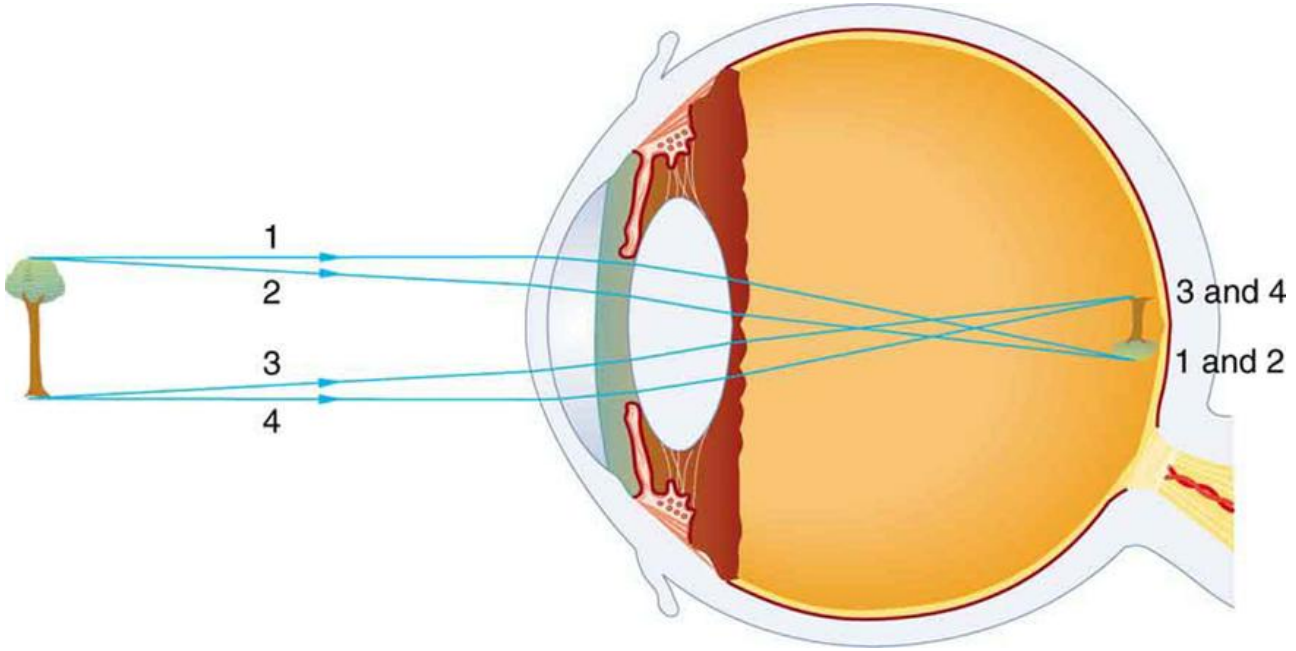


Figure 7.5 The lens is a biological tissue that flattens when we are focusing on something far away, and gets thicker when we focus up close. This process is called accommodation.

Lens shape & image reversal

- Consequence of shape of lens
- Image is both upside down and reversed (up is down, down is up, left is right, and right is left)



Visual field

- Portion of our surroundings that can be seen without moving head or eye
- Information on left half of our vision are in left visual field – projected to right half of both eyes
- Information on right half of our vision are in our right visual field – projected to left half of both eyes

Six muscles controlling eye movement

- Extraocular muscles
- Innervated by cranial nerves, CN III, IV, and VI

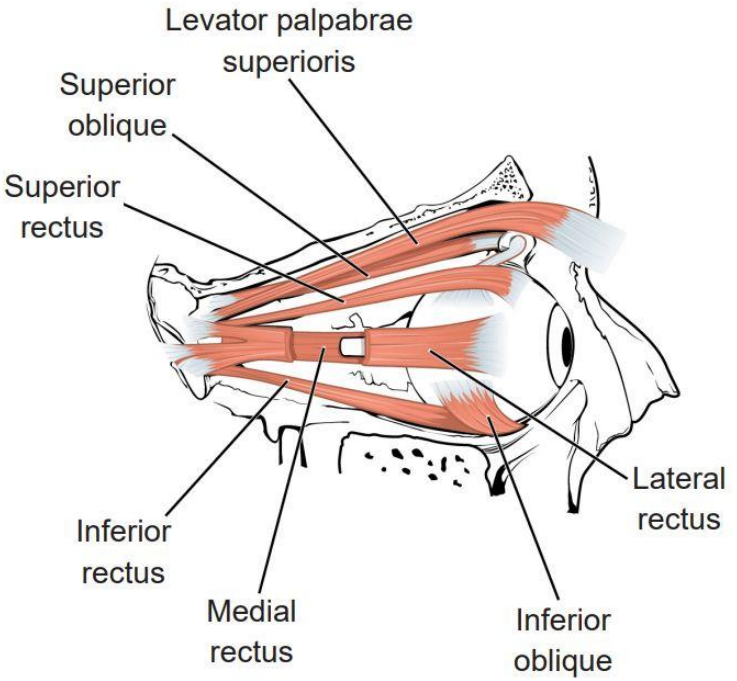


Figure 7.6 The extraocular muscles are a series of seven muslces, six of which control eyeball movement and one (leavtor palpabrae superioris)which controls the eyelid.

The Retina

- Back of the eyeball; beginning of the nervous system's involvement with the visual system (5 layers of neurons)
  - Nasal hemiretina
  - Temporal hemiretina
  - Upper hemiretina
  - Lower hemiretina
- Fovea – small pit in the center of the retina; where we have the highest acuity (clearest vision)
- Optic disk – area where information exits at the back of the eye
- Optic nerve

