CNS

Doctor 2021

Physiology

Modified (9)

Writer: Toqa Abushanab

Corrector:

Doctor: Fatima Ryalat

Physiology for medical students

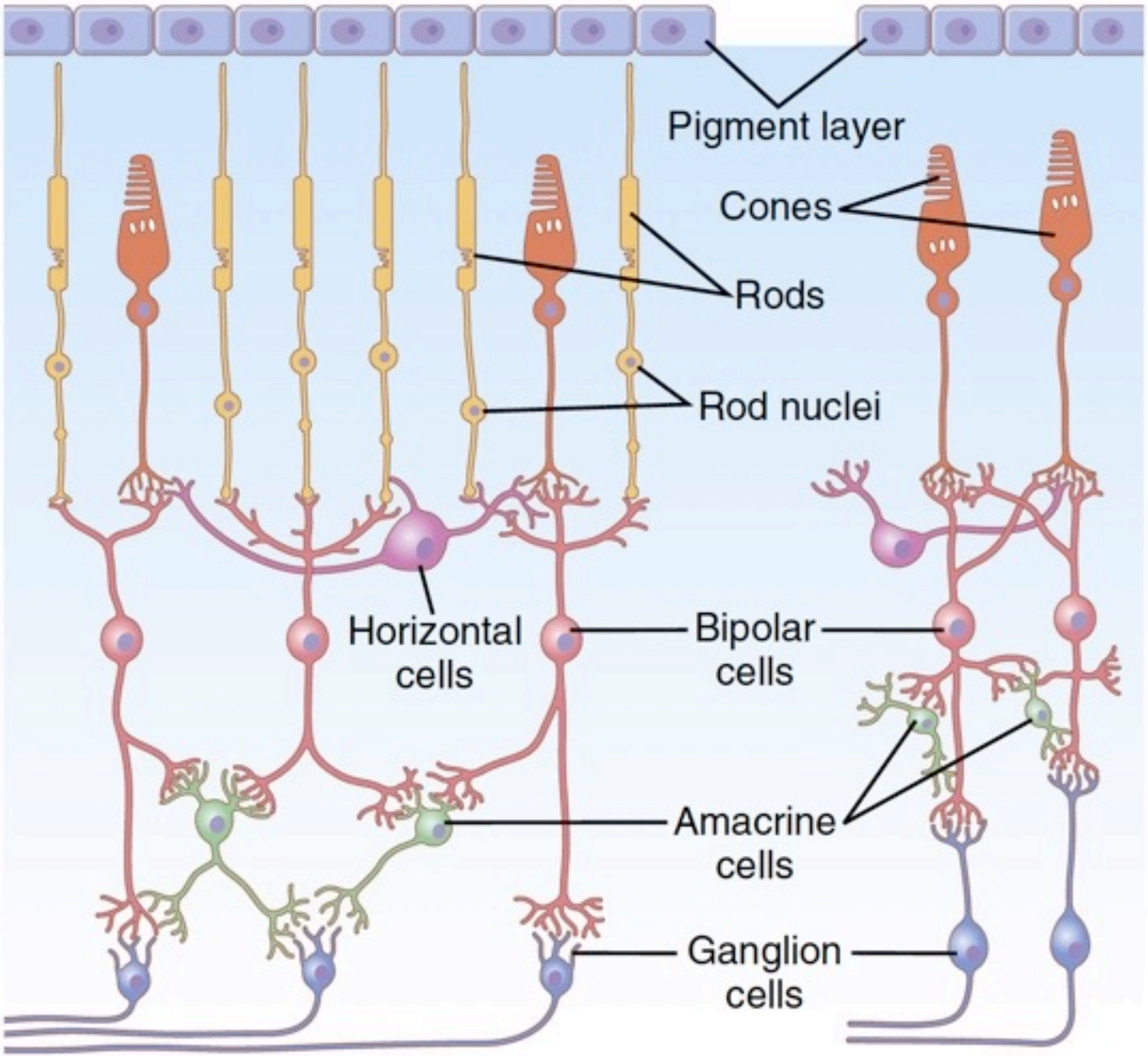
Vision-III

Fatima Ryalat, MD, PhD

Central vs peripheral retina

- major differences exist between the peripheral retina and the central retina.
- As one approaches the fovea, fewer rods and cones converge on each optic fiber, which increases the acuity of vision in the central retina.

- Another difference between the peripheral and central portions of the retina is the much greater sensitivity of the peripheral retina to weak light, that as many as 200 rods converge on a single optic nerve fiber in the more peripheral portions of the retina.



In the previous lecture, we discussed :

- the neural layer at the back of the eye that contains photoreceptor cells. There are two types of photoreceptors: **rods**, which are sensitive to dim light and provide black-and-white vision, and **cones**, which are responsible for color vision and are concentrated in the central region of the retina.
- When light enters the eye and reaches the photoreceptors, it triggers a chemical reaction that generates electrical signals. These signals are transmitted to bipolar cells, which act as intermediaries, and then to ganglion cells, which are the output cells of the retina.
- In between the photoreceptors, bipolar cells, and ganglion cells, there are horizontal cells and amacrine cells. These cells participate in lateral inhibition.

ON / OFF bipolar cells

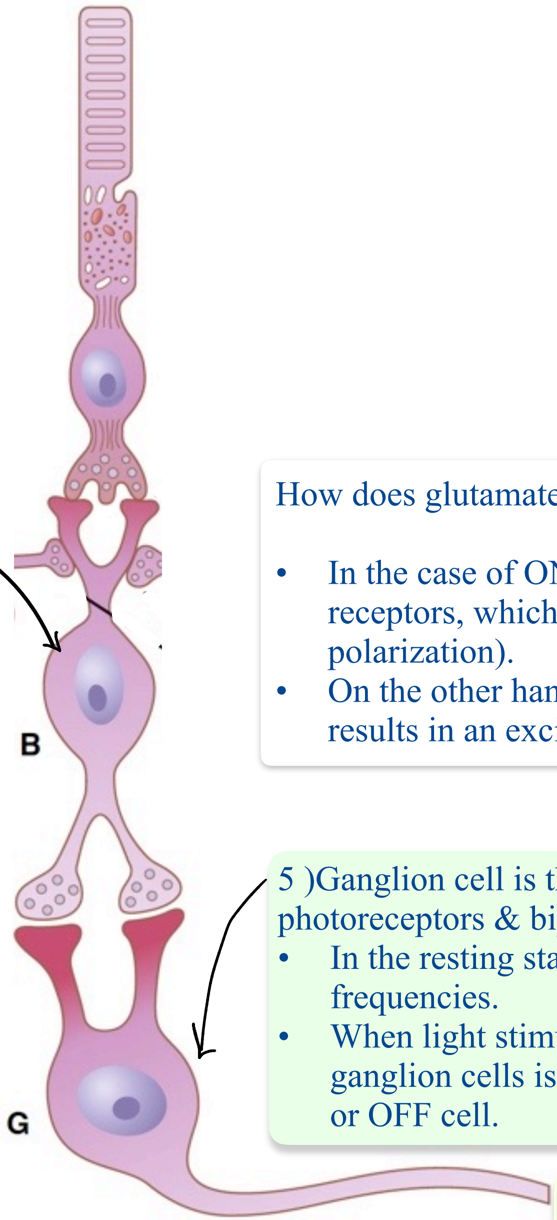
1) This photoreceptor is the rod. In its resting state, it secretes glutamate (which is an excitatory neurotransmitter), when the rod is activated, it results in hyperpolarization and a decrease in glutamate release.

