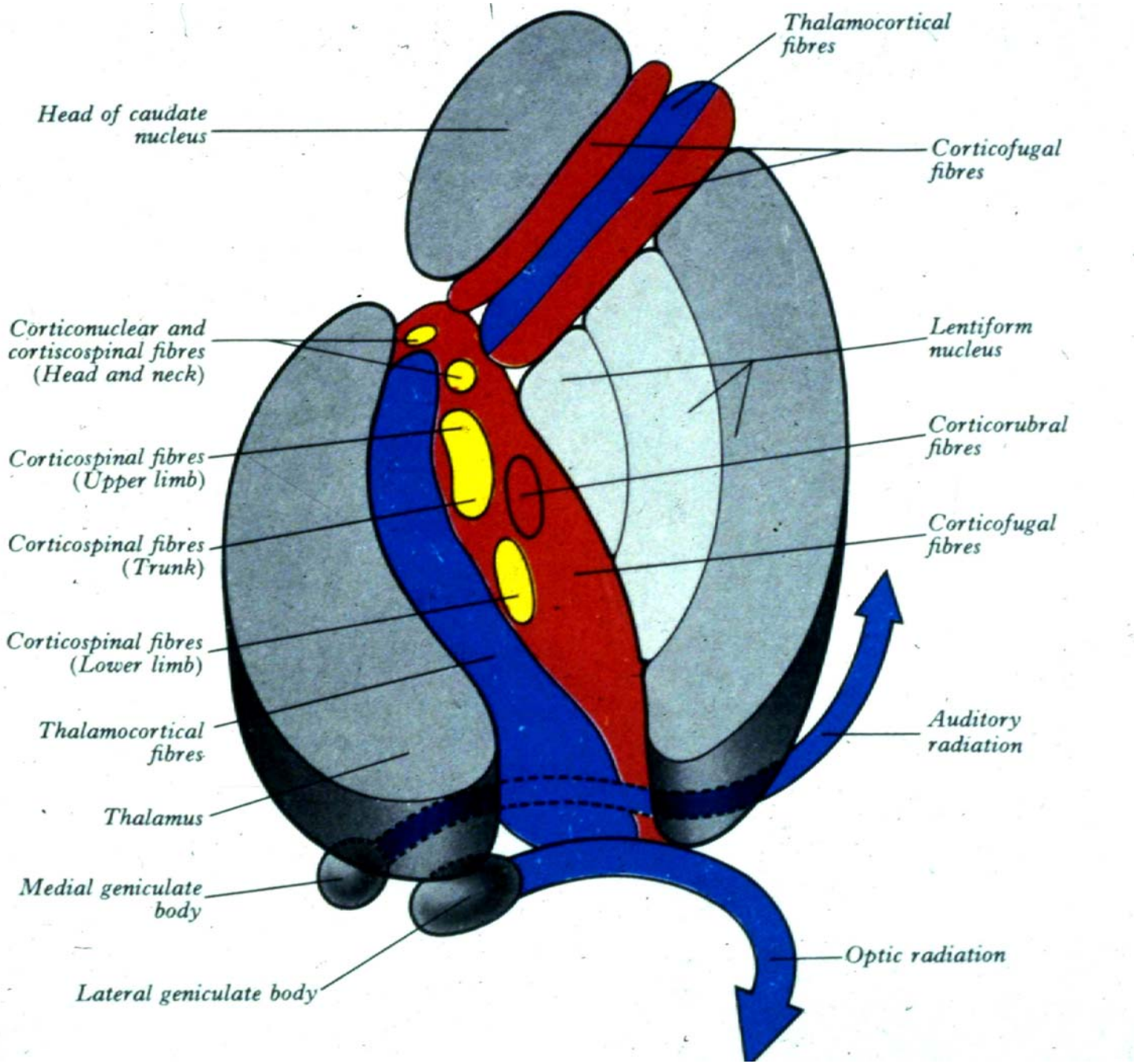
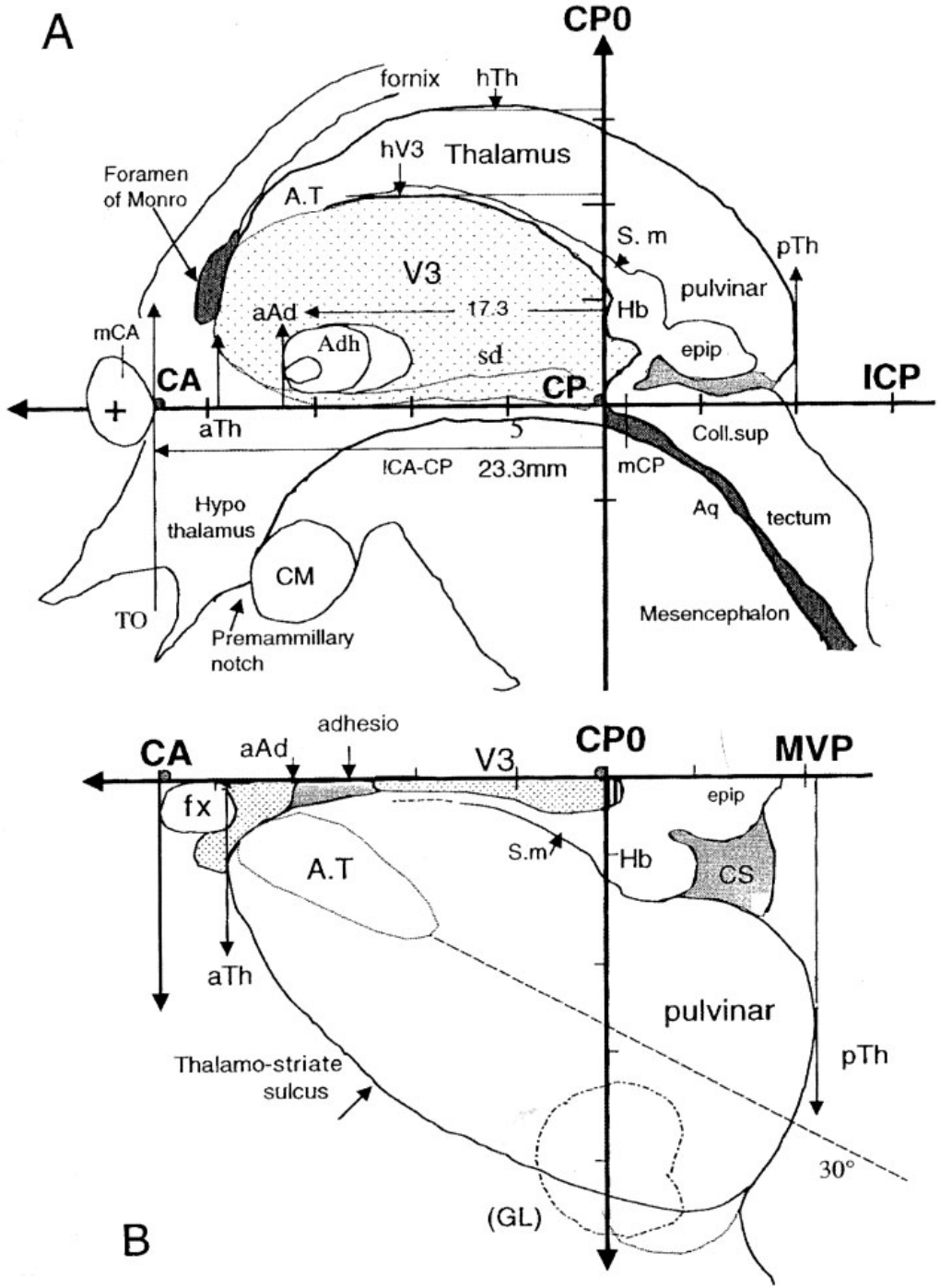
THALAMUS

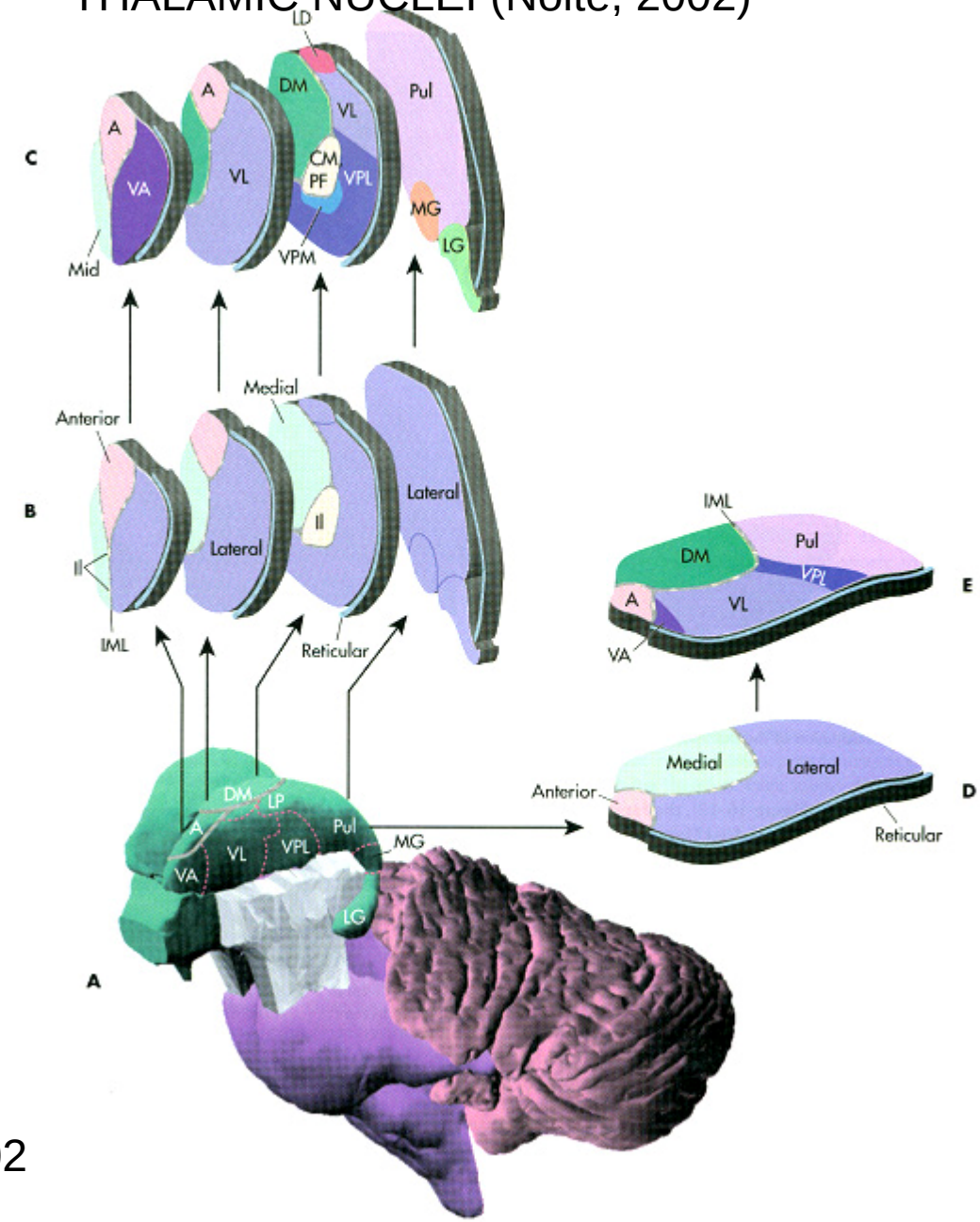
THALAMUS and INTERNAL CAPSULE



Mid-sagittal (A) and horizontal section through the third (3V) ventricle. Position of the thalamus in relation to other parts of the brain and to the CA-CP, CPO system of cooordinates. Percheron, 2004

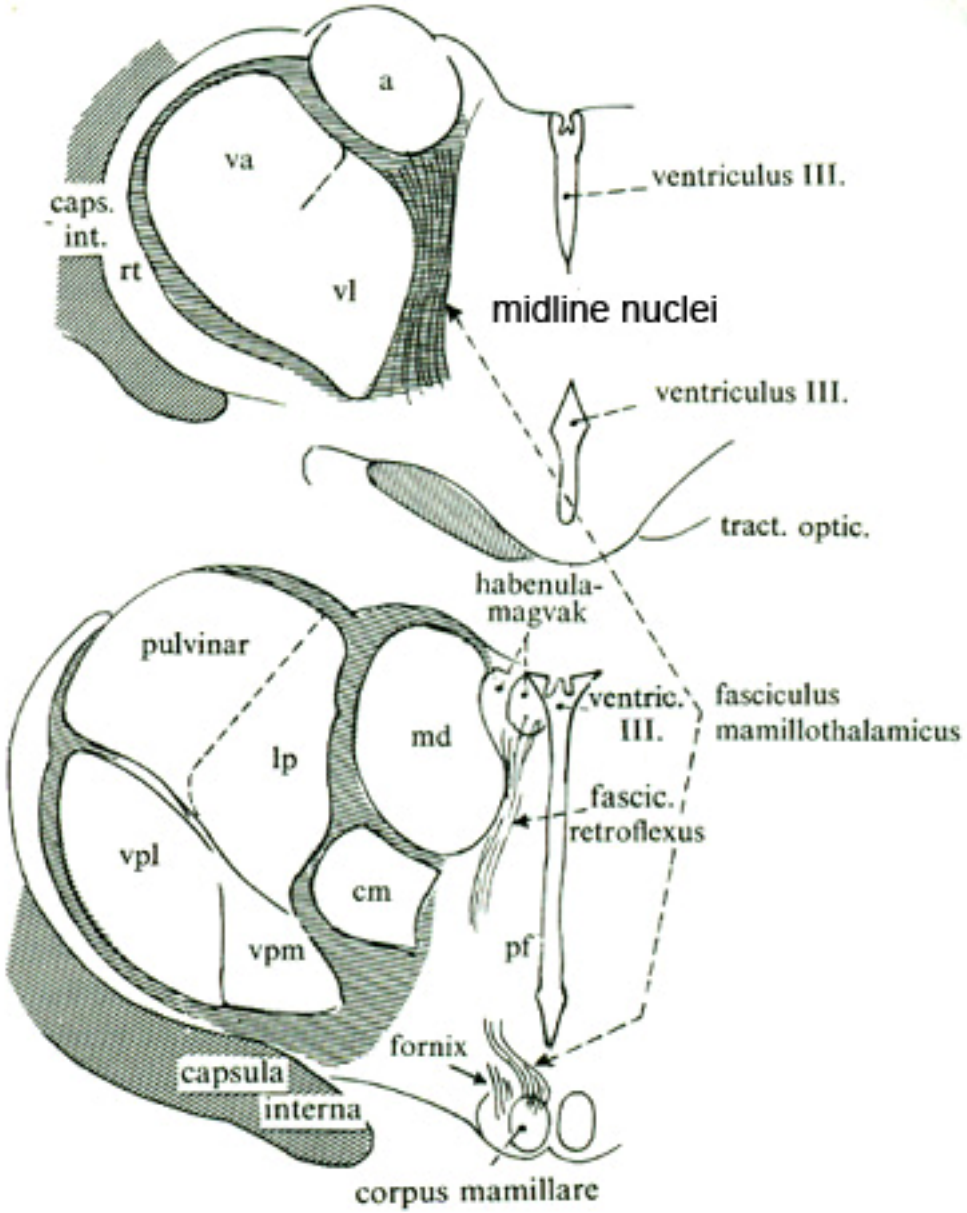


THALAMIC NUCLEI (Nolte, 2002)

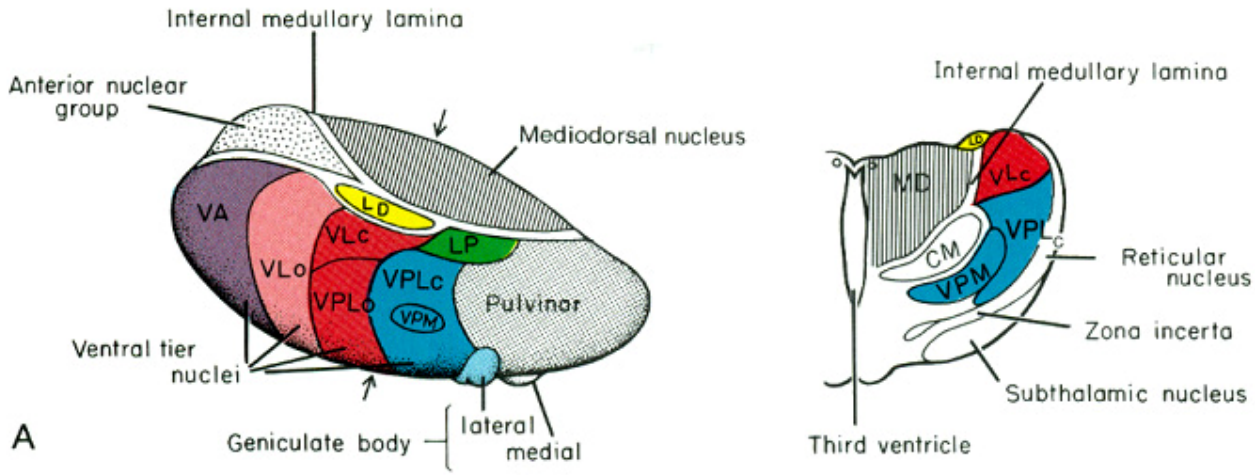


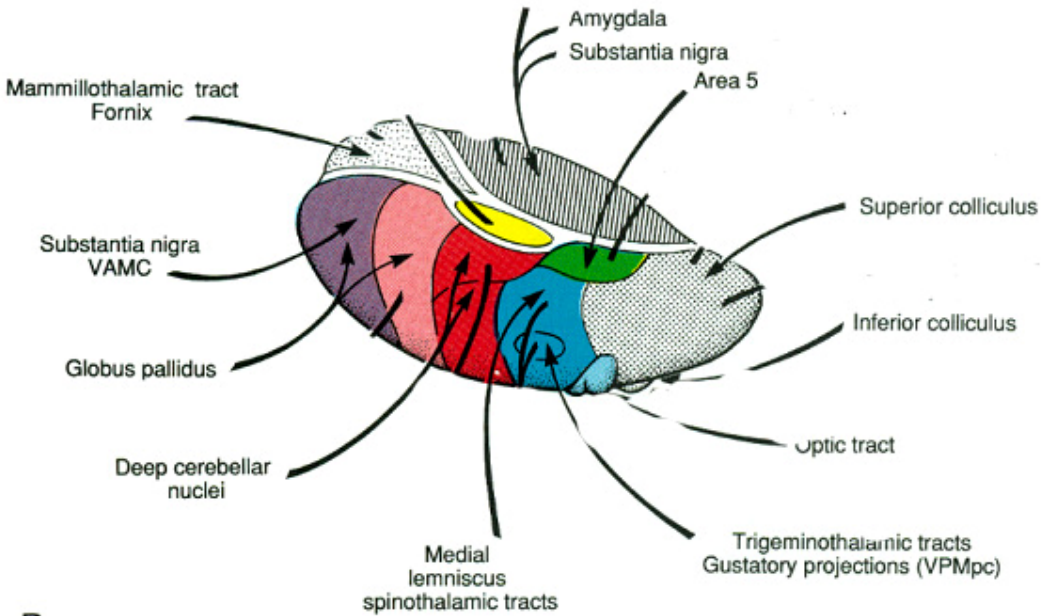
From Nolte, 2002

TWO CORONAL SECTIONS FROM THE THALAMUS

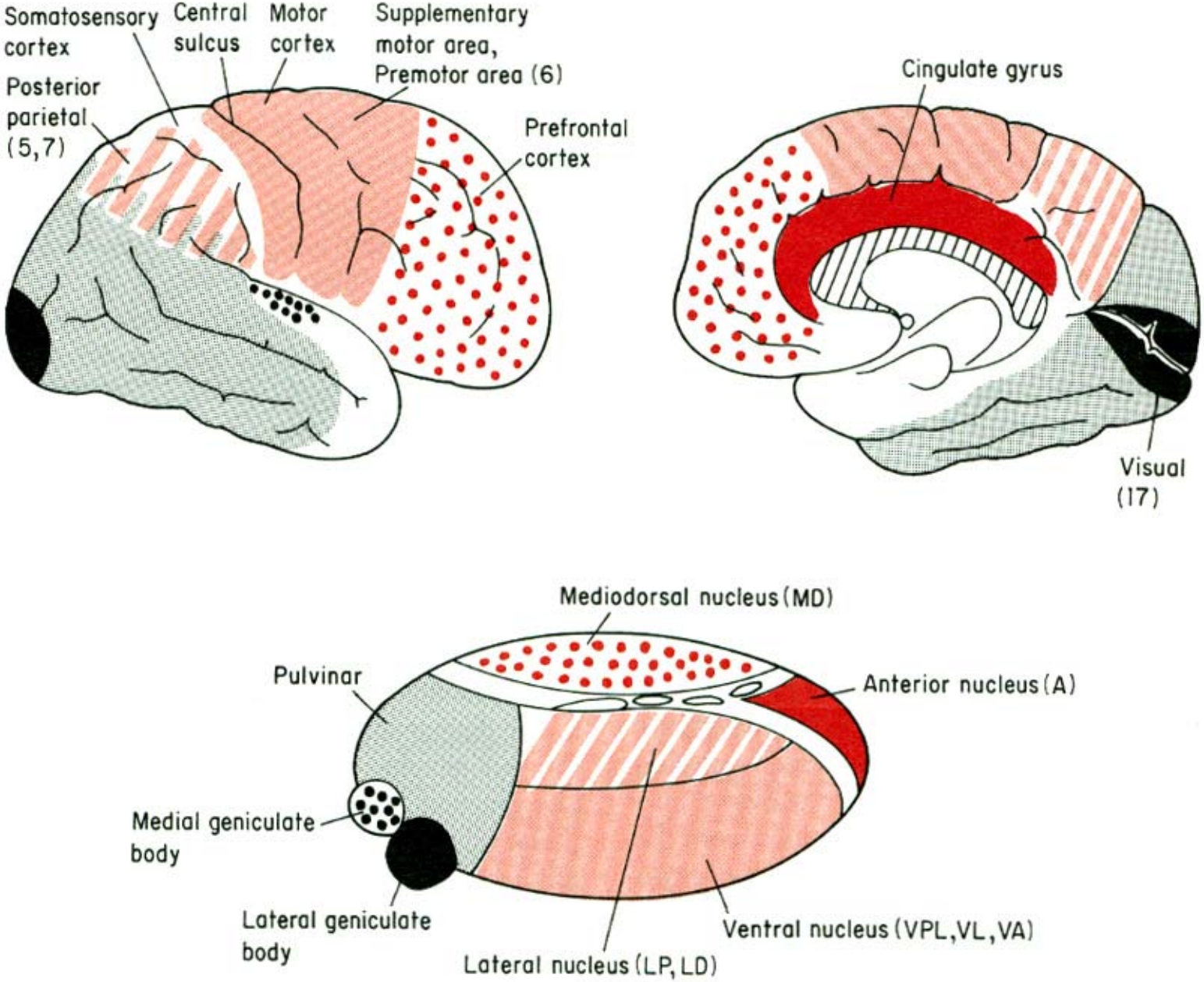


MAIN INPUTS TO TAHALAMIC NUCLEI (From Carpenter, 1191)

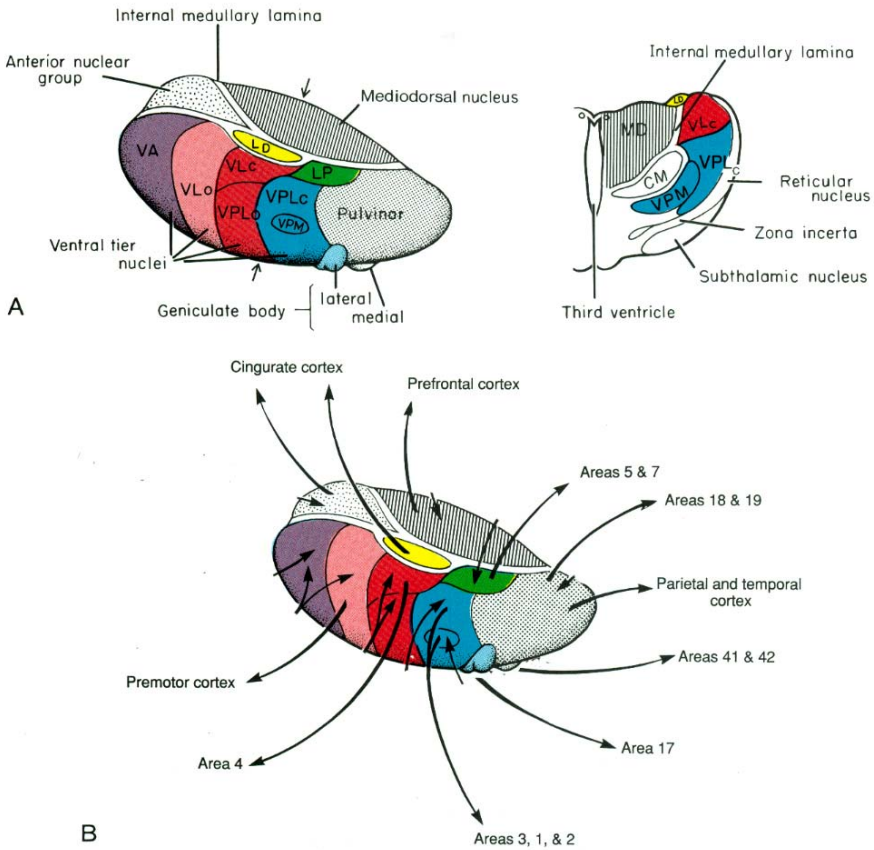


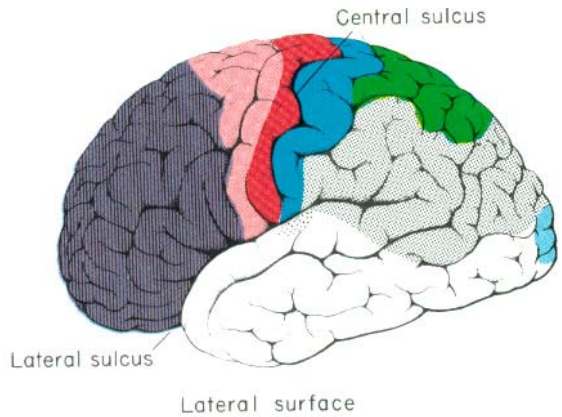


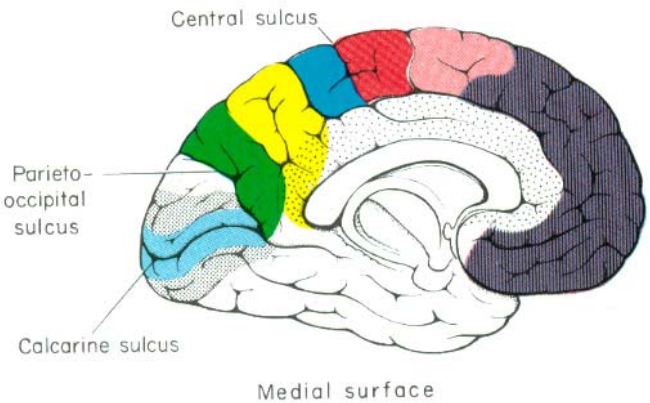
THALAMO-CORTICAL CONNECTIONS 1. (Brodal, 1991)

