Chapter 6: The Visual System

FUNCTIONAL ANATOMY

Anatomically separate visual paths mediate perception and ocular reflex function

- Retina contains photoreceptors which synapse on interneurons which synapse on ganglion cells
- Ganglion cell axons travel in optic nerve and some fibers decussate at optic chiasm, then course in optic tract

The pathway to the primary visual cortex mediates the perception of visual form, color, and movement

- Thalamic target of ganglion cells = lateral geniculate nucleus (analogous to VPN for somatic sensory processing)
- Lateral geniculate projects to primary visual cortex through optic radiations (within calcarine fissure)
- Projections from primary visual cortex have three paths
  - One path ascends to secondary and higher-order visual cortical areas (occipital lobe): each area of higher order visual areas serves specific function
  - Second path decussates in corpus callosum: unifies images from two eyes
  - Third path descends to oculomotor centers of midbrain: focusing image on retina

The pathway to the midbrain is important in voluntary and reflexive control of the eyes

- Some ganglion cells bypass lateral geniculate to enter midbrain
- Enter superior colliculus through brachium of superior colliculus: control rapid eye movements and coordinate movement of head with eyes
- Enter pretectal nuclei through brachium of superior colliculus: important in papillary reflexes
- Other diencephalic and brain stem projections of optic tract: hypothalamus (diurnal hormone secretion), to midbrain nuclei for reflexive control of eye position during head movement (called accessory optic system)

REGIONAL ANATOMY

The optical properties of the eye transform visual stimuli

- The visual field is the result of vision in both eyes, there is some overlap in the middle giving us binocular vision
- Line through fovea divides retina into a nasal hemiretina and a temporal hemiretina

The retina contains five major layers

- Retina is actually a displaced portion of the CNS derived from outpouching of diencephalons
- Fovea: located in center of macula lutea, center of vision, most acute
- Optic disk: ‘blind spot’, where optic nerve goes back to brain and optic blood vessels go to and from eye
- There are five layers to the retina, ‘outer’ means farthest from center of globe, ‘inner’ means closest from center of globe
  - Outer nuclear layer: contains cell bodies of rod cells (best for night vision, uses rhodopsin, most concentrated around but not in fovea) and cone cells

    - (best for day and color vision, very concentrated at fovea, three types for three colors- red, green, blue)
  - Outer synaptic layer: where connections are made between photoreceptors and cells of inner nuclear layer
  - Inner nuclear layer:
    - Biopolar cells: link photoreceptors directly with ganglion cells
      - Cone bipolar cells: receive input from small # of cone cells (high acuity, low light sensitivity)
      - Rod bipolar cells: receive input from large # of rod cells (low acuity, high light sensitivity)
    - Horizontal and amacrine cells: enhance visual contrast, amacrine cells contain dopamine
    - Muller cells: principal retinal glial cells, stretches depth of retina
  - Inner synaptic layer: where inner nuclear layer cells contact ganglion cells
  - Ganglion cell layer: contains cells whose axons make up optic nerve, non-myelinated to increase transparency on surface of retina, become myelinated once they form optic nerve
- Other nonneuronal parts of retina
  - Pigment epithelium: external to photoreceptors; phagocytic role by removing old segment discs; defective in retinitis pigmentosa; can become detached from rest of retina by blow to head or age
  - Arterial supply of inner retina is by branches of the ophthalmic artery; outer retina has no blood vessels, gets nourishment from choroidal circulation

Each optic nerve contains all of the axons of ganglion cells in the ipsilateral retina

- Fibers of ganglion cells from nasal hemiretina cross at optic chiasm while those from temporal hemiretina do not
- End result: info from left visual field goes to right half of visual cortex, info from right visual field goes to left half of visual cortex

The superior colliculus is important in oculomotor control and orientation

- Some fibers from optic tract skip the lateral geniculate nucleus and go to superior colliculus through brachium of the superior colliculus
- Contains 7 layers (first three are retinotopically organized)
  - 1: receives direct retinal projections
  - 2 and 3: receive indirect projections from interneurons of 1
  - 4-7: receive somatic sensory (ex. spinotectal tract of AL system), auditory info
- Superior colliculus helps to orient eyes and head to stimulus, superior colliculus does this by integrating info from different sensory systems
- Layers are aligned according to a spatial map of external world: ex. Neurons that respond to stuff from superior visual field will be dorsal to neurons that respond to sounds from above and in front of head
- Descending

