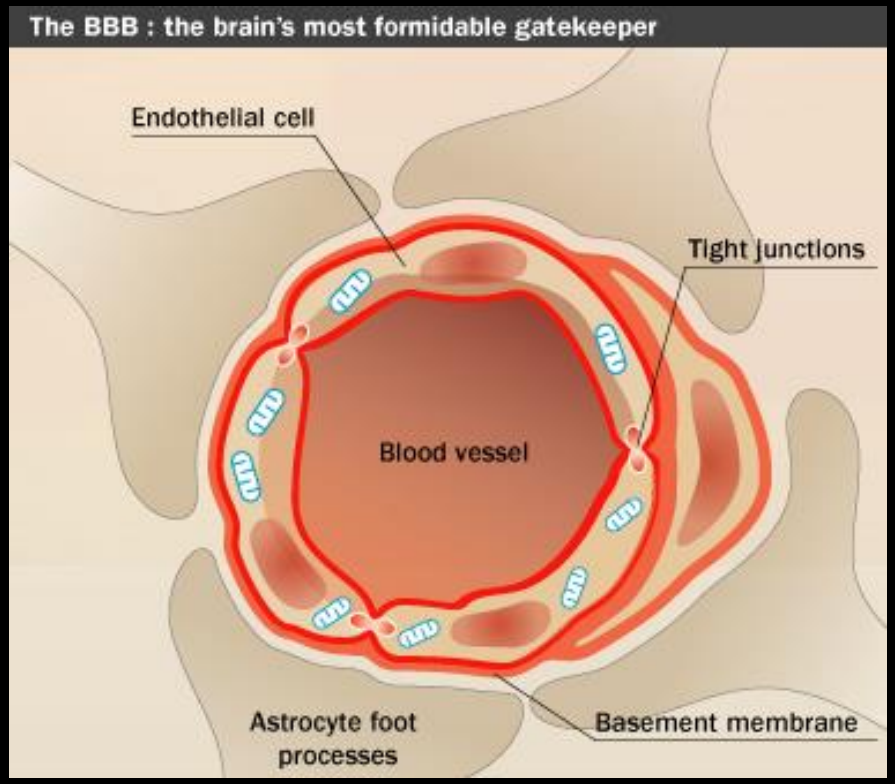
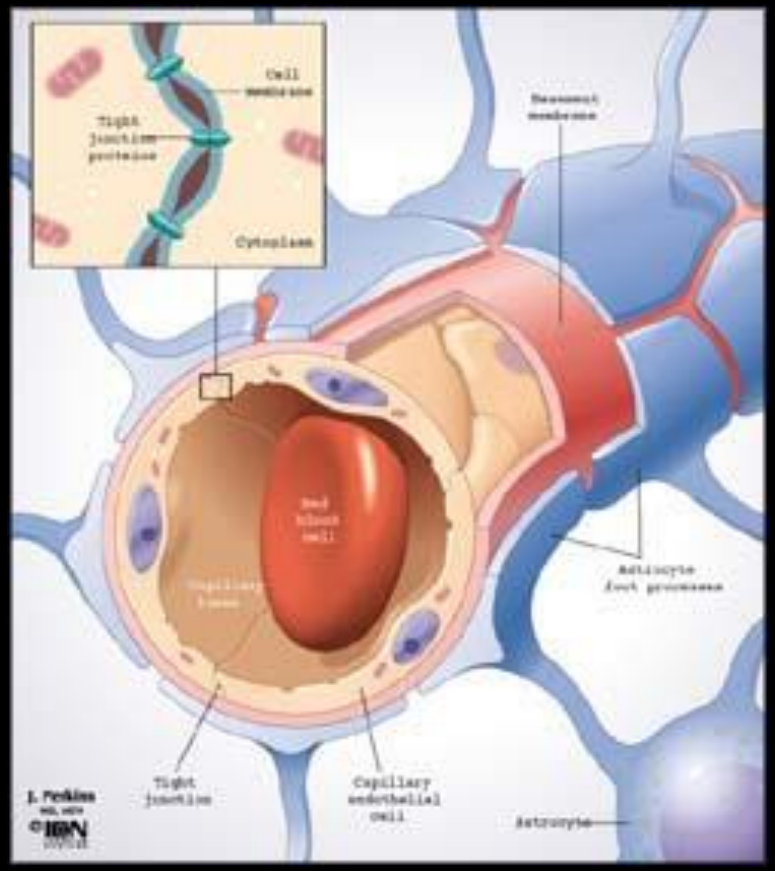
In vivo brain functional exploration

Why in vivo?