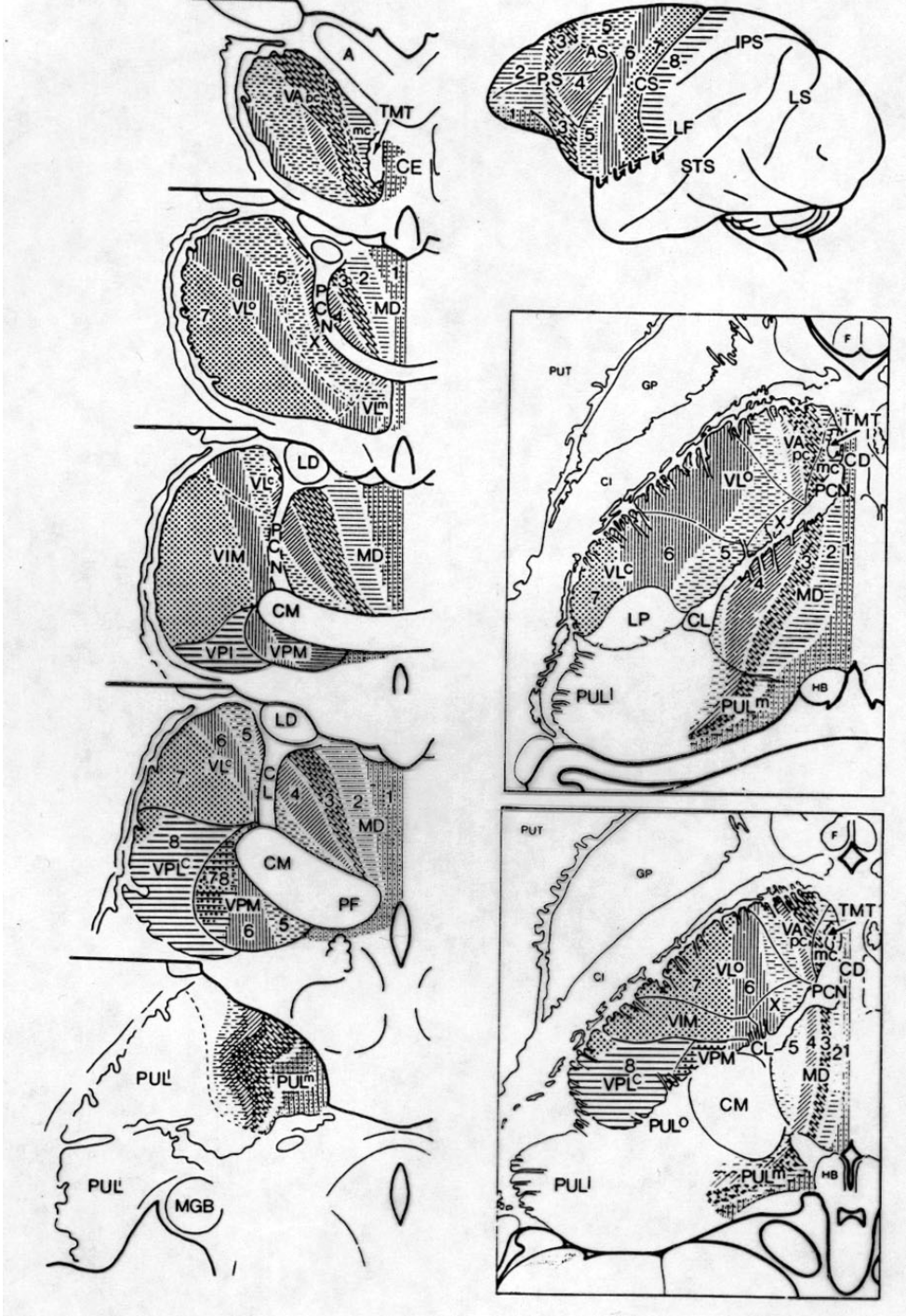


THALAMO-CORTICAL CONNECTIONS 2.(Carpenter)



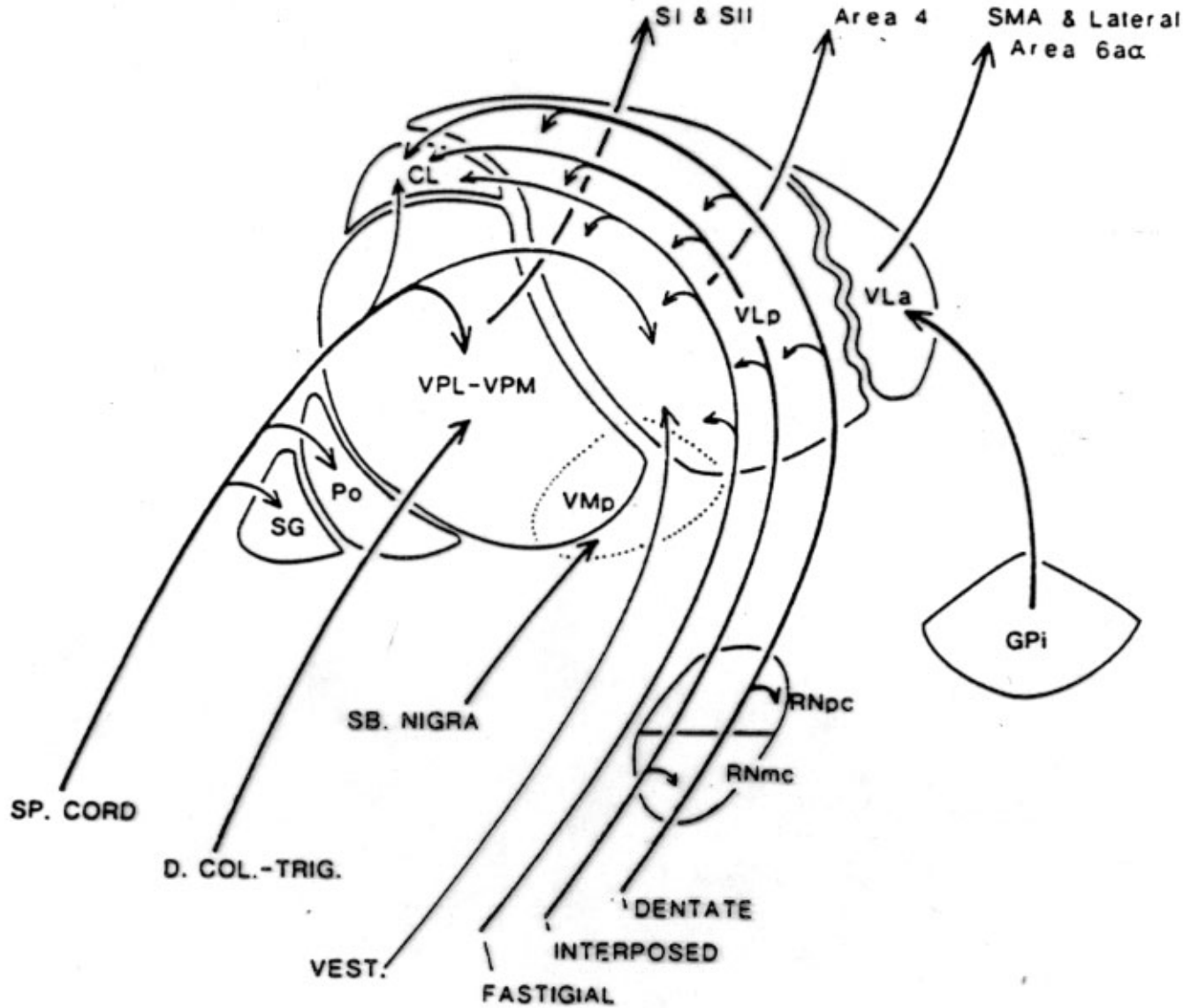






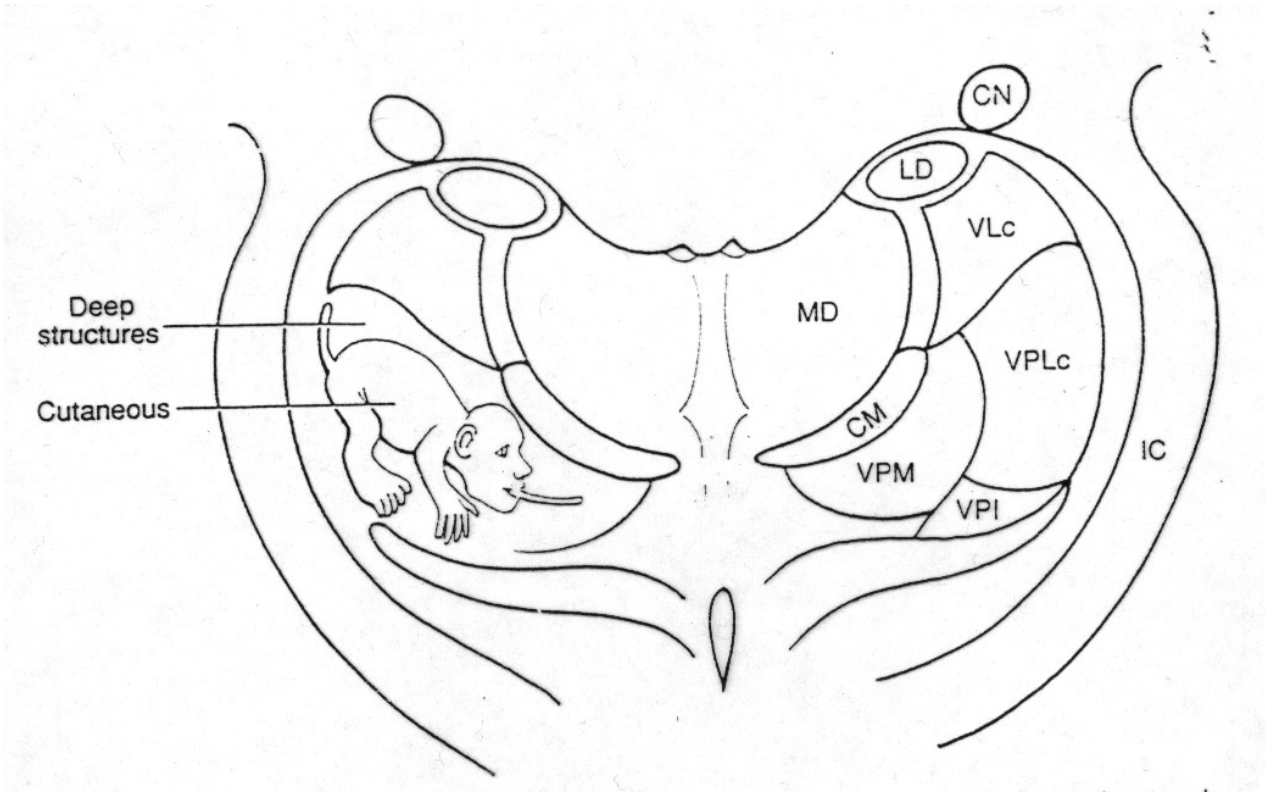
Somatotopic thalamocortical projections.

The top right panel shows a succession of frontally oriented discs of the cortex numbered 1-8. The other panels show the close-to-sagittal discs of the thalamus to which thet correspond. Left: frontal sections, framed section to the right: horizontal sections From Kievit and Kuypers, 1977.



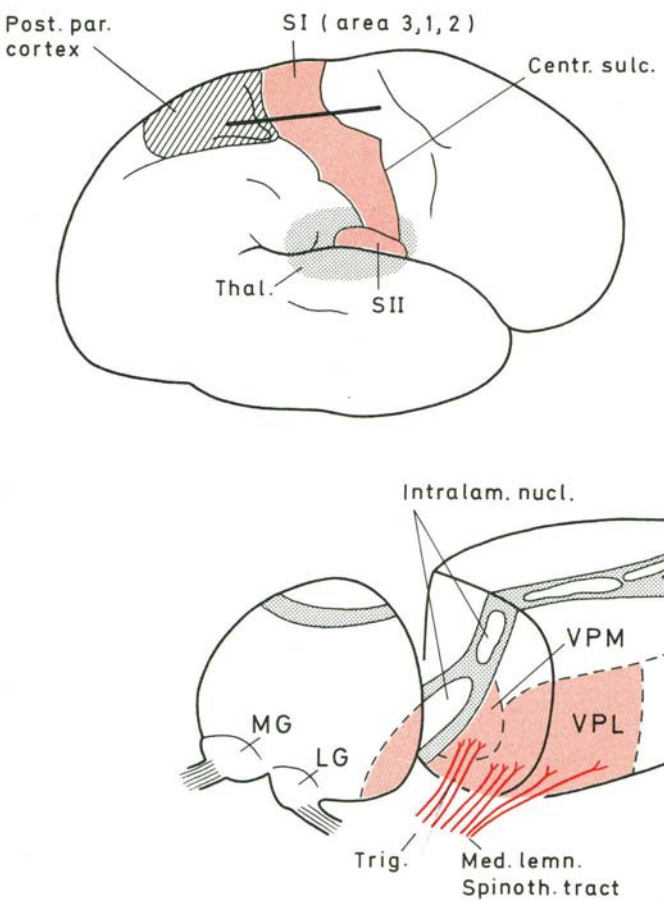
Schematic sagittal section indicating input–output relations of monkey ventral thalamic nuclei.

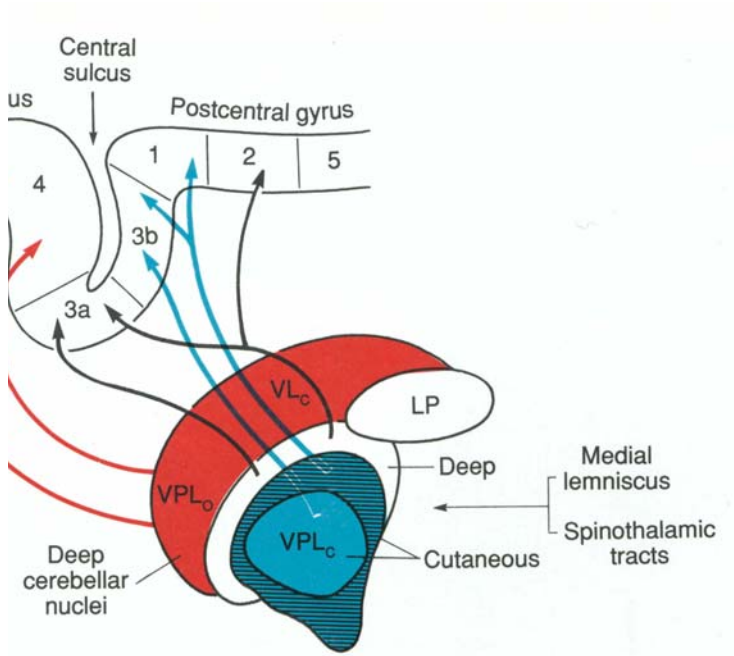
Somatotopy in the Monkey ventrobasal nucleus



Schematic diagram of the ventrobasal complex in the monkey, indicating the cutaneous somatotopic representation of the body surface on the left. Neurons responsive to stimulation of deep receptors lie in a dorsal shell. Areas representing the head, face and tongue lie in the ventral posteromedial (VPM) nucleus. The body is represented in the ventral posterolateral n. (VPLc) with the trunk dorsal and the extremities ventral (Carpenter).

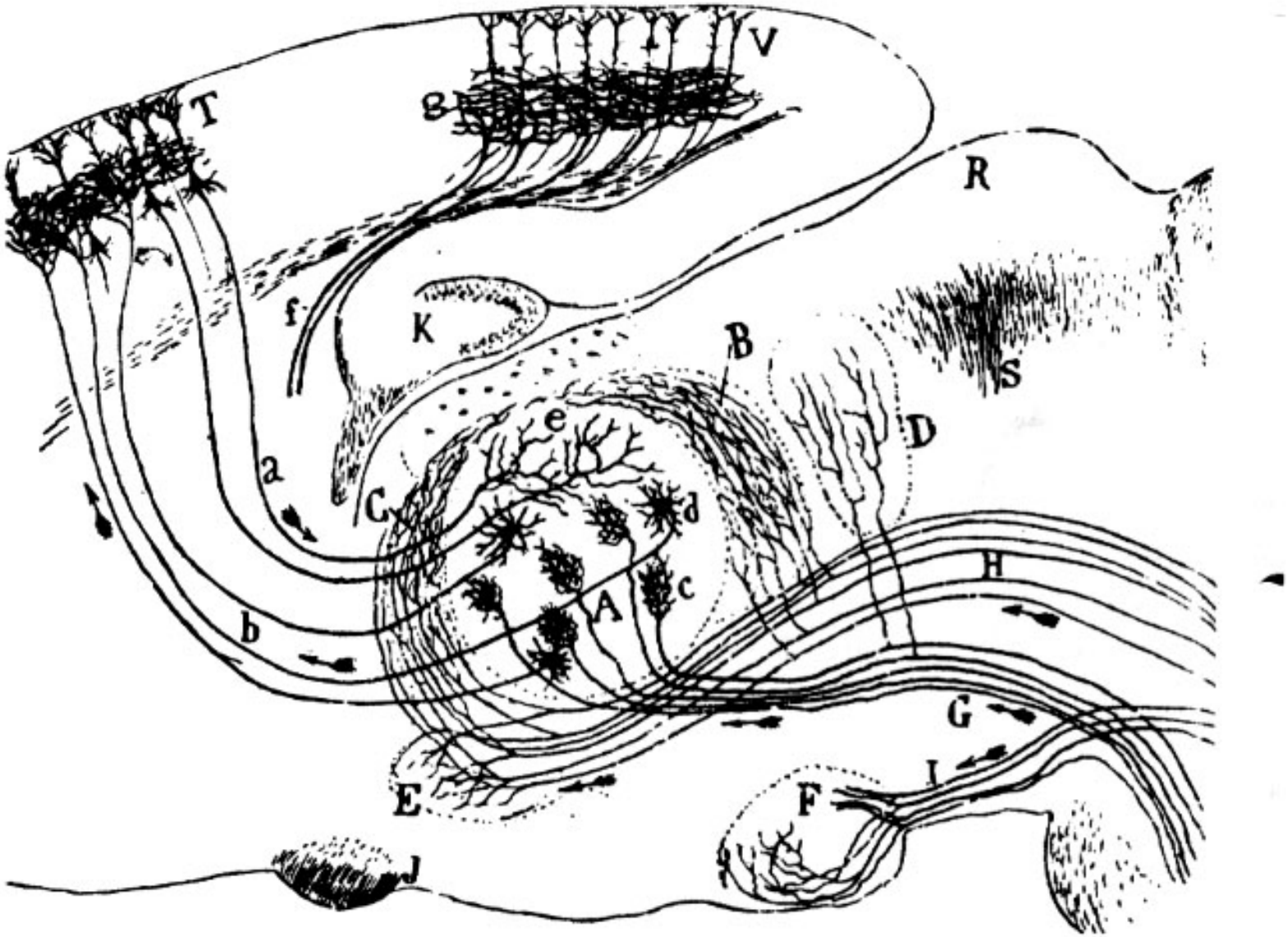
The somatosensory cortex and its thalamic afferent nuclei



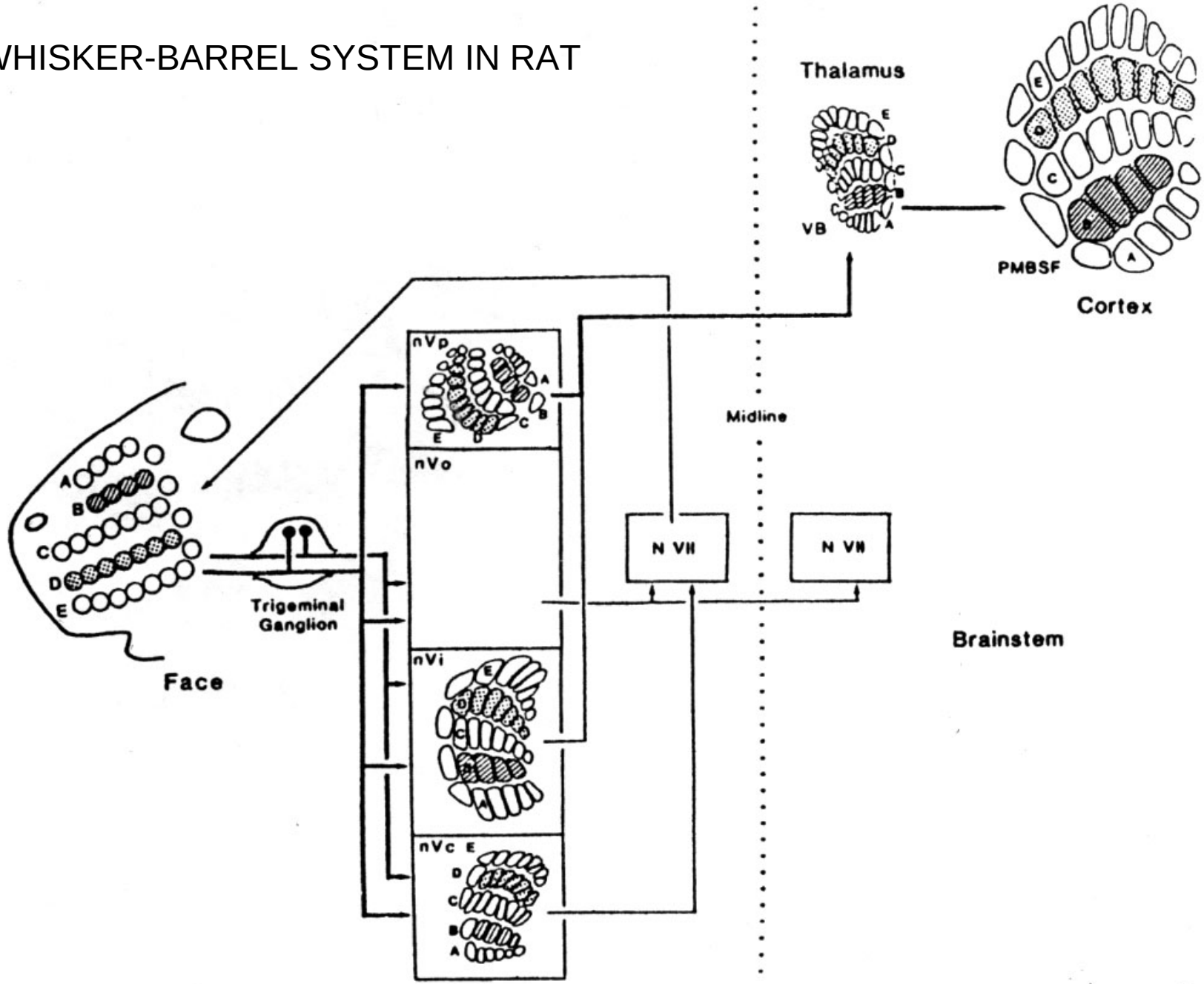


Schematic diagram in a sagittal plane showing projections of thalamic subdivisons to the sensorimotor cortex. Neurons in the ventral posterolateral (VPLc) and ventral poteromedial (VPM) nuclei (not shown) form a central core (blue) consisting of two parts (one represented by solid blue and another by lined blue) responsive to cutaneous stimuli and an outer shell (white) composed of neurons responsive to deep stimuli. Inputs to VPLc is via the medial lemniscus and the spinothalamic tracts. Cell in the outer shell project to cortical area 3a (muscle spindle) and to area 2 (deep receptors). Cells in the central core (blue) project to area 3b (cutaneous). These projections are somatotopic (Carpenter).

