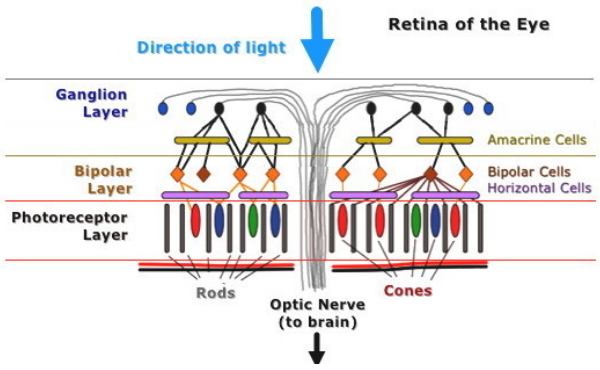
Class 20: The Neural Basis of Visual Perception (Sections 5.2 & 5.3) SIMPLIFIED

(based on Kalat, 2016, 12th ed. & earlier editions)

Note: Much of what we know about the visual system comes from research with other primates besides humans. We believe that there is a great deal of similarity between human other primates in respect to vision. However, further research may not bear all of this out.

I. Processing in the Retina



a. Photoreceptor Layer

- **6 million cones** (color) & **120 million rods** (grey)
- In or near the fovea, there tends to be one ganglion cell (see below) for each of the cones. However, in the rest of the retina, there is one ganglion cell for multiple cones and rods.

b. Bipolar Layer

- **Lateral inhibition** = reduced activity of bipolar cell because of activity of nearby bipolar cells: **sharpens boundary details between two objects in visual field**. (See diagram on left showing what happens as stimulation moves from the receptor layer to the bipolar layer)

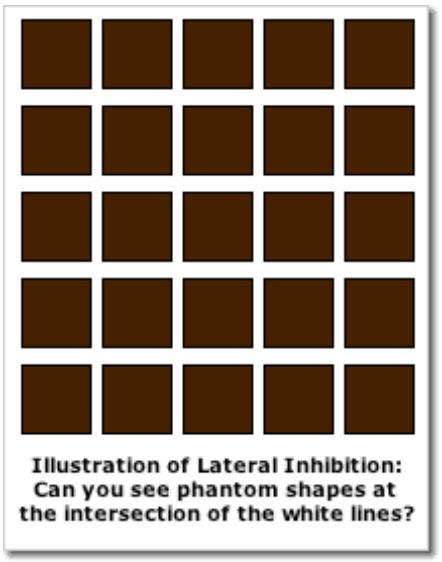
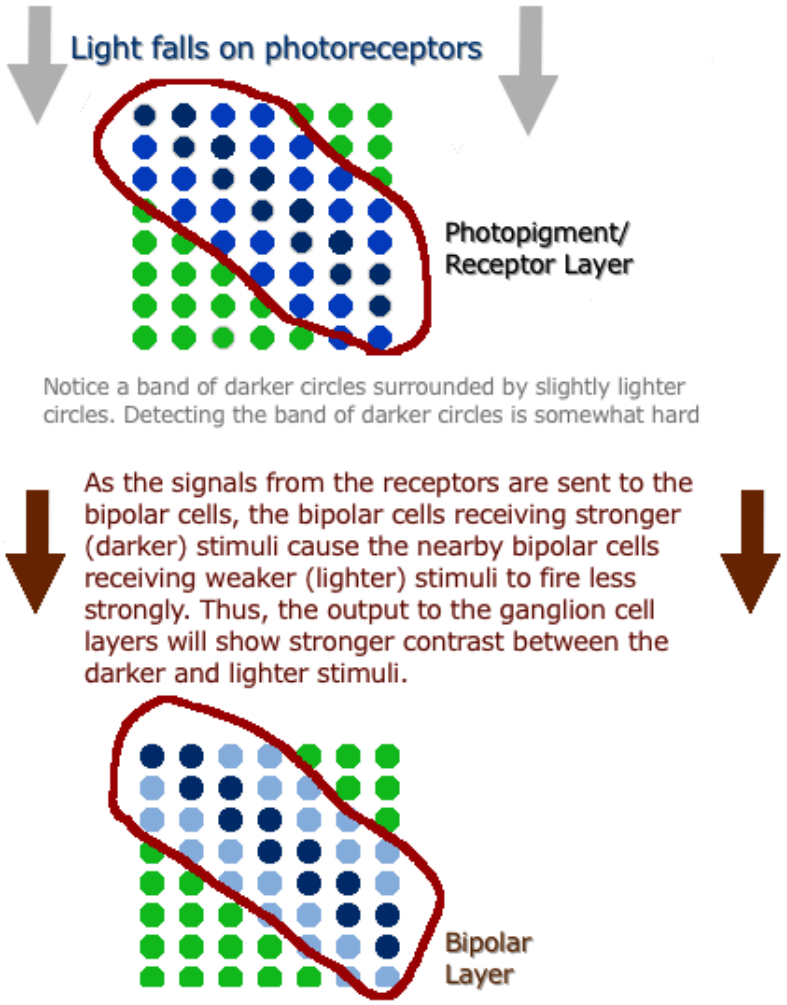


