# Neuroanatomy: Visual System – Eye Functional Anatomy and Vision Pathways

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# • Session Objectives

1. Students will be able to describe the neural, muscular and vascular anatomy of the eye.
2. Students will be able to describe neural processing within the eye.
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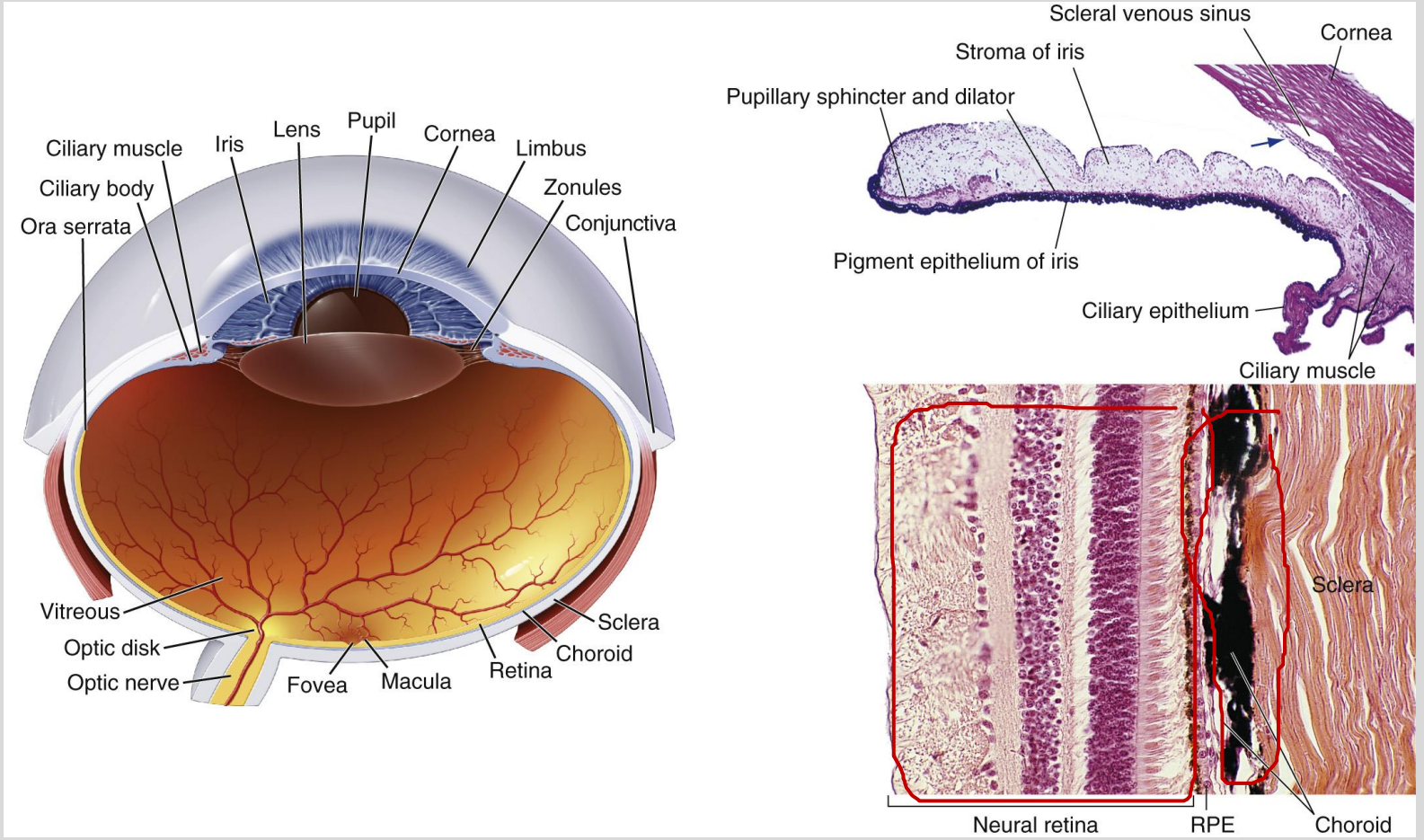
# • Eye has three concentric tissue layers and a lens

- Sclera
  - Cornea (transparent)
  - Sclera
- Choroid
  - Vascular layer
  - Ciliary Body
  - Iris
- Retina

  1) Retinal pigment epithelium (RPE)

  2) Neural retina (photoreceptors)

  - Anterior chamber: space from the iris to the cornea.
  - Posterior chamber: from the iris to the lens
  - The anterior and posterior chambers are filled with aqueous humor.

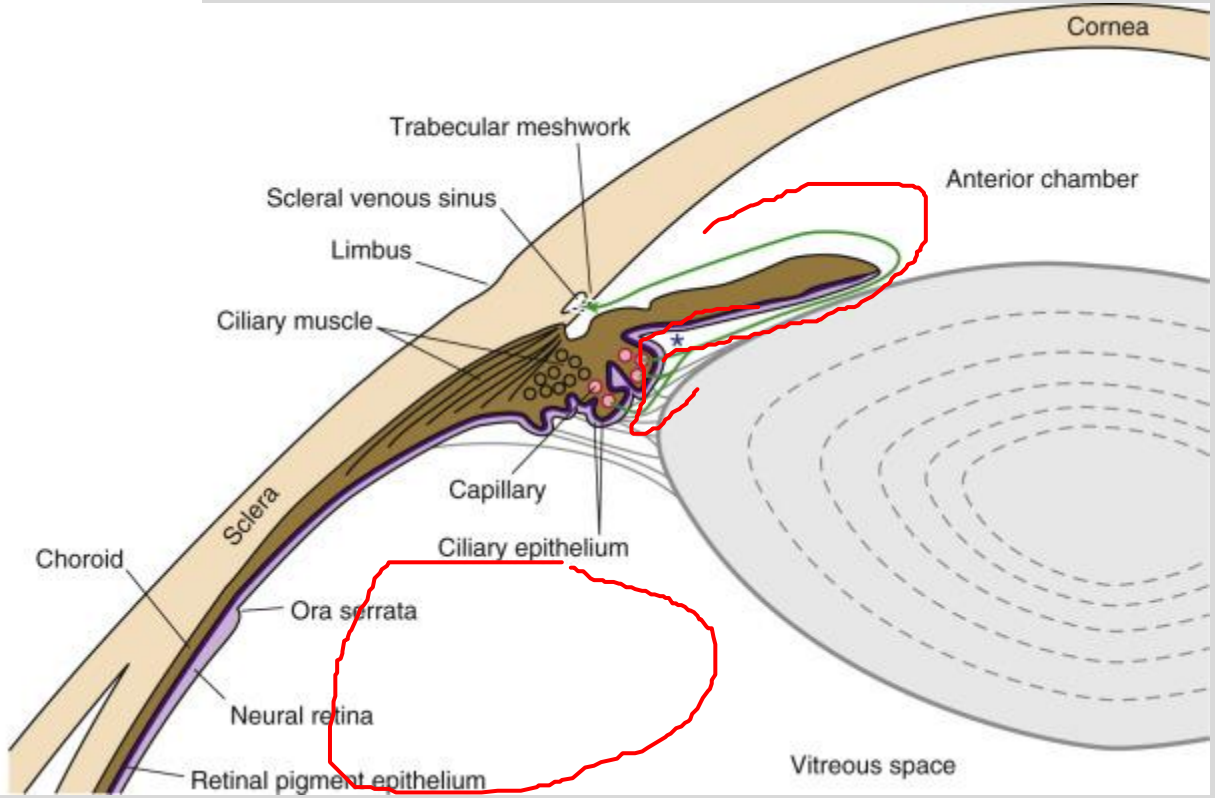



Separation between the RPE and neural retina compromises blood supply to the nerve cells resulting in neural death and blindness ( retinal detachment)

- Nolte's The Human Brain

# • Intraocular Pressure Maintains Shape of the Eye






- If eye were not rigid then lens would not be able to focus light onto the retina
- Ciliary Body secretes aqueous humor into the posterior chamber
- Aqueous humor flows from the Posterior Chamber → Anterior Chamber → Trabecular meshwork ( similar to arachnoid granulations) at the iridocorneal angle, and enters an endothelium-lined scleral venous sinus (the canal of Schlemm ), which communicates directly with the venous drainage of the eye.
- Vitreous humor is filled with a gelatinous material, so pressure in anterior eye is transmitted to rest of eye

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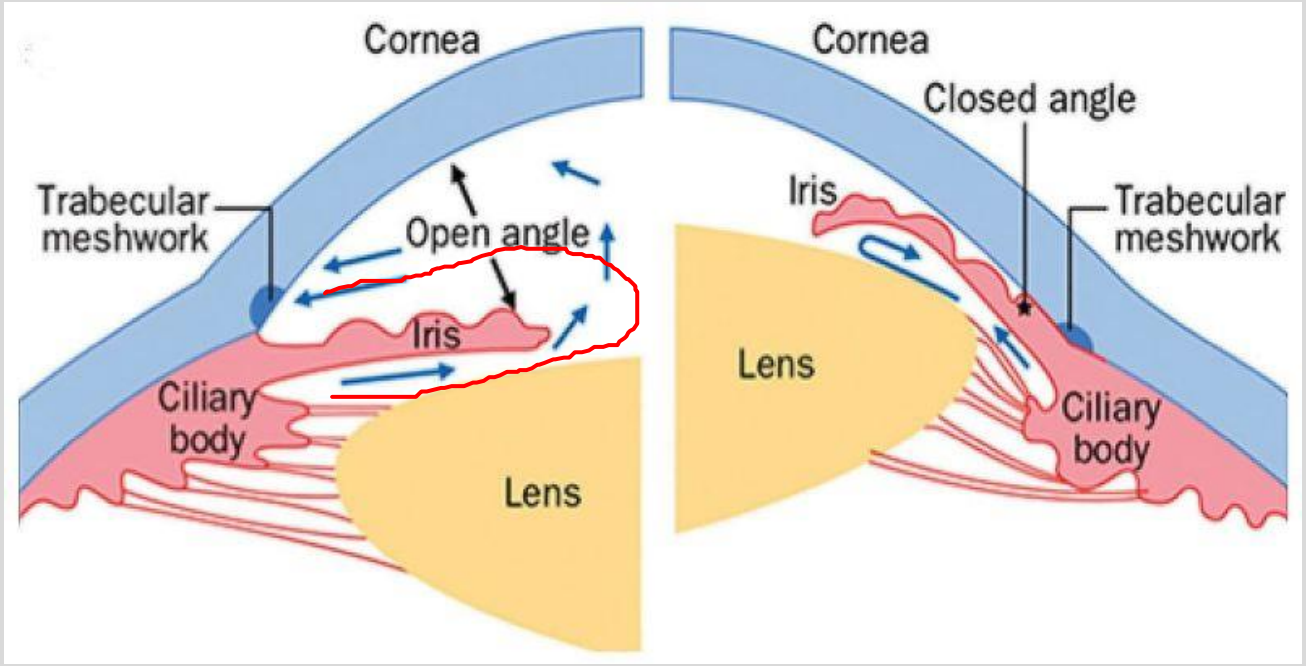
- Increased intraocular Pressure: glaucoma

**Open-angle glaucoma** **Closed-angle glaucoma**




**Open-angle glaucoma:** produced by slow draining through the meshwork (chronic condition).
**Closed-angle glaucoma:** which occurs when the iris mechanically blocks the drainage angle formed by the cornea and iris, blocking the trabecular meshwork (medical emergency).

- Redness in the affected eye
- Nausea
- Headache associated with blurred vision

- https://www.ncbi.nlm.nih.gov/books/NBK543075/figure/diseases_glaucoma.F7B/

# Cornea and Lens Focus images on the retina

- Focusing an image requires refraction of light across one or more interfaces where there is a change in refractive index
- Aqueous and Vitreous humor refractive indexes are only slight lower than refractive index of lens (so not much change)
- Most of the eyes refractive ability is at the air-water interface at the surface of the cornea