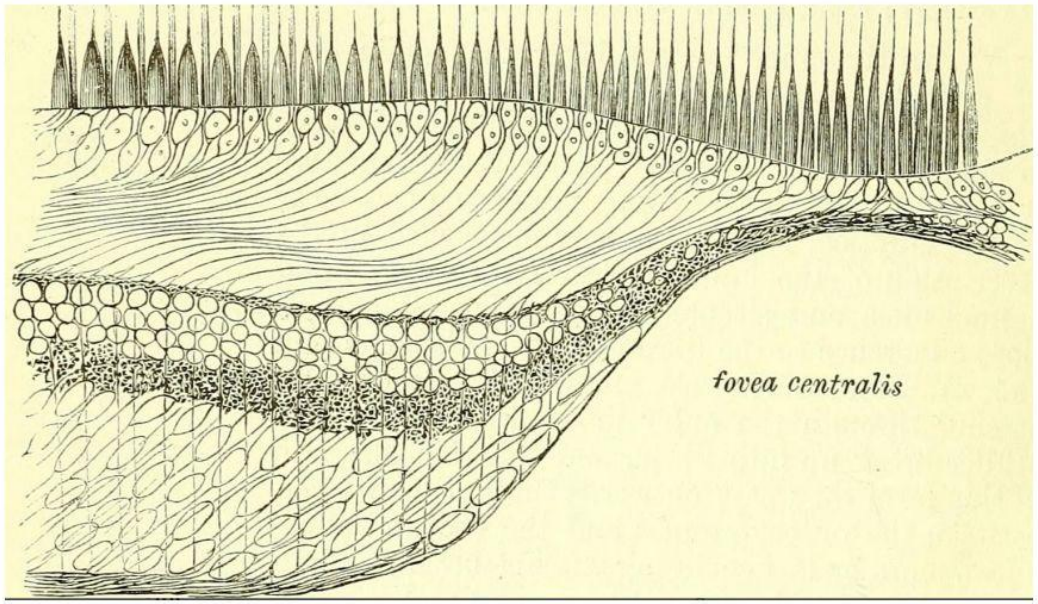


Figure 7.7 The fovea appears as a "pit" with the neuronal components swept away from the center of our vision.

Neurons of the retina

1. Photoreceptor cells
2. Horizontal cells
3. Bipolar cells
4. Amacrine cells
5. Retinal ganglion cells

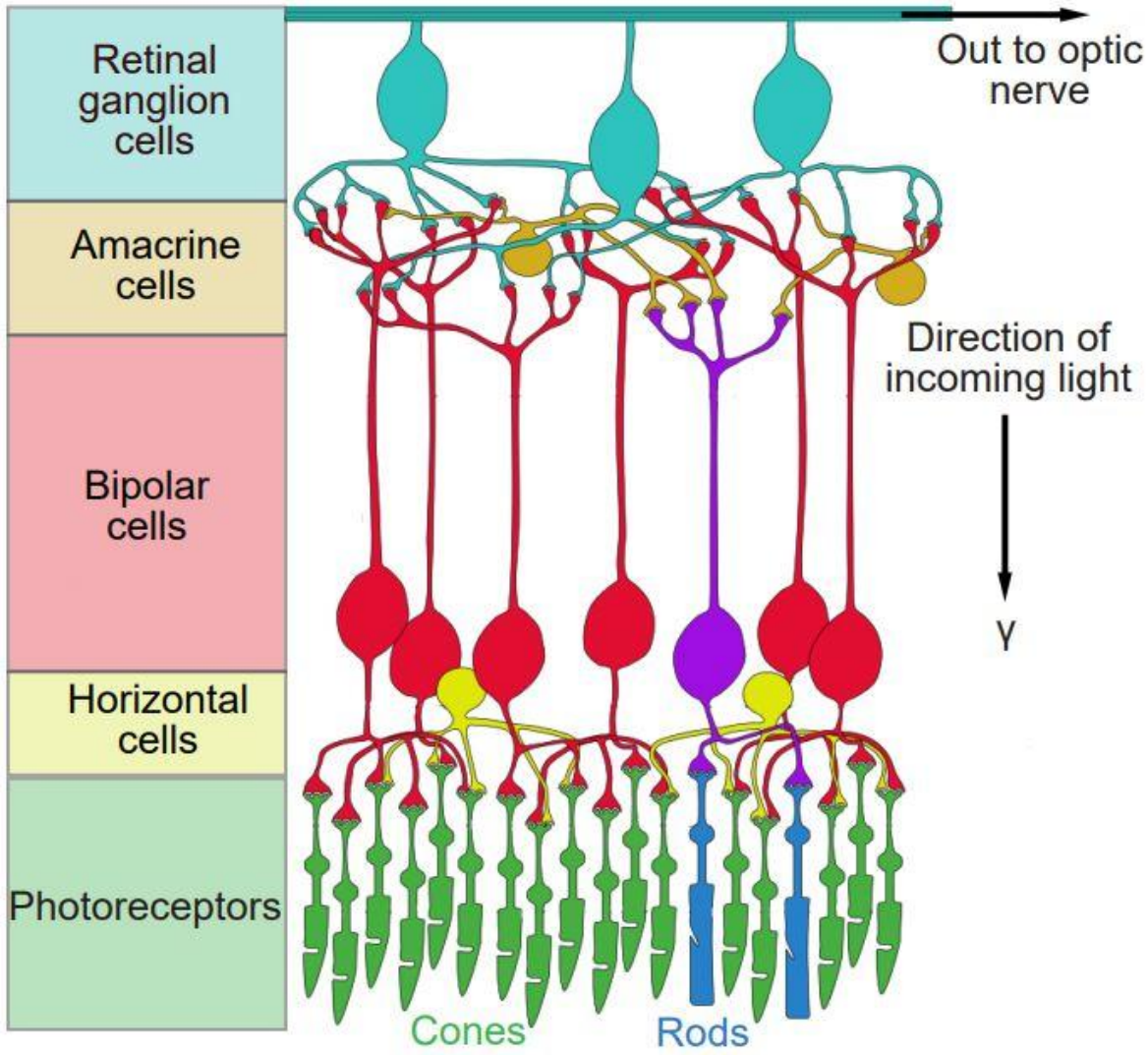


Figure 7.8 The five neuron layer of the retina.

Photoreceptor cells

- Cells that detect photons of light and convert them into neurotransmitter release (phototransduction)
- Have 2 parts: outer and inner segments
- Outer segment – contains stacks of membranous disks bounded within the neuronal membrane; disks contain hundreds of billions of photopigments
    - Photopigments: light-sensing components
    - Opsin: a protein that determines the wavelength the photopigment will absorb (multiple types, Ex. rhodopsin)
- Inner segment – contains the nucleus and other organelles; extending from this inner segment is the axon terminal
- Classified as rods or cones because of appearance and shape

Rod photoreceptor cells

- Most densely concentrated outside the fovea
- Detect information from peripheral vision
- Have high synaptic convergence (several – up to 30 – rod cells feed the bipolar cells)
  - Advantage: many small signals create a seemingly larger signal (ex. Stargazing)
  - Disadvantage: difficult to identify exactly which photoreceptor is activated, so accuracy is poor (cannot see text in peripheral vision)
- Most sensitive to light with a wavelength of 500 nm (blue-ish green)
- Light at other wavelengths still causes response, but to a lesser degree
- Optimal in low-light conditions
  - Purkinje shift – named after Czech anatomist Jan Purkinje; blue-ish tint at night

Purkinje shift

Figure 7.9 Demonstration of the Purkinje shift. At night, normal bright colors appear blue-ish due to increased activity of the rod photoreceptors.