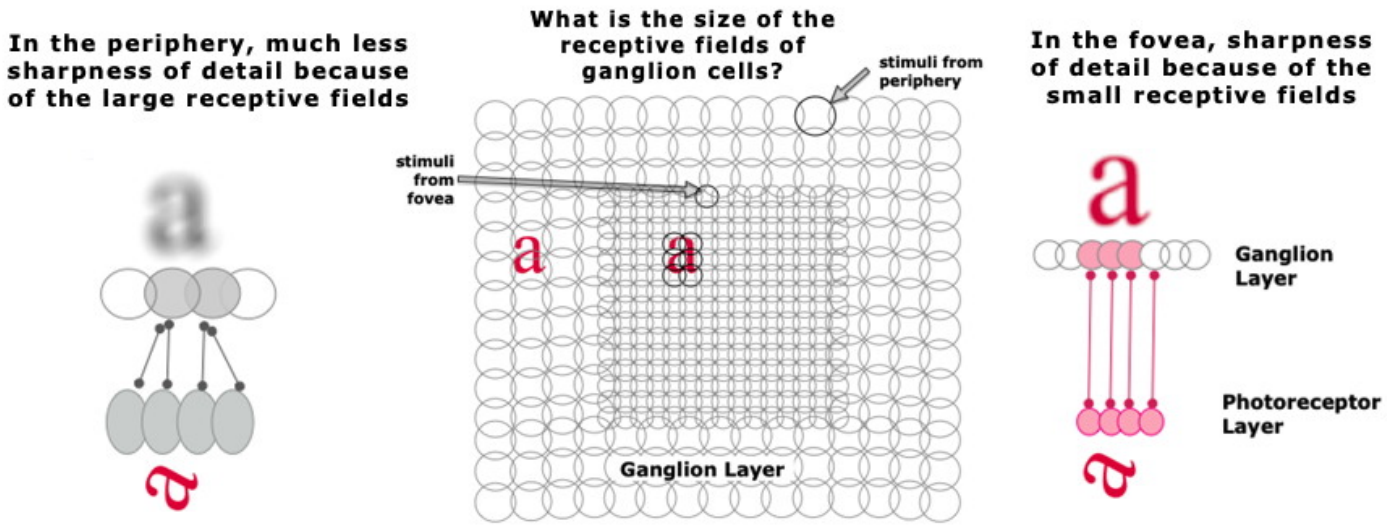
Illustration of Lateral Inhibition: Can you see phantom shapes at the intersection of the white lines?



c. Ganglion Layer

- **Receptive field** = that part of the visual field that causes excitement or inhibition of a ganglion cell. Each ganglion cell responds to a visual field that can be small (i.e., distinguishing finer details) or large (i.e., responding to broad or fuzzy details).