1. *in vitro* and *in vivo* differences
2. Anatomical 'constraints'

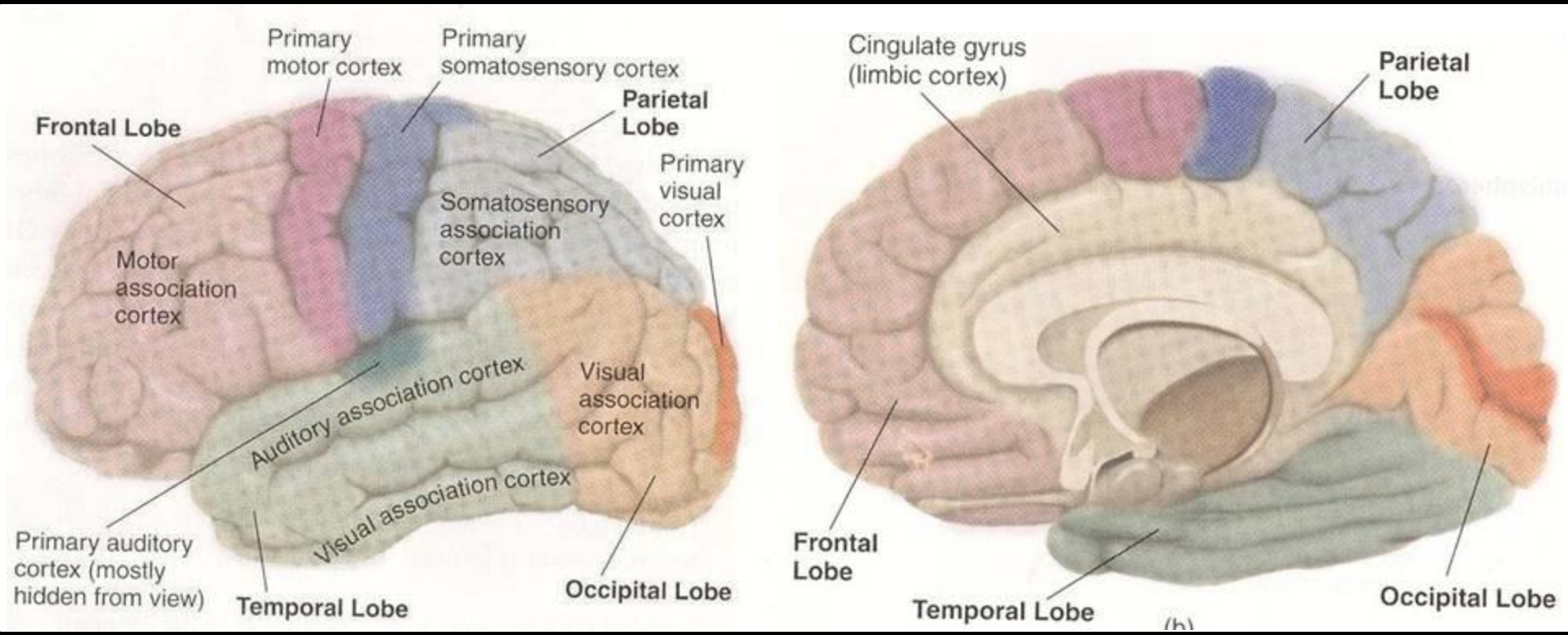




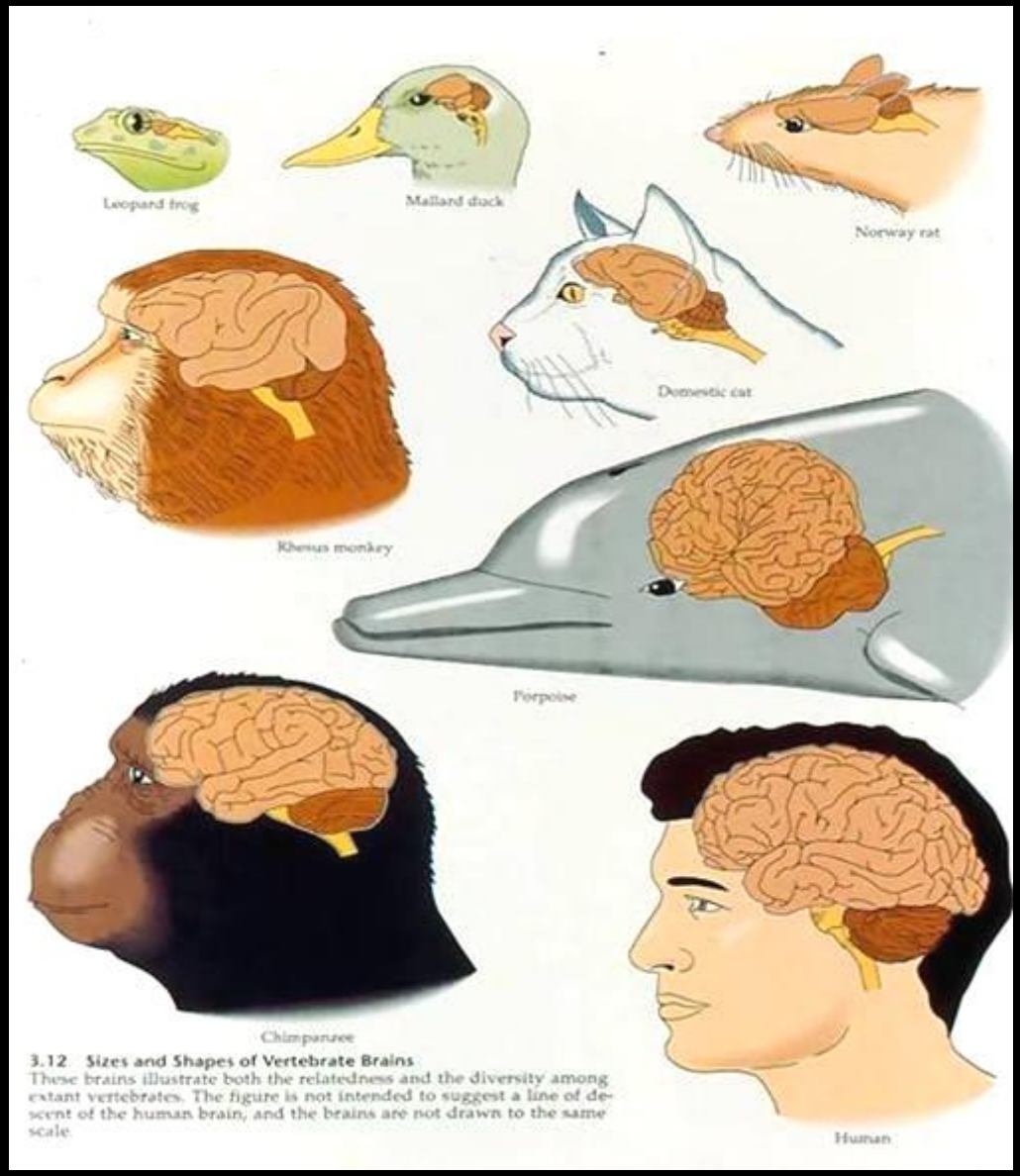
In vivo brain functional exploration

Why in vivo?