Cone photoreceptor cells

- Allow for high-acuity vision
- Most densely pack at the fovea, corresponding to center of visual field
- Minority of photoreceptors; outnumbered by rod cells by ~20 times
- Have low synaptic convergence (a single cone cell communicates with a single pathway to the brain)
  - Not additive, so they are less effective at low light conditions
  - Highly effective at precisely identifying the location of incoming light
- Responsible for processing our sensation of colour (cones = colour)
- Three types: S-cones, M-cones, and L-cones

Types of cones

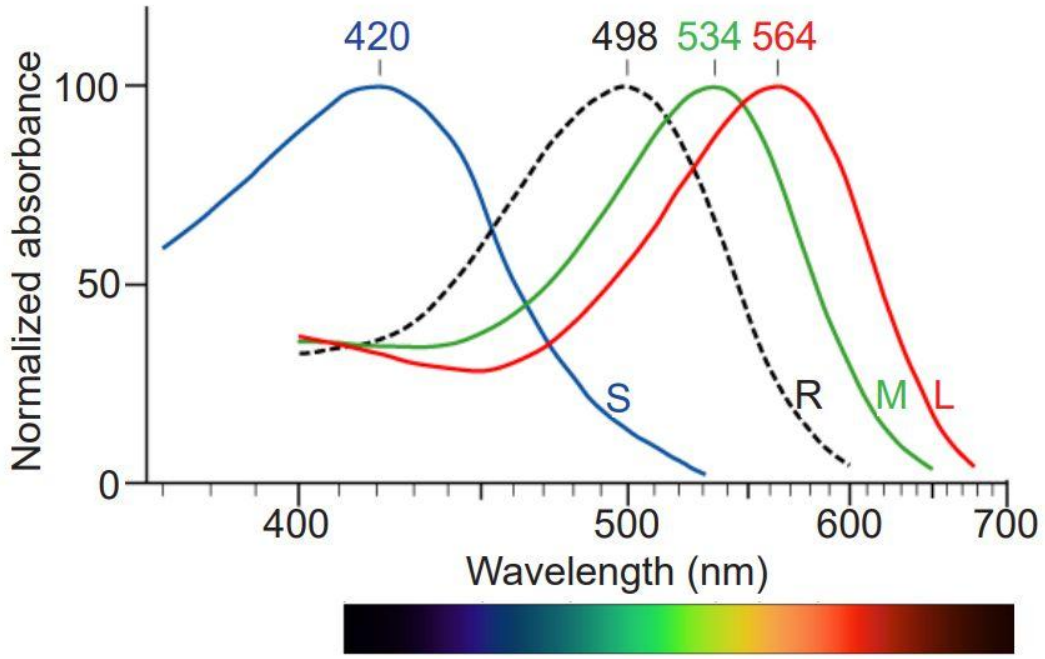


Figure 7.10 Different photoreceptor cells respond to different frequencies of light.

- Short wavelength (S-cones) respond best to 420nm (violet) light
- Middle wavelength (M-cones) respond best to 530 nm (green) light
- Long wavelength (L-cones) respond best to 560 nm (red) light
- Each is activated by other wavelengths, but to a lesser degree
- Every colour of visible spectrum is represented by a combination of activation of the three types of cones

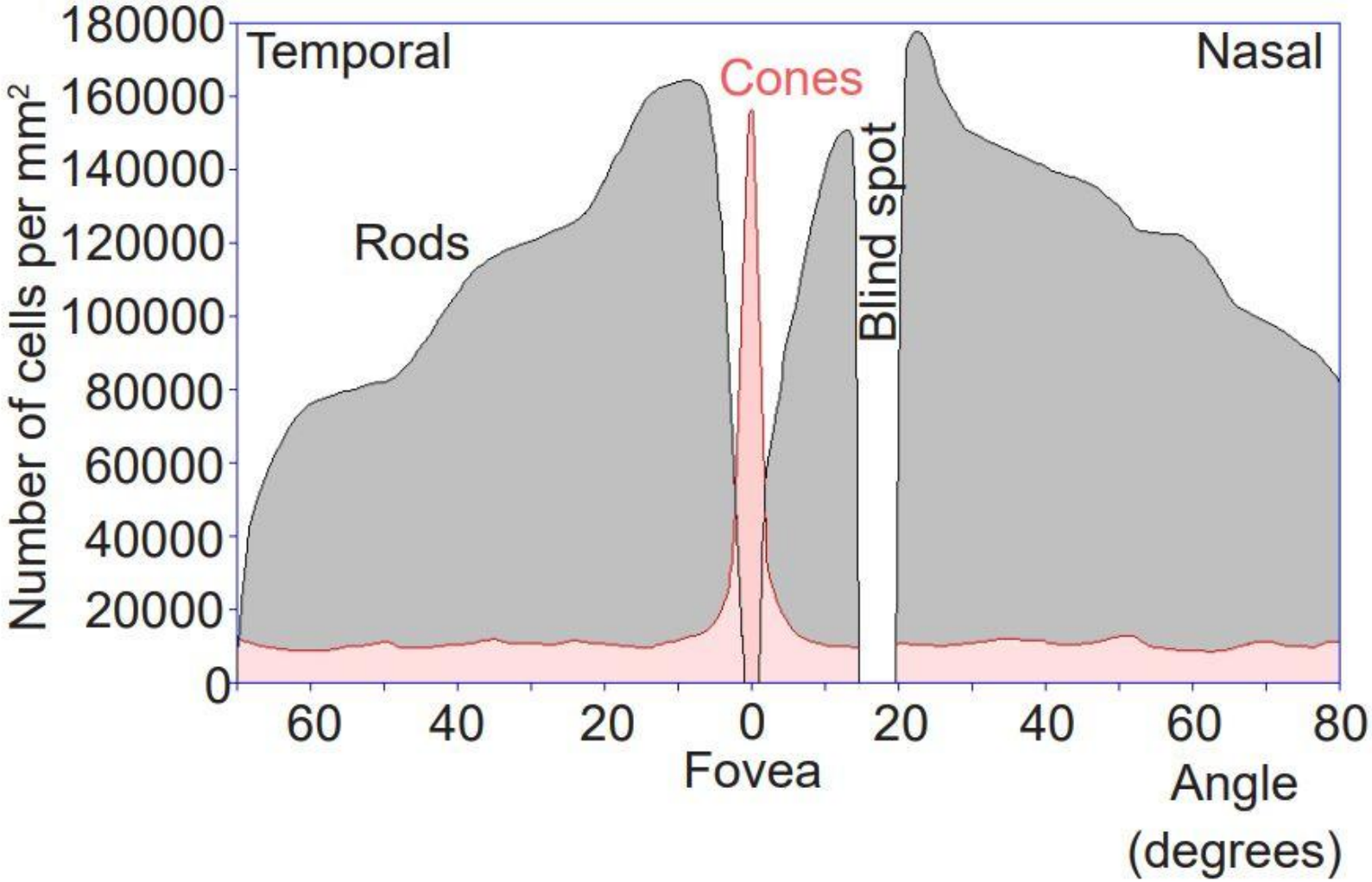


Figure 7.11 The cone photoreceptors are dense in the fovea, while the rod photoreceptors are mostly in the periphery.

