# The Central Visual System

## Introduction

There are more than 100 million photoreceptors in the retina. However, only about 1 million axons from ganglion cells leave the retina to carry information to the brain.

## Out of the Retina and into the Brain

### The Optic Nerves, Optic Chiasm, and Optic Tracts

#### Optic Nerves

- Axons from the retinal ganglion cells of the left eye leave the eye through the Left Optic nerve.
- Axons from the retinal ganglion cells of the right eye leave the eye through the Right Optic nerve.
- The retina of each eye is split into a left half and a right half

#### Optic Chiasm and Optic Tracts

- Axons from the left half of the retina of the left eye and the left half of the retina of the right eye go through the optic chiasms and continue as the left Optic Tract.
    - Axons of the left Optic Tract synapse in the left Superior Colliculus, left Hypothalamus, and left Lateral Geniculate Nucleus of the Thalamus.
- Axons from the right half of the retina of the left eye and the right half of the retina of the right eye go through the optic chiasms and continue as the right Optic Tract.
    - Axons of the right Optic Tract synapse in the right Superior Colliculus, right Hypothalamus, and right Lateral Geniculate Nucleus of the Thalamus.

## The Lateral Geniculate Nucleus (LGN) of the Thalamus

### Segregation by Eye

- There are six major layers in each Lateral Geniculate Nucleus LGN).
    - Layers 2, 3, and 5 of each LGN receive information from the ipsilateral eye (same side of body).
    - Layers 1, 4, and 6 of each LGN receive information from the contralateral eye (opposite side of body).
- Therefore information from the left and right eye remain separated:
    - Axons from the left half of the retina of the left eye synapse on neurons in layers 2, 3 and 5 of the left LGN.
    - Axons from the left half of the retina of the right eye synapse on neurons in layers 1, 4 and 6 of the left LGN.

  - Axons from the right half of the retina of the right eye synapse on neurons in layers 2, 3 and 5 of the right LGN.
  - Axons from the right half of the retina of the left eye synapse on neurons in layers 1, 4 and 6 of the right LGN.

### Segregation by Cell Type

- Layers 1 and 2 of the LGN contain Magnocellular neurons and receive information from M-type retinal ganglion cells.
  - These cells are responsive to large receptive fields and low contrast stimuli.
- Layers 3, 4, 5, and 6 of the LGN contain Parvocellular neurons and receive information from P-type retinal ganglion cells.
  - These cells are responsive to small receptive fields and high contrast stimuli.
- Ventral to each of these layers there are koniocellular neurons that receive information from nonM-nonP ganglion cells
  - These cells are responsive to color.

### Non-retinal inputs to the LGN

The retina is not the main source of synaptic input to the LGN.

- The major input to the LGN is from the Primary Visual Cortex which provide 80% of the excitatory synapses.
- Other inputs to the LGN come from the brainstem to modulate sensitivity of LGN neurons.

## Anatomy of the Striate Cortex

The Striate Cortex is also known as Primary Visual Cortex, V1, and Area 17.

### Retinotopy

- The two dimensional surface of the retina is mapped onto the two dimensional surface of the LGN and the striate cortex.
- Visual fields are distorted in proportion to the density of photoreceptors / ganglion cells.
  - More in and near the fovea, less in the periphery.
  - There are no “pictures” in the primary visual cortex.

### Lamination of the Striate Cortex

- There are “six” major layers in the striate cortex.
  - Layer 6 (VI)is next to the white matter
  - Layer 1 (I) is next to the pia mater
- Functionally there are at least nine layers; layer 4 (IV) is divided into IVA, IVB, IVCα, and IVCβ.
  - Spiny Stellate cells are found in IVCα and IVCβ.
    - These cells are small with short dendrites.

- Pyramidal cells are found in the other layers.
  - These cells are large with long branching dendrites that ascend toward the pia mater and with basal dendrites that branch horizontally.
  - Only pyramidal cells send axons out of the striate cortex.

### Inputs and Outputs of the Striate Cortex

LGN axons synapse largely in layer IVC

- Information from Magnocellular and Parvocellular layers from the right and left eye remain anatomically segregated in layer IVC
  - Magnocellular neurons synapse in layer IVCα.
  - Parvocellular neurons synapse in layer IVCβ
- Axons from LGN koniocellular neurons synapse in layers II and III.

### Ocular Dominance Columns

- Inputs to layer IVC from the right and left eye are laid out as alternating bands (or columns) when visualized perpendicular to cortical surface.

### Innervation of Other Cortical Layers from Layer IVC

- Layer IVC stellate cells send axons radially up to layers IVB and III.
  - Magnocellular neurons → layer IVCα → VIB
  - Parvocellular neurons → layer IVCβ → III
- In layers IVB and III an axon may form synapses with dendrites of pyramidal cells of all layers.

