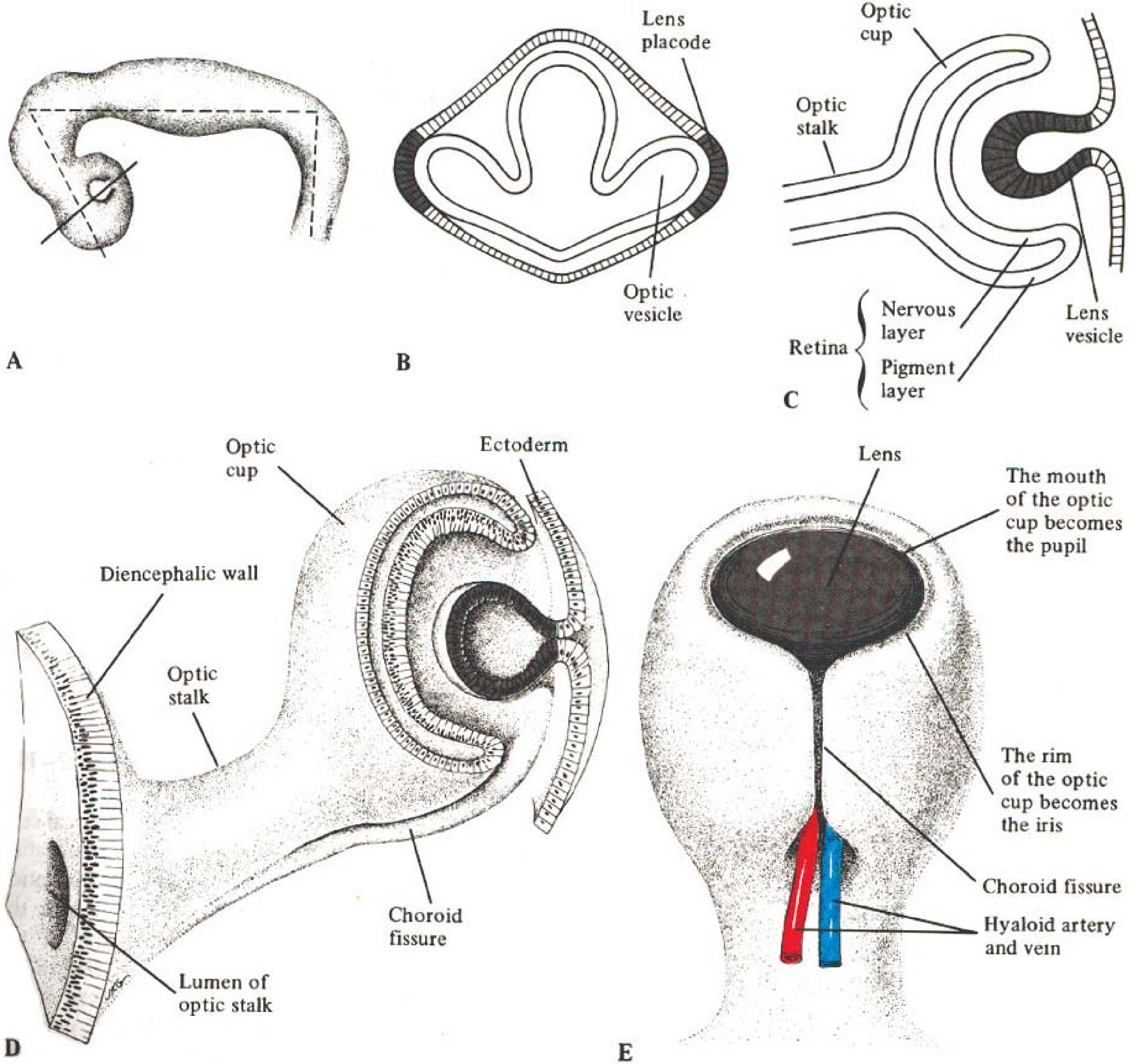
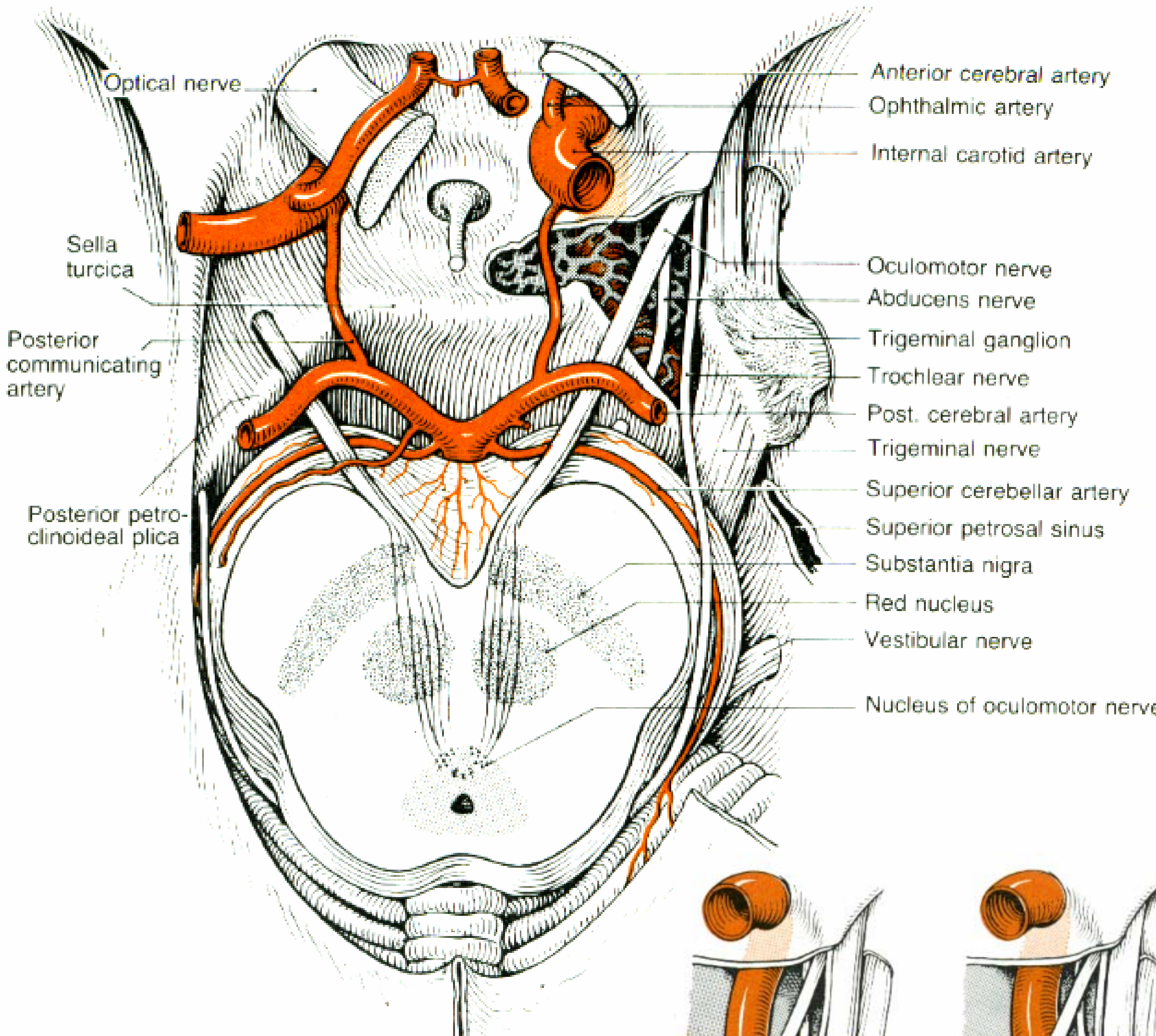
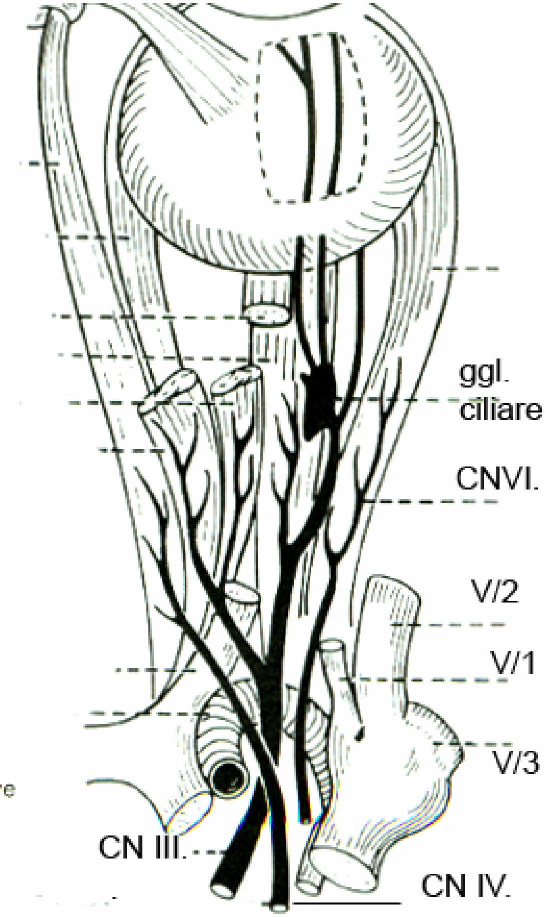
The Visual System



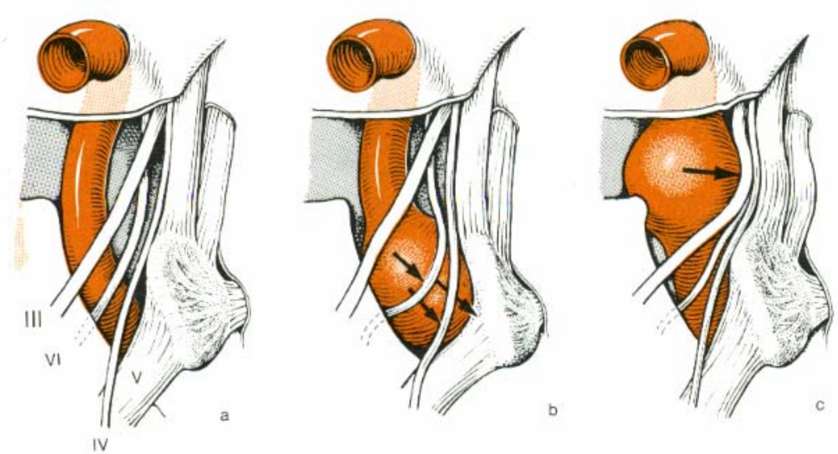
Development of the eye. The optic vesicles invaginate to form the retina, whereas the lens develops from the ectoderm (From Heimer, 1995)



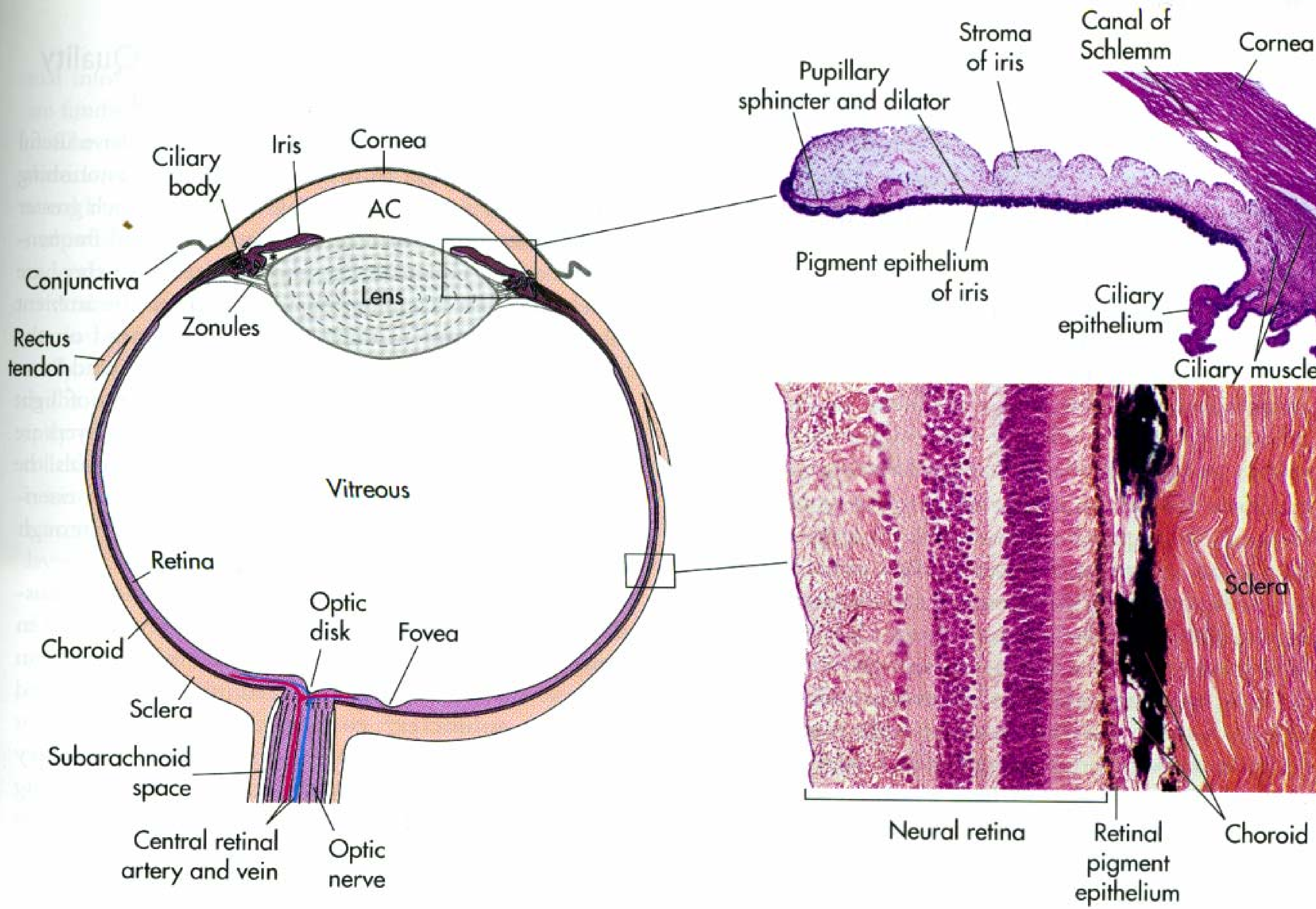
Optical nerve
Sella turcica
Posterior communicating artery
Posterior petro-clinoideal plica
Anterior cerebral artery
Ophthalmic artery
Internal carotid artery
Oculomotor nerve
Abducens nerve
Trigeminal ganglion
Trochlear nerve
Post. cerebral artery
Trigeminal nerve
Superior cerebellar artery
Superior petrosal sinus
Substantia nigra
Red nucleus
Vestibular nerve
Nucleus of oculomotor nerve



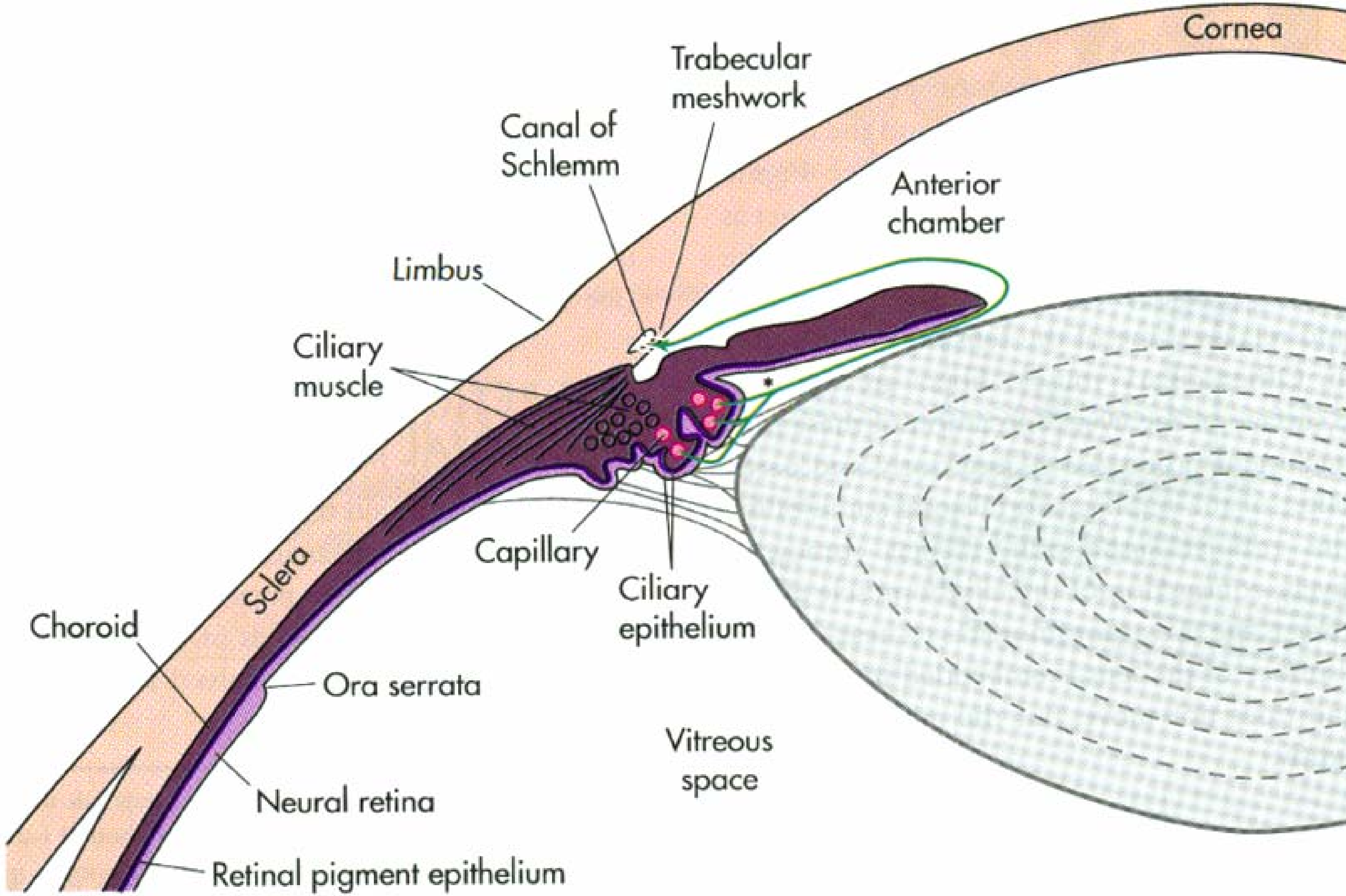
ggl. ciliare
CNVI.
V/2
V/1
V/3
CN III.
CN IV.

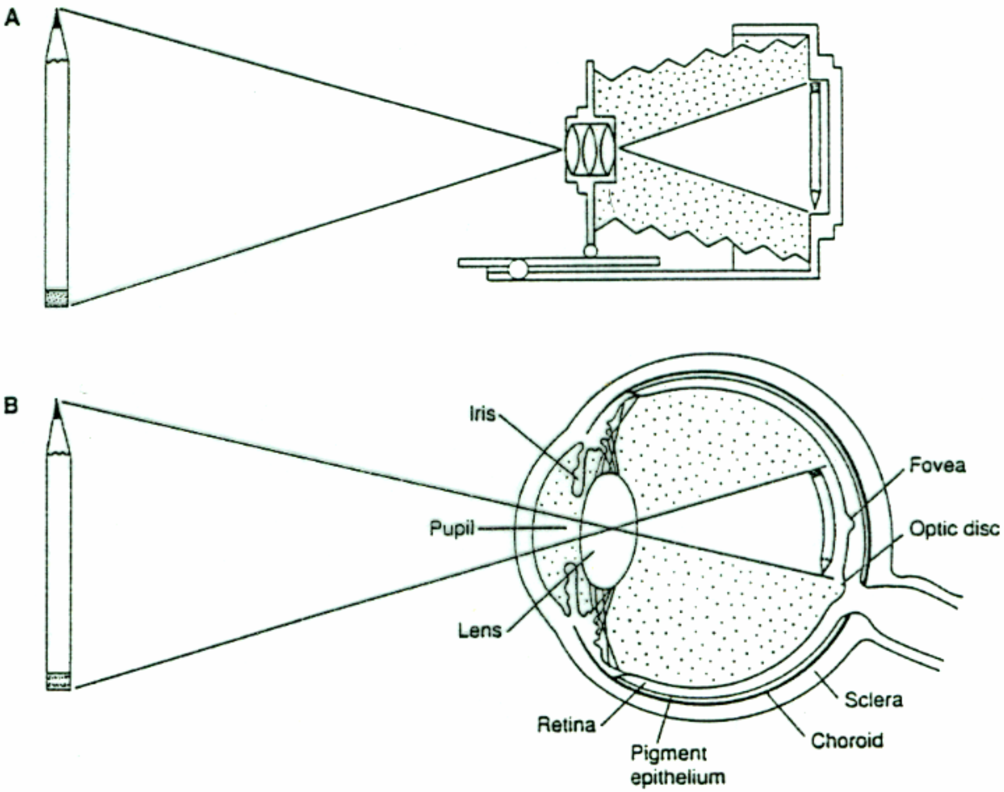


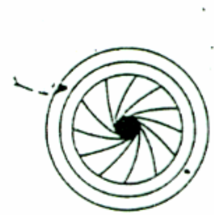
III
VI
V
IV
a
b
c

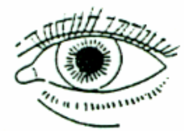


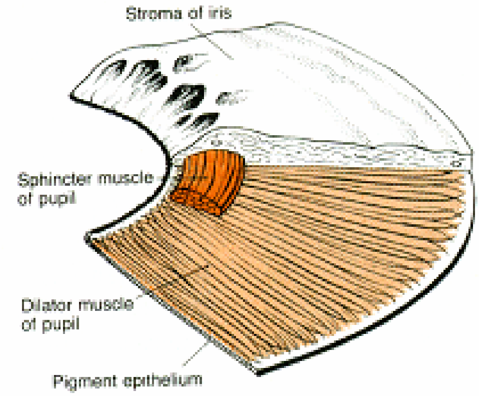
Cornea
Iris
Ciliary body
AC
Conjunctiva
Lens
Zonules
Rectus tendon
Vitreous
Retina
Choroid
Sclera
Optic disk
Fovea
Subarachnoid space
Central retinal artery and vein
Optic nerve
Stroma of iris
Canal of Schlemm
Cornea
Pupillary sphincter and dilator
Pigment epithelium of iris
Ciliary epithelium
Ciliary muscle
Sclera
Neural retina
Retinal pigment epithelium
Choroid

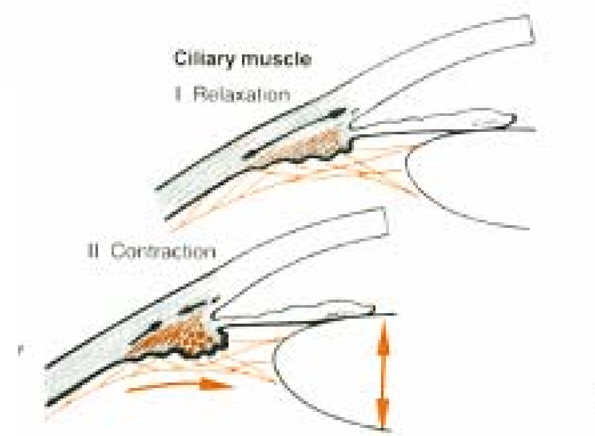

Cornea
Trabecular meshwork
Canal of Schlemm
Anterior chamber
Limbus
Ciliary muscle
Capillary
Ciliary epithelium
Sclera
Choroid
Ora serrata
Vitreous space
Neural retina
Retinal pigment epithelium





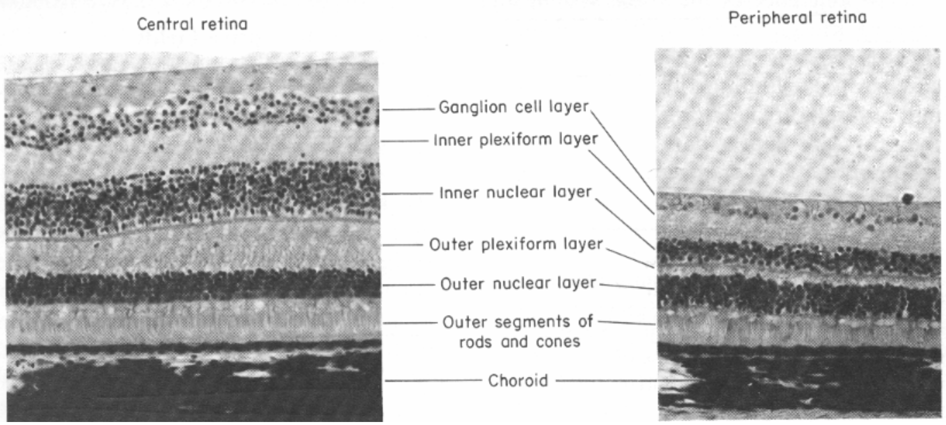


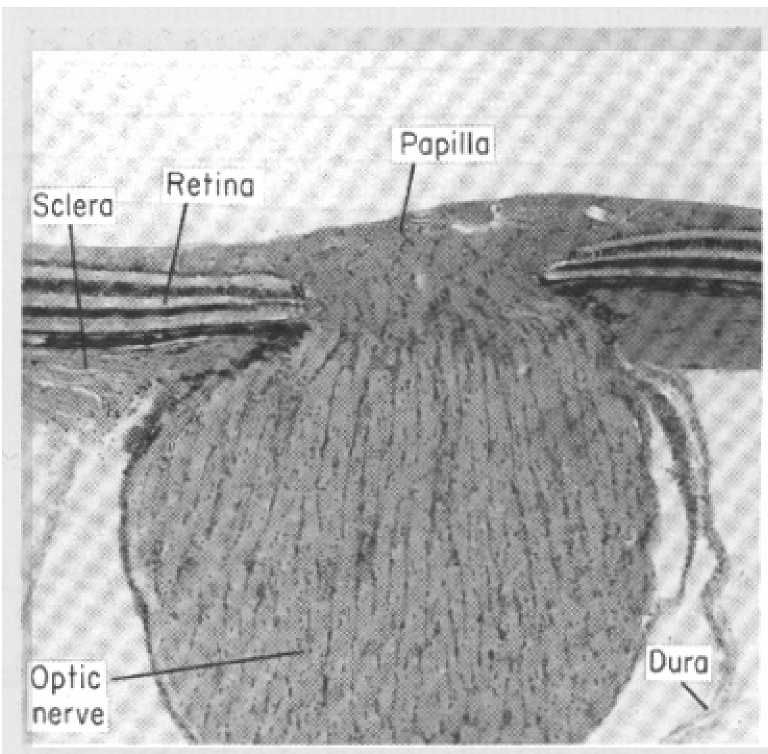




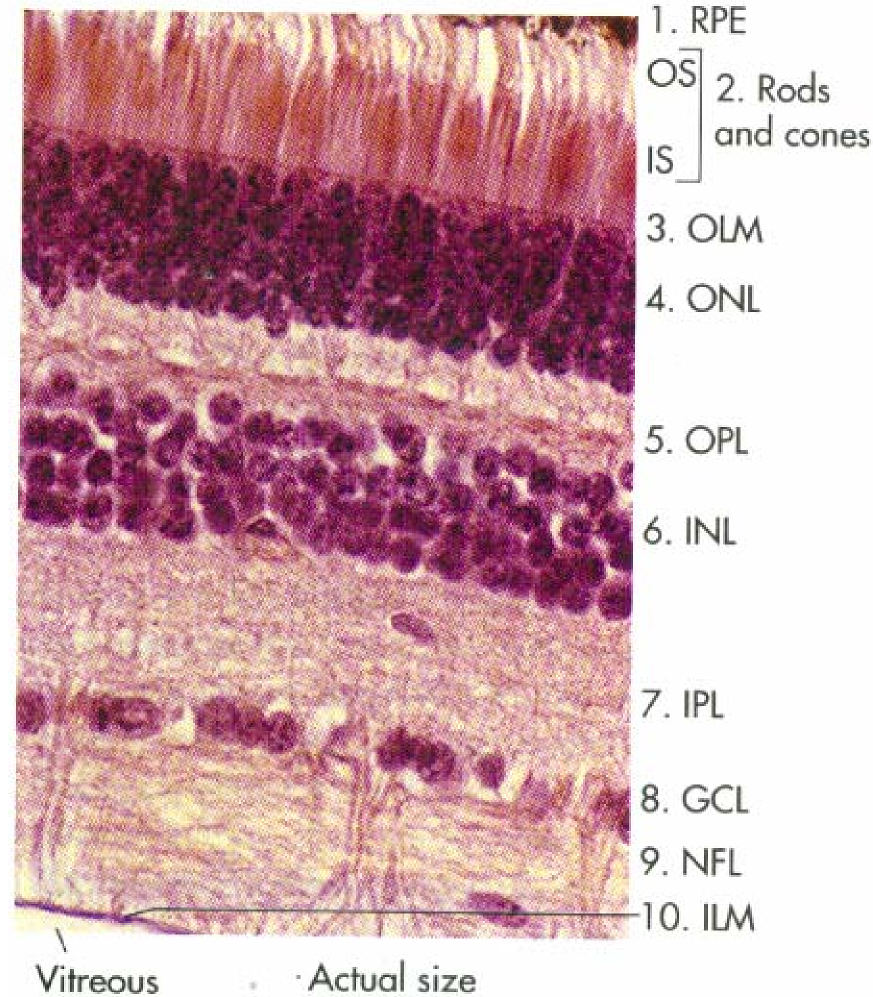
Conventional cameras are adjusted for near or far objects by moving their lenses closer to or farther from the film; contraction of the ciliary muscles allows the lens to fatten as the eye accomodates to near objects. At rest, the lens is flattened and the eye focused on distant objects. The iris affects the brightness and the optical performance of the eye (a smaller pupil improves just as a smaller aperture). The pupillary sphincter and the ciliary muscles are innervated by the parasympathetic component of the CN III.