Duplicity theory of vision

- Have two different cellular populations and circuits to perceive light
- Rods and cones are used simultaneously & complement each other
  - Photopic vision system uses cones, provides high-acuity sight and color in daytime
  - Scotopic vision is counterpart, uses rods, and allows us to see in low-light conditions

Read more

Clinical connection: color vision deficiency

- Dysfunction in cones photoreceptors
- Acquired (symptom of disease or side effect of exposure to certain chemicals) or inherited (more common; often recessive and located on X-chromosome)
- Sex-linked – more likely to occur in men (8%) than women (1%)

(green)
(red)
(violet)

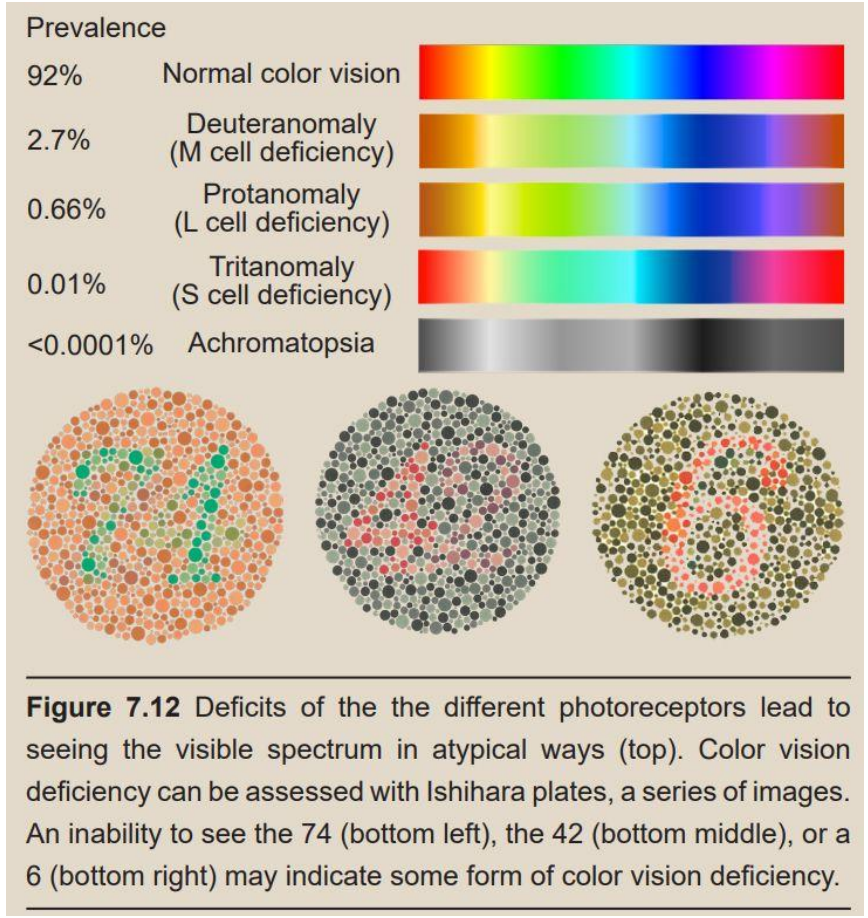


Figure 7.12 Deficits of the the different photoreceptors lead to seeing the visible spectrum in atypical ways (top). Color vision deficiency can be assessed with Ishihara plates, a series of images. An inability to see the 74 (bottom left), the 42 (bottom middle), or a 6 (bottom right) may indicate some form of color vision deficiency.

Videos

- https://www.youtube.com/watch?v=PXn8_bDGHMc
- https://www.youtube.com/watch?v=1D_nIlevdzc
- https://www.youtube.com/watch?v=jTEqoefv-pY
- https://www.youtube.com/watch?v=6o6RvlF504k
- https://www.youtube.com/watch?v=nmaNXVEL7Pw

Neuronal encoding of light

- Photoreceptors decrease in excitability when exposed to light (**counterintuitive**)
- They do not fire action potentials; rather, their membrane potential fluctuates
- Membrane potential determines amount of glutamate release
- Depolarization causes more glutamate release
- Hyperpolarization causes decrease in glutamate release
- In dark, leak sodium channels allow for extracellular sodium to enter neurons (dark current) - causing depolarization
- When photon strikes photoreceptor, cell decreases intracellular stores of cGMP, which in turn decreases the dark current
- Light causes neuron to become hyperpolarized and inhibits neurotransmitter release

Neuronal encoding continued

- Neurons sense light because of presence of photopigments in outer section
- Photopigment has 2 components: retinal & opsin
  - Retinal, synthesized from vitamin A, exists as 11-cis-retinal in the dark (low-energy molecular configuration); however, photon causes change to all-trans-retinal (high-energy configuration)
    - All-trans-retinal configuration triggers decrease in cGMP, blocking dark current, causing hyperpolarization
  - Opsin, a protein, exists in different forms
    - Opsins cause retinal to respond differently depending on wavelength of light