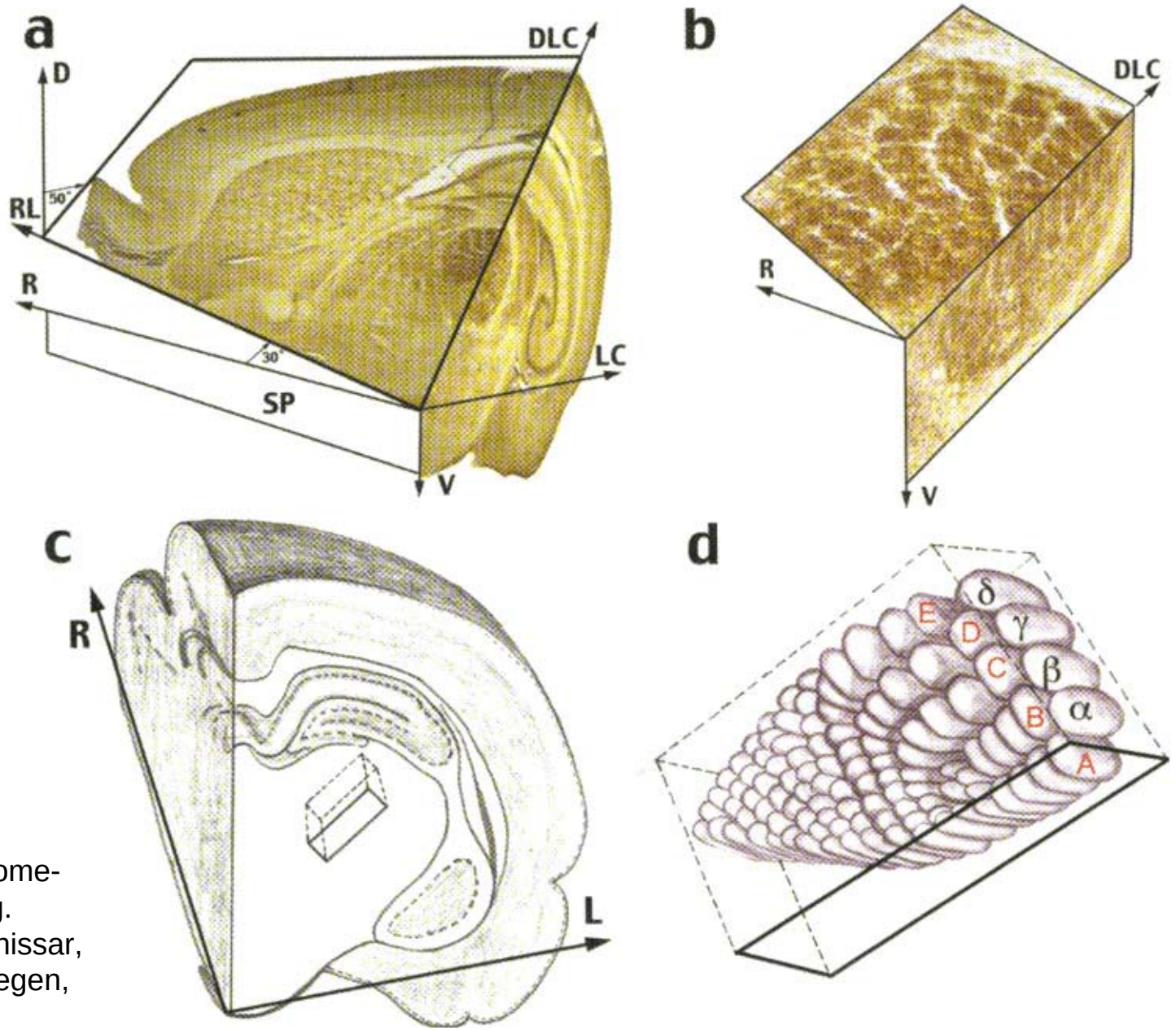
Axonal arborizations of lemniscal afferents in the somatosensory nucleus of the thalamus (Cajal)



WHISKER-BARREL SYSTEM IN RAT

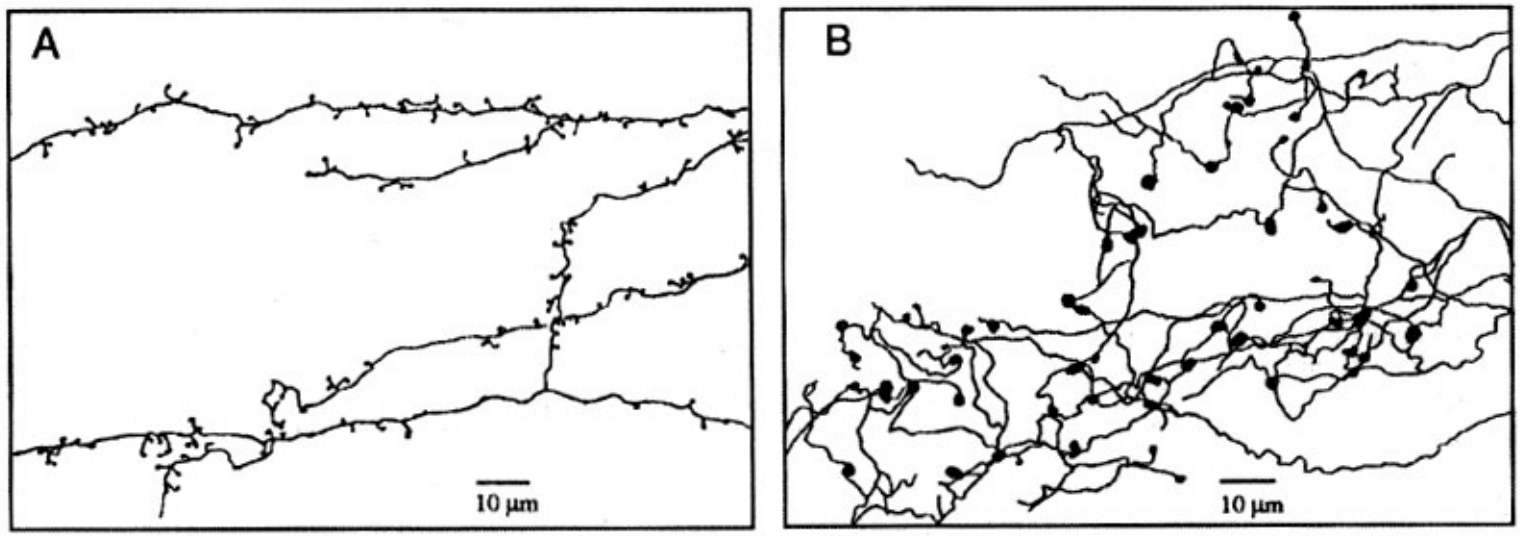


3d RECONSTRUCTION OF THE BARRELOIDS IN THE VPM OF THE RAT



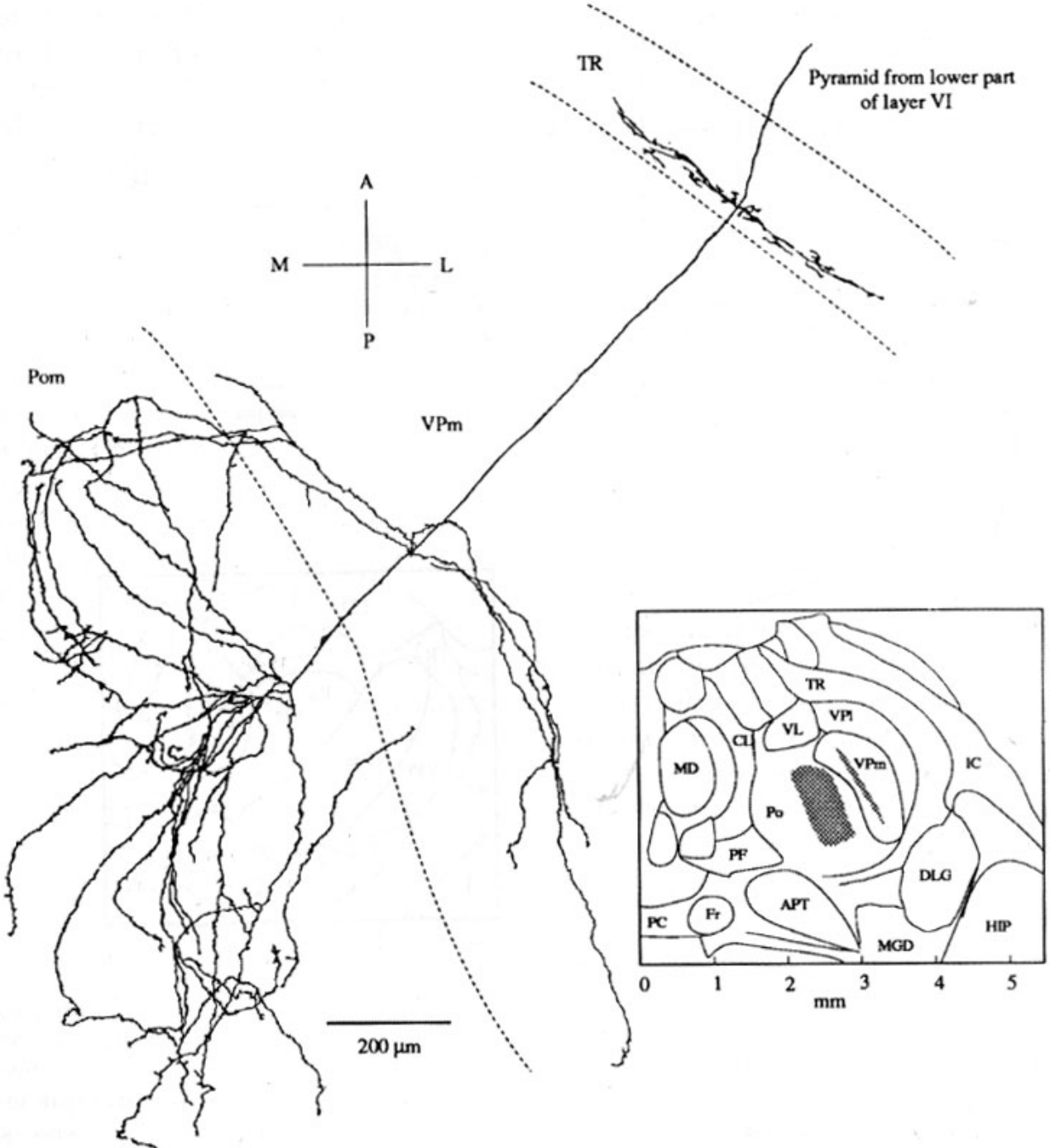
(a), (b): cytochrome-oxidase staining. Haidarliu and Ahissar, 2001; Groenewegen, 2004

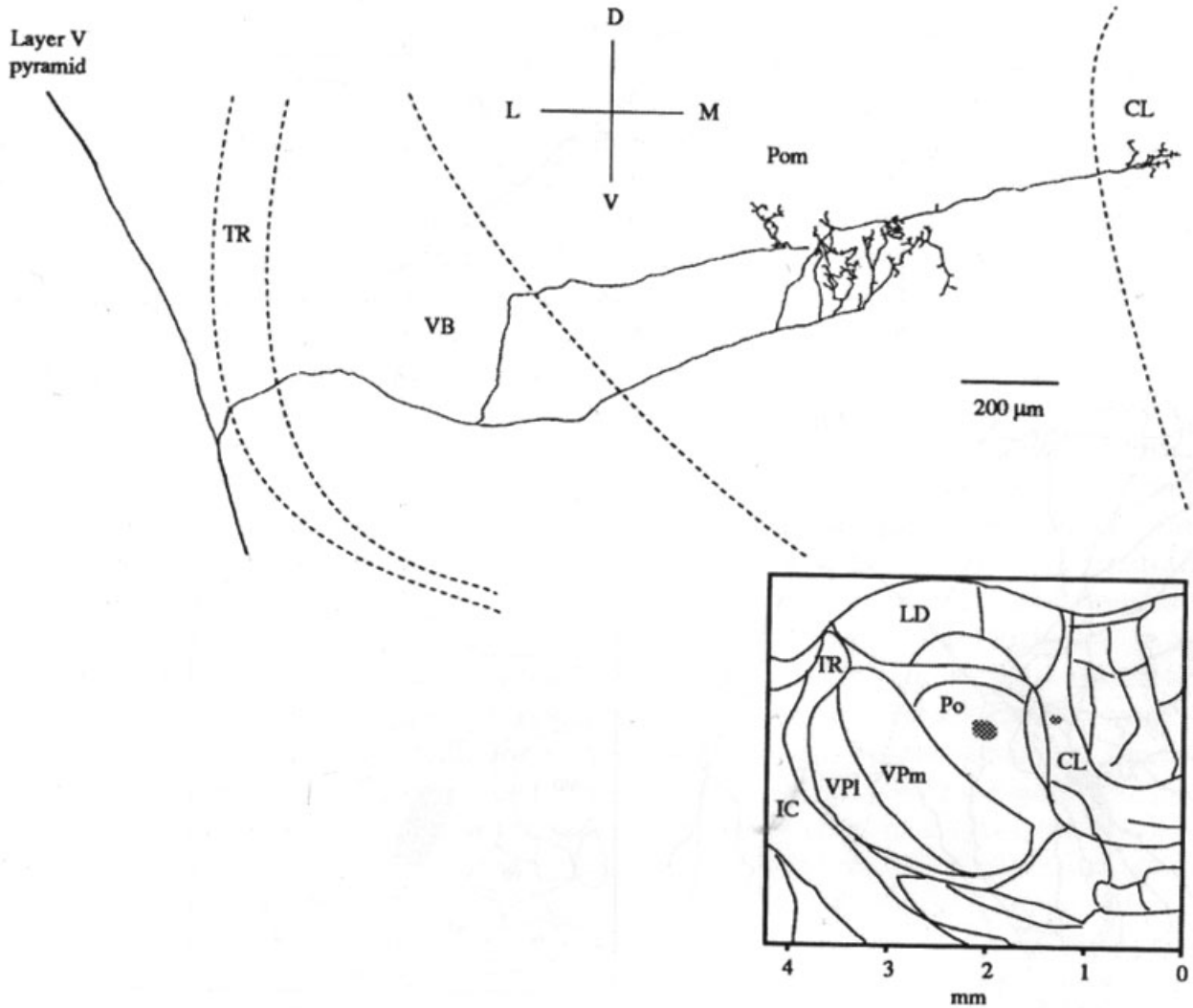
CORTICOTHALAMIC FIBER FROM LAYER 6 (A) and LAYER 5 (B)



The cortico-thalamic fibers originating in layer 6 are thin with many short-side branches and small-sized boutons (“modulator”). In contrast, the fibers from the layer 5 neurons, arising as collaterals from axons that are directed toward the brainstem and spinal cord, are thicker and have relatively few, but large boutons (‘drivers’). VPM of the thalamus. Bourassa et al., 1995; Groenewegen, 2004

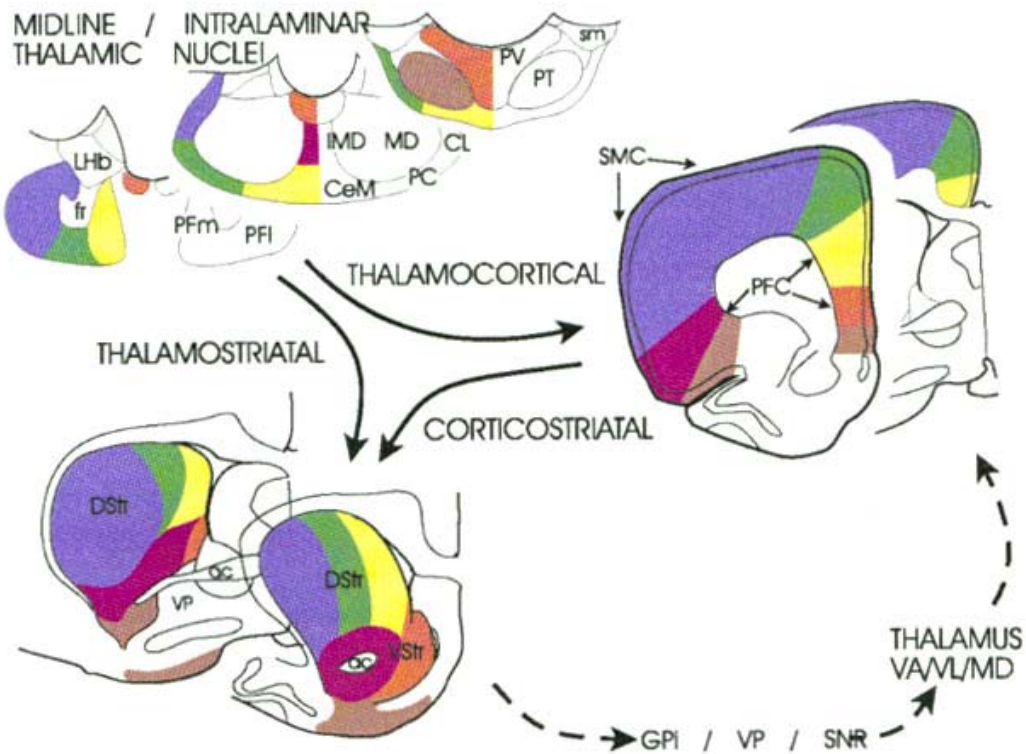
Intrathalamic arborization of a corticothalamic fiber arsing from layer VI pyramids of the barrel cortex. Note collaterals in the thalamic reticular nucleus (TR) and the extensive arborization in the posterior thalamic (Po) nucleus. Rat. Bourassa et al, 1995.





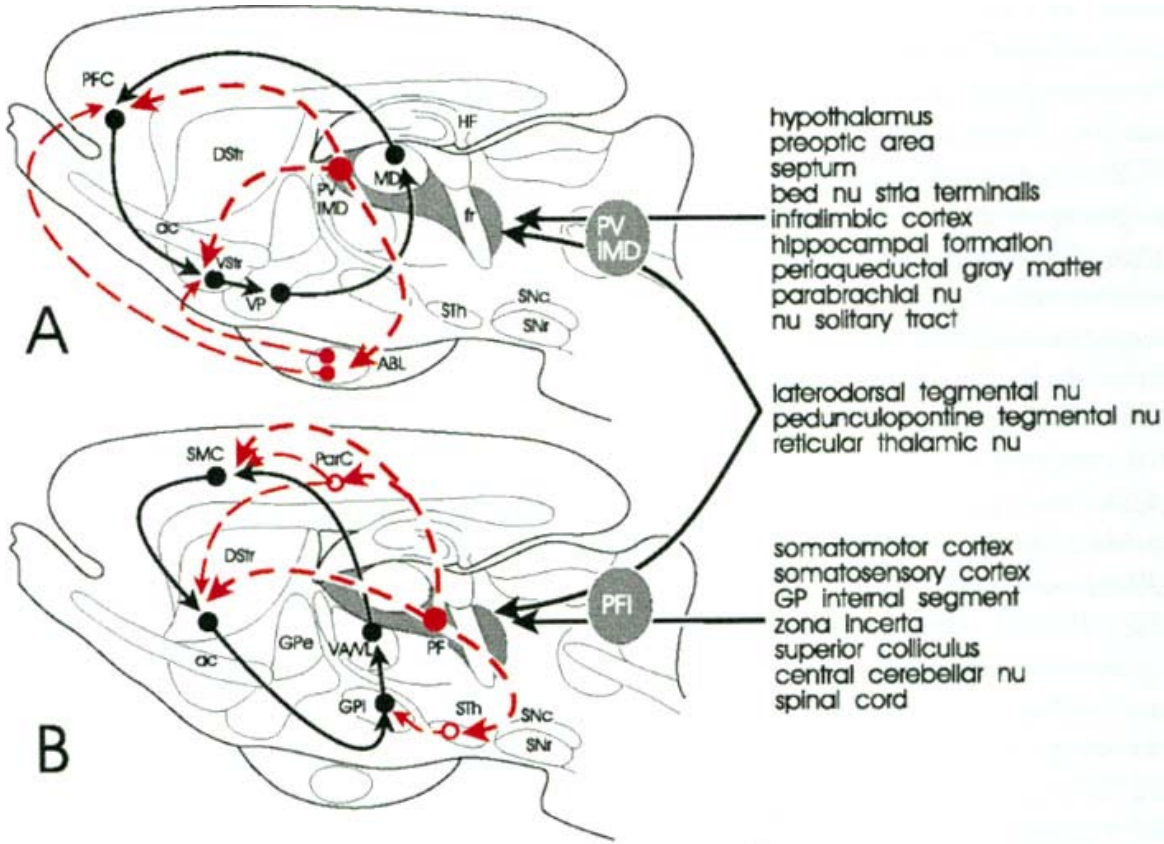
Camera lucida reconstruction of the intrathalamic axonal arborizations of a corticothalamic fiber arising from a pyramidal neuron in layer V of the barrel cortex (primary somatosensory cortex). The axons were filled following small injections of biocytin in the barrel cortex, filling only a limited number of neurons of which the projection fibers could be individually traced. The terminal fibers in the thalamus are issued as collaterals from axons that are directed toward the brain stem. There is strong clustering of axon terminals in the posterior thalamic nucleus (Po) and a few collaterals reach the central lateral nucleus (CL) of the intralaminar complex. Note the absence of collateral fibers in the reticular thalamic nucleus (TR). The drawing in the right-hand corner shows the location of the terminals in a horizontal section of the thalamus. Slightly modified from Fig. 8A of Bourassa *et al.* (1995)

INTRALAMINAR NUCLEI



Schematic drawing of the topographical organization of the projections from the midline– intralaminar thalamic complex to the striatum (cf. Berendse and Groenewegen, 1990) and the frontal cortex (cf. Berendse and Groenewegen, 1991) and of the projections from the frontal cortex to the striatum (cf. Berendse *et al.*, 1992). Interconnected parts of the midline and intralaminar complex, the cerebral cortex, and the striatum are indicated by corresponding colors. Solid lines indicate the convergence of connected parts of the thalamus, cerebral cortex, and striatum; broken lines mark the path of parallel circuits leading from the cerebral cortex via the basal ganglia and the thalamus back to the cortex. Abbreviations: ac, anterior commissure; CeM, central medial thalamic nucleus; CL, central lateral thalamic nucleus; DStr, dorsal striatum; fr, fasciculus retroflexus; GP, globus pallidus; GPi, internal segment of GP; IMD, intermediodorsal thalamic nucleus; LHb, lateral habenula; MD, mediodorsal thalamic nucleus; PC, paracentral thalamic nucleus; PF, parafascicular nucleus; PFC, prefrontal cortex; PFl, lateral part of PF; PFm, medial part of PF; PT, parataenial thalamic nucleus; PV, paraventricular thalamic nucleus; sm, stria medullaris; SMC, somatomotor cortex; SNR, pars reticulata of the substantia nigra; VA, ventral anterior thalamic nucleus; VL, ventral lateral thalamic nucleus; VP, ventral pallidum; VStr, ventral striatum. Slightly modified from Groenewegen and Berendse (1994).

INTRALAMINAR NUCLEI



Schematic illustration showing the distinctive and common inputs of the midline paraventricular–intermediodorsal thalamic nuclei (PV–IMD) and the intralaminar parafascicular nucleus, in particular its lateral part (PFl). In addition, the relationships of these midline and intralaminar nuclei with the parallel, functionally segregated basal ganglia–thalamocortical circuits are shown. (A) The involvement of the PV–IMD in the prefrontal cortical and ventral striatal way stations of "limbic circuits" is illustrated. The projections of these thalamic nuclei to the basal amygdaloid complex which, in turn, projects directly to the same cortical and striatal targets as the thalamic PV and IMD, are also indicated (cf. Wright and Groenewegen, 1995, 1996). (B) The influence of the PFl on the cortical and striatal way stations of the "motor circuits" is shown. Note that the PFl also projects to the lateral part of the subthalamic nucleus that is intimately involved in the motor circuits. Abbreviations: ABL, basal amygdaloid complex; ac, anterior commissure; DStr, dorsal striatum; fr, fasciculus retroflexus; GP, globus pallidus; GPe, external segment of GP; GPi, internal segment of GP; HF, hippocampal formation; IMD, intermediodorsal thalamic nucleus; MD, mediodorsal thalamic nucleus; PF, parafascicular nucleus; PFC, prefrontal cortex; PFl, lateral part of PF; PV, paraventricular thalamic nucleus; SMC, somatomotor cortex; STh, subthalamic nucleus; VA, ventral anterior thalamic nucleus; VL, ventral lateral thalamic nucleus; VP, ventral pallidum; VStr, ventral striatum. Slightly modified from Groenewegen and Berendse (1994).