THE RETINA





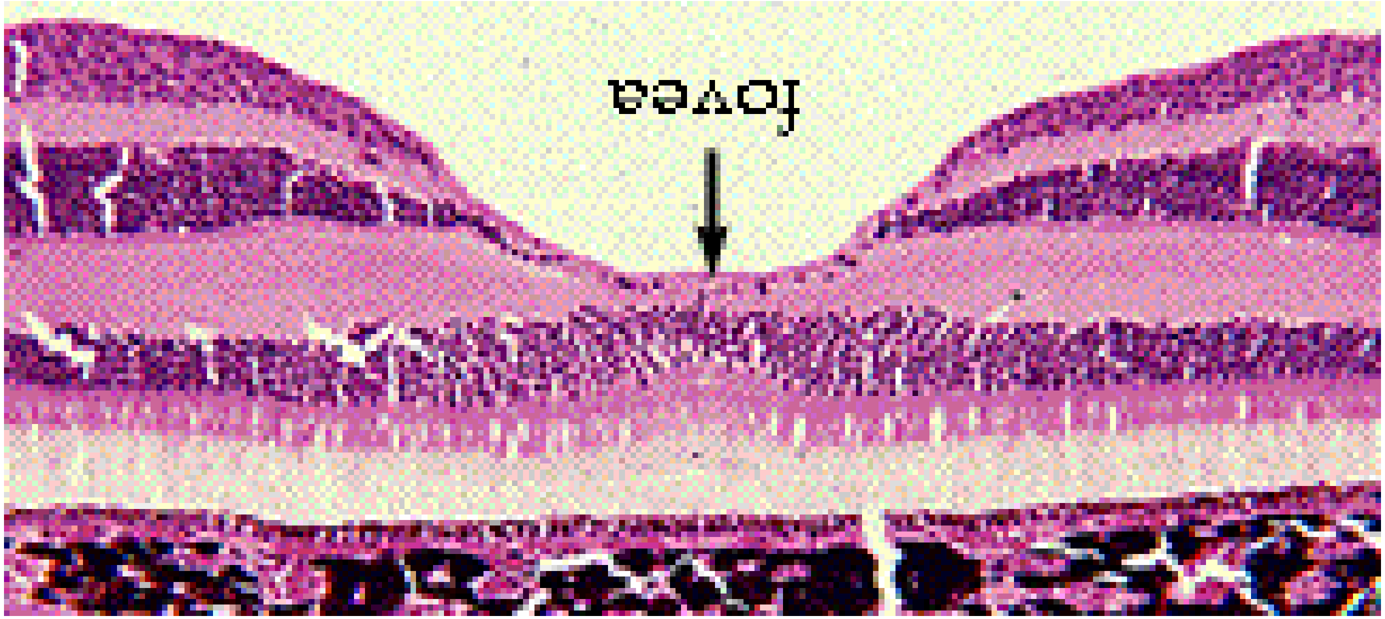
From Brodal

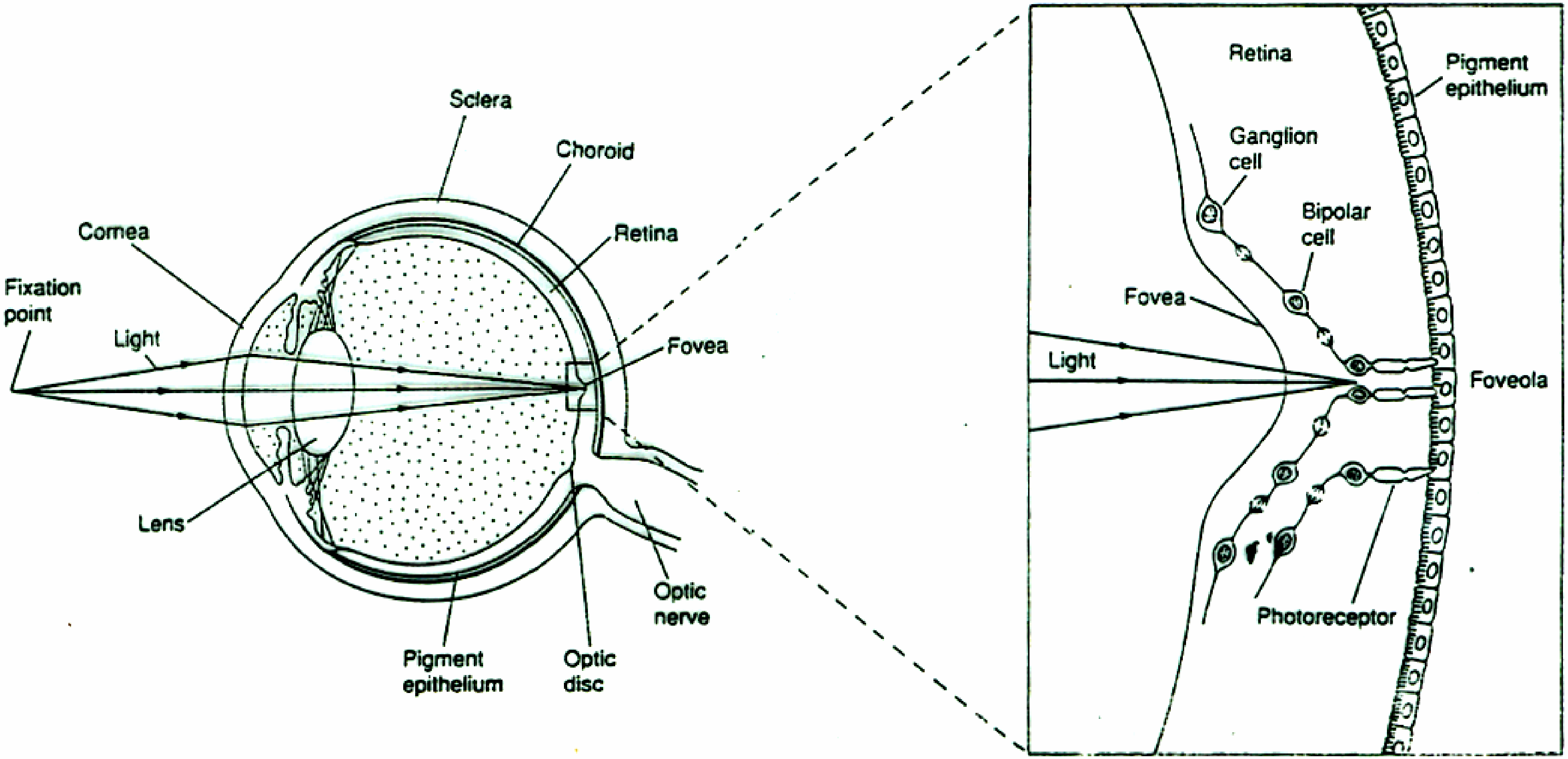


From Nolte

The Fovea Has High Spatial Acuity

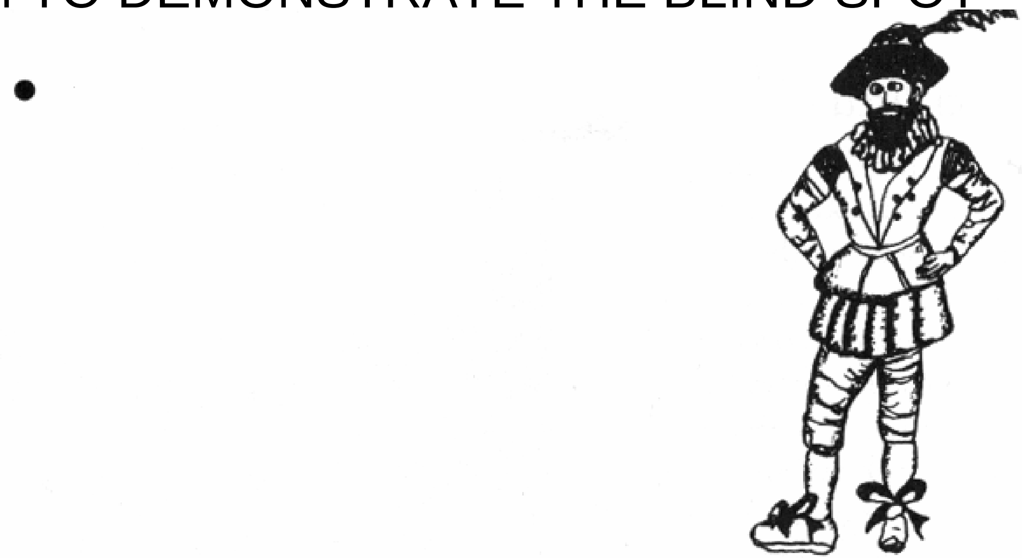
- Cones are concentrated in the fovea
- The outer layers of the retina get thinner at the fovea, allowing light to pass more easily and accurately to the photoreceptors



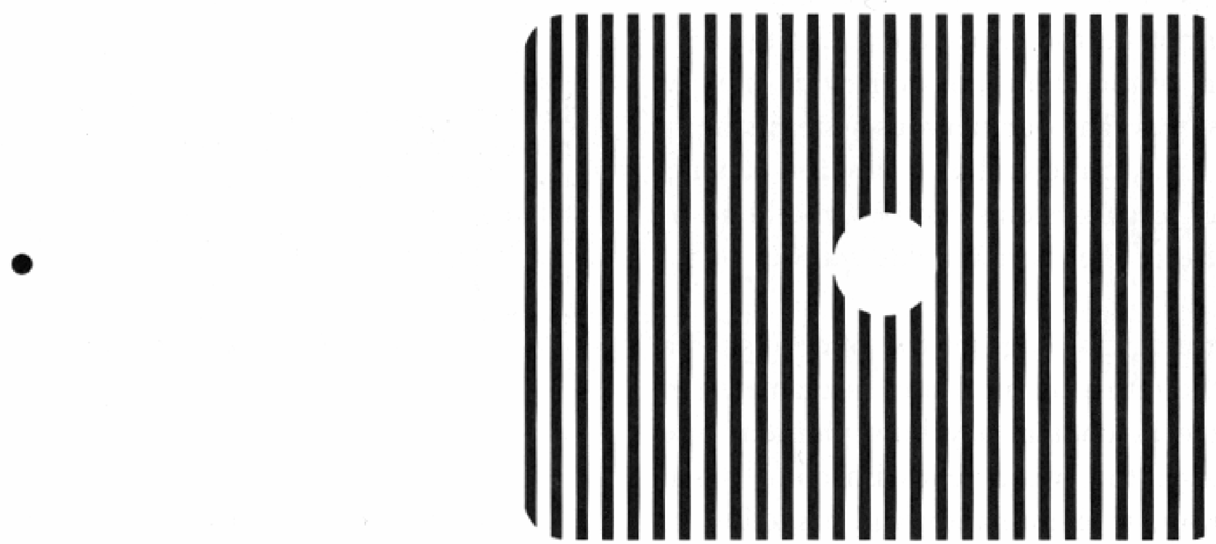


In most of the retina light must pass through layers of the nerve cells and their processes before it reaches the photoreceptors. In the centre of the fovea (macula lutea), these proximal neural elements are shifted to the side so that light has a direct pathway to the photoreceptors. As a result, the visual image received at the macula the least distorted. (From Kandel).

DIAGRAM TO DEMONSTRATE THE BLIND SPOT

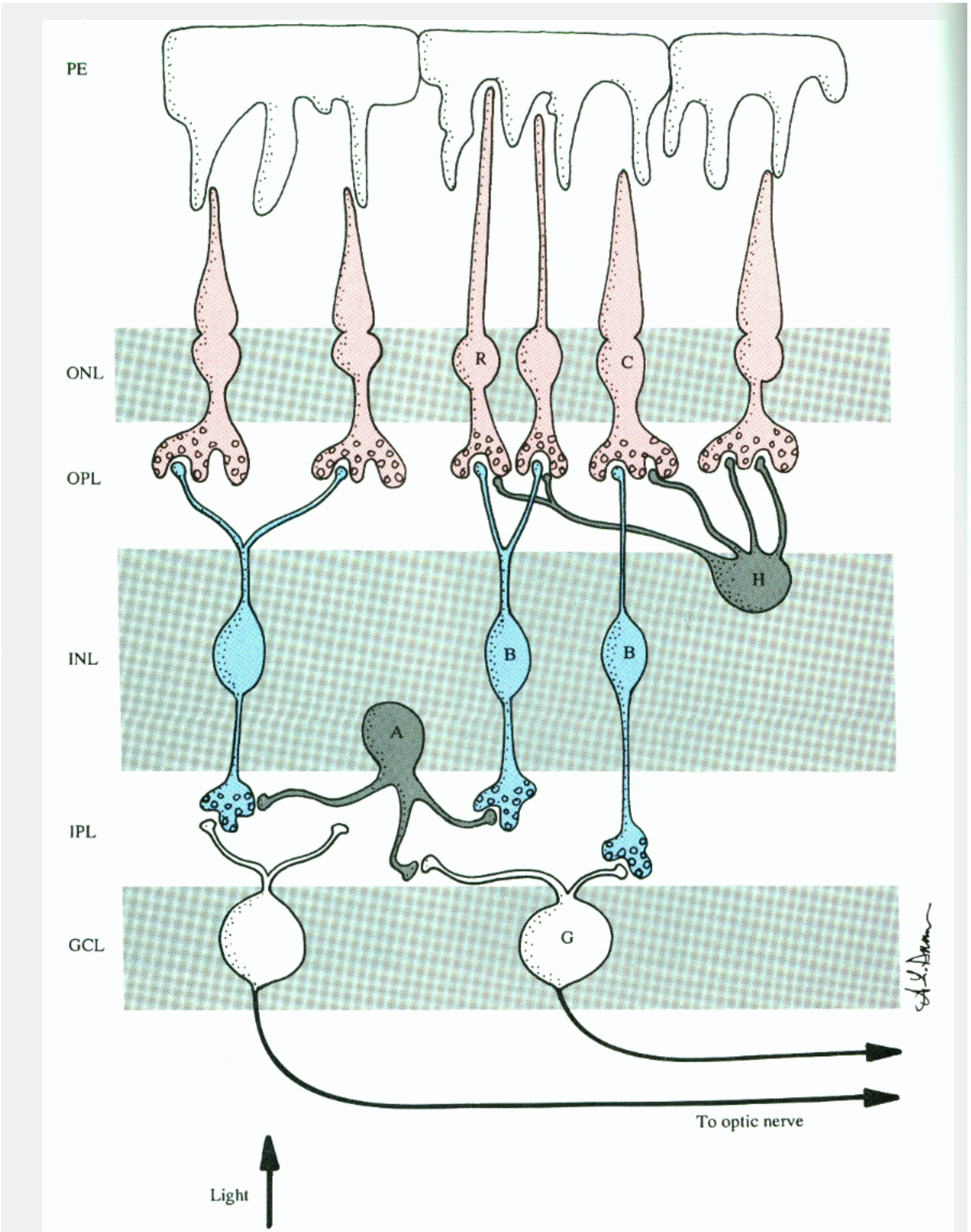


A

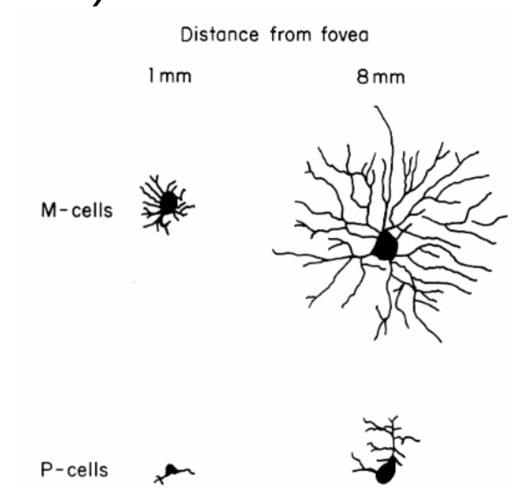


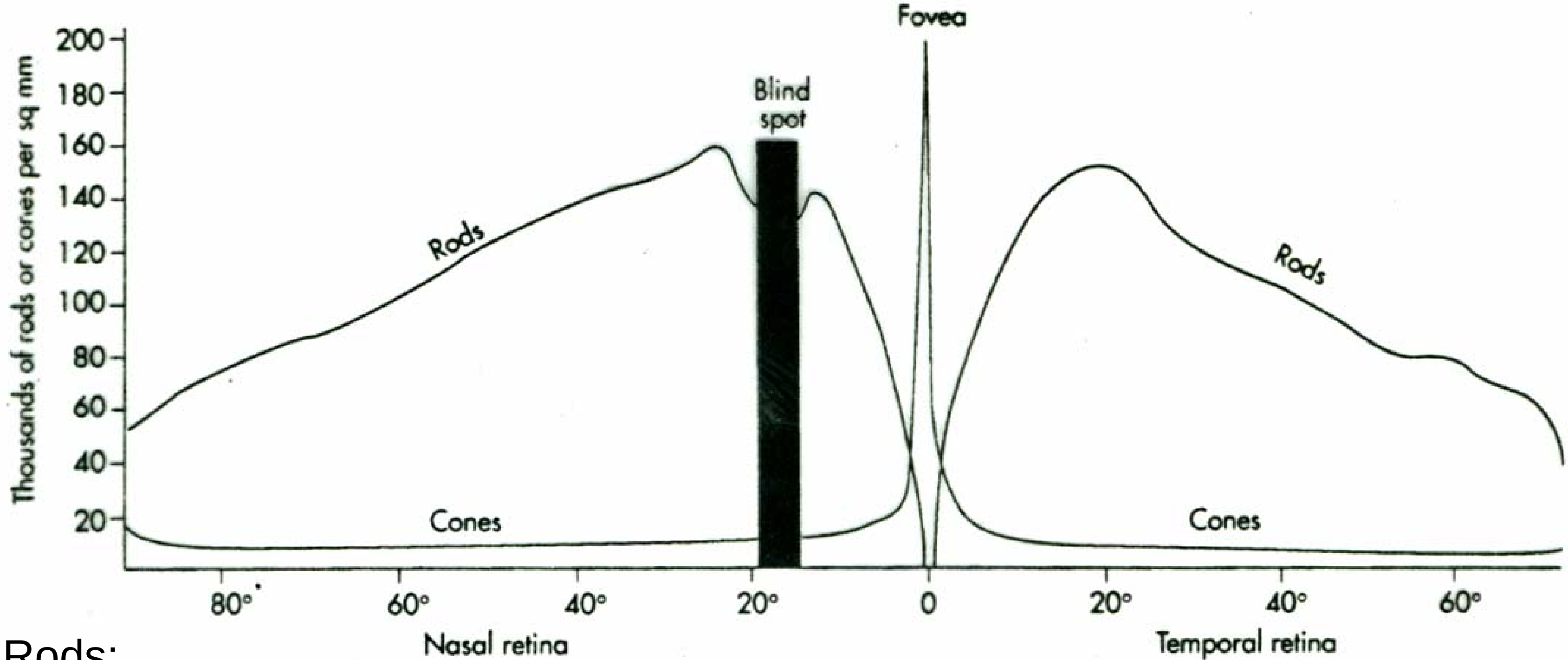
B

RETINAL NEURONS



Highly schematic figure of the organization of the retina. Note that only the cone bipolar cells (B) synapse directly with the ganglion cells (G) whereas the rod bipolar cells use the amacrine cells as intermediaries. PE-pigment epithelium; ONL-outer nuclear layer; OPL- outer plexiform layer; INL- inner nuclear layer; IPL- inner plexiform layer; GCL- ganglion cell layer (From Heimer)





Rods:

- Monochromatic

- Low spatial and temporal resolution

- Mostly in periphery of retina

Cones:

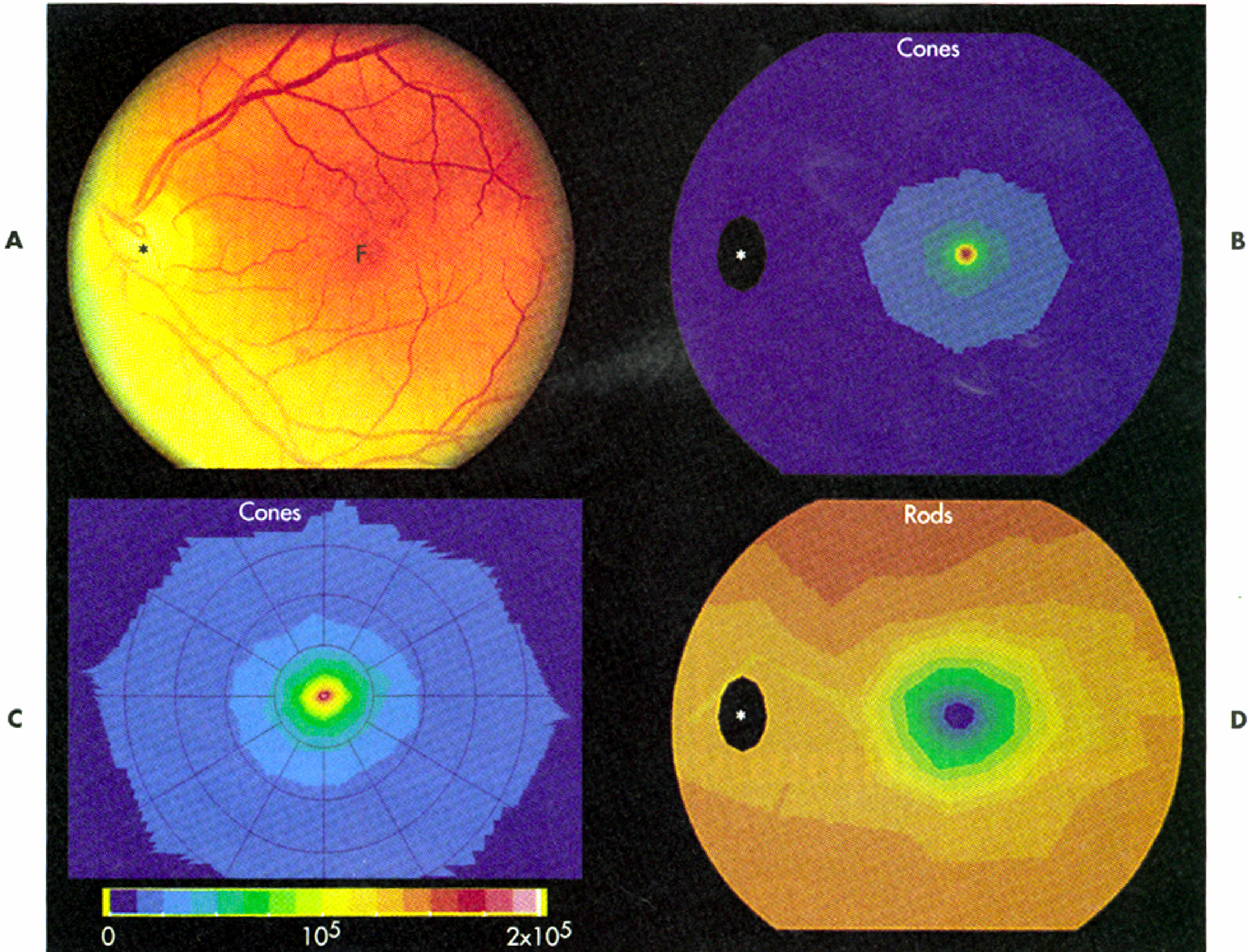
- 3 types respond to different wavelengths

- High spatial and temporal resolution

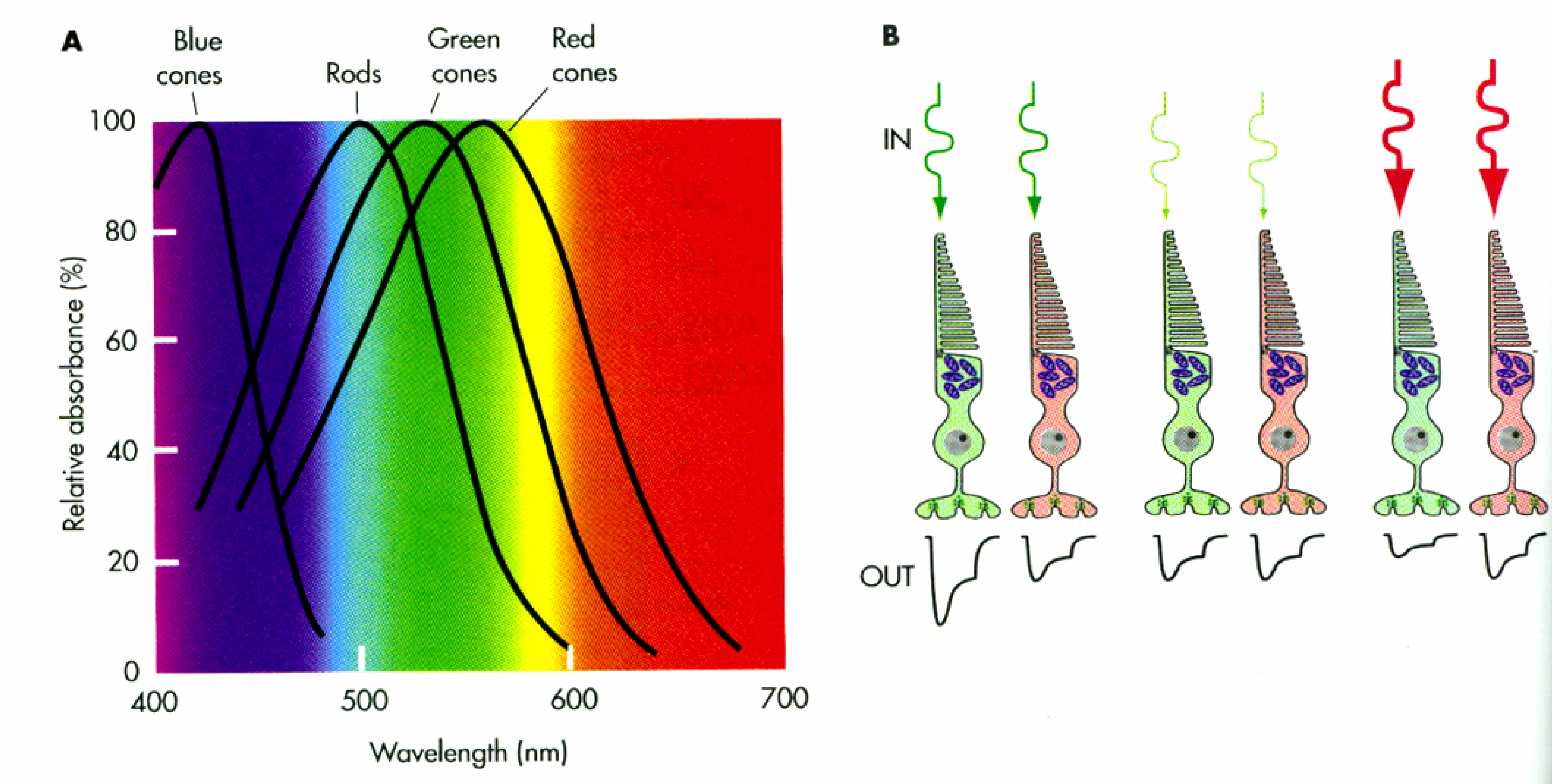
- Concentrated in fovea

Packing densities of rods and cones in the human retina along a horizontal band passing through the fovea/ (Ostenberg, 1935; Curcio et al., 1990).