2) This photoreceptor synapses with a bipolar cell. The decrease in the excitatory neurotransmitter (glutamate) inhibits the bipolar cell, leading to hyperpolarization ⇒ OFF neuron

3) However, this is not always the case. This bipolar cell could be an ON neuron, which means that the cessation of glutamate will actually result in its activation or stimulation.

4) How is it possible for the same cell type (bipolar cells) to exhibit different responses???

- the specific glutamate receptors present in these bipolar cells determine their response to change in glutamate release, leading to depolarization (in ON bipolar cells) or hyper polarization (in OFF bipolar cells) and subsequent transmission of visual signals.
- In general, glutamate is considered an excitatory neurotransmitter, but in the case of ON neurons, it acts as an inhibitory neurotransmitter.



How does glutamate affect both types of bipolar cells in the dark state?

- In the case of ON neurons, glutamate binds to **metabotropic** receptors, which results in an inhibitory response (hyper polarization).
- On the other hand glutamate binds to **ionotropic** receptors, which results in an excitatory response (depolarization) in OFF bipolar cell.

5)Ganglion cell is the only neural cell in the retina that sends action potential, in photoreceptors & bipolar cells its graded potential.

- In the resting state, ganglion cells always fairing action potentials at certain frequencies.
- When light stimulates the retina, the **frequency** of action potentials in ganglion cells is determined by the type of bipolar cell, whether it is an ON or OFF cell.

- Ganglion cells release glutamate
- Certain amacrine and horizontal cells release GABA

Receptive field

receptive fields refer to the specific regions of the visual field that can influence the activity of retinal neurons, particularly bipolar cells and ganglion cells.

The fovea has the highest concentration of photoreceptors and the smallest receptive field, while the periphery of the retina has the lowest concentration of photoreceptors and the largest receptive field.

- In the peripheral parts of the retina, there are primarily rods, and these rods converge onto a smaller number of ganglion cells. Convergence in rod cells is higher, with several rods converging onto a single ganglion cell.
- In the central part of the retina, the convergence is nearly absent. Each photoreceptor connects to a separate bipolar cell, resulting in minimal convergence. As a result, the receptive field is small in the central part of the retina, allowing for high visual acuity and detailed vision.

Regardless of the receptive field, bipolar cells will synapse onto a single ganglionic cell. In the peripheral region of the retina (as shown in Figure A), where there is a high density of photoreceptors, the signals from multiple photoreceptors converge and transmit to a smaller number of ganglionic cells. Additionally, these ganglionic cells receive information from the surrounding photoreceptors (we call them the surround), where their activation is opposite to the center.

Horizontal cells are responsible for lateral inhibition, it has a role in **contrast** sensitivity.

