46th Congress of the Canadian Neurological Sciences Federation

**Basic mechanisms of epileptogenesis and principles of electroencephalography**

# Cortical and subcortical anatomy: basics and applied

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## LEARNING OBJECTIVES

Know and understand:

- Two types of principal cell and five types of interneuron in the cerebral cortex.
- The layers of the cerebral cortex as seen in sections stained to show either nucleic acids or myelin.
- The types of cortex: allocortex and isocortex.
- Major differences between extreme types of isocortex. As seen in primary motor and primary sensory areas.
- Principal cells in different layers give rise to association, commissural, projection and corticothalamic fibres.
- Cortical neurons are arranged in columns of neurons that share the same function.
- Intracortical circuitry provides for neurons in one column to excite one another and to inhibit neurons in adjacent columns.
- The general plan of neuronal connections within nuclei of the thalamus and the interconnections of the thalamus and cortex.
- The location of motor areas of the cerebral cortex and their parallel and hierarchical projections to the brain stem and spinal cord.
- The primary visual area and its connected association areas, which have different functions.
- Somatotopic representation in the primary somatosensory and motor areas.
- Cortical areas concerned with perception and expression of language, and the anatomy of their interconnections.
- The long association fasciculi of the subcortical white matter and the cortical areas that they connect.

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Course: Basic mechanisms of epileptogenesis and principles of electroencephalography

Title of Presentation: Cortical and subcortical anatomy: basic and applied

Presenter's Name: Dr John A. Kiernan (University of Western Ontario)

In the last two years, I have/had a financial interest/arrangement or affiliation with one or more organizations that could be perceived as a real or apparent conflict of interest in the context of the subject of this presentation.

| Affiliation/Financial interest | Name of organization(s) |
|---|---|
| Grant/Research support: | Biological Stain Commission. Nothing to do with clinical neurology or neuroanatomy. |
| Consultant: | To two companies that develop automated technology for cyto- and histopathology. |
| Other financial/material interest: | Author of a neuroanatomy textbook that is used by medical students and residents (Barr's The Human Nervous System. 8th ed 2004; 9th ed 2009) |

Signature: 

Date of Signature: 1st April 2011

# CORTICAL NEURONS: Their organization and connections

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## Principal cells

**Pyramidal cells**

Present in all layers. The larger, more conspicuous ones are in Layers III and V. These are the principal cells of the cerebral cortex. **Betz cells** (a minority of the pyramidal cells in Layer V of the primary motor area) are exceptionally large.

**Fusiform cells**

Characteristic of Layer VI. At least some of these are principal cells.

## Interneurons

**Stellate cells**

Only in Layer IV. The only excitatory cortical interneurons (glutamate). They are excitatory to dendrites of pyramidal cells in the same column.

**Basket cells**

Inhibitory (GABA-ergic) to the cell-bodies of pyramidal cells in adjacent columns.

***Granule cells***. This term should not be used. It embraces all small cortical neurons, including interneurons and small pyramidal cells. Sometimes used specifically for basket cells.

**Retzius-Cajal cells**

Horizontally branching interneurons in Layer I.

**Martinotti cells**

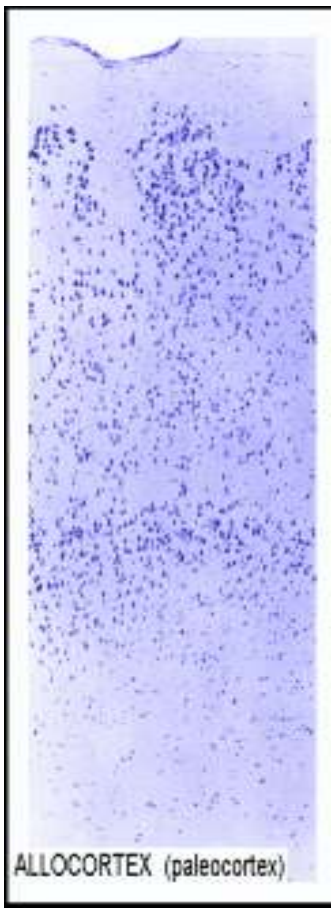
Interneurons in Layers III to VI. Their axons are directed towards the cortical surface.

Allocortex: Comprises

archicortex (one layer of neurons):

Hippocampus and dentate gyrus.

paleocortex (typically 3 layers). Medial temporal lobe - uncus, entorhinal area.



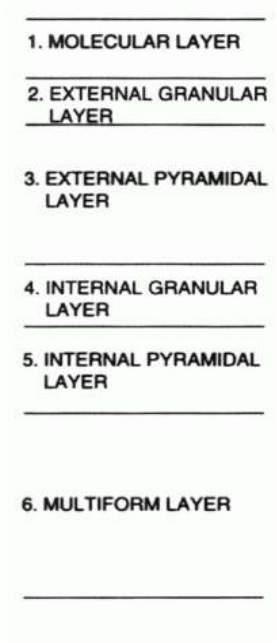

Isocortex (= neocortex; typically 6 layers). Most of the human cerebral cortex.

