NSII
Spring 2024
Lecture 3
Retinal processing of visual images and neurophysiology of central vision

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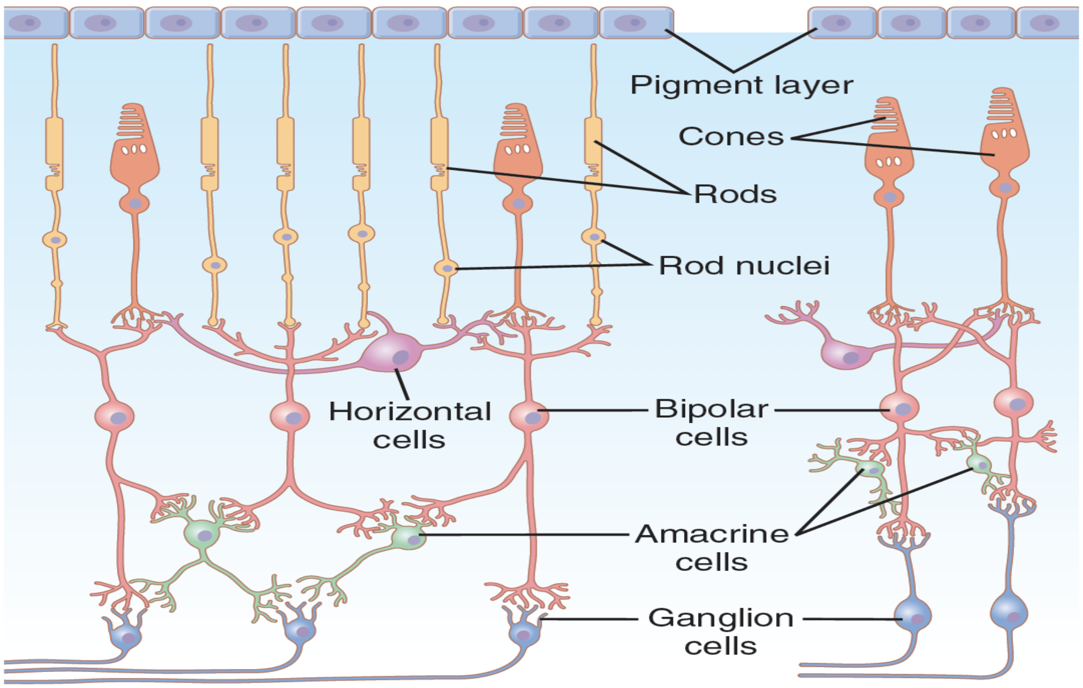
Lecture objectives

- Identify the functions of neuronal cells in the retina and their receptive field
- Review the neuronal central path ways of visual signals
- Describe the functions of LGN and the its laminar organization
- Describe the retinal input to the LGN and its out put to the visual cortex
- Identify the location of the primary and secondary visual cortex and their function
- Understand the columnar organization of the visual cortex
- Describe the receptive field of various cortical cells and their function

Synaptic connection in retina

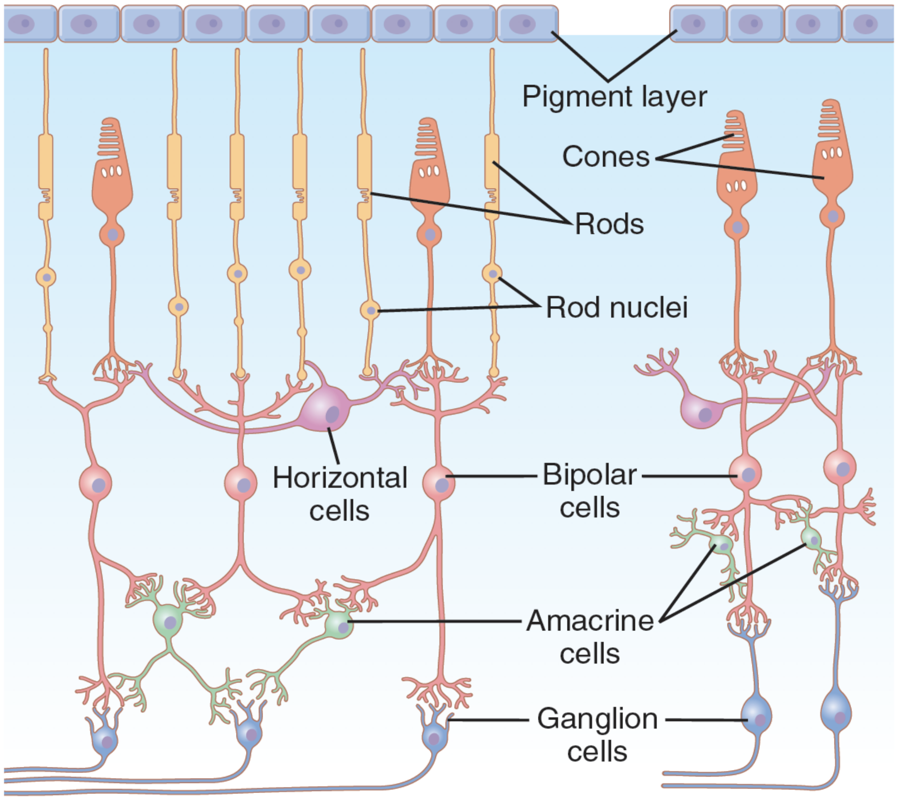


Synaptic Connections in retinal

- The photoreceptors—the rods and cones—which transmit signals to the outer plexiform layer, where they synapse with bipolar cells and horizontal cells
- The horizontal cells, which transmit signals horizontally in the outer plexiform layer from the rods and cones to bipolar cells
- The bipolar cells, which transmit signals vertically from the rods, cones, and horizontal cells to the inner plexiform layer, where they synapse with ganglion cells and amacrine cells
- The amacrine cells, which transmit signals in two directions, either directly from bipolar cells to ganglion cells or horizontally within the inner plexiform layer from axons of the bipolar cells to dendrites of the ganglion cells or to other amacrine cells
- The ganglion cells, which transmit output signals from the retina through the optic nerve into the brain