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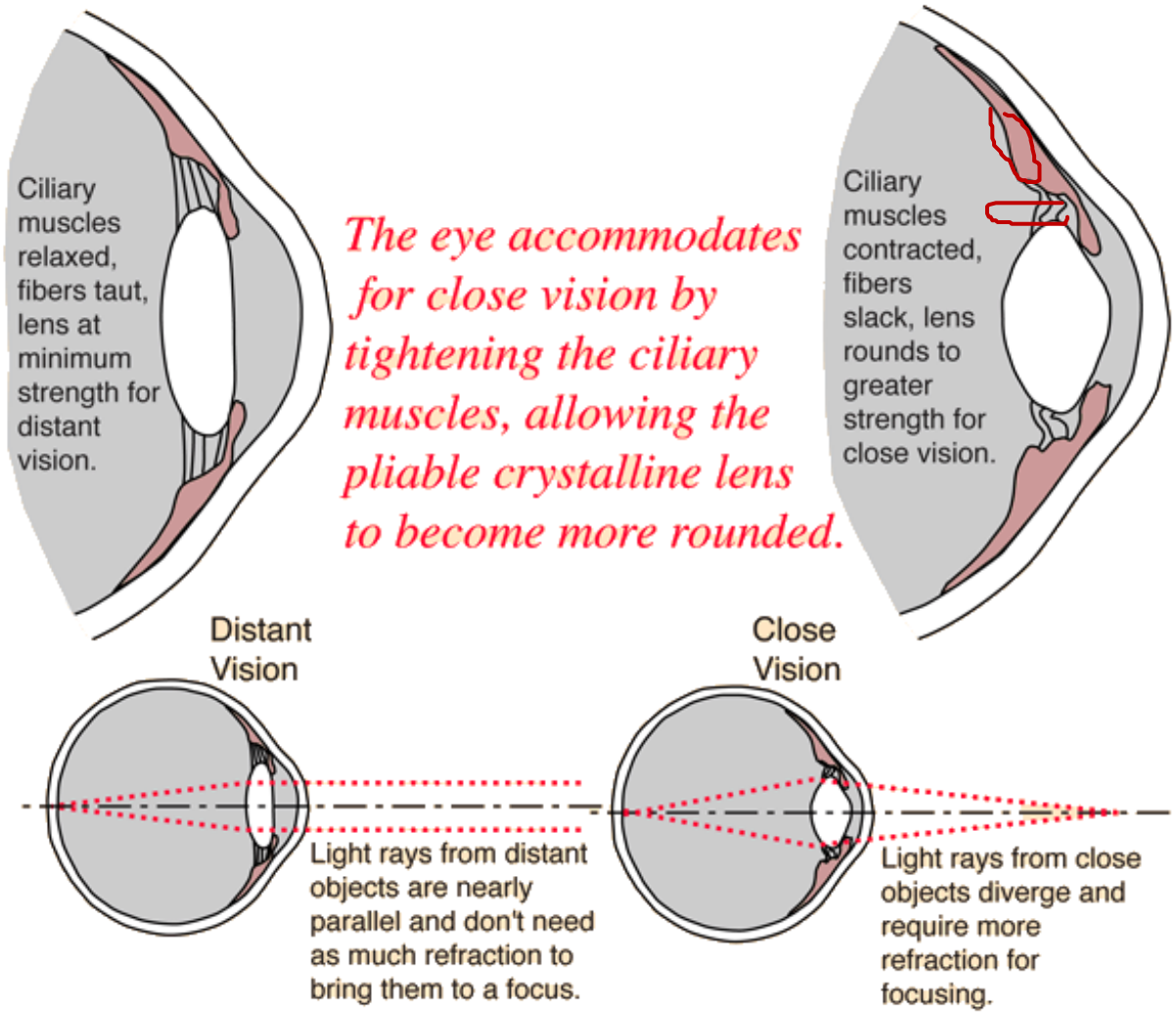
# Accommodation



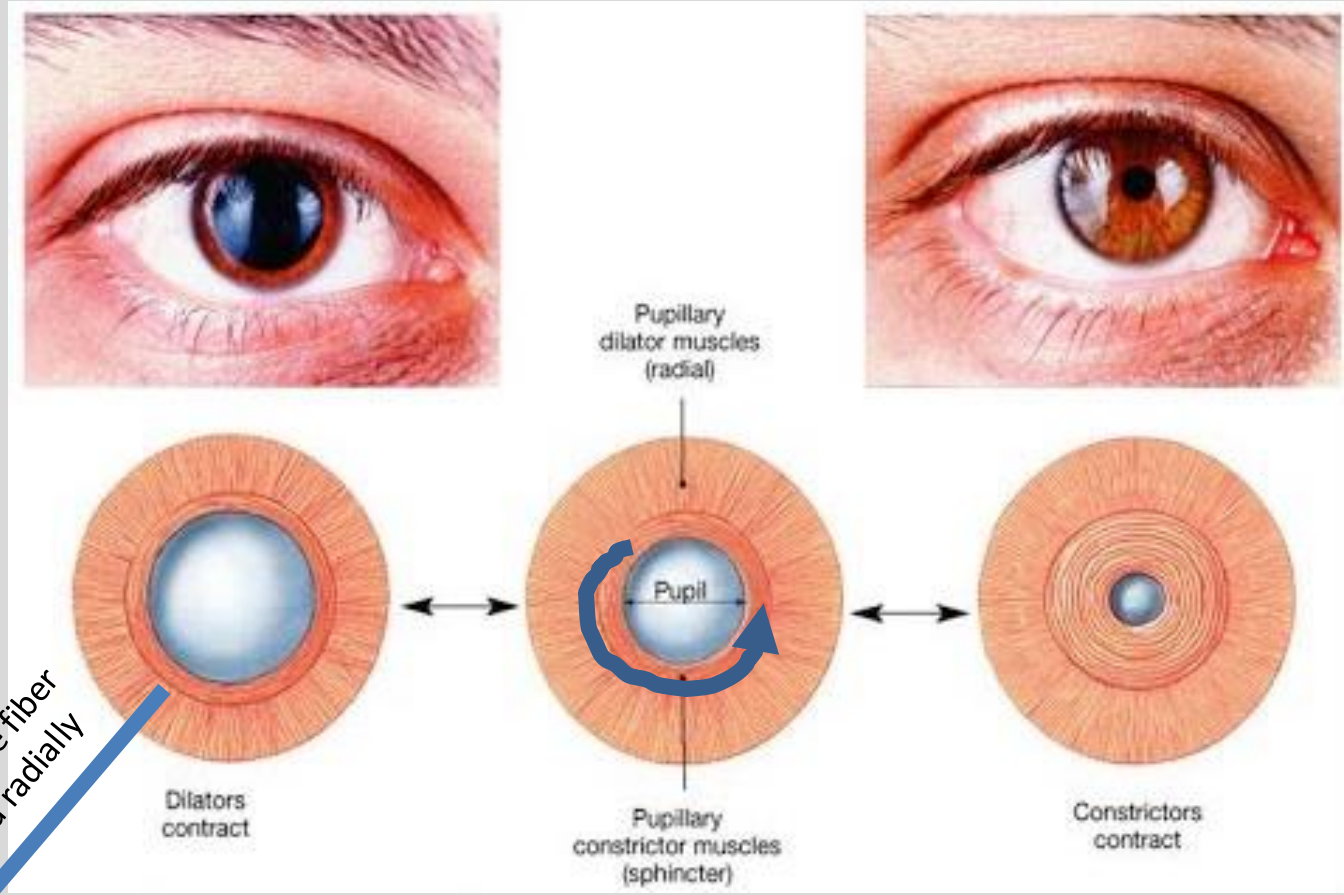

- Ciliary muscle contraction = Relaxed zonule fibers = rounder lens

- Iris affects brightness and quality

- Pupil – aperture in the middle of the iris
- Constriction = Parasympathetic control
- Dilation = Sympathetic control
- Smaller pupil

  pro: larger depth of field

  con: less light enter the eye




Circumferentially arranged muscle fibers in pupillary sphincter

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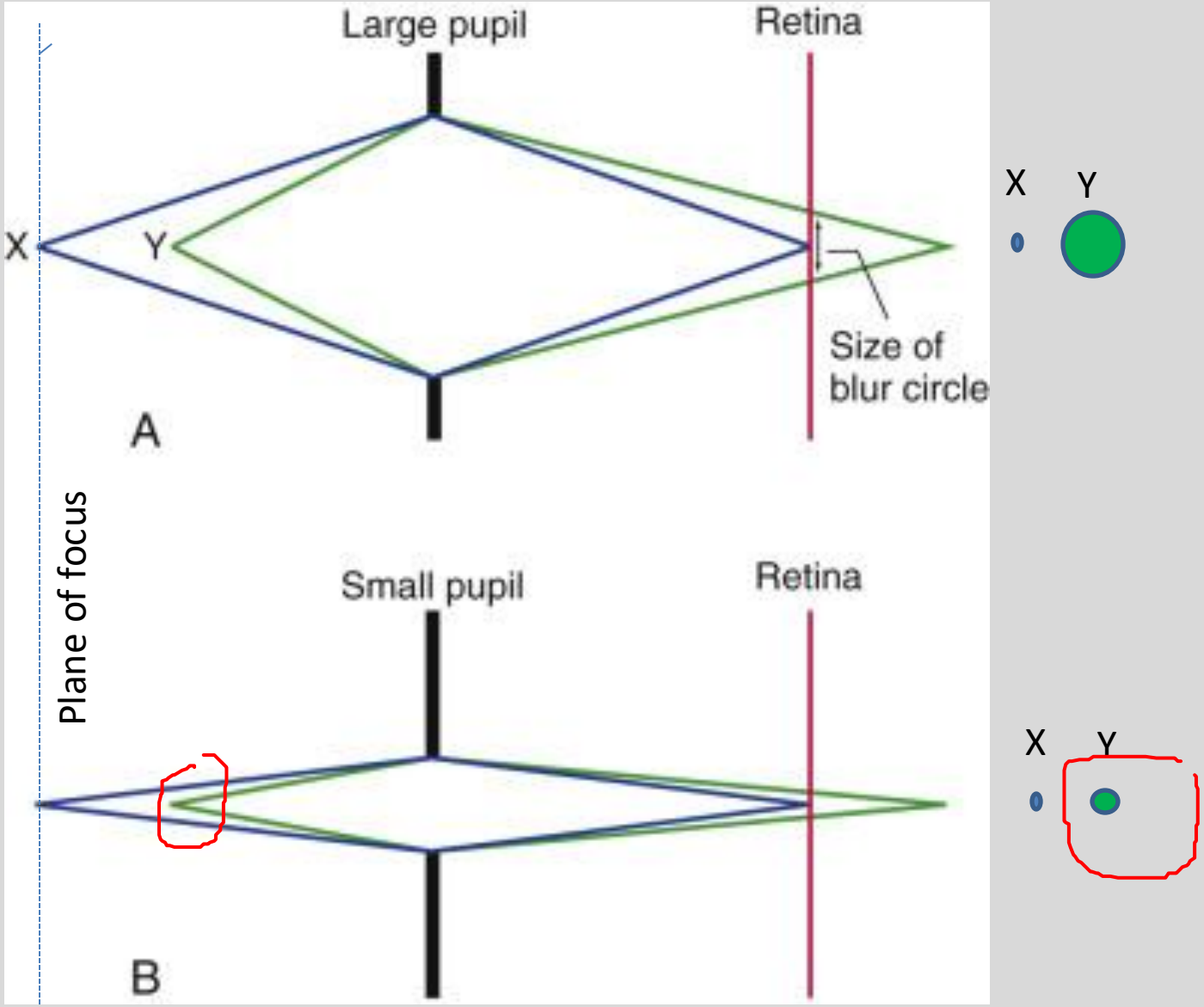
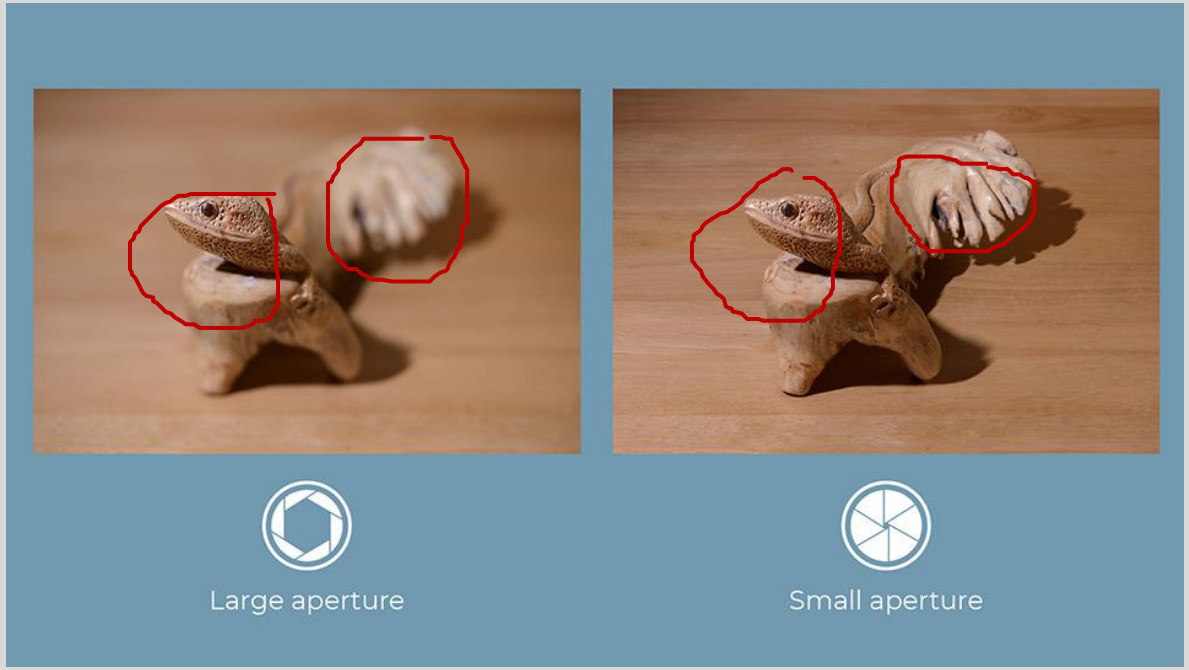
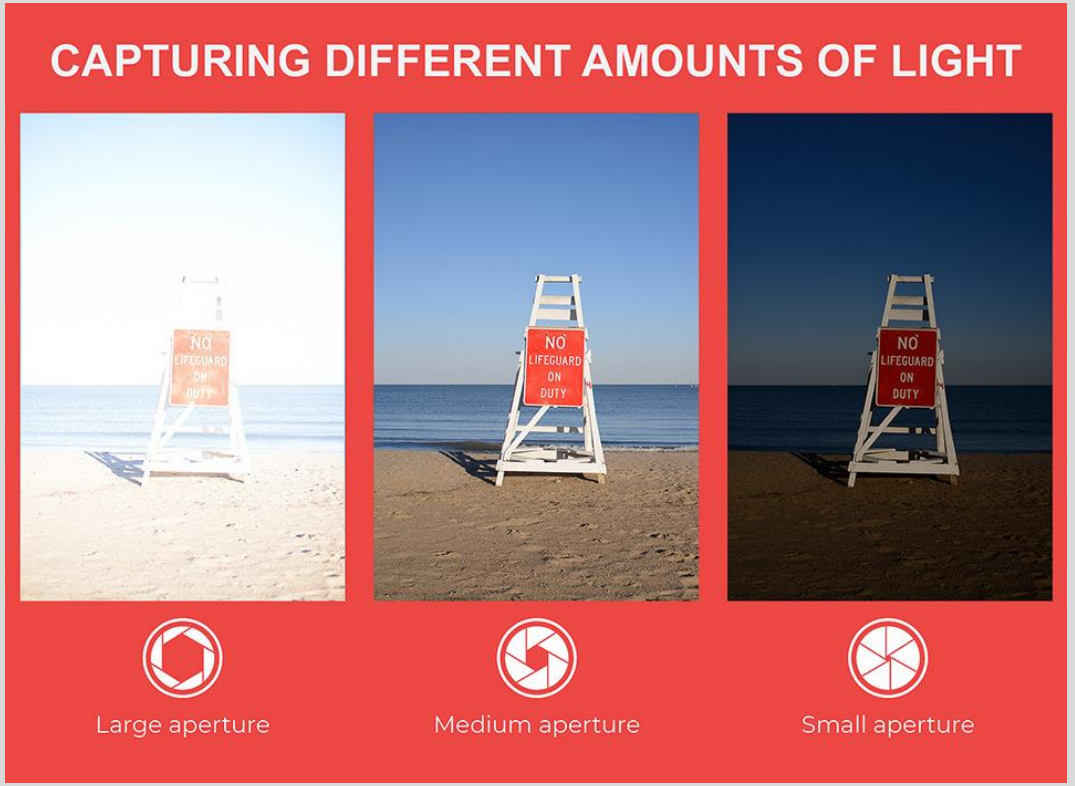
- Pupil contraction and depth of field of view