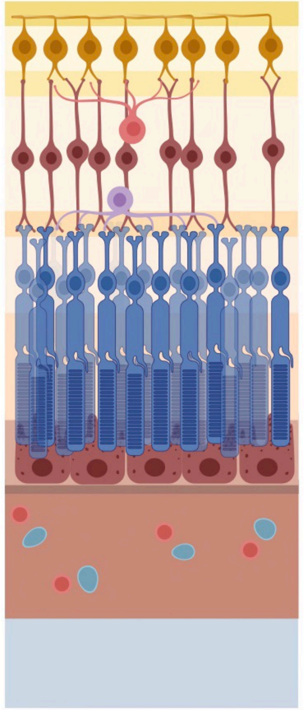


Figure A

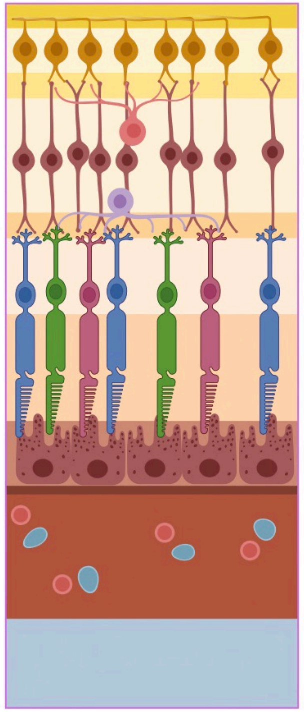
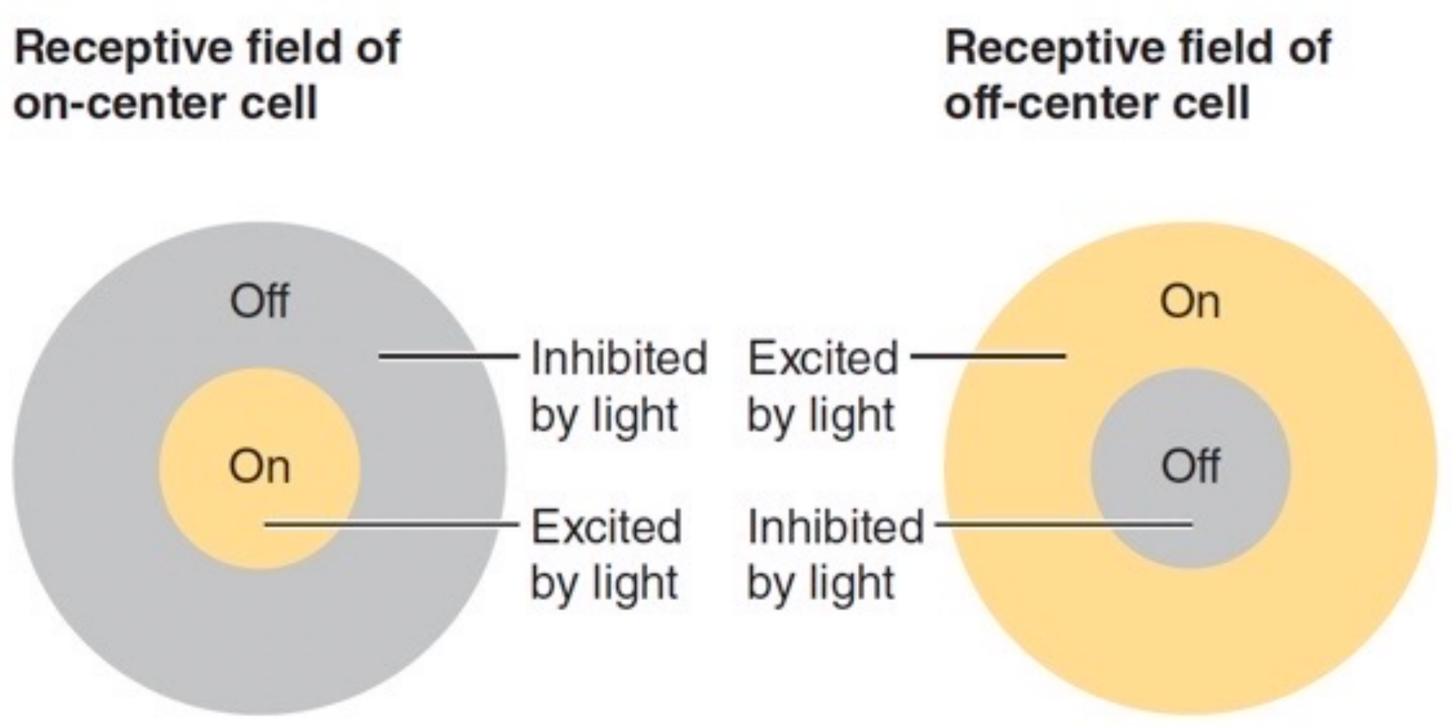
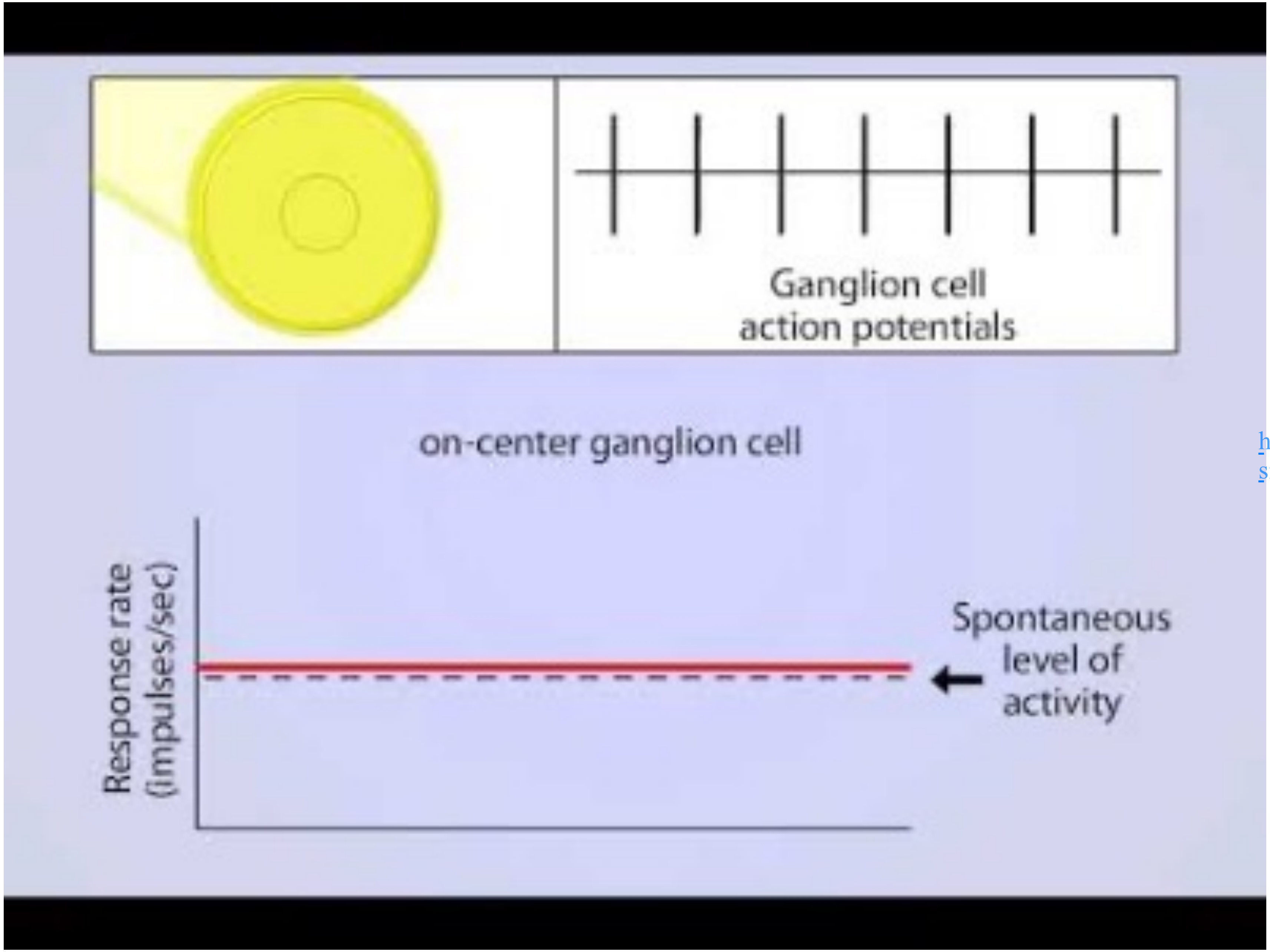


Figure B



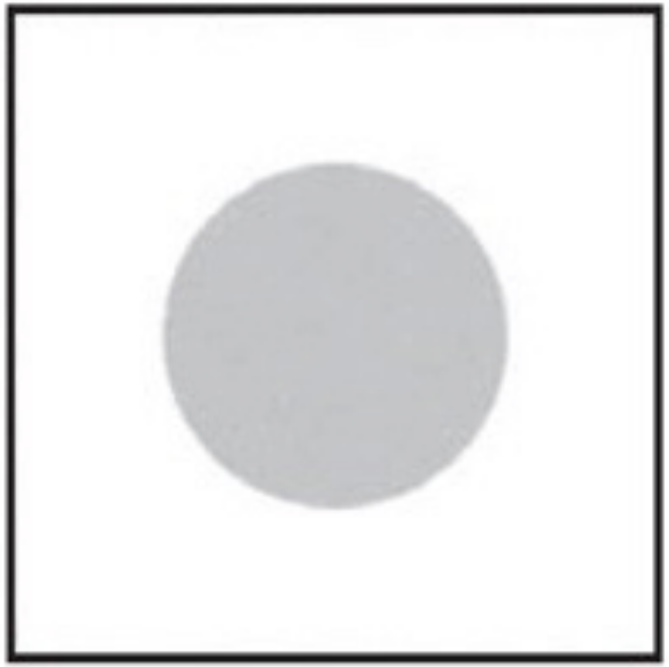
- When the bipolar cells in the center are ON, the surround is always OFF (still we're talking about the same ON/OFF bipolar cells concept).
- What is the advantage of lateral inhibition? Lateral inhibition plays a crucial role in enhancing **contrast perception** in the visual system.
- Contrast perception is crucial as it enables the object I am focusing on to be clearly distinguished from a dark background, enhancing visibility and facilitating visual differentiation, this is how it helps the visual cortex to process these informations.
- The vision processing starts in the retina, which is a super complex system.



https://youtu.be/4TeBArOVGwg?si=S6ebHzCbShTRiWi0

Figure A

Figure B



This is how our visual system tricks us!