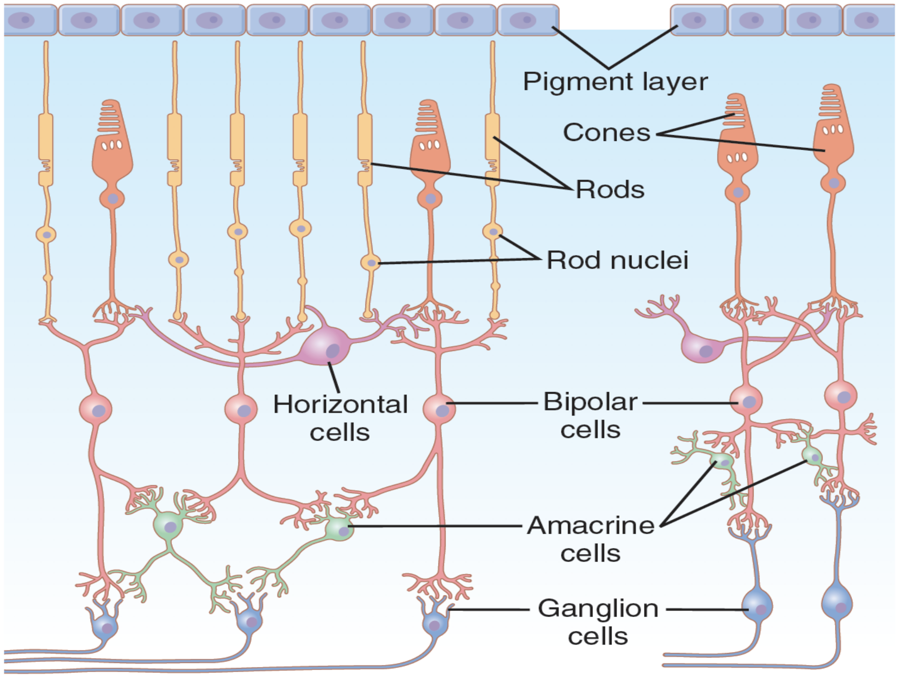
Foveal central vision
Con vision

- Direct pathway: (1) cones; (2) bipolar cells; and (3) ganglion
- Horizontal cells transmit inhibitory signals laterally in the outer plexiform layer, and amacrine cells transmit signals laterally in the inner plexiform layer. (Lateral inhibition)
- Low degree of convergence
- In the central fovea one cone make a synapse with one bipolar cells
- High degree of visual acuity



Peripheral visions

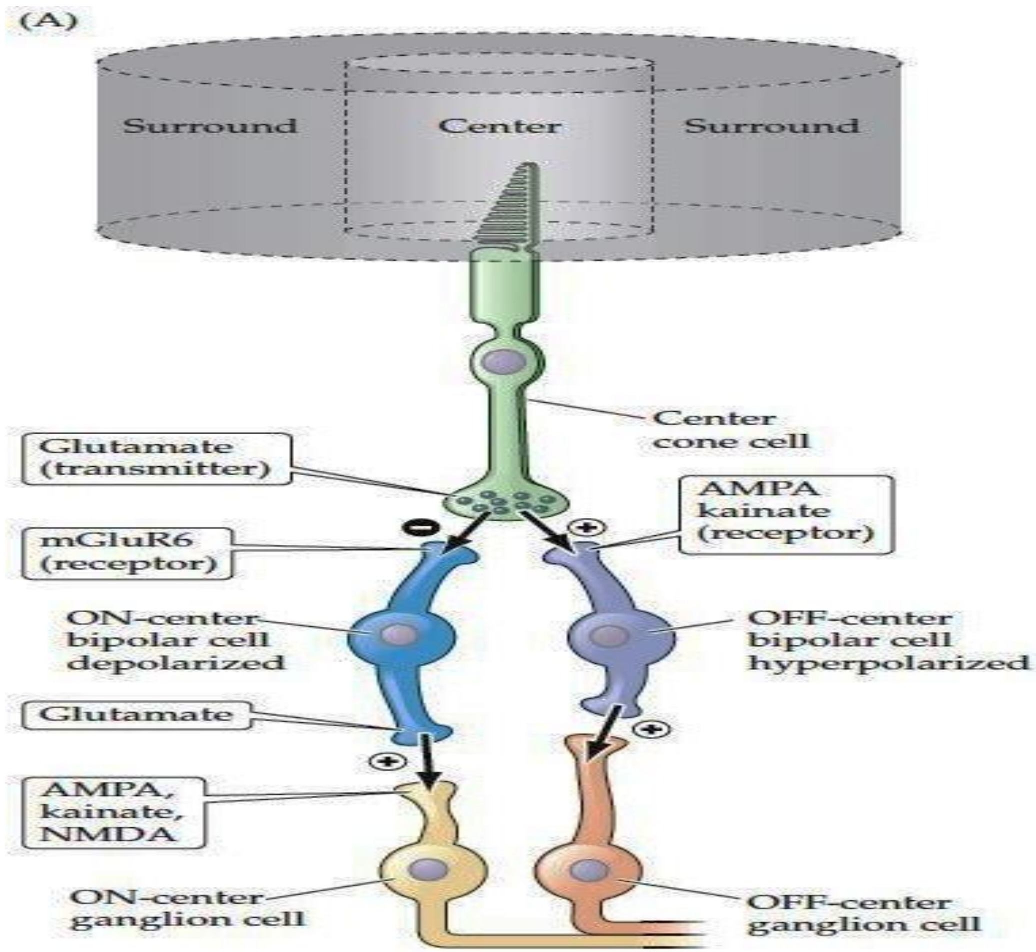
- Both rods and cones however higher density of rods
- Mainly for scotopic vision
- High degree of convergence
- Thus, for pure rod vision, there are four neurons (1) rods; (2) bipolar cells; (3) amacrine cells; and (4) ganglion
- Horizontal and amacrine cells provide lateral connectivity



Bipolar cells

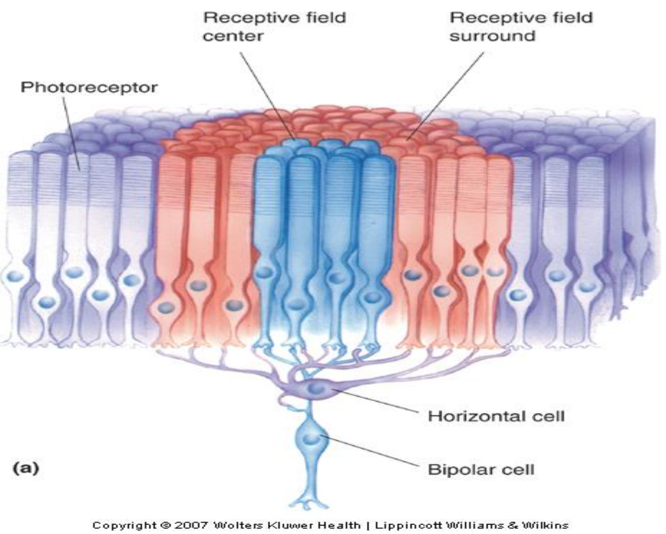
- do not generate action potentials.
- respond to the release of glutamate from photoreceptors with graded potentials (i.e., by hyperpolarizing or depolarizing).
- Depolarizing and Hyperpolarizing bipolar Cells.
- Some bipolar cells depolarize when the rods and cones are excited, and other cells hyperpolarize.
- allows half the bipolar cells to transmit positive signals and the other half to transmit negative signals.
- provides a second mechanism for lateral inhibition, in addition to the horizontal cell mechanism.