3. Functional segregation and integration



In vivo brain functional exploration

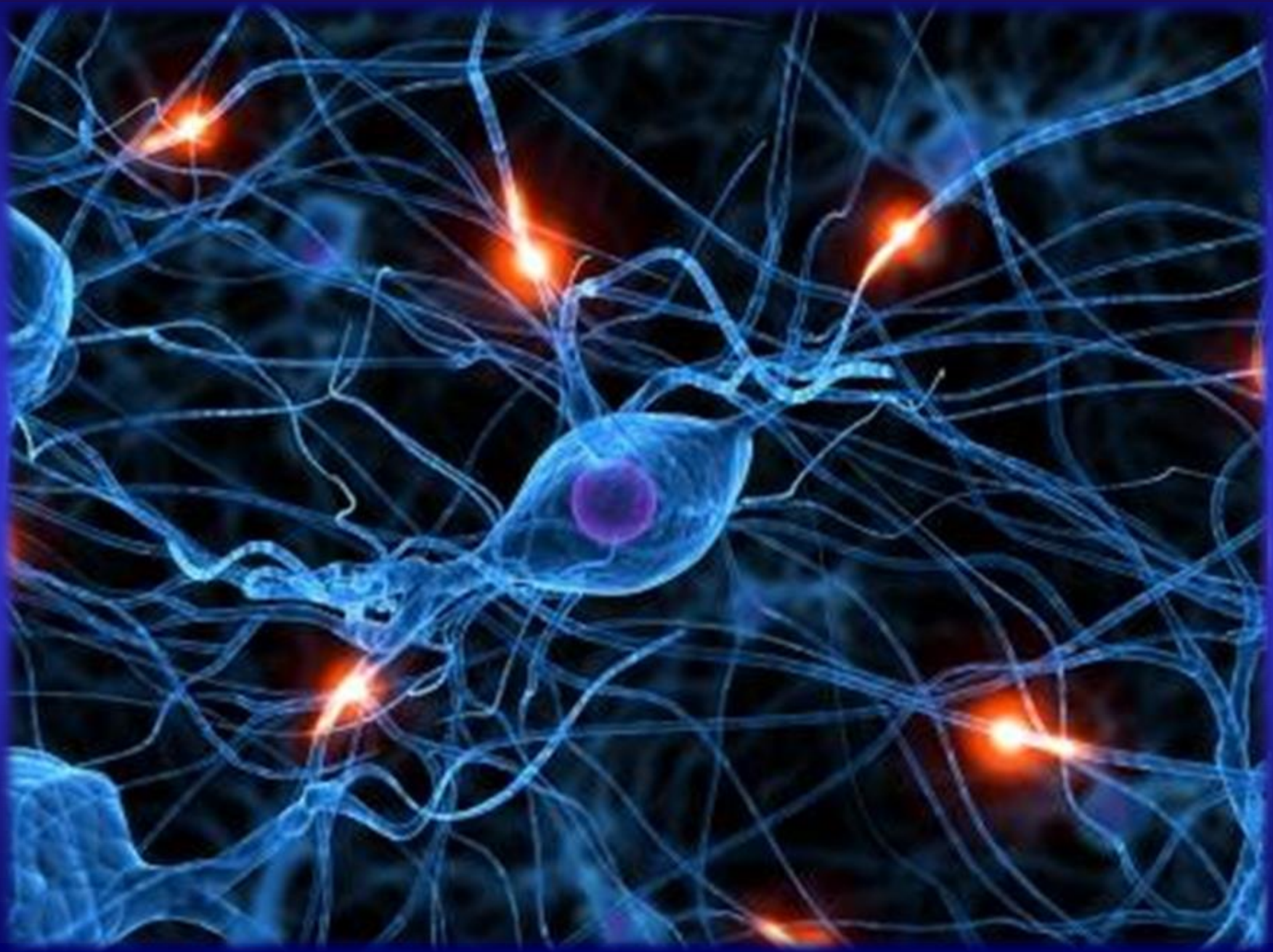


3.12 **Sizes and Shapes of Vertebrate Brains**
These brains illustrate both the relatedness and