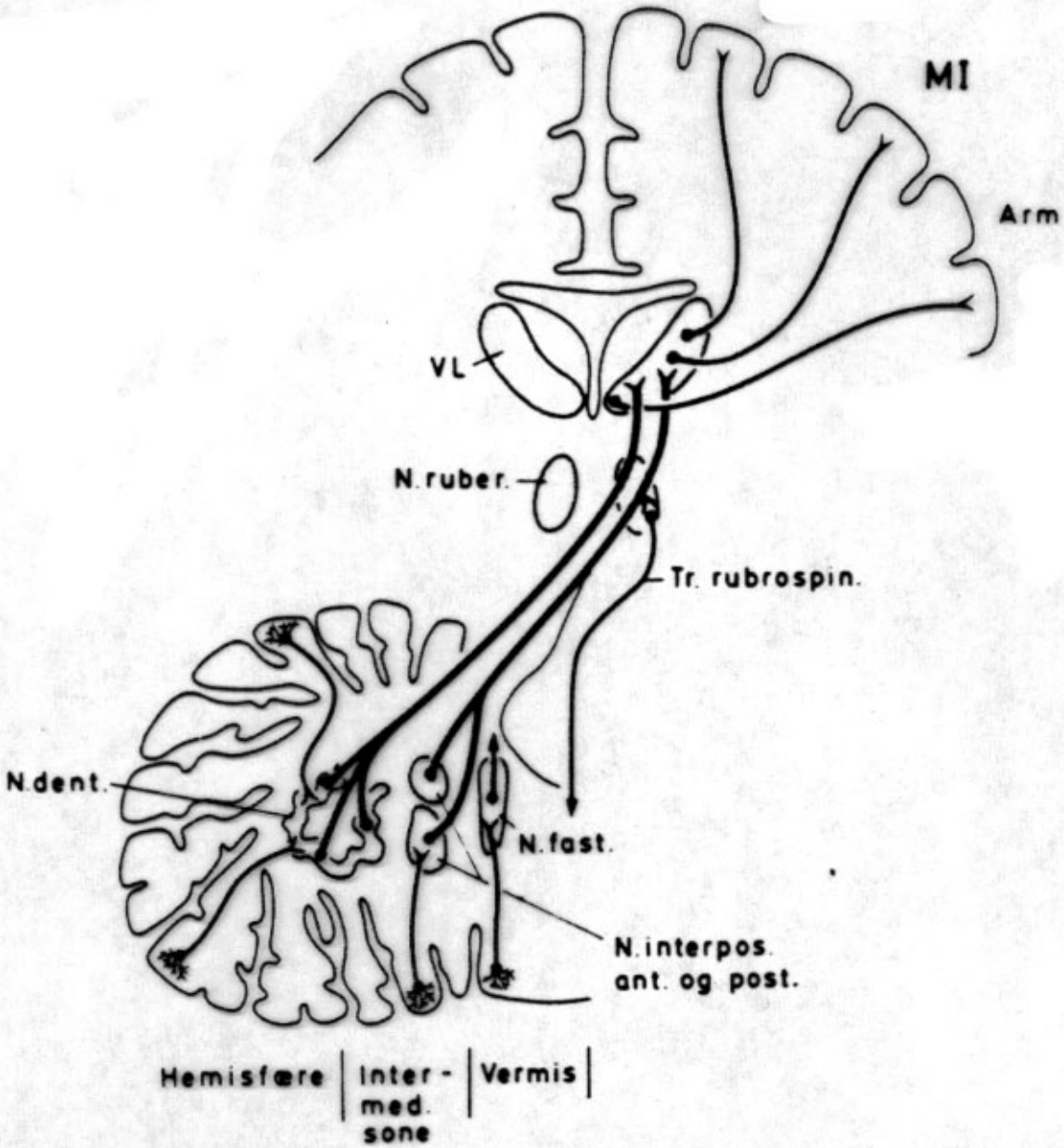
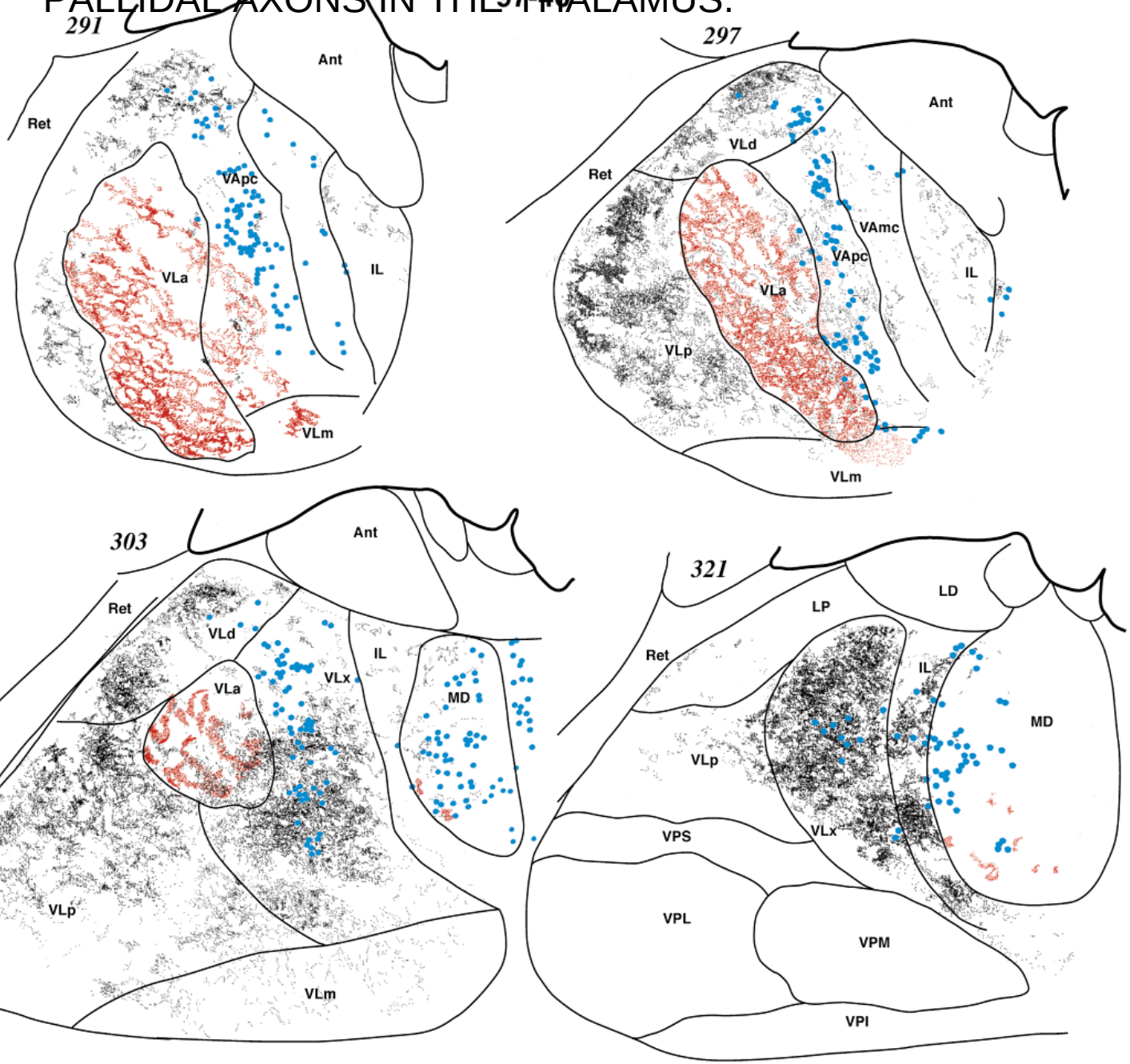


Diagram of the major corticocerebellar pathways. Cortical fibers to the inferior olivary nucleus are not shown. (Reproduced, with permission, from Brodal, 1990.)

CERBELLOTHALAMIC FIBERS ARE SEGREGATED FROM PALLIDAL AXONS IN THE THALAMUS.



Line drawing of coronal sections through the thalamus showing the distribution of pallidothalamic (red) and cerebellothalamic (black) anterograde label and the location of the pre-SMA projection neurons (blue) . Note the overlap of pallidal input with pre-SMA projecting neurons at the VApc/VLa border (section 297) and cerebellar input with such neurons in VLx, VLd, and IL (sections 297-321)

From Sakai et al., 2000.

CEREBELLOTHALAMIC CONENCTIONS 2.

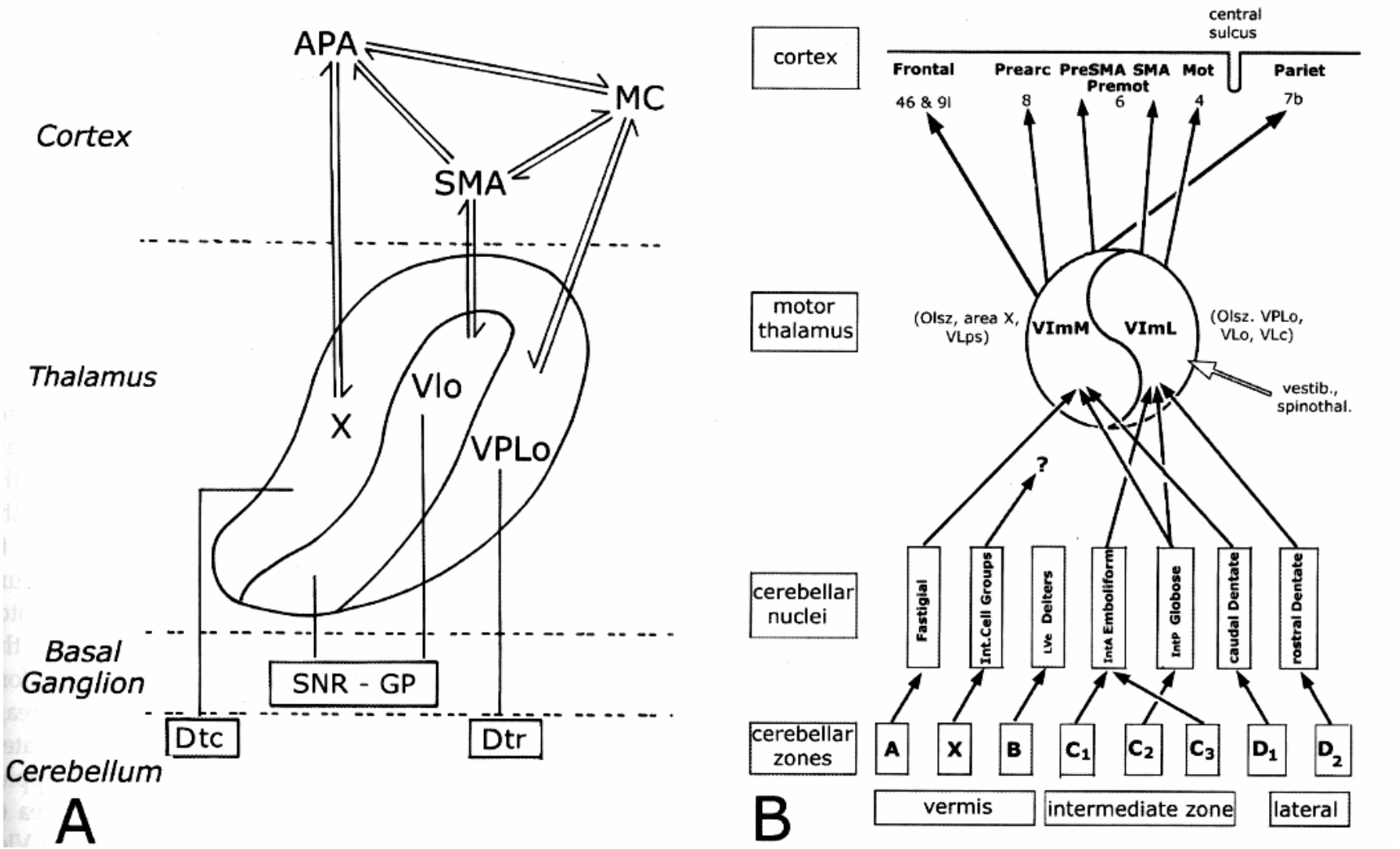


Diagram showing the connections of the basal ganglia and the crebellar nuclei with the motor cortex (MC), the supplementary motor cortex (SMA) and the anterior premotor area and their relay nuclei in the thalamus. A: Schell and Strick, 1984; B: Voogd, 2004

CEREBELLOTHALAMIC CONNeCTIONS 3

For comparison see the lemniscal and basal ganglia connections via the thalamus

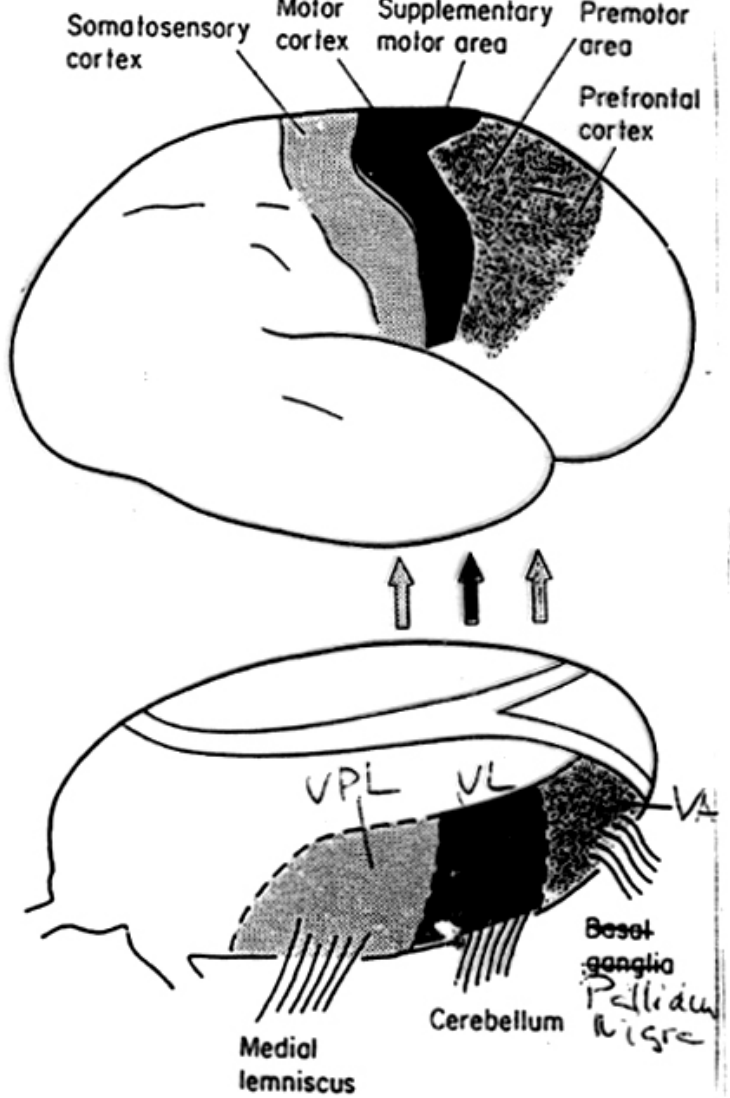
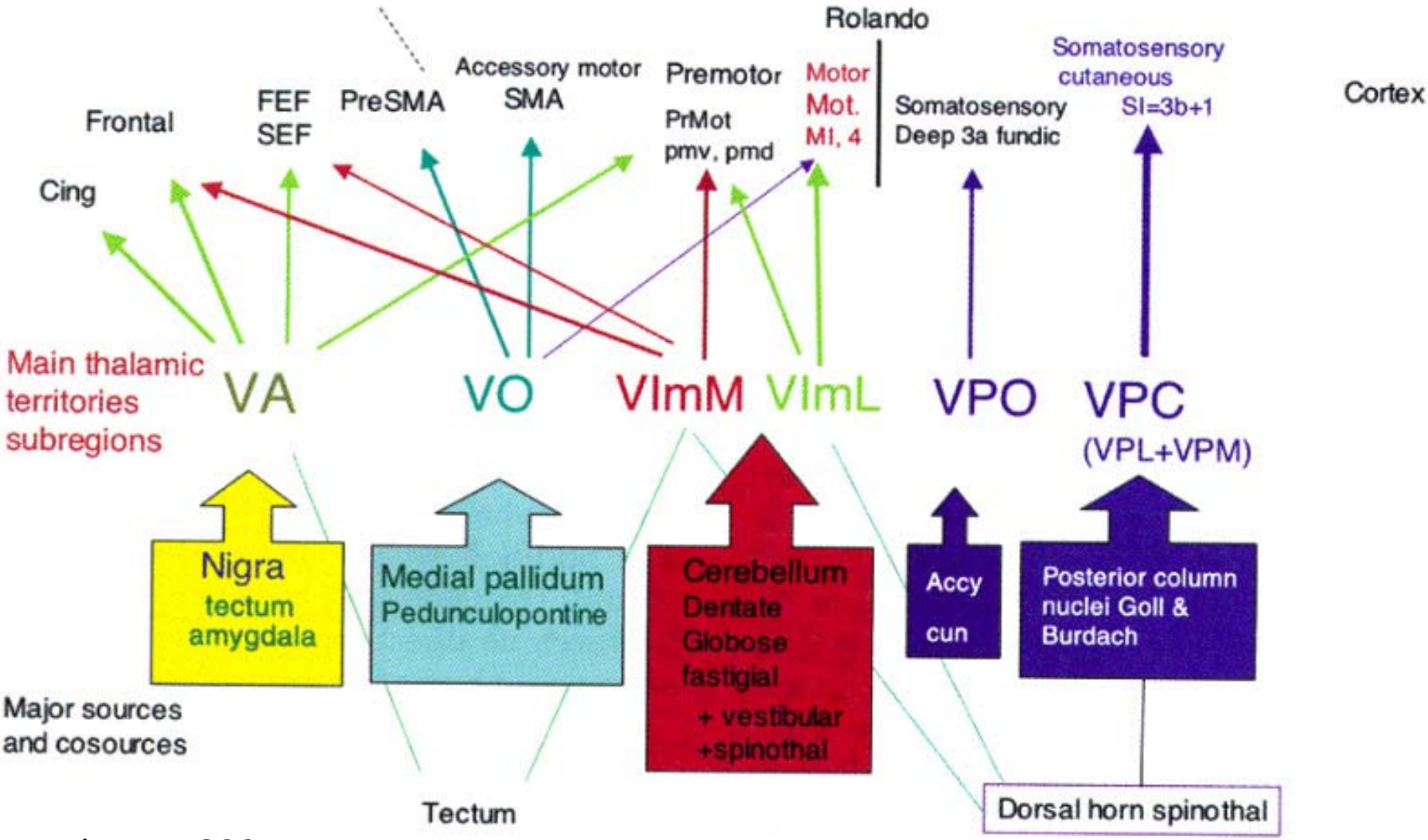


Fig. 11.14. *Thalamocortical connections.* Schematic presentation of the arrangement within the ventral thalamic nucleus of afferents from the somatosensory pathways, the cerebellum, and the basal ganglia and their further projections to the SI, MI, and the premotor cortex.

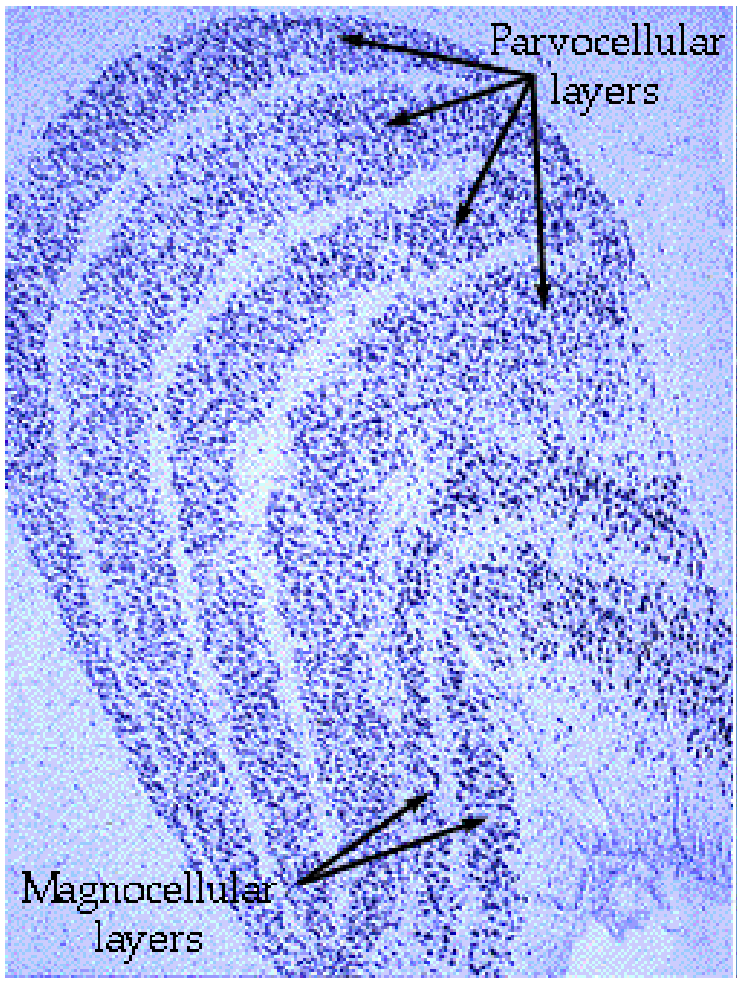
From Brodal

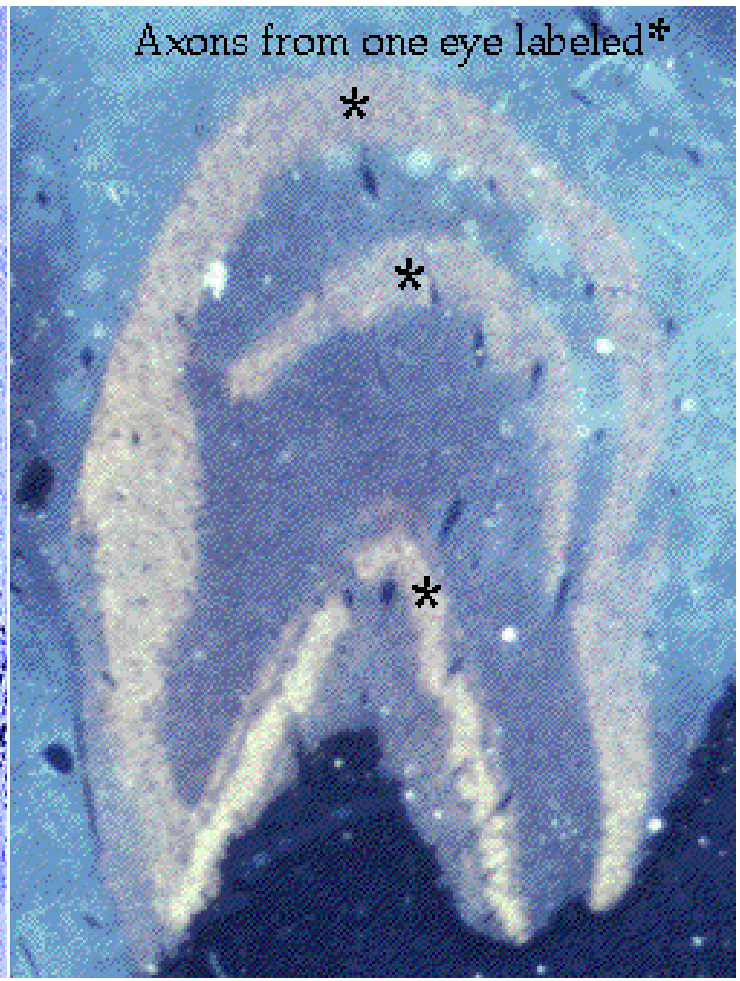
NIGRO-PALLIDO-CEREBELLAR INPUTS ARE SEGREGATED IN THE THALAMUS



Percheron, 2004

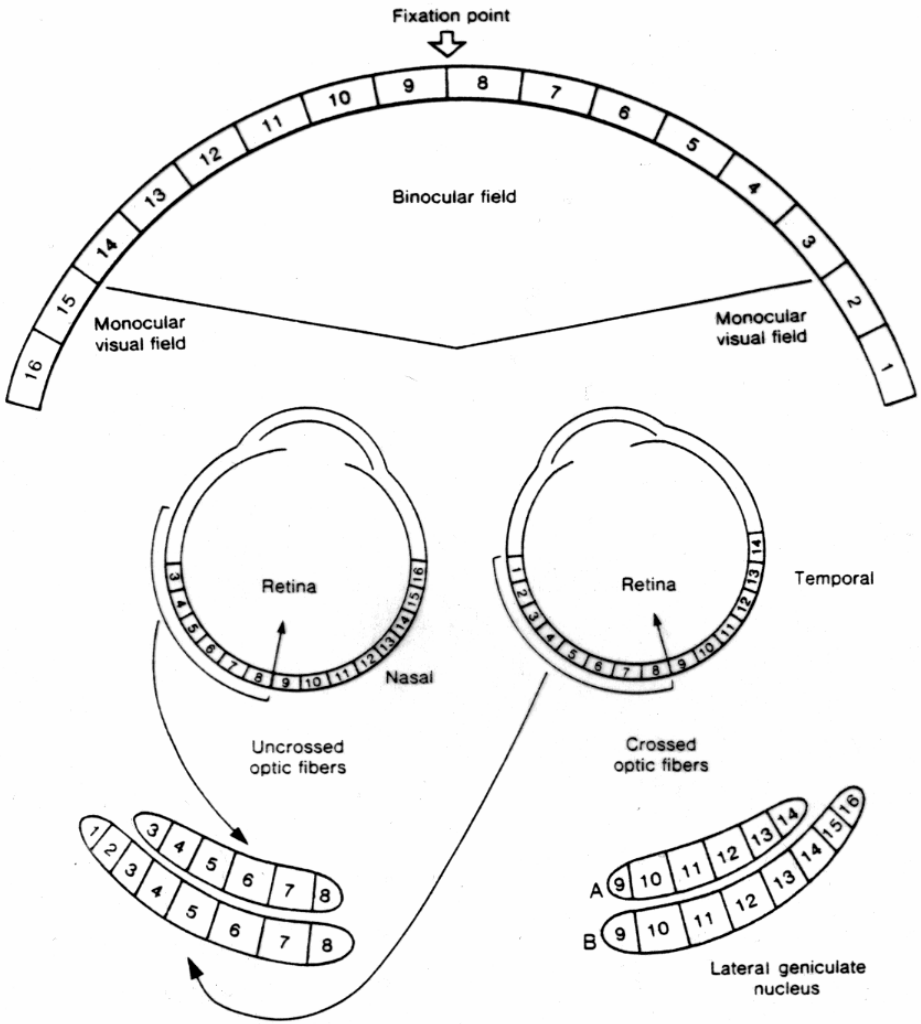
Parvocellular and Magnocellular Layers of the LGN