Depolarizing and hyperpolarizing Bipolar cells

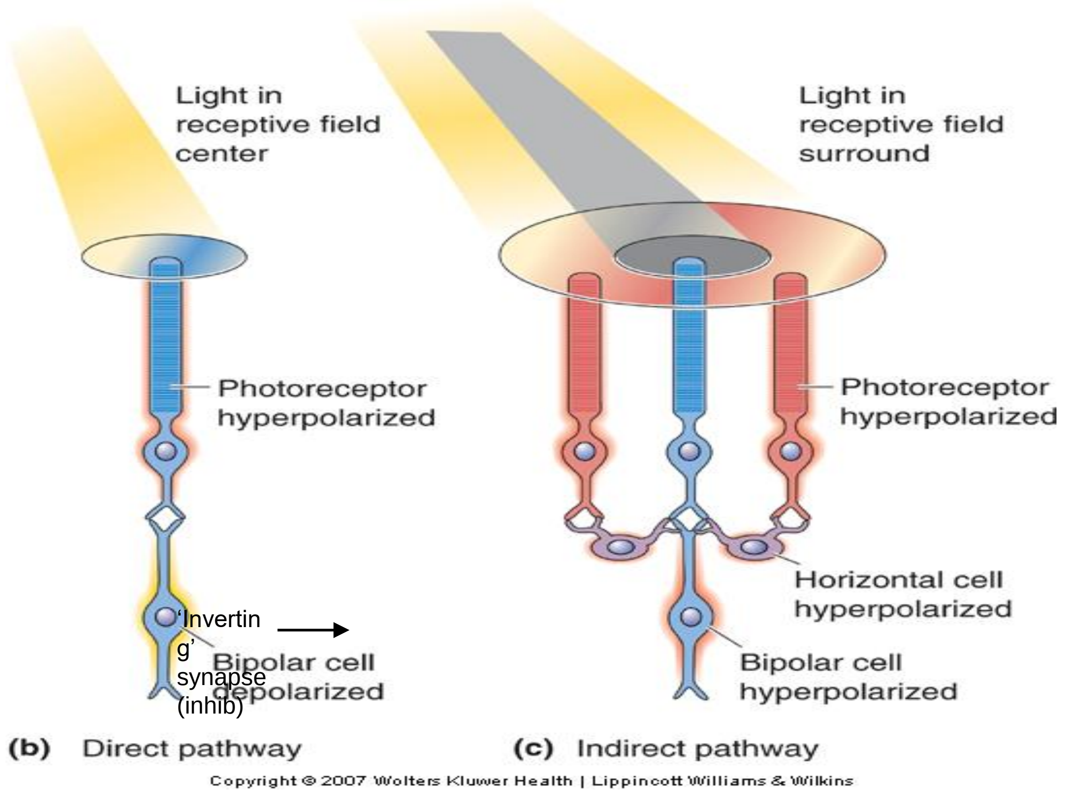


How to explain that we have depolarizing and hyperpolarizing cells

- One explanation is that the two bipolar cells are of entirely different types, with one responding by depolarizing in response to the glutamate neurotransmitter released by the rods and cones and the other responding by hyperpolarizing.
- The other possibility is that one of the bipolar cells receives direct excitation from the rods and cones, whereas the other receives its signal indirectly through a horizontal cell.



Bipolar cells

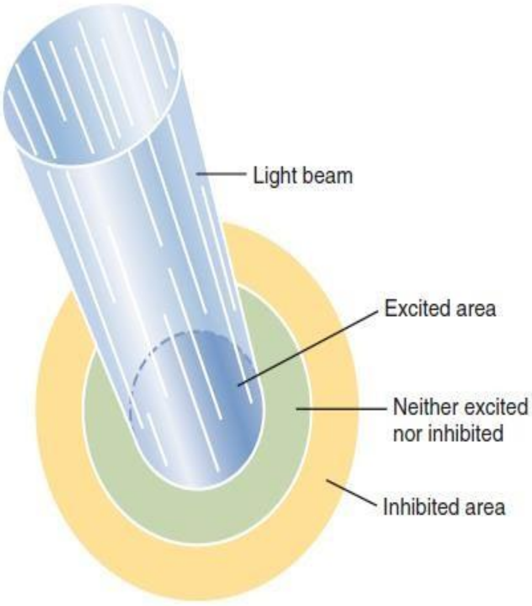


Excitation and inhibition of a retinal area caused by a small beam of light, demonstrating the principle of lateral inhibition

The inhibition of the response to central illumination by an increase in surrounding illumination is an example of lateral inhibition

This form of inhibition in which activation of a neural unit is associated with inhibition of the activity of nearby units.

It is a general phenomenon in mammalian sensory systems and helps sharpen the edges of a stimulus and improve discrimination and enhances visual contrast



Lateral Inhibition
Function of horizontal cells

- Enhance Visual Contrast.
- horizontal cells connect laterally between the rods and cones and the bipolar cells
- output of horizontal cells is always inhibitory.
- prevents the lateral spread of light excitation on the retina.
- Enhance Visual Contrast
- Essential for transmitting contrast borders in the visual image.
- 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.

Function of Amacrine Cells

- About 30 different types
- Major carrier of rods signals to ganglion cells
- Some involved in the direct pathway from rods to bipolar to amacrine to ganglion cells
- Some amacrine cells respond strongly to the onset of the visual signal, some to the extinguishment of the signal
- Some respond to movement and direction of movement of the light signal across the retina
- Amacrine cells are a type of interneuron that aid in the beginning of visual signal analysis in the retina
- Summary amacrine cells help analyze visual signals before they leave the retina.

Types of Ganglion Cells

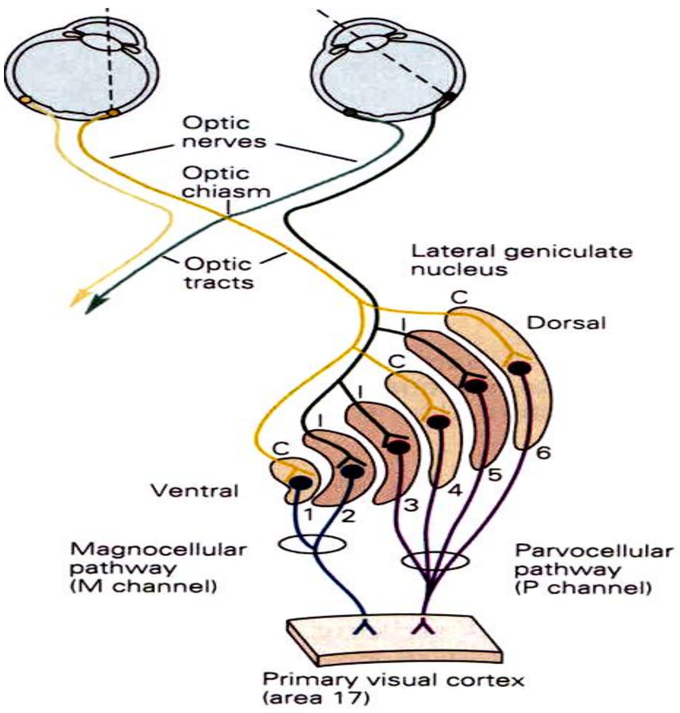
1- parvocellular (P) cells-beta/midget ganglion cells (in central retina)

- ✓project to the parvocellular (small cells) layer of lateral geniculate nucleus (LGN) of thalamus.