- Ganglion cells receiving input from the fovea have much smaller visual fields than those receiving input from the periphery of the retina. Thus, the neural signals sent into the brain from the fovea's ganglion cells contains much more detailed information than those signals sent from the peripheral ganglion cells. (see below)



The ganglion layer is made of at least 60 different types of neurons and 20 different types of ganglion cells. Of these, we will consider two types of importance to visual perception:

- **Midget Ganglion** or **Parvocellular Ganglion** cells: small cell bodies (mostly in & near fovea); small receptive fields; connect directly to the LGN (see below). Sensitive to
  - **Fine visual detail**
  - **Color**

- **Magnocellular** Ganglion cells: large cell bodies (evenly distributed across retina); large receptive fields; connect mostly to the LGN. Sensitive to
  - **Movement**
  - **Overall pattern** (large receptive fields don't register fine detail)
  - Not color sensitive

II. Pathways to the Lateral Geniculate Nucleus and Other Sites

a. Optic Nerve

- Formed by the axons of the ganglion cells. There are about 1 million axons in each optic nerve (range: 770,000-1.7 million; Jonas et al. 1992). Notice how these ~1 million axons must carry the information produced by the ~126 million receptors. Hence, the connections in the retina (particularly in the periphery) reduce the amount of information as it passes between the receptor layer and the ganglion layer.
- Projects to the **lateral geniculate nucleus** (LGN) of the thalamus (see diagram below)
- At the optic chiasm, axons from the left visual field of the left eye cross over to right side of the brain and the axons from the right visual field of the right eye cross over to the left side of the brain. Axons from the right visual field in the left eye stay on the left side of the brain and axons from the left visual field in the right eye stay on the right side of the brain (see diagram).

b. Other projections

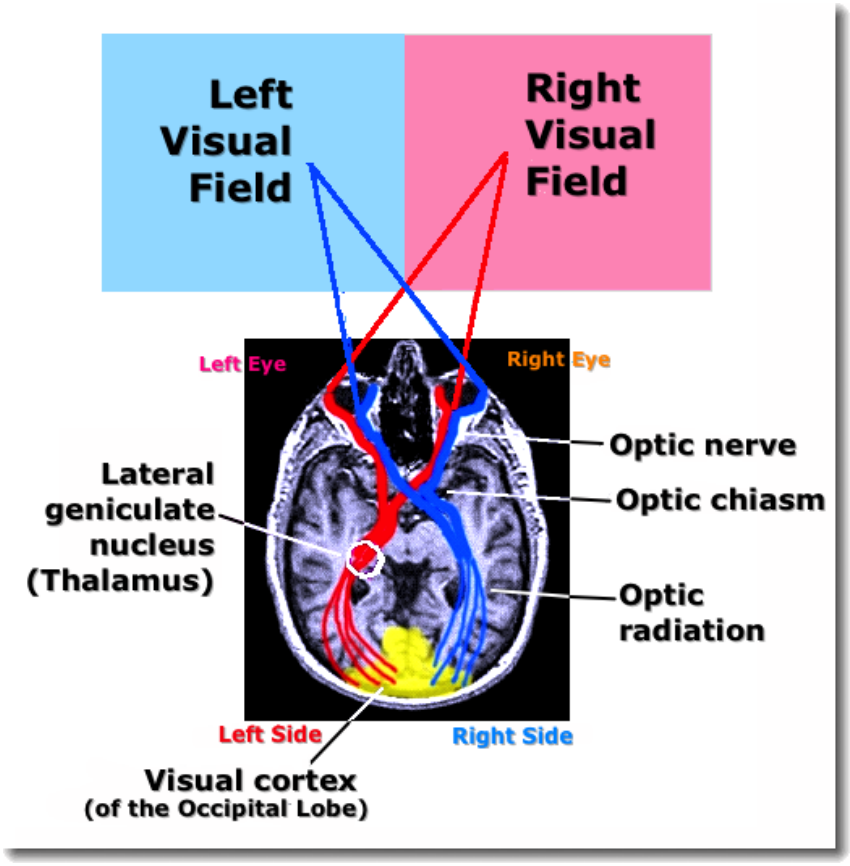
- Some axons project to the suprachiasmatic nucleus of the hypothalamus **& help control sleep-wake cycle**
- Other axons project to the superior colliculus in the midbrain which **controls pupil size** and **helps eye track moving objects through the visual field**.

c. Lateral Geniculate Nucleus (LGN) of Thalamus

- There are six layers of cells in the LGN. Ipsilateral (same side) visual information goes to layers 2, 3, & 5 while contralateral (other side) visual information goes to layers 1, 4, & 6.
- **Layers 1 & 2 are magnocellular**
- **Layers 3, 4, 5, & 6 are parvocellular**

d. Optic Radiation

- Axons from the cells in the LGN mostly project to the occipital lobe of the brain via the optic radiation.