the diversity among extant vertebrates. The figure is not intended to suggest a line of descent of the human brain, and the brains are not drawn to the same scale.

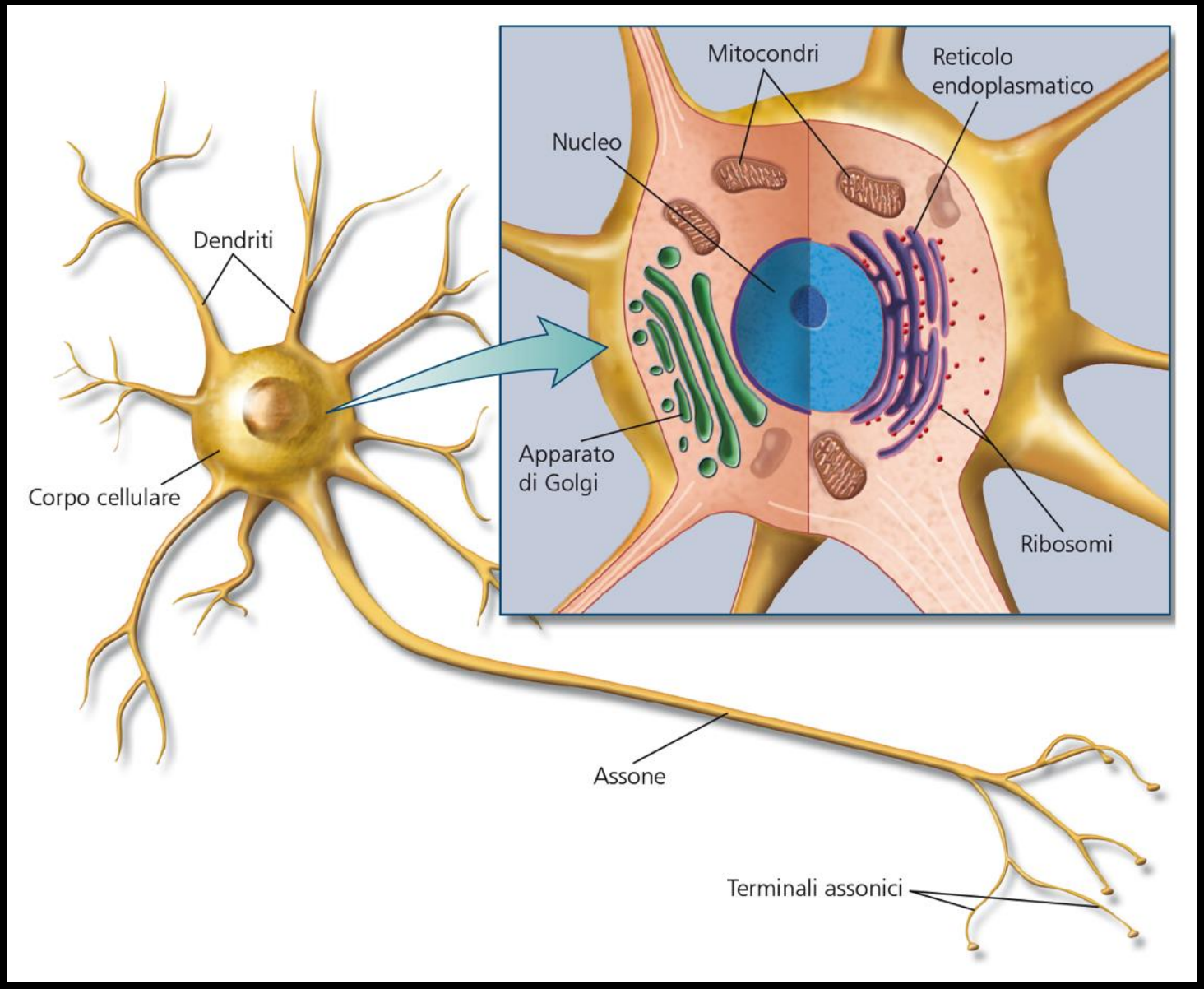
Why in vivo?