Video – more info than you need

Retinal & energy state

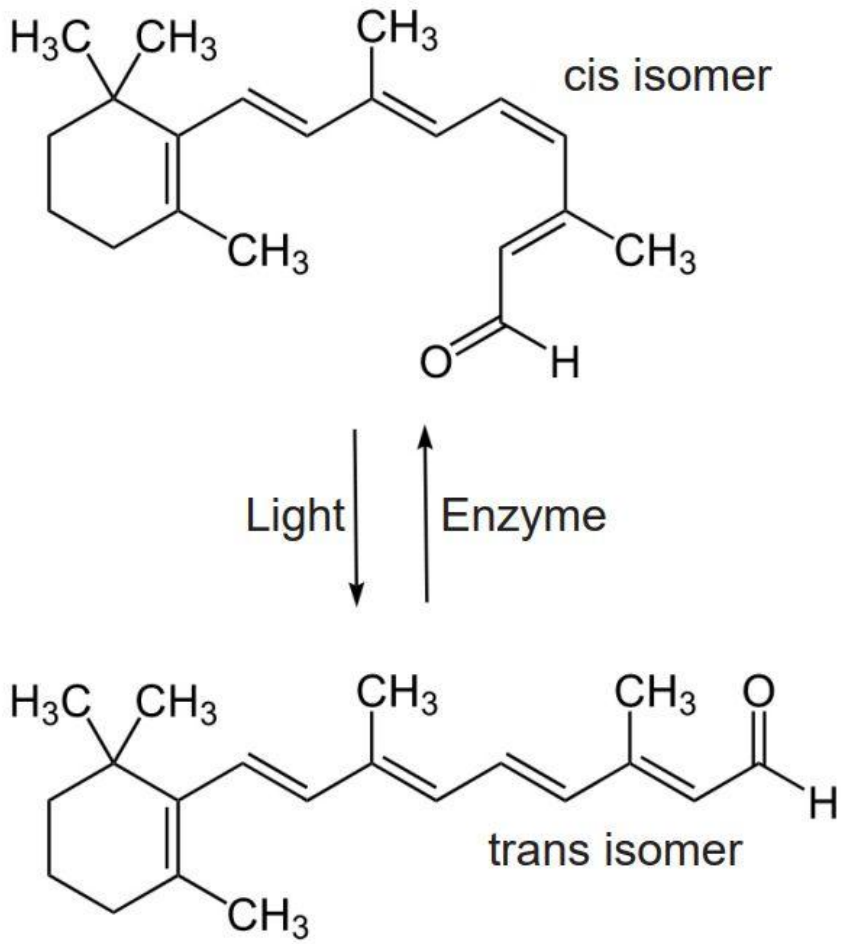


Figure 7.13 11-cis retinal can absorb a photon, causing retinal to enter the high energy state, 11-trans retinal.

Horizontal cells

- Interneurons that do not directly participate in pathway of signal in visual perception (lateral communication)
- Inhibitory
- Receive synaptic inputs from photoreceptors & form synaptic connections with axons of nearby photoreceptors
- Activation of a single photoreceptor inhibits adjacent photoreceptors, allowing us to isolate the origin of a light signal by minimizing noise around it

Hermann grid & lateral inhibition

- Lateral inhibition – horizontal cells, when activated, inhibit adjacent neurons at the same "level"
- Hypothesis: evolved to allow for edge detection, ability to differentiate outlines of objects
- Grey blobs disappear when you look at them because foveal photoreceptors are less susceptible to illusion (have very little convergence onto their bipolar cells)

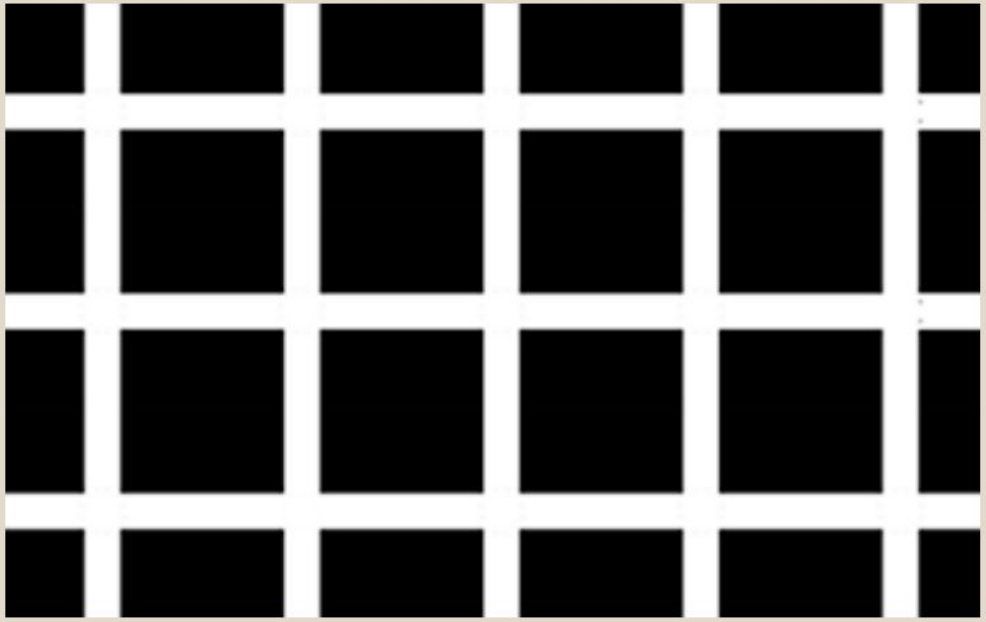


Figure 7.14 Gray blobs appear at the intersections of this Hermann grid because of lateral inhibition driven by horizontal cell activity.

Bipolar Cells

- "bipolar" - named because of morphology; project in two opposite directions
  - Review from cellular anatomy unit: What other morphologies of neurons are there?
- Dendrites receive information from photoreceptors (rod or cone, but not both) and axonal projections send information to amacrine and retinal ganglion cells
- Glutamate released by photoreceptor activates metabotropic mGluR6 receptors, which are inhibitory
- In light, decrease in glutamate release from photoreceptors; this leads to increase in bipolar cell activity

Amacrine cells

- Interneurons that are not directly involved in light sensation (like horizontal cells)
- Modulate the activity of nearby neurons
- Synthesize and release inhibitory neurotransmitter GABA
- Help us detect directional motion, which helps us know when to transition between scotopic or photopic vision systems
- Some also perform circadian regulatory functions

Retinal ganglion cells

- Receive input from bipolar cells
- Retinal ganglion cells' axons bundle together and form optic nerve which exits through optic disk – unmyelinated at this part of axon
- Communicate via action potentials
- Most receive information from photoreceptors and bipolar cells; however, a small number (1-2%) are photosensitive
- Those that are photosensitive contain melanopsin & contribute to our ability to adjust circadian rhythms based on external light cues

Rationale for visual acuity at fovea

1. Neurons are swept away from center of fovea
   - Cell bodies are made up mostly of lipids, which distort the passage of light
   - Fewer cells are present here
   - Photons of light that reach fovea are not refracted by presence of other neurons
2. Mostly cones present - Little to no converging signals at fovea, allowing pinpointing of location of incoming light

Blind spot

- Elliptical (1.9 mm vertical by 1.75 mm horizontal)
- Optic disk where optic nerve exits the eye
- Absence of photoreceptors
- ~15 degrees temporal from the fovea
- Only comes into effect when monocular vision is used
- "filling in" the blind spot with adjacent visual stimuli

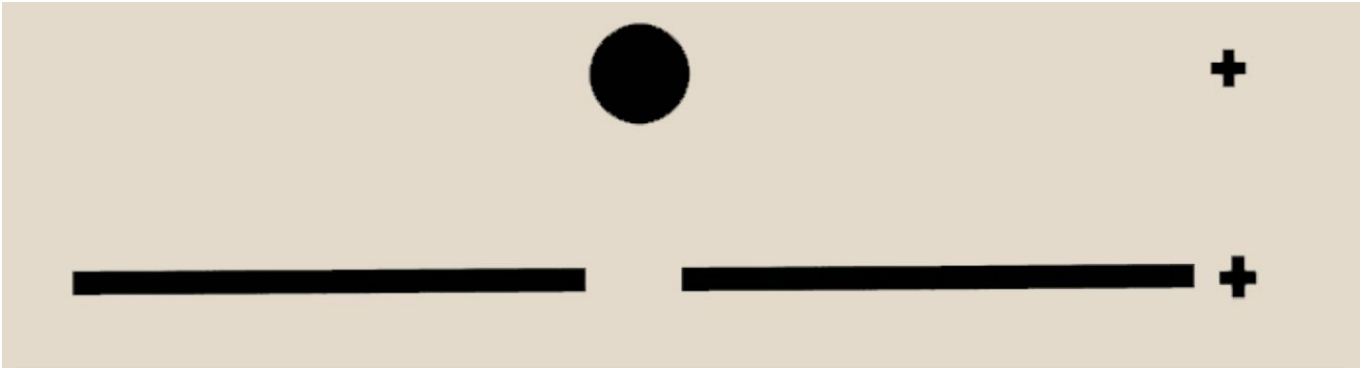


Figure 7.15 The blind spot can be observed in monocular vision with stimuli like these.

