EYE form and function (Part 1) and retinal circuitry (Part 2) have already been described. This segment of our discussion of vision explores the central pathway. The images of the two eyes must be merged into one picture. The picture must be drawn and colored and placed in the world by primary visual cortex. These circuits ultimately lead into the associations of memory and mentation, where we recognize and understand what is being seen...the so-called "mind's eye"...which can be tapped by dreams and hallucinations as well.

The Eye and Sense of Vision

PART THREE
Central Visual Pathways

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Vision Contents

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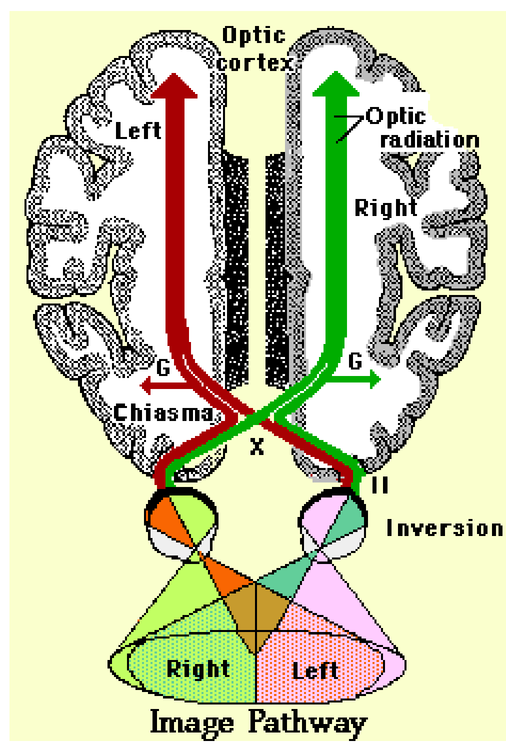
Continuity

THE IMAGE DRAWN onto the retina by eye optics is transduced chemically in the rods and cones. This chemistry closes channels in their plasma membranes, and that increases their polarity. Their synapses onto bipolar and horizontal cells slow or stop in their activity, and this **releases** bipolars and horizontals from inhibition. Both of these cells are also leaky (pacemakers), and they can activate their synapses--which are also inhibitory.

The principal target of bipolars is ganglion cells, which have been pacing action potentials to higher brain centers in a disordered fashion. The activation of bipolars because appropriate light has struck their receptor cells--imposes inhibitory order onto this ganglion cell discharge, creating a rough image that is projected centrad.

The principal target of horizontals is receptor cells or bipolars in adjacent retinal columns. Activated horizontals inhibit their targets, substantially changing their signal and creating a surround around the principal active visual column. This modification and contrast is superimposed onto the ganglion cell discharge to sharpen the image and to add aspects of color and motion and dimensionality to it. This is the data of the optic nerve.

Optic Tract and Chiasma

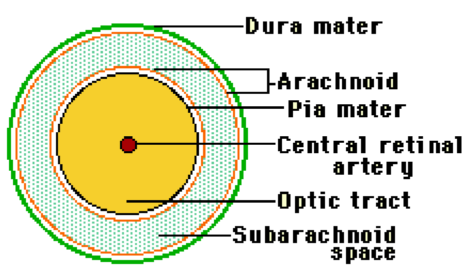


GRANULE CELL AXONS converge from the entire retina on an area medial to the visual axis of each eye, and at this point they gain their myelin sheath (which would not have been transparent on the surface of the retina!) and exit the retina and the eyeball as the optic "nerve." In humans there are about 1,000,000 axons in each nerve, and these take up space. Which means that where they exit the eye, there is no room for retinal columns, and this creates a blind spot. Since the two spots in the two eyes do not coincide in their retinal fields, one eye sees what the other does not. You learn to ignore this hole in your vision.

To demonstrate this blind spot, cover your left eye and look at the plus mark in the figure above, while moving your head backward and forwards. At some point, the disk you are **NOT** looking at will disappear from your peripheral vision as its projected image comes to overlie the blind spot. This should occur with your face about 45 cm from the screen. Is the blank area colored or white?