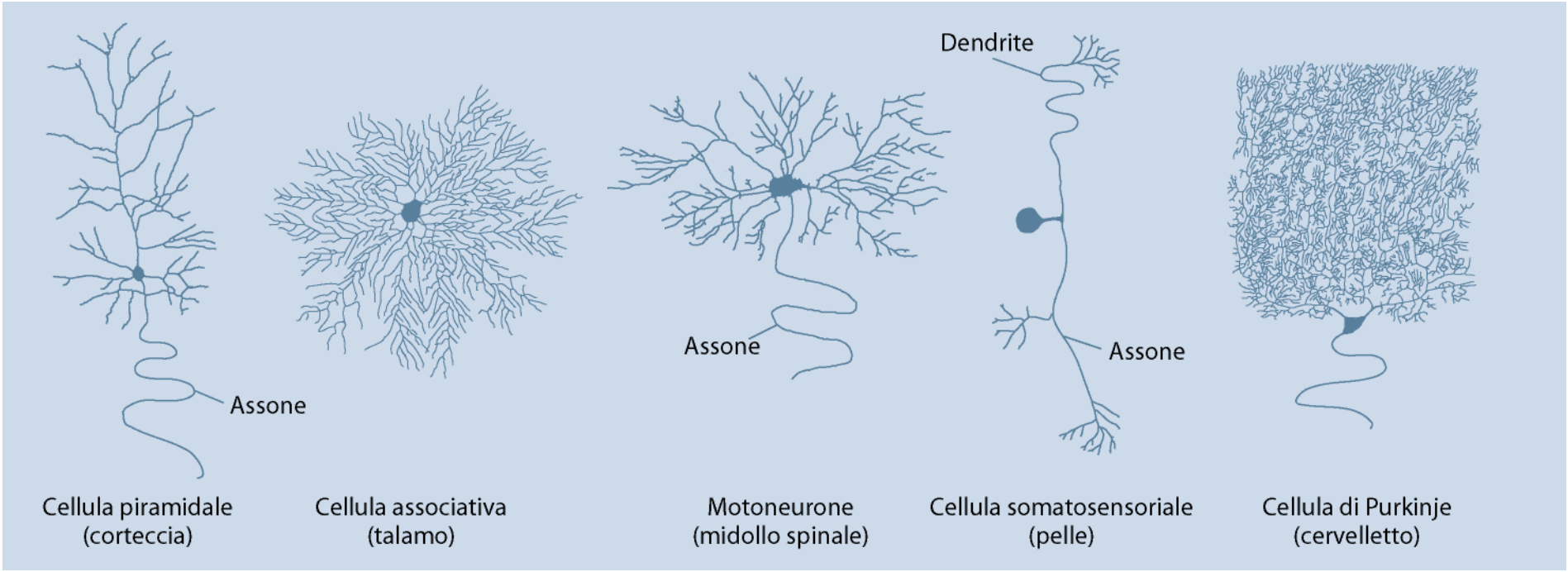
4. Limitations of animal models

In vivo brain functional methodologies

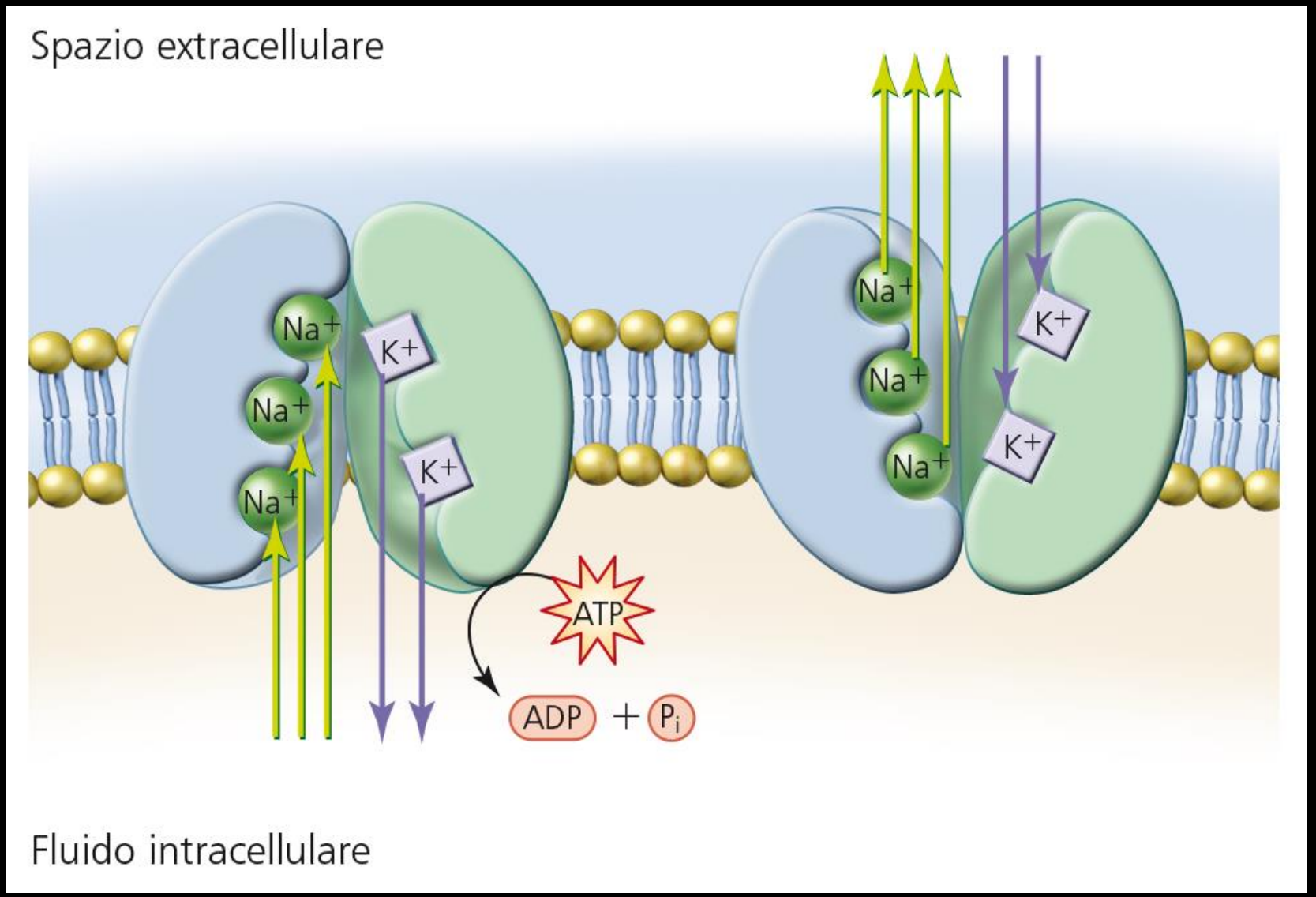


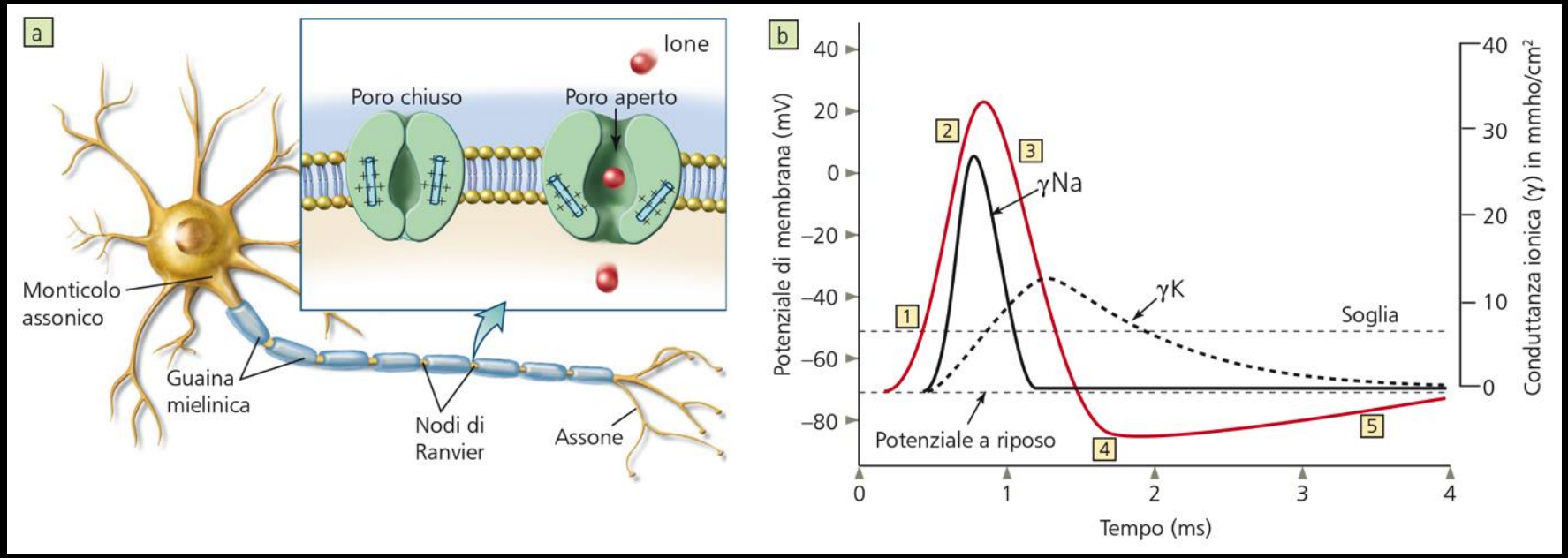