III. Pattern Recognition in the Cerebral Cortex

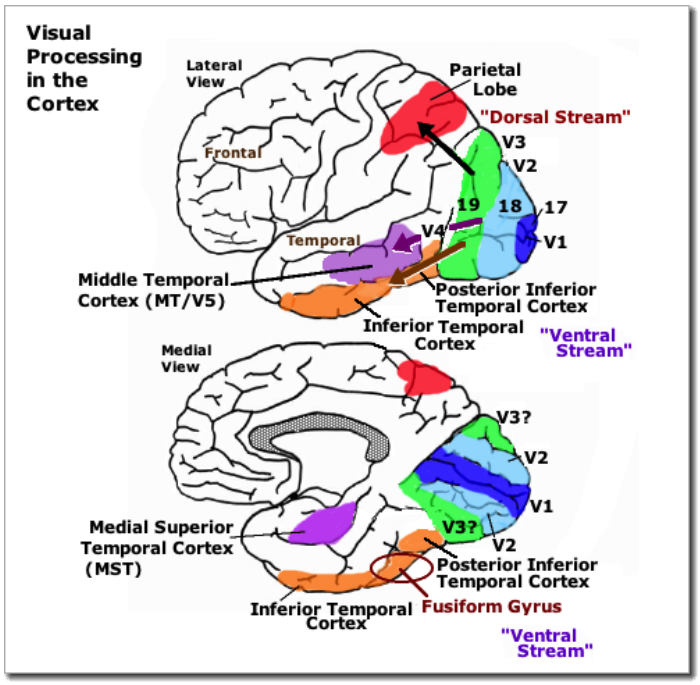
A. Occipital Cortex

- The optic radiations from the LGN go to the region of the occipital lobe known as V1 (or Brodmann area 17; see diagram below which identifies these areas).
- The occipital cortex is comprised of six major layers with multiple sublayers.
- Damage to V1 leads to cortical blindness, i.e., one has no sense of seeing anything

- However, some people experience **blindsight**, i.e., ability to respond to visual information even without consciousness of seeing anything. For example, a person might accurately point to where something was even if they cannot "see" it.
- How can we understand blindsight? Two possible answers (1) Recently a direct connection was discovered between the (koniocellular) neurons in the LGN and the middle temporal cortex (MT which is involved in sensing movement); this connection bypasses the occipital cortex and may help explain blindsight (Ajina et al, 2015). (2) There may be small areas of healthy tissue remaining in the occipital cortex which is not enough for conscious perception, but enough for other visual tasks.

B. Processing by the Visual Cortex

- Area V1 (primary visual cortex) interacts with Area V2 (secondary visual cortex; Brodmann area 18).
- There appear to be two major visual pathways from V2:
  - **Ventral Stream ("What" Pathway)** to the **temporal cortex: shape recognition & identification.**
  - **Dorsal Stream ("Where/How" Pathway)** to the **parietal cortex: integrating vision with movement, i.e., finding objects, reaching for or manipulating them, etc.**