You need to begin to understand that part of what you see in this world is what you expect to see. To demonstrate this, use the plus mark and the broken line to "see" the blind spot. Again position your head, as before. When the gap in the line overlies the blind spot, the gap disappears and the line seems unbroken. You see something that isn't there.

The nerve passes through a tendonous ring, which is the origin of the recti muscles, and enters the cranial cavity via the orbital foramen. At this point the tough fibrous sheath of the nerve (which is continuous with the sclera) merges with the dura mater lining the cranial cavity. Beyond this point, the CNS affiliation of the tract is evident from the various meningeal relations (figure: "Optic Tract & Meninges). In its route, the tracts are still passing medially as well as posteriorly, and the nerves of the two sides meet at the **optic chiasma**.



Optic Tract & Meninges

In vertebrates with laterally-directed eyes, the nerves may cross entirely at this decussation, but in man, where the eyes have converged with much binocular overlap, only about half of these axons cross over. These visual fields Up were shown in detail in the description of retinal function. The effect of this mixed projection to the optic cortex is that the entire visual field (as opposed to retinal field) is projected to the contralateral cortex. If you observe carefully, you may see this. Often when you first awake, your eyes will have moved out of coherence, and when you first open them, one of the images will shift to match the other slowly enough for you to see it "snap" into place.

Lateral Geniculate Body

The **optic tract** (as it is now called) enters the diencephalon and extends to the **lateral geniculate nucleus** ("G" on the image pathway drawing above). Some tract axons simply pass through the geniculate without synapsis on their way to motor centers (lateral arrows...notice from their color code that the motor projections correspond to perceived fields rather than being true to eye). To say it again, this tract is a mixture of left eye/ right eye axons; the geniculate is a 6-layered nucleus, and the fibers are sent to differing layers from each eye. The layer/eye relationship is firmly maintained, so that each eye projects exclusively to three of the six layers on each side. The function of the lateral geniculate is to merge the two images into one seamless picture before forwarding (post-synaptically) the visual data onward to the visual cortex. There is *visuotopic* representation, "local visual sign" of the projection of ganglion cells to the geniculate, but understand that the image is distorted in this representation by the demographics of retinal columns...about half of the cells in the geniculate are receiving input from the fovea--itself half of the retina in ganglion cell population.

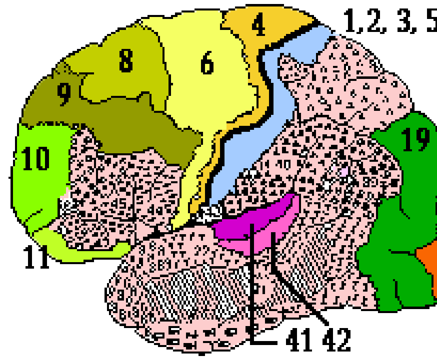
Only about 10-20% of geniculate cells receive input from the retina. Two layers of large cells apprently is devoted to movement of the image in the two eyes. The remaining layers are of smaller neurons (cell bodies) and analyze the two images for color and for picture details. The remaining majority of input to the geniculate comes from other brain regions. This data apprently influences the projection to the visual cortex. For example, part of the afferent geniculate inflow is from the reticular system. Among other jobs, this enormous and diffuse mass of neurons governs your level of consciousness (and attention) and such exotica as sleep (during which you are functionally blind) and dreaming. At least a certain amount of this circuity is a feedback loop. Not only does your level of alertness affect what you "see" but also what you see affects your level of alertness and concentration.

Against the backdrop of these generalities, realize that very little is understood about lateral geniculate function.

Primary Visual Cortex

P

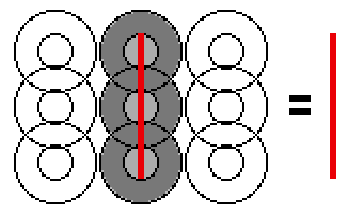
OSTSYNAPTIC FIBERS after the lateral geniculate body fan out in the optic radiation, a tract that extends back to the occipital lobe of the cerebral hemisphere. The primary visual cortex includes Brodmann areas 17, 18, and 19. Appreciation of the image is done in a variety of association areas, particularly on the parietal and temporal lobes of the hemisphere.