Neurons


Mitocondri
Reticolo endoplasmatico
Nucleo
Dendriti
Apparato di Golgi
Corpo cellulare
Ribosomi
Assone
Terminali assonici

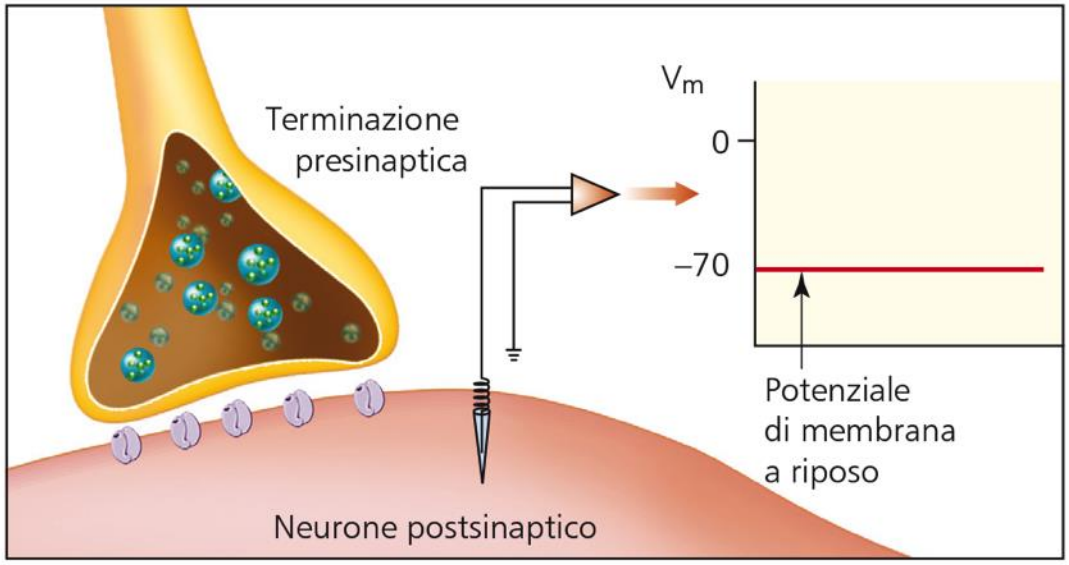


Cellula piramidale (corteccia) | Cellula associativa (talamo) | Motoneurone (midollo spinale) | Cellula somatosensoriale (pelle) | Cellula di Purkinje (cervelletto)