DIFFERENTIAL DISTRIBUTION OF RODS AND CONES IN THE RETINA

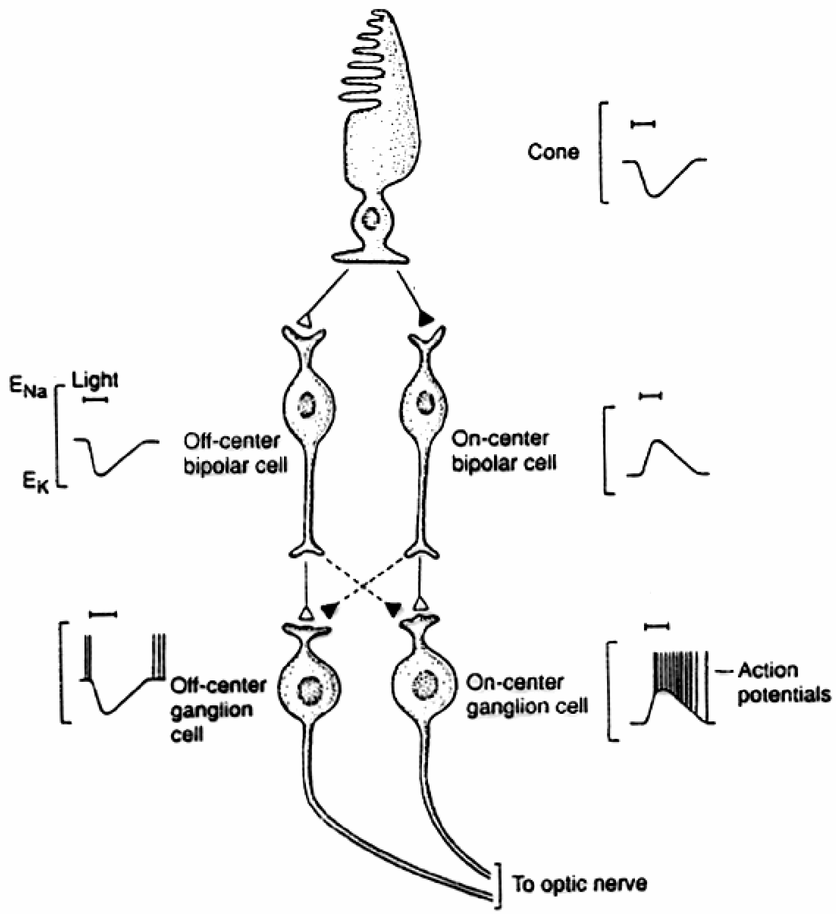


Cones are Tuned to Different Wavelengths of Light



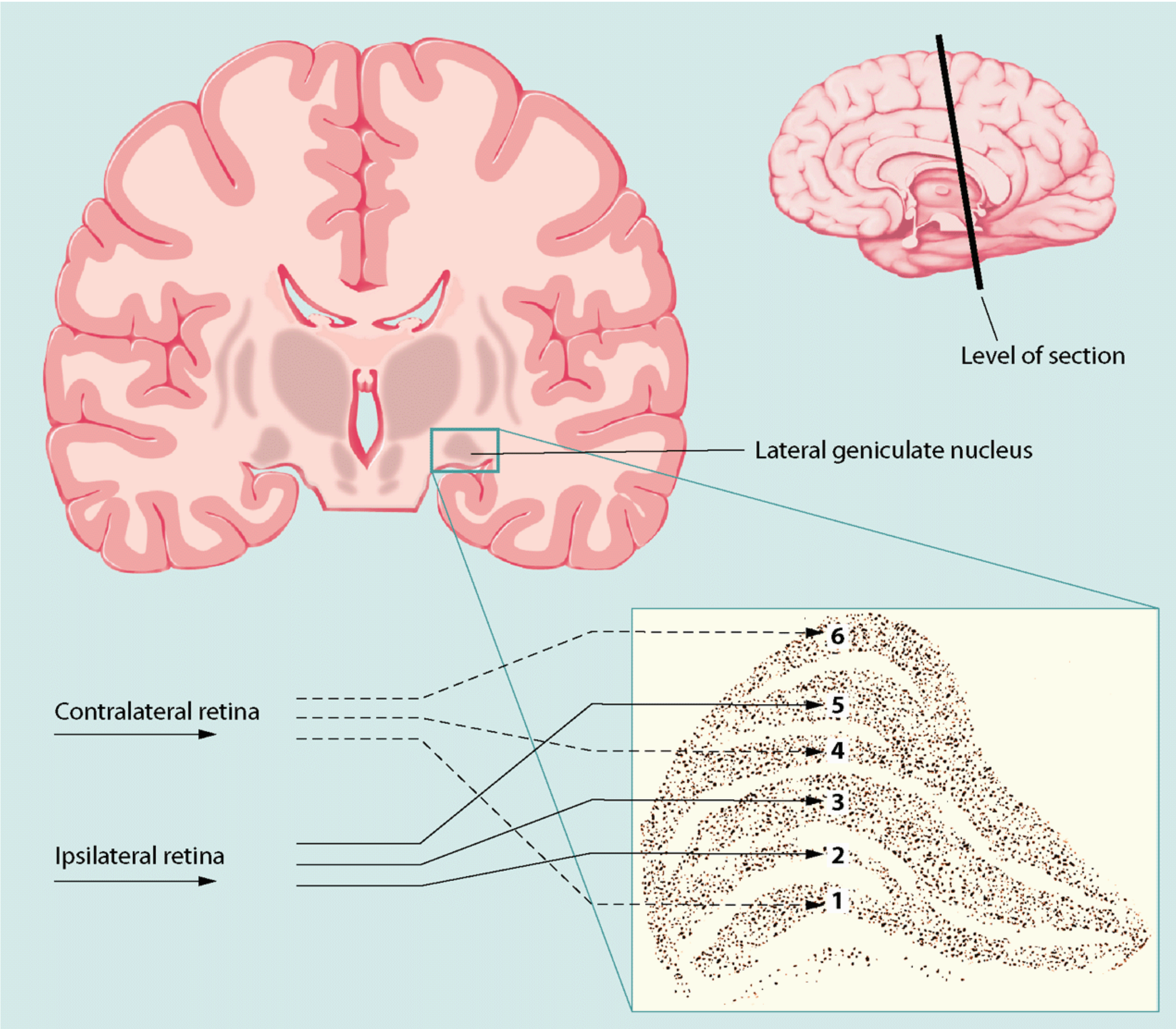
Absorption spectra of rode and cone visual pigments. Schematic indication of the necessity for multiple cone types to discriminate wavelengths. (From Nolte)

Lateral Inhibition in the Retina



The responses of the ggl cells are largely derermined by inputs from bipolar cells. Each type of bipolar cell makes exc. Conenctions with ganglion cells of the same class. Thus on-center bipolar cells depolarized by illumination of its receptive filed center will depolarize the on-center ggl cells connected to ot. In addition, each type of bipolar cell also inhibits ggl cells of the opposite class (dashed lines) From Kandel

ORGANIZATION OF THE LATERAL GENICULATE BODY



Each of the 6 layers have a retinotopic representation

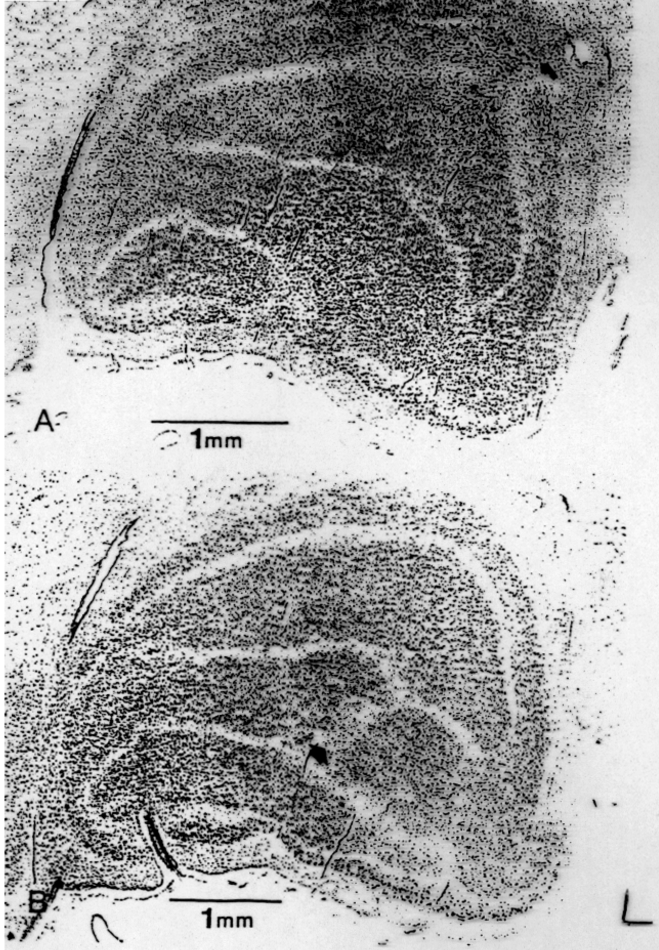
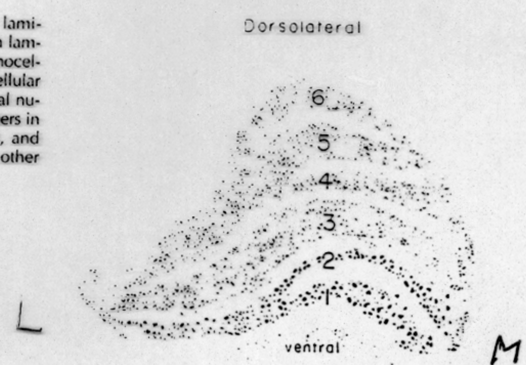
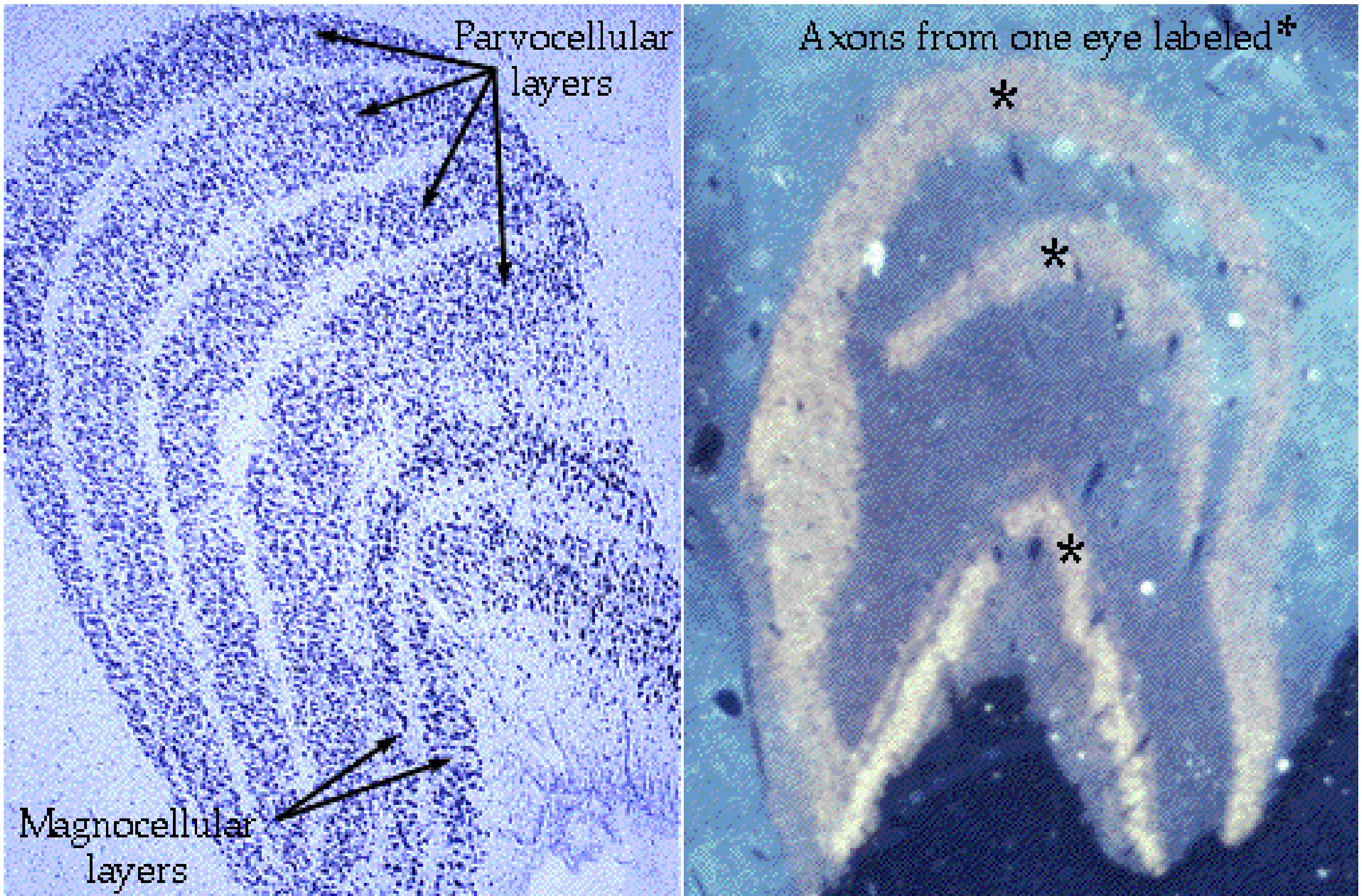


Figure 9.21. Photomicrographs of sections of the human lateral geniculate body. The blind spot is represented by discontinuities in laminae 6 (*A*, *arrow*) and 4 (*B*, *arrow*). Laminae 4 and 6 fuse laterally (*right*) in both *A* and *B* producing the bilaminar segment ventrally. The bilaminar segment receives input from the most medial contralateral nasal retina that subserves the monocular visual field (i.e., the monocular crescent.) See Figure 9.23. (From Hickey and Guillery, 1979; courtesy of the Wistar Institute Press.)

Figure 9.20. Drawing of the cellular lamination in the lateral geniculate body with laminae numbered from the hilus. The magnocellular laminae (*1* and *2*) and the parivcellular laminae (*3* through *6*) constitute the dorsal nucleus of the lateral geniculate. Crossed fibers in the optic tract terminate in laminae *1*, *4*, and *6*; uncrossed optic fibers terminate in the other laminae.



Parvocellular and Magnocellular Layers of the LGN



Parvocellular layers process information about details, while the Magnocellular layers process information about motion

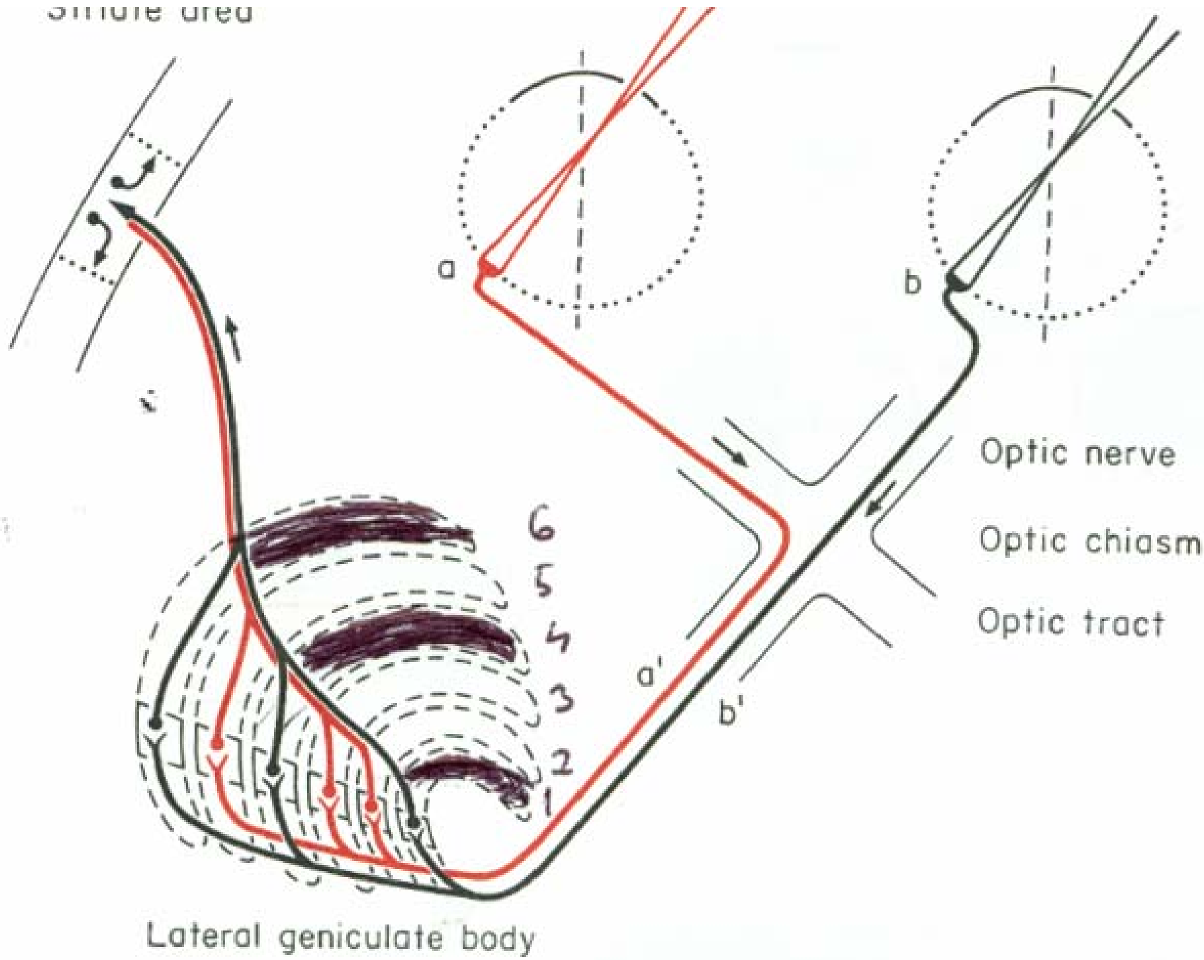
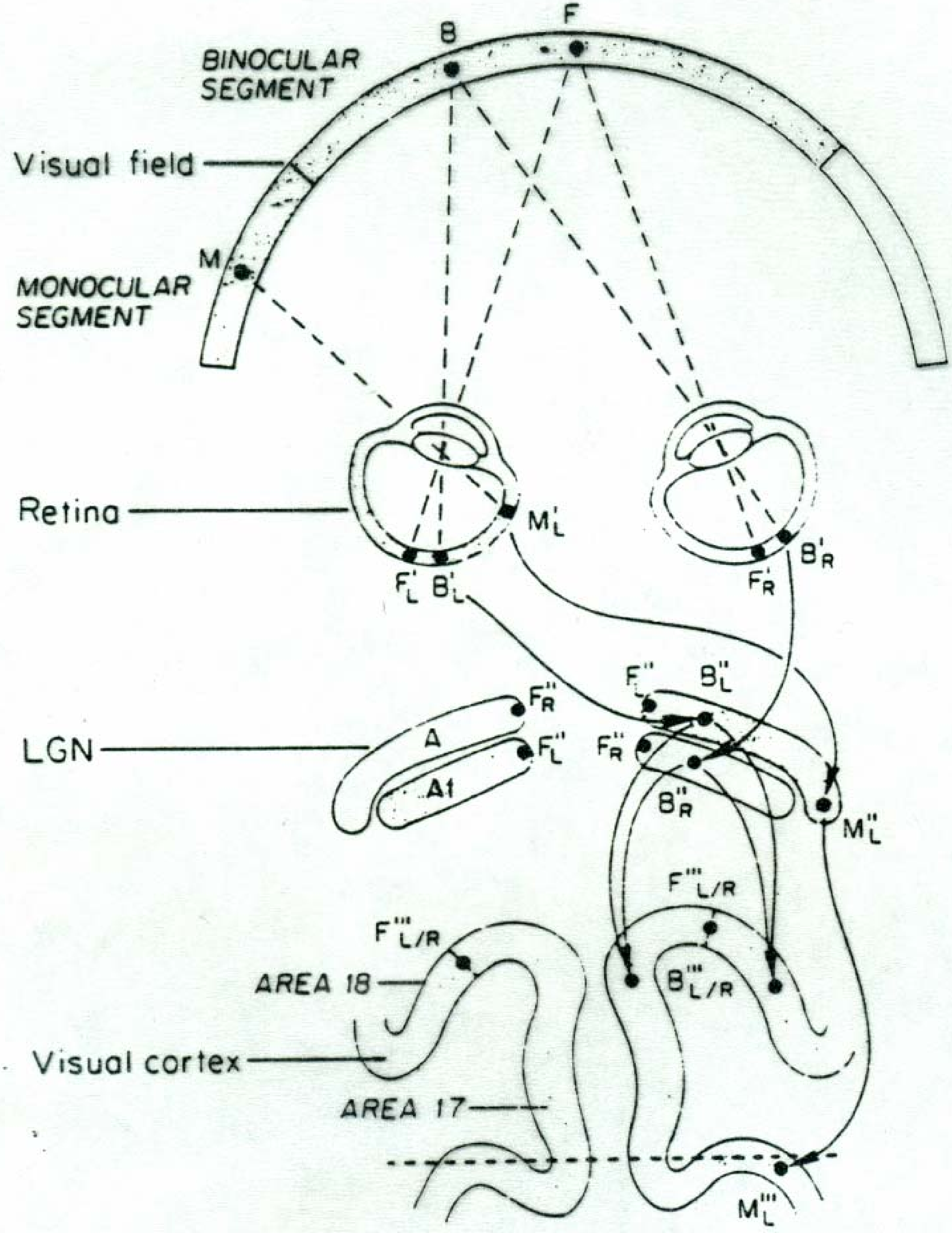
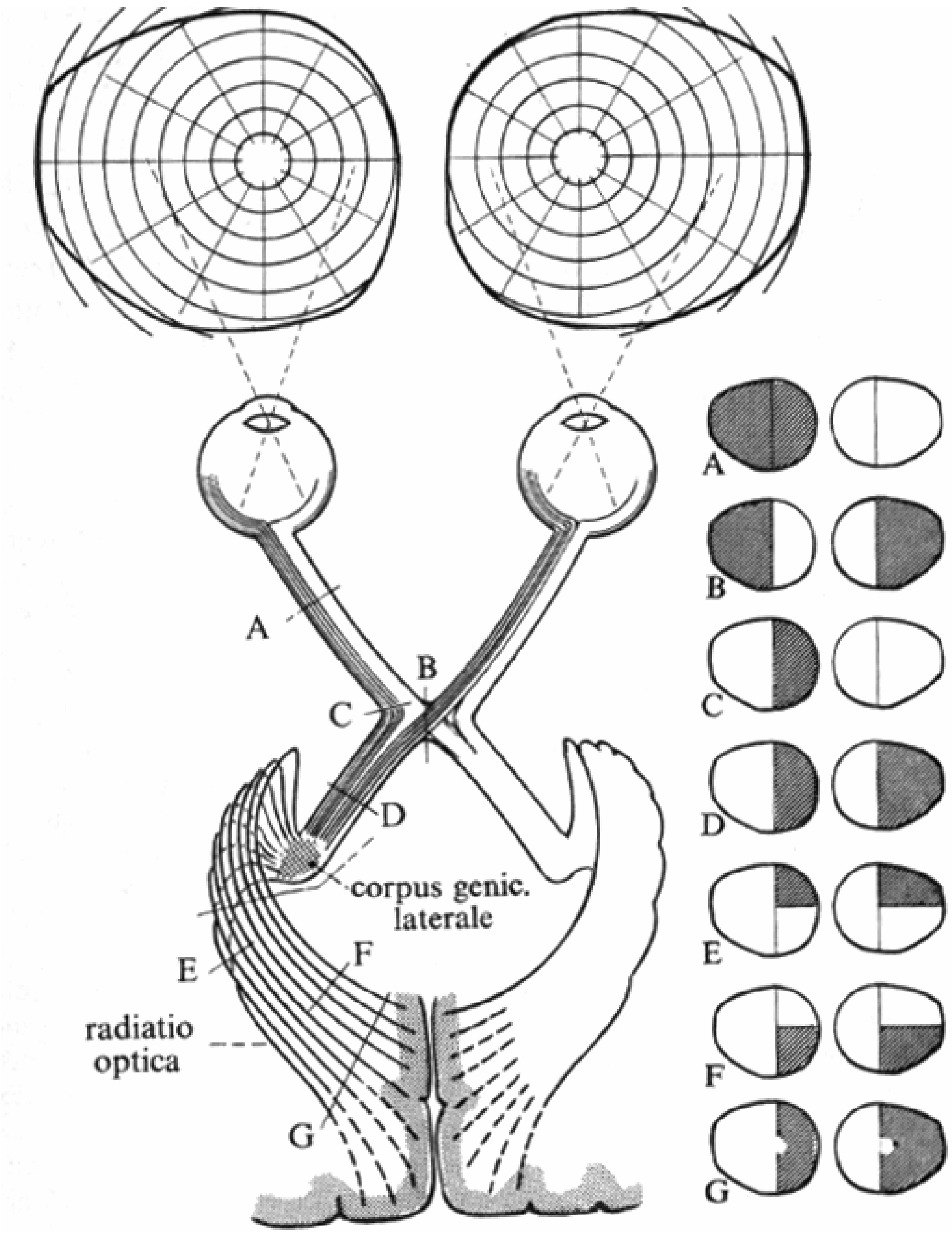


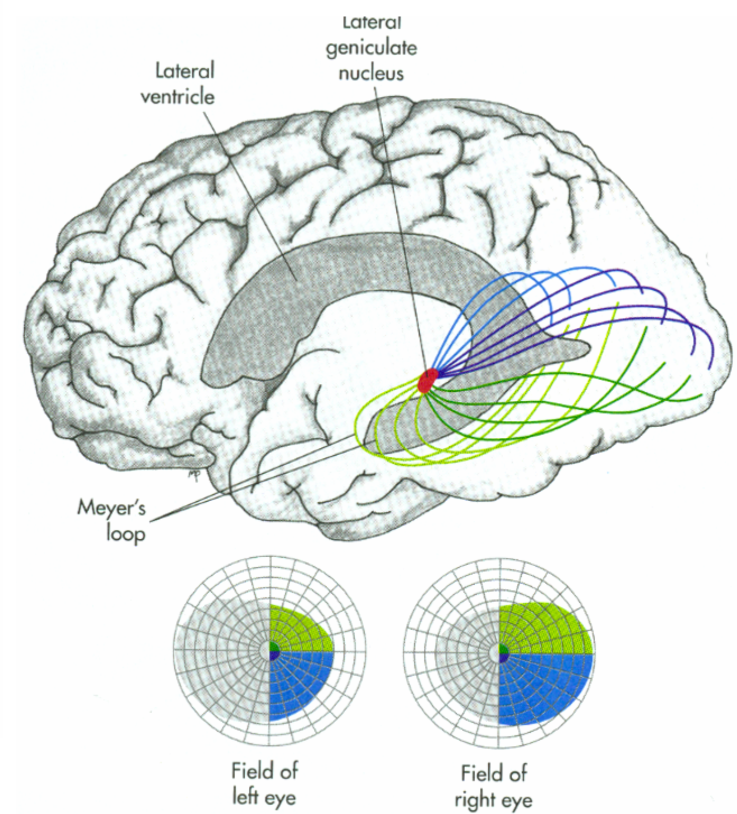
Fig. 5.14. *Fusion of the visual images.* The impulses from corresponding points on the two retinae end in different layers of the geniculate—that is, impulses from the two eyes are kept separate at this level. The convergence of impulses takes place in the striate area.


B
F
BINOCULAR SEGMENT
Visual field
M
MONOCULAR SEGMENT
Retina
M'L
F'L
B'L
F'R
B'R
LGN
A
A1
F''R
F''L
F''L
B''L
F''R
B''R
M''L
F'''L/R
AREA 18
Visual cortex
AREA 17
F'''L/R
B'''L/R
M'''L

VISUAL PATHWAYS



B: bitemporal hetereonymous hemianopia (pituitary tumor, craniopharyngeoma, meningeoma of the tuberculum sellae) D: right homonymous hemianopia. G: note that the light falling on the involved halve of the retina produces pupillary reaction as compared to D, in which case no pupillary reflex can be elicited. (the pupillosensory fibers are crossing in the pretectal area- comm. post, but they are destroyed in lesion D) (From Szentagothai)



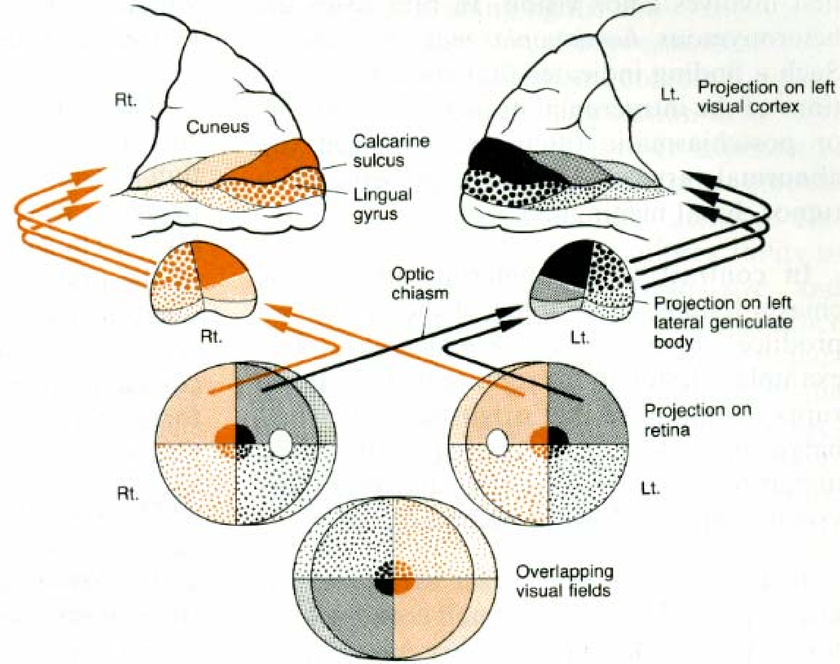


Fig. 3.**10** Projection of visual fields on retina, in lateral geniculate body, and in visual cortex.