2- magnocellular (M) cells-alpha/parasol cells

- ✓project to magnocellular (large cells) layer of LGN

3- Melanopsin containing cells: control circadian rhythms

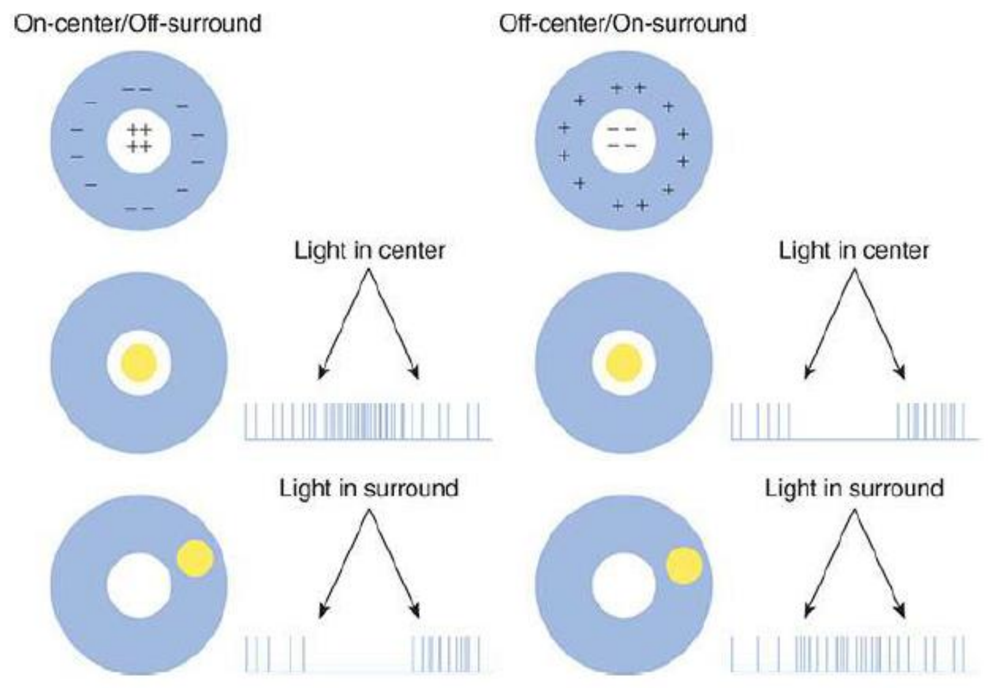


Comparison between P and M Cells

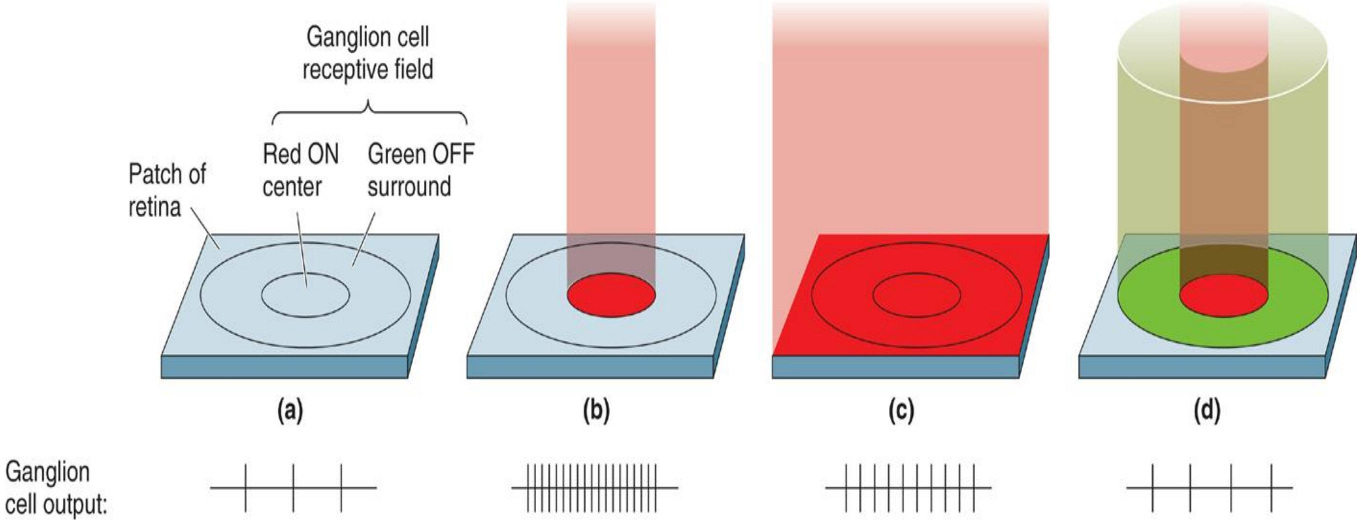
	P cells	M cells
Receptive fields	smaller	larger
Conduction	slower	faster
Response to stimuli	sustained	transient
Sensitivity to color	sensitive	Not sensitive
Sensitivity to black & white	Less sensitive	More sensitive
Function	Fine details (color and texture)	Detection of movement and change in light intensity

Response characteristics of ganglion cell to light
On center -off surround response

An *on center/ off-surround* cell responds with an increase in firing rate when the light is
placed in the center of the receptive field and with a decrease in firing rate when
the light is placed in the surround portion of the receptive field. **Right side:** An *off-center/on-surround* cell responds with a decrease in firing rate when the light is placed in the center and with an increase in firing rate when the light is placed
in the surround.
This pattern f response could be due to
1. the presence of depolarizing and hyperpolarizing cells
2. Lateral inhibition

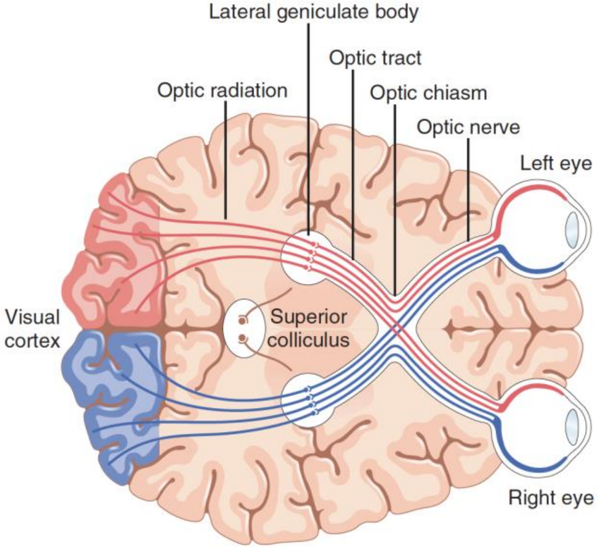


Ganglion cell response to color



Visual Pathways to the Brain

- optic nerve.
  - axons of ganglion cells of the retina.
- optic chiasm.
  - all fibers from the nasal halves of the retina cross to the opposite side and join fibers from the opposite temporal retina to form the optic tracks.
- synapse in the dorsal lateral geniculate nucleus (LGN).
- from LGN→ geniculocalcarine fibers to primary visual cortex by way of the optic radiation (geniculocalcarine tract).
- visual cortex in calcarine fissure in medial occipital lobe.