### Striate Cortex Outputs

- Pyramidal cells in layers II, III, and IVB send axons to other cortical areas.
- Pyramidal cells in layer V send axons down to the superior Colliculus and pons.
- Pyramidal cells in layer VI send axons down to the LGN.

### Cytochrome Oxidase Blobs

Pillars of cytochrome oxidase neurons are centered on ocular dominance columns – these pillars are called “blobs.”

- Blobs receive direct LGN input from koniocellular layers and from Parvocellular and Magnocellular layer IVC

# Physiology of the Striate Cortex

### Receptive Fields

The receptive fields of neurons in IVC are similar to the Magnocellular and Parvocellular LGN neurons providing their input.

- Neurons in IVC have small monocular center-surround receptive fields.
- In IVCα the neurons are insensitive to the wavelength of light.
- In IVCβ the neurons exhibit center-surround color opponency.

## Binocularity

- Most neurons superficial to IVC are binocular.

## Orientation Sensitivity

- Many (most) neurons outside of IVC respond best to an elongated bar of light and are orientation specific.
- The preferred orientation remains constant for neurons encountered radially from layer II down to layer VI.
- A complete 180° shift in preferred orientation seen with about a 1mm movement of electrode tangentially.
- Orientation selective neurons appear to be specialized for analysis of object shape.

## Direction Selectivity

- Direction selective neurons appear to be specialized for analysis of object motion.

## Simple and Complex Receptive Fields

- "Simple Cells" are orientation selective neurons with distinct on and off regions.
- "Complex Cells" are orientation selective neurons with <u>no</u> distinct on and off regions.

## Blob Receptive Fields

- Most "Blob Cells" are wavelength sensitive, monocular, and lack orientation and direction sensitivity.
- Receptive fields are circular.
- Make up the great majority of color sensitive neurons outside of IVC.
- Specialized for the analysis of object color.

## Parallel Pathways and Cortical Modules

## Parallel Pathways

- Magnocellular Pathway
    - M-type Ganglion Cells → Magnocellular layers of LGN → Layer IVCα of striate cortex → Layer IVB.
    - Analysis of object motion and guidance of motor actions.
- Parvocellular Interblob Pathway
    - P-type Ganglion Cells → Parvocellular layers of LGN → Layer IVCβ of striate cortex → Layer II and III Interblob regions
    - Analysis of fine object shape.
- Blob Pathway
    - nonM-nonP Ganglion Cells → Koniocellular layers of LGN → Cytochrome Oxidase Blobs of Layer II and III of striate cortex
    - Analysis of object color.

### Cortical Modules

A 2x2 mm chunk of striate cortex is (maybe) necessary and sufficient to analyze a point in space.

- Two complete sets of ocular dominance columns.
- 16 blobs.
- A complete sampling twice of all 180° of possible orientations.

# Beyond the Striate Cortex

Processing of visual information continues past the striate cortex into regions of the parietal lobe and temporal lobe. There appear to be at least two streams of processing; a dorsal stream and a ventral stream

- The Dorsal stream analyzes visual motion and visual control of action.
    - Properties of neurons in this stream are similar to the Magnocellular neurons of the striate cortex.
- The ventral stream appears to be involved in the perception of the visual world and in the recognition of objects.

## The Dorsal Stream

### Area MT

- The middle temporal lobe (MT) (cortical area V5) receives retinotopically organized input from cortical areas V2 and V3 and directly from layer IVB of the striate cortex.
- Neurons in this area have large receptive fields.
    - Neurons respond to movement in a narrow range of directions.
    - Almost all of the neurons are direction sensitive.
    - Neurons are organized into direction-of-motion columns.

### Dorsal Areas and Motion Processing

- Beyond area MT and into the parietal lobe there are many neurons with specialized movement sensitivity.
    - Some neurons are responsive to simple linear motion (as in MT)
    - Other neurons are responsive to radial motion or circular motion.
- Together, current evidence suggests that dorsal areas may be involved in:
    - Navigation; by detection of the speed and direction of moving objects.
    - Directing eye movements; by following movement of objects in peripheral vision.
    - Motion detection and perception; by interpretation of moving objects.

## The Ventral Stream

### Area V4

- Cortical area V4 receives input from the Blob and Interblob regions of striate cortex via cortical area V2.
- Neurons in this area have larger receptive fields than in the striate cortex
  - Many cells are orientation selective and color selective.
- Area V4 appears to be important for both shape perception and color perception.

### Area IT

- The inferior temporal lobe (IT) contains neurons that have complicated spatial receptive fields.
  - Some neurons respond strongly to pictures of faces.
- The inferior temporal lobe appears to be important for visual perception and visual memory.