- both circles are of the same color & shape; but because we perceive things in relative to the surrounding.
- Since Figure B is surrounded by white color, it appears darker than the one in Figure A, even though they have the exact same color.

Action potential in the retina

- The only retinal neurons that always transmit visual signals via action potentials are the ganglion cells.
- The importance is that it allows graded conduction of signal strength.
- Thus, for the rods and cones, the strength of the hyperpolarizing output signal is directly related to the intensity of illumination; the signal is not all or none, as would be the case for each action potential.

Horizontal cells

- The outputs of the horizontal cells are always inhibitory. Therefore, this lateral connection provides the same phenomenon of lateral inhibition that is important in helping to ensure transmission of visual patterns with proper visual contrast.

- This process is essential to allow high visual accuracy in transmitting contrast borders in the visual image.

Horizontal cells in the retina are responsible for mediating lateral inhibition, which plays a significant role in enhancing contrast sensitivity in the visual system

Amacrine cells

- Some of the amacrine cells probably provide additional lateral inhibition and further enhancement of visual contrast in the inner plexiform layer of the retina as well.

Retinal Ganglion cells

- Even when unstimulated, ganglion cells still transmit continuous impulses at various rates.
- Two general classes of retinal ganglion cells that have been studied most, are designated as magnocellular (M) and parvocellular (P) cells.
- The P cells, in the central retina, project to the parvocellular (small cells) layer of the lateral geniculate nucleus of the thalamus.
- The M cells project to the magnocellular (large cells) layer of the lateral geniculate nucleus.

So these cells are named according to the area they project to in the thalamus .

Retinal Ganglion cells

- The main functions of M and P cells are obvious from their differences:

Smaller in size

- The **P cells** are highly sensitive to visual signals that relate to fine details and to different colors but are relatively insensitive to low-contrast signals. P cells receive input primarily from cone photoreceptors

- the **M cells** are highly sensitive to low-contrast stimuli and to rapid movement visual signals.

Retinal Ganglion cells

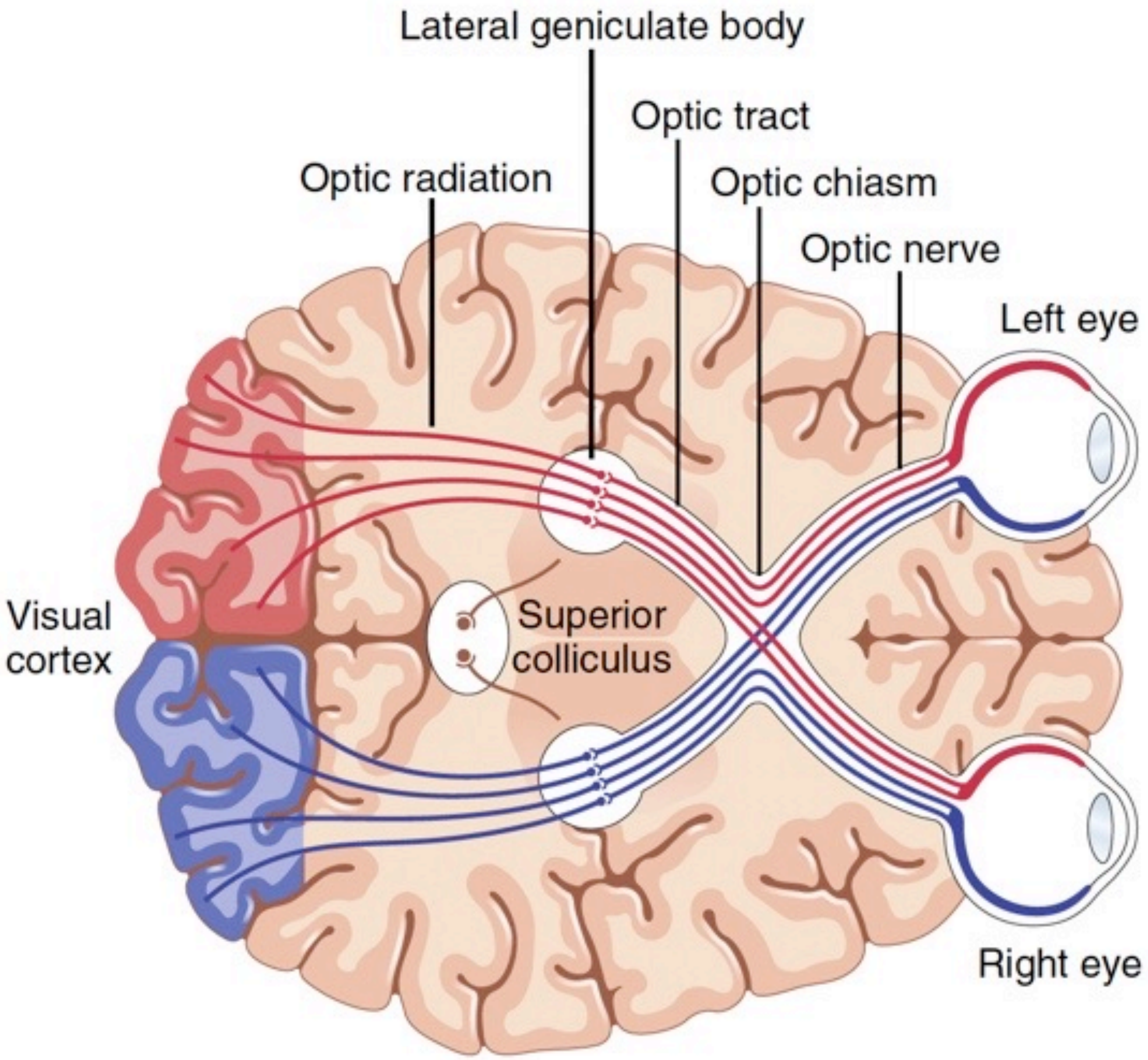
- A third type of photosensitive retinal ganglion cell has been described that contains its own photopigment, melanopsin.

- These cells appear to send signals mainly to nonvisual areas of the brain, particularly the suprachiasmatic nucleus of the hypothalamus, the master circadian pacemaker.

  - This type of photoreceptors have the information whether it's light or dark & transmit the signal to the suprachiasmatic nucleus for the regulation circadian rhythm.
  - There are other types of ganglion cells.
  - Ganglion cells are the only cells that generate action potential in the retina.
  - The advantage of having graded potentials in photoreceptors and bipolar cells, instead of action potentials, is that it allows for the gradation of intensity, contrast of colors, and graded colors.
  - Ganglion cell axons converge to form the optic nerve.

Retinal ganglion cells

- Some of the ganglion cells are excited by only one color type of cone but are inhibited by a second type.
- The importance of these color contrast mechanisms is that they represent a means whereby the retina begins to differentiate colors.
- Thus, each color contrast type of ganglion cell is excited by one color but inhibited by the “opponent” color. Therefore, color analysis begins in the retina.