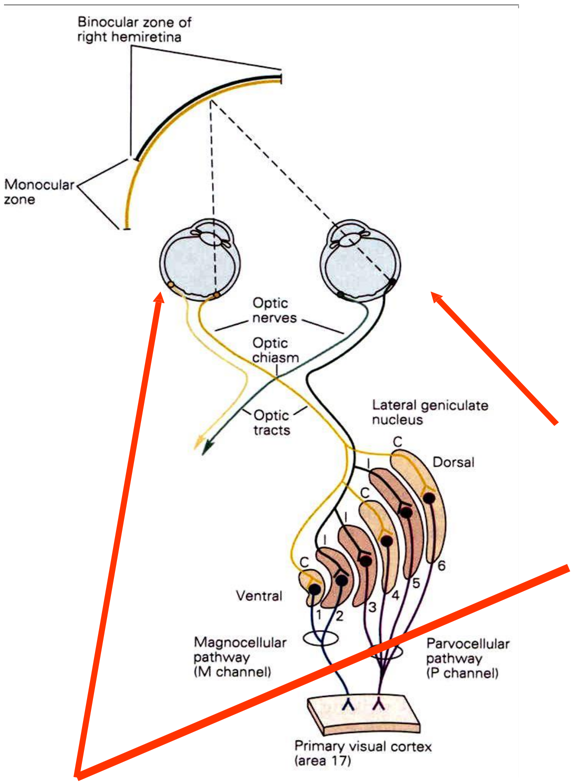
Optic tract Projections to Subcortical Regions

- suprachiasmatic nucleus of the hypothalamus.
  - control of circadian rhythms??
- pretectal nuclei.
  - pupillary light reflex.
  - accommodation of the lens.
- superior colliculus
  - rapid directional movement of both eyes.
- ventral lateral geniculate
  - control of bodies behavioral functions??

Function of the LGN

- Relay of information to primary visual cortex
- Gate Control" of information to primary visual cortex
- LGN receives input from corticofugal fibers originating in the primary visual cortex.
- input from reticular areas of the midbrain.
- both inputs are inhibitory and can turn off transmission of the signal in select areas of the LGN.
- both inhibitory inputs presumably control the visual input that is allowed to pass to the cortex

Lateral Geniculate Nucleus Layers and retinal inputs



Half of the fibers in each optic tract are derived from one eye, and half from the other eye.

Signals from the two eyes are kept apart in the LGN.

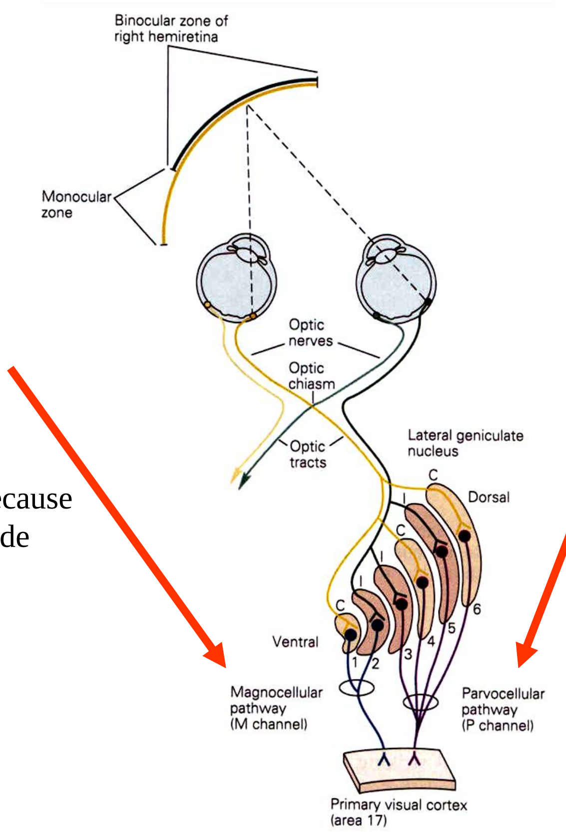
Layers 2, 3, and 5 receive input from ipsilateral eye

Layers 1, 4, and 6 receive input from
contralateral eye

Functional Organization of the LGN

magnocellular layers

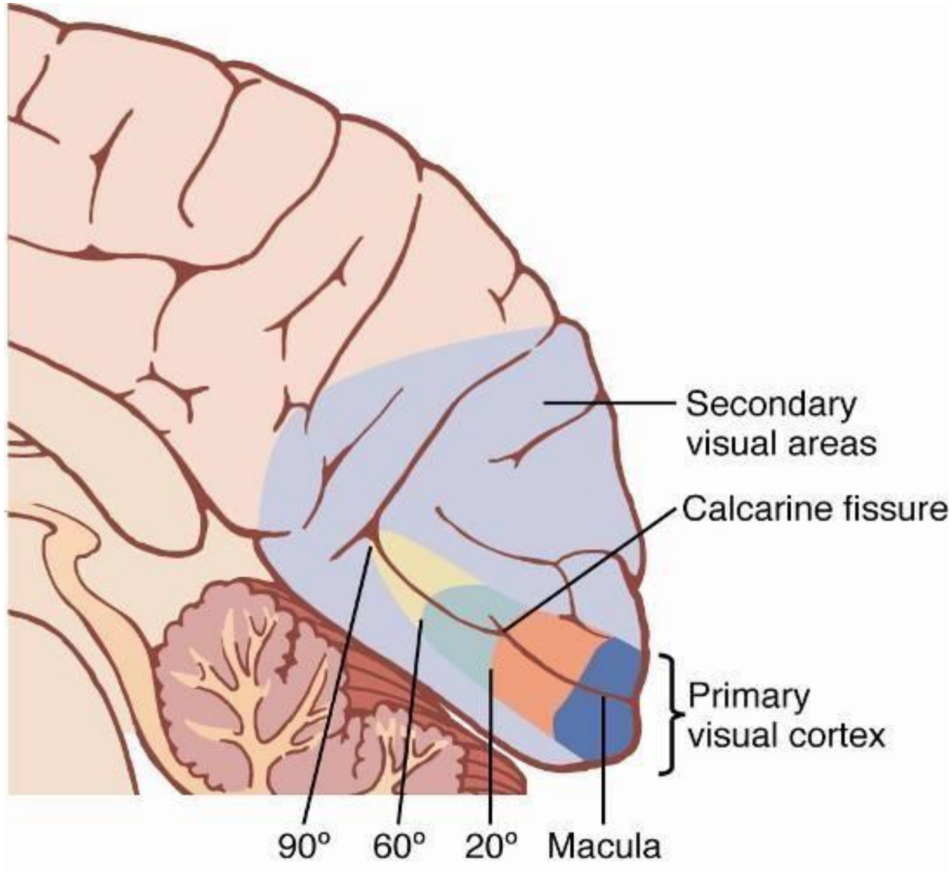
Layers 1-2
Large neurons
Input from M retinal ganglion cells
Rapid conduction
Blak & white vision
Magnocellular pathway
poor point-to-point transmission because of limited number of M cells & wide dendritic spread in retina.



parvocellular layers

Layers 3-6
Small-medium neurons
Input from P type ganglion cells
Moderate conduction
Color vision
Parvocellular pathway
Accurate point-to-point transmission