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

BINOCULAR AND MONOCULAR VISUAL FIELDS



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

Guillery

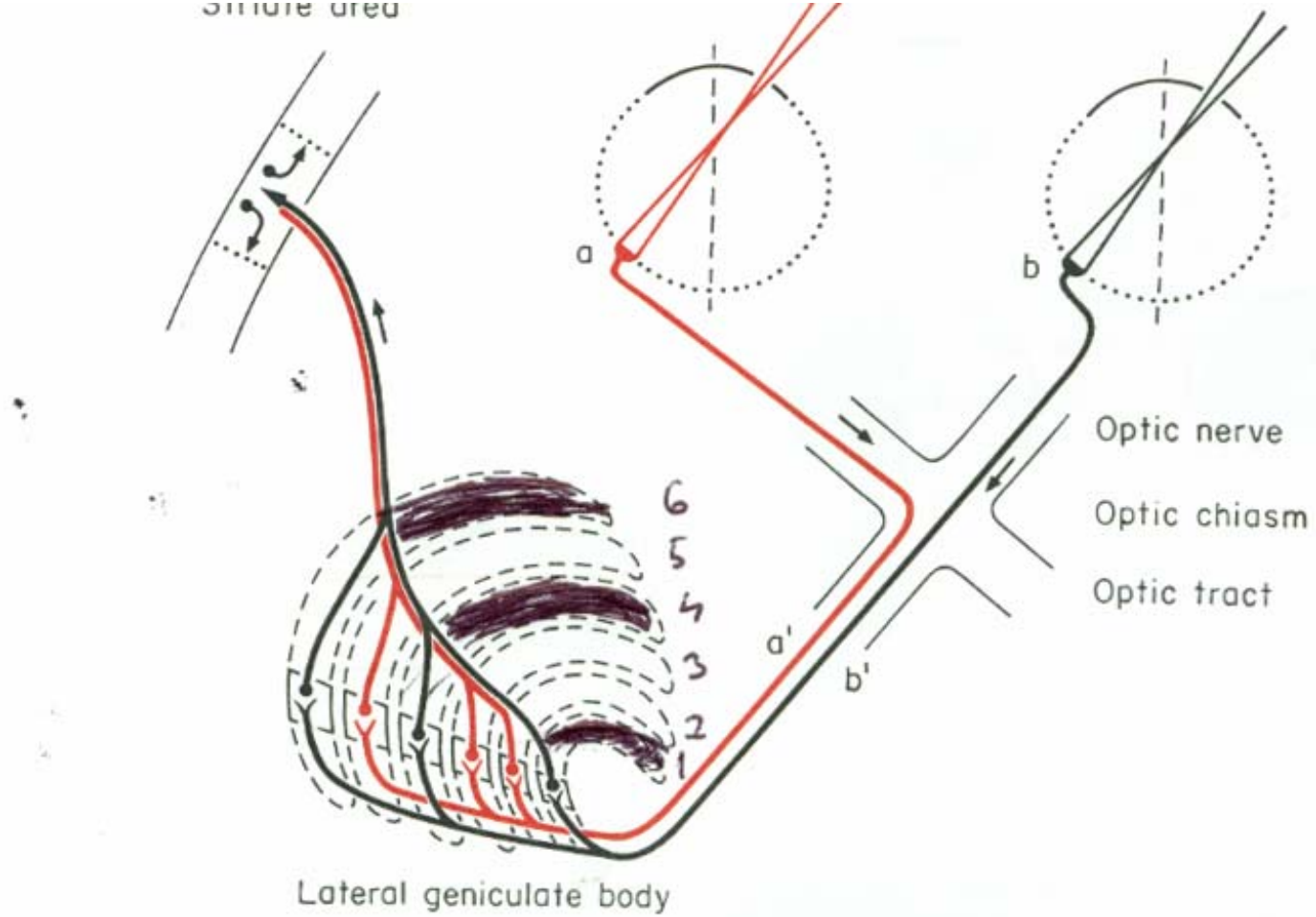
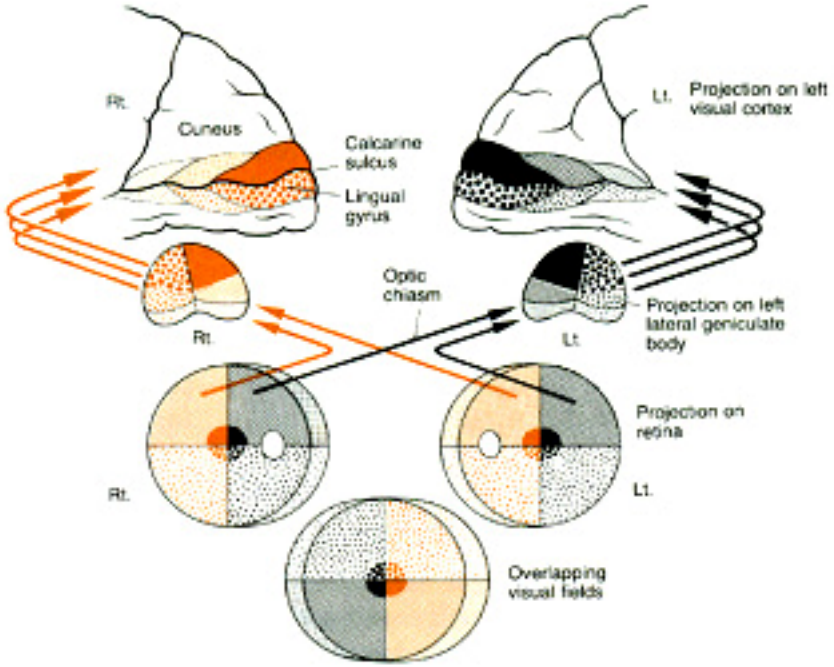
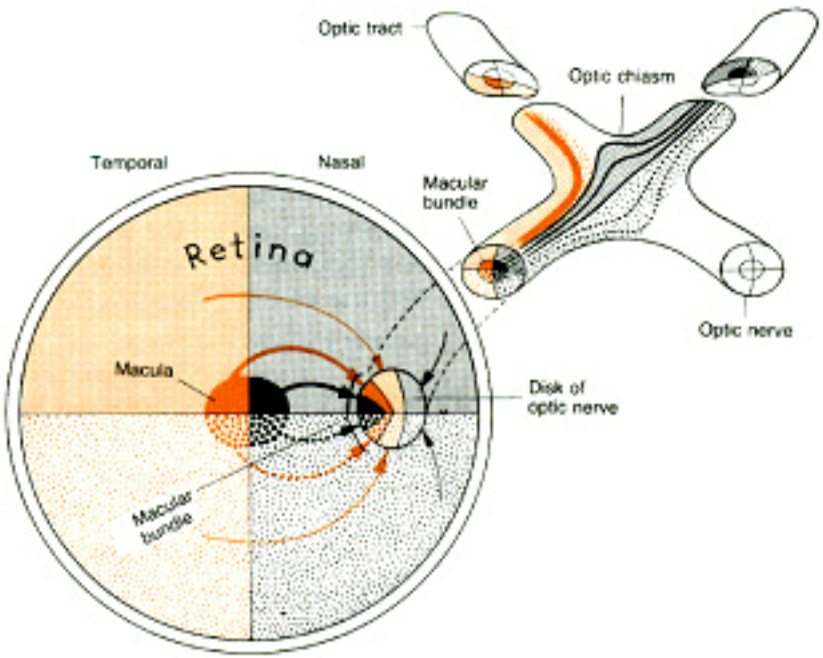
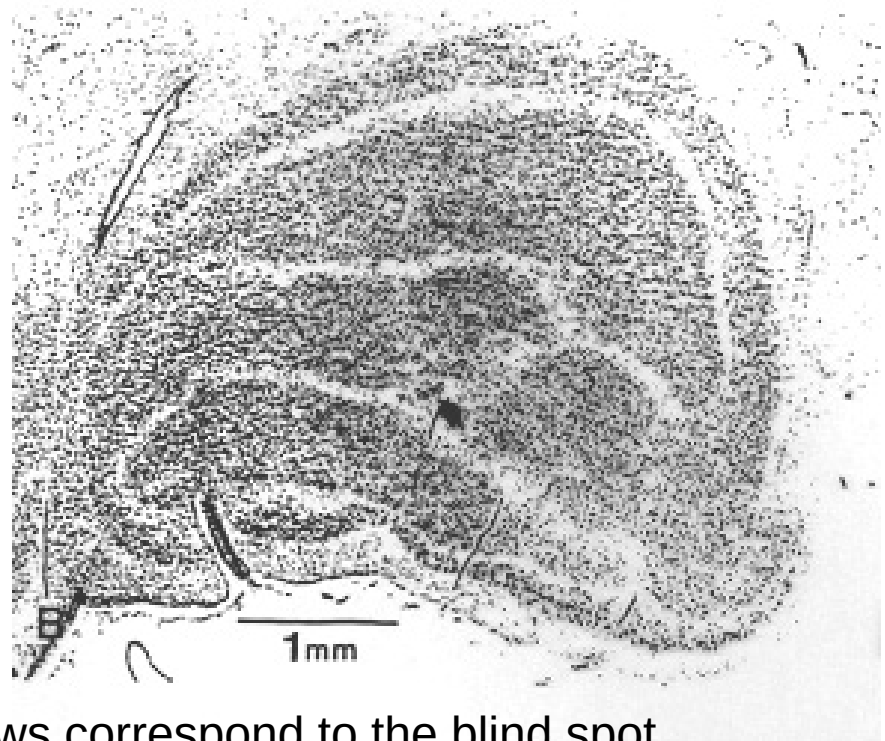


Fig. 5.14. *Fusion of the visual images.* The impulses from corresponding points on the two retinae end in different layers of the geniculate—that is, impulses from the two eyes are kept separate at this level. The convergence of impulses takes place in the striate area.

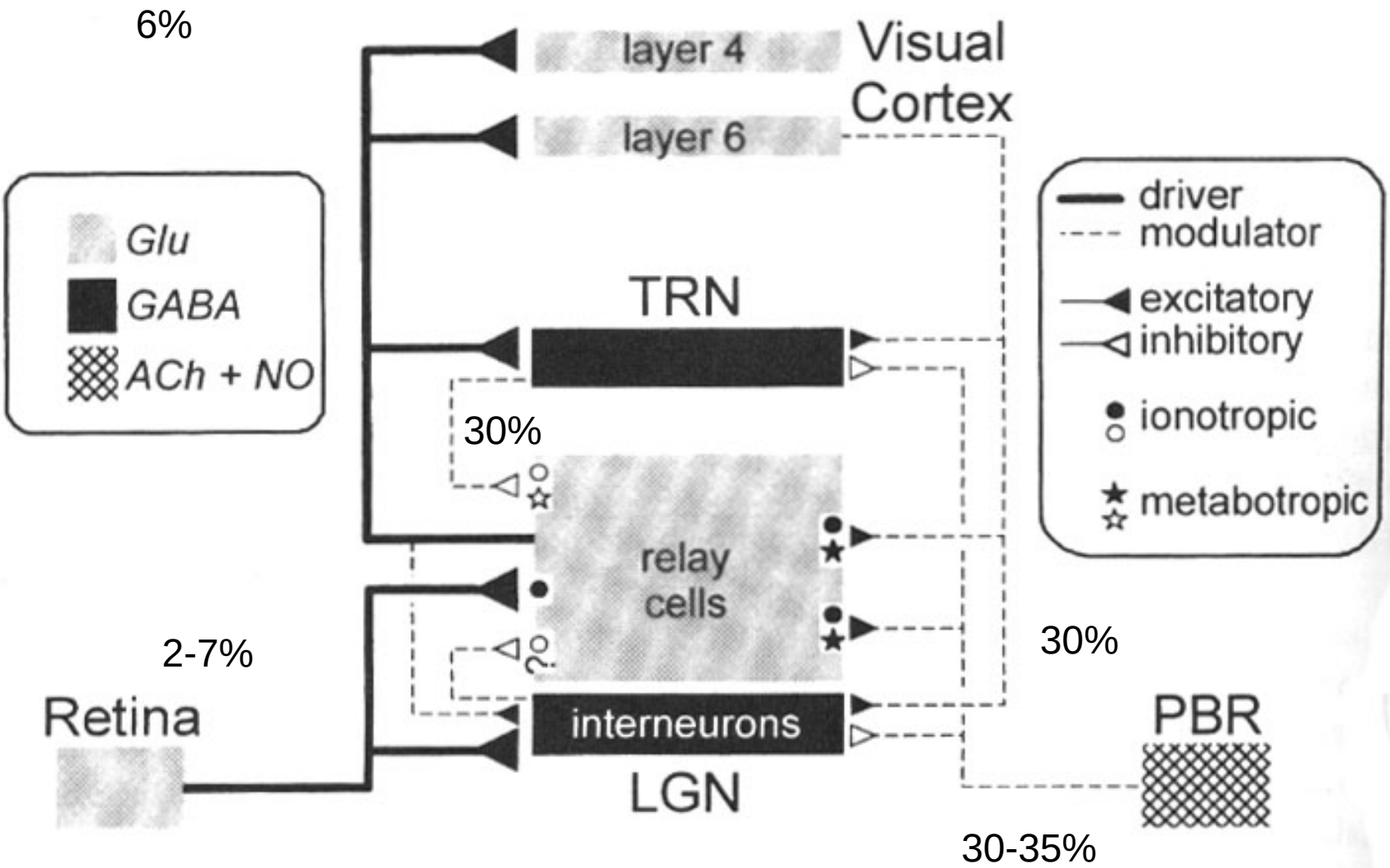
Topography of fibers in the LGB







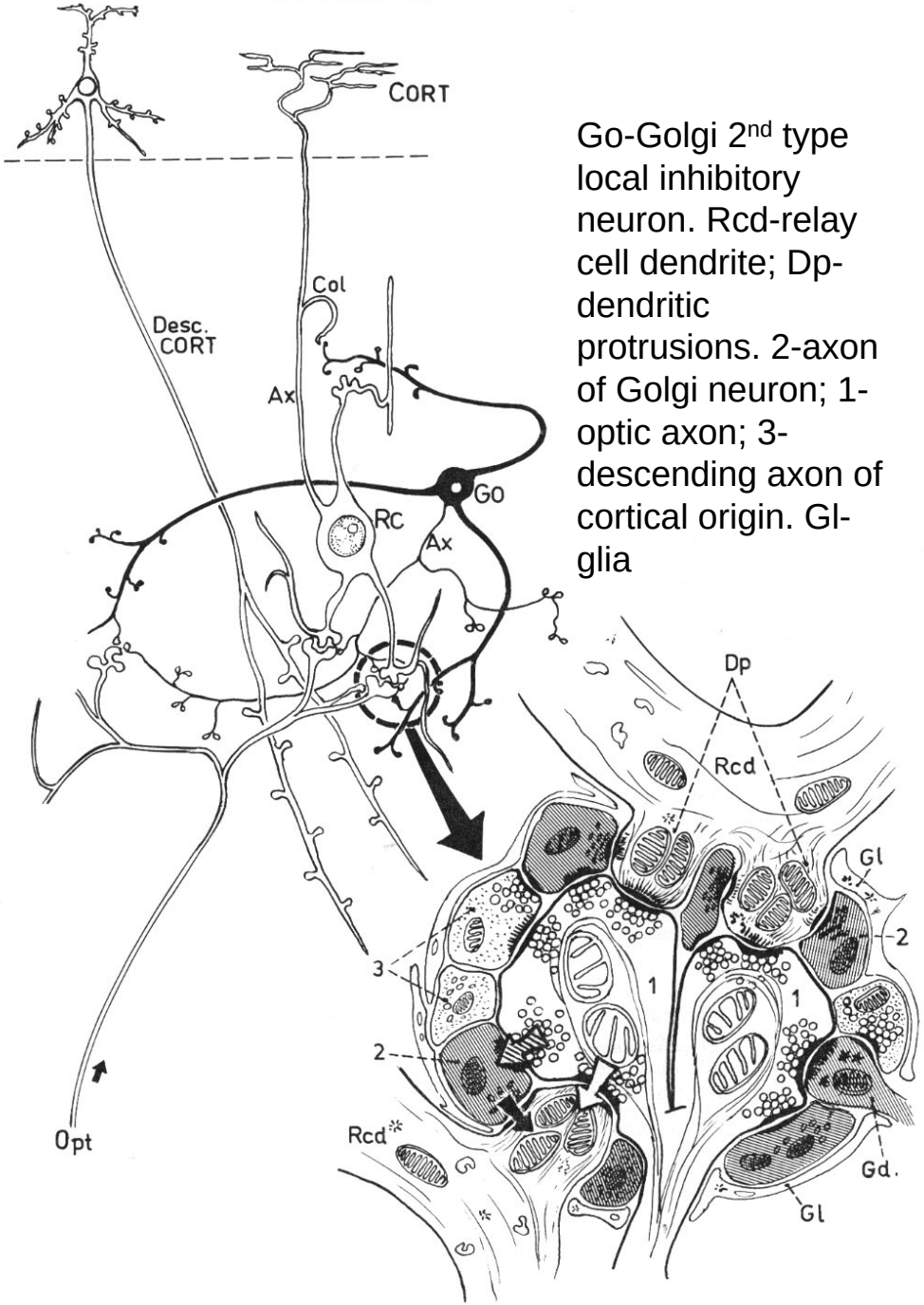
Arrorws correspond to the blind spot



Schematic view of details of the main connections of the lateral geniculate nucleus. Indicated are the inhibitory or excitatory nature of the synapses, the postsynaptic receptors activated by each input on relay cells, and the neurotransmitters involved. Abbreviations: LGN, lateral geniculate nucleus; PBR, parabrachial region; TRN, thalamic reticular nucleus.

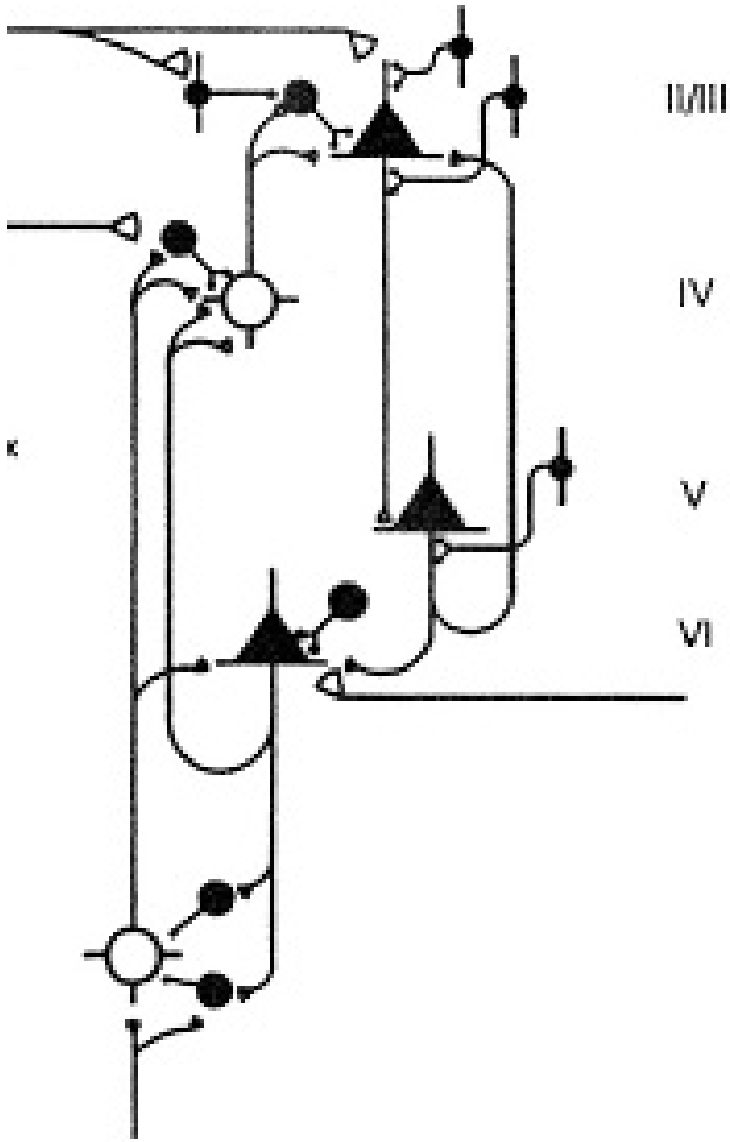
Percentage values: approximate contribution of synapses to the relay neuron. Sherman and Guillery, 2004

Lateral Geniculate Body

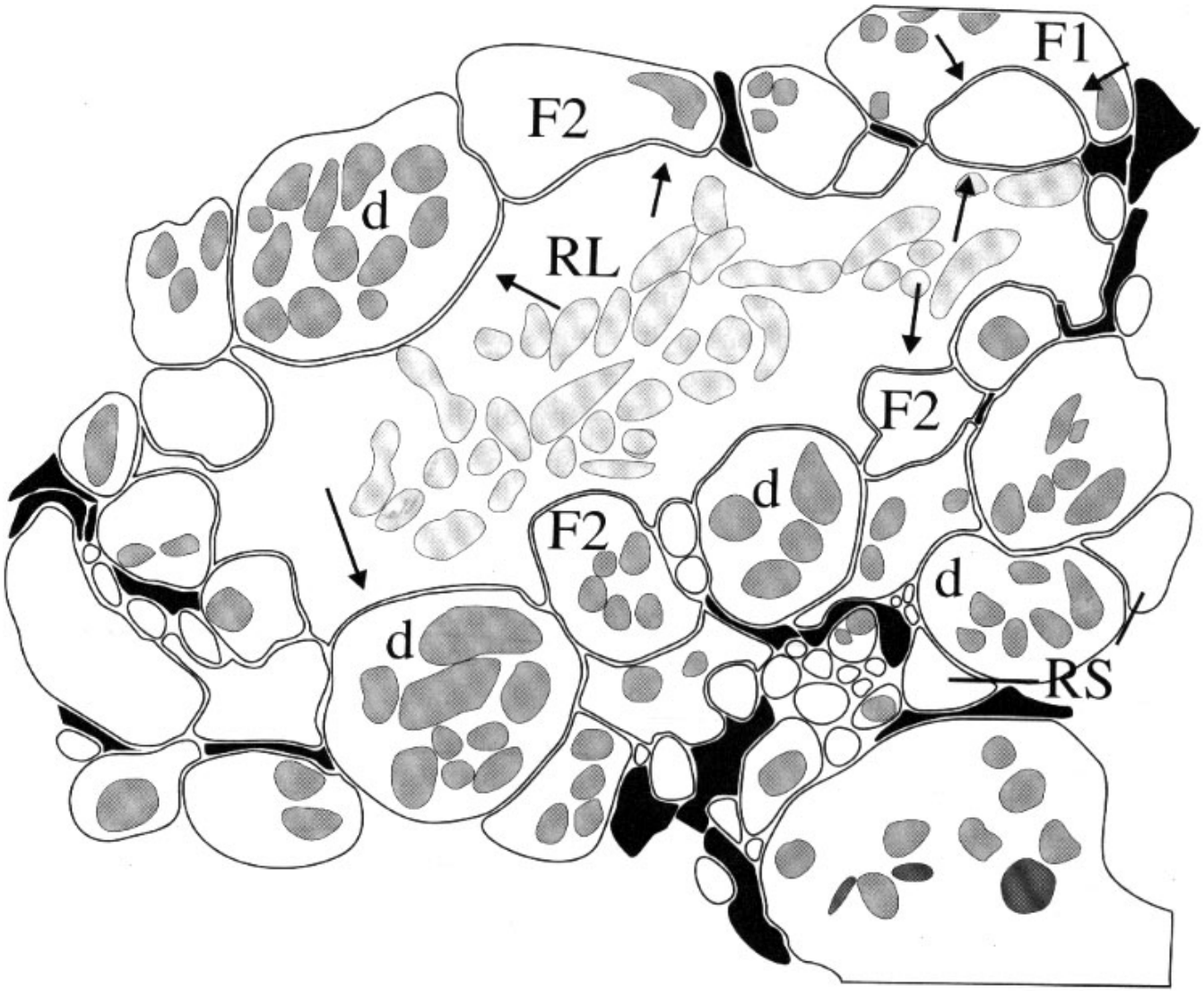


Go-Golgi 2nd type local inhibitory neuron. Rcd-relay cell dendrite; Dp-dendritic protrusions. 2-axon of Golgi neuron; 1-optic axon; 3-descending axon of cortical origin. Gl-glia