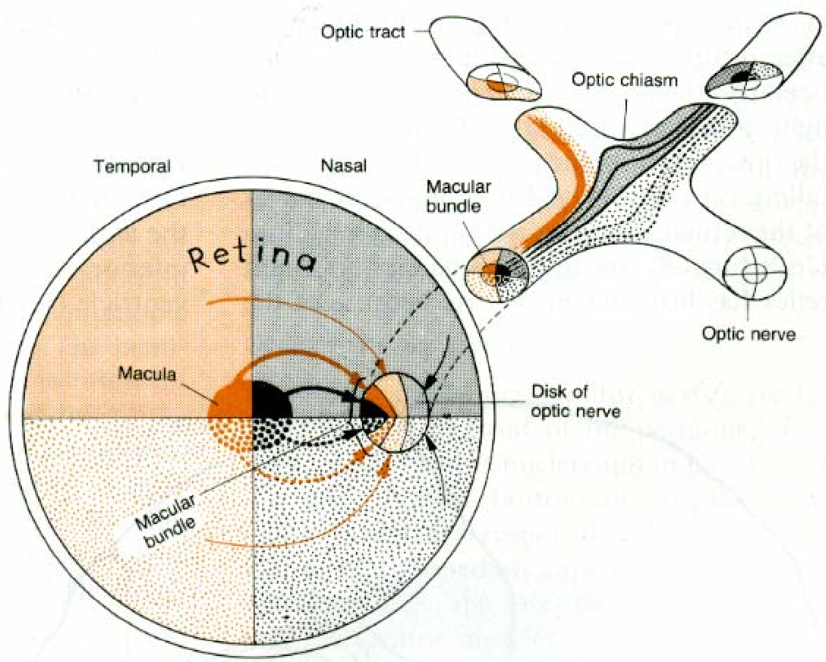
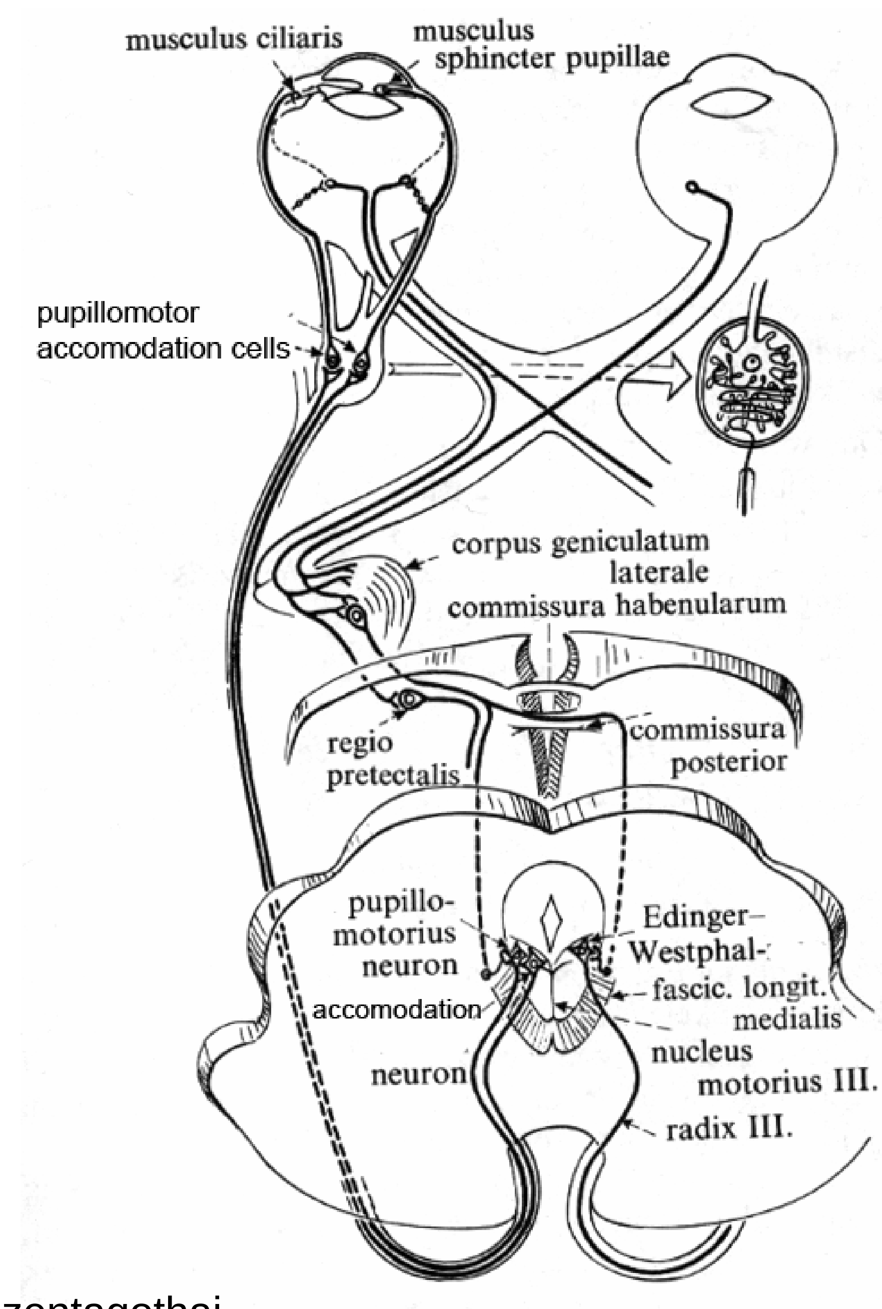
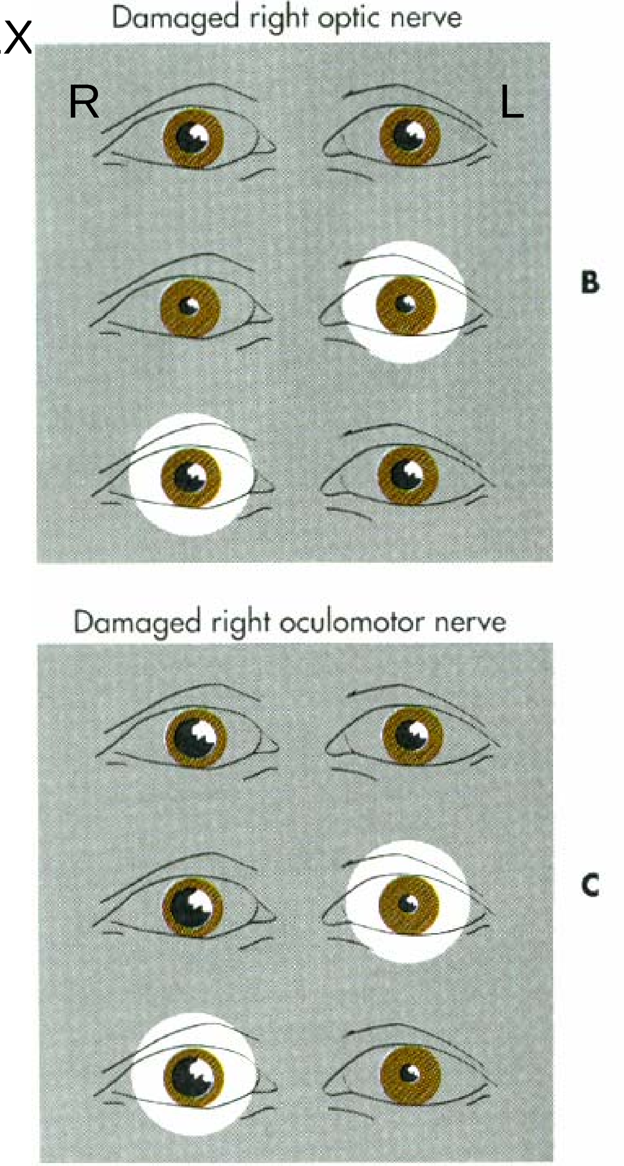


Fig. 3.**11** Arrangement of macular bundles in retina, optic nerve, and optic chiasm.

THE PUPILLARY LIGHT and ACCOMODATION REFLEX



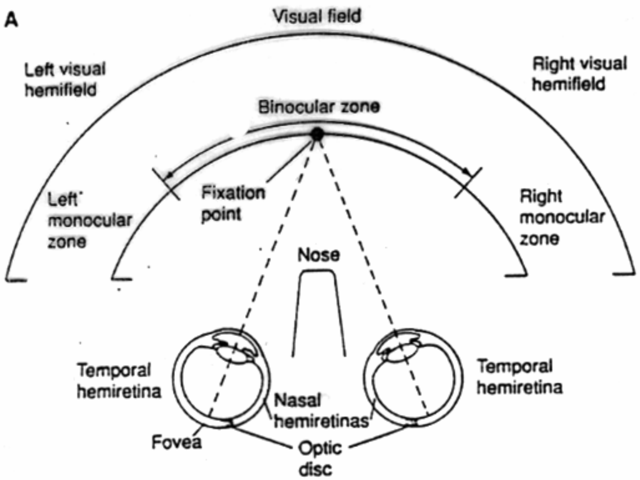


In each, the upper image show the relative size of the pupils in dark, the middle and lower images the expected responses to illumination of the left or right eyes. From Nolte

Szentagothai

MONOCULAR AND BINOCULAR VISUAL FIELDS

A

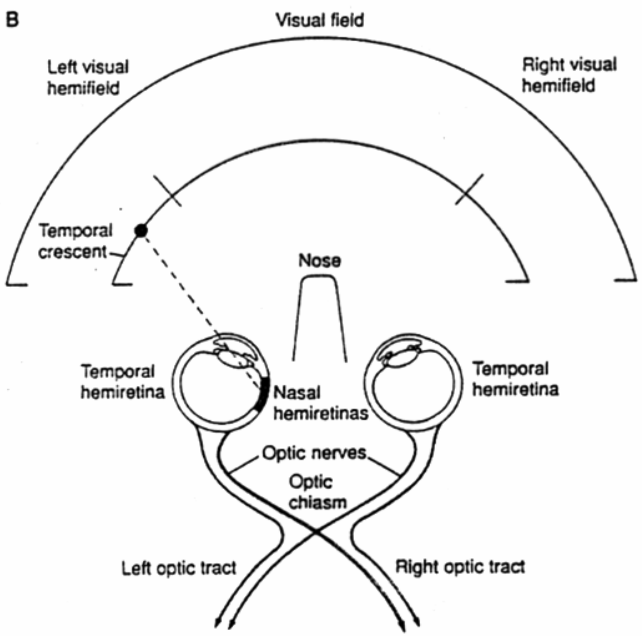


A. Light from the binocular zone (indicated in black) strikes both eyes, whereas light from the monocular zone strikes only the eye on the same side. The hemiretinas are defined with respect to the fovea, the region in the center of the retina with the highest acuity. The optic disc, the region where the ganglion cell axons leave the retina, is free of photoreceptors and therefore creates a gap, or blind spot in the visual field for each eye (see Figure 29–2).

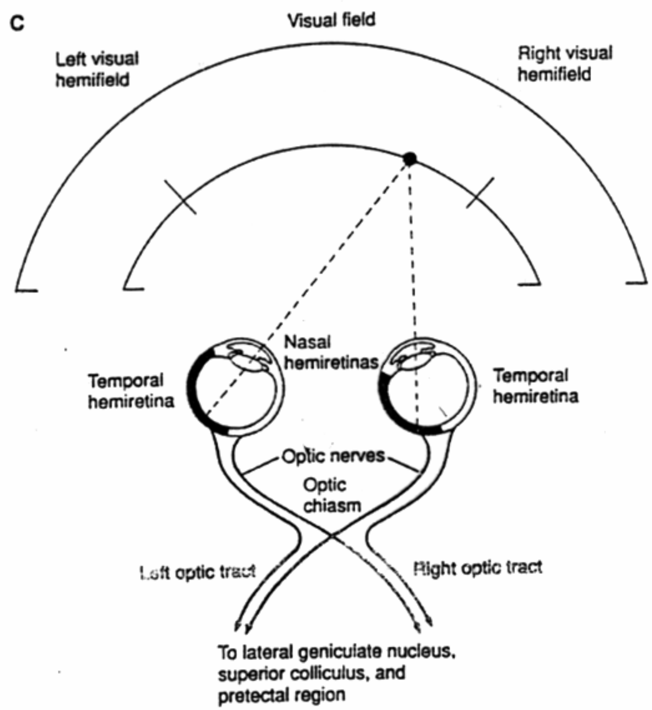
B. Light from a monocular zone (temporal crescent) falls only on the ipsilateral nasal hemiretina and does not project upon the contralateral retina because it is blocked by the nose.

C. Each optic tract carries a complete representation of one half of the binocular zone in the visual field. Fibers from the nasal hemiretina of each eye cross to the opposite side at the optic chiasm, whereas fibers from the temporal hemiretina do not cross. In the illustration light from the right half of the binocular zone falls on the left temporal hemiretina and right nasal hemiretina. Axons from these hemiretinas thus contain a complete representation of the right hemifield of vision (see Figure 29–6).

B

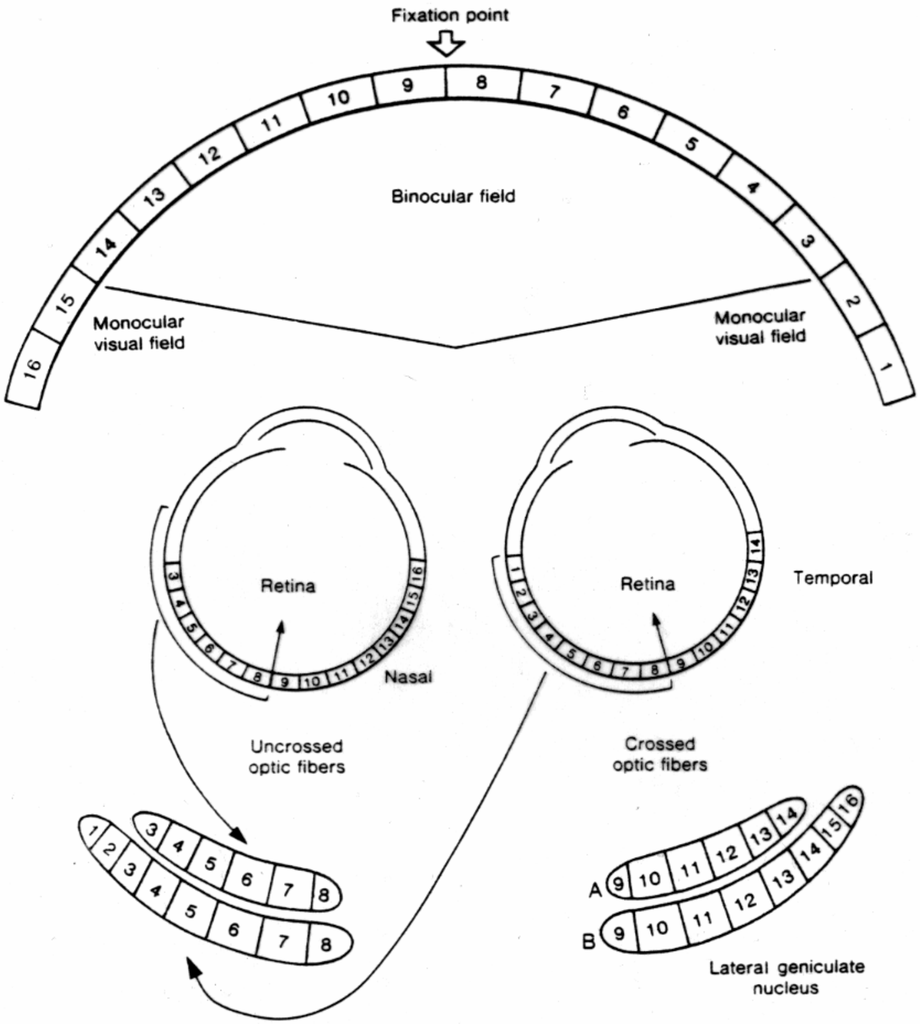


C



From Kandel

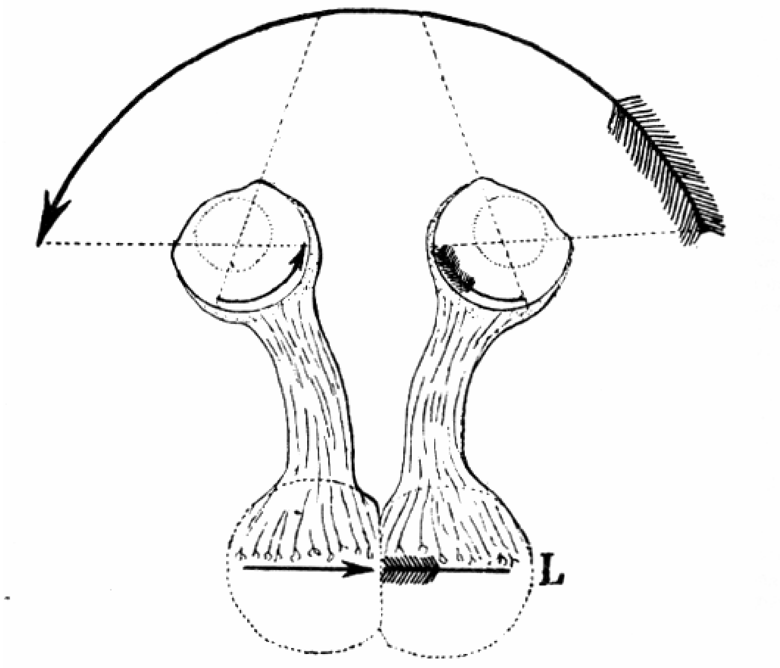
BINOCULAR AND MONOCULAR VISUAL FIELDS

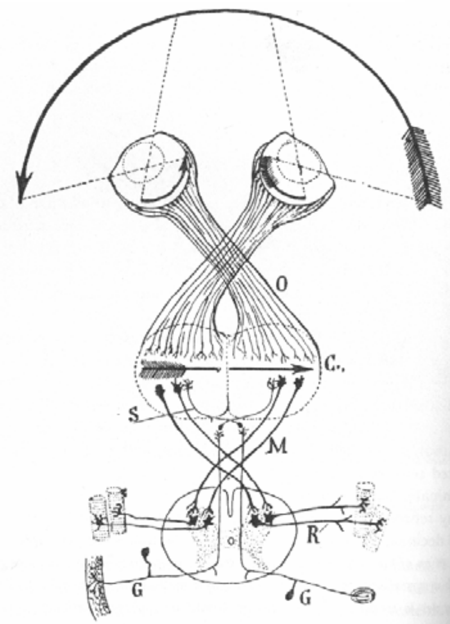


Guillery

Schematic representation of the visual field in the retina and in the lamina of the LGN. Crossed and uncrossed retinofugal fibers proejct on columns of cells in different laminae of the LGN. **A** represent laminae receiving uncrossed fibers (i.e. laminae 2,3,5); B represents laminae receiving crossed fibers (i.e. 1,4,6). Light from the right monocular field (sector 1, 2) falls on retinal receptors in the most medial ipsilat nasal retina. Crossed retinal fibers from sectors 1-2 project to cell columns on the same number in the left LGN. Sectors 1-2 in the LGN form the bilaminar segment in which cells of laminae 4 and 6 are fused

CAJAL’S EXPLANATION OF THE CENTRAL IMAGE FORMATION





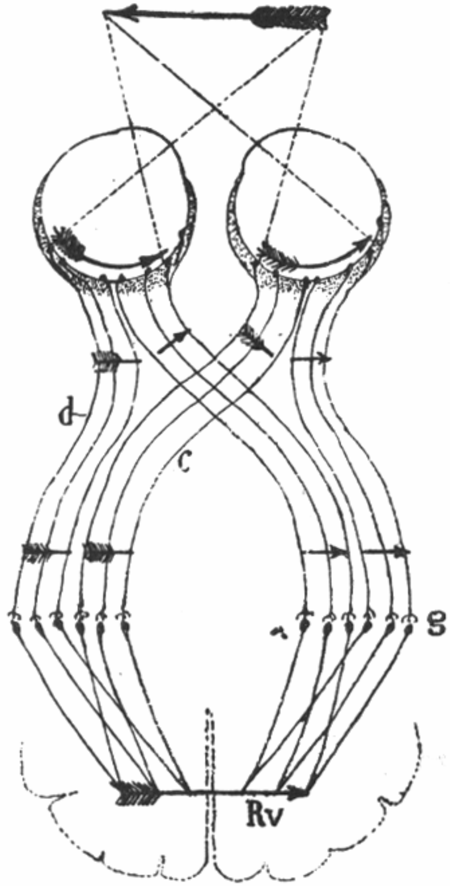
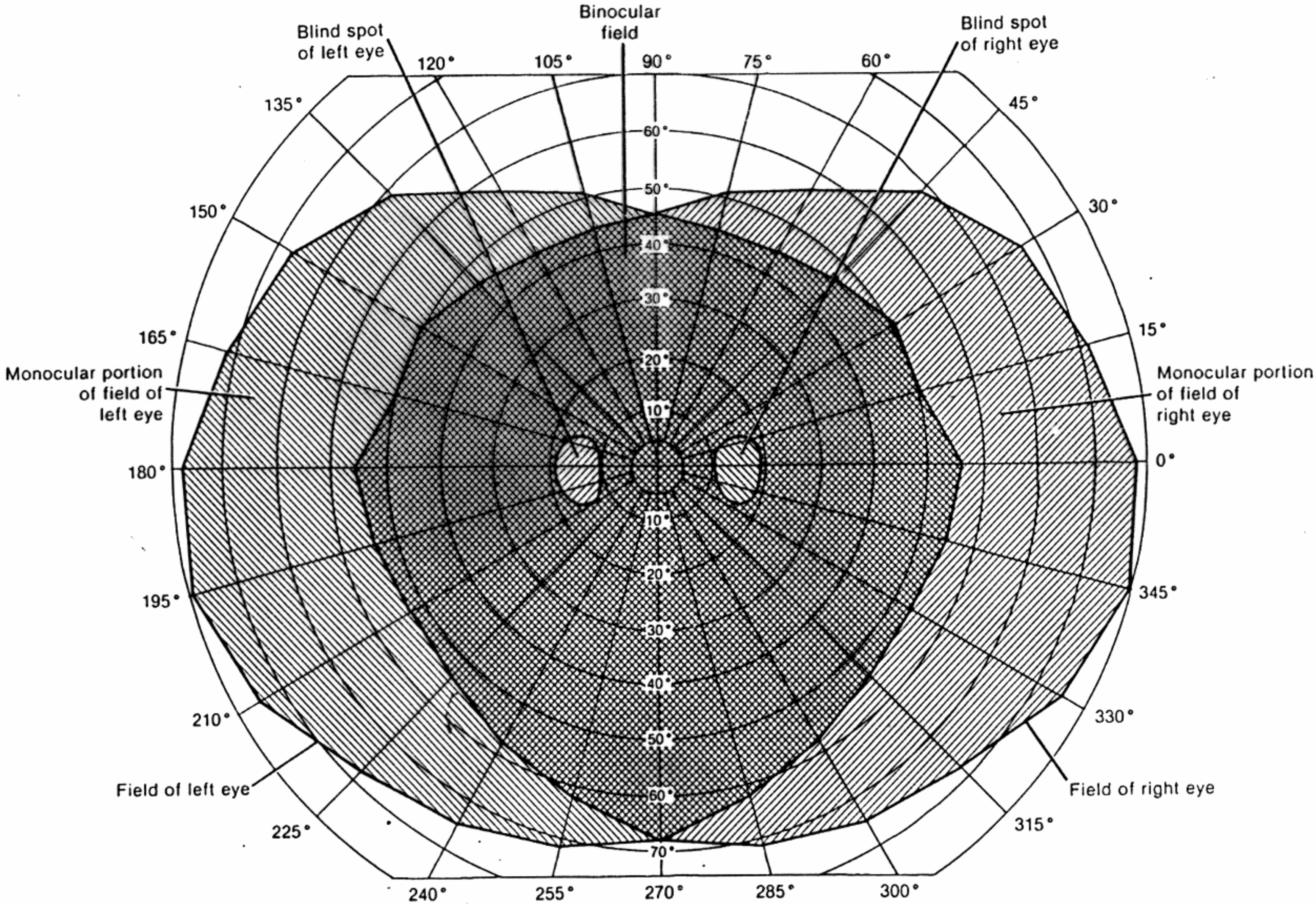


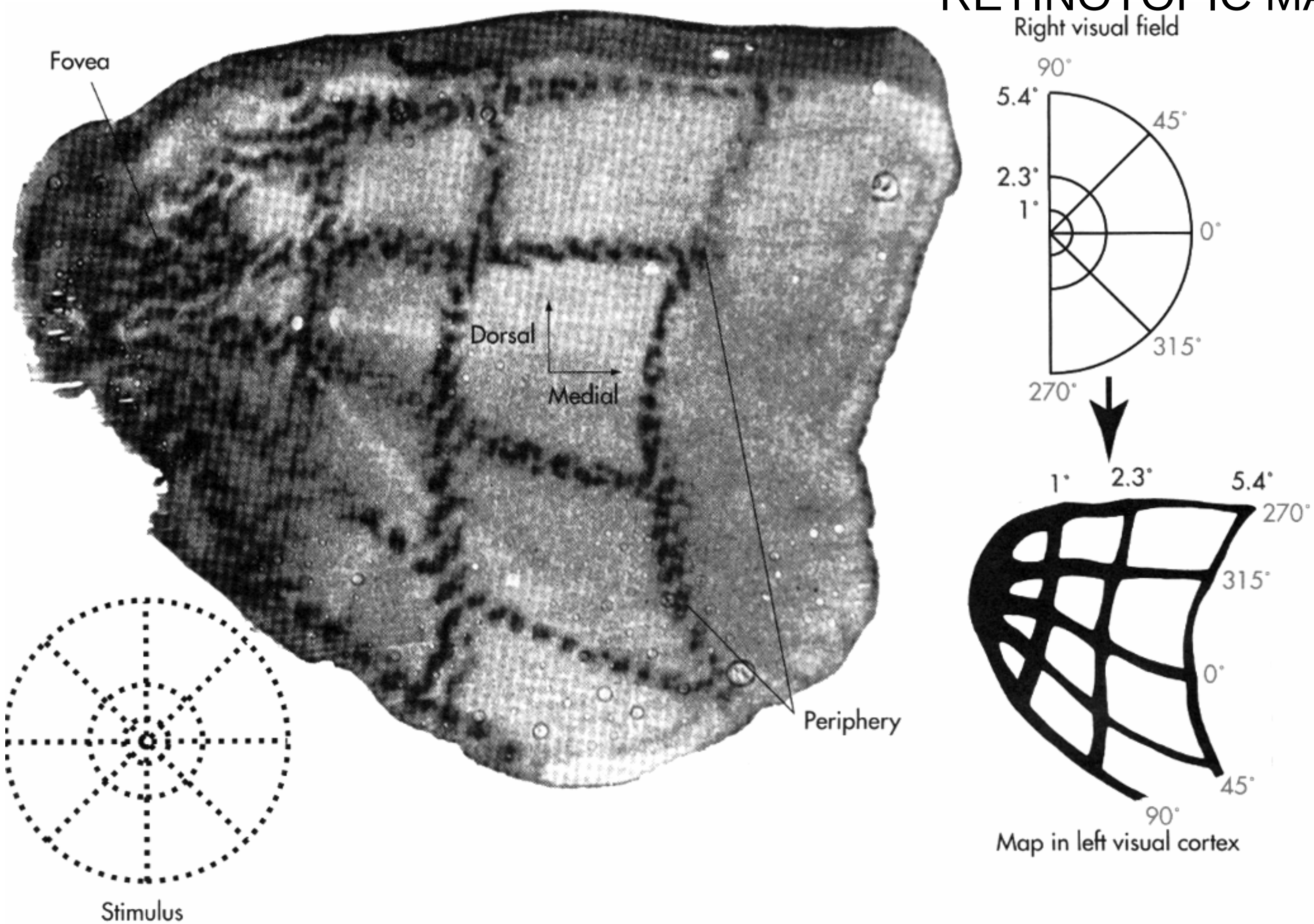
Diagram to illustrate the incongrousness of the central projection of the images from the two eyes if there were no intercrossing of the optic nerve

Diagram to show how in mammals with stereoscopic vision the central image is formed by combination of two representations of the object, transmitted by the two optic nerve

Normal visual fields for the two eyes, superimposed on each other

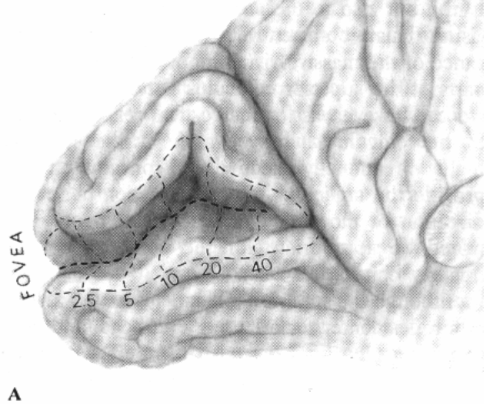


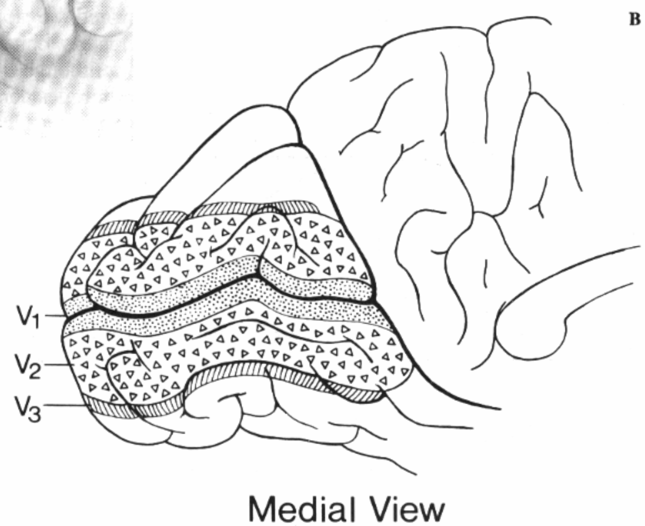
RETINOTOPIC MAP ONTO V1



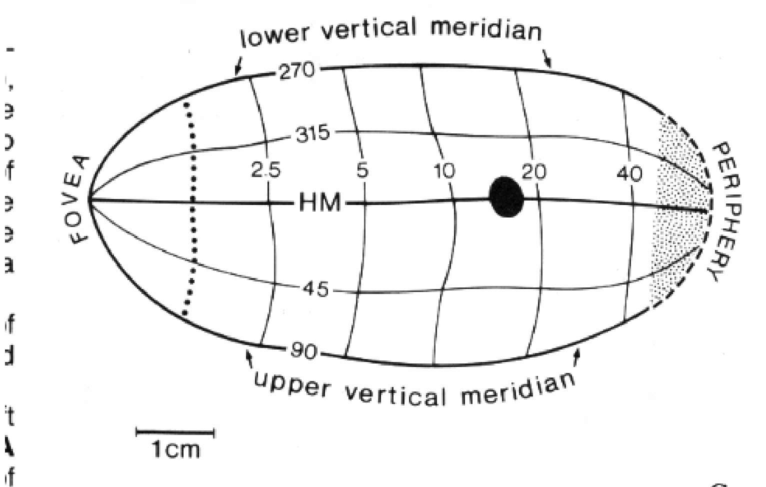
The stimulus was an array of dashed rings and lines on a gray background; during the experiment, the black and white segments reversed in contrast (the black segments turned white, and vice versa) at a frequency of 3Hz. While the monkey watched the stimulus with one eye open, the animal was injected with 14C-2deoxyglucose.Subsequent autoradiography of a tangential section through the left visual cortex revealed a distorted but precise map of the right half of the stimulus; each dark area corresponds to a small group of neurons that receive input from a particular small area of the visual field primarily via the eye that was open during the experiment. Note that the line segments in the cortical map get progressively thicker in moving toward the macula (Tootell, 1988).