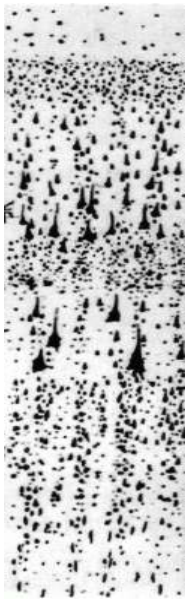
[Histology intermediate between allo- and iso- is seen in parts of the cingulate gyrus and is designated mesocortex.]

Cytoarchitectonics – based on Nissl-stained sections. A cationic dye sticks to polyanions. In the CNS, polyanions = nucleic acids: nuclear DNA of all cells, especially glia and small neurons, and RNA (ribosomes [Nissl substance] and nucleoli) of neurons.

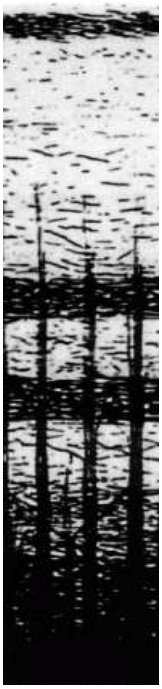
Myeloarchitectonics – based on sections stained to show myelinated axons.

Golgi preparations – dark intracellular precipitate in perhaps 1 in 100 cells. Shows dendritic architecture in thick sections.

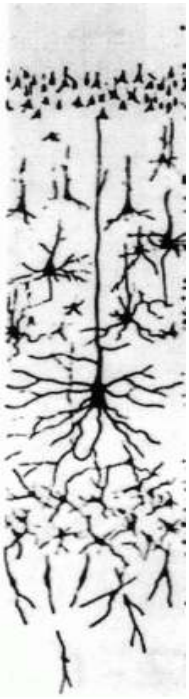


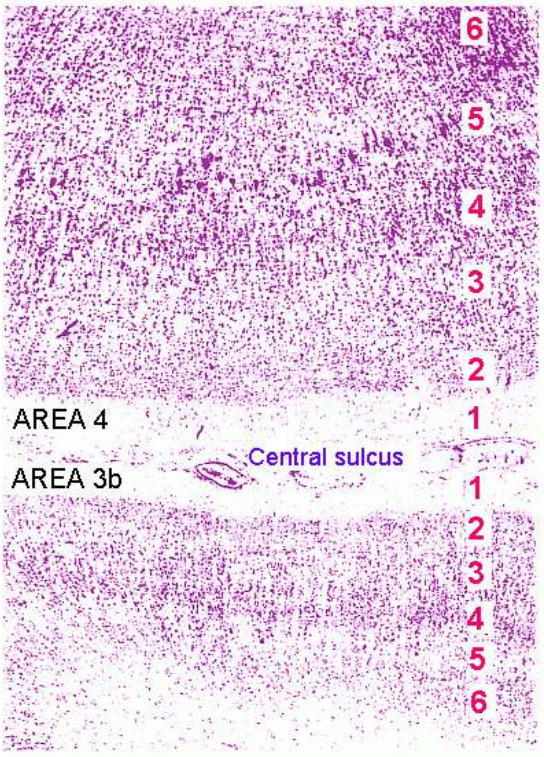
Nissl



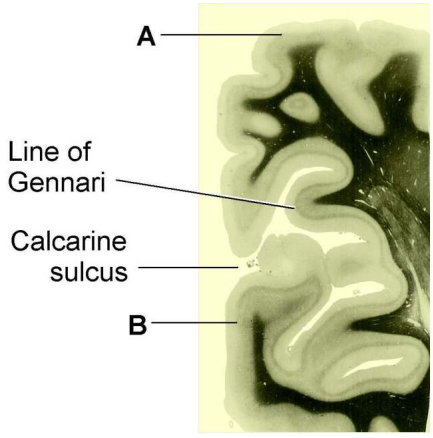
Myelin



Golgi




Primary motor area




Primary visual area (Striate cortex)