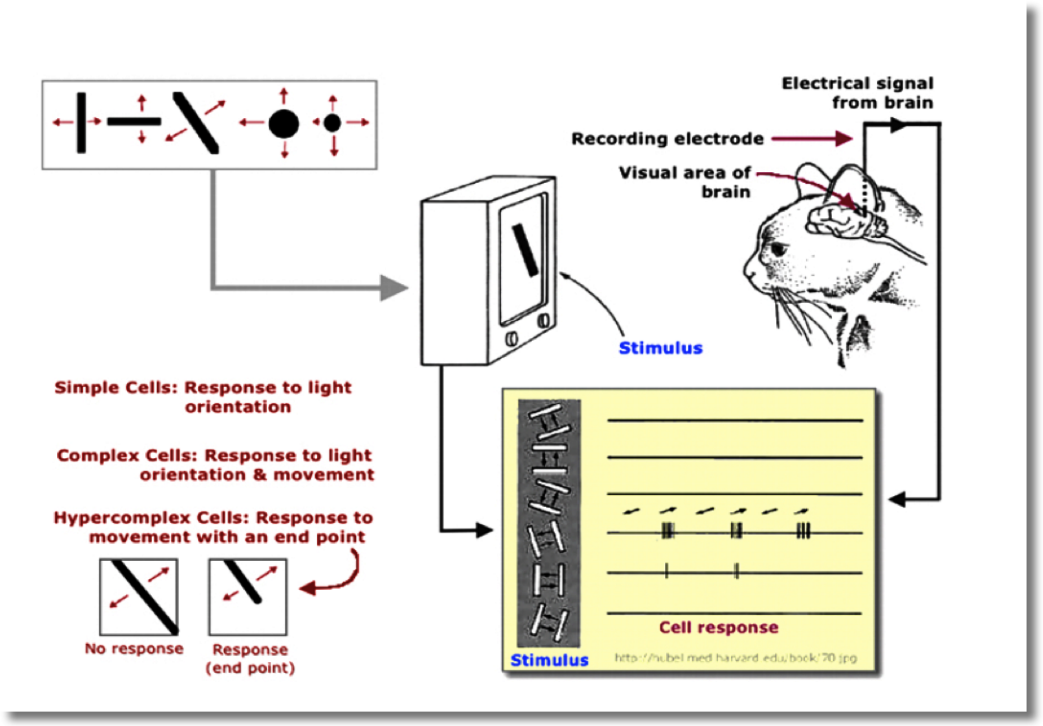
C. Processing Shape

Understanding how the visual cortex processes shape arose from the experiments of two neurophysiologists, **David Hubel** and **Torsten Wiesel**. First at John Hopkins and then Harvard Medical School they worked as researchers on the visual system. Beginning in the late 1950s, they recorded electrical activity from individual neurons in the visual cortex of cats. Their findings won them a share in the Nobel Prize for Physiology or Medicine in 1981. Note that this is the same prize that was shared with **Roger Sperry** for his work with split-brain patients on hemispheric specialization that we will discuss later in the semester.

David Hubel (1926-2013; b. Canada) **Torsten Wiesel** (1924- ; b. Sweden)

A diagram showing their experimental set-up and findings can be found on the top of the next page.

Here is a link to a 3'15" YouTube video of their work with the visual cortex of cats.



- Areas V1 (primary visual cortex) & V2 (secondary visual cortex) contain three types of cells with various receptive field characteristics as Hubel & Wiesel's experiment above demonstrated:
  - **Simple Cells** (V1 only): fixed excitatory or inhibitory zones. Responsive to bars of light in vertical, horizontal, or intermediate orientations.
  - **Complex Cells** (V1 & V2): responds mostly to patterns of light oriented in a specific way within a relatively large receptive field, e.g., bar at 45 degree angle moving.
  - **End-stopped (**or "**Hypercomplex**") **Cells** (V1 & V2): like complex cells, but also highly responsive to bars with end-points. Very large receptive fields.
- Columnar Organization: Specific receptive fields map to cells which are grouped in columns
- Areas V1/V2 connect ventrally to the **inferior temporal cortex** (in the "ventral stream") which responds to very complex shapes in three-dimensional space. These neurons contribute toward the experience of **shape constancy**, i.e., our ability to recognize objects despite changes in location or point-of-view.