Lateral geniculate body
Optic tract
Optic radiation
Optic chiasm
Optic nerve
Left eye
Visual
cortex
Superior
colliculus
Right eye

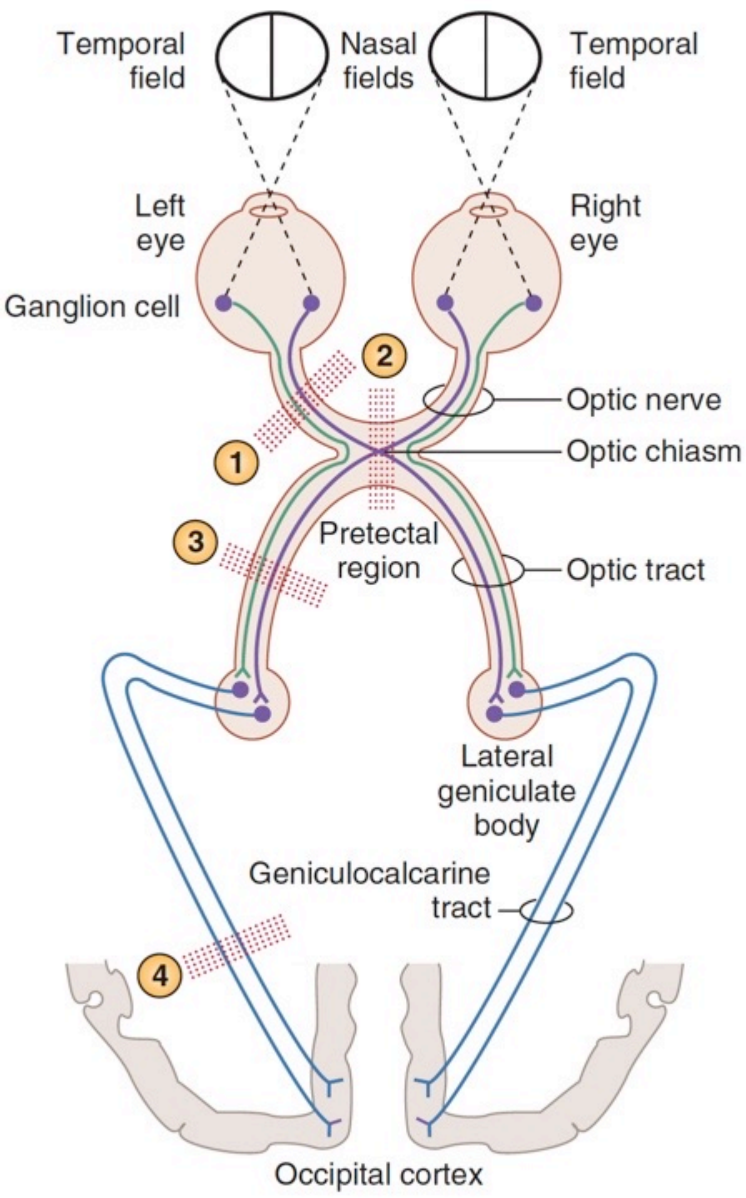
The optic nerve has two parts :

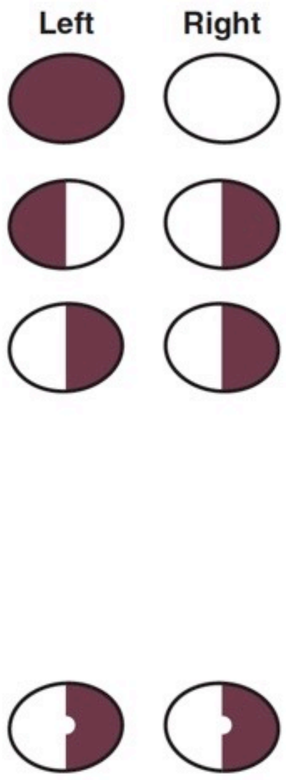
1. Nasal part 2. Temporal part.

- The nasal part of the optic nerve fibers will decussate at the optipretectal while the temporal part will continue without crossing over. From there, the optic tract is formed. Certain fibers, such as melanopsin-containing fibers, will project to the suprachiasmatic nucleus for regulation of circadian rhythm. Other fibers will project to the superior colliculus, involved in the startle reflex, or to the pretectal area for pupillary reflex. Finally, the remaining fibers will continue to the visual cortex in the occipital lobe, where visual information is processed.

- It's important to note that not all signals follow this exact pathway. Some fibers, like those containing melanopsin, have specific destinations such as the suprachiasmatic nucleus. Other fibers have different targets, such as the superior colliculus or the pretectal area for the pupillary reflex.

LESIONS OF OPTIC PATHWAYS





Lesion in the optic nerve at one side

Lesion of the optic chiasm (tunnel vision) associated with pituitary adenoma/ hyperplasia.
Mainly the nasal field is effected rather than temporal.

Lesion in the optic tract

Visual pathways

- the visual pathways can be divided roughly into an old system to the midbrain and base of the forebrain and a new system for direct transmission of visual signals into the visual cortex located in the occipital lobes.

Old system ⇒ processing in the brainstem (to superior colliculus, pretectal area).
New system ⇒ processing in the visual cortex, it must pass through the thalamus.

Visual pathways

- Visual fibers also pass to several older areas of the brain:
- (1) from the optic tracts to the suprachiasmatic nucleus of the hypothalamus, presumably to control circadian rhythms that synchronize various physiological changes of the body with night and day.

- (2) into the pretectal nuclei in the midbrain to elicit reflex movements of the eyes to focus on objects of importance and activate the pupillary light reflex.

Visual pathways

- (3) into the superior colliculus to control rapid directional movements of the two eyes.

- (4) into the ventral lateral geniculate nucleus of the thalamus.

Superior colliculus

- a sudden visual disturbance in a lateral area of the visual field often causes immediate turning of the eyes in that direction.
- This turning does not occur if the superior colliculi have also been destroyed.
- To support this function, the various points of the retina are represented topographically in the superior colliculi in the same way as in the primary visual cortex, although with less accuracy.

The spatial orientation present in the retina is preserved in the superior colliculus during its functioning.

Thalamus

- After passing the optic chiasm, half the fibers in each optic tract are derived from one eye and half are derived from the other eye, representing corresponding points on the two retinas.
- However, the signals from the two eyes are kept apart in the dorsal lateral geniculate nucleus.
- This nucleus is composed of six nuclear layers.

In the geniculate nucleus, both the parvocellular and magnocellular areas are present.

Dorsal lateral geniculate nucleus

- 1. Layers I and II are called magnocellular layers because they contain large neurons. These neurons receive their input almost entirely from the large type M retinal ganglion cells.
- This magnocellular system provides a rapidly conducting pathway to the visual cortex.
- However, this system is color blind, transmitting only black-and-white information.
- Also, its point to point transmission is poor because there are not many M ganglion cells, and their dendrites spread widely in the retina.