THE STRIATE CORTEX

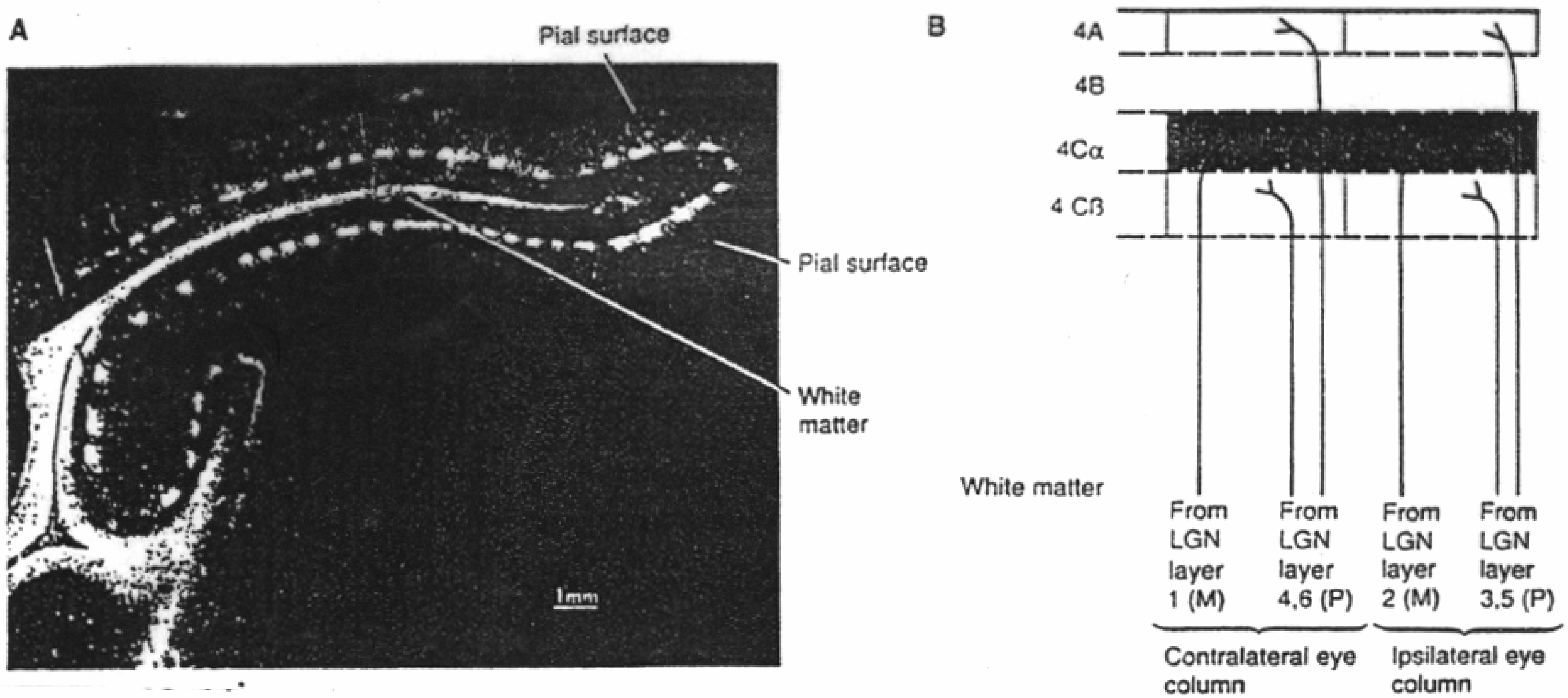




A: Medial view of the occipital cortex with the calcarina sulcus opened to expose the visual cortex, most of which is buried within the sulcus. B: schematic diagram to show the location of V1-V3. C: projection of the right visual hemifield on the left visual cortex by transposing th emap illustrated in A onto aflat surface. The visual cortex has the shape of an ellipse, with the fovea represented on the lateral brains surface (the row of dots indicate where the striate cortex folds around the occipital pole). The black oval shows the location of the blind spot. From Heimer, 1995

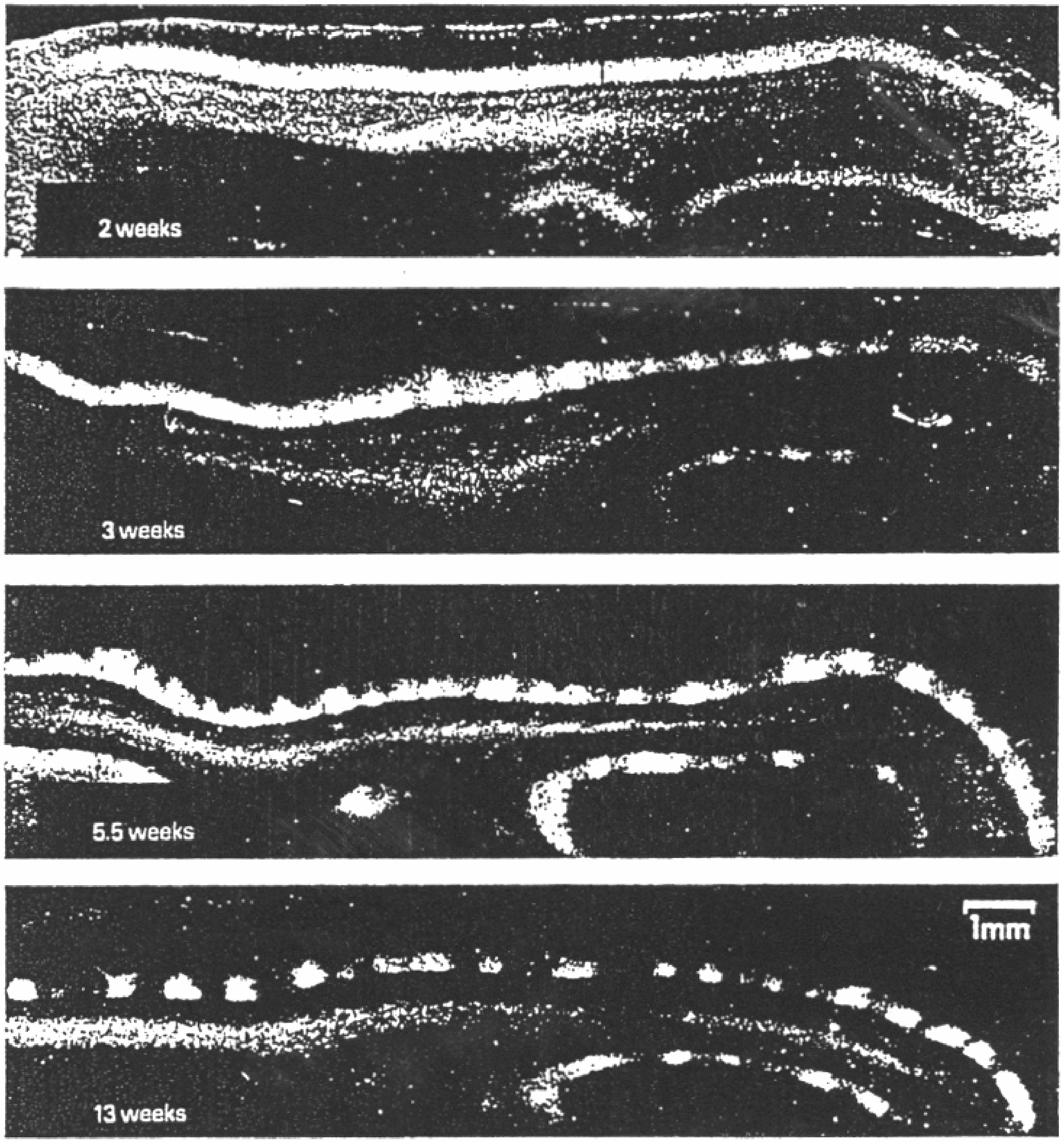


THE OCULAR DOMINACE COLUMNS



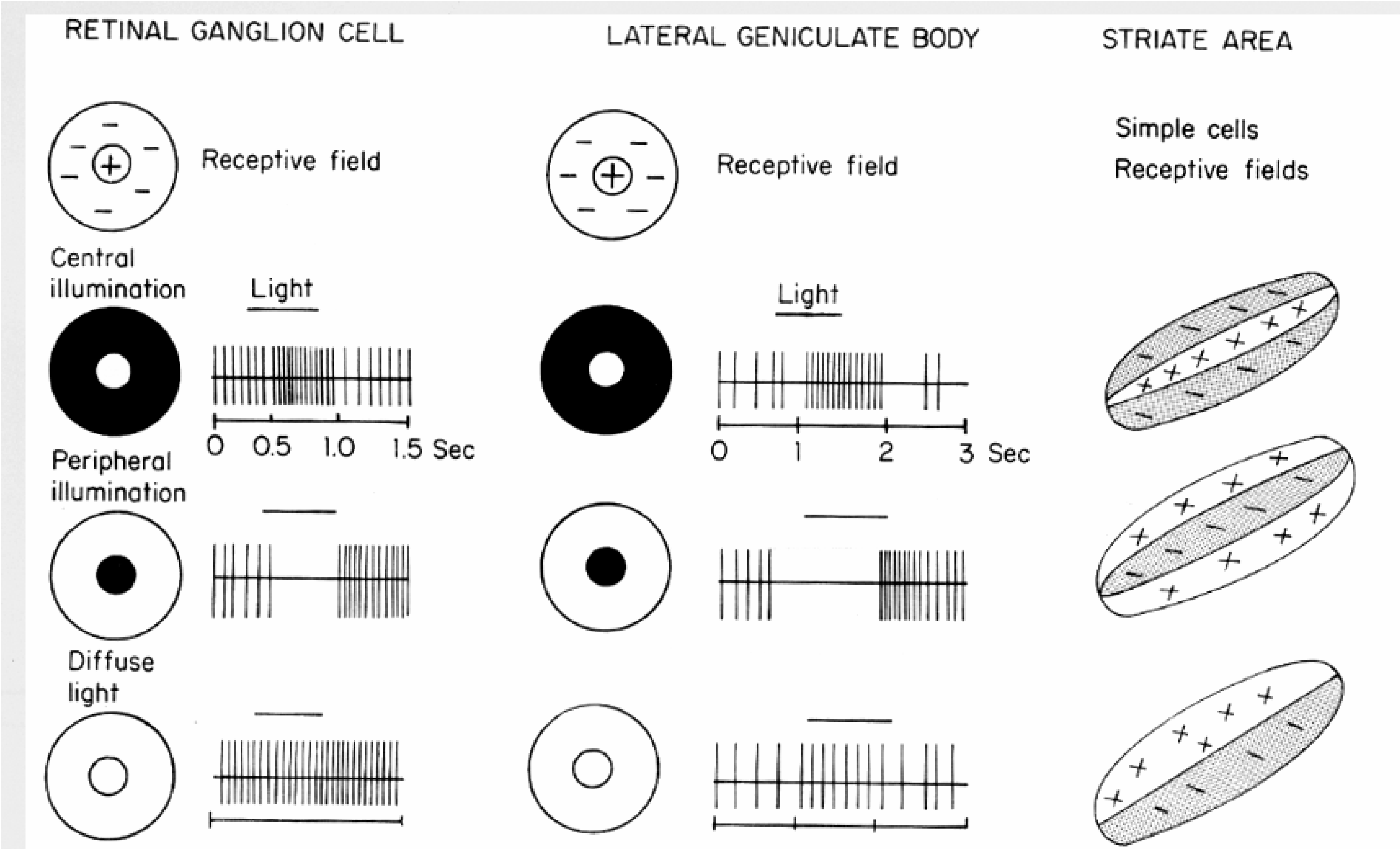
Hubel and Wiesel, 1979)

DEVELOPMENT OF OCULAR DOMINANCE COLUMNS IN CAT



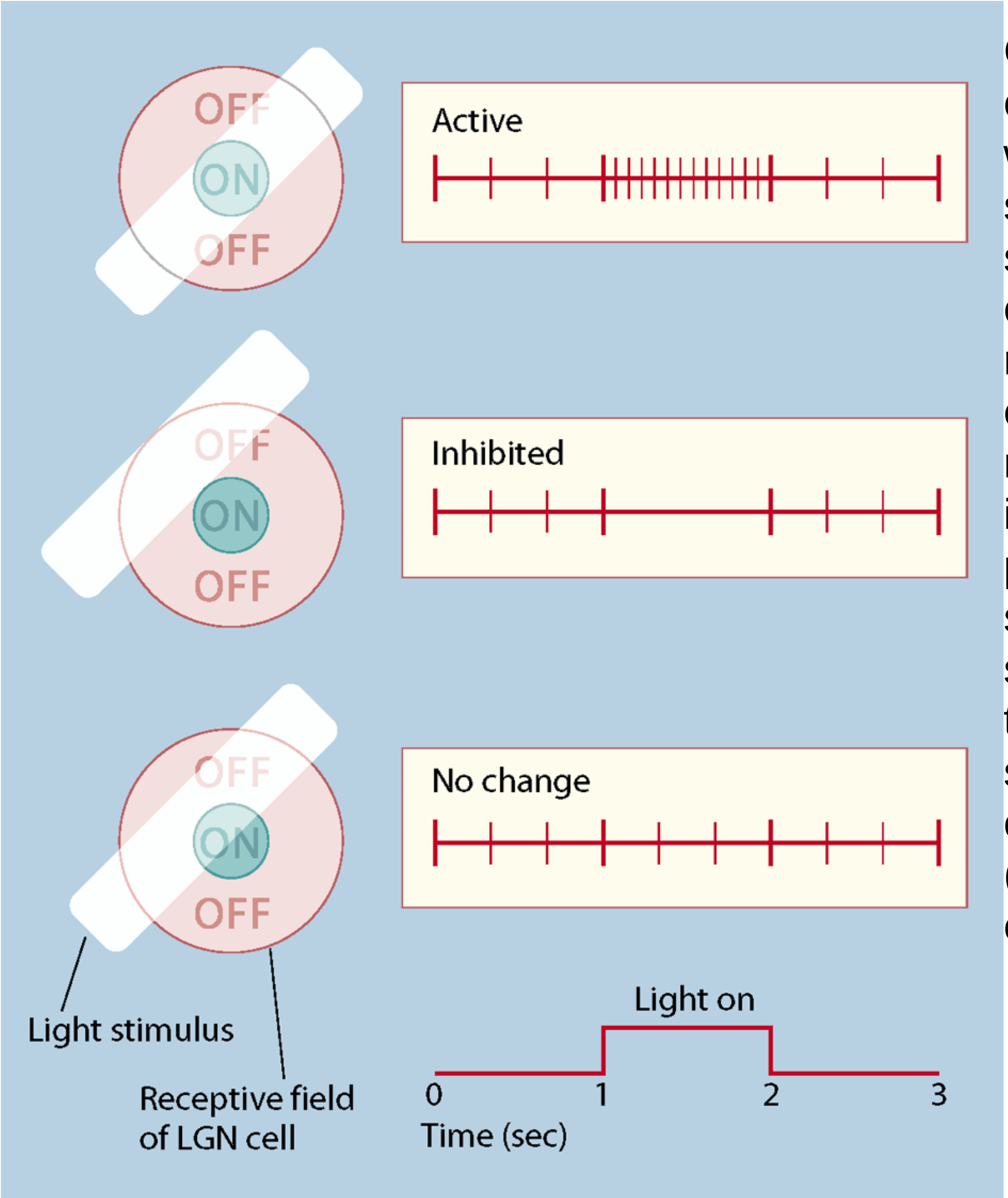
LeVay, Stryker and Shatz, 1978

RECEPTIVE FILEDS OF CELLS AT VARIOUS LEVELS OF THE VISUAL PATHWAYS



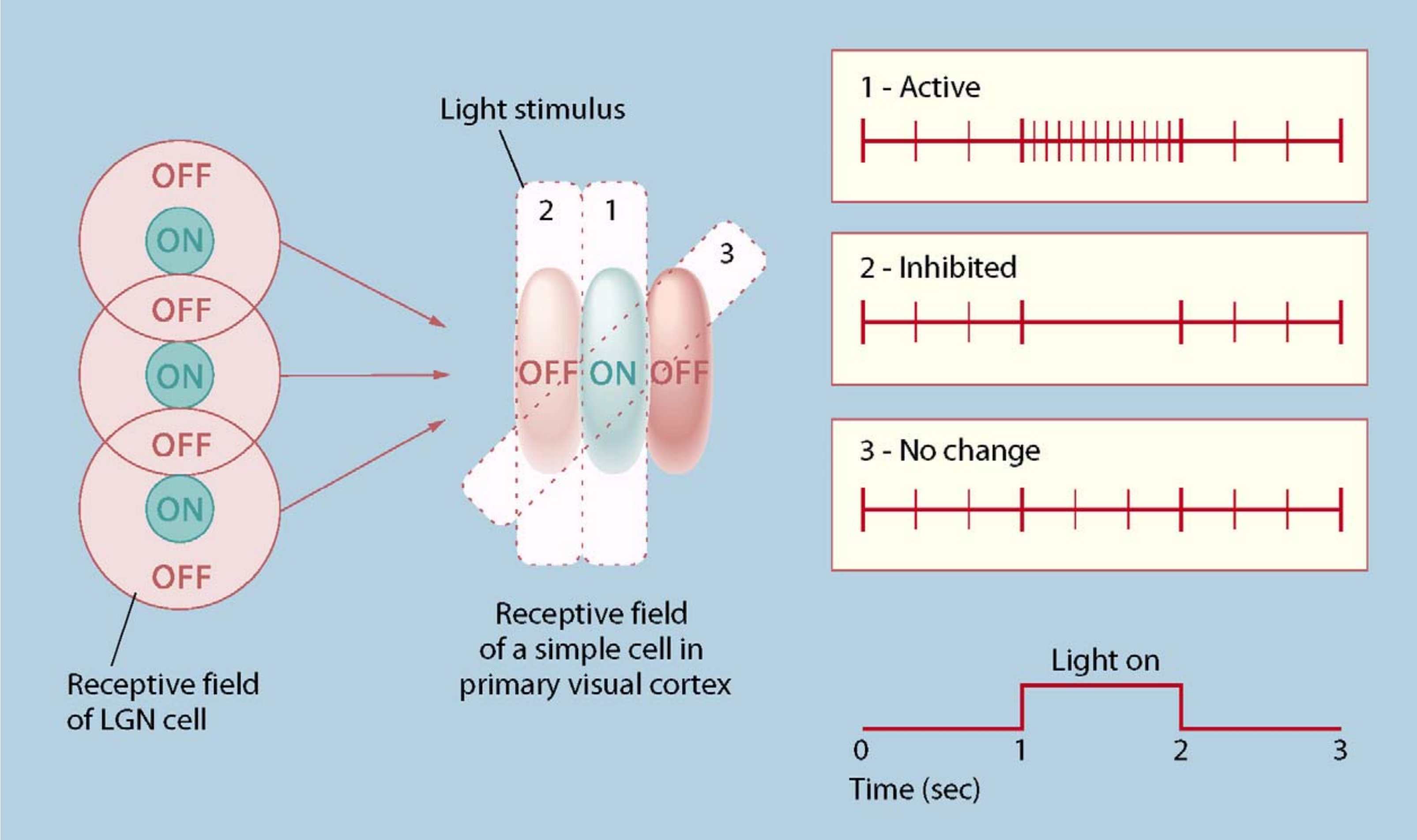
Only on-center field cells are shown. The receptive fields of simple cells of the area striata are typically oblong with an excitatory and inhibitory zone. The cells are called orientation specific because they respond preferentially to a stripe of light with specific orientation (Kuffler, 1984; Brodal)

RECEPTIVE FIELDS OF LGN NEURONS



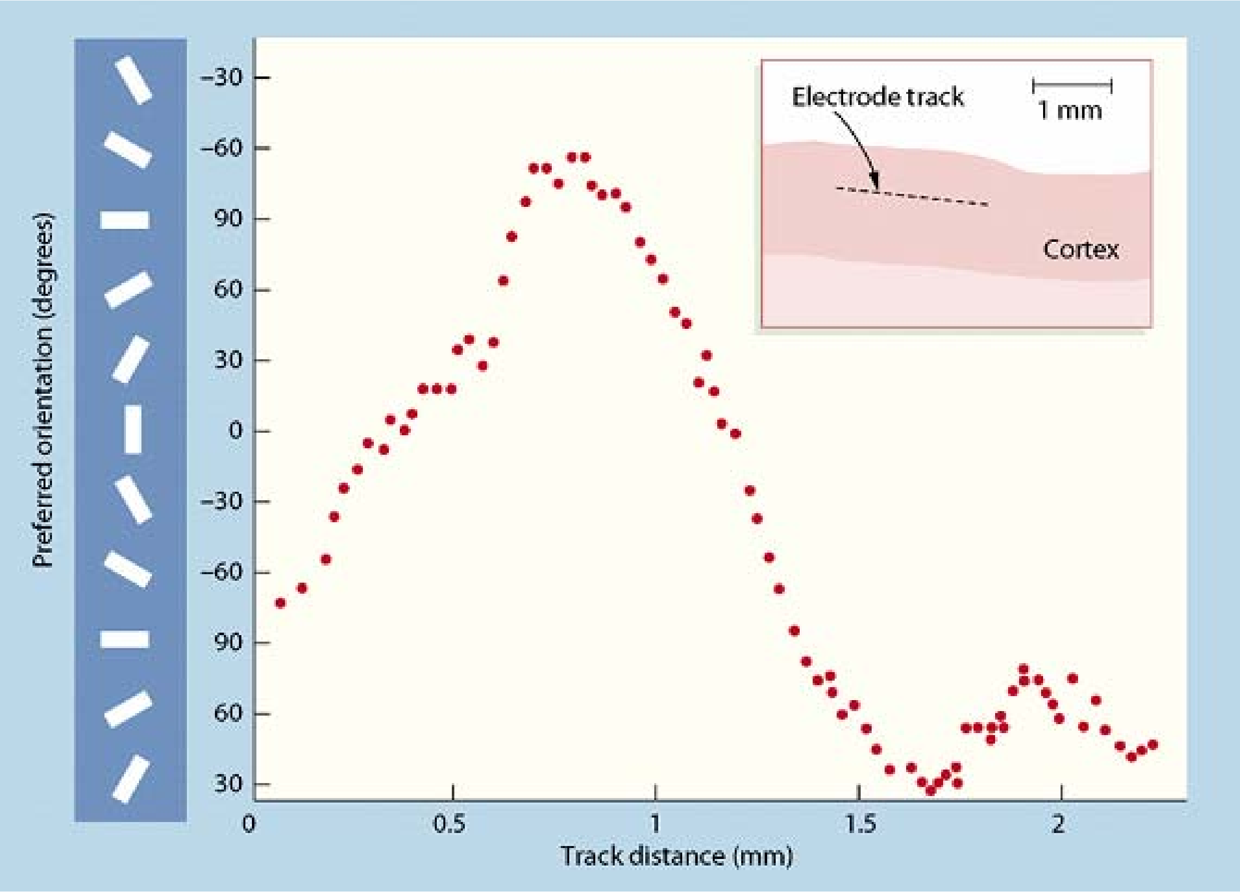
Cells in the LGN have concentric receptive fields with either on center-off surround or off center-on surround. This on center-off surround cell fires rapidly when the light encompasses the center region (top) and is inhibited when the light is positioned over the surround (middle) A stimulus that spans both the center and the surround produces little change in activity (bottom). From Gazzaniga et al., 2002)

Parvocellular Pathway – Interblob Regions Respond to Orientation



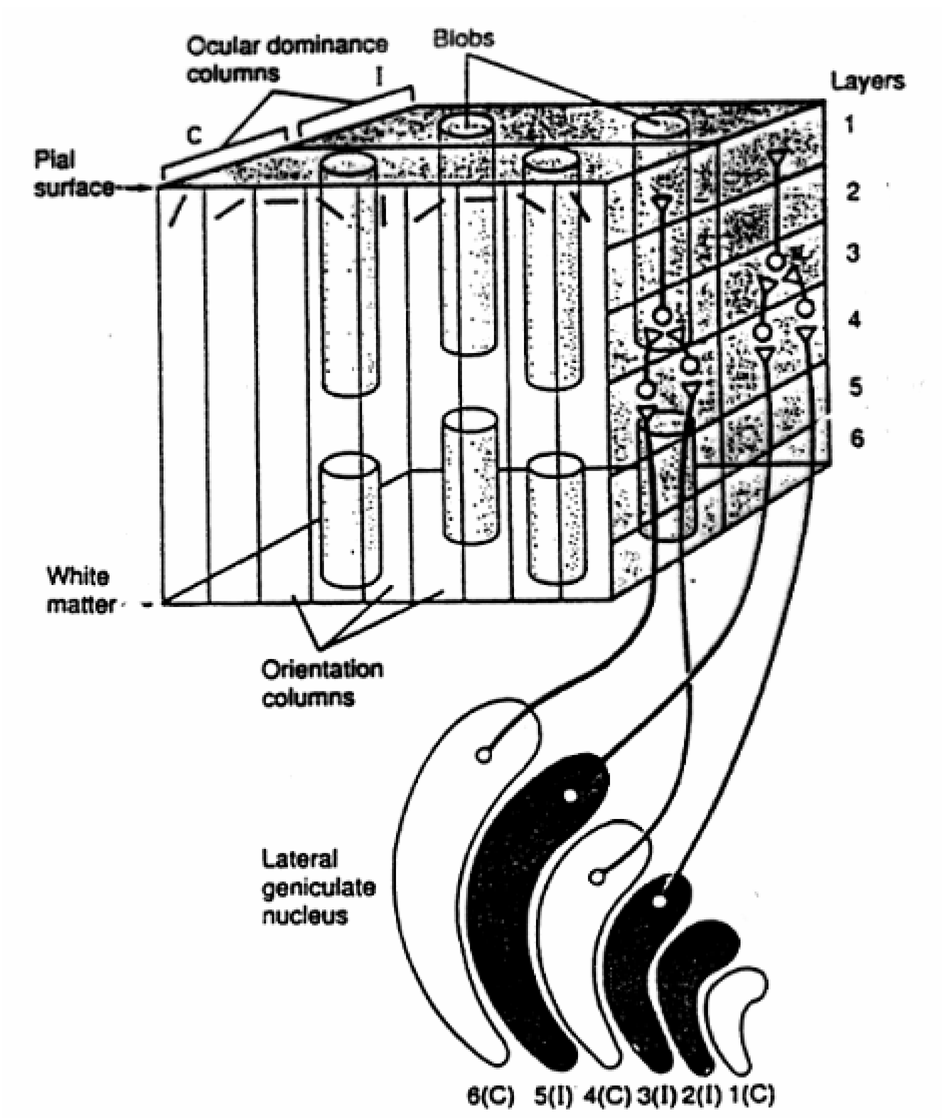
Orientation tuning gradually shifts across adjacent areas of V1

As the recording electrode is moved along the cortex, the preferred orientation of the cells varies in a continuous manner. The preferred orientation is plotted as a function of the location of the electrode (Hubel and Wiesel, 1968)

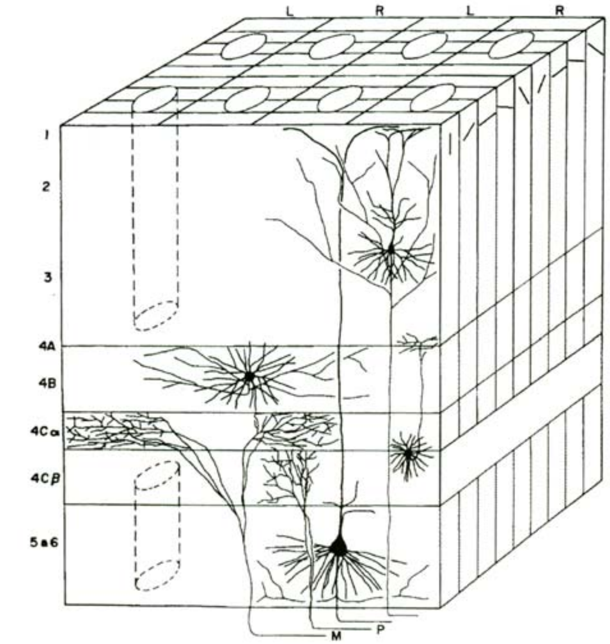


HYPERCOLUMNAR ORGANIZATION OF THE VISUAL CORTEX

A

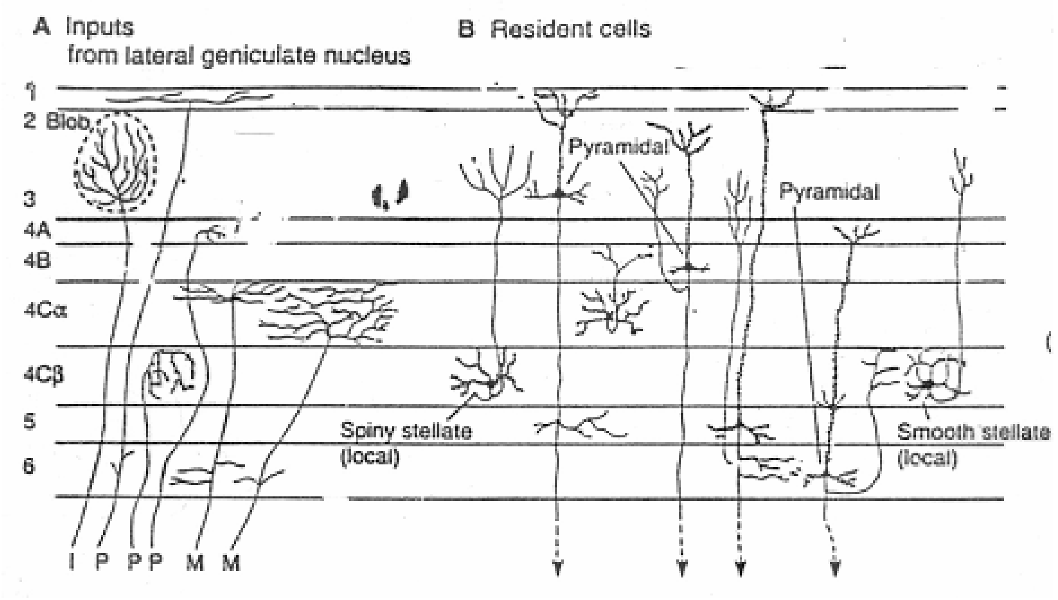


B

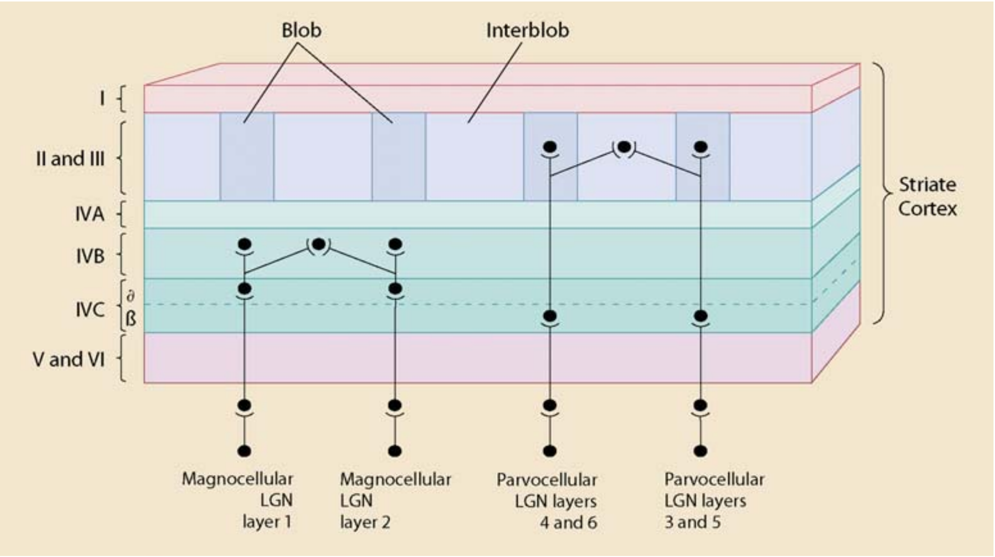


A single hypercolumn contains a complete set of orientation columns, representing 360º, a set of left and right ocular dominance columns, and several blobs, region of the cortex in which cells are specific for coloD: Ice cube model of visual cortex . L,R:ocular dominace columns. The narrower orientation columns run orthogonally. The cytochrome oxidase rich blobs appear as cylinders in the center of the ocular dominance columns (A from Kandel, B Douglas and Martin, 1998)