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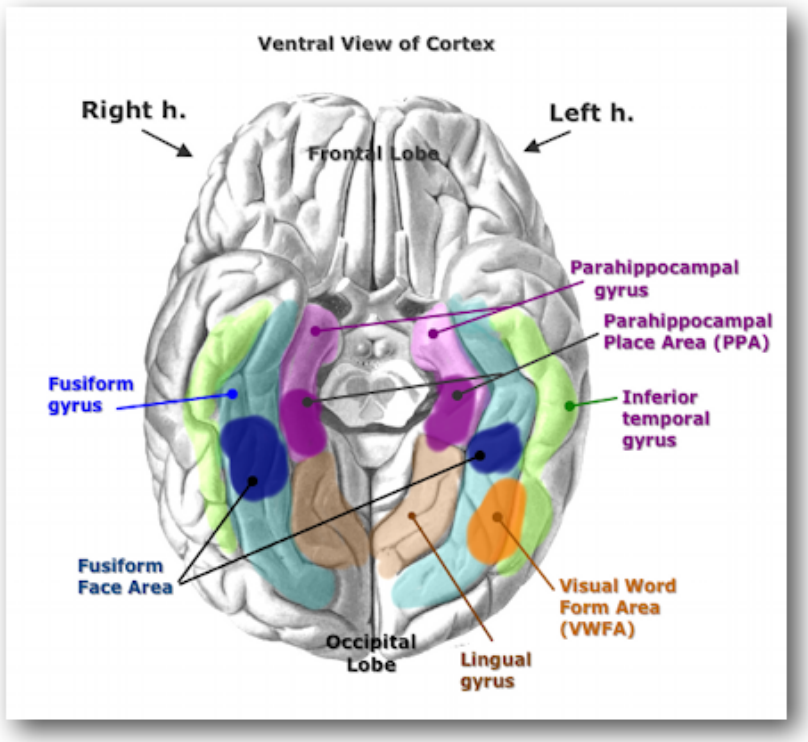
D. Disorders of Object Recognition

Over the last three decades researchers have identified various regions of the **medial inferior temporal cortex** that are highly important to identifying, recognizing, or learning about visual materials (objects, faces, printed letters, spatial information). This research has helped understand various disorders of object recognition as a result of brain damage.



- **Visual agnosia** = Inability to recognize objects despite satisfactory vision. Usually the result of temporal lobe damage.

- **Prosopagnosia** = inability to recognize the face of other people (including those who are well-known to us). Results from damage to the **fusiform face area (FFA) of the fusiform gyrus** of the inferior temporal cortex (particularly in the right hemisphere).

- **Pure alexia** = "Pure alexia is a selective impairment of reading in the absence of other language deficits and occurs as a consequence of brain injury in previously literate individual" (Starrfelt & Shallice, 2014, p. 367). It is usually the result of damage to the **verbal word form area** (**VWFA**) of the lateral occipital-temporal sulcus of the left hemisphere.

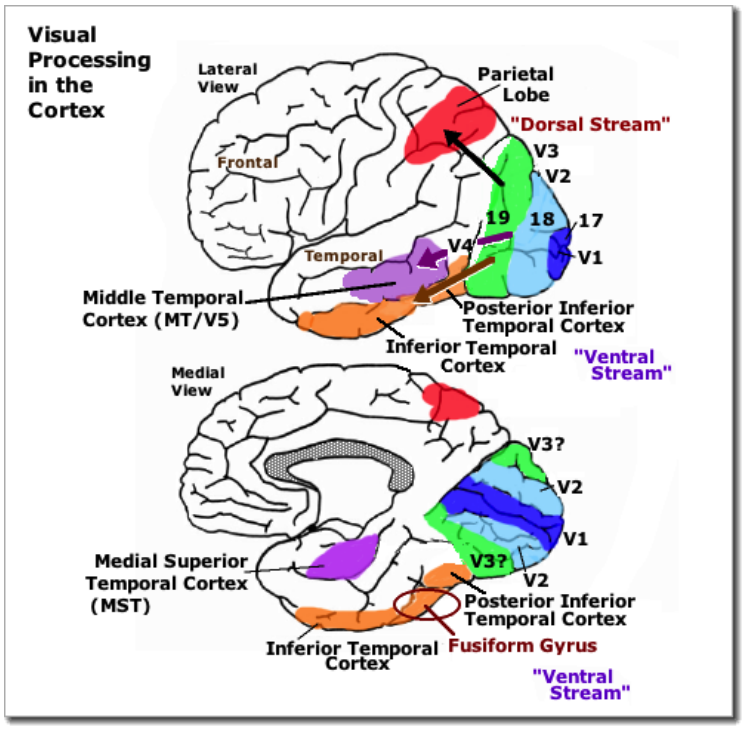
- **Impaired learning for space/topographic information**. Lesions (damage) to the **parahippocampal place area** (**PPA**) often results in difficulty learning how to navigate an environment or recognize where one is located.