First somatosensory area

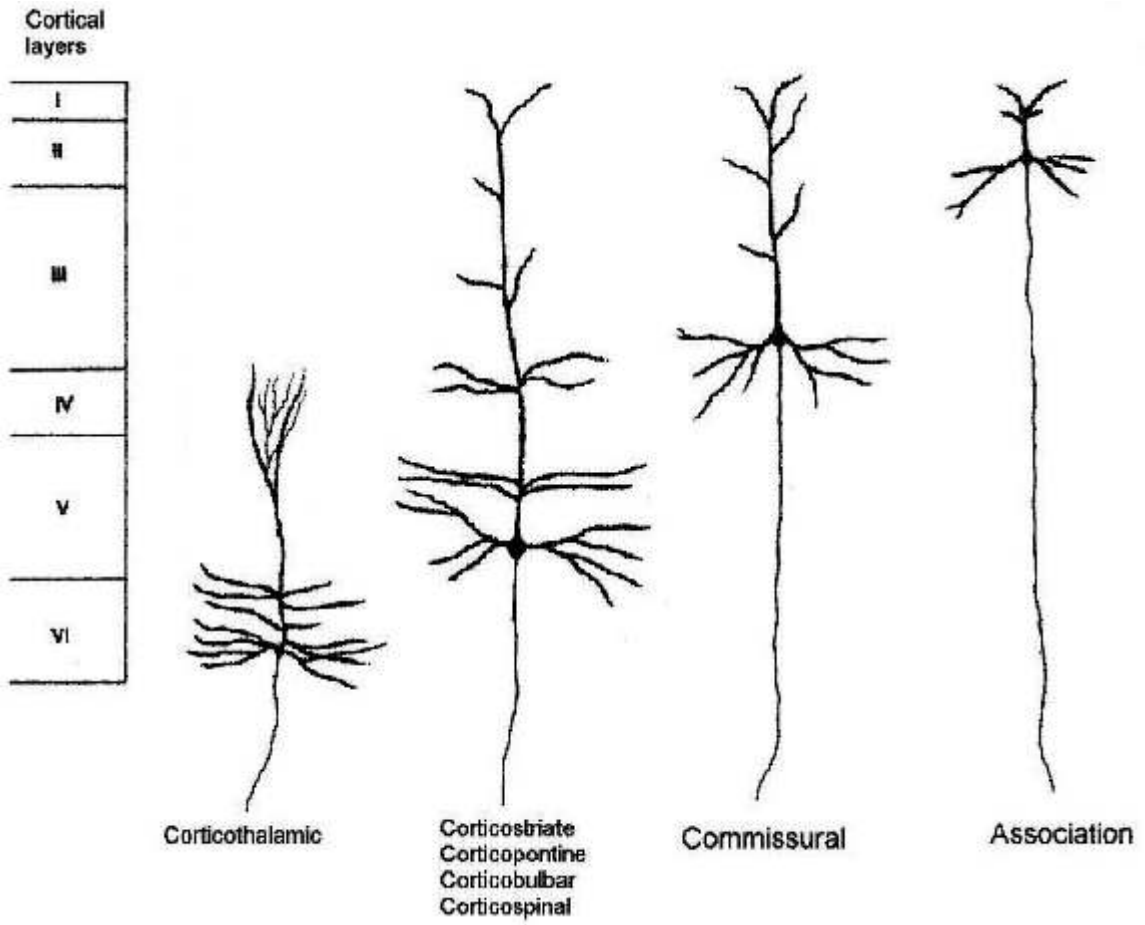
Pyramidal (and fusiform) neurons are the principal cells of the cortex.

They are glutamatergic – excitatory at their synaptic terminals.

Interneurons.

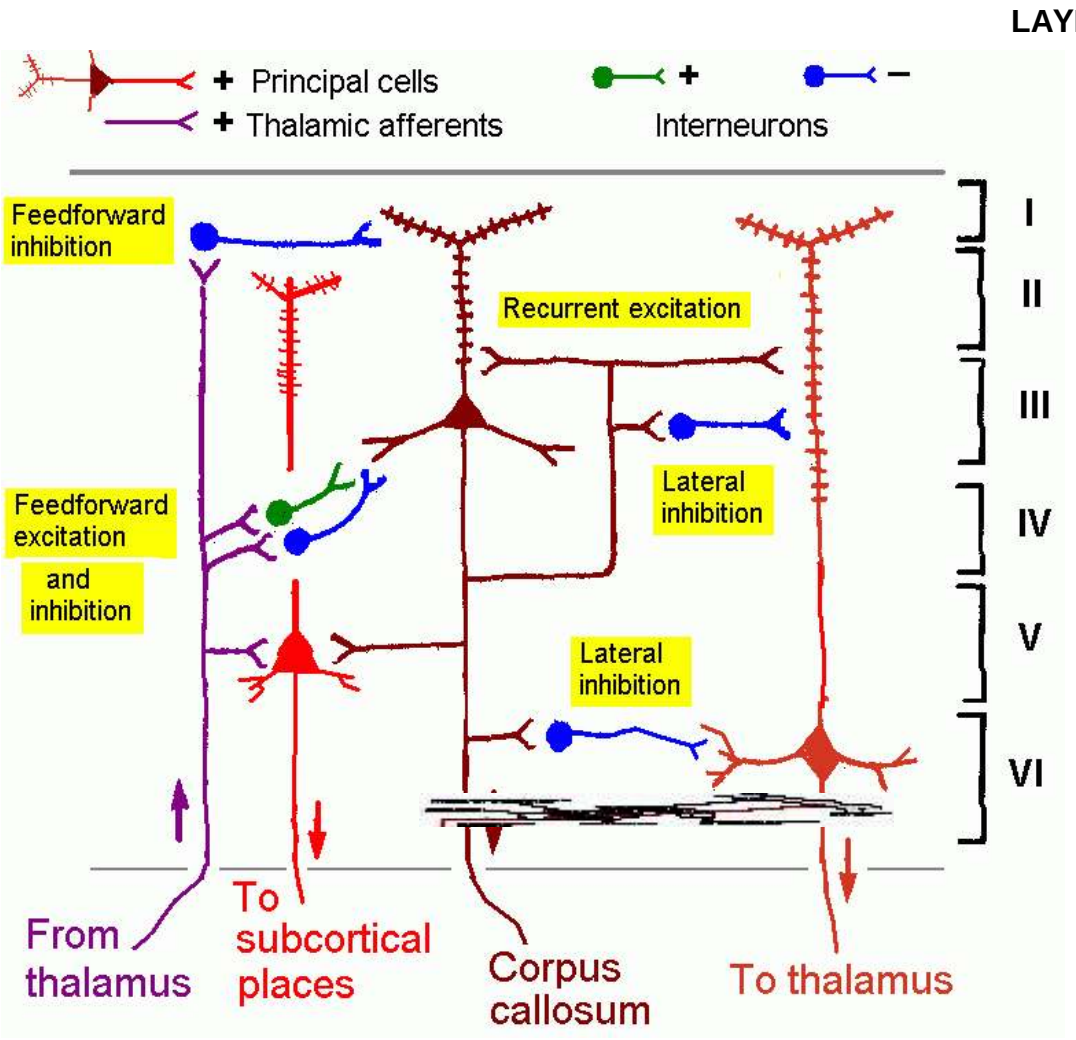
Most types are inhibitory (GABA). Stellate cells (in Layer IV) are excitatory (glutamate).