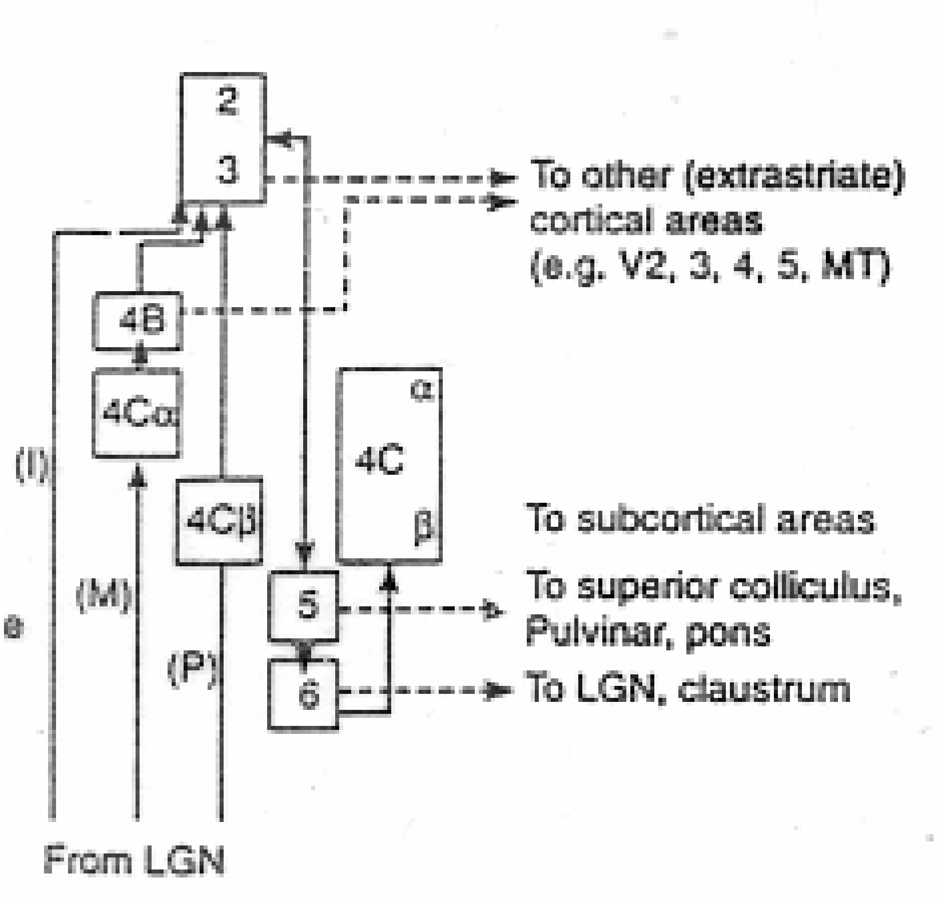
Parvocellular and Magnocellular Projections to the Visual Cortex

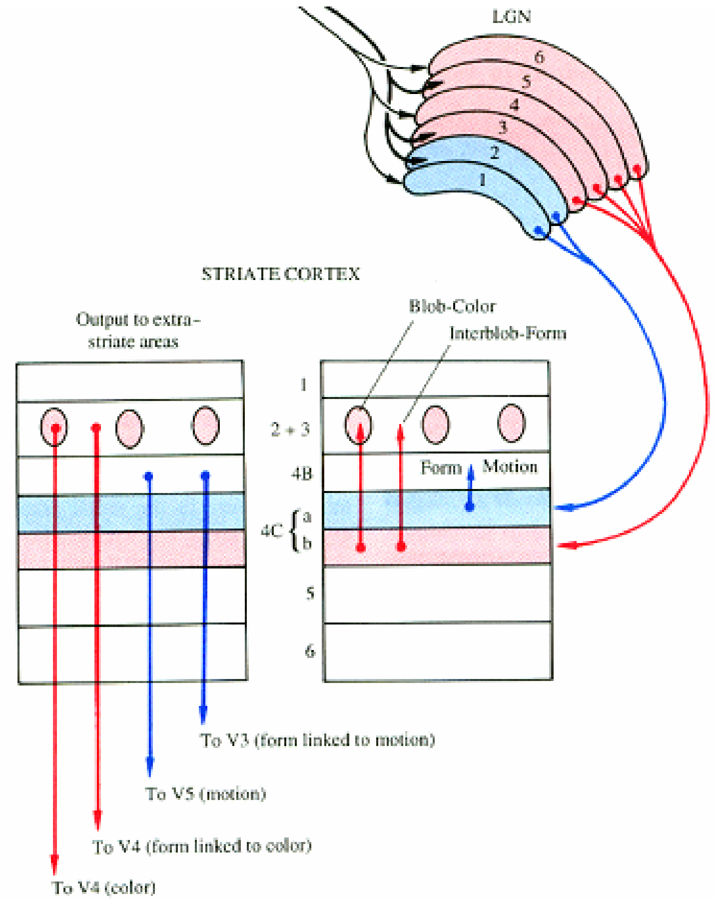


C



LOCAL PROCESSING AND OUTFLOW

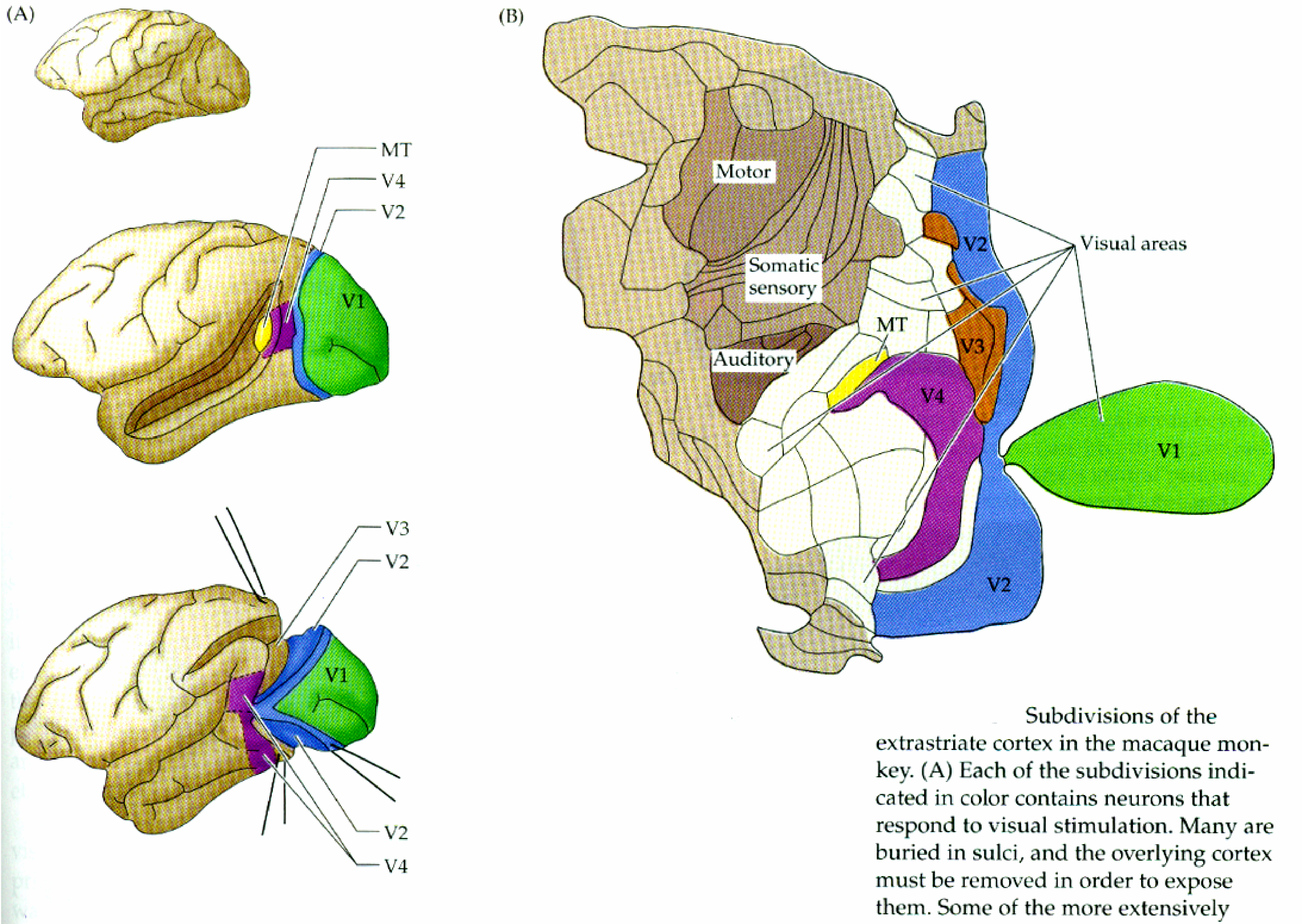




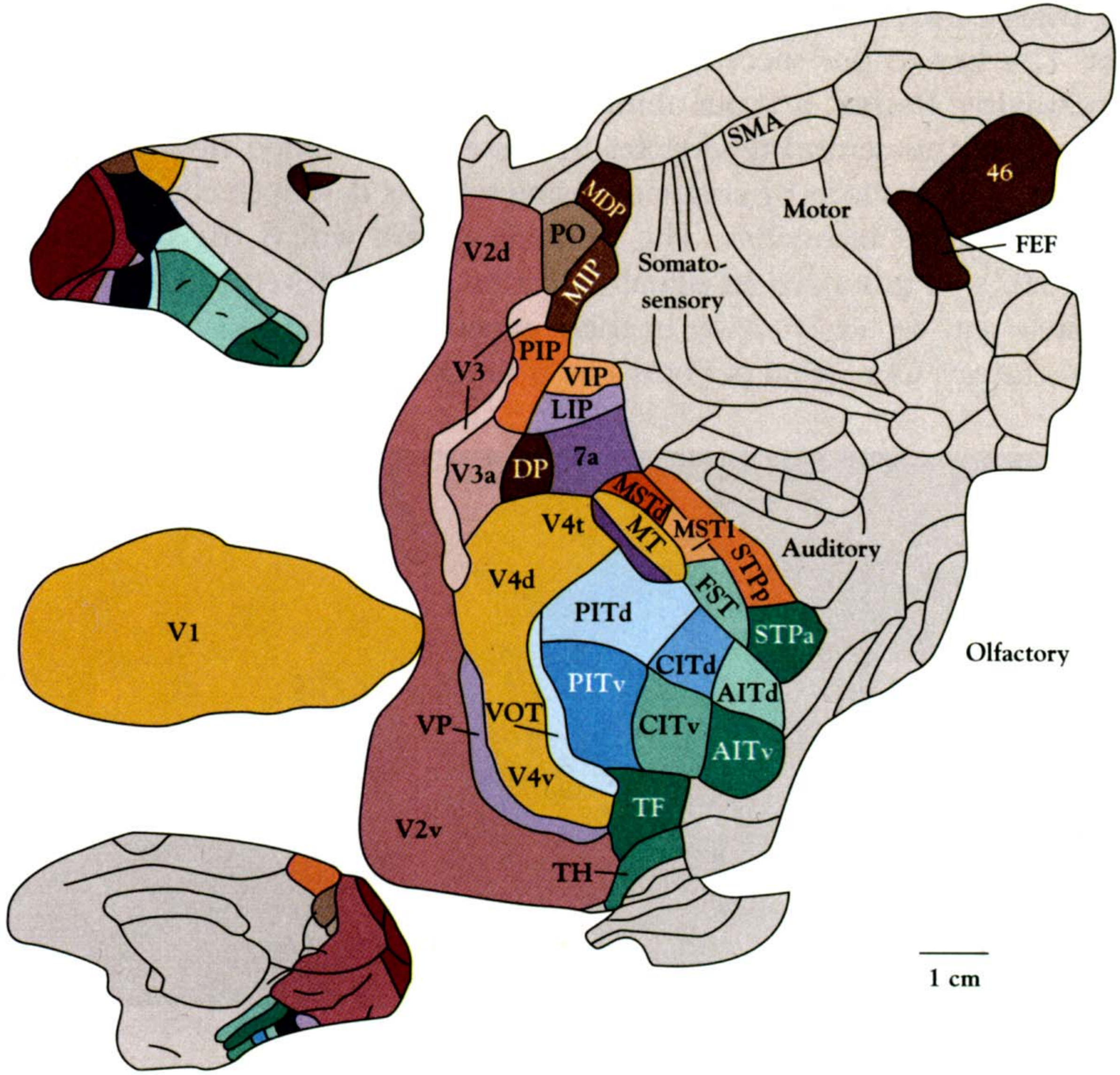
Afferents from M and P cells of the LGN end on spiny stellate cells in layer 4C, and these cells project axons to layer 4B and the upper layers 2 and 3. Cells from the interlaminar zones (I) in the LGN project directly to layers 2-3. From there, pyramidal cells project axon collaterals to L5 pyramidal cells, whose axon collaterals project both to L6 cells as well as back to cells in L2-3. Axon collaterals of L6 pyramidal cells then make a loop back to L4C onto smooth stellate cells. Each layer, except for 4C, has different outputs. The cells in L5 project to the superior colliculus, the pons, and the pulvinar. Cells in L6 project back to LGN and the claustrum (Lund, 1988) .

The two original (magno and parvoc) pathways give rise to four parallel channels to the extrastriate visual areas. But the segregation is not complete. There are significant interactions between the functional compartments as all stages along the visual pathways (From Heimer, 1995)

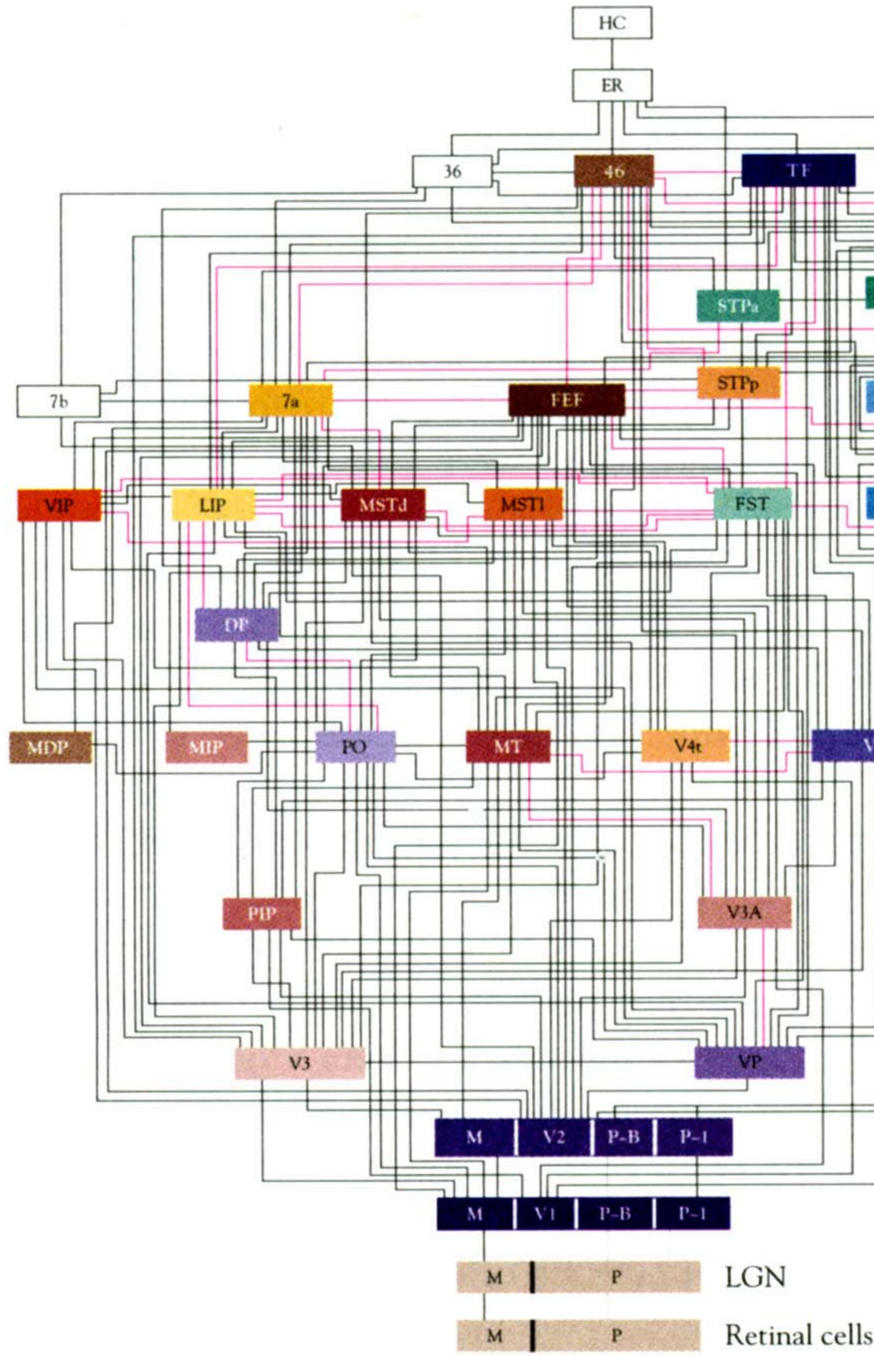
VISUAL AREAS IN MONKEYS



Subdivisions of the extrastriate cortex in the macaque monkey. (A) Each of the subdivisions indicated in color contains neurons that respond to visual stimulation. Many are buried in sulci, and the overlying cortex must be removed in order to expose them. Some of the more extensively studied extrastriate areas are specifically

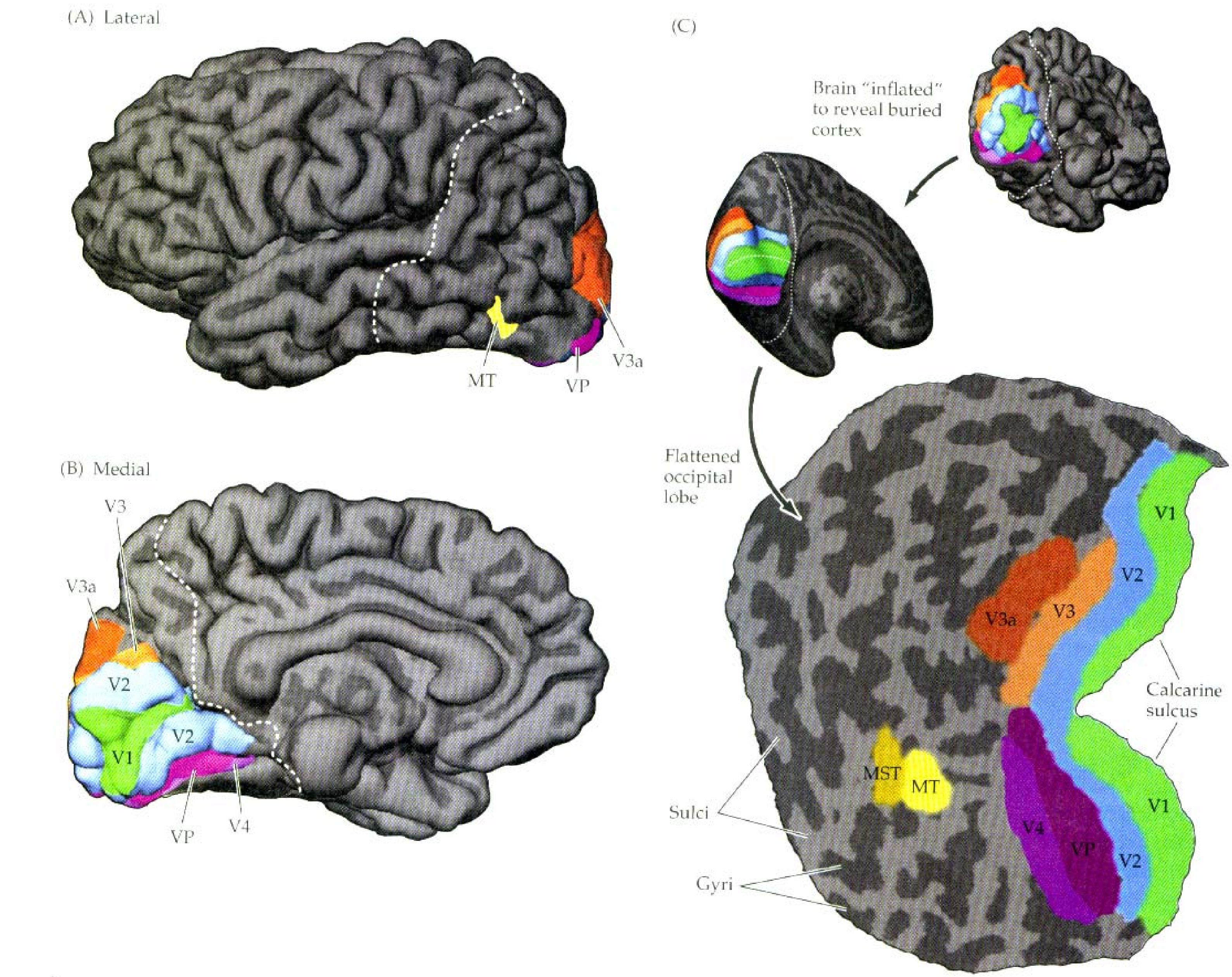


Two-dimensonal flattened map of the cerebral cortex of the macaque monkey with different visual areas (Van Essen and Maunsell).

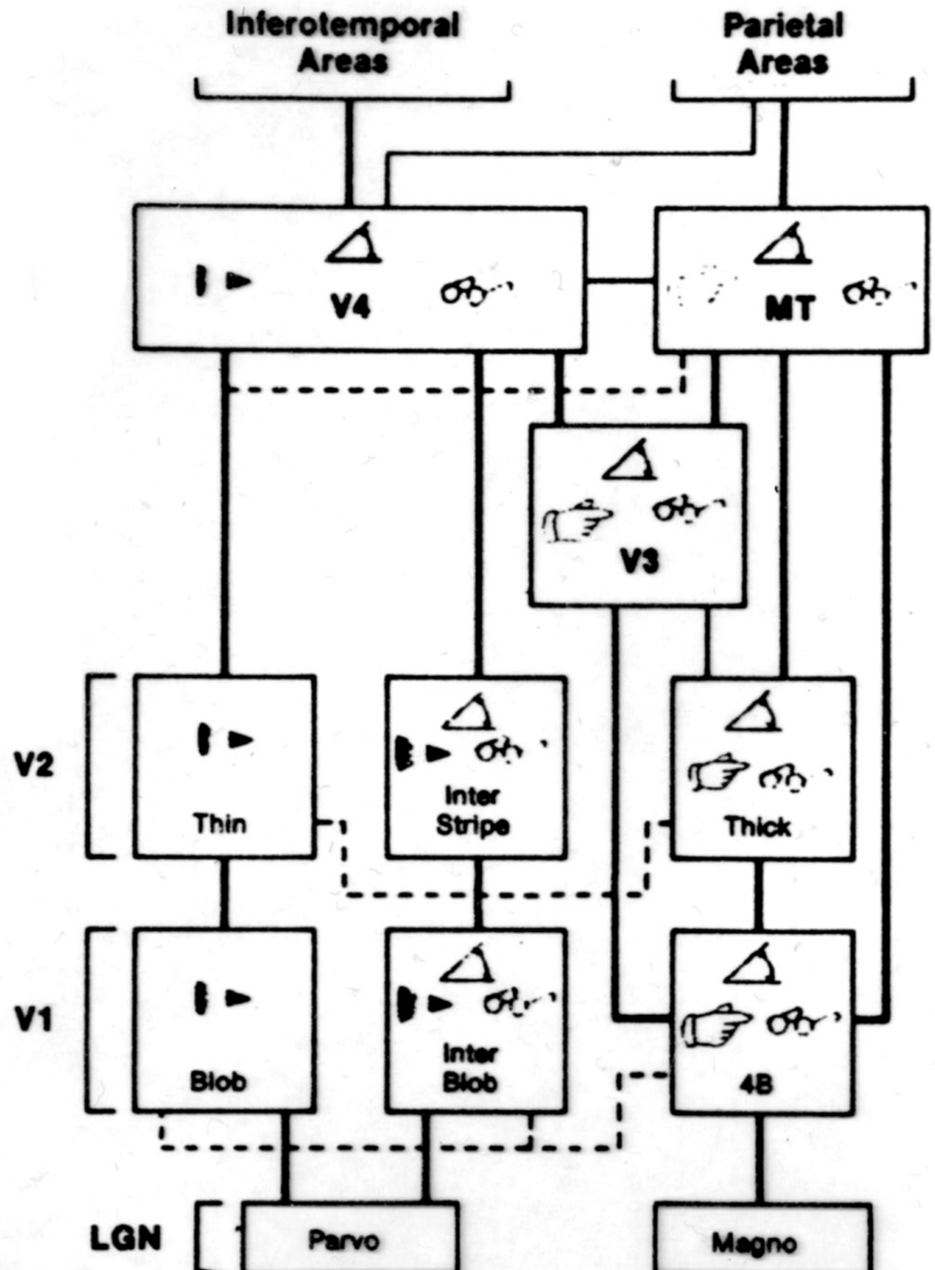


HC
ER
36
46
TF
TH
STPa
AITd
AITv
7b
7a
FEF
STPp
CITd
CITv
VIP
LIP
MSTd
MSTl
FST
PITd
PITv
DP
VOT
MDP
MIP
PO
MT
V4t
V4
PIP
V3A
V3
VP
M
V2
P-B
P-I
M
V1
P-B
P-I
M
P
LGN
M
P
Retinal cells

VISUAL AREAS IN HUMANS



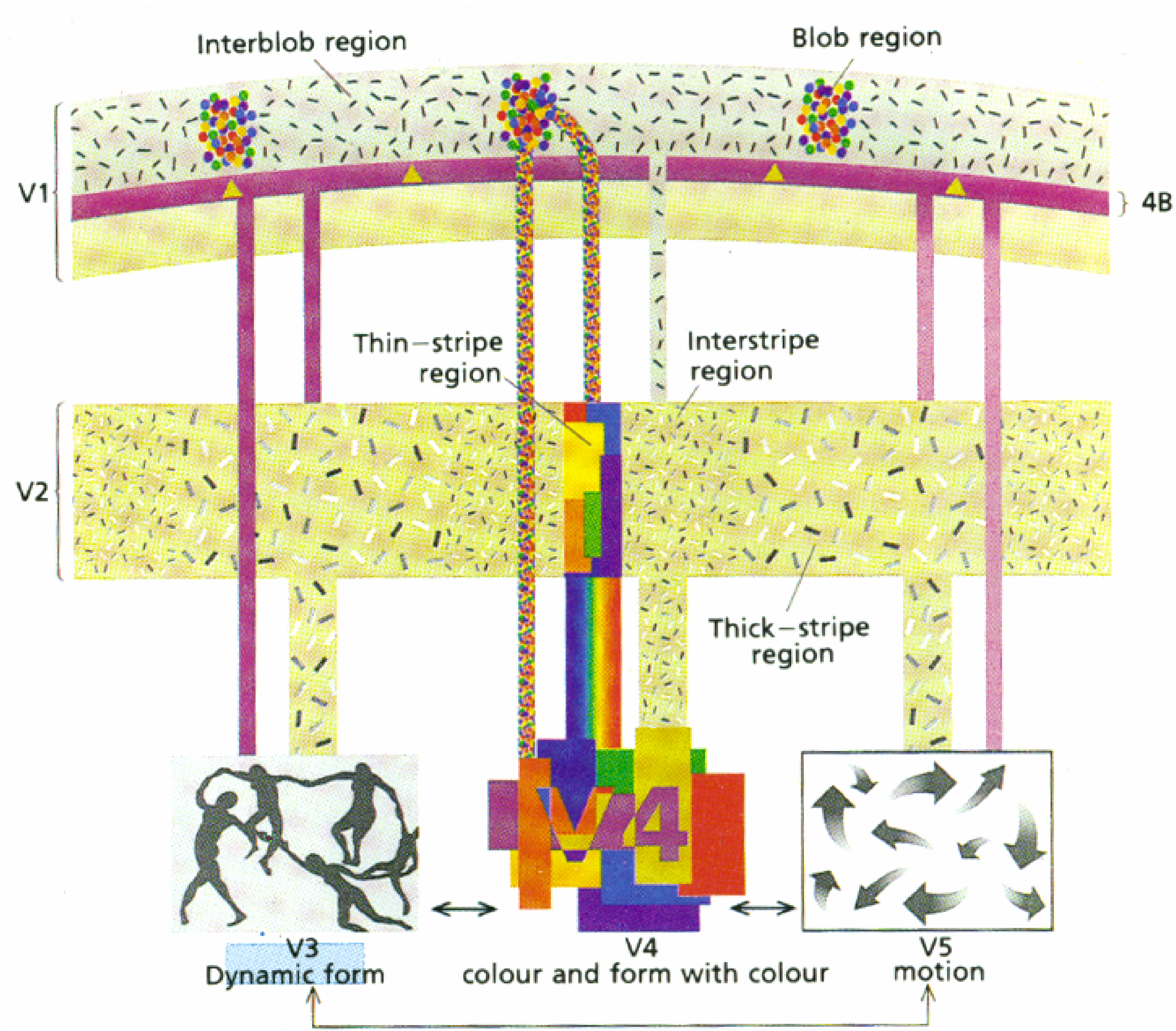
Neuronal selectivities in the immediate visual areas of the macaque monkey



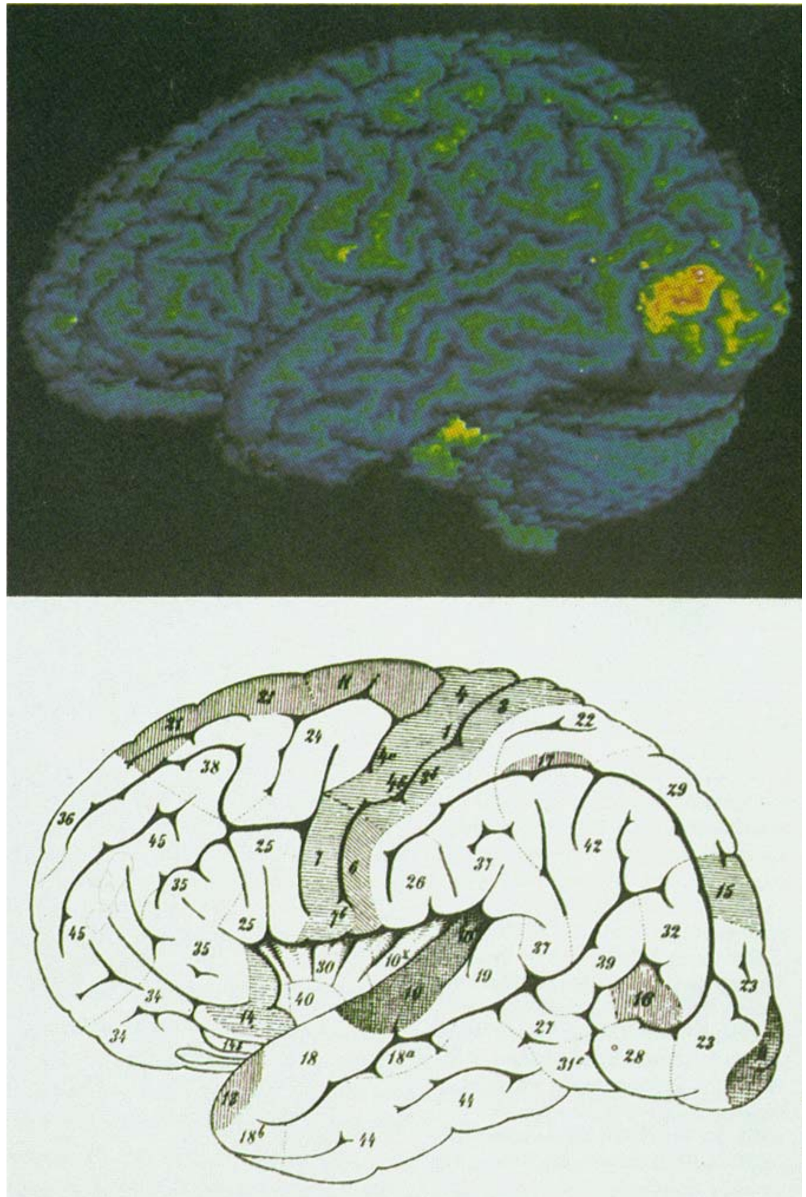
LGN=lateral geniculate nucleus with the parvocellular (narrow-band) and magnocellular (broad-band) parts; 4B lamina 4B of V1. Blob, thick and thin stripes rich in cytochromoxidase (CO) regions; Interblob and interstripe, poor in CO;

rainbow: tuned or opponent wavelength selectivity by at least 40% of neurons; angle: orientation selectivity by at least 20% of neurons; spectacles: binocular disparity selectivity by at least 20% of neurons; pointing hand: direction of motion selectivity by at least 20% of neurons .