The visual cortex
Primary and secondary visual cortex



Location of visual areas in the cortex

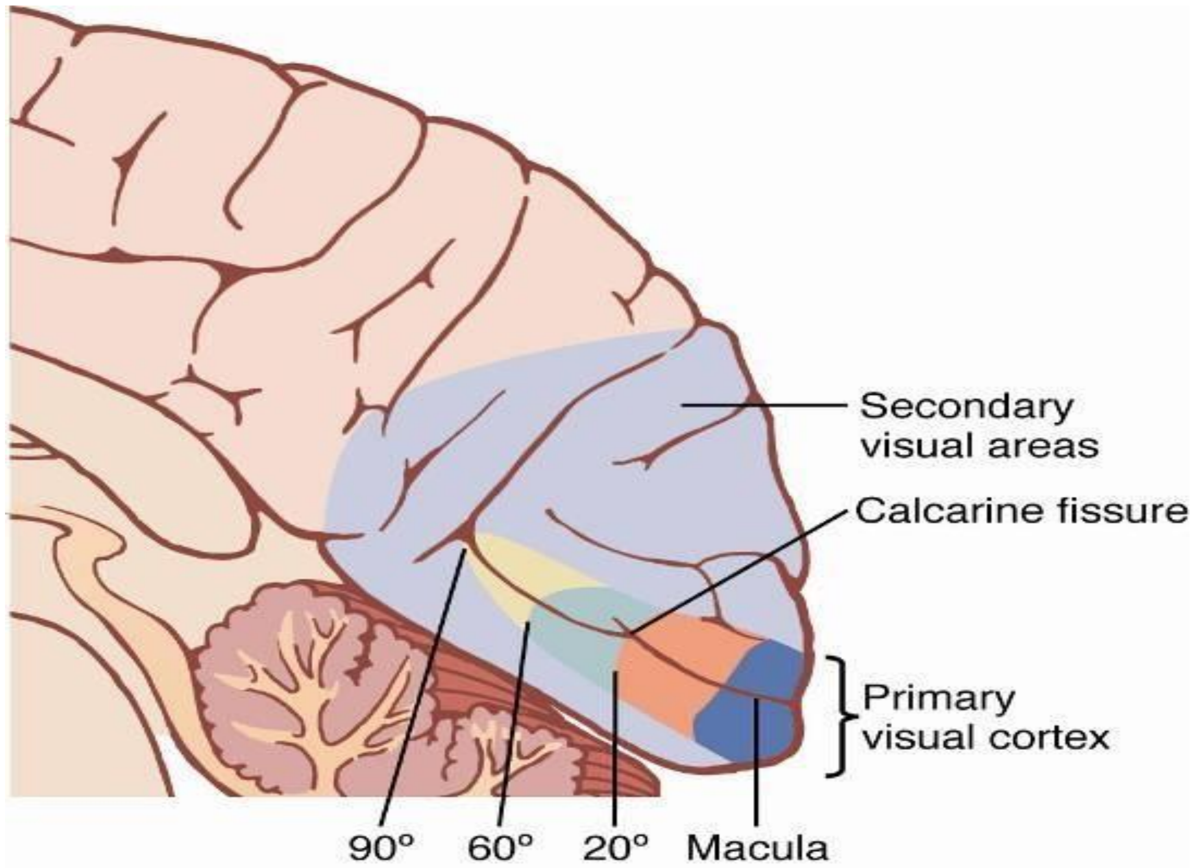
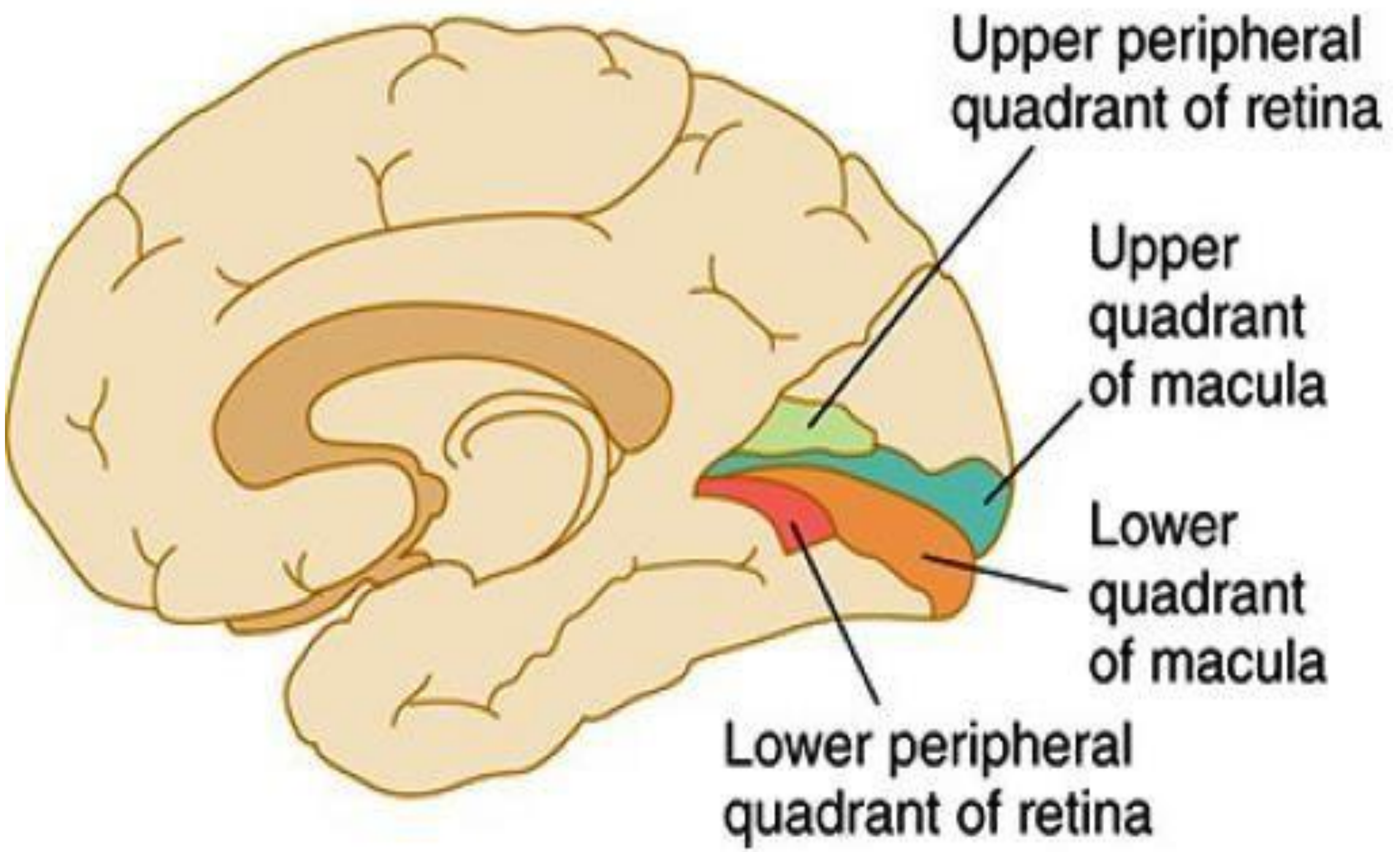
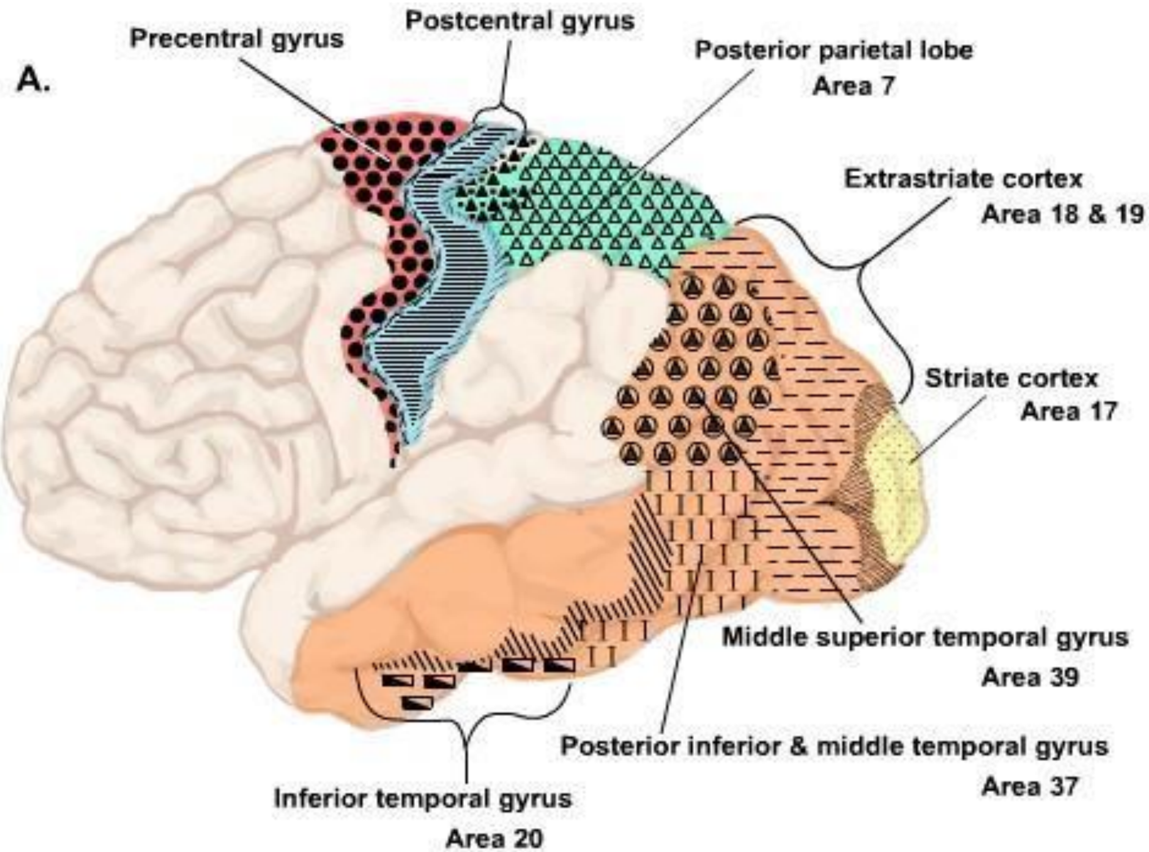