Pupil contraction causes that objects that are not in the focal plane become less blurred in the image at the retina



- Iris plays the same role in photography as the aperture




- https://photographylife.com/what-is-aperture-in-photography

- Near Reflex

- When focusing on a nearby object three things happen in a reflex manner
  1. Convergence of two eyes
  2. Contraction of ciliary muscles (lens accommodation)
  3. Pupillary contraction (larger depth of field of view)
- Cortex & Cerebellum play important role in reflex

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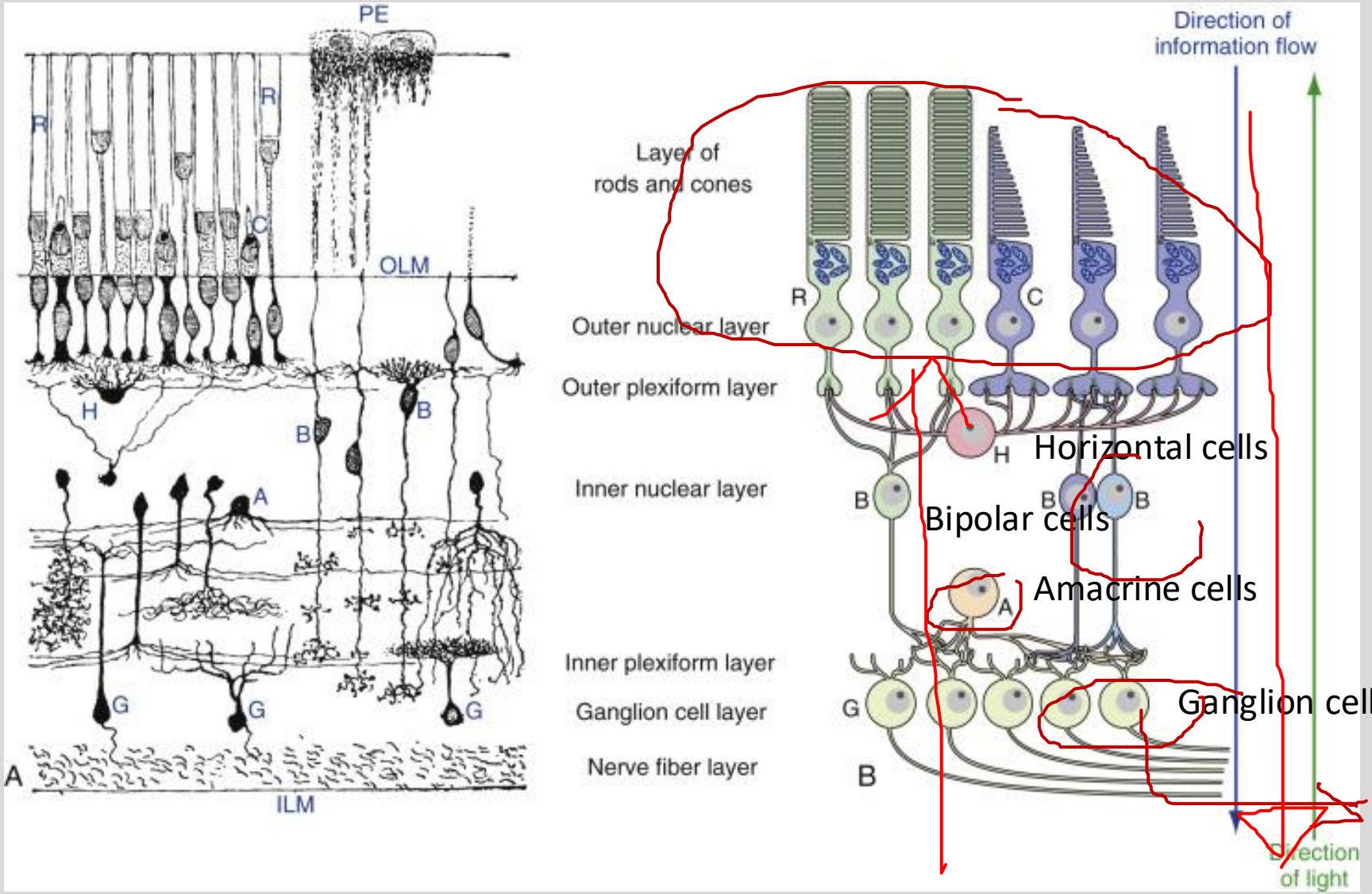
# Structure of the neural retina



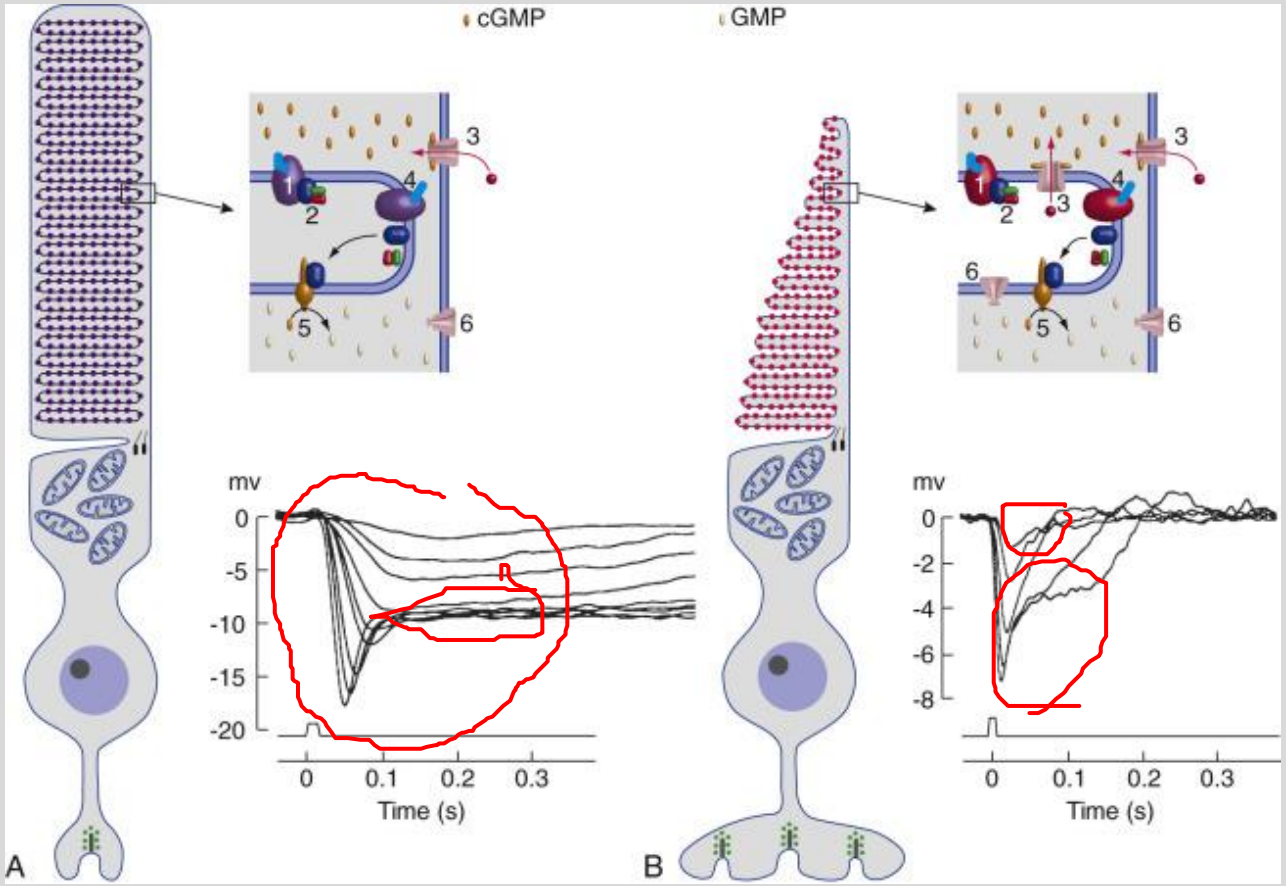

Information flows from photoreceptors ->bipolar cells ->ganglion cells which are the output cells of the retina

Amacrine cells and horizontal cells combine information across multiple photoreceptors and modify the information flow

# Photoreceptors: rods and cones

Rods

Cones




- Photoreceptor cells have large membranes, which give them their name. Rods have larger membranes, therefore they are more sensitive to light.
- Different opsins in rods and cones: rhodopsin → rods, cone pigments -> in cones
- The opsins binds to 11- *cis* retinal.
- Light isomerizes 11- *cis* retinal to all- *trans* retinal that is bound to the opsin.
- The light induced isomerization of the retinal causes a conformational change in the opsin.
- This activates transducin, which in turn activates an enzyme (phosphodiesterase) that hydrolyzes cGMP.
- Decreased availability of cGMP causes the cGMP-gated cation channels to close. Cells hyperpolarize
- Photoreceptor *reduce* neurotransmitter release in response to light
- Rods are more sensitive but saturate
- Cones are less sensitive but do not saturate

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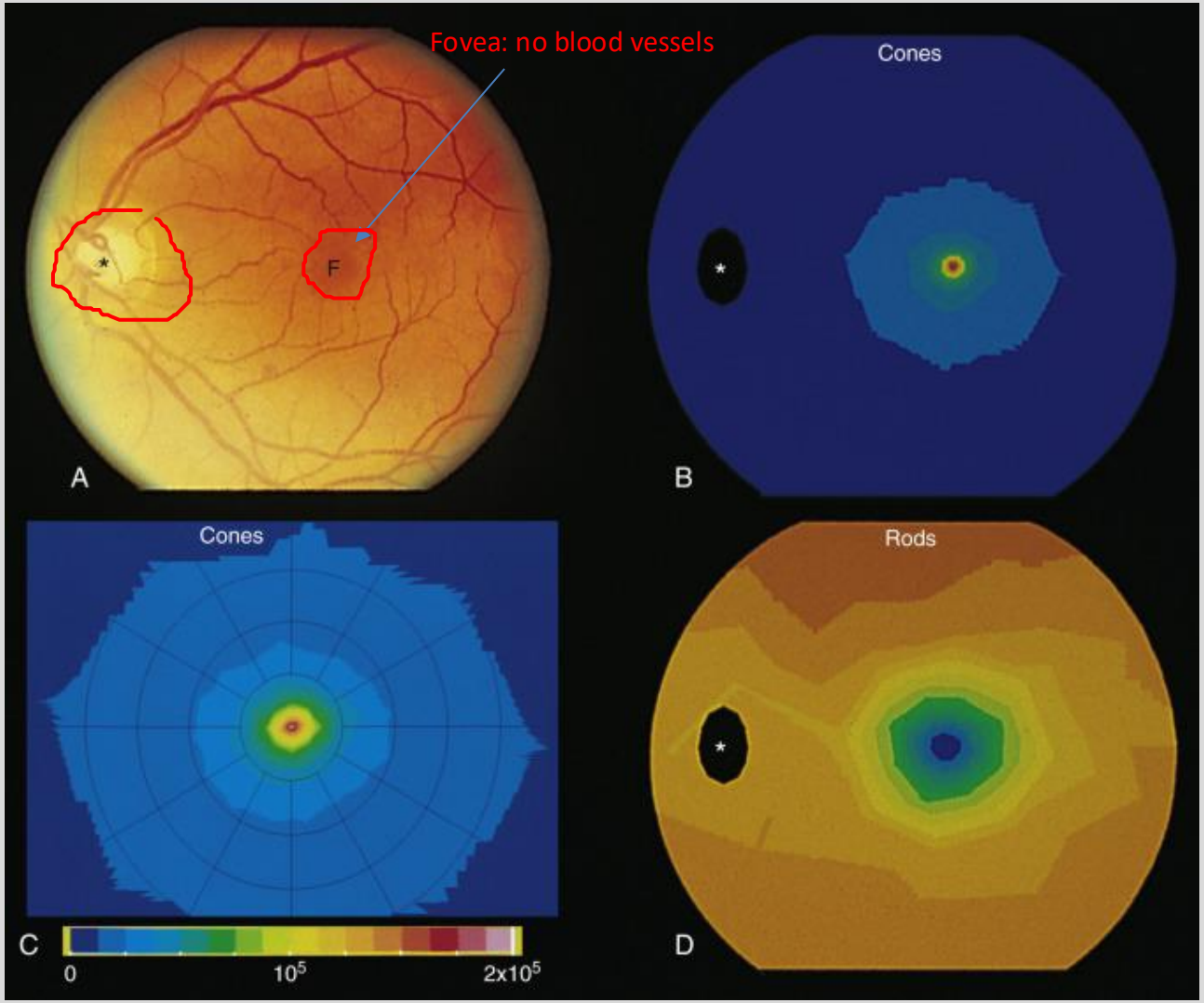
# The retina is not uniform