Ganglion cell axons from the ipsilateral and contralateral halves of the retina terminate in different layers of the lateral geniculate nucleus

- The major retinal projection is to the lateral geniculate nucleus

    - Has a dorsal part
    - And a ventral part
- Lateral geniculate nucleus has 6 layers: each layer receives projections from either the contra or ipsilateral visual field (1,4,6 = contralateral, 2,3,5 = ipsilateral)

The primary visual cortex is the target of projections from the lateral geniculate nucleus

- These projections are called the optic radiations
- Fibers take an indirect course around lateral ventricle to reach target
- Some fibers representing superior visual field course rostrally within the temporal pole before going to cortex, this is called Meyer's loop (see figure 6-10)
- The primary visual cortex = area 17, higher level visual areas = 18 and 19 and are around it
- Primary visual cortex has 6 layers, 4^{th} is divided into sublaminae and contains the stripe of Gennari

The mangocellular and parvocellular systems have differential laminar projections in the primary visual cortex

- Layers of lateral geniculate receive info from either M or P cells, give rise to two information channels: magnocellular and parvocellular systems
- Ventral two layers of LGN receive input from M cells: gross features of an object
- Dorsal four layers of LGN receive input from P cells: detail, color
- Neurons from LGN project to all layers of primary visual cortex, but mostly to layer 4
    - Magnocellular projects to 4Cα
    - Parvocellular projects to 4A and 4Cβ
- Interneurons of layer 4 then send connections to other layers which distribute info

The primary visual cortex has a columnar organization

- This occurs because layer 4 sends projections vertically to other layers
    - Ocular dominance columns: receive visual input primarily from ipsi or contralateral eye
    - Orientation columns: maximally sensitive to stimuli with similar spatial orientation
- Also aggregates of neurons in layers 2 and 3 which are sensitive to color, not actually columns because only in two layers

Input from the lateral geniculate nucleus is segregated into separate ocular dominance columns in the primary visual cortex

- Axons of LGN remain segregated according to if they're ipsi or contralateral as they project to layer 4 of the visual cortex
- Above and below layer 4 info from both eyes is integrated by binocular neurons
- Binocular neurons receive most input from same eye as projects to corresponding layer 4 and a little bit from other eye, this is the basis for the formation of ocular dominance columns
- Ocular dominance columns are important for depth perception

Orientation columns are revealed by an autoradiographic mapping technique that images functional organization

- Most neurons in visual cortex respond best to a bar of a particular orientation

- Cells selective for stimulus orientation are located from layer 2 to 6, sparing a part of 4

High levels of cytochrome oxidase activity distinguish clusters of color-sensitive neurons in layers 2 and 3

- Parvocellular color sensitive neurons send a few axons to layers 2 and 3
- Aggregates of neurons that respond to a particular wavelength are located in the center of ocular dominance columns, these cells have a high concentration of cytochrome oxidase (regions are called blobs)
- Blobs look like small dots on the primary visual cortex, like alternating thick and thin stripes in secondary visual cortex (see figure 6-16)

Higher-order visual cortical areas analyze distinct aspects of visual stimuli

- Each higher order visual area contains a partial or complete representation of the retina
- Receive input from primary visual cortex and a little from the pulvinar and lateral posterior nucleus (pulvinar may be important in distinguishing the important from the unimportant, visual salience)
- Connections between visual cortical areas demonstrate both hierarchical and parallel processing
    - Motion pathway: M cells send info to magnocellular layers of LGN, info goes to layer 4Cα of cortex, then to 4B, project directly to V5 (important for motion detection and regulating slow eye movement) and indirectly to thick cytochrome oxidase stripes of V2 (important for analyzing aspects of visual form in motion)
    - Pathway for color: P cells send info to parvocellular layers of LGN, info goes to layer 4Cβ, then to color blobs, then to thin stripes in V2, and finally to V4
    - Form vision pathway: P cells send info to parvocellular layers of LGN, info goes to 4Cβ, to V2 and finally to V4
- These pathways explain brain injuries, like how people with damage to inferior temporal lobe lose object recognition, and people with damage to posterior parietal lobe can't localize objects, suggests existence of two different streams of info
    - Dorsal stream: concerned with 'where', primarily magnocellular info
    - Ventral stream: concerned with 'what', primarily parvocellular info

The visual field changes in characteristic ways after damage to the visual system

- See figure 6-22 and accompanying explanation (I can't really shorten it)