The optic nerve

- Optic nerve = CNII (paired)
- Each nerve exits posterior end of eyeball and merges at the optic chiasm before diverging again as they travel posteriorly to thalamus

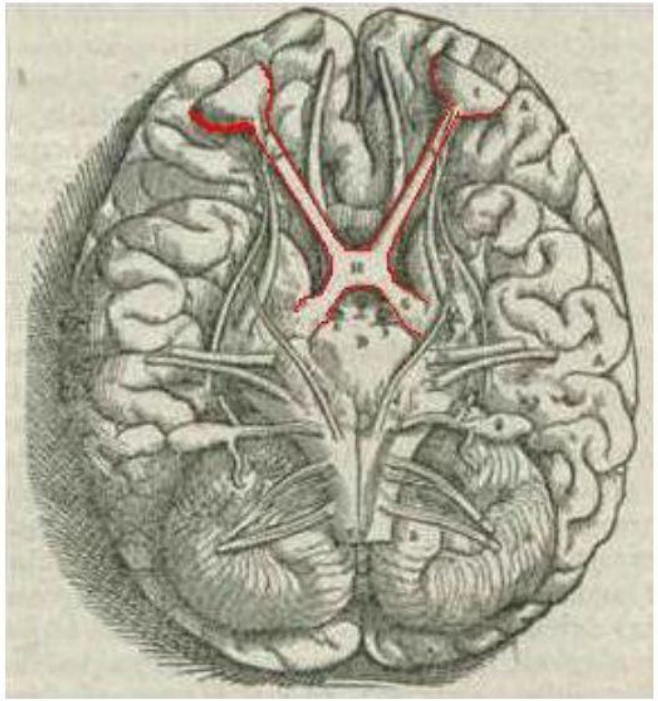


Figure 7.16 Cranial nerve II, or the optic nerve (highlighted in red), exits each of the eyeballs and meet at the optic chiasm before diverging.

Axonal projections of optic nerve

- Axons from the nasal hemiretina cross the midline and head towards contralateral hemisphere of brain
- Temporal hemiretina fibers meet at chiasm and project to ipsilateral hemisphere
- All information from left visual field enters right hemisphere, while all info from right field enters left hemisphere
- Because of lens reflecting light, objects in left visual field are represented on right half of each eyeball

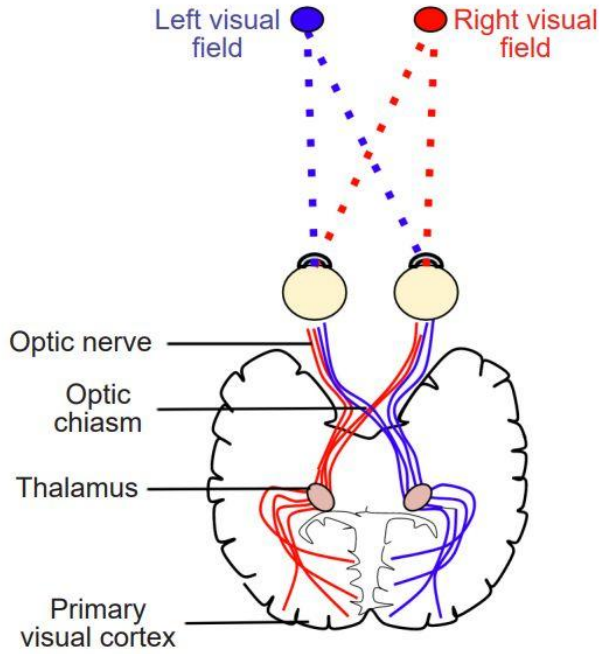


Figure 7.17 Visual information from the left visual field (blue) is carried into the right hemisphere of the brain, and visual information from the right visual field (red) is carried into the left hemisphere.

Signaling pathways of optic nerve axons

- To the thalamus
- To the midbrain pretectal area
  - Primitive functions
  - Ex. Ability for the eyes to follow something unconsciously as it moves across field of view
    - Called smooth pursuit (a reflex)
- To the retinohypothalamic tract (RHT)
  - Does not carry conscious visual information
  - Conducts light information from retinal ganglion cells
  - Forms a synapse with suprachiasmatic nucleus (SCN)
  - SCN helps body adapt its sleep-wake cycle as day-night patterns change

Clinical correlation: Glaucoma

- Condition that causes optic nerve destruction
- Affects more than 250 000 Canadians[1]
- Easily detected by annual exam
- Causes: High intraocular pressure, physical trauma, medications, or genetics
- High intraocular pressure is greatest risk factor; hypertension compresses axons, decreasing blood flow to optic nerve
- Treatment: decrease pressure

[1]https://www.cnib.ca/en/sight-loss-infoyour-eyeseye-diseases/glaucoma?region=on

Visual perception in the brain

- First synapse is formed in thalamus, at lateral geniculate nucleus (LGN)
  - Geniculate = bend
  - Latin geniculum, "knee”
  - Another brain region with similar name?
- LGN is divided into 6 layers (ventral to dorsal)
- LGN has 3 different types of neurons
  1. Magnocellular cells (M cells; large-diameter; ~20 μm)
  2. Parvocellular cells (P cells; small-diameter; ~10 μm);
  3. Koniocellular cells (K cells; konio means dust)
- Synaptic inputs to LGN follow a specific organization depending on the origin of the retinal ganglion neurons
  - Temporal retinal ganglion neurons synapse on layers 2,3, and 5 of ipsilateral LGN
  - Nasal retinal ganglion neurons synapse on contralateral layers 1, 4, and 6