(DeYoe and van Essen, 1988)



Summary diagram of the four perceptual visual pathways and their connections from V1 to specialized areas of the peristraite cortex (Zeli, 1993)

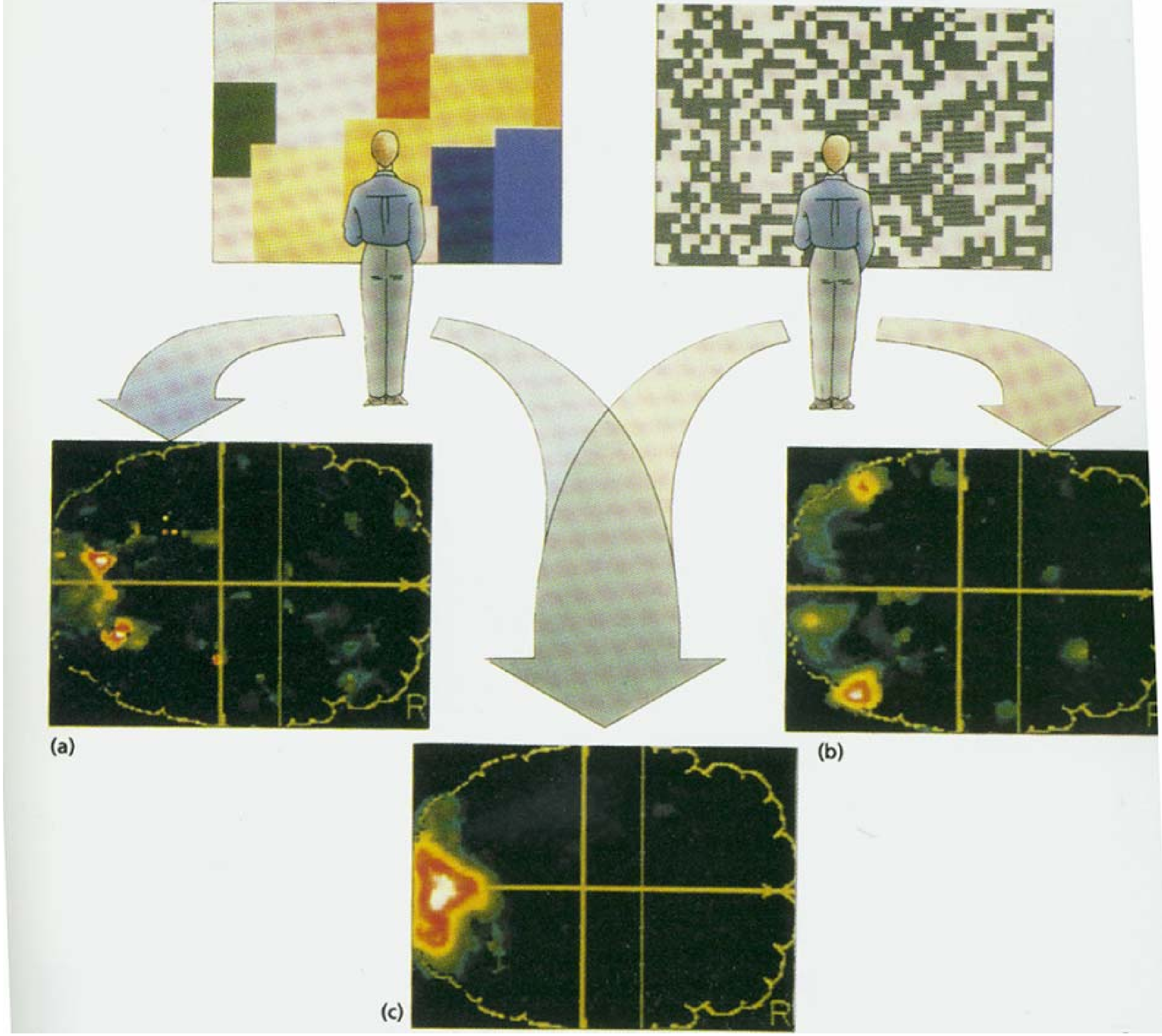


Location of the cerebral area which is active when human subjects perceive visual motion, using PET.
The area is similar in location as defined Feld 16, by Flechsig found to be myelinated at birth (Zeki, 1993).

V1

V4

V5

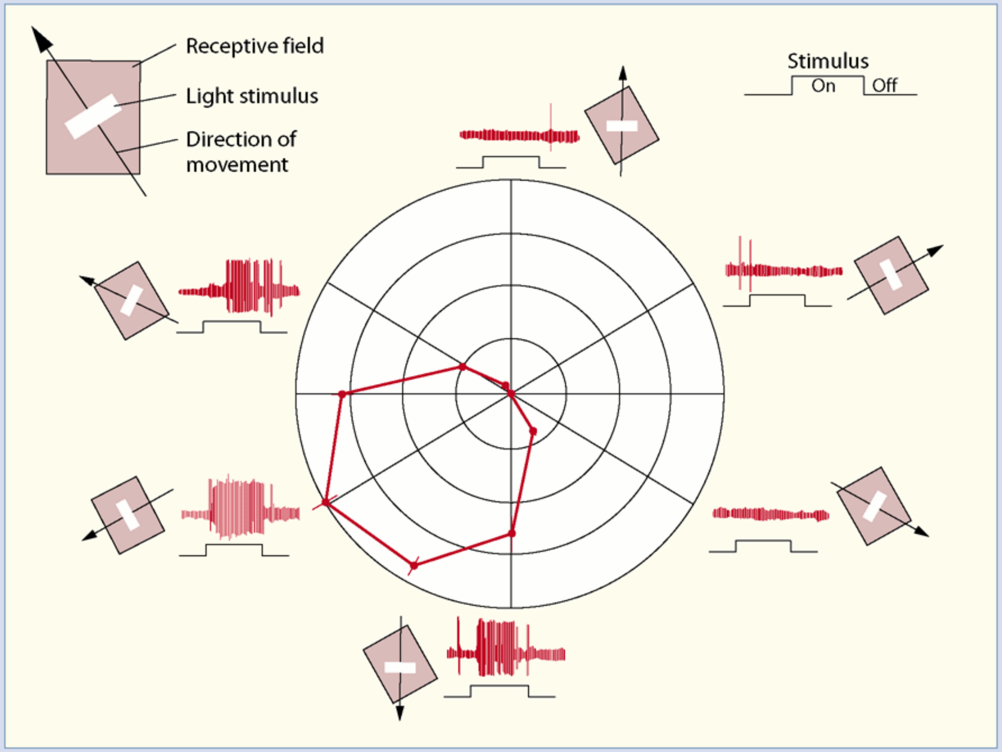


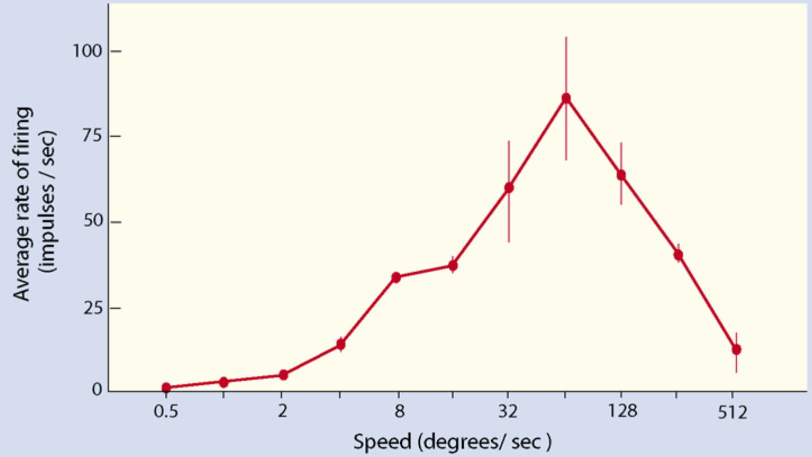
The regions of increased CBF in the brain when subjects view (a) a multi-colored Mondrian display an a pattern (b) of moving squares. Note the difference in location between the area activated by the color stimulus (V4) and the one activated by the motion stimulus (human V5). Note the area V1 and the adjoining area V2 were active with both stimuli, suggesting that both color and motion signals reach V1 and are distributed from it to the sepcialized areas V4 and V5 (Zeki, 1993)

Area MT processes movement information (directional and speed) from the magnocellular pathway

Top: a rectangle was moved was moved through the receptive field of this cell in various directions. The red traces beside the stimulus cartoons indicate the response of the cell to these stimuli. In the polar graph, the firing rates are plotted with the angular direction of each point indicating the stimulus direction and the distance from the centre indicating the firing rate as a percentage of the maximum firing arte. The polygon formed by conencting the points indicates that the cell was maximally responsive to stimuli moved down and to the left; the cell responded minimally when the stimulus moved in the opposite direction.

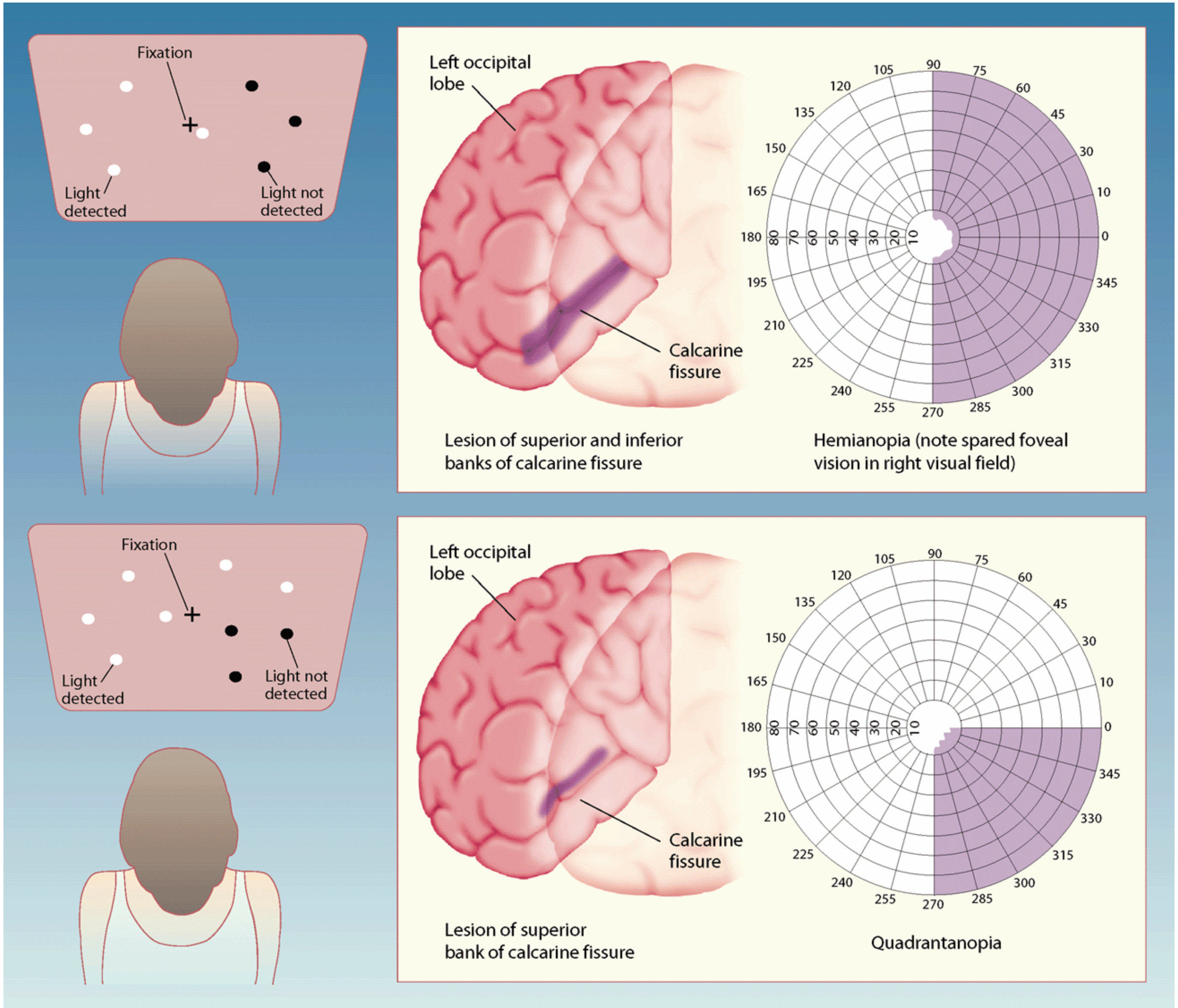
Bottom: the graph shows speed tuning for a cell in MT. This cell responded most vigorously when the stimulus moved at 64 degrees/sec. Maunsell and Van Essen, 1983; Gazzaniga et al., 2002





Lesion of V1 Causes a Scotoma

While the patient fixates on a central marker, a small light is flashed at various locations. The patient is asked to report when she sees the stimulus. If the lesion includes both the upper and lower banks of the calcarine fissure, the scotome will include the entire contralesional hemifield (hemianopia). If the lesion is restricted to the upper bank, the patient will have a quadrantanopia. Although each eye is tested separately, the scotoma will be essentially identical because the lesions are in the cortex (From Gazzaniga et al., 2002)



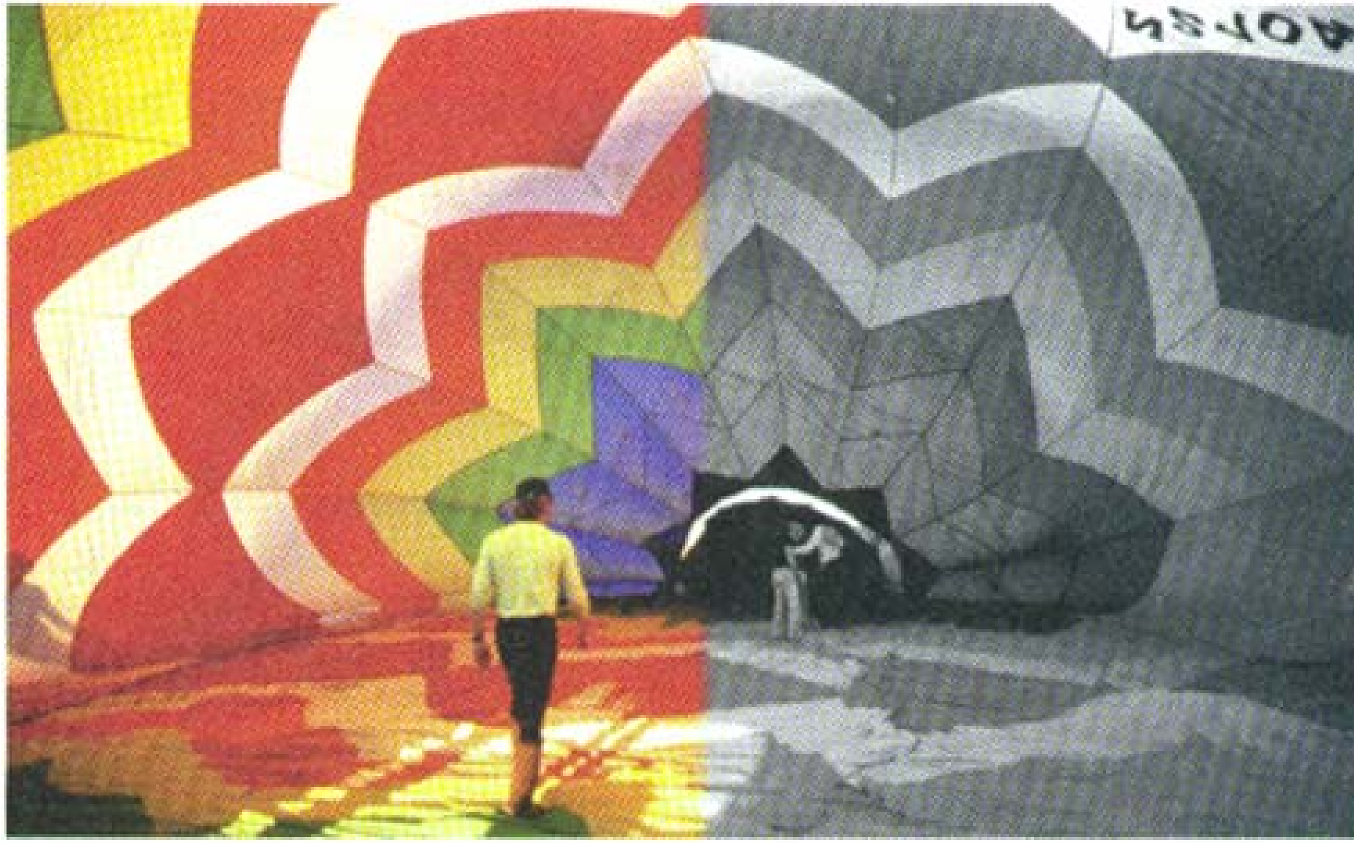
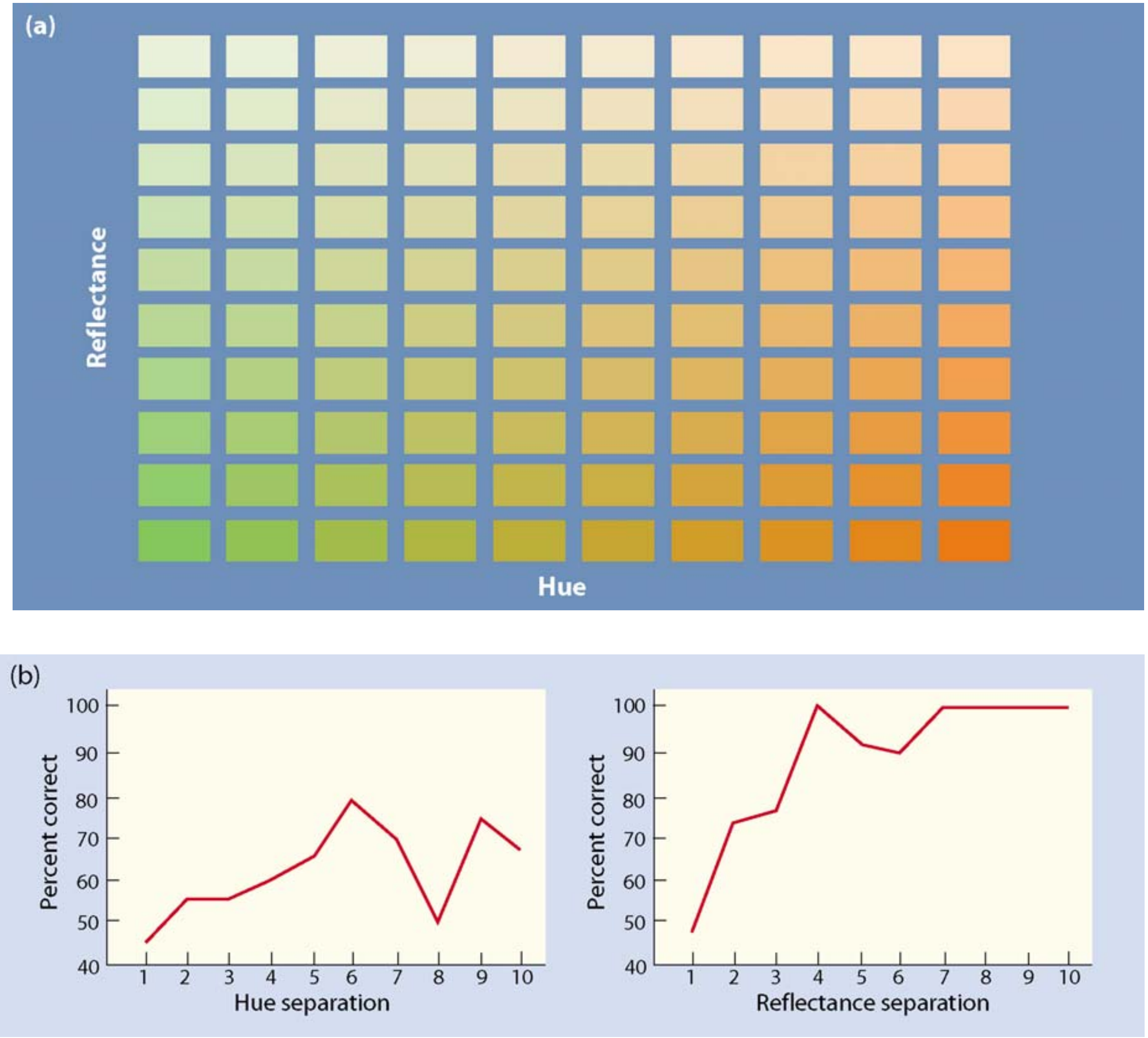
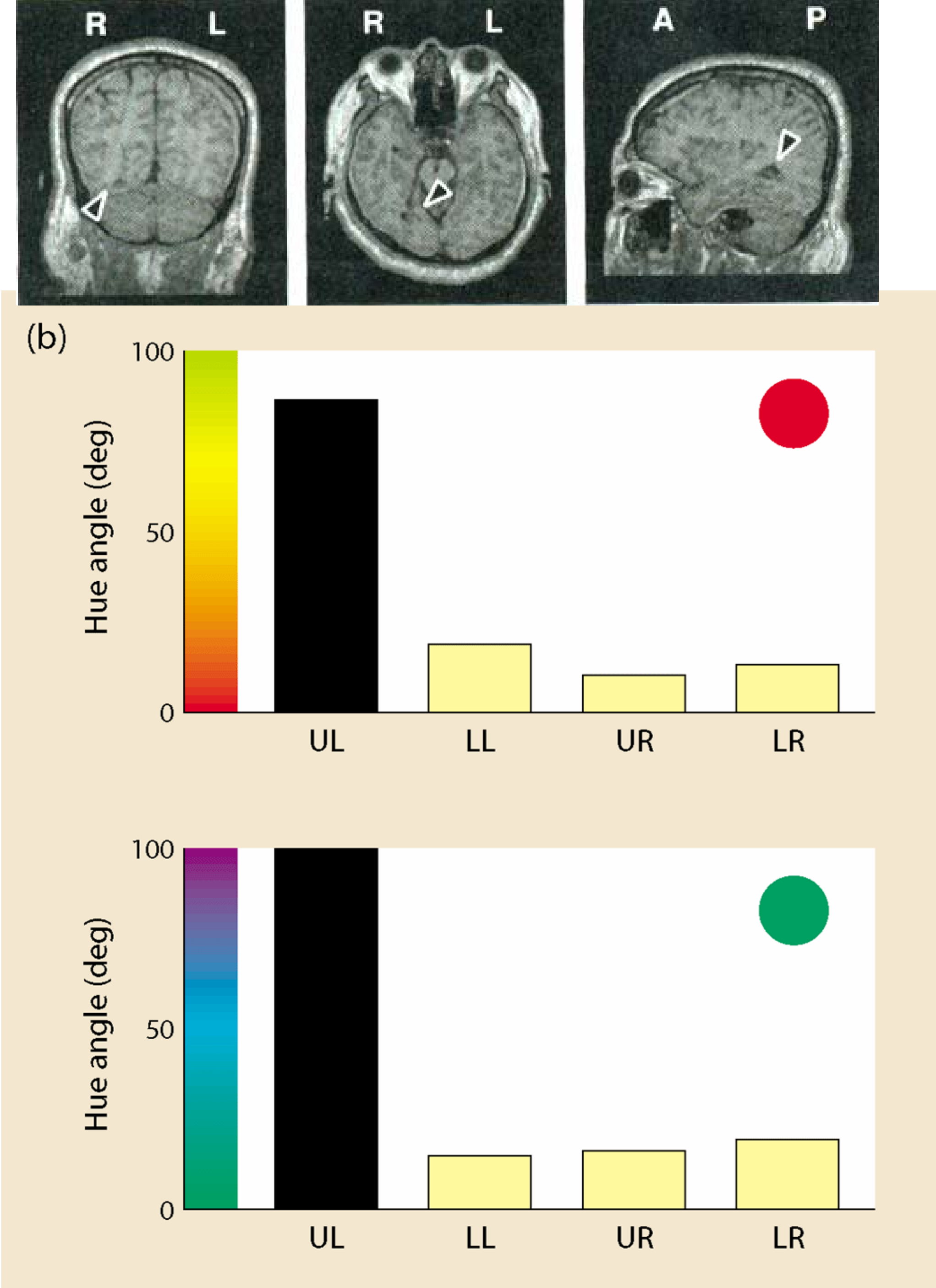


Figure 5.23 In achromatopsia, the world is seen as devoid of color. Because color differences are usually correlated with brightness differences, the objects in a scene might be distinguishable and appear as different shades of gray. This figure shows how the world might appear to a person with hemiachromatopsia. In most cases, there is some residual color perception, although the person cannot distinguish between subtle color variations.