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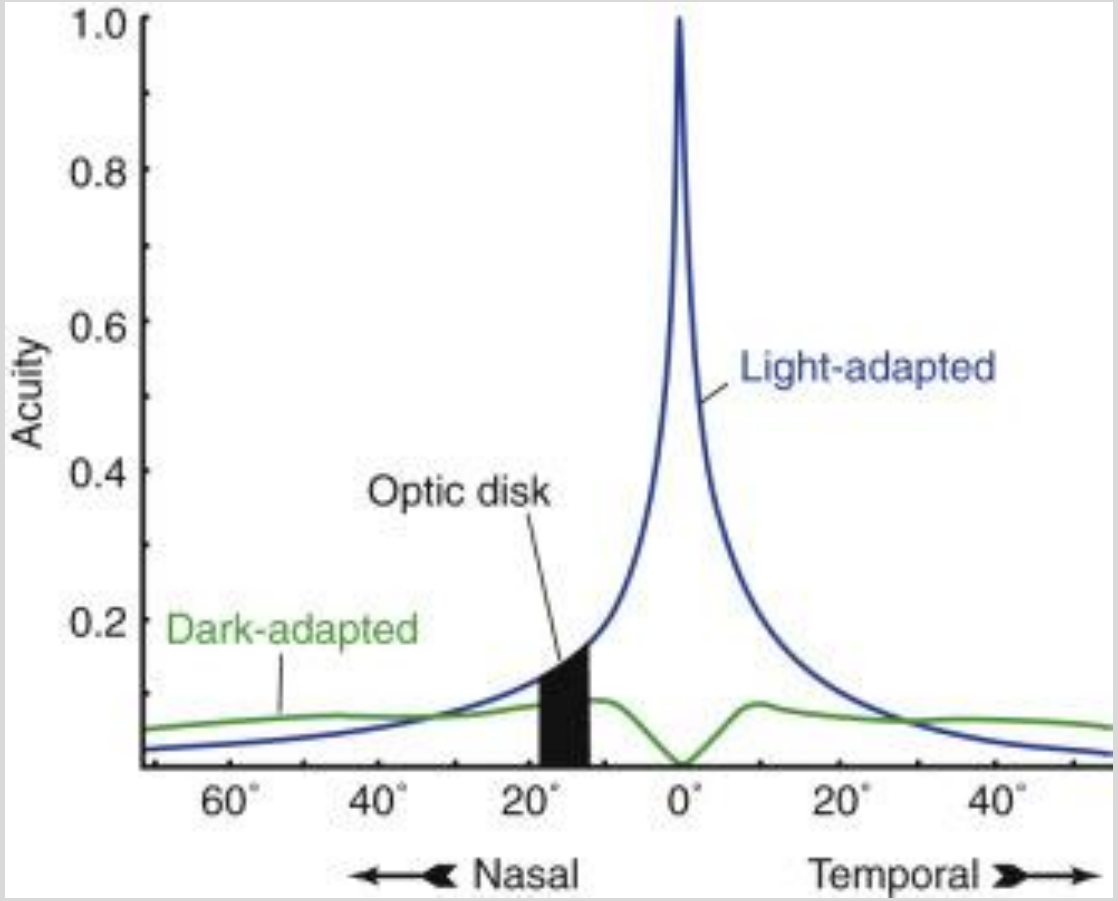
- Funduscopic view of the left retina.
- Arteries and veins emerge from the optic disk
- High concentration of cones in the fovea (color, high acuity vision, panel A, f)
- High concentration of rods outside the fovea

# Retinal Zones

- Near the edge of the optic disk is a circular portion of the retina about 5mm in diameter → **Macula Lutea**
- The center of the macula is a depression called the **fovea** which is particularly rich in cones → color vision
- The central fovea is specialized for vision of the highest acuity: all the neurons and capillaries are present elsewhere.
- Periphery → cones and rods (B&W + color)

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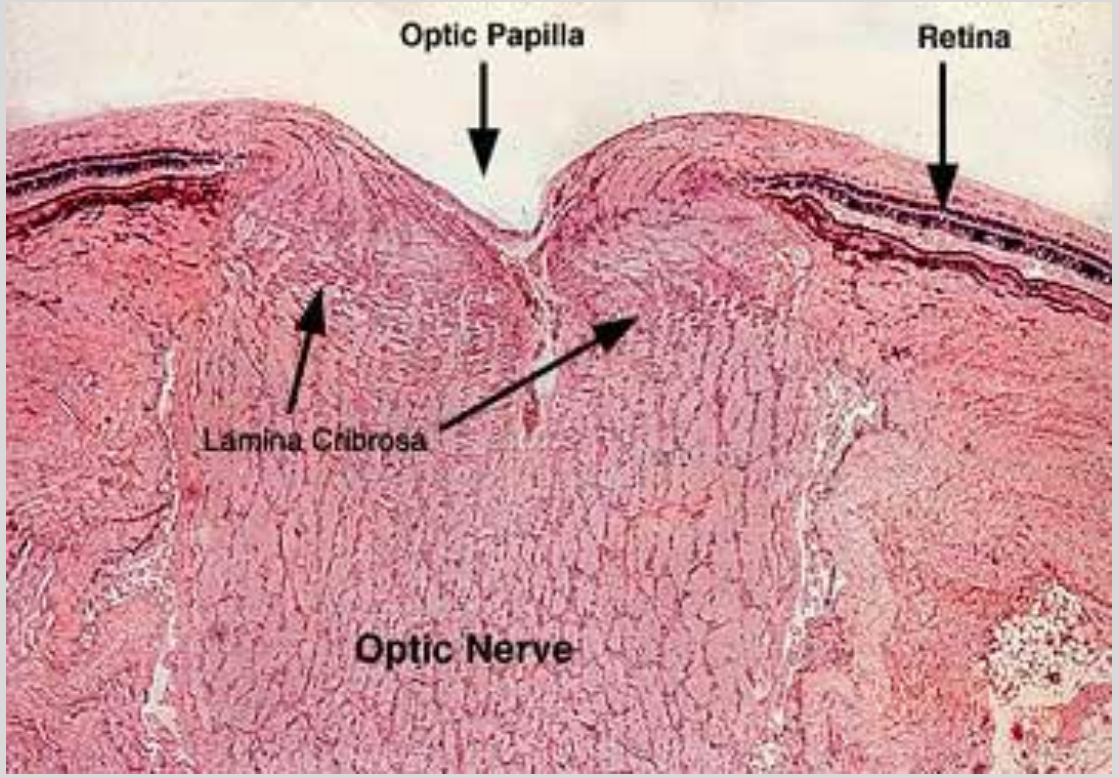
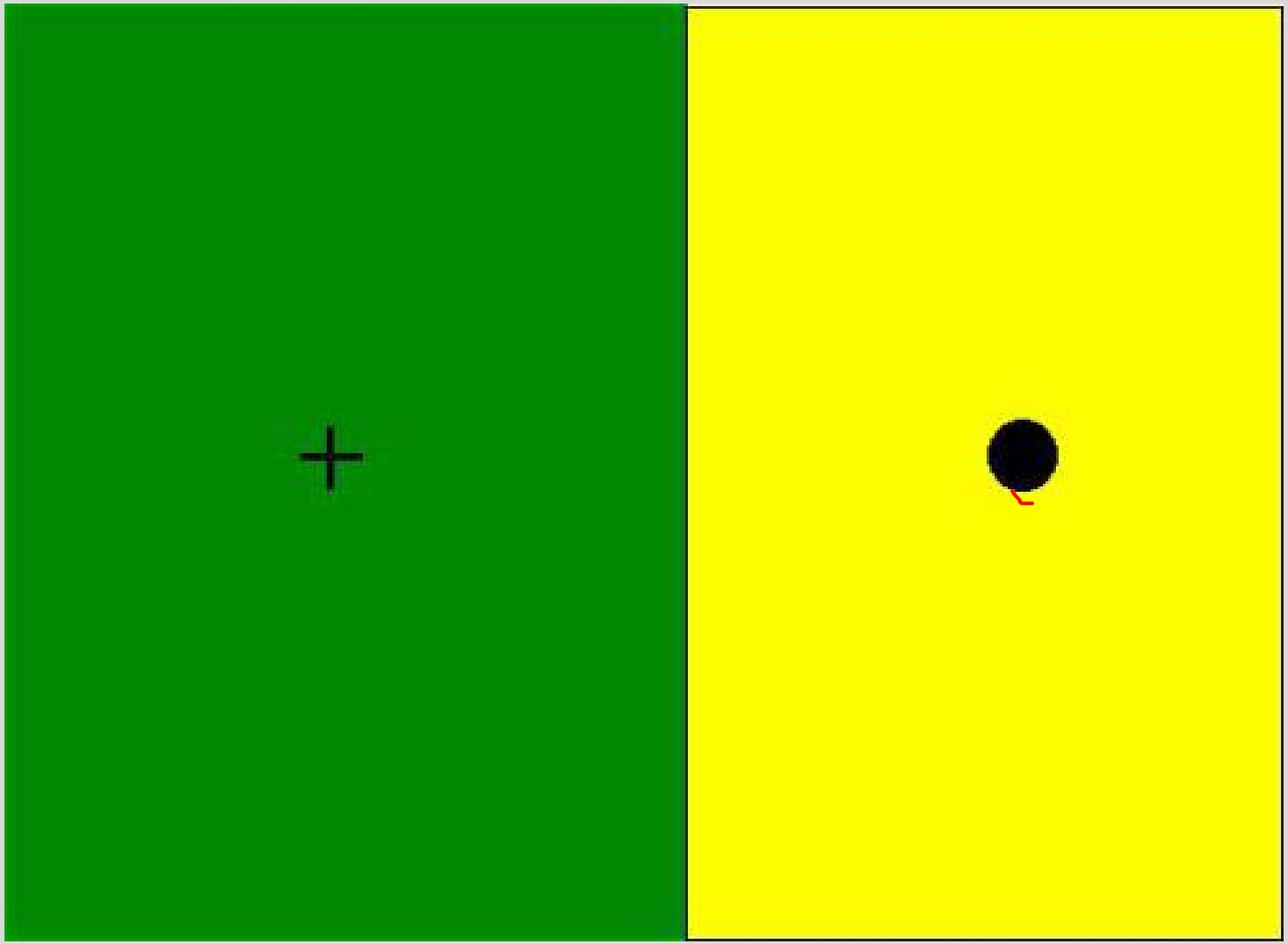
# Retina Regions: Optic Papilla

- At the optic papilla, optic nerve penetrates the retinal layer and leaves the eye, and the retinal blood supply enters and exits (optic disc). This creates a **blind spot** in the retina.
- The blind spot is located 15 degrees temporally
- We are not aware of the blind spot because the nervous system “fills it in”



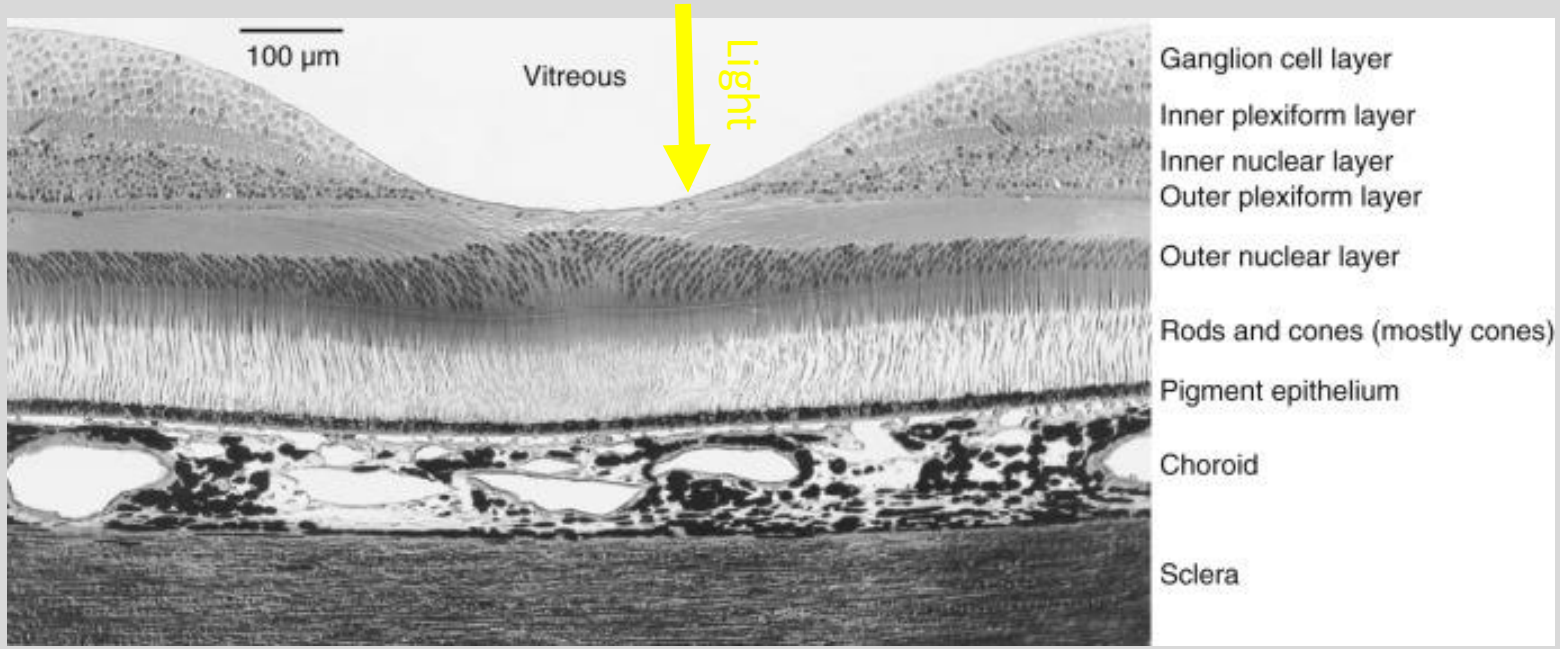
# Blind Spot Test





Cover your left eye and stare at the + in the green square. Now move your head closer to the screen, at one point the circle will disappear and your brain will “fill it in” with its surrounding color.