F. Pathways for Color, Motion, & Depth Perception

- **Color Constancy**: the ability to recognize a specific color under different lighting conditions. This appears to be related to activity of the **V4** area in monkeys (corresponding to the **temporal-parietal cortex junction** in humans.) Primarily a function of the **parvocellular pathway**.This is the area which caused you to see green in those tinted photographs of the grass from the previous class.

- **Stereoscopic Depth Perception** = the ability to detect depth because of the disparity between what the two eyes see. This appears to be a particular function of the **magnocellular pathway**.

- **Visual motion detection** is related to processing in the **middle temporal cortex** (**MT** or Area **V5**) and the **medial superior temporal cortex** (**MST**; see diagram). Primarily a function of the **magnocellular pathway.**



- **MST** neurons distinguish between actual motion of objects in the physical world and the motion of your head (and, therefore, the movement of visual images across the retina).

- Cortical processing is momentarily **lowered during rapid eye movements** (called **saccades**).

- Damage to the MT cortex may produce **motion blindness**, i.e., the inability to see the direction, speed, or even fact of an object in motion. Neurologist Oliver Sacks describes a strange case of extreme motion blindness in which a person could only see objects at rest; moving objects seemed to disappear to this patient.

G. Visual Attention

- We can selectively attend/pay attention to specific objects in our visual field. When we do so, the result is heightened activity in Area V1 related to what we are looking at and decreased activity in areas not related to what we are looking at.

- This is a form of "top-down" processing, i.e., we aren't reacting to stimuli (a kind of "bottom-up" process) but deciding what we will pay attention to. Our intentionality, thus, affects how the brain processes the visual information.

Update (October 2017)

Recently published research (e.g., Freud et al., 2017) suggests that the functional distinction between the ventral and dorsal streams (ventral = shape/"what" and dorsal = position-movement/"where-how") is not absolute. Rather, fMRI data argue that the dorsal stream is also sensitive to shape information that is intimately connected to using that information to guide motor responses. However, that dorsal stream does not, by itself, process visual data sufficiently actually to identify the object being observed.

Summary of Visual Processing

Occipital Lobe

- **Simple → Complex → Hypercomplex** [end-stopped] cells = respond to & builds up information on different aspects of (moving) shape
  - **Simple**: bar or edge → light vs. darkness
  - **Complex**: pattern of light moving in a particular direction, e.g., horizontal or vertical bar
  - **Hypercomplex**: Same as complex plus inhibitory response at one end of bar (→ emphasis on where an edge is)
- Overall: Simple aspects of shape (edges, orientation in space)
- Stereoscopic depth perception (magnocellular)

Ventral Stream (Temporal Lobe)

→ **"What" pathway** oriented toward perception

- Complex shape-object recognition (parvocellular, ITC)
- Face recognition (fusiform gyrus)
- Letter/word recognition (left lateral occipito-temporal sulcus)
- Landscape/topography (parahippocampal gyrus)
- Color & brightness (mixed magno/parvo-cellular, ITC)
- Movement recognition (magnocellular; MST/MT)

Dorsal Stream (Parietal Lobe)

→ **"Where/How" pathway** oriented toward goal-directed action

- Convert vision into action
- Know the location of objects
- (Recognize objects sufficiently so that vision/action can be integrated)

ITC = inferior temporal cortex
MST/MT = medial superior temporal/middle temporal cortex

References

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