Dorsal lateral geniculate nucleus

- 2. Layers III through VI are called parvocellular layers because they contain large numbers of small to medium-sized neurons.

- These neurons receive their input almost entirely from the type P retinal ganglion cells that transmit color and convey accurate point to point spatial information, but at only a moderate velocity of conduction rather than at high velocity.

Thalamus

- The dorsal lateral geniculate nucleus serves two principal functions.

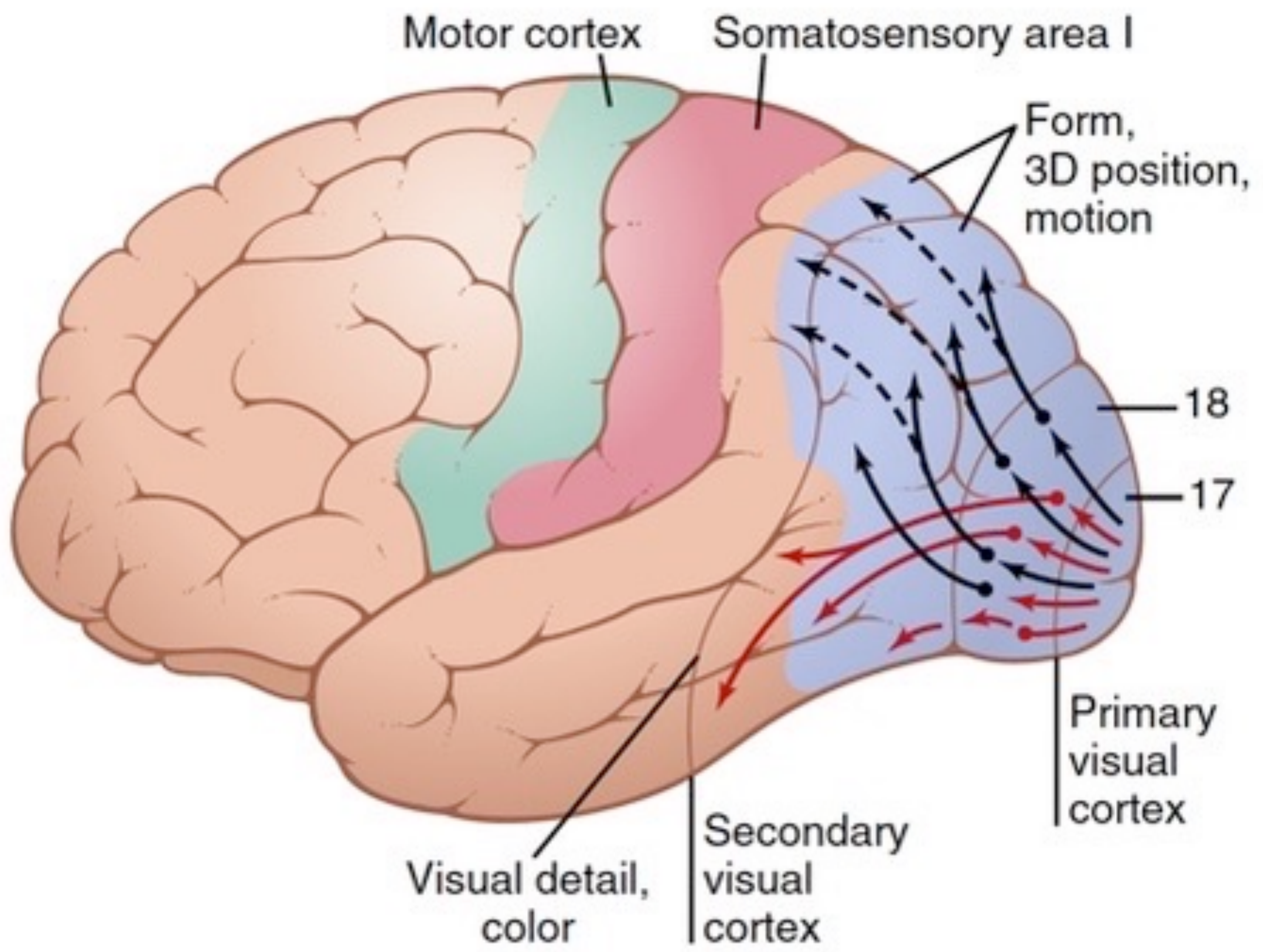
1) - First, it relays visual information from the optic tract to the visual cortex by way of the optic radiation.
- This relay function is so accurate that there is exact point to point transmission with a high degree of spatial fidelity all the way from the retina to the visual cortex.

Thalamus

2) • The second major function of the dorsal lateral geniculate nucleus is to “gate” the transmission of signals to the visual cortex—that is, to control how much of the signal is allowed to pass to the cortex.

- The nucleus receives gating control signals from two major sources:
- (1) corticofugal fibers returning in a backward direction from the primary visual cortex to the lateral geniculate nucleus.

- (2) reticular areas of the mesencephalon. Both of these sources are inhibitory and, when stimulated, can turn off transmission through selected portions of the dorsal lateral geniculate nucleus.


Motor cortex
Somatosensory area I
Form,
3D position,
motion
18
17
Primary
visual
cortex
Secondary
visual
cortex
Visual detail,
color