# Retina Regions: Fovea




- High density of cones in the fovea
- No blood vessels, or other cell in the light path.
- Maximum acuity

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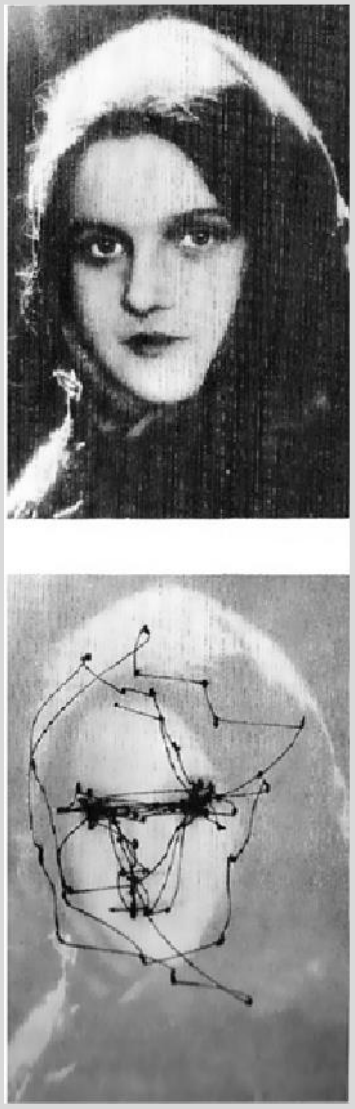
# Age-related macular degeneration(AMD)



(b) Yarbus(1967)

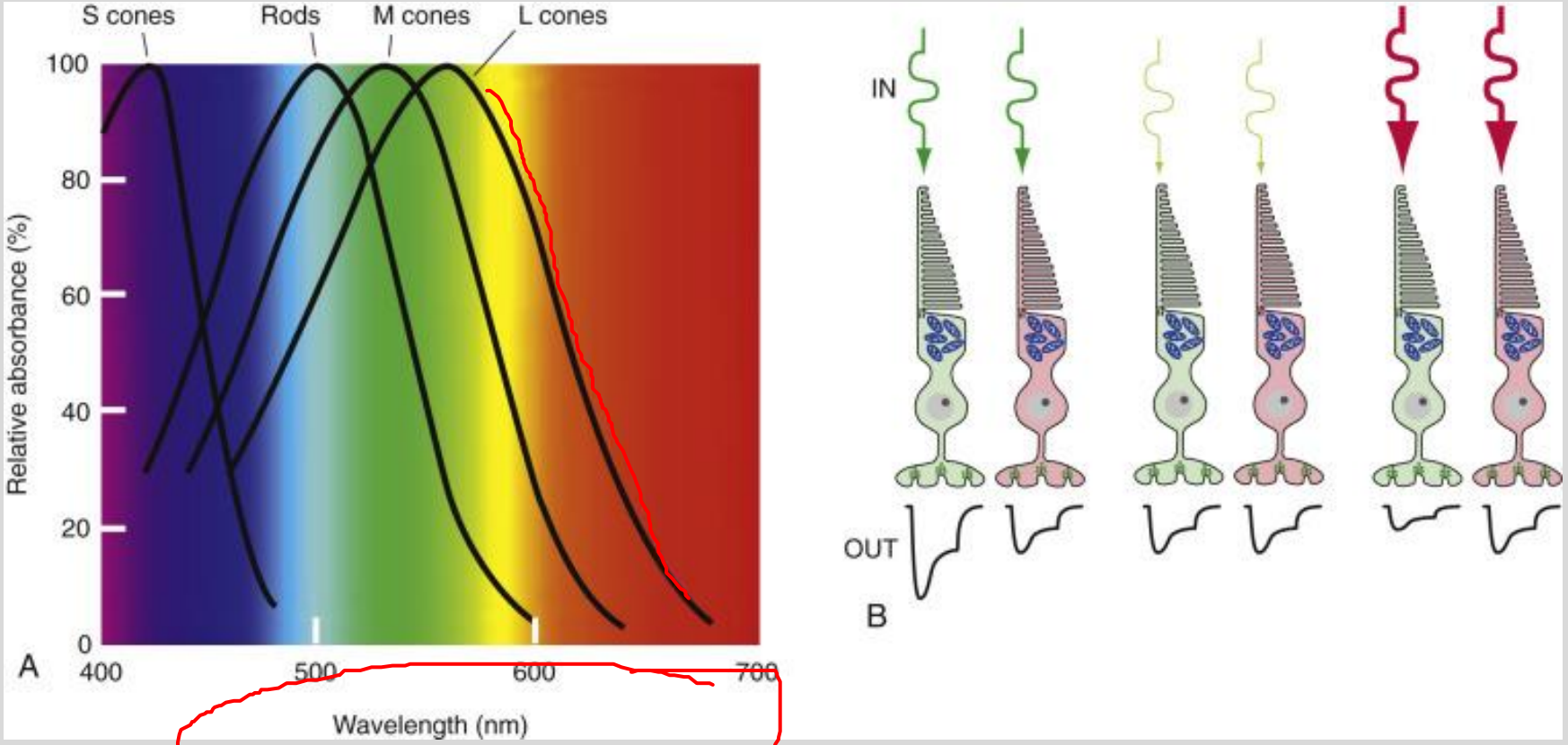
AMD causes damage to the macula but spares most of the retina.

AMD by itself does not lead to complete blindness, with no ability to see. However, the loss of central vision in AMD can interfere with simple everyday activities, such as the ability to see faces, drive, read, write, or do close work, such as cooking or fixing things around the house.

Humans move the eyes to scan an image using the fovea.

# Types of Cones






- Three different types of cones – adapted for different wavelengths of light
- L cones – peak absorption is yellow-green, but they are responsible for the perception of red colors.

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# Receptive fields of ganglion cells have center-surround structure

- Ganglion cells respond to contrast.
- Different types of ganglion cells.
- Numerically dominant class of small ganglion cells sensitive to color and form.
- Larger ganglion cells are more sensitive to movement and contrast.

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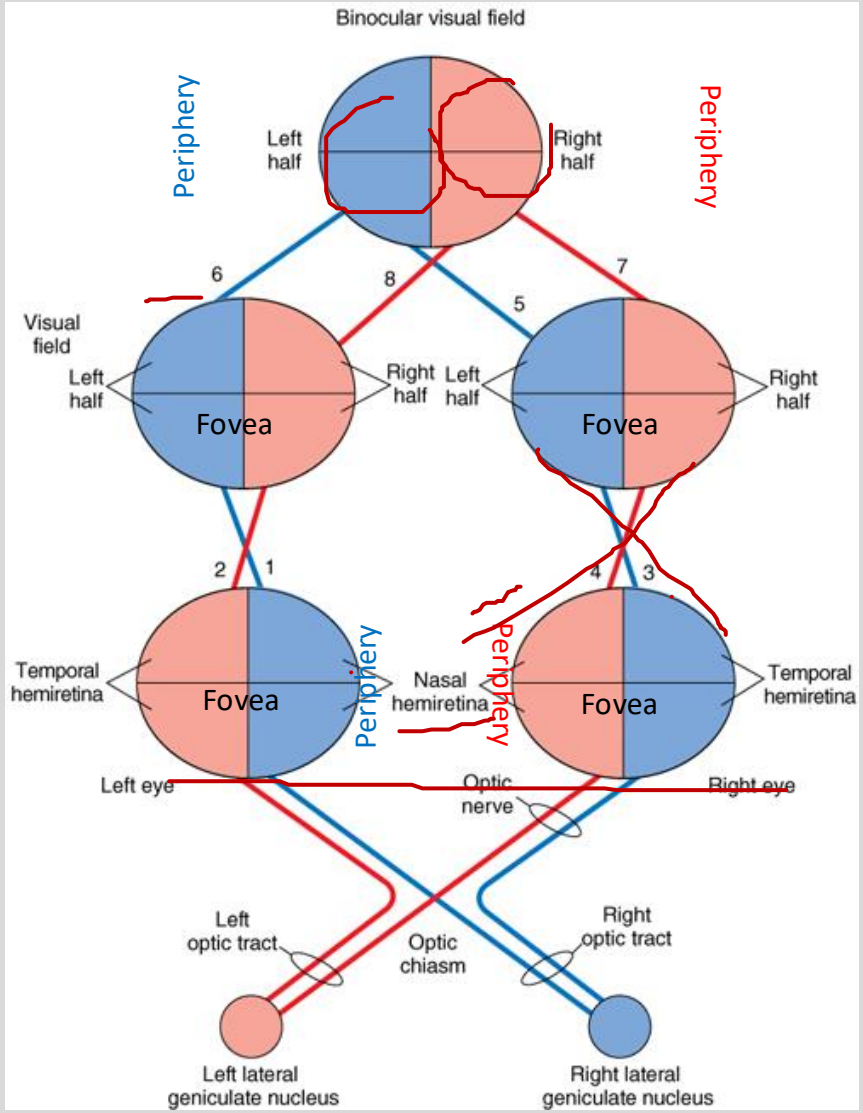
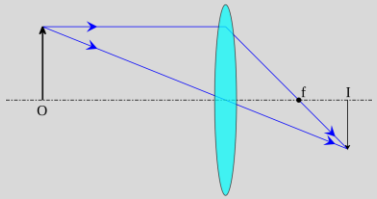
# Visual fields and retinal fields






Siegel, Essential Neuroscience

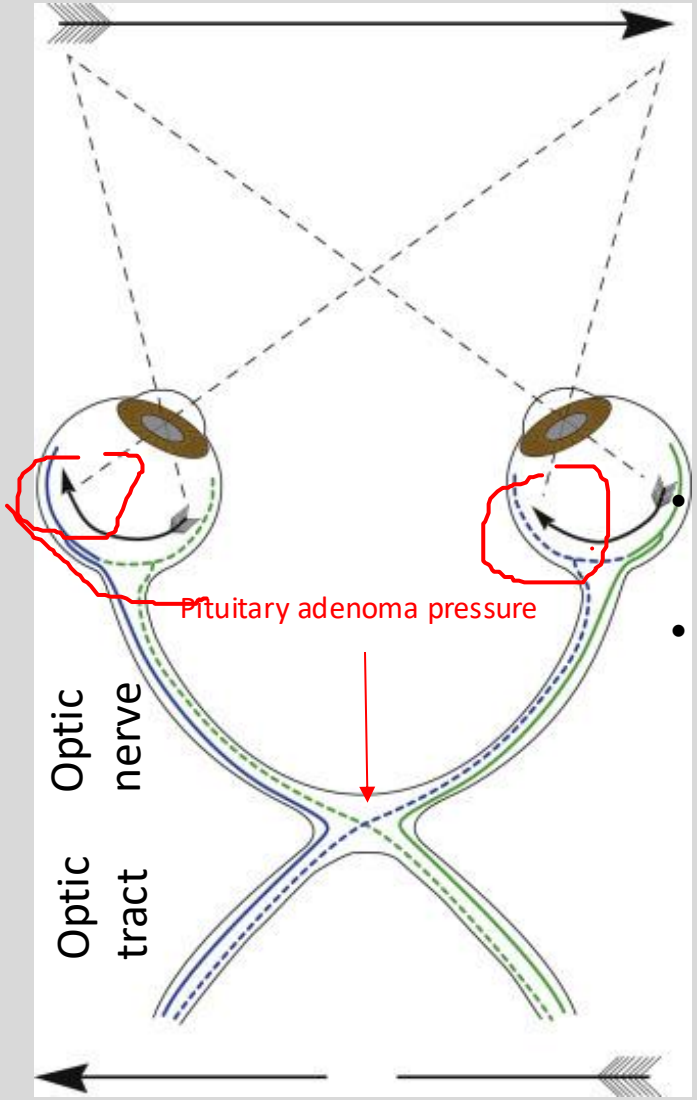



Wikipedia

- Because of the presence of the lens, the images projected into the retina are inverted!

- Visual field of each eye: Region of space that the eye can see looking straight ahead without movement of the head. The fovea of each retina is aligned with a point, called the fixation point, in the visual field.
- Peripheral images fall on the nasal hemiretinas.
- Visual field are represented in the contralateral cortex.
- **Left eye**: In the binocular field, images in the left half of the visual field fall on the nasal hemiretina. Images present in the right half of the visual field of the left eye fall on the temporal hemiretina of the left eye

# Optic Tracts




- Optic chiasm is located above the pituitary gland.
- Pituitary adenoma pressure would cause affect temporal field of view of both eyes (peripheral view affected)

- Ganglion cell axons travel in the optic nerve to the **optic chiasm**
- **Partial** decussation of optic nerve fibers into optic tracts at the optic chiasm permits binocular vision.
- All fibers from the nasal half of each retina cross to the contralateral optic tract; all fibers from the temporal half of each retina pass through the lateral portions of the chiasm without crossing and enter the ipsilateral optic tract.
- **To create a 3D representation of the images of the left side visual field in the right visual cortex we will need:**
  - **Right eye temporal hemiretina**
  - **Left eye nasal hemiretina**

The optic tract contains the fibers from the temporal retina of the ipsilateral eye and the nasal retina of the contralateral eye.