From Szentagothai

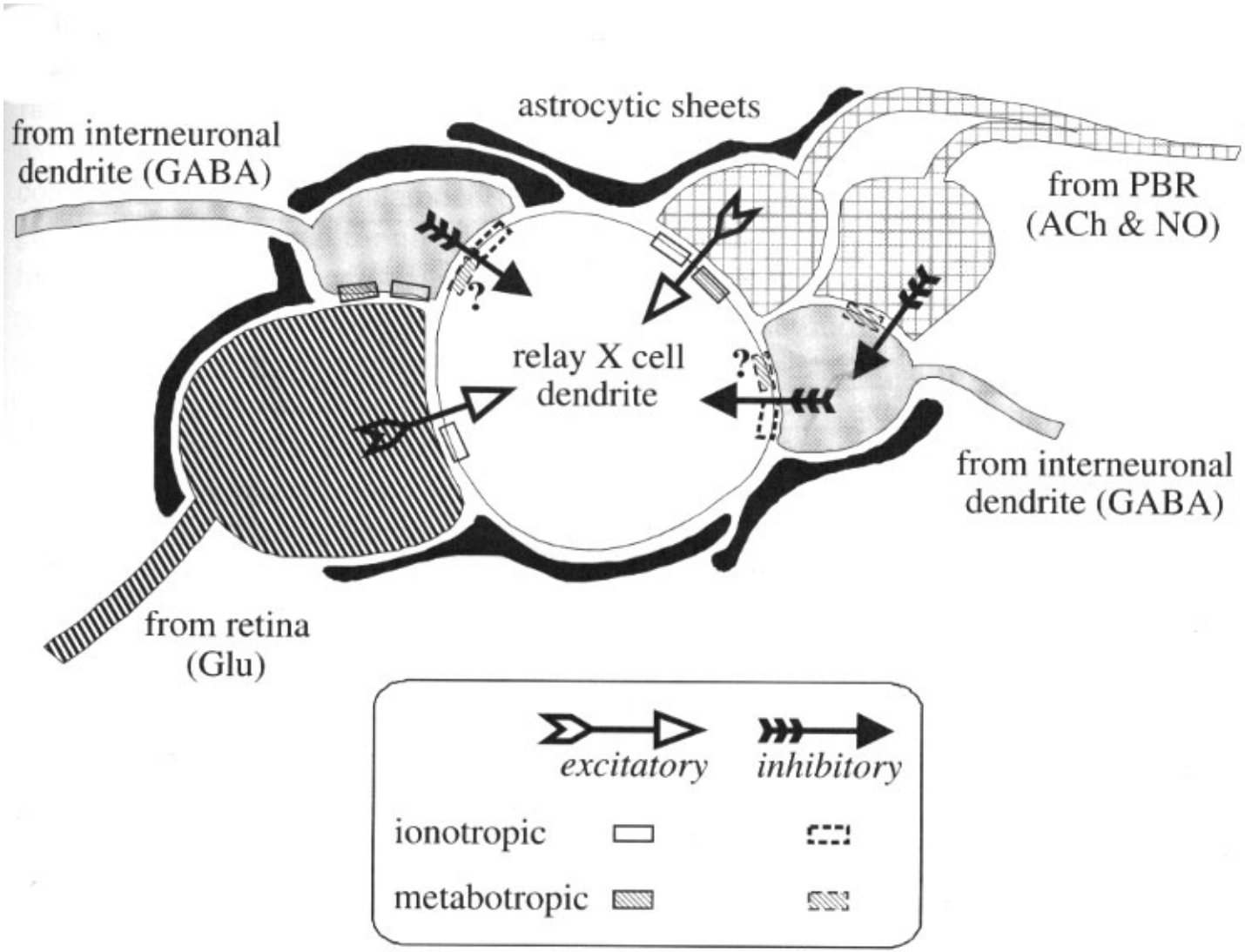


Sillito

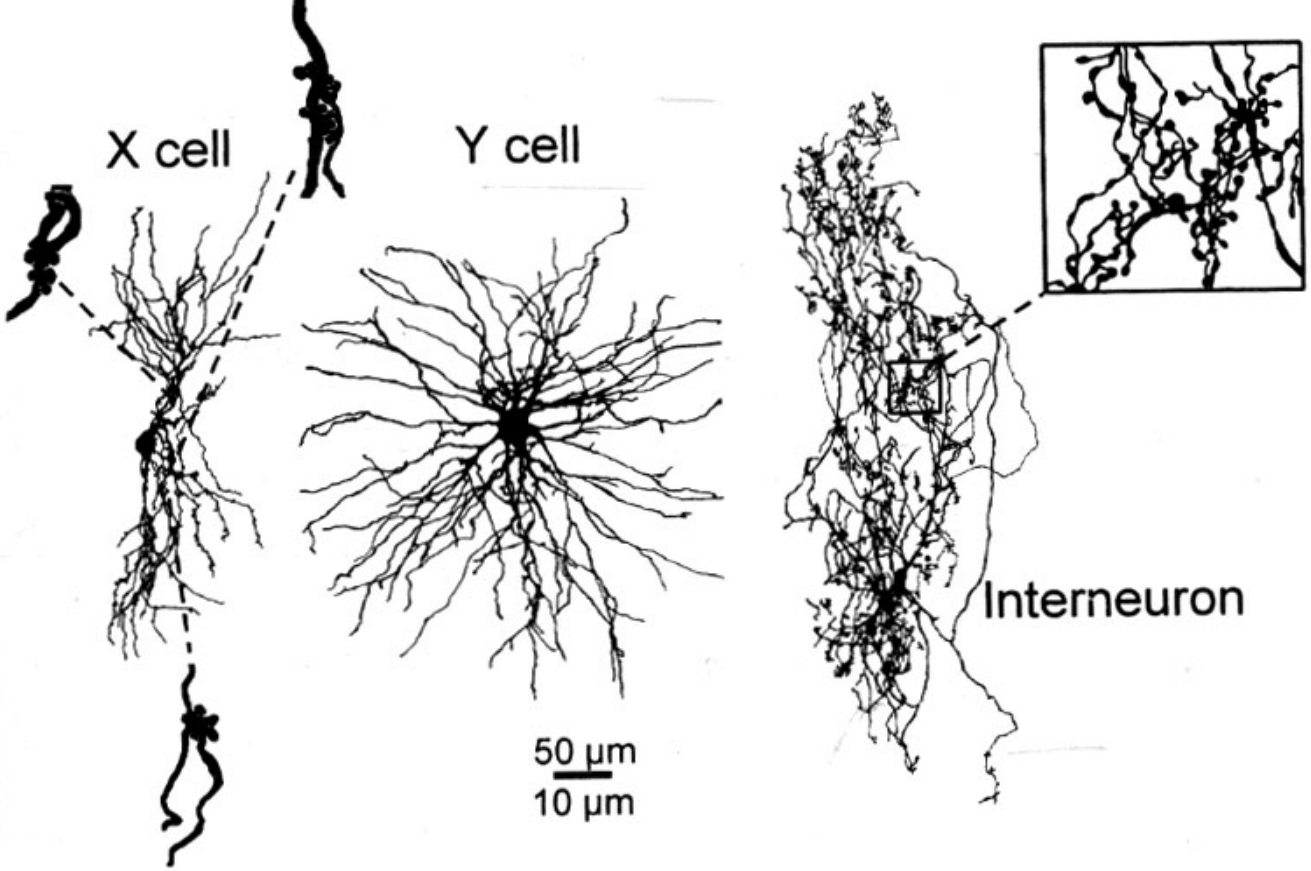


RL-round vesicles, large profiles=retina; RS-round vesicles, small profiles: corticothalamic, brainstem; F1-flattened vesciles: axonal presynaptic:reticular and interneurons F2-flattened, dendritic:-bothe pre and postsynaptic: dendritic processes of interneurons

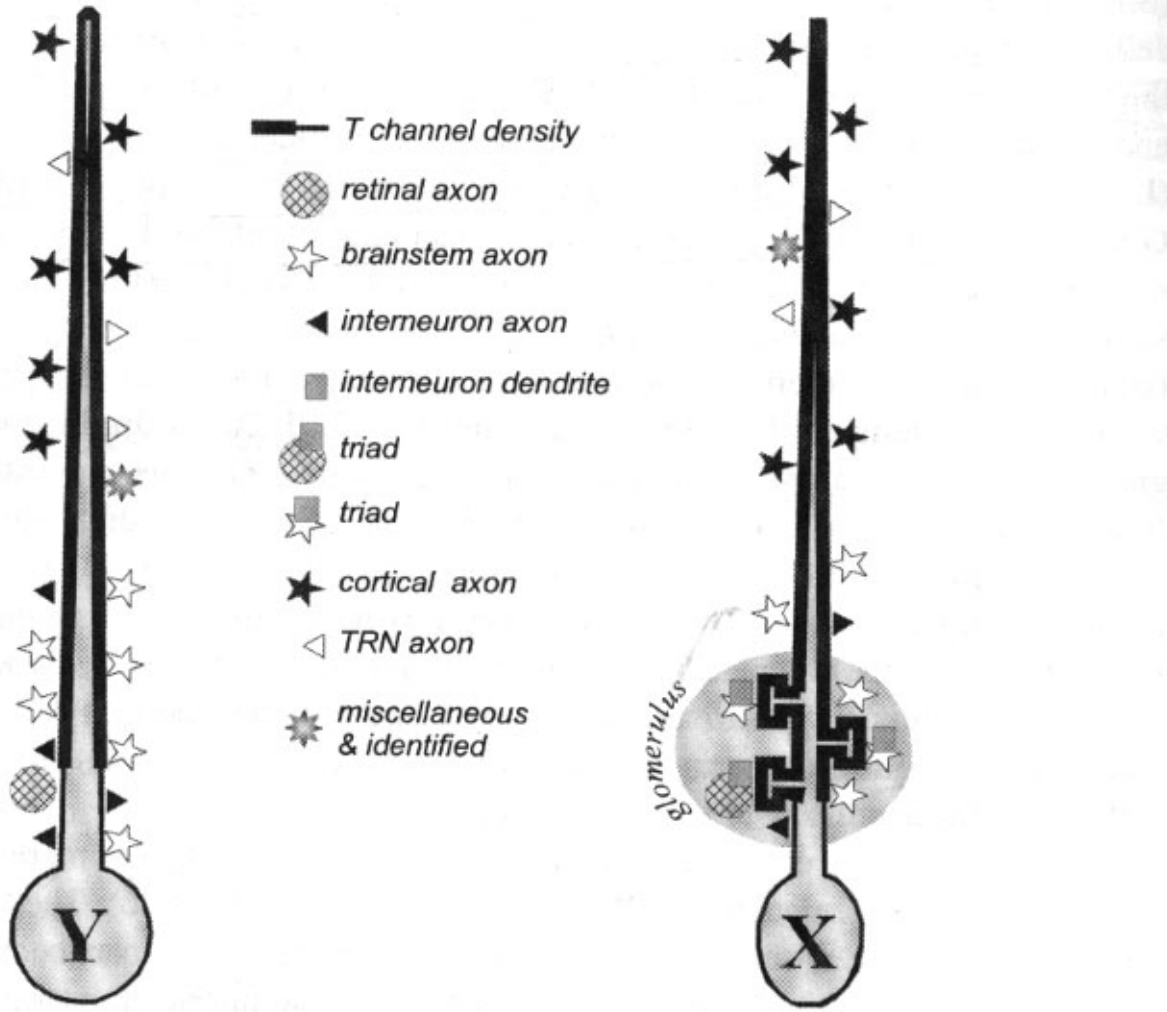
Glomerular synaptic complex in the LGB (Sherman and Guillery, 2001)



Schematic view of a small glomerulus showing synatic triads. Arrows indicate direction of synaptic function, pointing from presynaptic to postsynaptic elements. The ? Postsynaptic to the dendritic terminals of interneurons indicate that it is not clear whether metabotropic (GABAB) receptors exist there. (Sherman and Guillery, 2004)

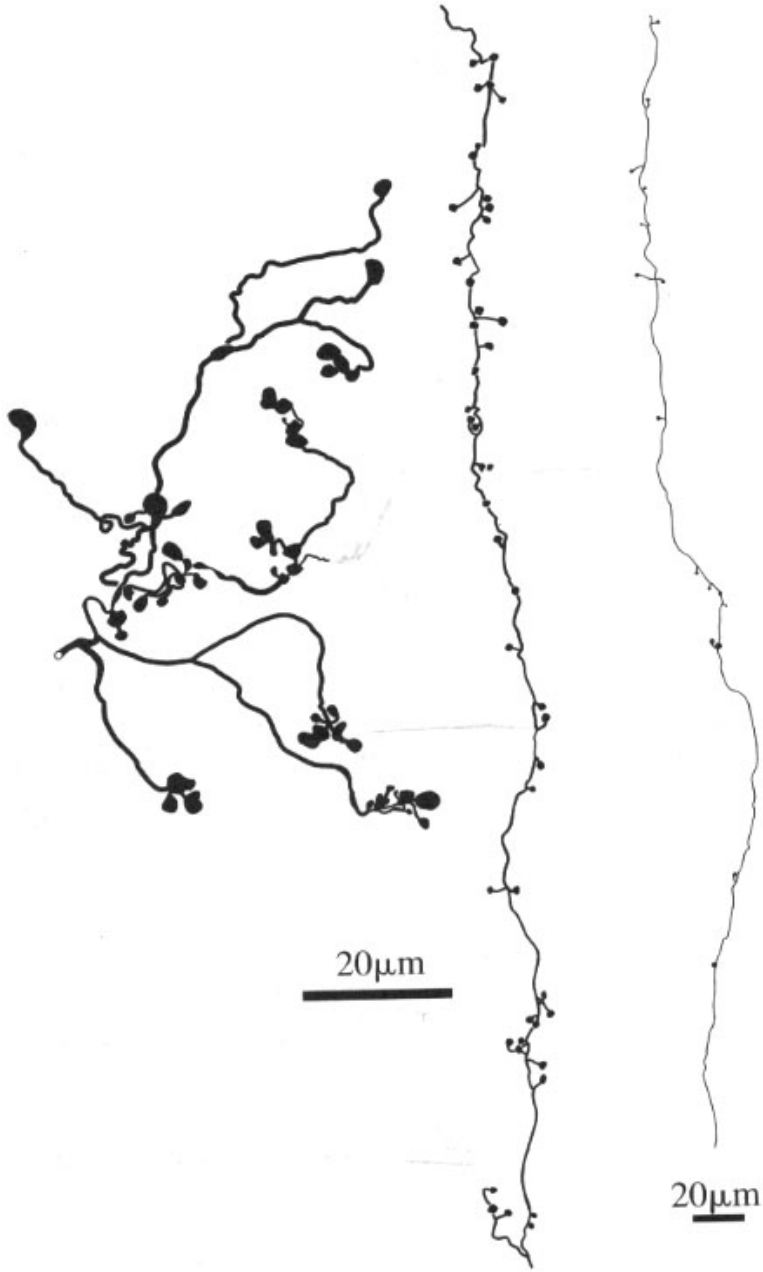


Tracings of a relay X and Y cell and interneuron from the A layers of the cat's lateral geniculate nucleus. These were all physiologically identified during *in vivo* recording and filled intracellularly with horseradish peroxidase for morphological analysis (Friedlander et al., 1981; Hamos et al., 1985). The dendritic arbor of the X cell is tufted and elongated, oriented perpendicular to the plane of the layers, whereas the Y cell dendrites show a stellate distribution with an approximately spherical arbor. The X cell also has prominent clusters of dendritic appendages near proximal branch points. These are hard to see in the cell reconstructions, so three examples are shown at greater magnification, with dashed lines indicating their dendritic locations (the scale is 50 μm for the cell reconstructions and 10 μm for the dendritic appendage examples). The interneuron is also elongated in a direction perpendicular to the layers and has richly branched, thin dendrites with an axoniform appearance. The upper inset shows an enlarged view of the dendritic terminals (the scale, again, is 10 μm for this). [Redrawn from Sherman and Guillery, 2001.]

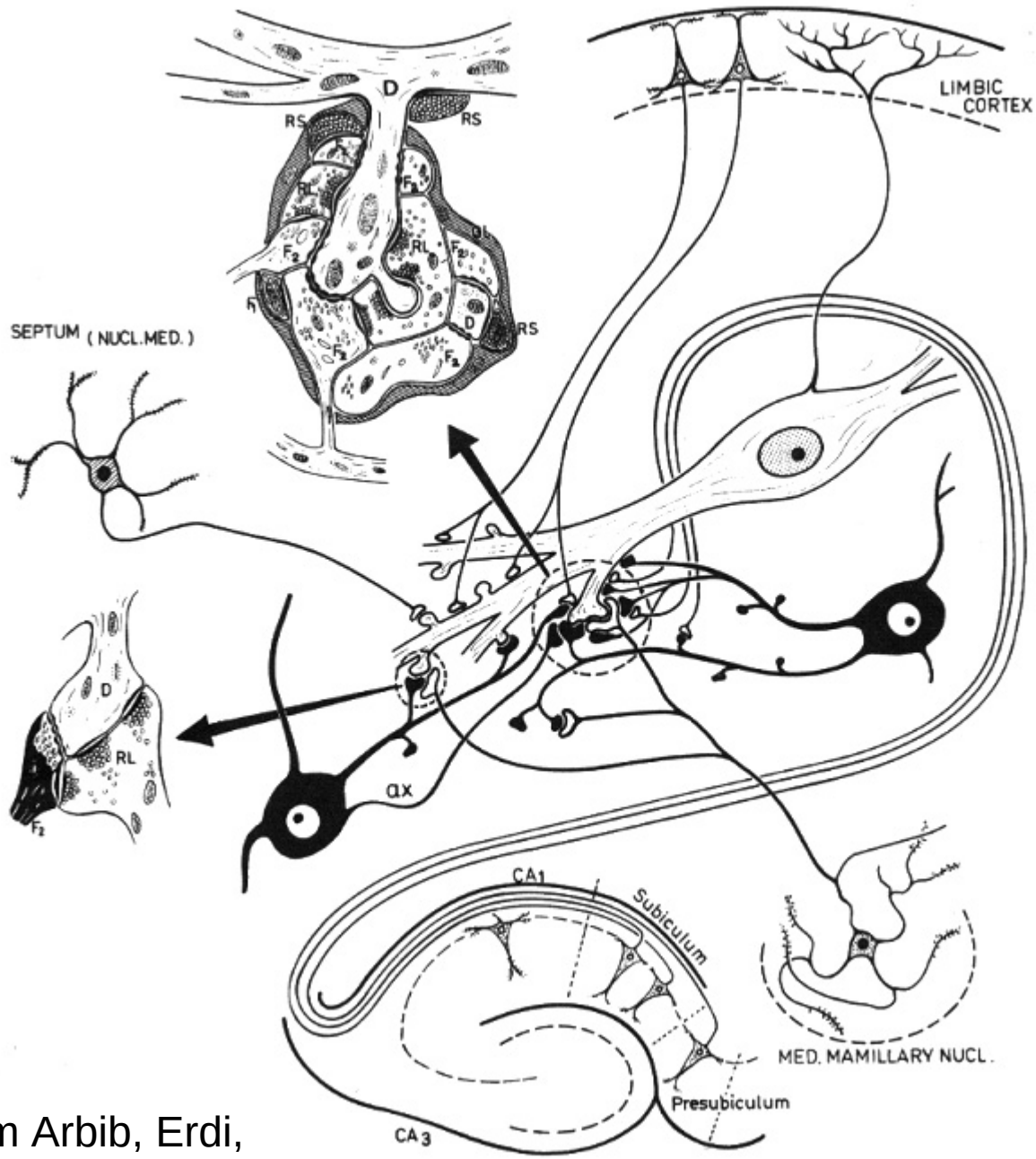


Schematic view of synaptic inputs onto an X cell and a Y cell of the lateral geniculate nucleus of the cat. The T channels are also shown. They are found throughout the cell body and dendritic membranes but are denser on the dendrites than on the cell body. Note that retinal, interneuronal, and parabrachial inputs contact proximal dendrites, whereas cortical and reticular inputs are concentrated on peripheral dendrites. [Redrawn from Sherman and Guillery, 2001.]

Terminal arbors of three corticothalamic axons in the pulvinar. The axon on the left displays driver morphology from cortical layer 5, and the two on the right, displays modulator morphology (Sherman and Guillery, 2001)

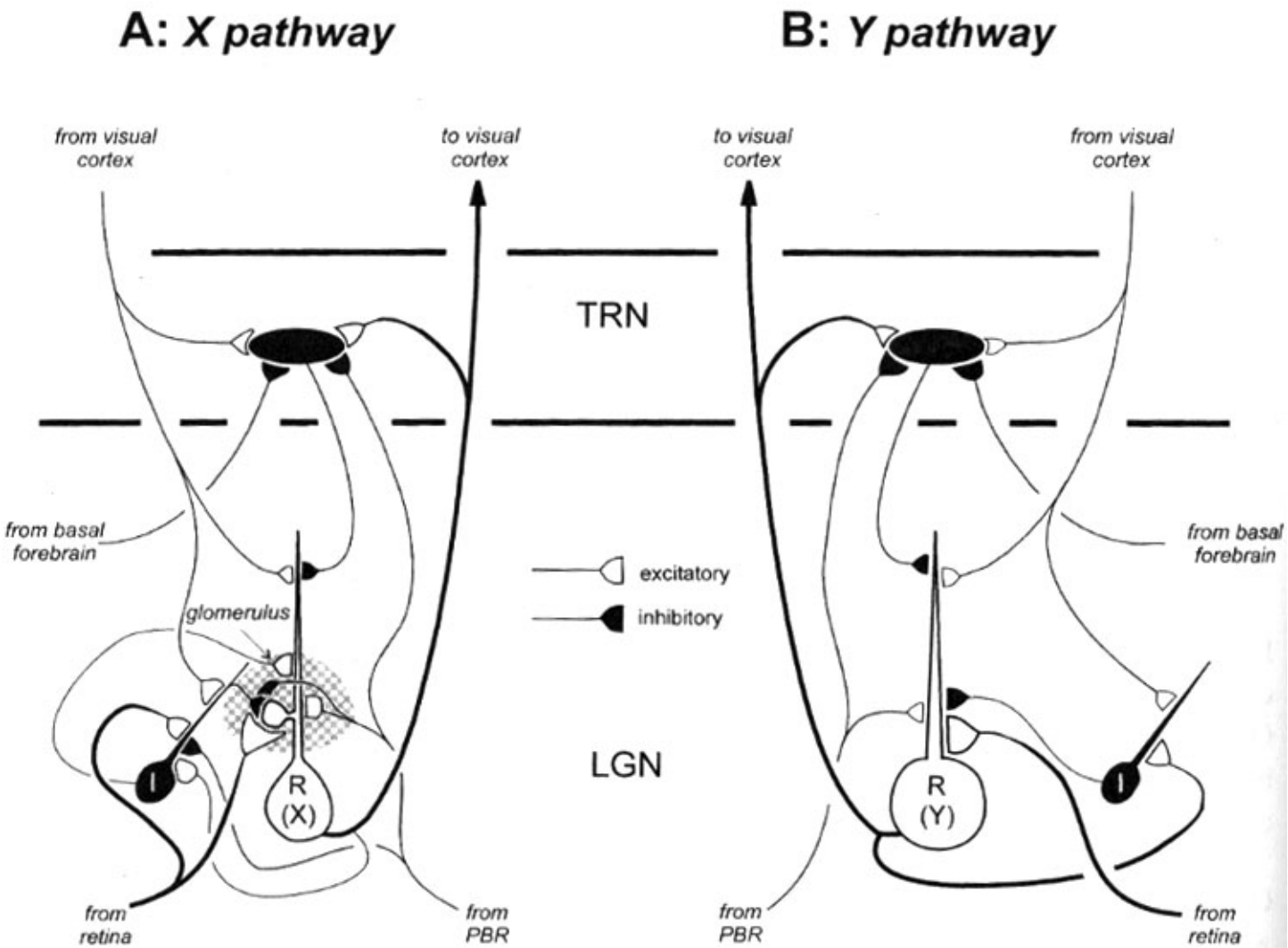


PULVINAR



Main connections of the anterior pulvinar based on electron micrographs of a synaptic triad. RL, RS, F2 boutons, see explanation in previous fig.

From Arbib, Erdi, Szentagothai, 1998



Detailed circuitry related to X and Y relay cells of the lateral geniculate nucleus of the cat. Abbreviations: I, interneuron; LGN, lateral geniculate nucleus; PBR, parabrachial region; R, relay cell; TRN, thalamic reticular nucleus.