Primary visual cortex

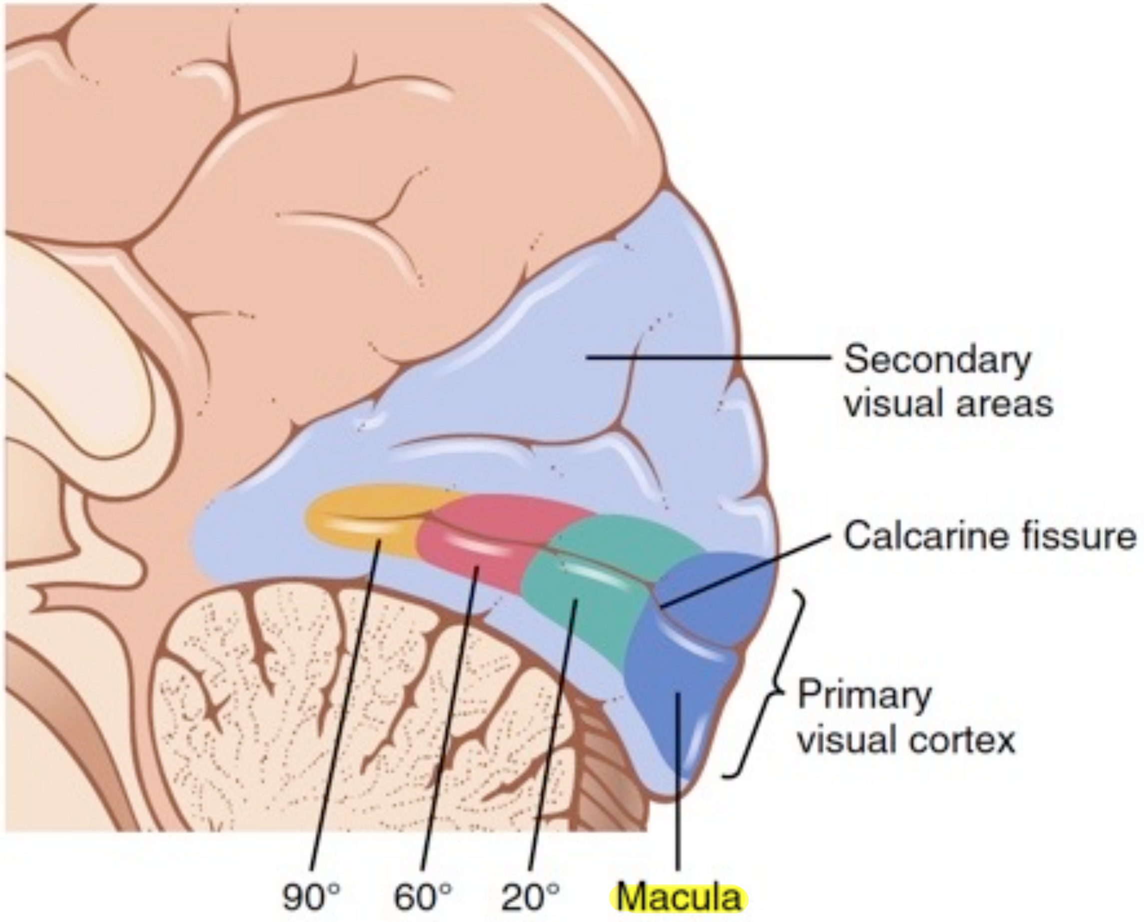
The cerebral cortex is composed of six layers, with the fourth layer being responsible for receiving sensory information.

- Layers and columns

Each column within the cerebral cortex functions as a team member, working together to integrate information for the visual system.

- Based on retinal area, the fovea has several hundred times as much representation in the primary visual cortex as do the most peripheral portions of the retina.

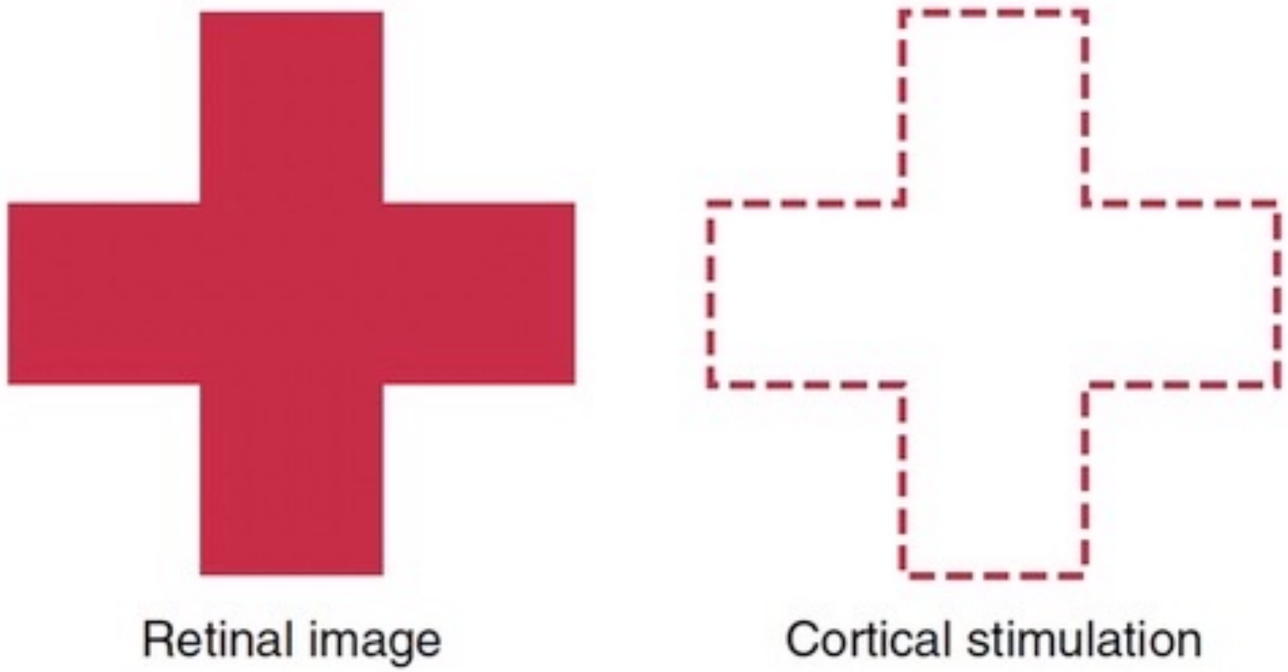
Like in somatosensory tract there were a representation of the body called homunculus, here also we have representation for the retina, where fovia and macula have the highest representation.



These degrees represent the reflection of light on the retina.

Primary visual cortex

- The areas of maximum excitation occur along the sharp borders of the visual pattern.
- Thus, the visual signal in the primary visual cortex is concerned mainly with contrasts in the visual scene, rather than with noncontrasting areas.
- Color is detected in much the same way that lines are detected—by means of color contrast.


Retinal image
Cortical stimulation

Primary visual cortex

- The visual cortex detects not only the existence of lines and borders in the different areas of the retinal image but also the direction of orientation of each line or border—that is, whether it is vertical or horizontal or lies at some degree of inclination.
- This capability is believed to result from linear organizations of mutually inhibiting cells that excite second-order Neurons when inhibition occurs all along a line of cells where there is a contrast edge.
- Thus, for each such orientation of a line, specific neuronal cells are stimulated.
- A line oriented in a different direction excites a different set of cells. These neuronal cells are called simple cells. They are found mainly in layer IV of the primary visual cortex.

Visual cortex

- “Complex” Cells Detect Line Orientation When a Line Is Displaced Laterally or Vertically in the Visual Field.

- Some neurons in the outer layers of the primary visual columns, as well as neurons in some secondary visual areas, are stimulated only by lines or borders of specific lengths, by specific angulated shapes, or by images that have other characteristics. That is, these neurons detect still higher orders of information from the visual scene.

- They respond selectively to changes in contrast that occur at the boundaries between different regions of a visual scene.
- Remember the most important concept in vision is the **contrast**

Visual pathways

- after leaving the primary visual cortex, the visual information is analyzed in two major pathways in the secondary visual areas:

- 1. Analysis of Third-Dimensional Position, Gross Form, and Motion of Objects.
- The signals transmitted in this position-form-motion pathway are mainly from the large M optic nerve fibers of the retinal M ganglion cells, transmitting rapid signals but depicting only black and white with no color.

Imagine that around 40% of the cerebral cortex is involved with processing visual information !!!!