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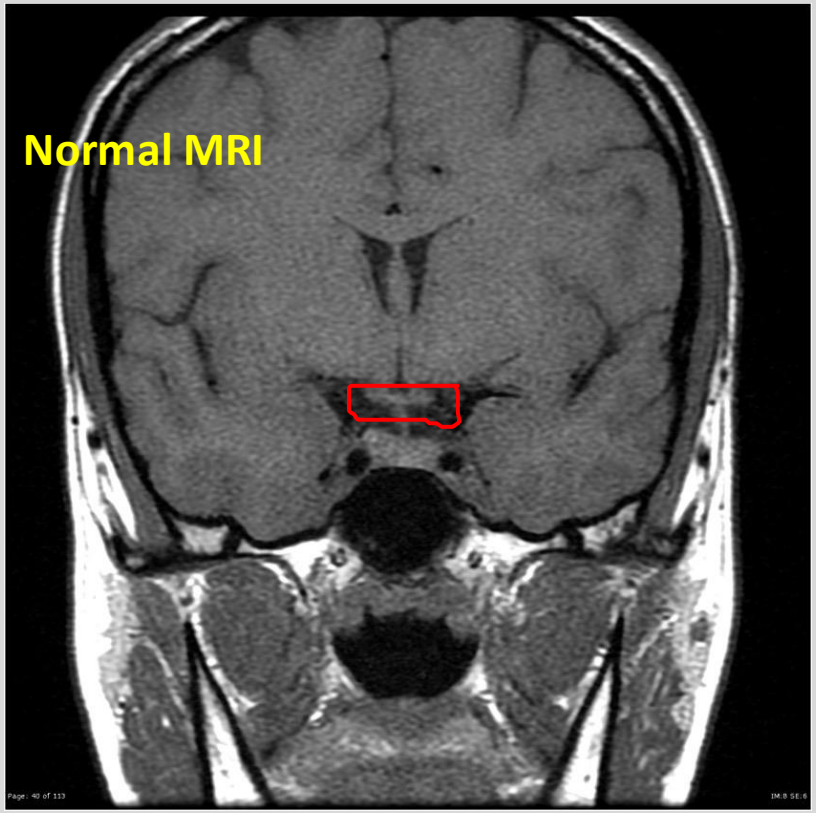
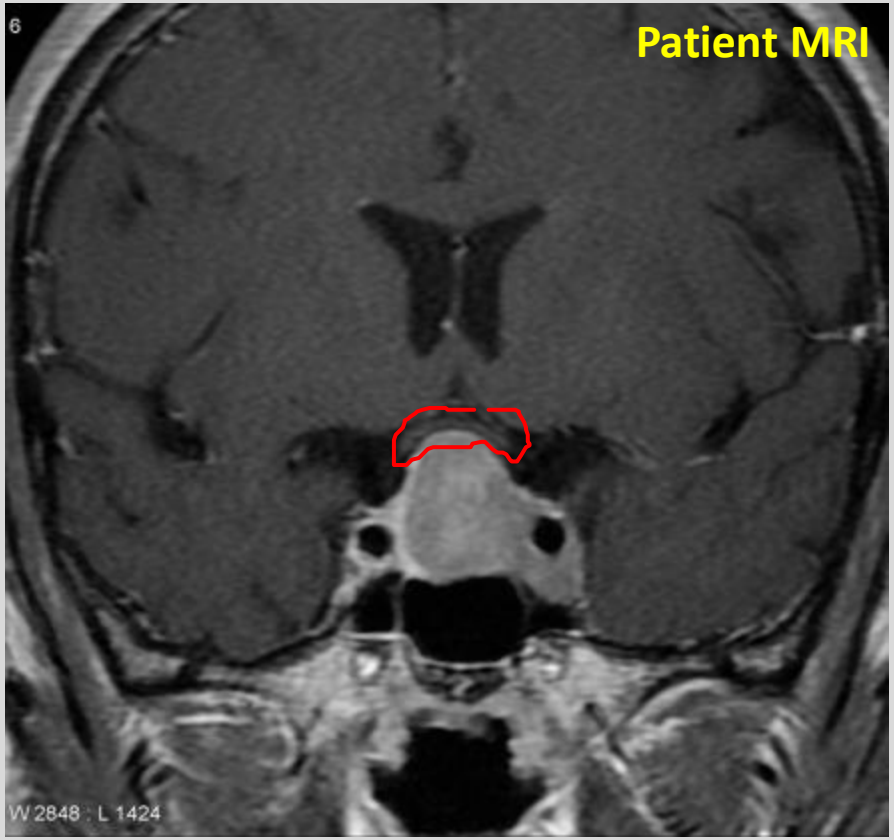
# Patient MRI with pituitary adenoma



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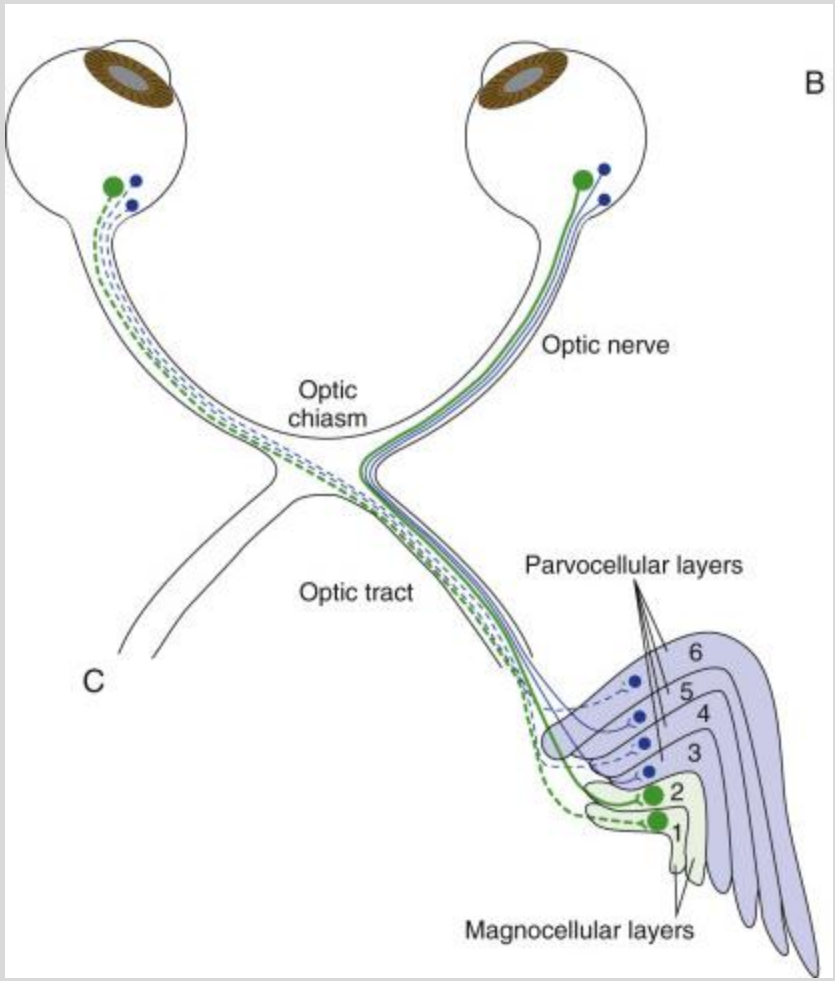
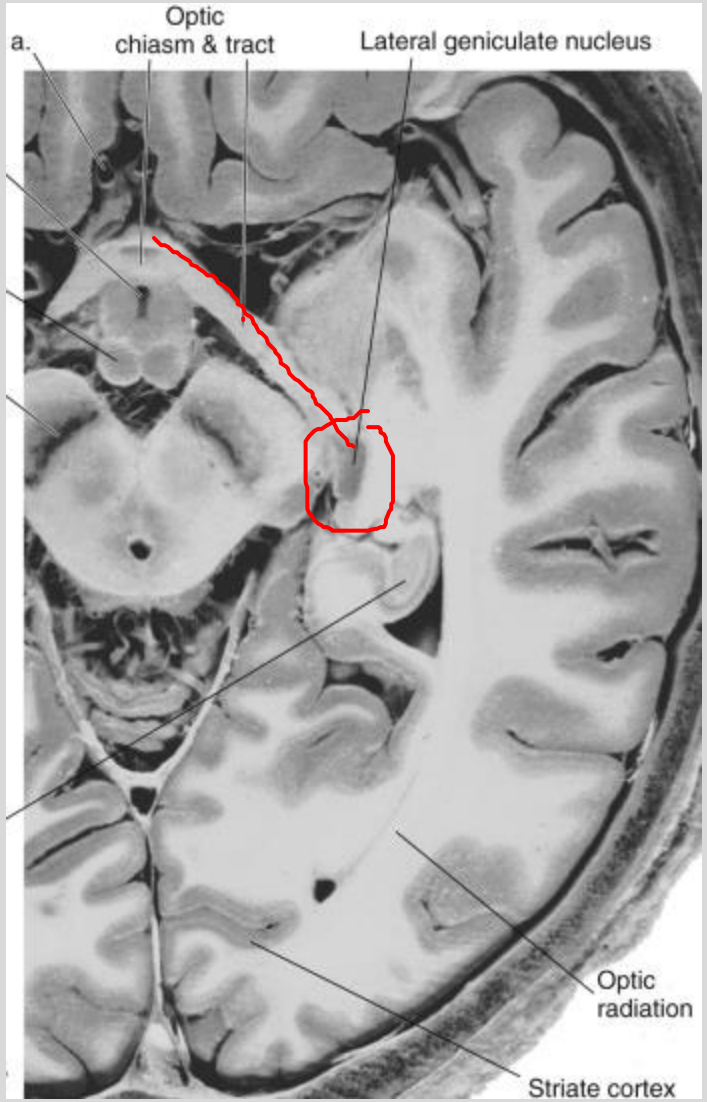
# Visual thalamus






- Most of the fibers in the optic tract  make synapses onto the lateral geniculate body (LGN) of the thalamus.

- Neurons in the LGN are contacted by fibers originating from one eye and have monocular receptive fields. Layers 1, 4, and 6 (most superior) from the contralateral eye, and layers 2, 3, and 5 from the ipsilateral eye
- Magnocellular layers (1,2) respond to contrast and movement, parvocellular layers (3-6) respond to color and form.

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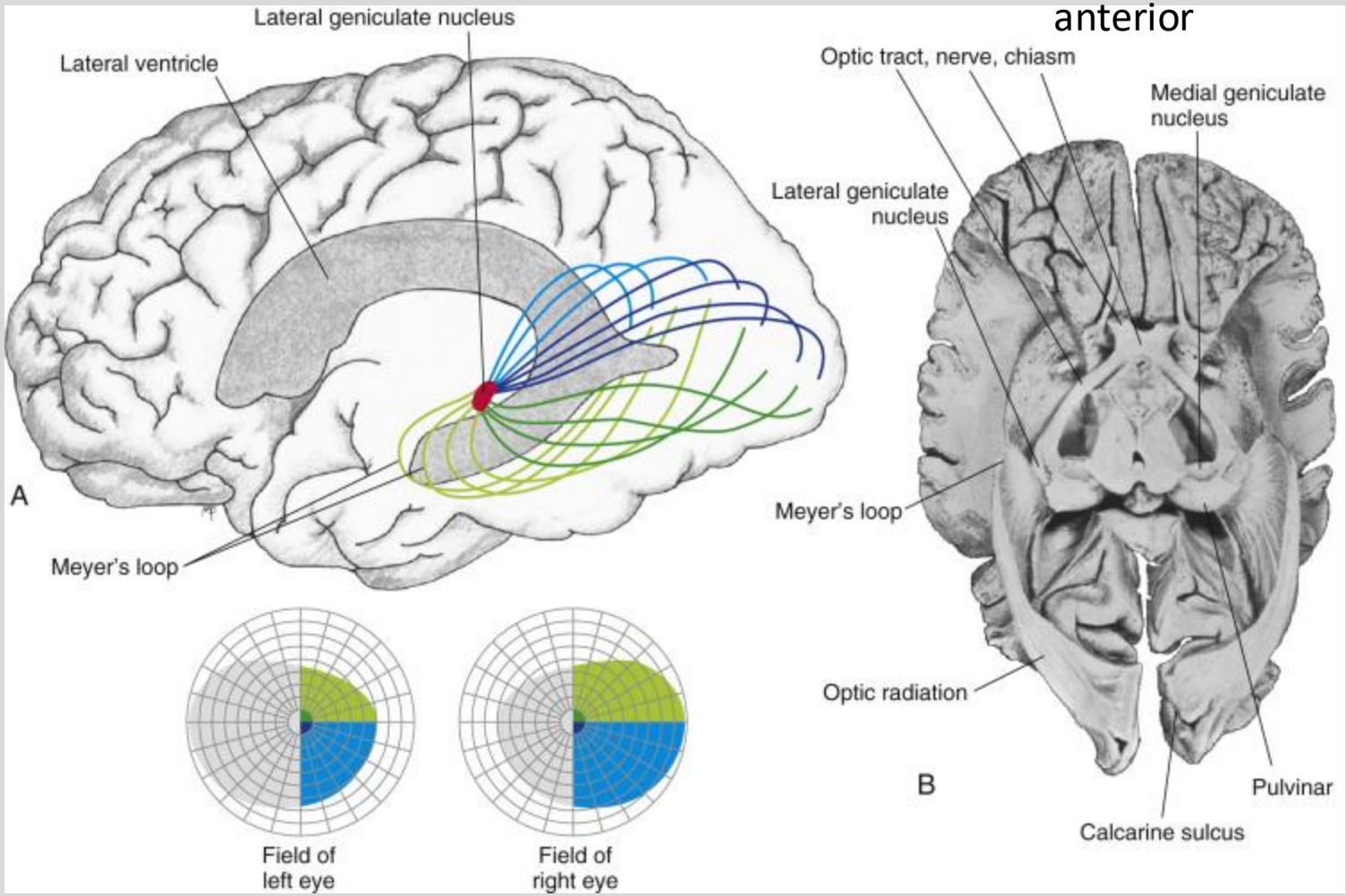
# LGN projection to visual cortex