Types and locations of cortical principal cells.




| Projection | Projection | Commissural | Association |
|---|---|---|---|
| Every cortical area **receives** excitatory afferents from one or more nuclei of the thalamus, and **sends** excitatory signals to the same thalamic nuclei. | Efferents from all neocortical areas to the **striatum** (= caudate nucleus and putamen, including nucleus accumbens) and to the **pontine nuclei**. Corticospinal and Corticobulbar fibres from frontal and anterior parietal cortex. | Connect mainly symmetrical cortical areas. Axons are in **corpus callosum** (most) and in **anterior commissure** (interconnects temporal lobes). | Interconnect cortical areas of the same hemisphere. The longest association fibres, which connect different lobes, form named fasciculi that can be revealed by dissection. |

Some intracortical circuits.

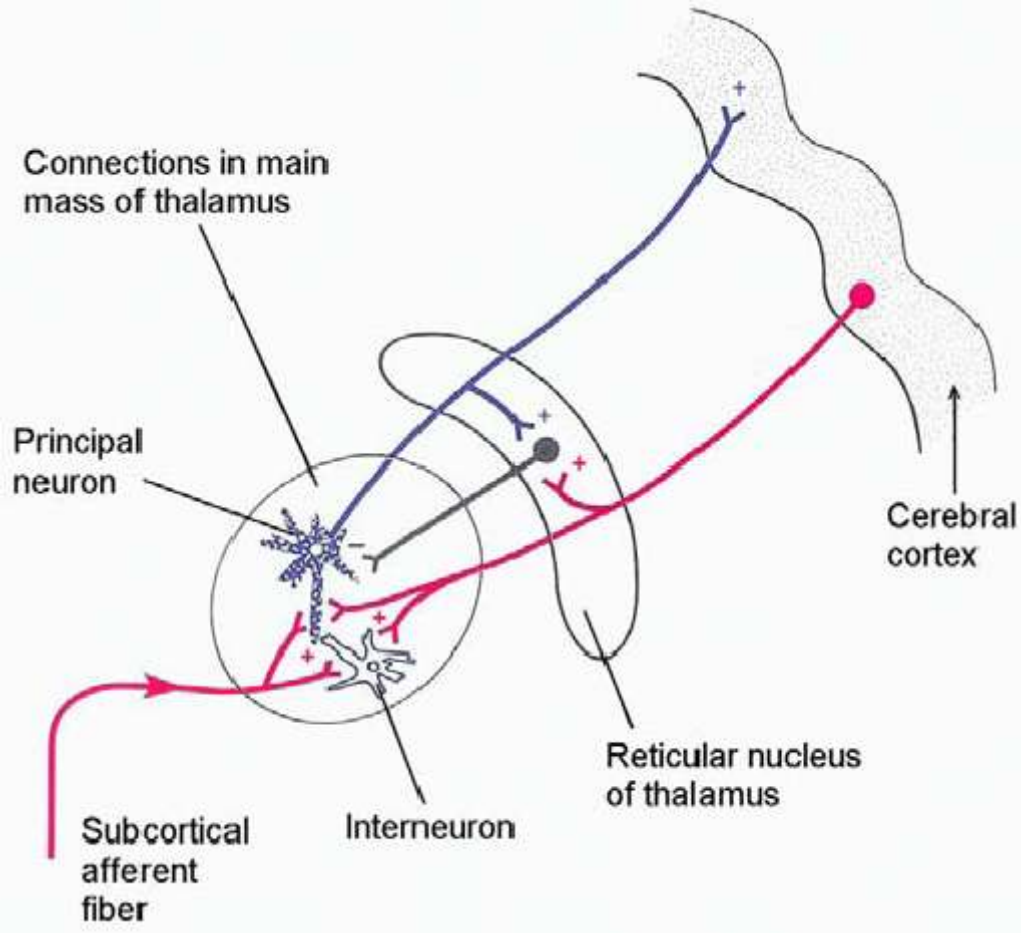



Excitation of neurons in the same column. Inhibition of neurons in adjacent columns.

Every projection from thalamus to cortex is reciprocated by a corticothalamic projection.