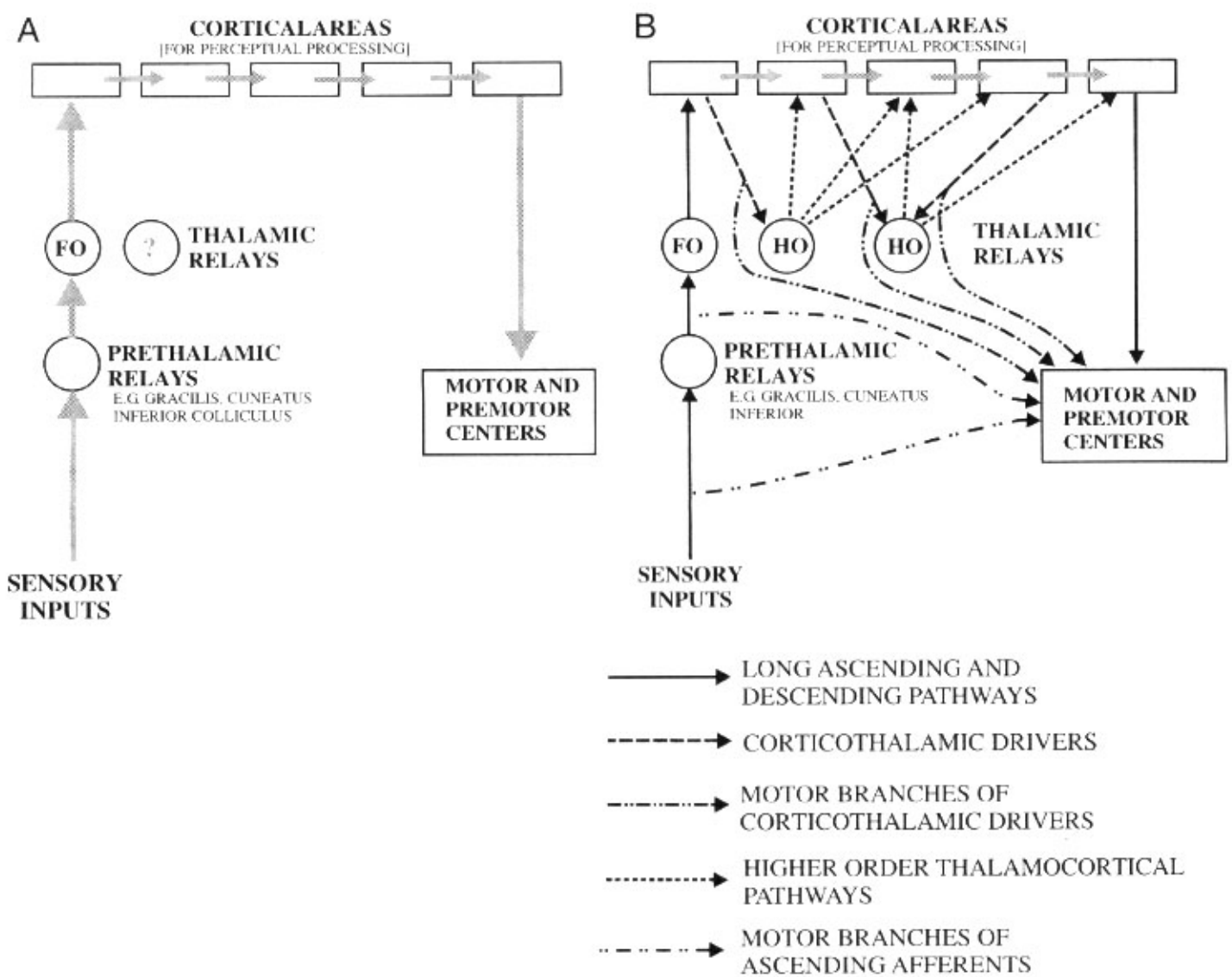
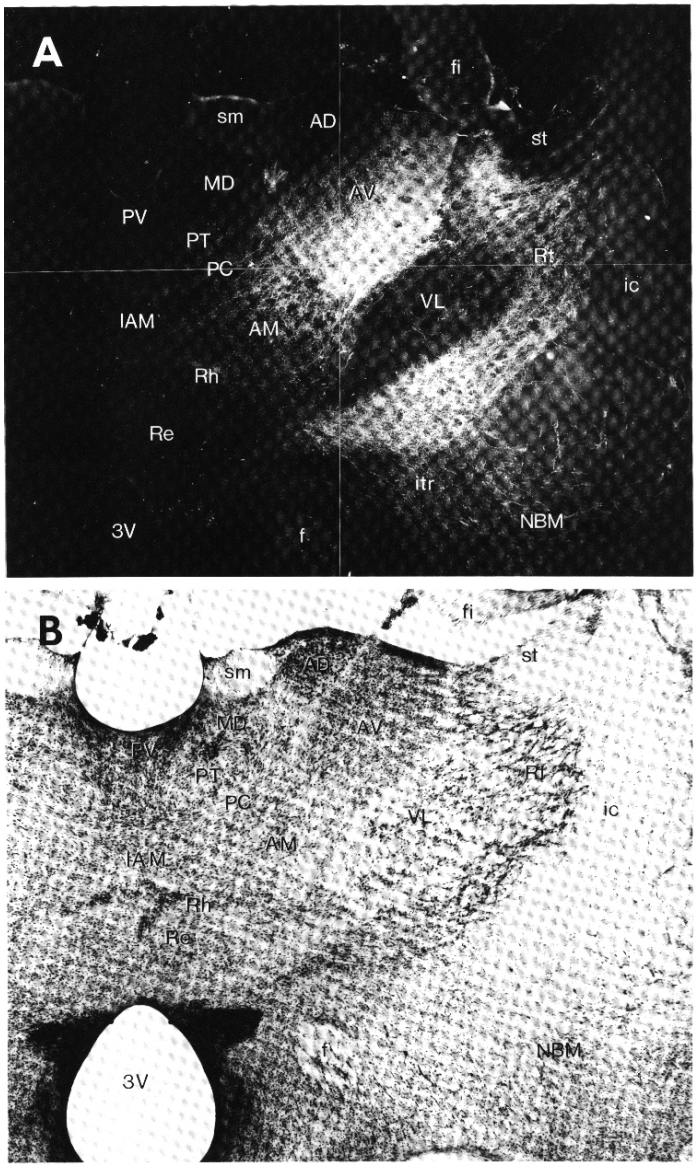
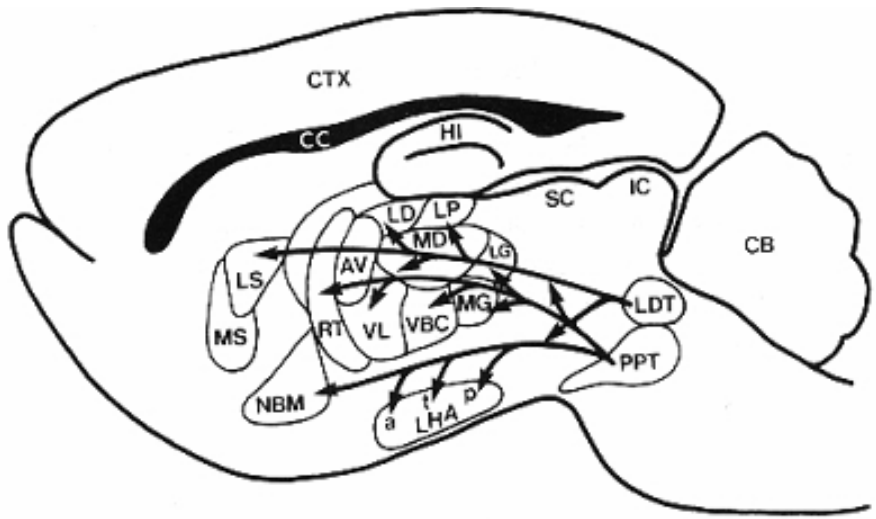


Fig. 8.17. Schematic representation of thalamocortical relationships. **A:** Conventional view of thalamocortical processing in relation to motor outputs. **B:** Connections documented here, showing the transthalamic corticocortical pathways and the connections to motor centers at all levels of the classic sensory pathways. Abbreviations: FO, first order relay; HO, higher order relay. Further details in the text.

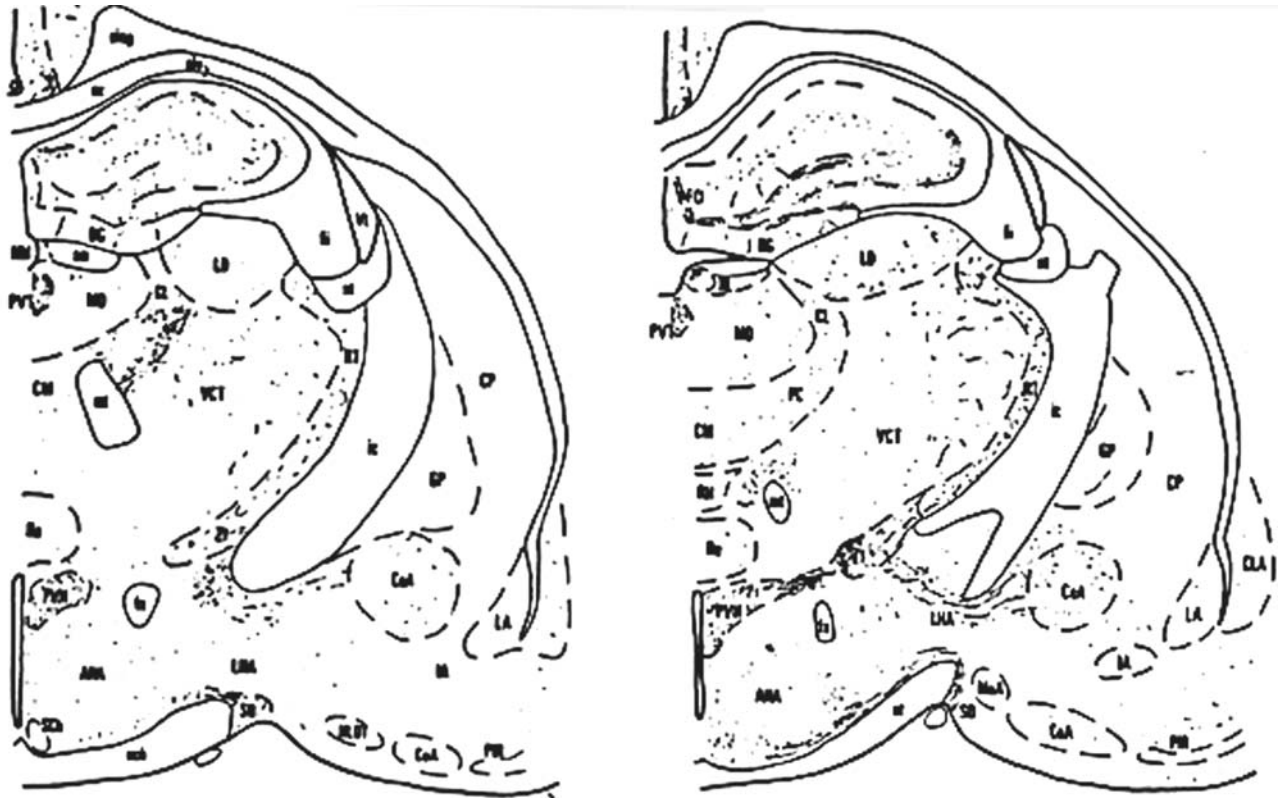
Cholinergic innervation of the thalamus



Cholinergic innervation of the thalamus originating in the mesopontine tegmentum (PPT-pedunculopontine tegmental nucleus, LDT-laterodorsal tegmental n. A: Choline acetyltransferase staining, B: Adjacent Nissl-stained section (Levey et al., 1987)

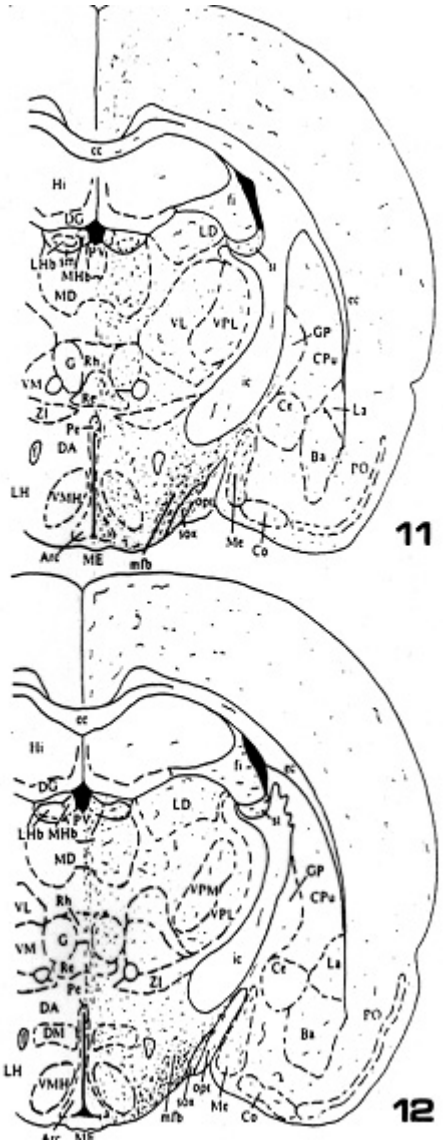


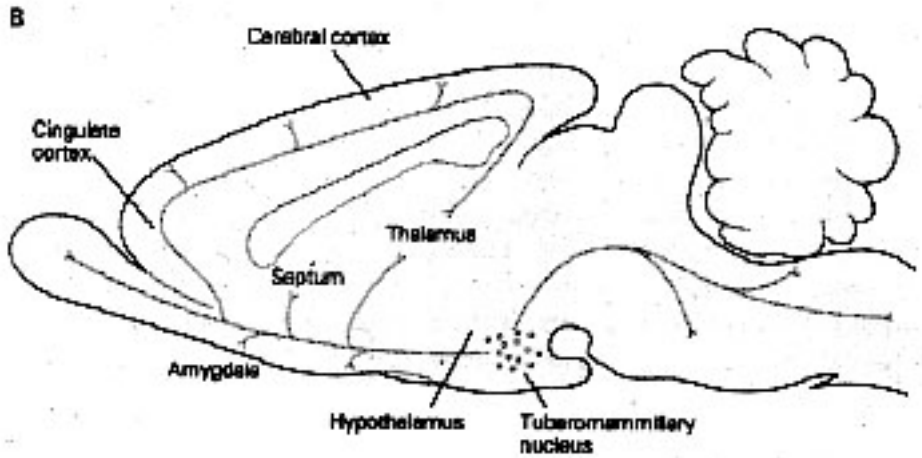
NE and /or E innervation of the thalamus



Distribution of dopamine-Beta-hydroxylase immunoreactivity at mid-thalamic level (Swanson and Hartman, 1997). Note the dense innervation in the thalamic reticular nucleus. Most of the axons originate in the locus coeruleus.

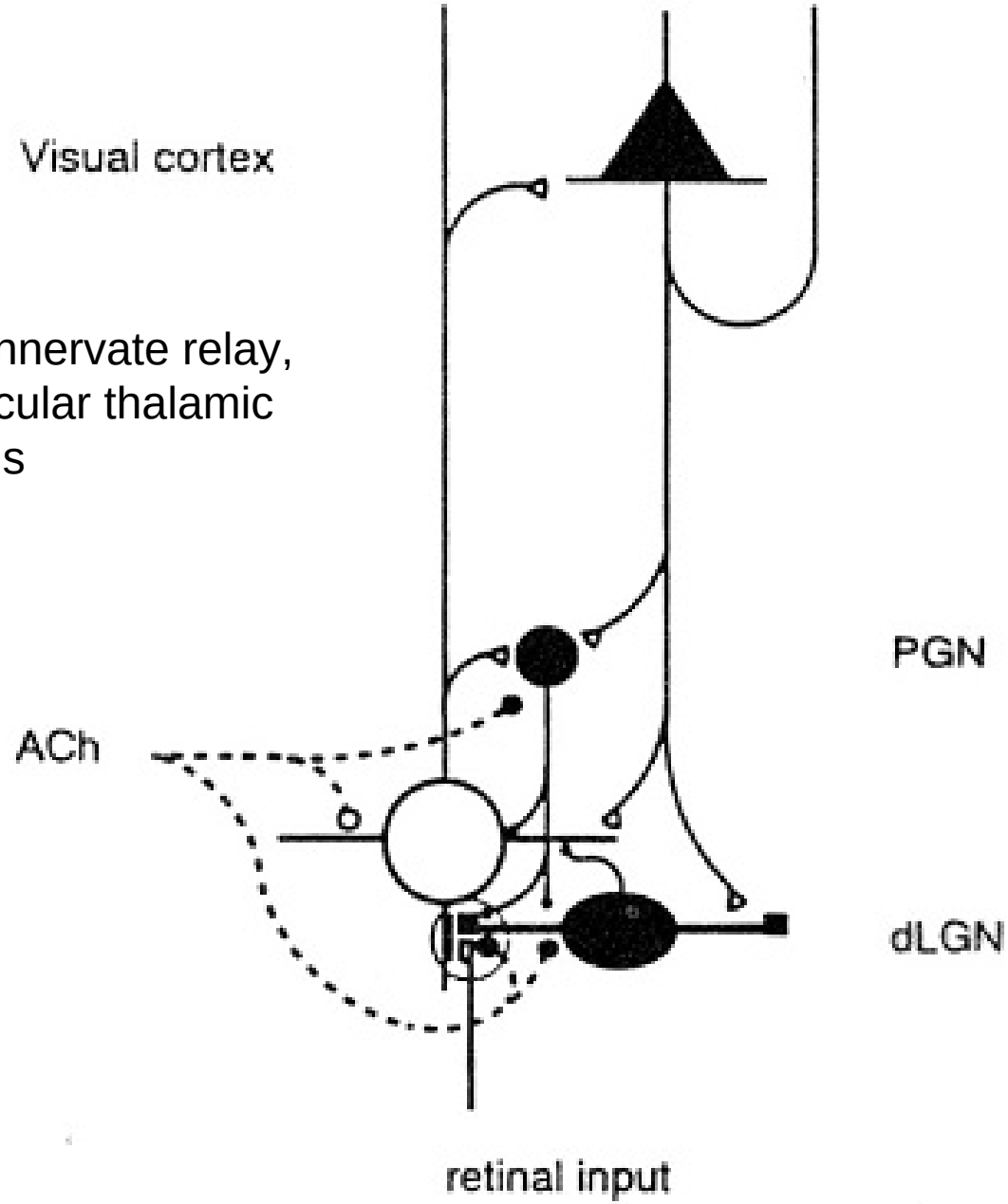
Histaminergic innervation of the thalamus



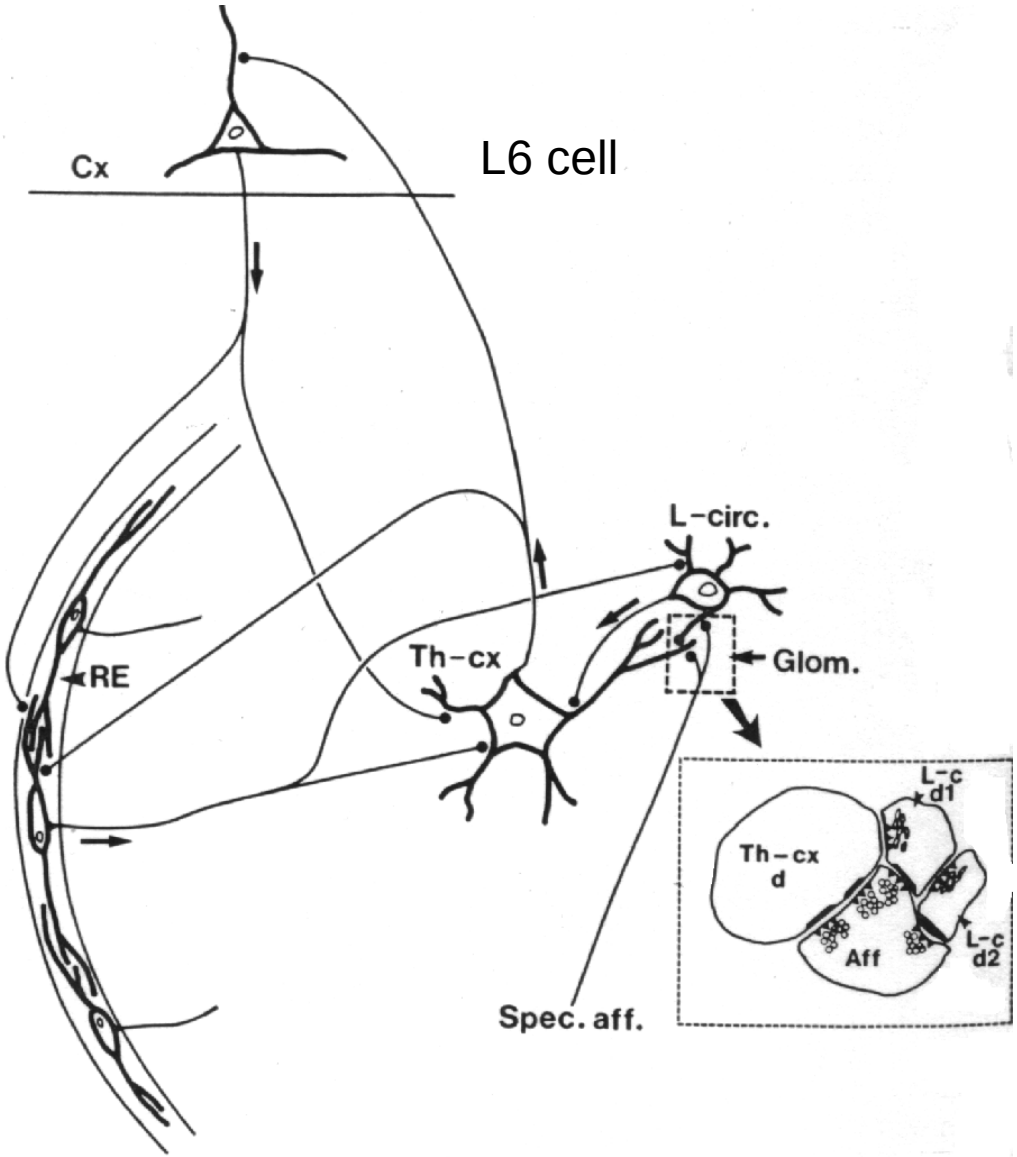


Distribution of histidine decarboxylase-positive fibers at two levels in the forebrain (Inakagi et al., 1988).

Cholinergic axons innervate relay, local and PGN (reticular thalamic component) neurons



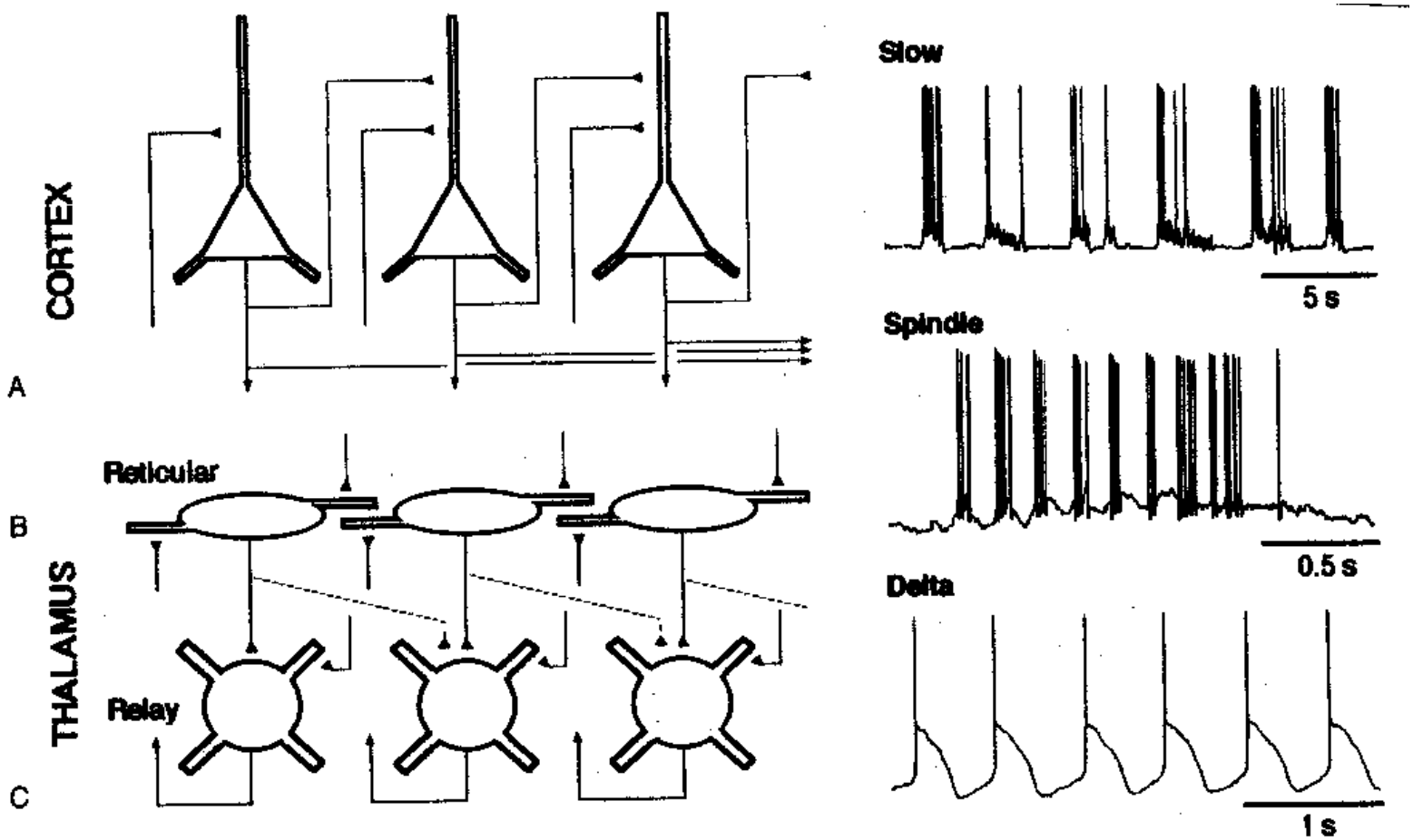
Synaptic organization of the thalamus 1. Thalamic reticular nucleus (RE)-Relay nuclei



RE: reticular thalamic nucleus; Th-cx: thalamocortical n.; Cx: pyramidal n.; L-circ: local circuit n.; Inset: synaptic contacts within a glomerulus

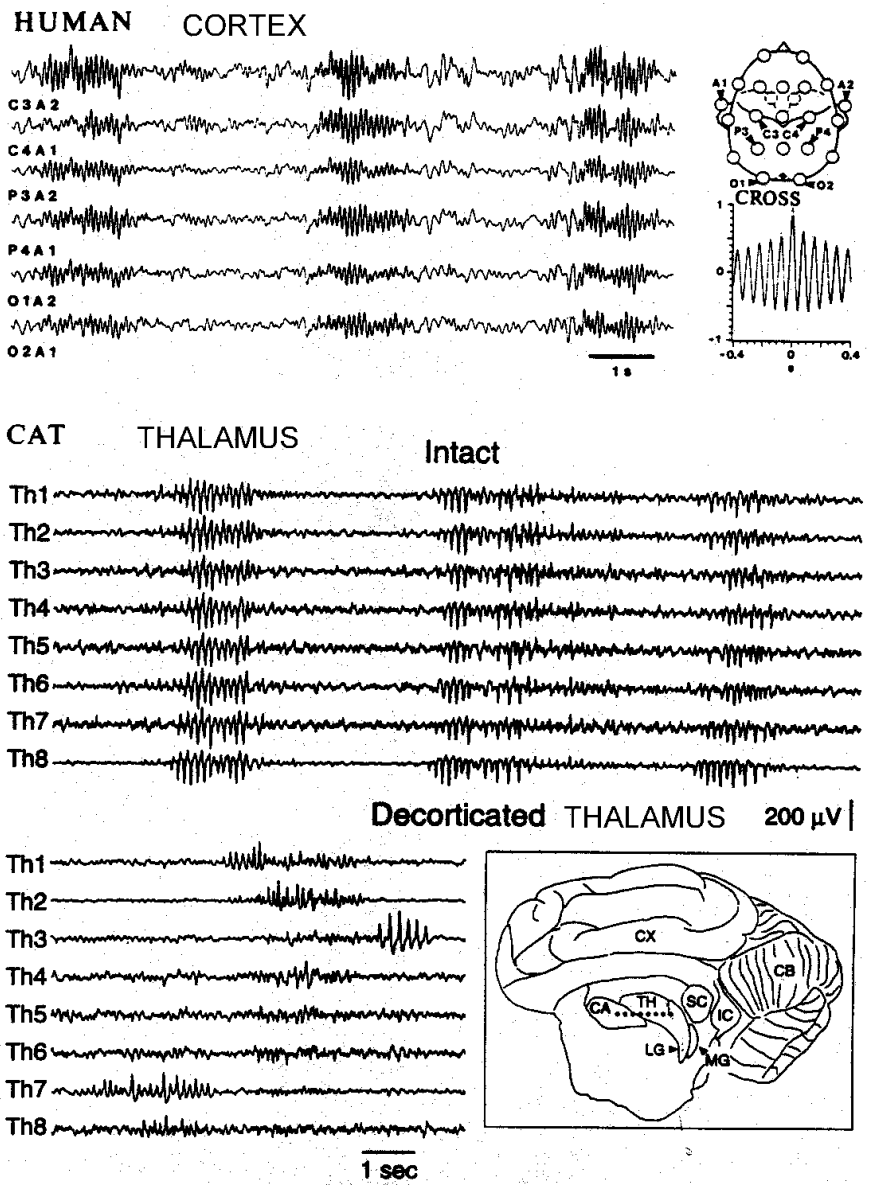
(Llinas and Steriade, 1988)

Different types of NREM sleep oscillations in the thalamocortical circuit



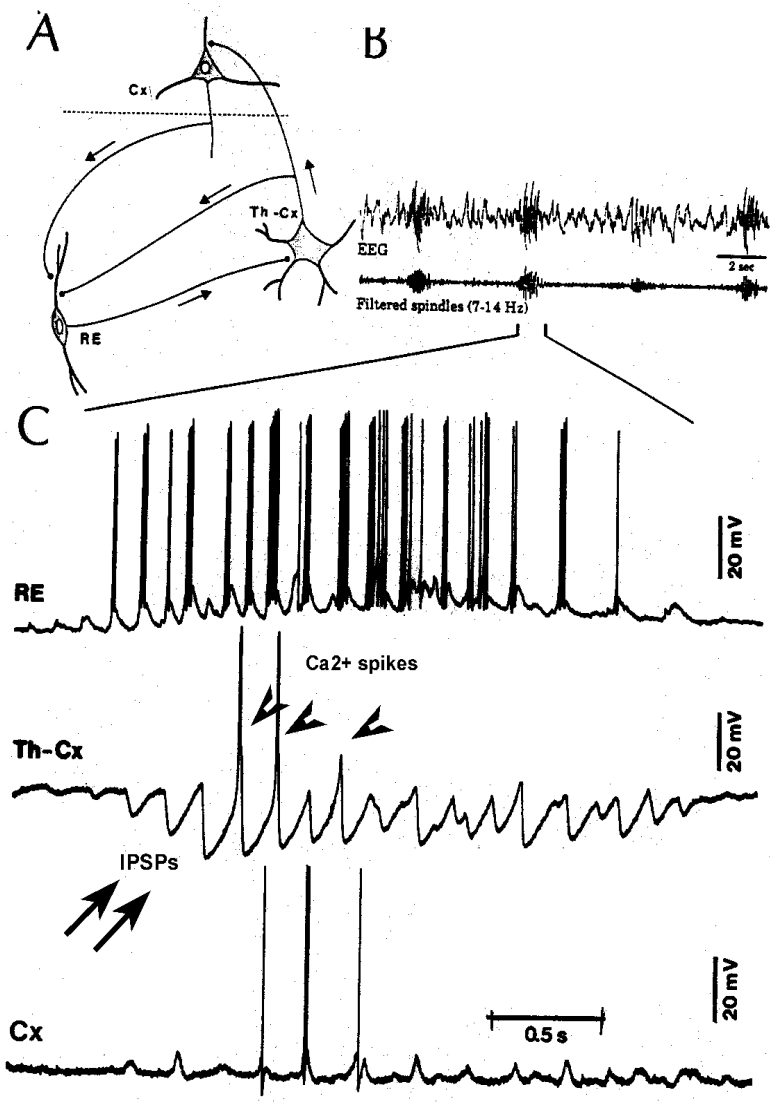
Three rhythmic electrical activities characterizes SWS: spindles (7-15 Hz) that are generated in the GABAergic RE neurons , delta waves (1-4Hz), that are generated in the cortex and thalamus and slow oscillation (0.5-1Hz) that is generated intracortically. Note the different time calibrations. (Steriade, 2000). Each of them is blocked by brainstem or forebrain cholinergic system.