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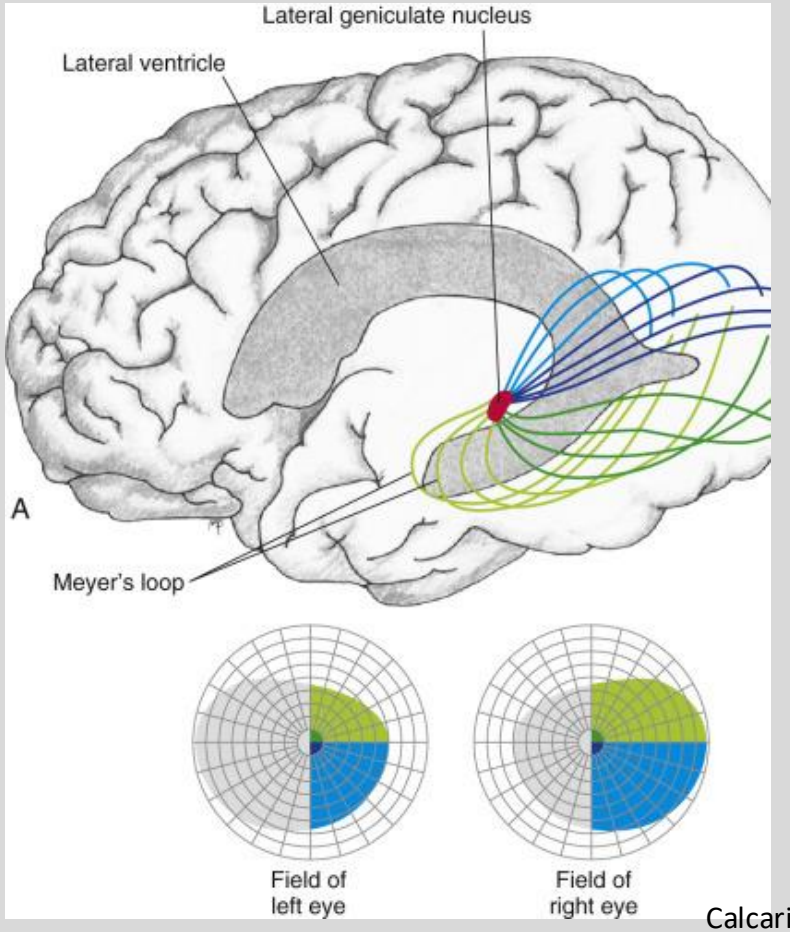
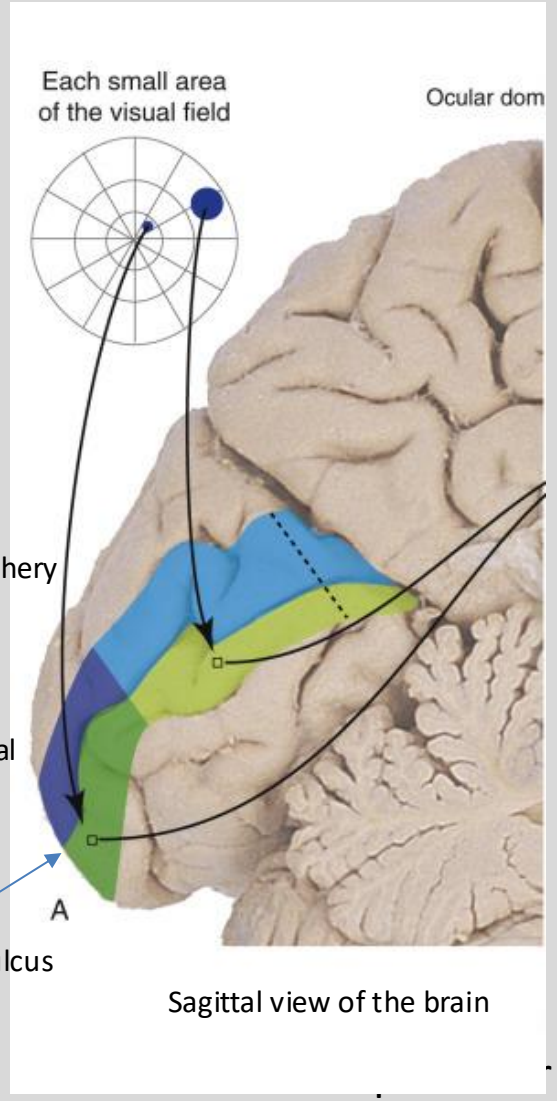
- Geniculocalcarine tract: from the L**G**N to the primary visual cortex , which borders the **calcarine** sulcus.
- Radiate in a broad sheet around the lateral ventricles
- Meyers loop = superior visual field quadrants goes through temporal lobe.
- Damage to the Meyer loop affects the superior field ("pie in the sky"). Might indicate damage to the temporal lobe hemisphere contralateral to the loss of field of view.
- Upper optical radiation (inferior optical field)passes under the parietal lobe ("pie in the floor"). Might indicate damage to the parietal lobe
- Blockage of the middle cerebral artery and its branches might affect the Meyer loop or the upper optical radiation.
- Individual fibers still carry information from only one eye, so damage here often results in deficits that are overlapping but not identical in the two eyes.

# Retinotopical representation in primary visual cortex






Sagittal view of the brain

- Primary visual cortex located in the occipital lobe.
- Inferior visual fields project to the cortex above the calcarine sulcus.
- Superior fields project to the cortex below the sulcus.
- The macula is represented more posteriorly and peripheral fields more anteriorly

- Blood supply provided by the posterior cerebral artery.

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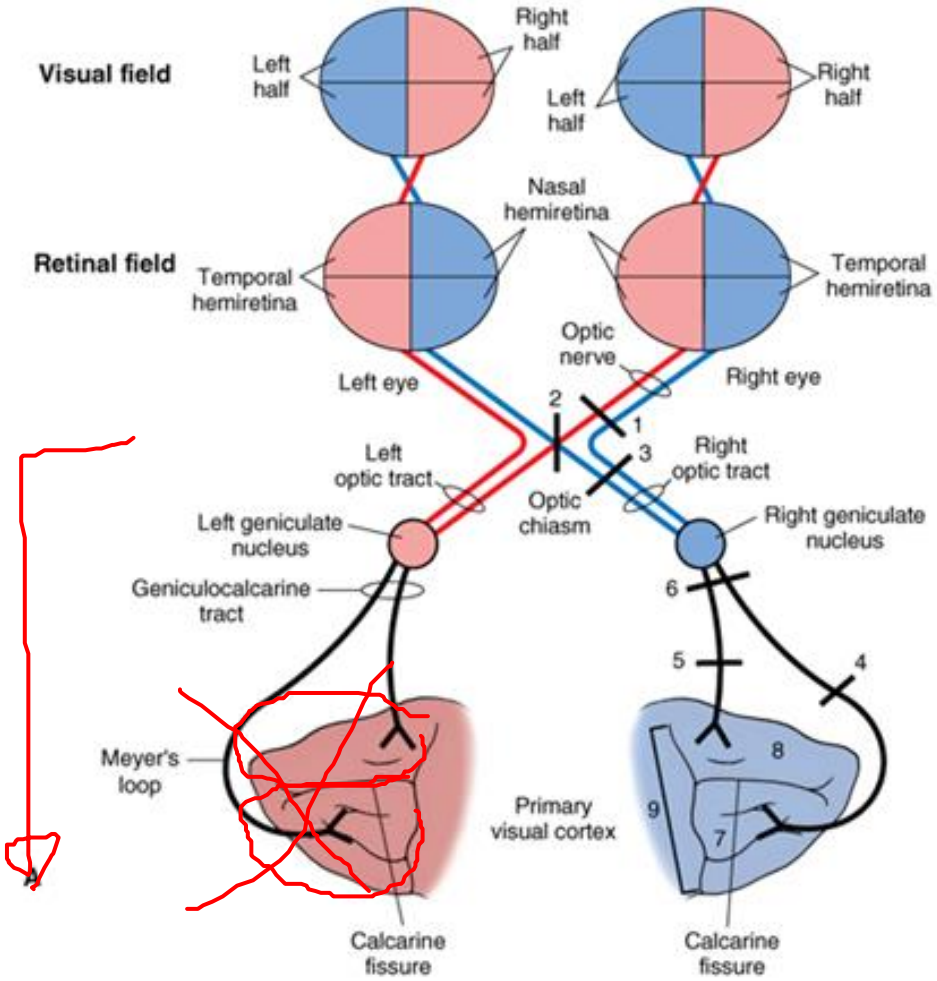
# Visual Tract Lesions






| Site of Lesion (Right side) | Deficit in the visual field: Left eye | Deficit in the visual field: Right eye | Name of the disorder |
|---|---|---|---|
| Optic nerve: 1 | | | a. Total loss of vision in the right eye |
| Optic chiasm (midline): 2 | | | b. Nonhomonymous bitemporal hemianopia |
| Optic tract: 3 | | | c. Contralateral (left) homonymous hemianopia |
| Temporal lobe (Meyer's loop): 4 | | | d. Superior left homonymous quadrantanopia (pie in the sky disorder) |
| Parietal lobe: 5 | | | e. Inferior left homonymous quadrantanopia (pie on the floor disorder) |
| Geniculocalcarine tract: 6 | | | f. Contralateral (left) homonymous hemianopia |
| Inferior bank of calcarine fissure: 7 | | | g. Superior left homonymous quadrantanopia (with macular sparing) |
| Superior bank of calcarine fissure: 8 | | | h. Inferior left homonymous quadrantanopia (with macular sparing) |
| Both banks of calcarine fissure: 9 | | | i. Contralateral (left) homonymous hemianopia (with macular sparing) |

B

Hemianopia → Loss of half a visual field
Quadrantanopia → Loss of quarter a visual field
Homonymous → Visual field losses are similar for both eyes
- Congruous – identical losses
- Non congruous – overlapping but not exactly the same

Heteronymous → Two eyes have nonoverlapping field losses

Essential Neuroscience, 3e
Allan Siegel, Hreday N. Sapru

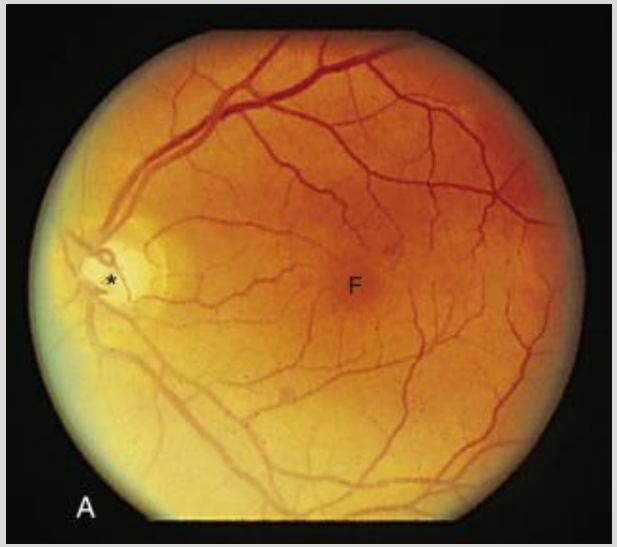
# Macular sparing



1) Although the entire visual cortex is supplied by the calcarine artery, a branch of the posterior cerebral artery, caudal parts of the visual cortex also receive blood from collateral branches of the middle cerebral artery.
2) Large area to represent the fovea in primary visual cortex.
3) Permits to differentiate between medial cerebral artery infarction affecting the geniculocalcarine tract (no macular sparing) from posterior cerebral artery infarction (with macular sparing).