Some Brodmann Areas

Area 17

Area 17 essentially draws the lines and boundaries of objects in the image. Lateral geniculate output is directed to this cortex. The centers and surrounds described above for the retina are translated into **simple** and **complex fields** of cortical columns. Points of light, which can stimulate the retina very effectively, cause almost no response in visual cortex. Instead, lines of excited centers/surrounds cause a strong reaction within rectangular fields of cortical columns.



Cortical fields are usually depicted as a central rectangle flanked by two surround rectangles. The placement of excitation within the boundaries of these three rectangles is based on the projections from the retina/geniculate, but an expanded rule is applying--multiple centers in line are drawing the image. With **simple** cells, an image alighned along a row of appropriate centers yields a very strong response. Moving that line into the surround or changing the orientation (angle) of the line has a strong effect on signal; if the bar is rotated 90° into a horizontal position, the signal generated by these particularl cortical fields would disappear entirely at about a 45° angle.

Complex fields are generated in a different layer of the cortex from the simple fields. Complex fields are usually larger in perimeter than are simple fields. On/off relationships are not so well demarked, Angle of the the stimulus is not so important, but movement of a wave of excitation across a field (representing movement of the image across the retinal ganglion cells) has a very strong effect.

The cortex of area 17 is a mixture of simple and complex fields, and their interaction draws both the outlines (including stopping points) and relative movement of visual images. Apparently in the hierarchy of evaluation, the simple fields analyze multiple cells of the eye/geniculate input, while complex fields analyze multiple simple fields.

Area 18

Area 18 participates in the coloration of the drawn image of area 17, but 17 is involved with this process as well. The actual process of recognition of colors is only poorly understood and involves layers of the cortex which are organized as "blobs" outside the system of simple and complex fields. Since an on-center might be related to a green cone, while off-surround cells may be cones of another color or also of green--it gets very complex! The eye is also able to correct for variation of ambient light color (such as, for example, sunset) in reconstructing the color shades of objects.

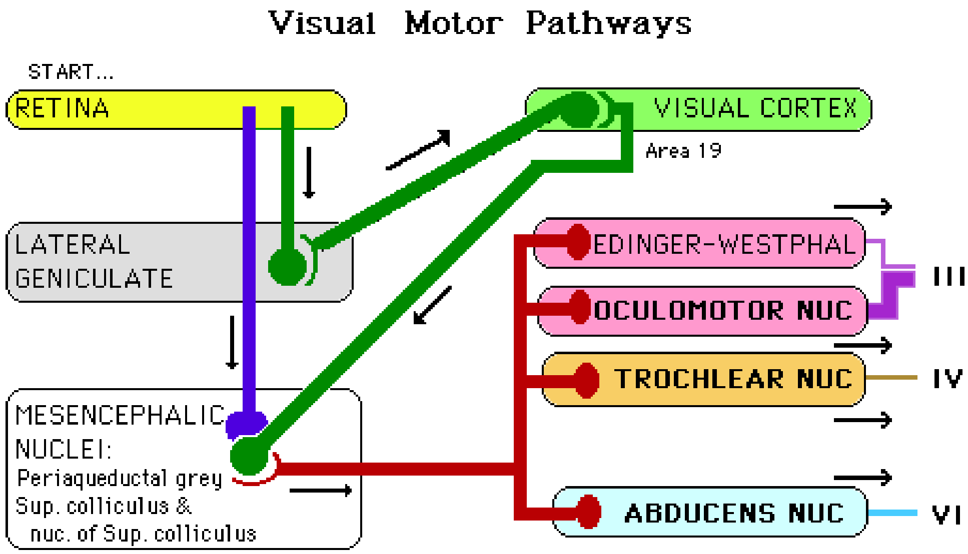
Area 19

Area 19 of the occipital cortex is a motor association area which receives input from the lateral geniculate and many other regions. This area is aware in a geographical sense, translating the image into motor coordinates that are referred onward to the mesencephalic tectum, described above. These motor calculations track the movement of objects and also changes in position of the eyes and of the head so that the image is not blurred and is projected to the "correct" position in the outside world. But area 19 doesn't actually "see" anything.