Coherence of cortical and thalamic spindles



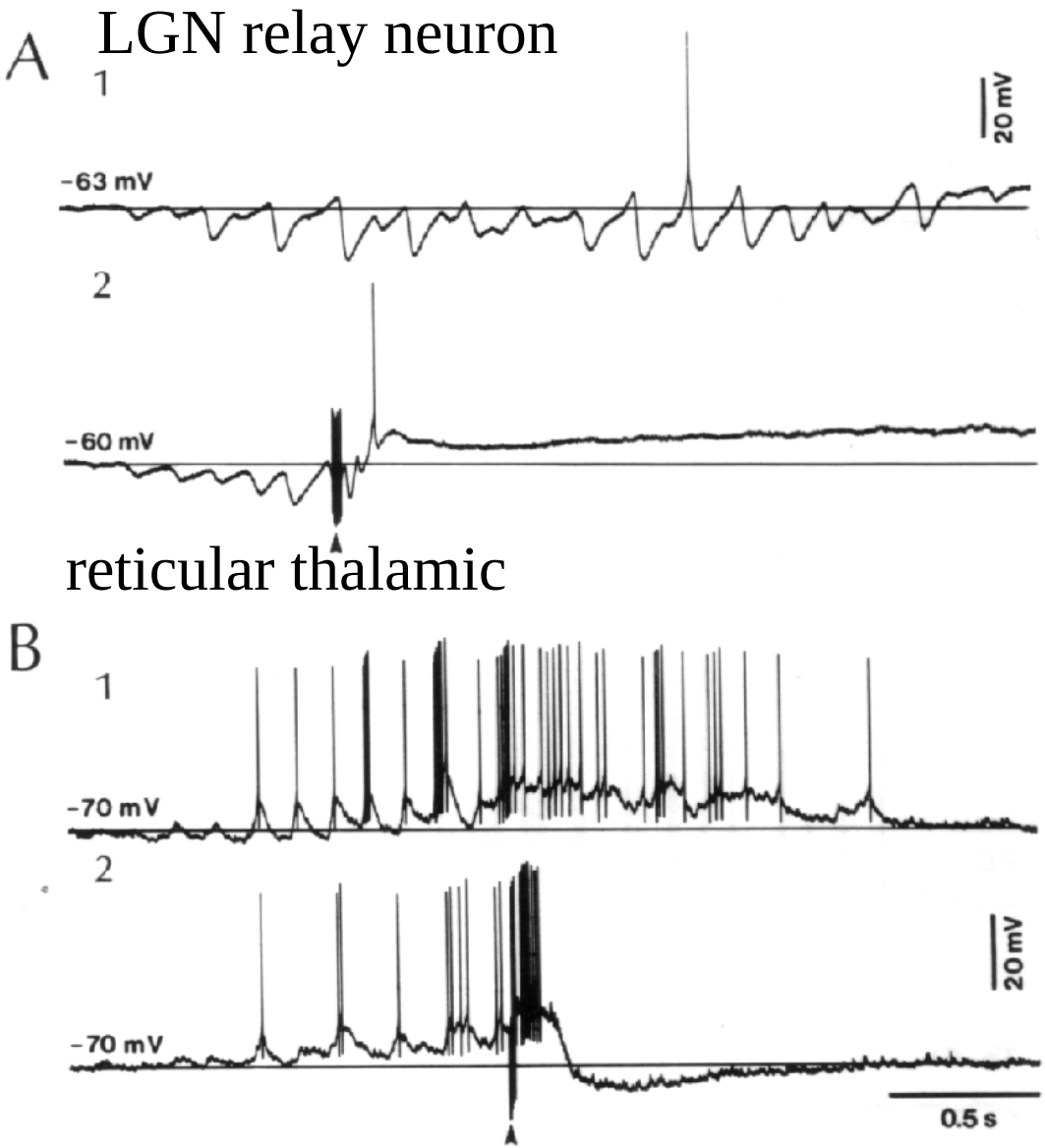
Cortical spindle sequences occur nearly simultaneously during natural sleep of humans and cats but decorticltion disorganizes the widespread coherence of thalamic spindles. Averaged correlations shows rhythmicity at 14 Hz . After decortication, recordings from virtually same thalamic sites showed disorganization of spindle simultaneity (Steriade, 2000).

Intracellular aspects of spindling in the thalamocortical system



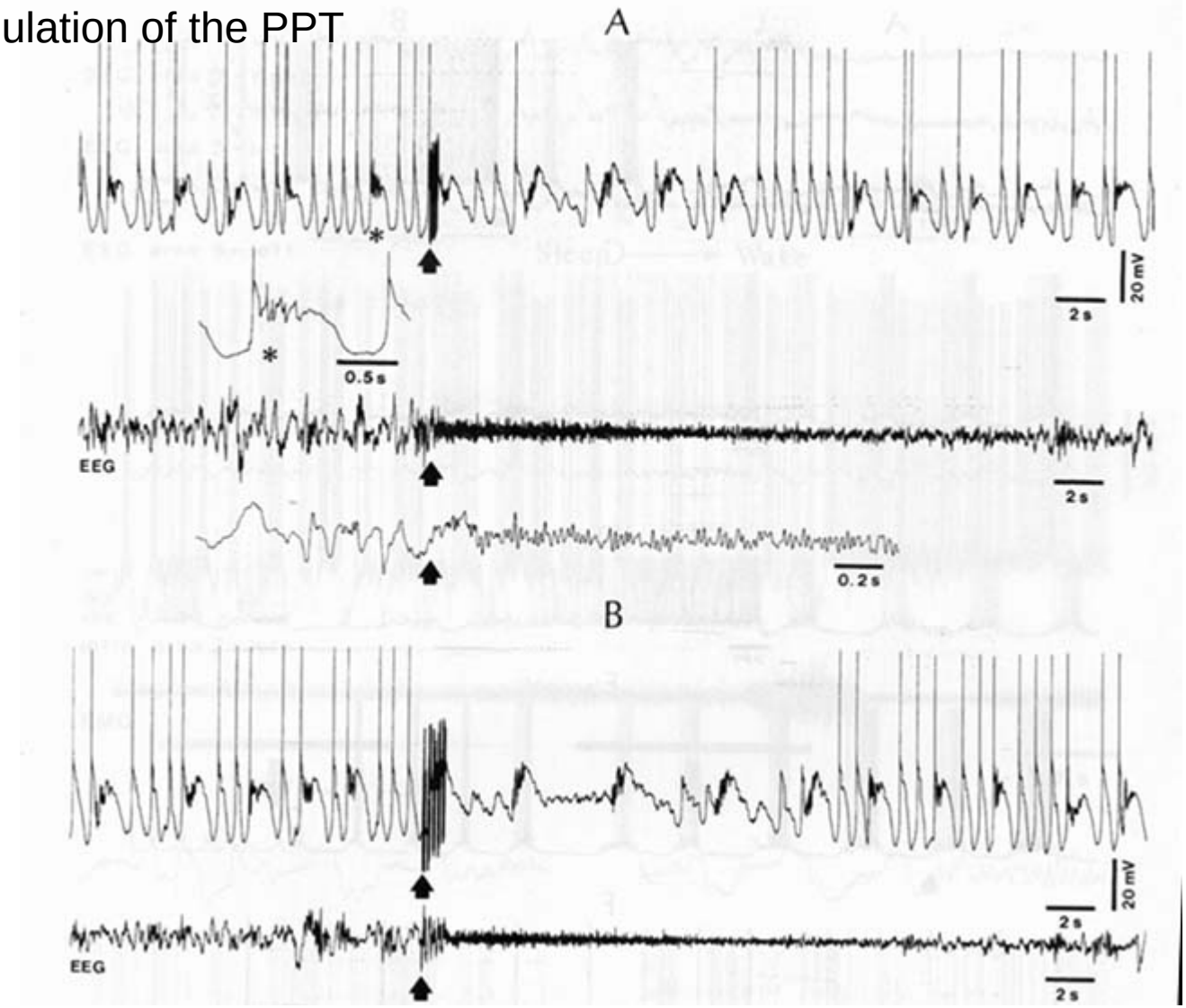
Spindle oscillations in reticular (RE), thalamocortical(Th-Cx, VL) and cortical (Cx, motor) neurons. **A**: Circuit of 3 neurons. **B**: Two rhythms (7-14 Hz and 0.1-0.2 Hz) of spindle oscillations in cortical EEG. **C**: Intracellular recording in cats under barbiturate anesthesia. Note rhythmic spike-bursts of RE neuron during a spindle sequence and concomitant IPSPs leading to post-inhibitory rebound bursts in Th-Cx and Cx neurons. (Steriade, 2002). The spikes in cortical cells is evident in the EEG as spindles.

Blockage of thalamic spindle oscillation by peribrachial stimulation



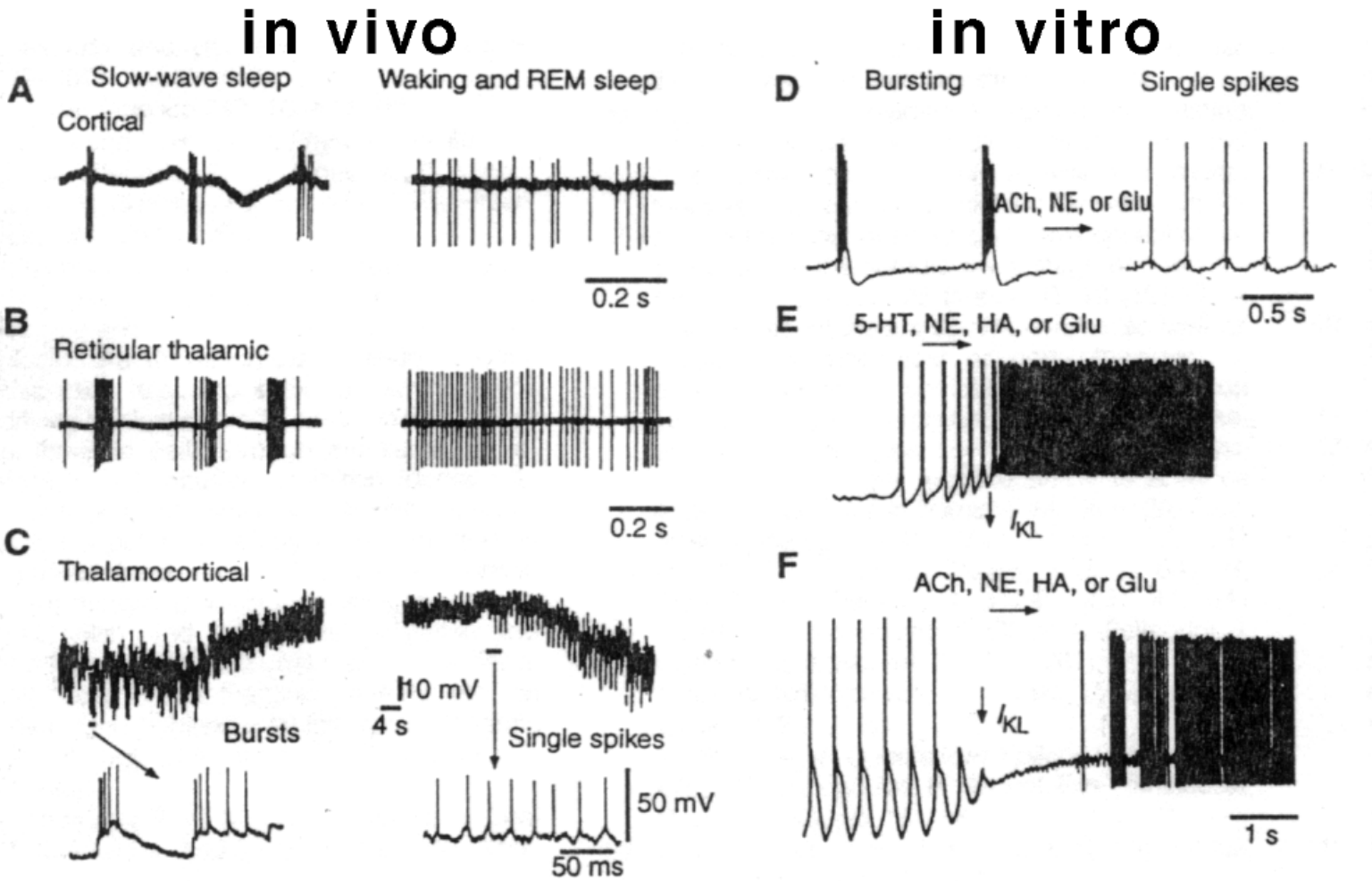
Blockage of spindle oscillations in intracellularly recorded thalamocortical and reticular thalamic (RE) neurons of unanasthetized encephale isole cats with deafferentation of trigeminothalamic pain pathways. **A**: an Lateral geniculate relay neuron.**B**: a neuron recorded in the perigeniculate sector of the RE. Arrowhead: brainstem mesopontine cholinergic (peribrachial) area stimulation. The disruption of spindles occur in the RE where sleep oscillation is generated (Hu, Steriade, Deschenes, 1989).

Supression of the clock-like delta oscillation in a thalamocortical cell by stimulation of the PPT



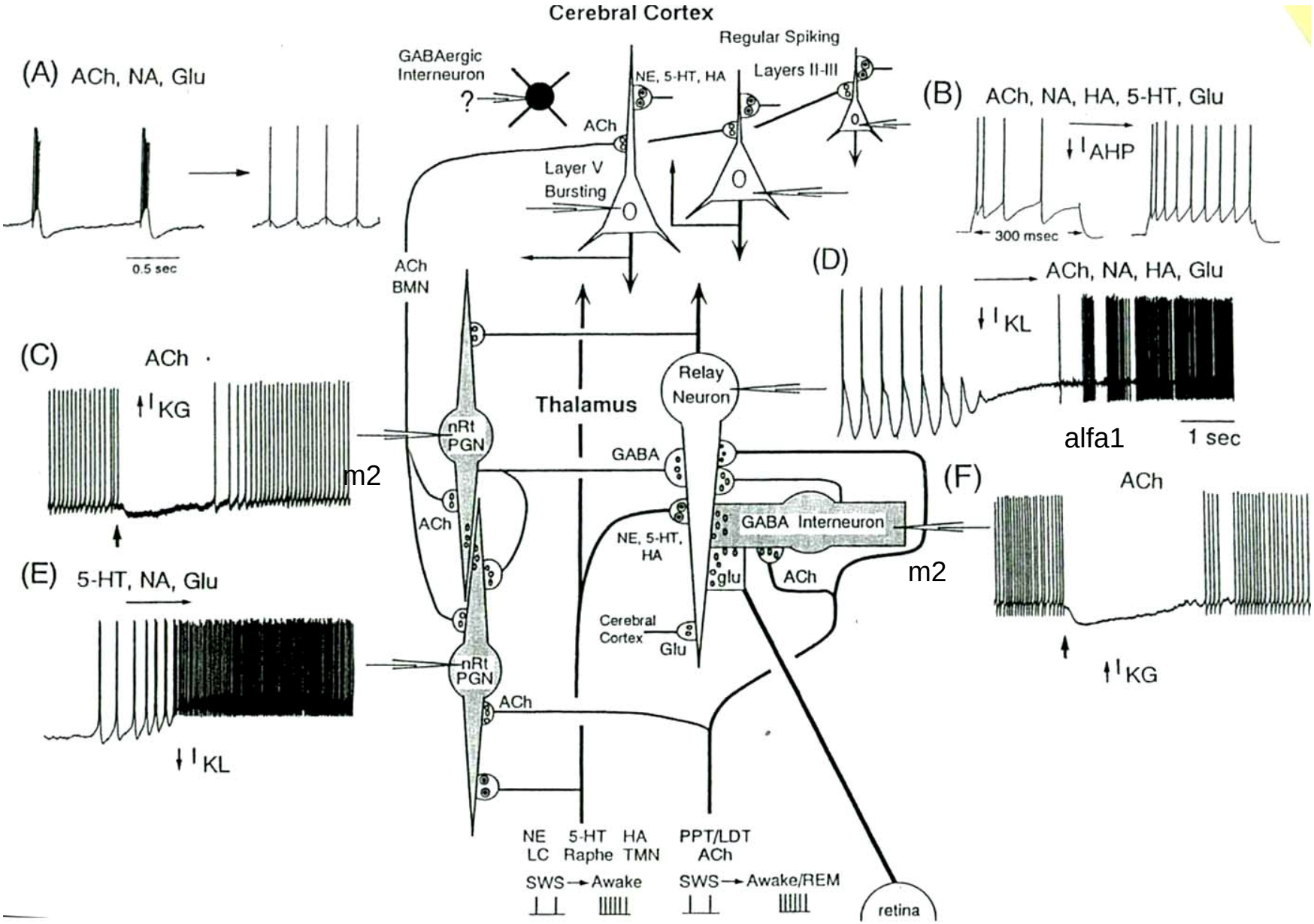
Cat, urethane anaesthesia.Intracellular recording from thalamocortical cell in the LP thalamus together with EEG from postcruciate gyrus. A: a pulse-train to PPT; B: 5 pulse trains to PPT (From Steriade).

State-dependent activities in cortical and thalamic neurons



Neurons in the cerebral cortex (A), thalamic reticular nucleus (B) and thalamic relay nuclei (C) change their activities in vivo from periodic and rhythmic spike bursts during natural, SWS to tonic firing of trains of single spikes during waking and REM-sleep in behaving cats with chronic implants (D-F). Similar changes in firing pattern occur in vitro in these neurons in response to various neurotransmitters released by brainstem modulatory systems (Steriade et al., 1993).

Summary of action of ACh in the thalamus and cerebral cortex



McCormick, 1997

Explanation: following page

1.Thalamocortical cells and thalamic reticular cells can generate action potentials either as rhythmic bursts or as tonic, single-spike acticvity, depending upon the membrane potential of the cell. Activation of muscarinic, alfa1-adrenergic, H1-histaminergic or metabotropic glutamate receptors (mGluR)results in depolarization of relay neurons through reduction of I_{KL}. This depolarization subsequently shifts these neurons to the single-spike mode of action potential generation. Similarly, activation of alfa1-adrenergic, 5-HT2 receptors, mGluR receptors has similar effect in the thalamic reticular neurons (McCormick, 1997).

2. In contrast, activation of muscarinic receptors in the thalamic reticular neurons or local GABAergic neurons results in inhibition of their output through an increase in potassium conductance (I_{KG}) (McCormick).

3. In the cerebral cortex, activation of muscarinic, alfa1-adrenergic, or mGluR results in abolition of burst firing of layer V burst generating neurons and a switch to tonic, single-spike mod of action potential generation. In regular spiking cells, activation of muscarinic, beta-adrenergic, Hz-histaminergic, serotoninergic and mGluR receptors results in a decrease in spike frequency adaptation by blocking I_{AHP} (and I_M for Ach and 5HT). These responses allow ascending modulatory transmitter systems to prepare thalamocortical systems for sensory transmission, processing (McCormick).

4.The three brain rhythms (spindle, delta and slow oscillation) are obliterated by brainstem cholinergic and n. basalis cholinergic and GABAergic actions exerted on thalamocortical,, thalamic reticular and neocortical neurons. The blockade of low-frequency (<15 Hz) sleep oscillations, which are widely synchronized, is accompanied by the occurrence of fast (20-60Hz) rhythms, which are synchronized over restricted cortical territories and well defined corticothalamic systems. The fast rhythms appear during the sustained depolarization of thalamic and neocortical neurons in wakefulness and REM sleep, as well as during the depolarizing phases of the slow oscillation in non-REM sleep. Thus, fast rhythm are voltage dependent and do not necessarily reflect high cognitive and conscious processes (Steriade, 2004).

 Roland, 1994

TABLE 15.3. Tasks Changing rCBF or rCMR in Thalami

Task	Site	Sides	Authors
Writing signature[a]		C	Mazziotta et al., 1985
Listening to story		B	Mazziotta et al., 1984
Ravens advanced matrices[b]		R	Haier et al., 1991
Social philosophic speech		B	Pawlik et al., 1987
Memorizing historical dates		B	Pawlik et al., 1987
Calculation of primes	MD	B	Pawlik et al., 1987
Visuomotor game	PL-LP	R	Haier et al., 1991
Anticipatory fear[c]		L	Raichle, 1990
Vigilance, somatosensory		I	Pardo et al., 1991
Route finding	PL-LP	B	Roland et al., 1987
Tactile learning	VL-VPL(C)	ANT (I)	Seitz et al., 1991
Visual recognition	PI-LP	(B)	Roland et al., 1990a
Visual scrutinizing	PL-LP	(B)	LaBerge and Buchsbaum, 1990
Preparation for reaching	VL	C	Decety et al., 1992
Feature uncertainty			Gulyás et al., 1991
Visual learning[c]	MD	(R)	Roland et al., 1990a
Thermal pain		C	Jones et al., 1991a
Attention, velocity		L	Corbetta et al., 1991a
Shape-divided		L	Corbetta et al., 1991a
Vigilance	VPL	C	Pardo et al., 1991

[a]Only in a few subjects.
[b]Negative correlation with performance.
[c]Decreases and increases.
Ant: anterior nuclei; MD: N medialis dorsalis; VL-VPL: ventral complex; PI-LP: posterior complex; R = right; L: left; C: contralateral; I: ipsilateral; B: bilateral.

TABLE 2 *Thalamic transmitters (and 'modulators')*

Classical transmitters	
1. The great afferent pathways	glutamate
2. The thalamocortical transmitter	glutamate
3. The thalamostriatal transmitter	glutamate
4. The pallido-(and nigro-) thalamic transmitter	GABA
5. The corticothalamic transmitter	glutamate
6. The thalamic interneurons (intrinsic and RTN)	GABA
7. Diffuse brainstem inputs to the thalamus	NA, 5HT, ACh
Neuropeptides	
1. To intralaminar nn., ventral thalamus, etc.	ENK, SRIF, CCK, SP, NPY
2. In reticular nucleus cells	SRIF
3. To certain relay nn.	CCK, SP, NT
4. To epithalamus	SRIF, NPY, NT, DYN