Figure 51-2

Medial view of the human right cerebral hemisphere showing projection of the retina on the primary visual cortex in the occipital cortex around the calcarine fissure.



Primary and visual association areas



Primary Visual Cortex
visual area I or the *striate cortex*

- located in the occipital lobe in the calcarine fissure region.
- large representation in visual cortex for the macula (region for highest visual acuity).
- layered structure like other cortical areas.
- columnar organization as well.
- receives the primary visual input from LG .

Visual cortex

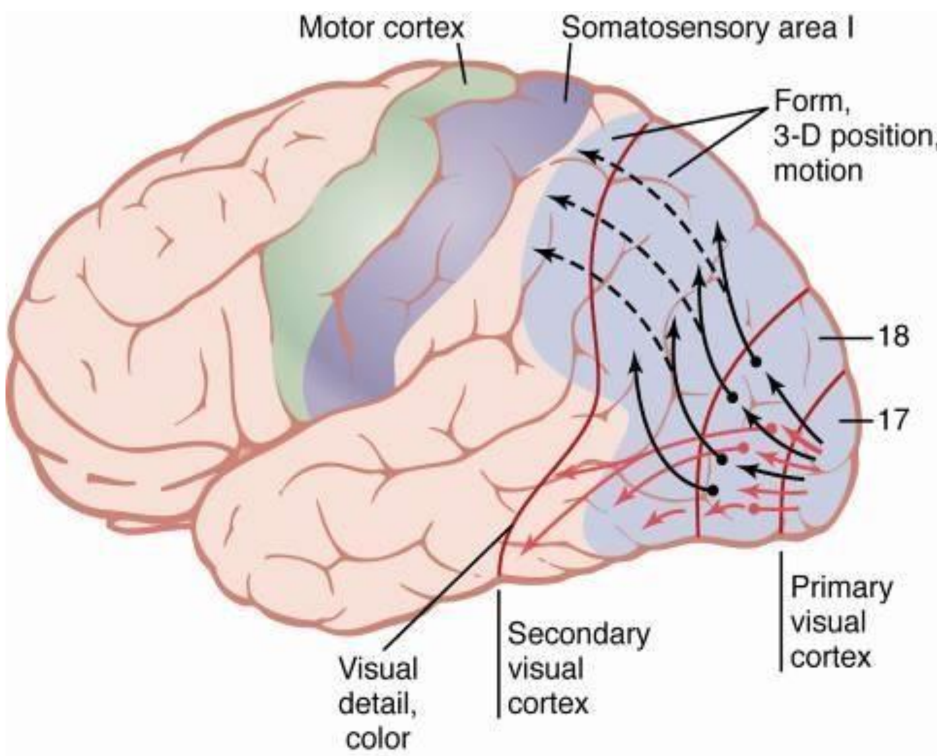
- Signals from the macular area of the retina terminate near the occipital pole
- signals from the more peripheral retina terminate at or in concentric half circles anterior to the pole but still along the calcarine fissure on the medial occipital lobe.
- The upper portion of the retina is represented superiorly, and the lower portion is represented inferiorly.

Function of visual association area

- The visual association cortex extends anteriorly from the extrastriate cortex to encompass adjacent areas of the posterior parietal lobe and much of the posterior temporal lobe
- visual association cortex responsible for analyzing the visual information related to
  - dimensional position
  - gross form, shape and motion.
  - color analysis
  - location and motion

Visual Perception and visual association area

Ventral stream Inferior, ventral,* and *medial regions* of the *occipital* and *temporal cortex
Visual details colors and object recognition
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.



Dorsal stream posterior mid temporal area and upward into the broad *occipitoparietal cortex.*

Figure 51-3

Function of dorsal visual association area

- These dorsally located visual association neurons are responsible for producing our sense of spatial orientation
- the location, the movement and the movement , direction and velocity of objects in space.
- The dorsal stream processes information about the "where" is the visual stimulus).
- Damage the dorsal visual association cortex results in deficits in spatial orientation, motion detection and in guidance of visual tracking eye movements.