Synaptic input at LGN

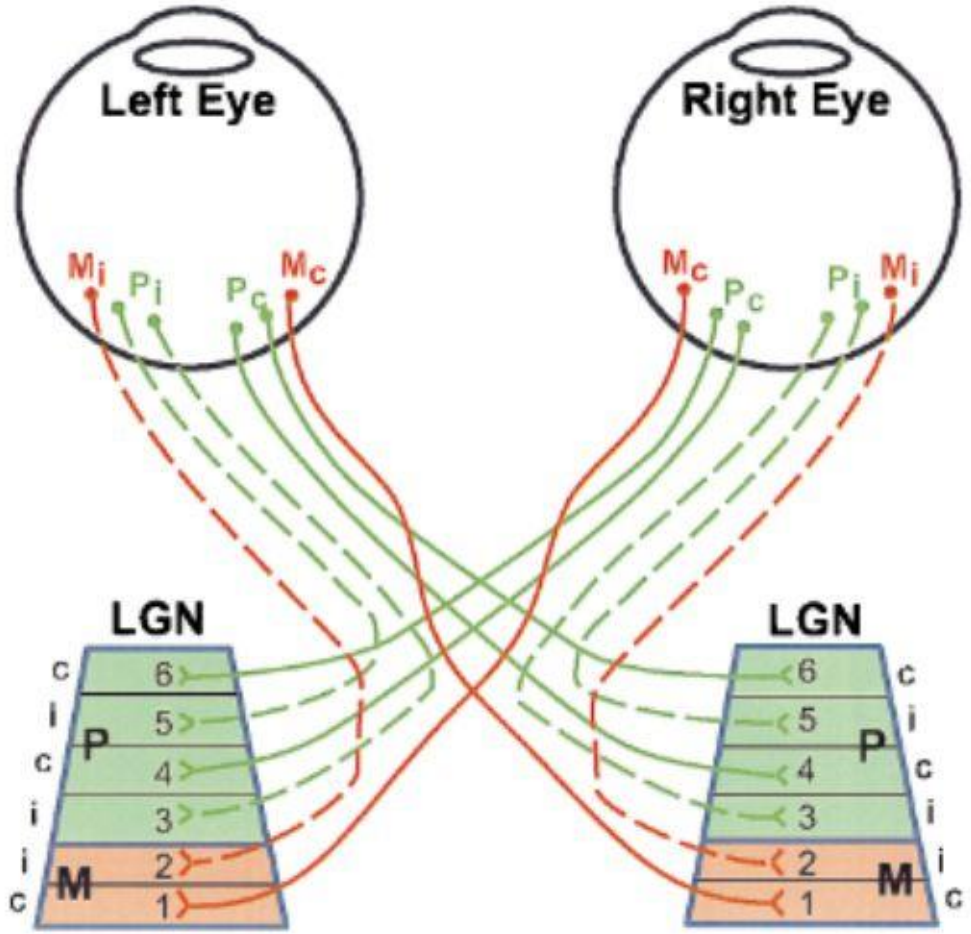


Figure 7.18 Synaptic circuitry showing the inputs into the layers of the lateral geniculate nucleus of the thalamus.

Clinical connections: Anatomy of vision loss

- Health care professionals can diagnose location of an injury based on specific deficits in visual field
- Hemianopsia = loss of half of visual field
- Quadrantanopsia = loss of a fourth, or one quadrant, of visual field

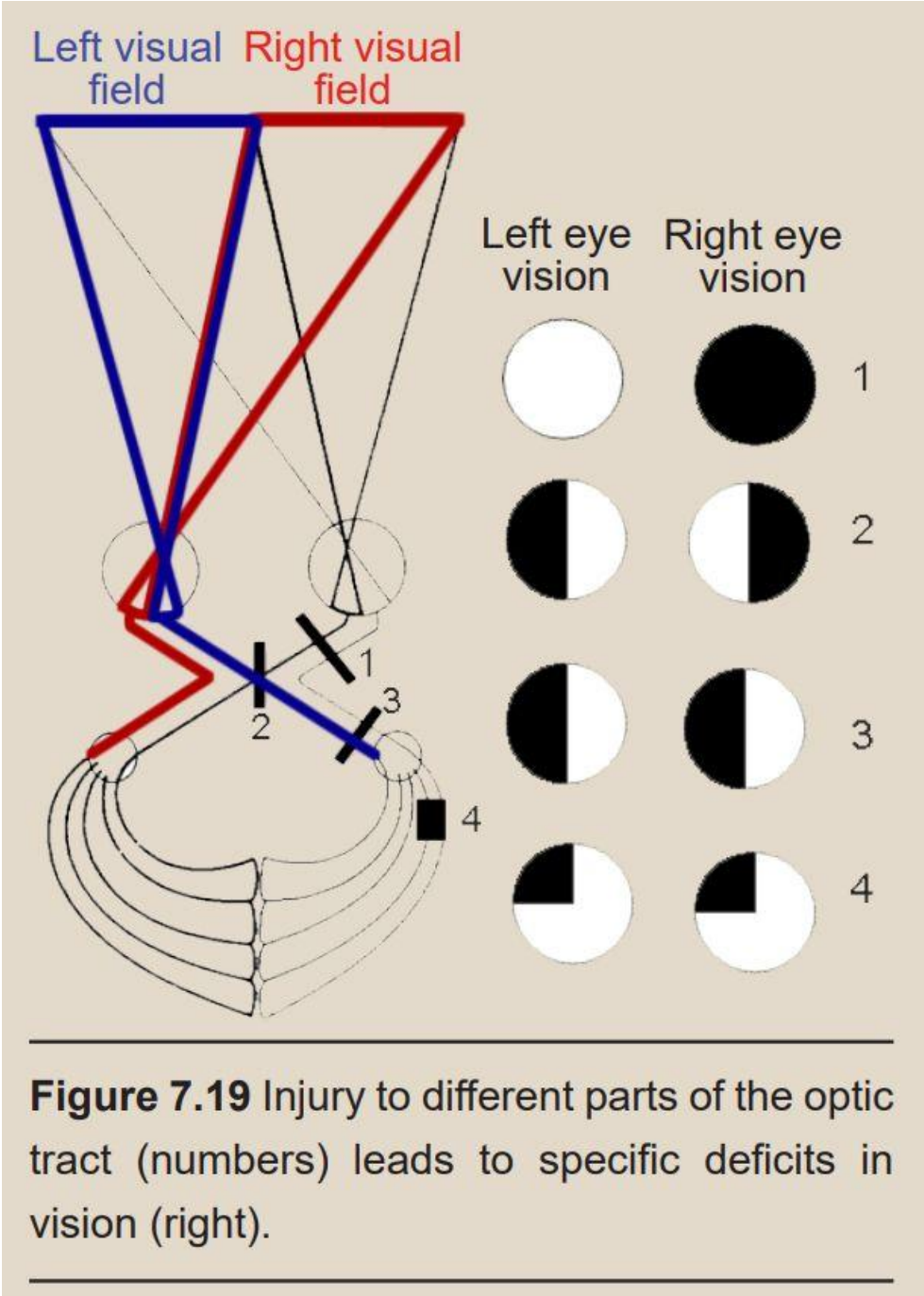


Figure 7.19 Injury to different parts of the optic tract (numbers) leads to specific deficits in vision (right).