A stroke lesioning V4 can lead to Achromatopsia



(**a**) Psychological scaling techniques are used to create norms for the similarity of neighbouring pairs across the different diemnsions of a color (hue, saturation, reflectance), (b) pairs of color chips were presented and the achromatopsia patient was asked to judge whether they were the same or different. This patient's ability to make such judgements was severely impaired when the pairs differed in hue, even when the stimuli differed by 10 units. His ability to discriminate brightness, although not normal, was much better. Here he almost always labeeld the stimuli as different when they were separted by at elast 4 units (Heywood et al, 1987; Gazzaniga et al., 2002)

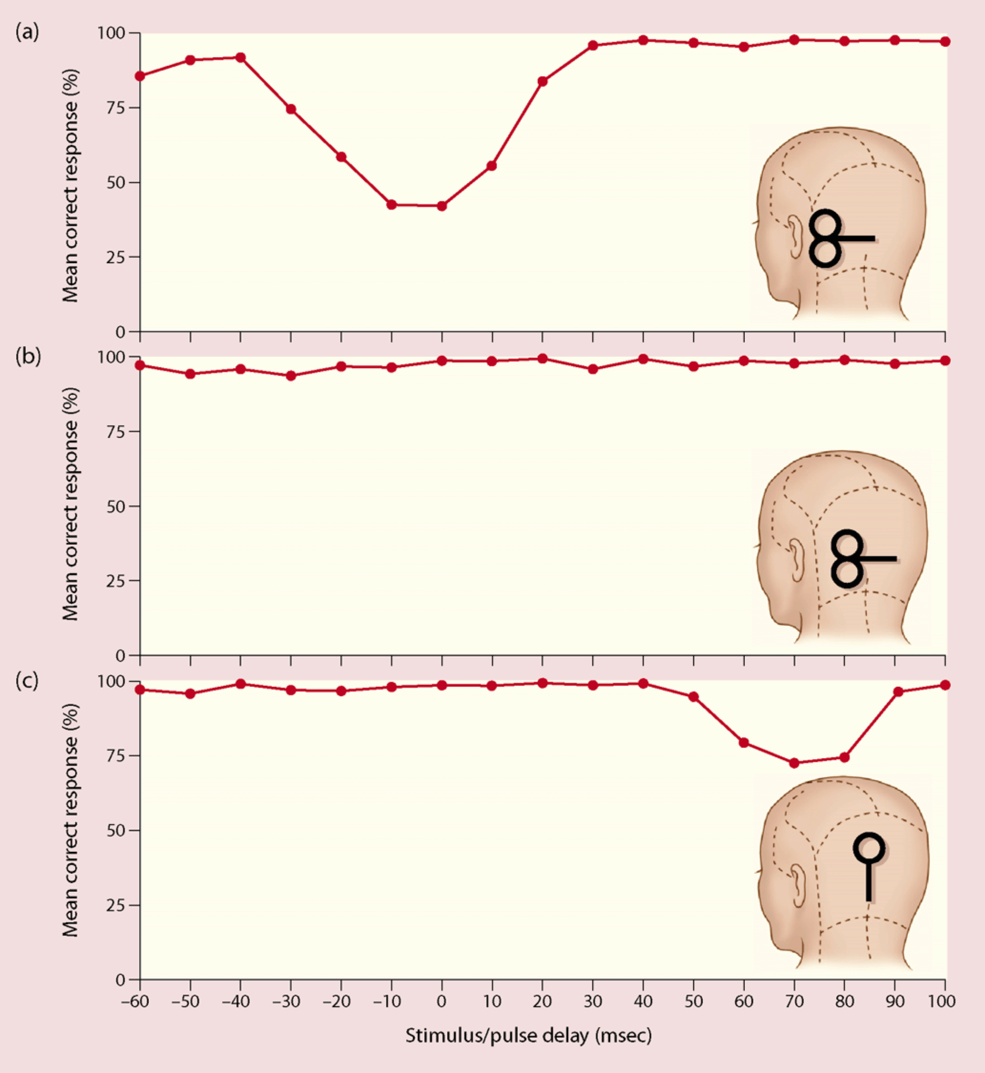


Color perception in a patient with unilateral lesion of V4. (**a**) MRI scans showing a small lesion encompassing V4 in the right hemisphere. (b) Color perception thresholds in each visual quadrant. Th ey axis indicates the color required to detect a difference between a patch shown in each visual quadrant and the target color shown at the fovea. The target color was red forth eresults shown in the top panel and green for the result shown in the bottom panel (Gallant et al., 2000; From Gazzaniga et al., 2002)

Deficits in motion perception: Akinetopsia

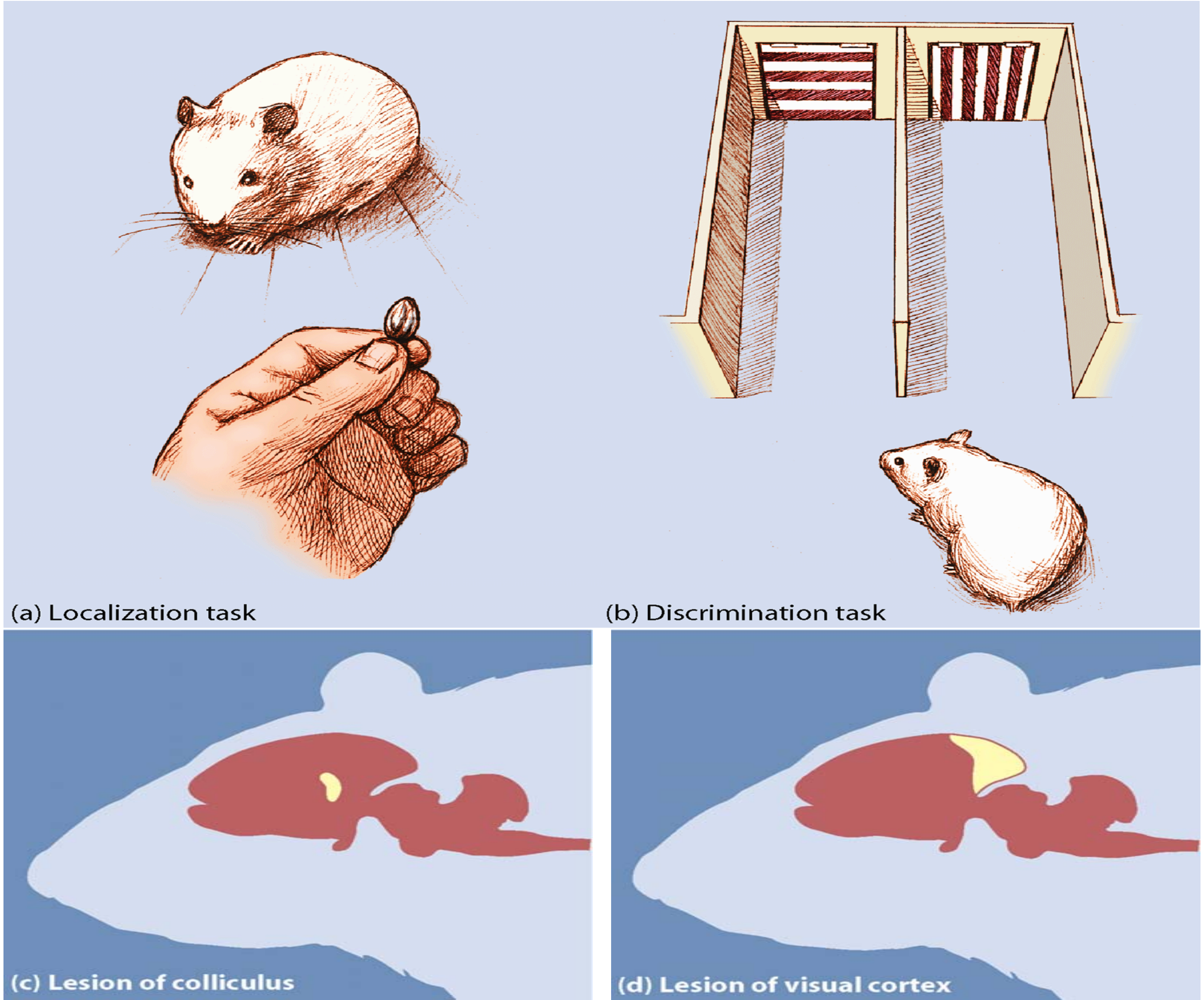
For the patient with motion blindness, the world appears as static images; there is no continuity from one image to the other.

Lesions in the M System lead to Akinetopsia



Temporary brain inactivations using transcranial magnetic stimulation (TMS) over area MT can produce deficits in motion perception. Results are rates of accuracy in dteremining the direction of motion as a function of the time between stimulus onset and the TMS pulses applied over area MT just prior to the onset of the stimulus(**a**), V1 (**c**) and an extrastriate region between these two (**b**). When the TMS was delayed until 40 msec after stimulus onset, the performance was perfect. Note that much longer delays did TMS disrupt performance over V1, suggesting that MT may receive direct input from LGN M bypassing V1. Beckers and Zeki, 1995, From Gazzaniga et al., 2002

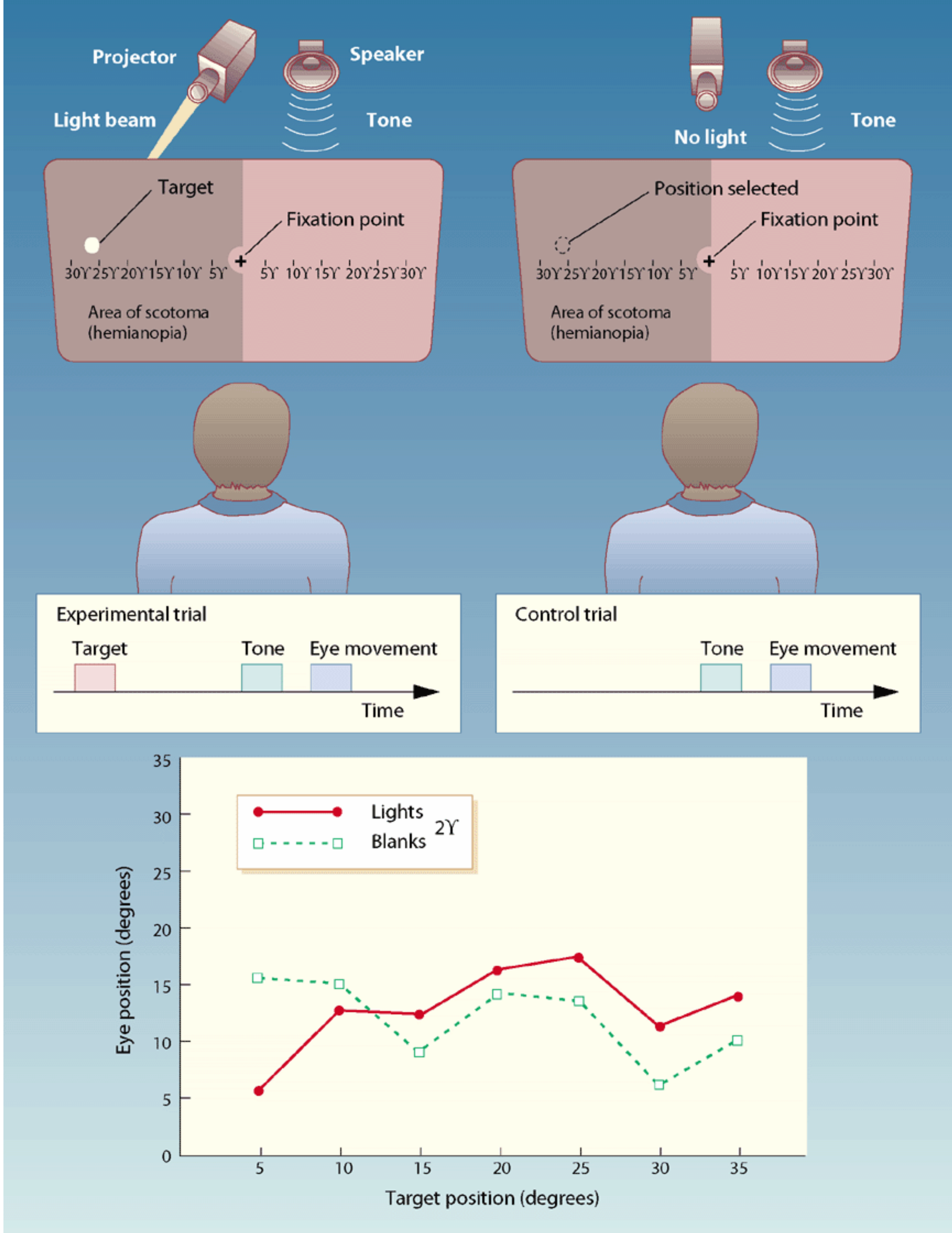
Subcortical Visual Pathways



(a) In the localization task, the animals were trained to collect sunflower seeds that were held at various location in space (b) in the discrimination task, the animals were trained to run down one of the two alleys that differed in terms of whether the stripes were horizontal or vertical. (c) Lesions of the colliculus selectively disrupted performance on orientation task (d) in contrast, lesions of the visual cortex impaired performance on the discrimination task (Schneider, 1969, From Gazzaniga et al., 2002)

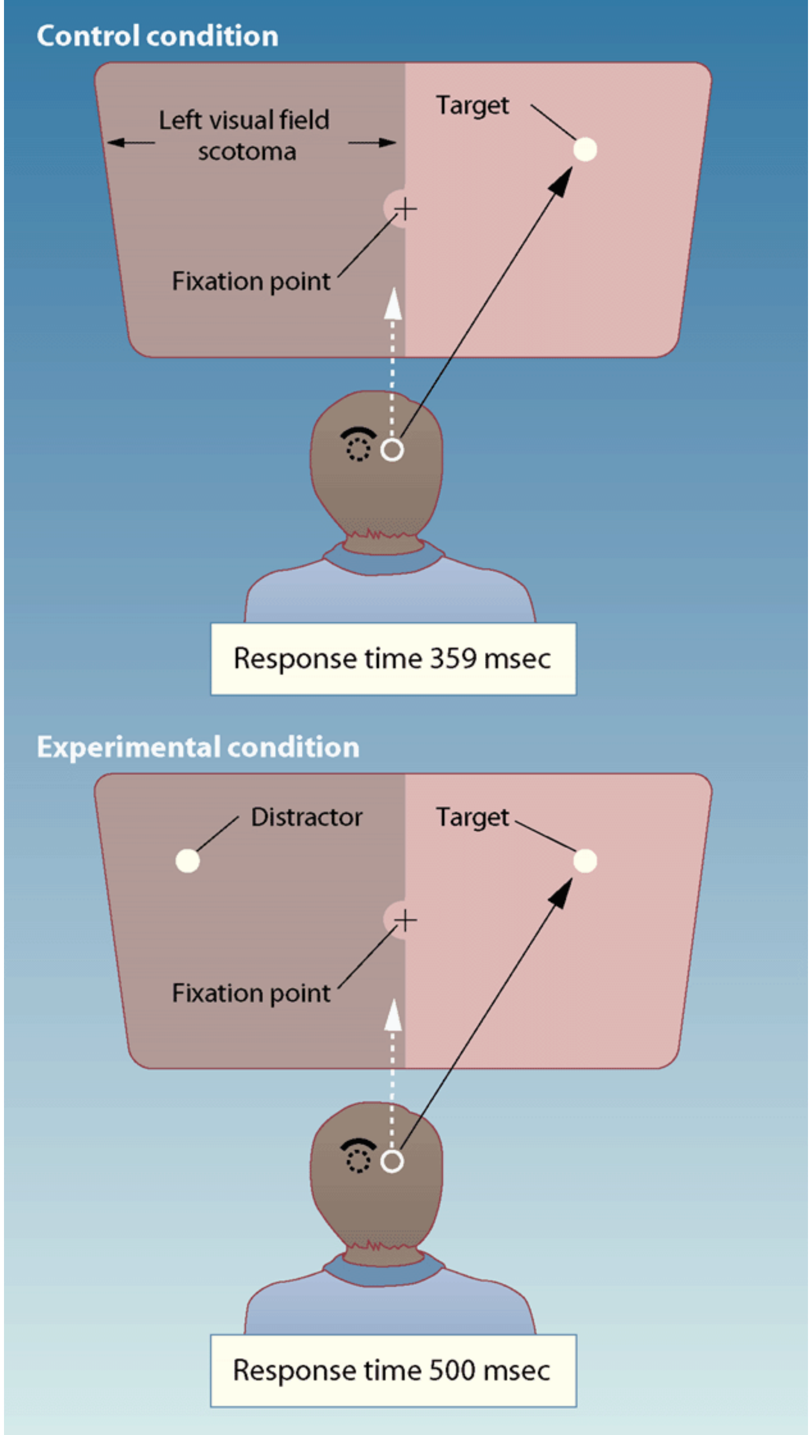
Blindsight

An ability to react to the presence of an object in the area of a scotoma without conscious perception of the object (Weiskrantz, 1986; From Gazzaniga et al., 2002)



Blindsight

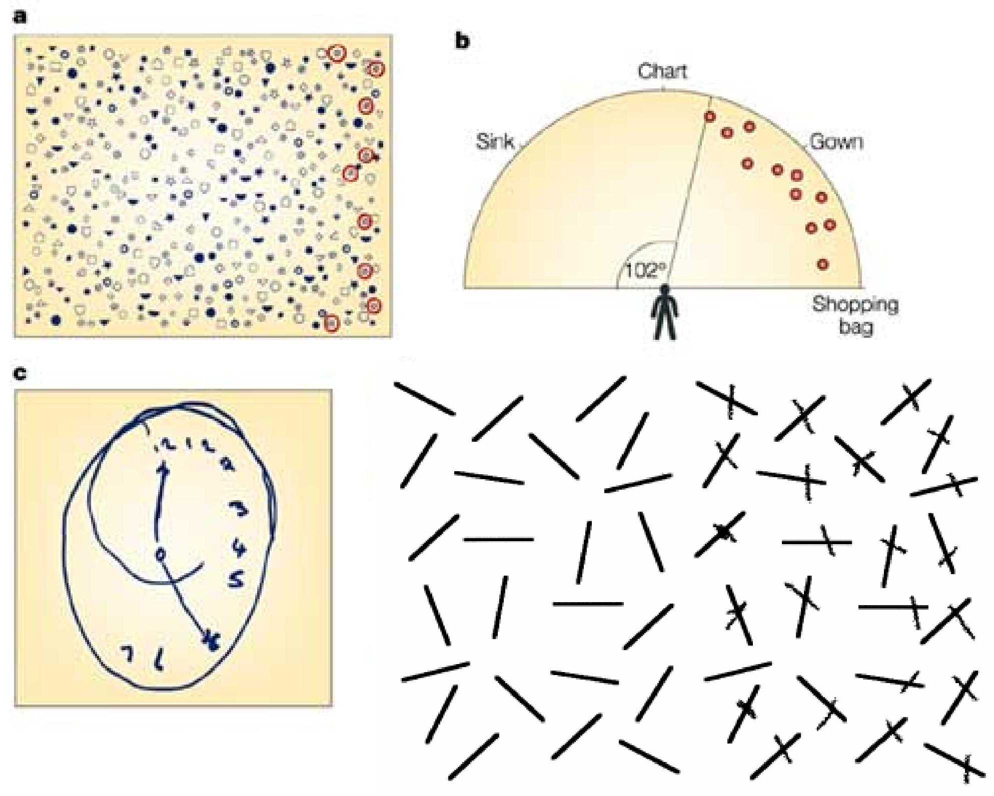
Blindsight may utilize subcortical areas and higher visual cortical areas in the absence of V1 processing (From Gazzaniga et al., 2002)



Damage to Temporal Cortex Leads to Visual Agnosia

- Patients can describe the visual features of an object, but cannot name the object. The patient insisted that the object is a telephone.
- Patients can easily name objects presented through other modalities (auditory description, smell, etc.)
- A particular type of visual agnosia, call prosopagnosia involves impaired recognition of faces (Gazzaniga et al., 2002)

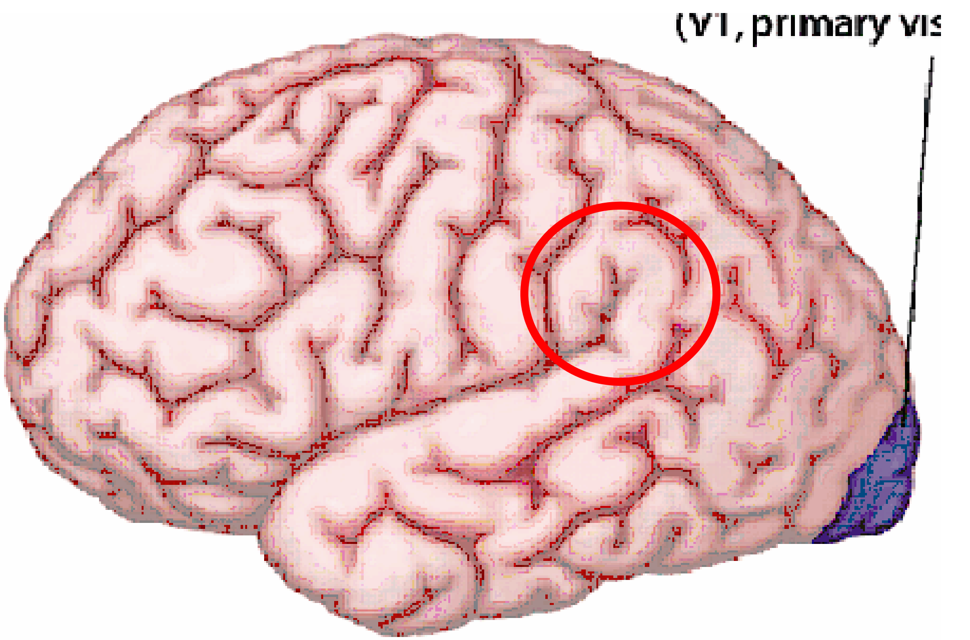
Unilateral Damage to Parietal Cortex Leads to Hemispatial Neglect



Gazzaniga et al., 2002)

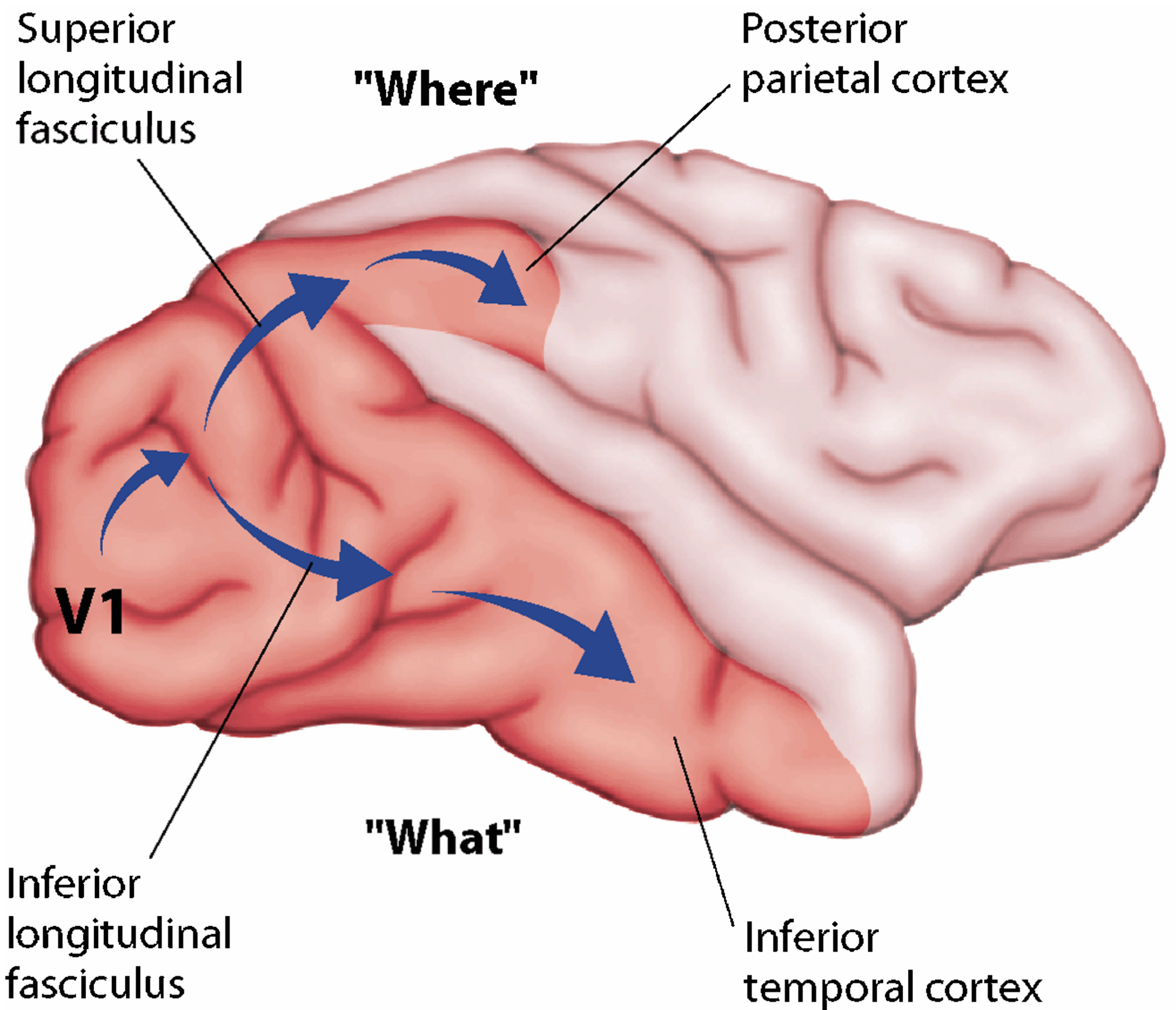
Alexia is Caused by Damage to the Left Angular Gyrus

- Alexia is a deficit in the perception of words
- Ball may be misread as doll or snake as stale

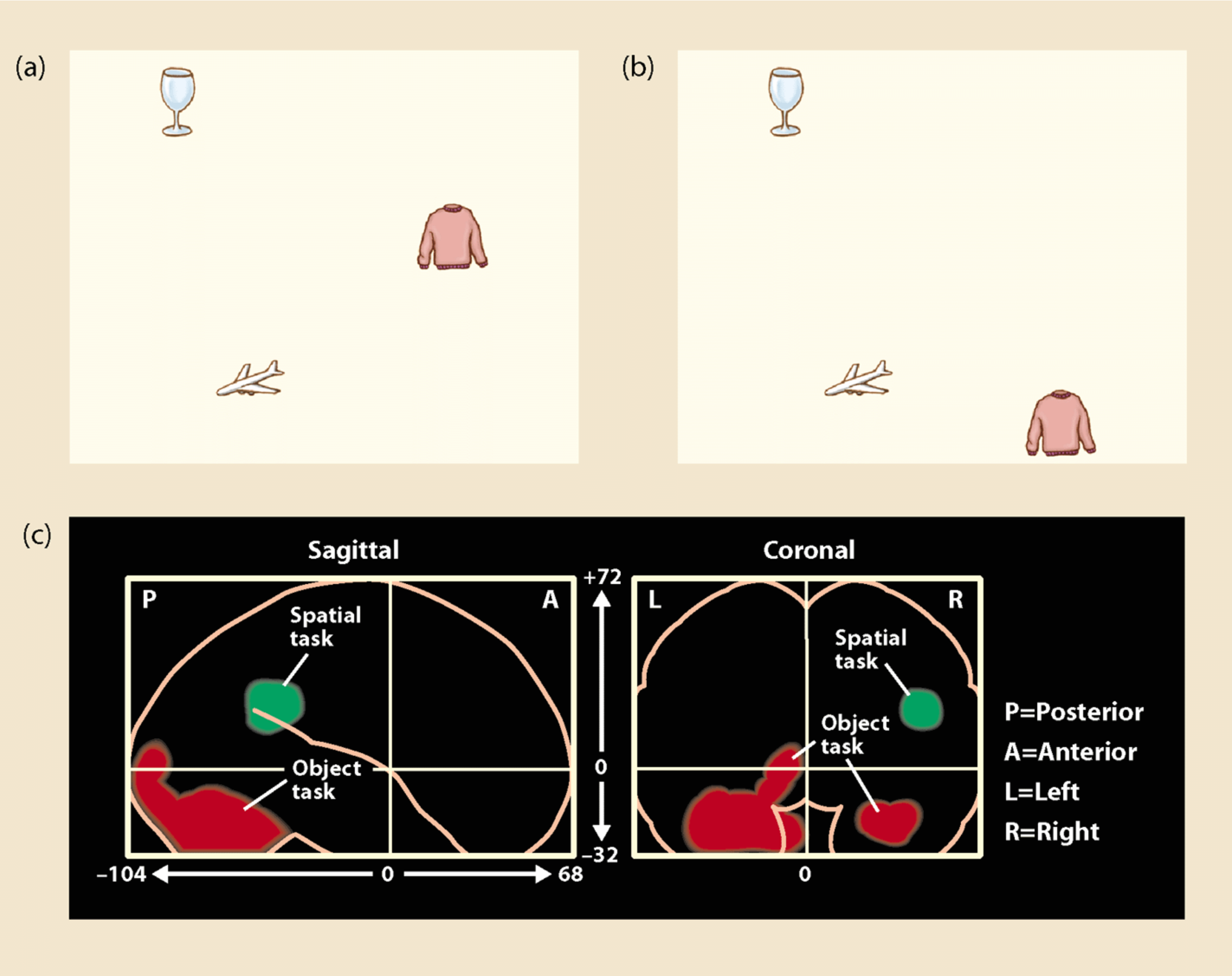


Alexia and Prosopagnosia do not occur together, but agnosia for objects is always accompanied by a deficit in either word or face perception (Gazzaniga et al., 2002)

Dorsal Vs. Ventral Streams

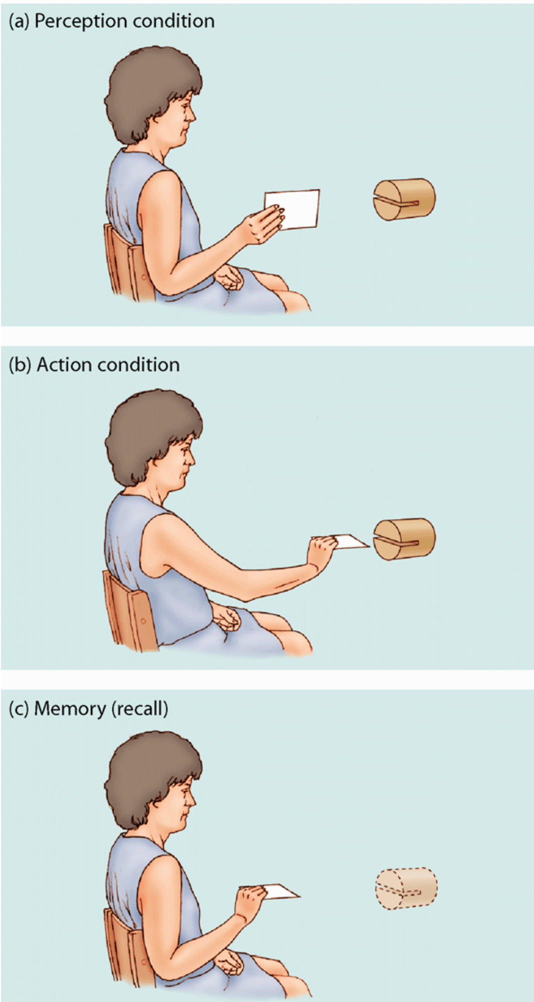


PET Imaging Supports "What" and "Where" Roles for the Ventral and Dorsal Streams



(a) Sample stimulus; (b) test stimulus in which a same response would be required in the object task and a different response would be required in the spatial task. (c) Sagittal section showing activation for the object task (red) and spatial task (green) (Kohler et al., 1995; From Gazzaniga et al., 2002)

Some Deficits Argue for “What” Vs. “How” Distinction



(“What” deficit)

DF, a 34-year old patient, suffered carbon monoxide intoxication, and the MRI revealed bilateral occipital lesions. She had severe disorder of object recognition. When asked to name houshol ditems, she made errors such as labeling a cup an ashtray or a fork a knife. She usually gave crude description of an object; for example a screwdriver was ‘long, black and thin’. Her deficit was not anomia (a problem with naming objects); whenever an object was placed in her hand, she identified it. Her visual acuity was normal. (**a**) DF was asked to view a circular block into which a slot has been cut. In the recognition task DF was given a card and asked to orient her hand so that the card would fit into the slot. She failed, she oriented the card vertically even the slot was horizontal. (**b**) When asked to insert the card into the slot, DF quickly reached forward and inserted the card. (**c**) The patient also did not show any impairment in the memory condition, verifying that her knowledge of orientation was intact. Df-s performance shows that processing systems make use of different sources of perceptual information. From the first task, it is clear that DF could not recognize the orientation of a 3D object (‘**what’ deficit**). She was OK with the where, accordingly the where system appears to be essential for more than determining the location of the different objects; it is also critical for guiding interactions with these objects. Indeed, Goodale and Milner (1995) sugegsted to replace the ‘where’ system with the ‘how’, to emphasize that the dorsal visual system provides a strong input to the motor system to compute how a movement should be produced (From Gazzaniga et al., 2003).

Optic ataxia: problem with the where (how) sytem

Figure 2.5
Optic ataxia in Bálint's syndrome.

Patient with optic ataxia can recognize th eobject yet cannot use visual information to guide their action (From Rafal, 2003)