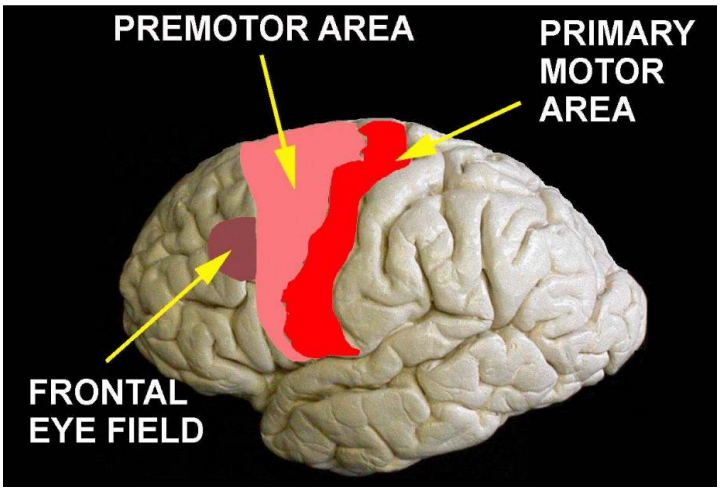
\+ = excitatory (glutamate)

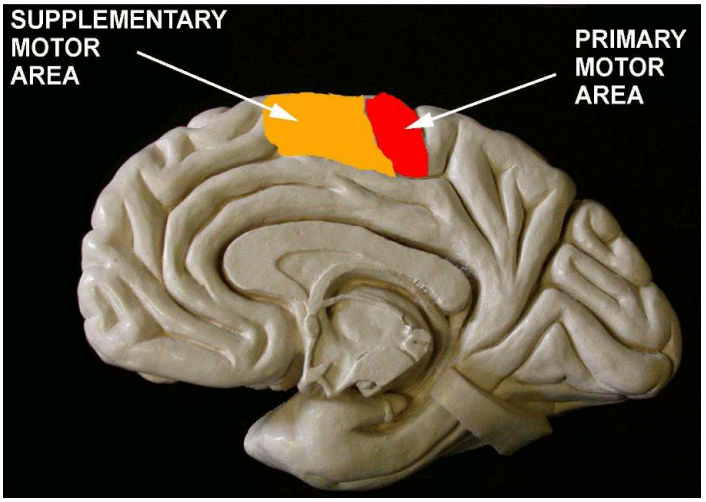
\- = inhibitory (GABA)