Visual pathways

- 2. Analysis of Visual Detail and Color:
- the principal pathway for analysis of visual detail.
- Separate portions of this pathway specifically dissect out color as well.
- Therefore, this pathway is concerned with recognizing letters, reading, determining the texture of surfaces, determining detailed colors of objects, and deciphering from all this information what the object is and what it means.

Stereopsis

- Because the two eyes are more than 2 inches apart, the images on the two retinas are not exactly the same.
- The closer the object, the greater the disparity.
- Therefore, it is still impossible for all corresponding points in the two visual images to be exactly in register at the same time.
- This degree of nonregister provides the neural mechanism for stereopsis, an important mechanism for judging the distances of visual objects.
- the distance is determined by which set or sets of pathways are excited by nonregister or register. This phenomenon is also called depth perception.

Eye movement

- To summarize, posterior “involuntary” occipital cortical eye fields automatically “lock” the eyes on a given spot of the visual field and thereby prevent movement of the image across the retinas.

Lock the eye on a given spot of visual field = لما شخص يسرح

- To unlock this visual fixation, voluntary signals must be transmitted from cortical “voluntary” eye fields located in the frontal cortices.

Voluntary eye movement such as blinking, this voluntary movement will be controlled by the premotor area.

Saccadic movement

- When a visual scene is moving continually before the eyes, such as when a person is riding in a car, the eyes fix on one highlight after another in the visual field, jumping from one to the next at a rate of two to three jumps per second. The jumps are called saccades.
- The saccades occur so rapidly that no more than 10% of the total time is spent moving the eyes, with 90% of the time being allocated to the fixation sites. Also, the brain suppresses the visual image during saccades, so the person is not conscious of the movements from point to point.

Eye movement

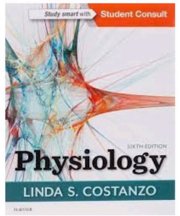
- During the process of reading, a person usually makes several saccadic movements of the eyes for each line.
- In this case, the visual scene is not moving past the eyes, but the eyes are trained to move by means of several successive saccades across the visual scene to extract the important information.

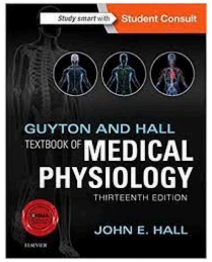
- The eyes can also remain fixed on a moving object, which is called pursuit movement.
- A highly developed cortical mechanism automatically detects the course of movement of an object and then rapidly develops a similar course of movement for the eyes.

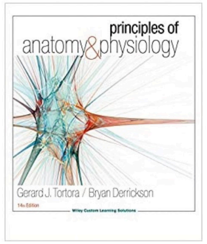
سعيت دومًا نحو المعرفة والحقيقة، وآمنت بأني لكي أتقرب إلى الله، ليس
هنا أفضل من أن أبحث عن المعرفة والحقيقة.— الحسن ابن الهيثم.

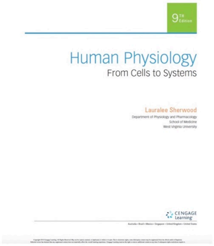
References

المرجع الأساسي يعود للحسن ابن الهيثم، أول من شرّح العين وواضع علم البصريات.









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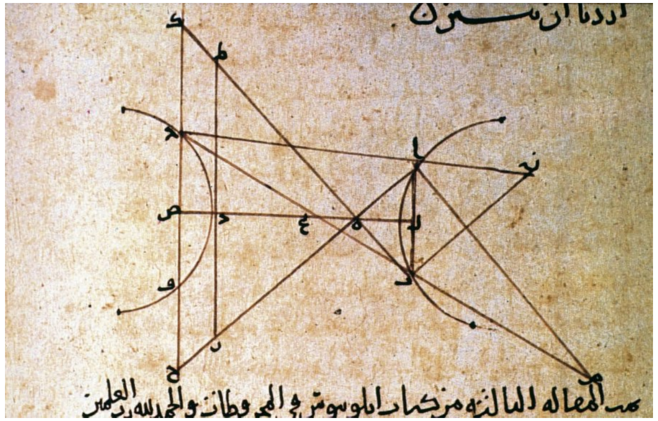

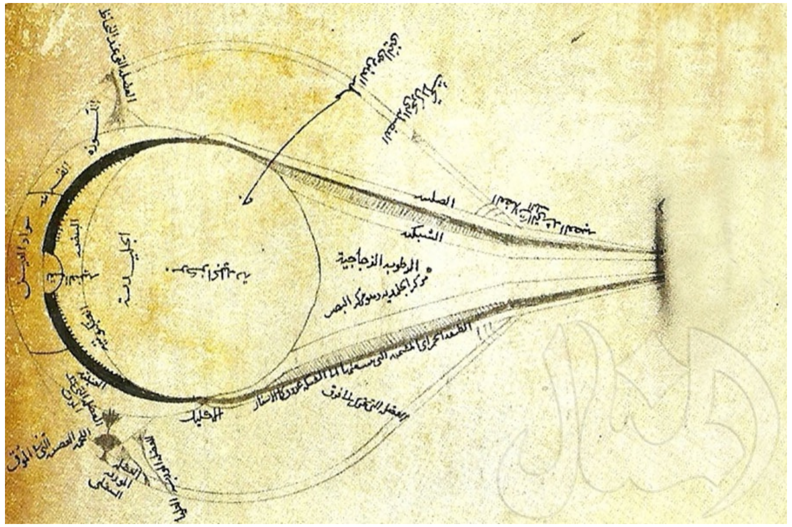

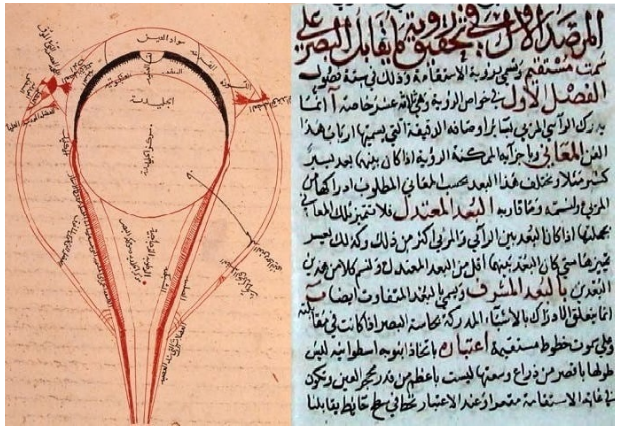

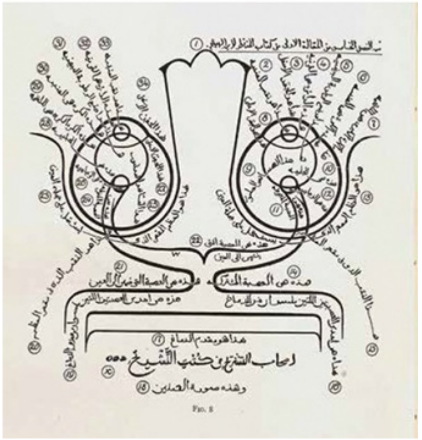

Thank you