LGN outputs

- Series of axonal bundles called optic radiations
- Divided into two main bundles: upper and lower
- Upper divisions carry information from lower visual field, while lower divisions carry information from upper visual field
- Optic radiations project to occipital lobe
- Process then becomes about perception, rather than sensation
- No single area is responsible for any one compartmentalized function
- Precise function of some areas of visual cortex are yet to be understood

Visual cortices

- Primary visual cortex (V1; AKA striate cortex)
- Large white stripe seen in dissection; bundle of incoming optic tract axons which are heavily myelinated
- Each neuron in V1 receives visual information from a specific patch of retinal cells

Retinotopic organization of visual field

- Each neuron in V1 receives visual information from a specific patch of retinal cells

- Notice: visual information from fovea (representing only 1% of total visual field) takes up about half of all neurons in V1

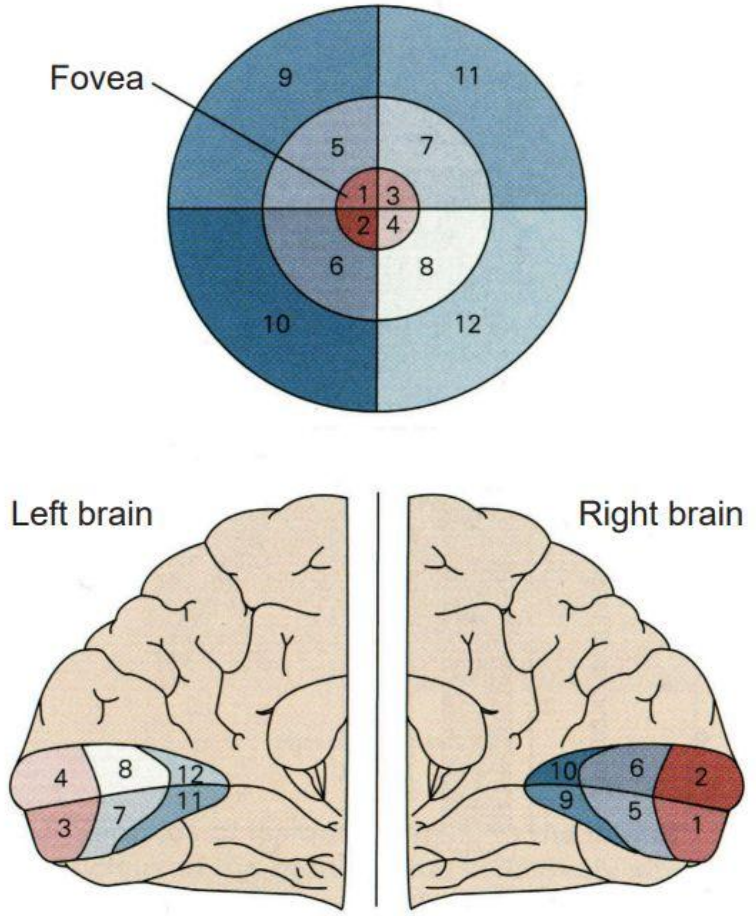


Figure 7.20 Retinotopic organization of the visual field. Note that adjacent areas of the visual field are represented in adjacent areas of the cortex, and that the visual information in the fovea is represented very heavily in the cortex.

Visual cortices continued

- After processing in V1, information is passed to secondary visual cortex (V2)
- Beginning of visual association cortices
- V3 and V5 help us comprehend motion
- V4 contributes to color perception
- V6 helps with understanding our position in our surroundings
- •A visual of these cortices

Overview

- 10-Minute Neuroscience covering visual pathway

Dual stream hypothesis

- After V2, visual information passes through 2 streams:
  1. Dorsal stream – the "where" pathway; contributes to perception of motion and sense of spatial awareness
  2. Ventral stream – the "what" pathway; helps identify objects we see; has structures important to visual memory
     - Fusiform face area (FFA) and parahippocampal place area (PPA)
- Not independent of each other

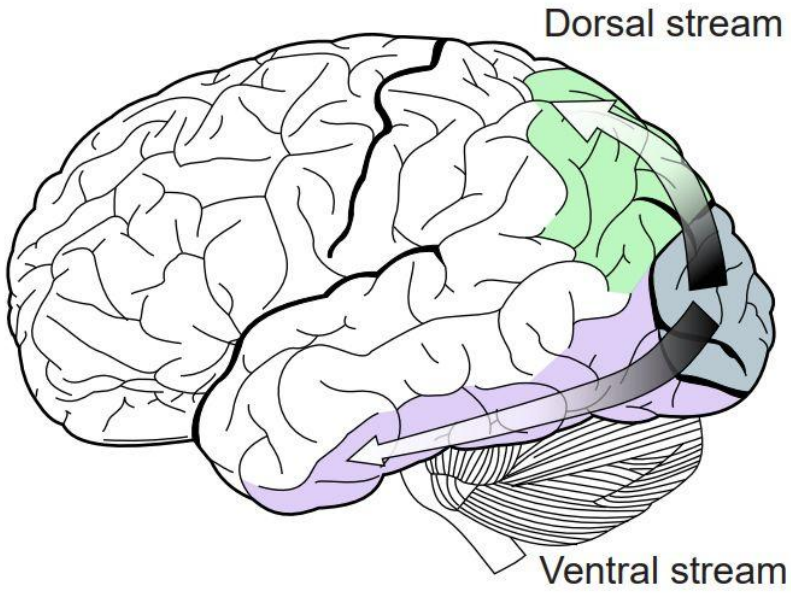


Figure 7.21 The dual stream hypothesis proposes that visual information is processed by two related neural pathways after leaving V2, a dorsal stream (green) and a ventral stream (purple).

Clinical Connection: Dysfunction of Dual Stream

- Unusual visual perception disorders from atypical neural communication
- Akinetopsia (motion blindness)
  - Inability to perceive objects in motion
  - Instead, see world as a series of “freeze frames” that refresh occasionally or whenever the object stops moving
  - Very rare
  - Usually a result of brain injury (stroke or trauma)
- Prosopagnosia (face blindness)
  - See eyes, nose, and mouth (know it’s a face), but not sure to whom they belong
  - Sometimes cannot recognize self in mirror
  - More common than akinetopsia; ~1% of people have some degree (estimate)

Saccadic eye movements

- As focus is shifted, eyes make tiny, rapid, jerking motions over the different objects
- Rapid movements, driven by extraocular muscles, are called saccades
- Can scan several objects with fovea (for high acuity) and allow brain to build a representation of visual field

Figure 7.22 Eye tracking (right) allows us to observe the saccades that may happen when we scan over this facial stimulus (eye).