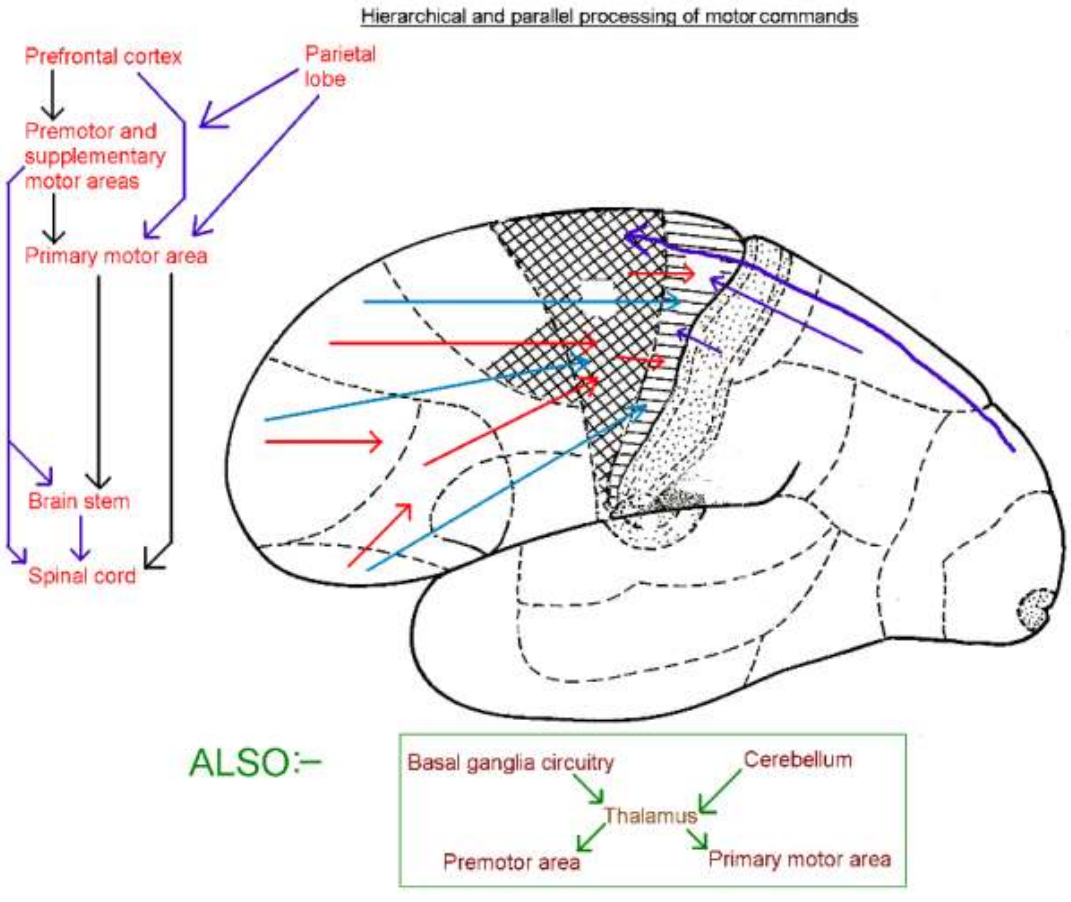

In rats, the anterior (rostral) part of the thalamic reticular nucleus is connected with predominantly motor cortical areas and also receives afferents from parts of the pallidum (ventral pallidum and substantia nigra pars reticulata), whereas the posterior (caudal) part of the thalamic reticular nucleus is connected with predominantly sensory cortical areas and lacks pallidal afferents. In mutant rats with generalized absence epilepsy, durations of spike-and-wave discharges were increased by injecting bicuculline into the caudal part of the reticular nucleus. Injection into the rostral part had the opposite effect. Bicuculline generally excites neurons by blocking one of the GABA receptors (Acker et al. 2006. *Brain Res.* **1111**:213-221).

# FUNCTIONAL CORTICAL AREAS AND THEIR INTERCONNECTIONS

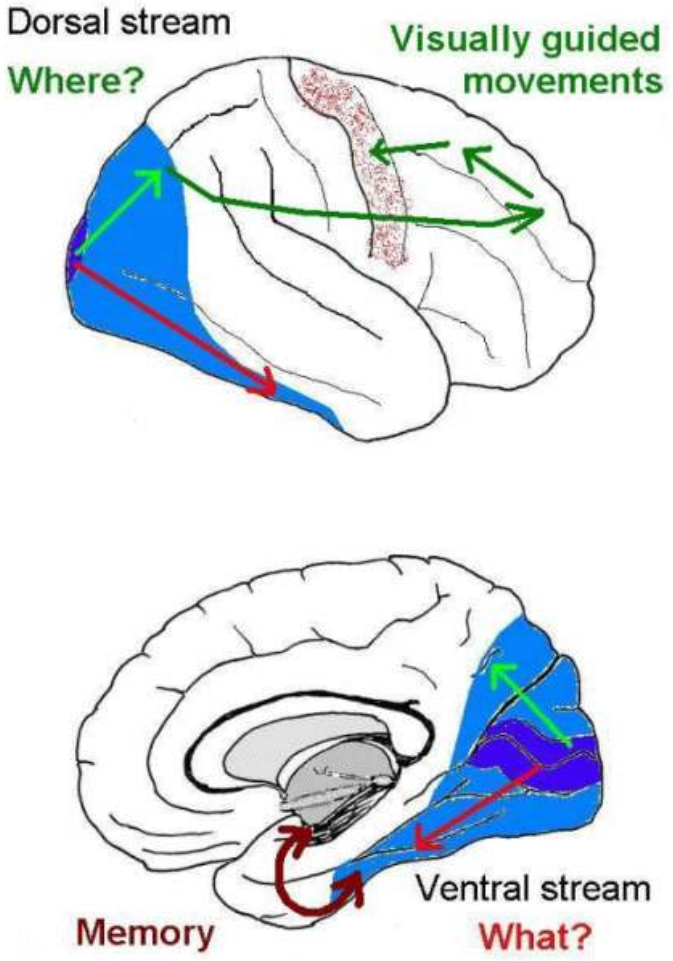



Primary, premotor and supplementary motor areas (as well as somatosensory cortex) are sources of descending (notably motor) tracts – corticospinal, corticobulbar, corticoreticular - parallel processing. There is also hierarchical or serial processing, by way of subcortical association fibres: prefrontal (also parietal, temporal) cortex —> pre- and supplementary motor areas —> primary motor area. The SMA is active before making a movement.



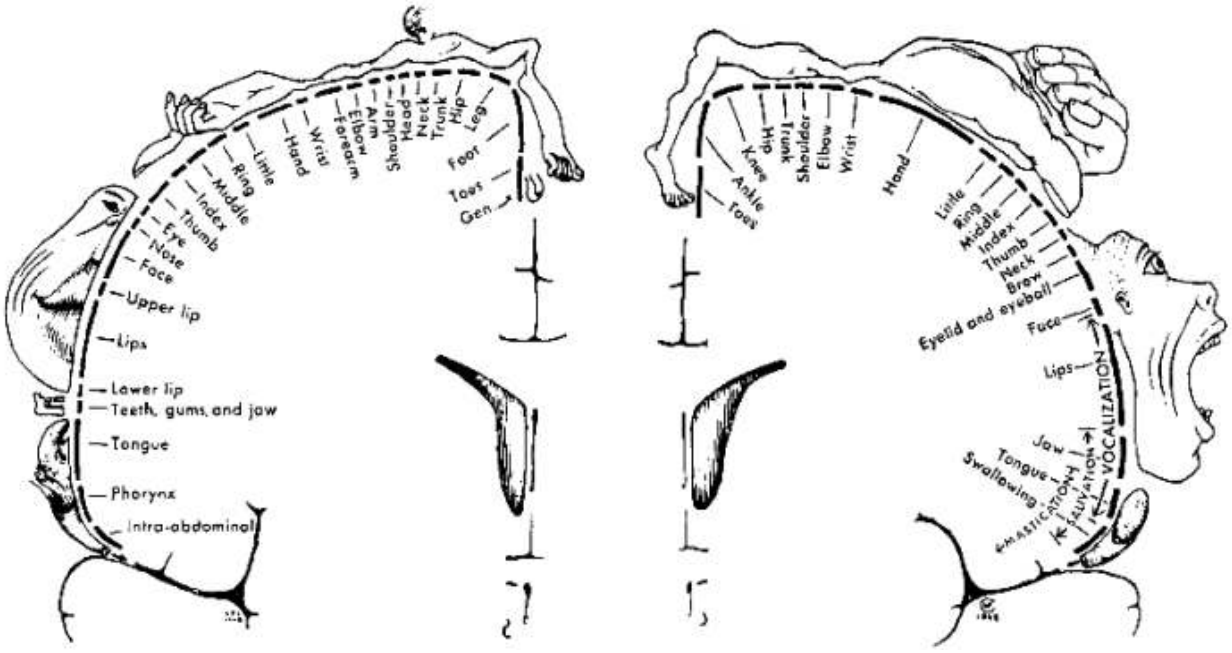
Some cortical association pathways used by the visual system.