Function of ventral association visual area

- The Ventral Stream: The neurons in the inferior temporal visual association cortex process information and enable us to recognize
- objects and colors
- read text and learn and remember visual objects (e.g., words and their meanings)
- This ventral stream processes information about the “what” is the visual stimulus
- Damage to the inferior visual association cortex produces deficits in complex visual perception tasks, attention and learning/memory.

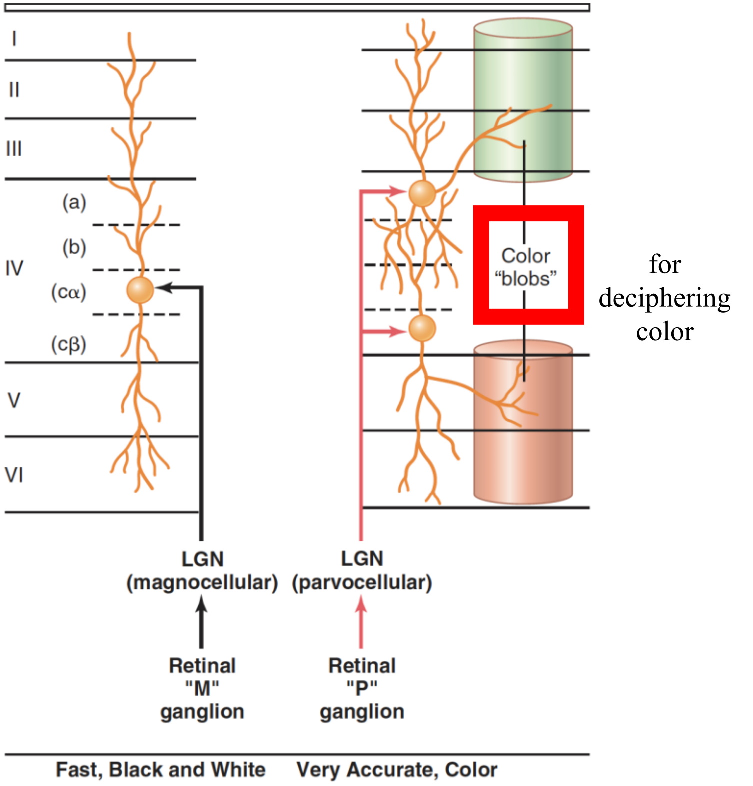
Layered/columnar structure of primary visual cortex

- 6 layers/several million vertical columns

- **geniculocalcarine** fibers terminate mainly in layer **IV-** subdivisions.
- signals from M ganglion cells →IVcα→ cortical & deeper levels.
- signals from P cells → layer IVa & IVcβ→ cortical & deeper levels.
- cortical surface & deeper levels→ to decipher separate bits of visual information at successive stations along the pathway

- signals to layers I, II, and III eventually transmit signals for short distances **laterally** in the cortex.

- signals to layers V and VI excite neurons that transmit signals much greater distances.



Vertical Neuronal Columns in the Visual Cortex

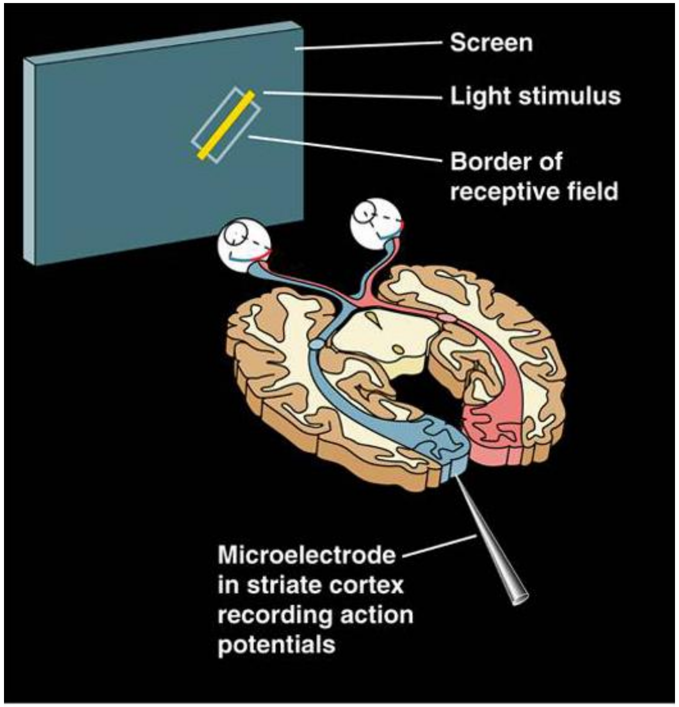
- The visual cortex is organized structurally into several million vertical columns of neuronal cells, with each column having a diameter of 30 to 50 micrometers.
- Each column represents a functional unit. One can roughly calculate that each of the visual vertical columns has perhaps 1000 or more neurons.
- **Color Blobs" in the Visual Cortex.** Interspersed among the primary visual columns, as well as among the columns of some of the secondary visual areas, are special column-like areas called *color blobs*. They receive lateral signals from adjacent visual columns and are activated specifically by color signals. Therefore, these blobs are presumably the primary areas for deciphering color.

Responsiveness of cortical neurons

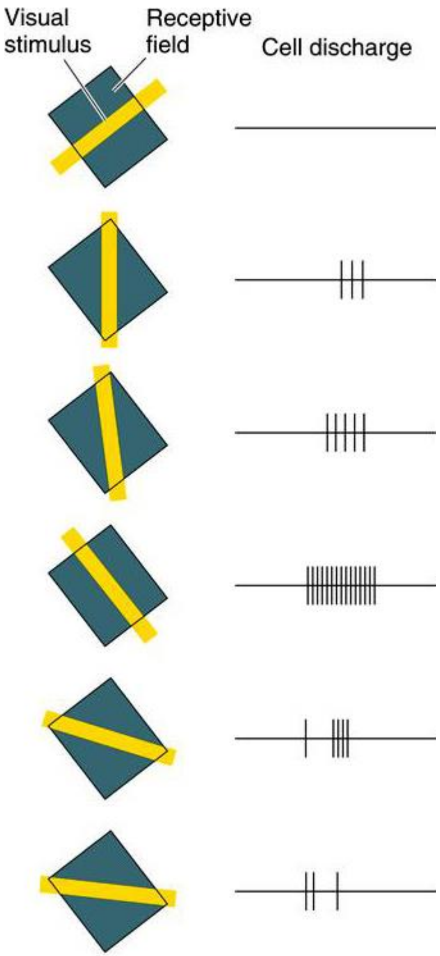
- Visual Cortex cells Detects Orientation of Lines and Borders (simple cells)
- Detect Line Orientation When a Line Is Displaced Laterally or Vertically in the Visual Field (Complex” Cells)
- Some neurons in the outer layers of the primary visual columns, as well as neurons in some secondary visual areas, are stimulated only by lines or borders of specific lengths, by specific angulated shapes, or by images that have other shapes and characteristics

Physiology of the Striate Cortex

- Cortical Receptive Fields
  - Orientation Selectivity



(a)



(b)

Physiology of the Striate Cortex

- Cortical Receptive Fields
  - Direction Selectivity
    - Neuron fires action potentials in response to moving bar of light