Retina to Motor Paths

IF YOU HAVE studied the brain stem and cranial nerves previously, you have already seen the illustration below. About 20% of the fibers from each eye pass through the geniculate without synapsis and are distributed to the roof (tectum) of the mesencephalon. This divergence is represented in the drawing above by bilateral arrows at "G" and notice that the colors of those arrows indicate the laterality of the motor data.

This entire tectum area is nuclear, and some neurobiologists suggest it is truly a cortex. The midbrain tectum also receives axons from Brodmann area 19 of the cerebral cortex--the part of the primary occipital lobe cortex devoted to conscious direction of the gaze based on reception and appreciation of images.



In any event, three cranial nerve nuclei are clearly distinguishable--oculomotor nucleus, Edinger-Westphal (both c.n. III), and trochlear nucleus (c.n. IV). In addition, there is tectal input to the abducens nucleus in the medulla (c.n. VI). The functions of these nerves are summarized briefly below:

Cranial Nerve	**Nerve Target**
Oculomotor, cn III	Innervates superior, medial, inferior rectus, inferior oblique, and levator palpebrae muscles
Edinger-Westphal, cn III	Smooth muscle of ciliary body and iris
Trochlear, cn IV	Superior oblique m.
Abducens, cn VI	Lateral rectus m.

There is additional motor input from the inner ear for reflex direction of the eye toward a loud sound source. The nucleus of the inferior colliculus is involved. The eye movements are also influenced by the vestibular apparatus--sense of balance--so that the visual axis is directed toward the direction of acceleration. For instance, during a fall, the eyes are pointed toward the point of impact. Similarly, input via the spino-tectal tract drives reflex movement of the head, also to point the eyes properly. The motor output in this case is tectospinal, which has terminations in the nucleus of the spinal accessory nerve, c.n. XI. This tectospinal tract does not extend below the cervical cord level.

Finally, there is motor return to the retina itself.

Eye and Visual Pathology

The loss of lens elasticity, also beginning about 40, was described in "Eye Structure." This is a normal sequel to aging and should not be considered pathology.

A second effect of this lens packing with crystalline protein is not so benign. Diffraction becomes exaggerated so that resolution is decreased. This has a spectral component in that the lens has more of a yellowish cast, and passage of blue light (short wave lengths) is affected most. As this condition advances, the lens becomes ever more opaque, a condition known as cataract. Routine treatment for this presently may be removal of the lens, but a variety (different link) of treatments are coming on line. The French impressionist, Monet, attempted to repaint some of his canvases after cataract surgery because they appeared too blue to him. Advertising executives for geriatric products should use red rather than blue to capture attention.

Other web pages of interest

YOU MIGHT be interested in some of these other vision-related web pages. If you are tempted to ask if these will be on the exam, don't bother to look at any of them.

- HUGE review of eye form and function--really a masterful piece of work
- Retina structure
- Histology of the eye
- Eye and retina...some nice pictures
- Outline of eye structure--thorough and dull
- This one could become interesting as he progresses.--An Aussie/American
- The English point of view
- Post-retinal pathways--this is part of a group of pages and you may have already looked at their 'retina' site.
- Short review quiz on eye from someone else.
- Physiology of the eye
- An alternate point of view
- Stargardt's disease--The last time I checked, the Himmelfarb Library did not subscribe to a single journal relative to ophthalmology. Interesting. If medicine is in your future, maybe you should visit their library when you go to on-campus interviews!
- Retinitis pigmentosa

That's enough to get you started to searching, if you are interested in vision. This list of sites has VERY little information on:

- post-chiasmatic pathways of vision
- primary visual cortex--areas 17, 18, and 19
- secondary visual cortex--appreciation and association of images
- mesencephalic control or coordination of ocular movement and accomodation.
- pathology (esp. blindness)

I'll let you chase those down. If you find a particularly good site, email me.

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Contact himself.