Visual cortical areas are numbered from V1 (around the calcarine sulcus) to V6: areas in the occipital, parietal and temporal lobes that process increasingly complex features of images. The inferior temporal cortex remembers complex scenes.

Dorsally directed association fibres carry signals that direct movement of the hand to a seen target.

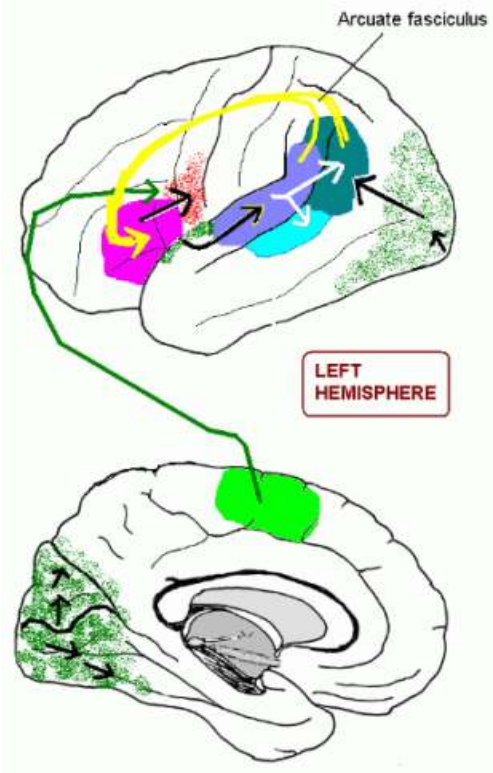
Ventrally directed projections from V1 and adjacent visual areas associate with parts of the temporal lobe that are involved in moving short-term experiences into permanent storage.




Somatosensory (left) and motor (right) homunculi, after Penfield.

There has been controversy over representation of the face (cf: Nakamura et al 1998 NeuroImage 7: 377-386; Servos et al 1999 NeuroReport 10:1393-1395). Recent magnetoencephalographic (Nguyen et al 2004 Neurosci. Res. 50:227-232) and fMRI (Moulton et al 2009 Human Brain Mapping 30:757-765) studies indicate that Penfield's sensory map was probably quite accurate, with representation of the thumb adjacent to that for the forehead. Functional imaging indicates that movements of the fingers and different parts of the face involve activity in complex overlapping regions that extend beyond the precentral gyrus (Meier et al 2008: J. Neurophysiol. 100:1800-1812).

Some corticocortical connections relating to reading and speech.




Superior longitudinal fasciculus — Conduction aphasia

Visual association cortex — Visual agnosias; optic ataxia etc. Pure alexia (L. Side, + callosal fibres)

Angular gyrus — Agraphia without aphasia

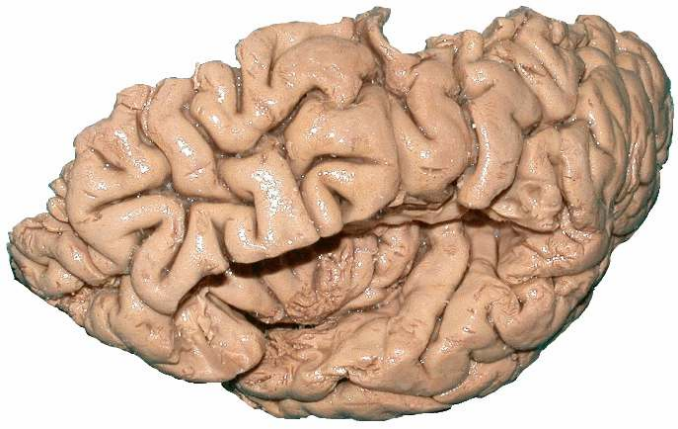
Middle temporal gyrus — Receptive transcortical aphasia

Wernicke's area — Receptive aphasia

Supplementary motor area — Paralysis; mutism (bilateral lesions)