# Papilledema

- Optic nerve is part of CNS embryologically → Has meningeal coverings like other areas of the CNS
- Sclera continues as dural sheath lined inside by arachnoid and pia mater
- Subarachnoid space is continuous with subarachnoid space around optic nerve
- Elevated intracranial pressure (ICP) is transmitted through the optic nerve
- Compression of optic nerve = **Papilledema**
- **Non-invasive tool to measure intracranial pressure with funduscopic exam.**




Nolte's The Human Brain

swelling of the optic disk

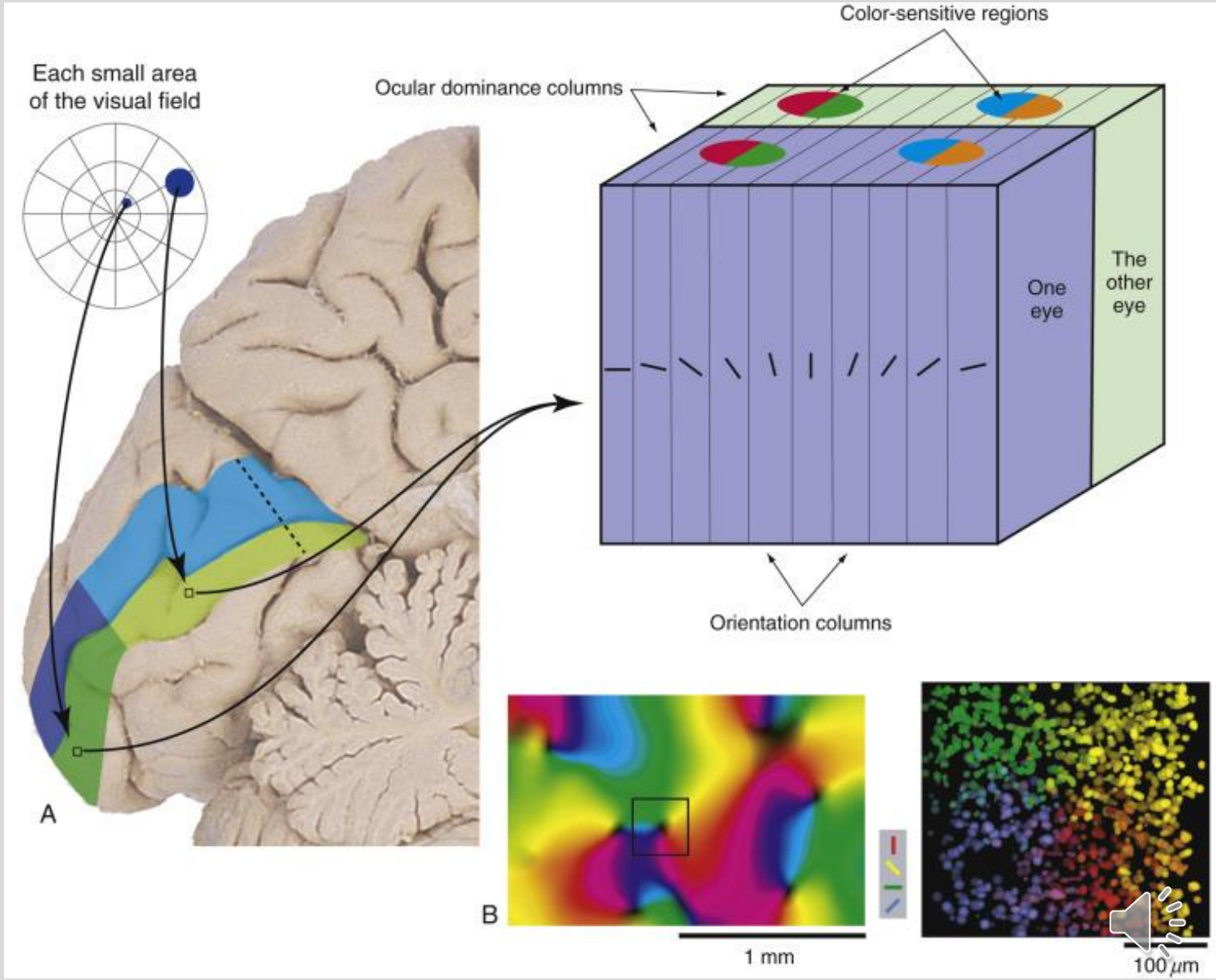

https://medpix.nlm.nih.gov/case?id=073406ac-24a0-4d2b-8fbf-e3ec53b5e2ab

# Additional Optic Tract branches

- Superior Colliculus
  - Head orientation, eye movements – more important in lower animals
- Accessory Optic Nuclei
  - Retinal Image Stabilization
- Hypothalamus
  - Superchiasmatic nucleus
  - Photic input → light regulates circadian rhythm

# Visual Information Processing

- Visual Info is sorted and distributes it in the cortex
  - Orientation, color, depth, motion, etc
- Each different part analyzes the information simultaneously
- Much faster to analyze all the parts separately and integrate into a final image
- Columnar Organization – each column responds to a certain type of stimulus

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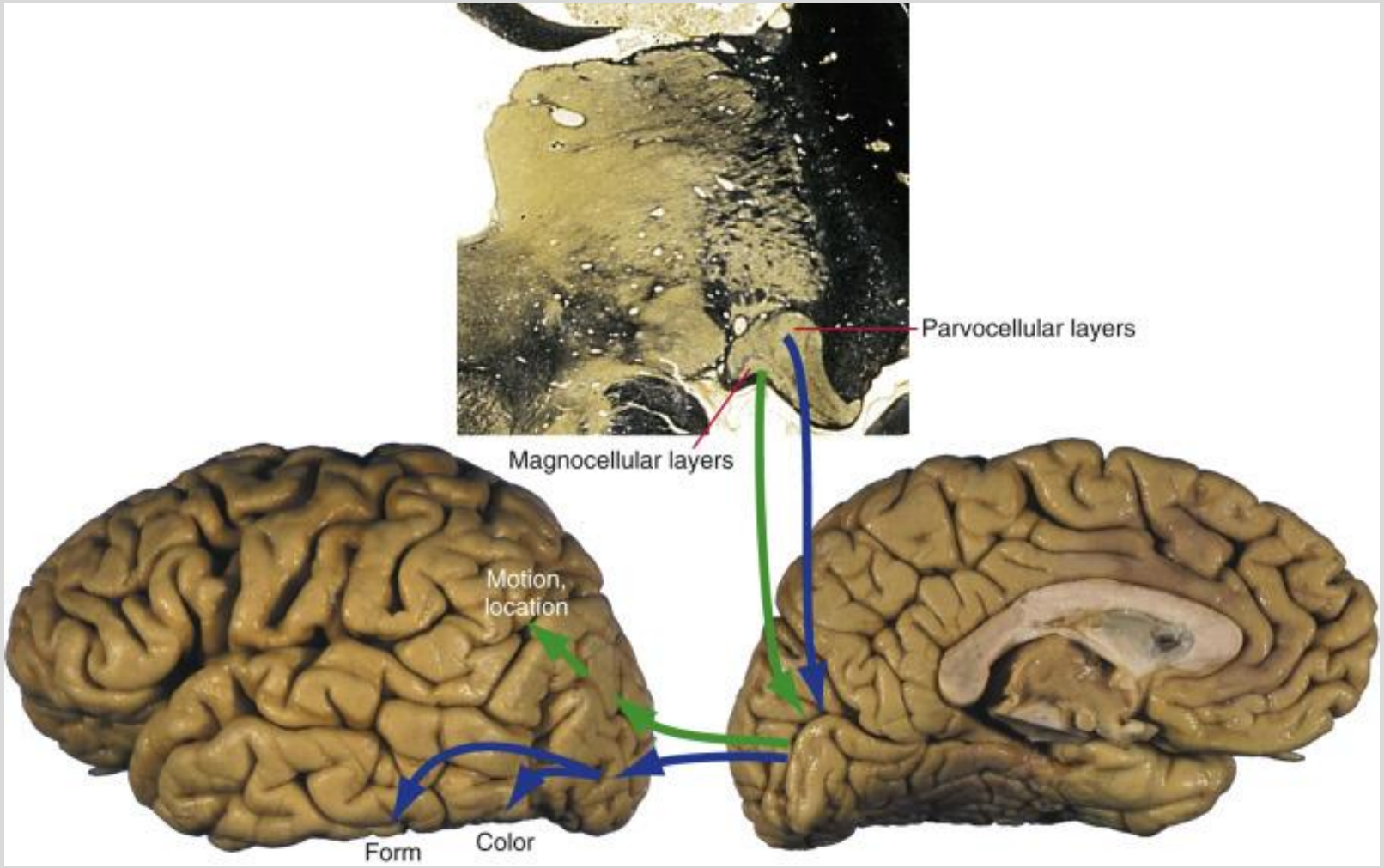
# Dorsal and Ventral Streams






- Dorsal stream of connections – location & motion (**Where Pathway**)
- Ventral stream of connection – Form & Color (**What Pathway**)
- Sorting to different layers begins at lateral geniculate nucleus and continues till extrastriate cortex

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- Loss of Visual Capabilities

- Damage in the posterior brain usually affects optic radiation or striate cortex (visual cortex) → full visual loss in some aspects of the visual field
- Damage to other areas can cause selective visual deficits

# Motion Blindness

- 43 year old woman suffered bilateral infarcts of lateral parts of the parietal, occipital, and posterior temporal lobes
- Visual fields, color vision, depth perception, and reading were unaffected
- Can sense moving sounds and feel movement on skin
- Deficit in visual motion
- **Dorsal Stream Lesion**

# Motion Blindness



# Color blindness & Prosopagnosia

- A 51-year-old man experienced the abrupt onset of headache and confusion one evening. He did not lose consciousness but subsequently remembered nothing that occurred during the next 12 hours. He was taken home and helped to bed, and when he awoke the next morning he became aware of several visual deficits.
- Some visual field deficits
- Inability to recognize color (achromatopsia)
- Inability to recognize faces (prosopagnosia)
- **Ventral Stream Lesion**

# Posterior Parietal Cortex

- Filled with association areas for multiple senses
- A “processing” center
- Damage to the left side is usually less frequent and transient as compared to right sided damage
- Right hemisphere is dominant for spatial attention. After left hemisphere damage, the right hemisphere can direct attention to both the contralateral and ipsilateral sides, but after right hemisphere damage, the left hemisphere can only manage to attend to the contralateral side, so the left side of the world is neglected.

# Partial Neglect

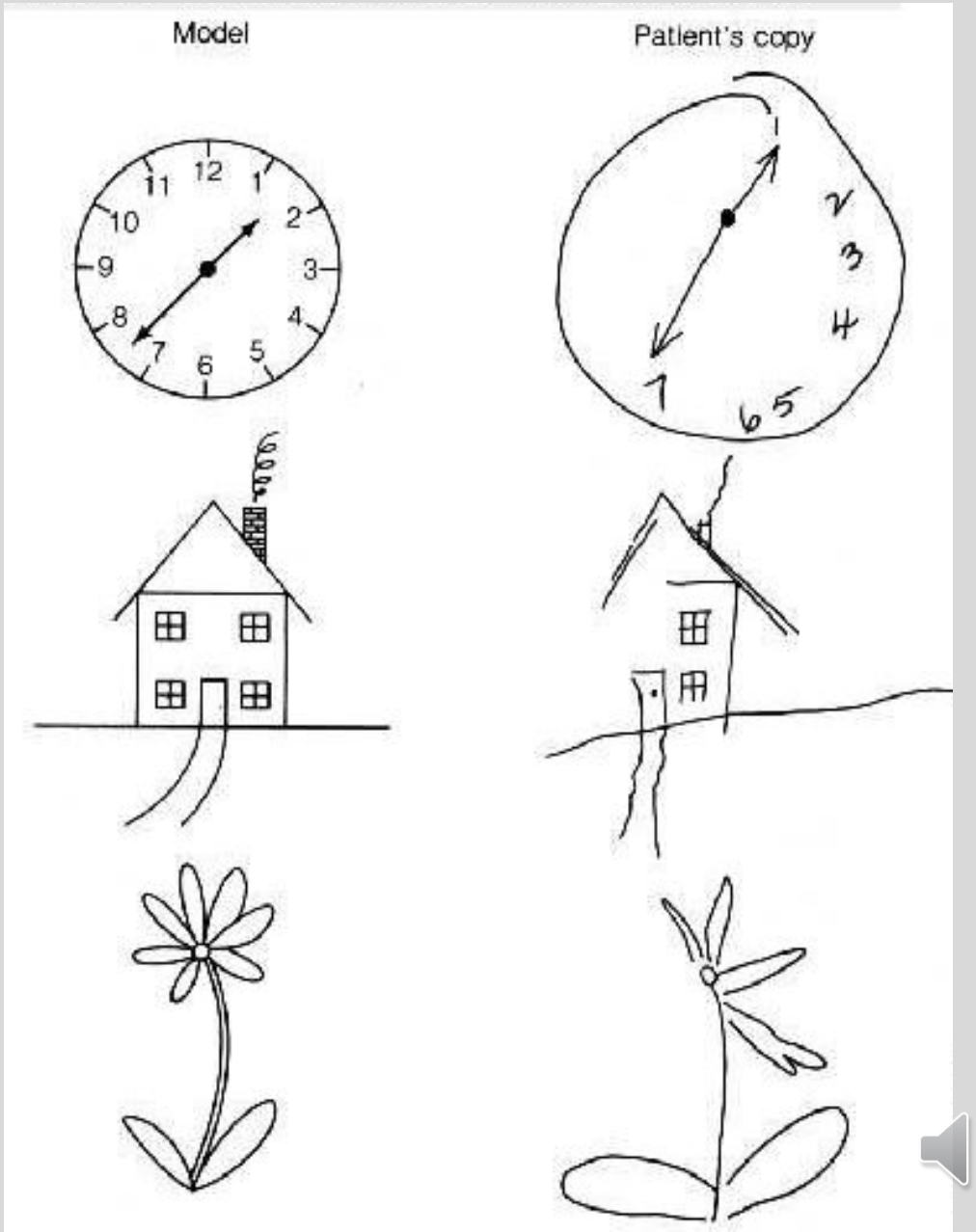


You are seeing a 65 year old man in your office. He is accompanied by his wife. He had a right sided stroke last year and is currently undergoing PT to recover some of his motor control. For the last month now he has been able to feed himself. His wife interjects during your H&P stating that for some reason his plates of food look like this when he is done.

Nolte's The Human Brain

# Partial Neglect

- You ask the patient to copy the following drawings.
- Classically associated with **right posterior parietal** cortex lesions
- Mostly contralateral… some cases of ipsilateral deficit
- Damage to processing of image, not same as hemianopia




Nolte's The Human Brain

# Blindsight

- Lesions in Primary Visual Cortex → Cortically blind
- Respond to visual stimuli that they do not consciously see
- Guess aspects of visual stimuli at rates significantly above chance (is the object moving or no?)
- Do perceptions have to enter our consciousness to affect behavior?
- Using rudimentary primitive visual system

# Lecture Feedback Form:

https://comresearchdata.nyit.edu/redcap/surveys/?s=HRCY448FWYXREL4R