Broca's area — Expressive aphasia

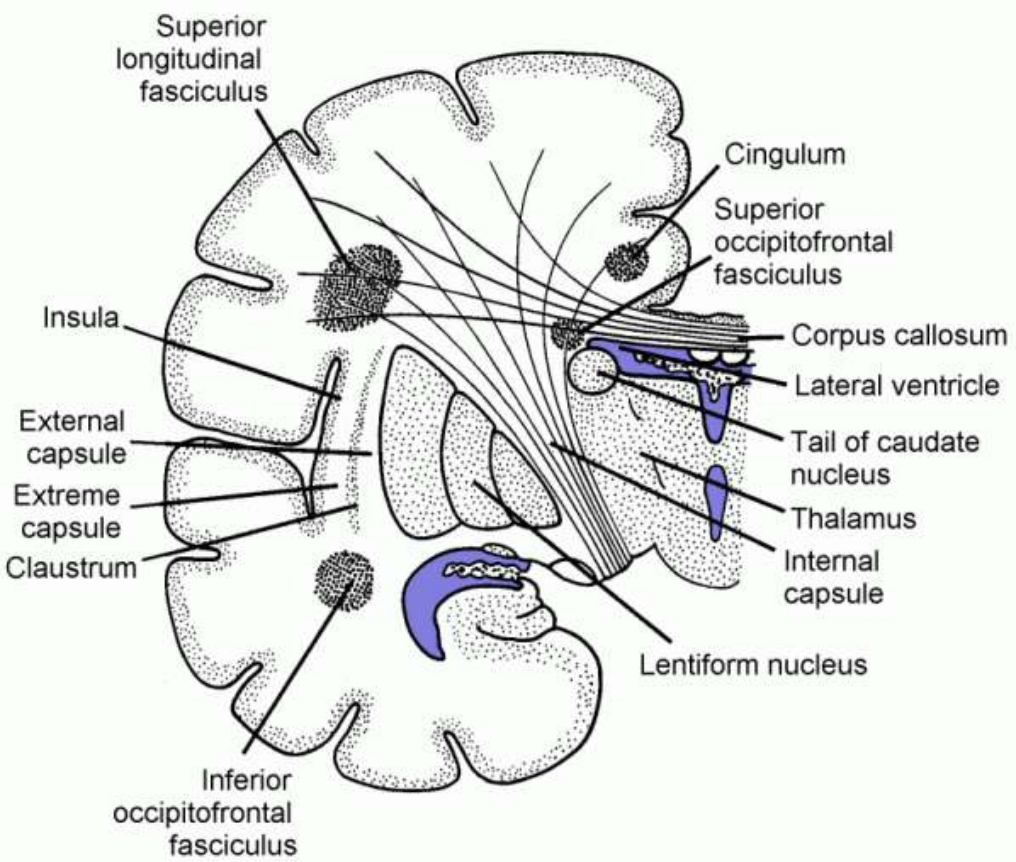
Primary motor area — Paresis of vocal muscles

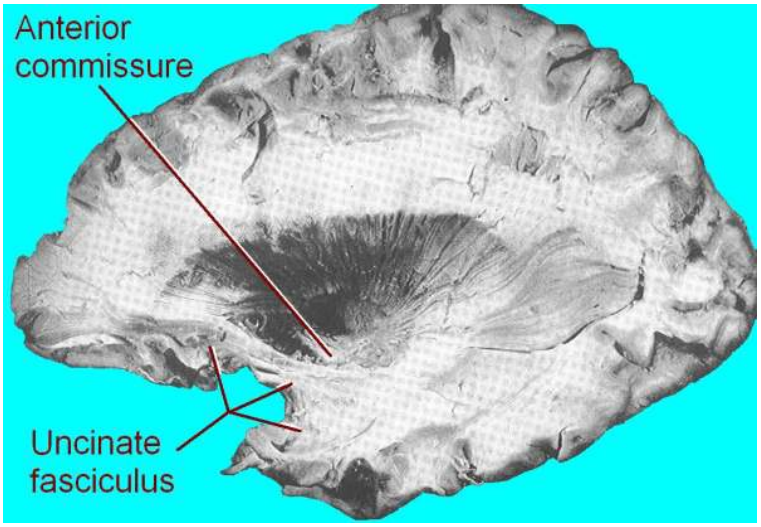


Frontal and parietal opercula removed, to show insula, primary auditory area and planum temporale.

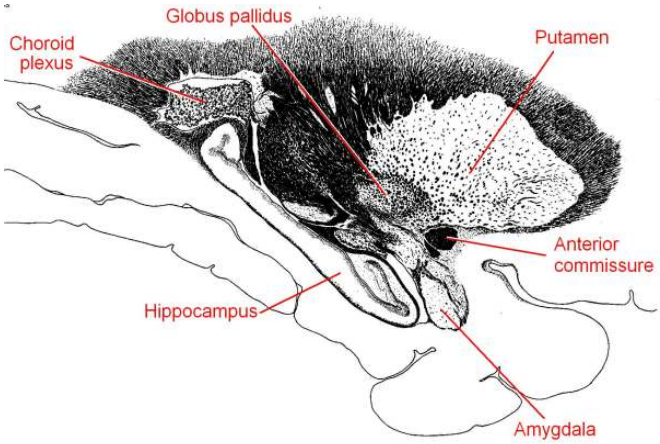
Dissection to show superior longitudinal (arcuate) fasciculus and external capsule.

More association and commissural fibres.




Dissection showing frontal-temporal association and temporal-temporal commissural connections.




A sagittal section (myelin stained black) passing through the medial parts of the temporal lobe.