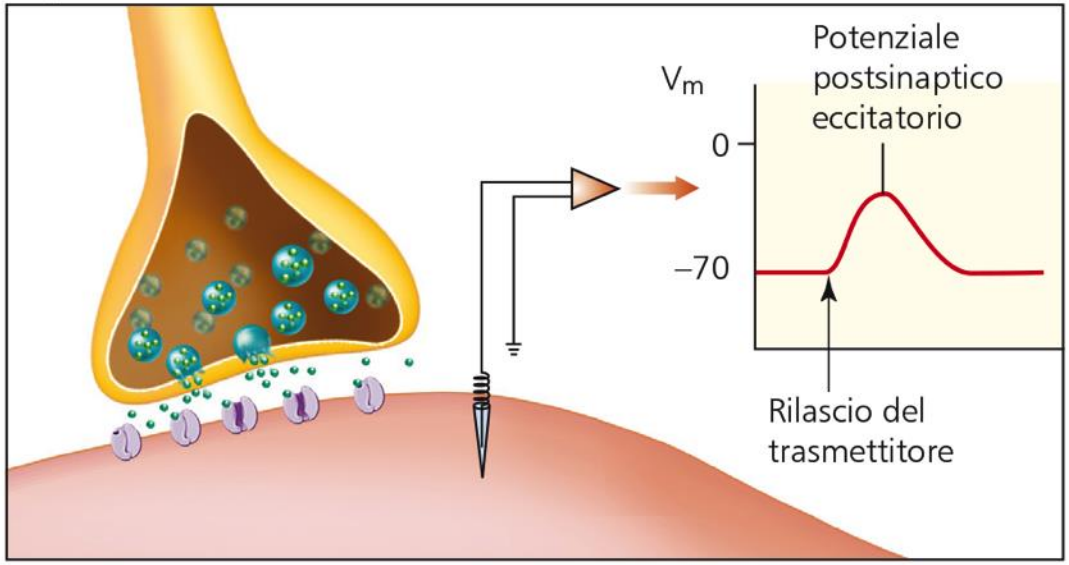

Spazio extracellulare
Na+
Na+
Na+
K+
K+
Na+
Na+
Na+
K+
K+
ATP
ADP + Pi
Fluido intracellulare


a
Ione
Poro chiuso
Poro aperto
Monticolo assonico
Guaina mielinica
Nodi di Ranvier
Assone
b
Potenziale di membrana (mV)
40
20
0
−20
−40
−60
−80
γNa
γK
Soglia
Potenziale a riposo
1
2
3
4
5
0
1
2
3
4
Tempo (ms)
Conduttanza ionica (γ) in mmho/cm²
40
30
20
10
0

Prima del rilascio del trasmettitore



Dopo il rilascio del trasmettitore



To summarize:

- **Na/K pump**
- **Summation**
- **Action Potential**
- **Synaptic transmission**

THE STRUCTURES OF NEUROTRANSMITTERS

STRUCTURE KEY: Carbon atom | Hydrogen atom | O Oxygen atom | N Nitrogen atom | R Rest of molecule

ADRENALINE
Fight or flight neurotransmitter

Produced in stressful or exciting situations. Increases heart rate & blood flow, leading to a physical boost & heightened awareness.

NORADRENALINE
Concentration neurotransmitter

Affects attention & responding actions in the brain, & involved in fight or flight response. Contracts blood vessels, increasing blood flow.

DOPAMINE
Pleasure neurotransmitter

Feelings of pleasure, and also addiction, movement, and motivation. People repeat behaviours that lead to dopamine release.

SEROTONIN
Mood neurotransmitter

Contributes to well-being & happiness; helps sleep cycle & digestive system regulation. Affected by exercise & light exposure.

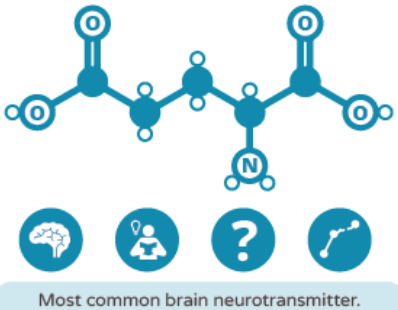
GABA
Calming neurotransmitter

Calms firing nerves in CNS. High levels improve focus; low levels cause anxiety. Also contributes to motor control & vision.

ACETYLCHOLINE
Learning neurotransmitter

Involved in thought, learning, & memory. Activates muscle action in the body. Also associated with attention and awakening.

GLUTAMATE
Memory neurotransmitter



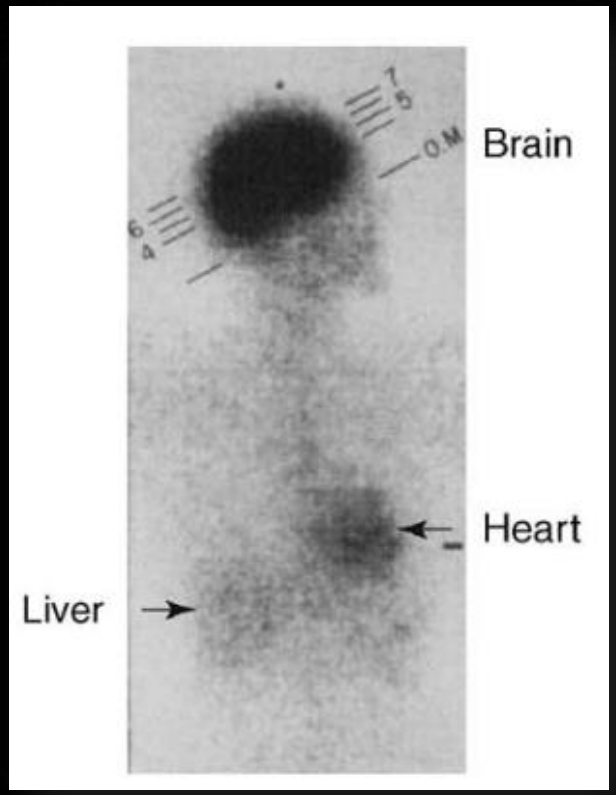
Most common brain neurotransmitter. Involved in learning & memory, regulates development & creation of nerve contacts.

ENDORPHINS
Euphoria neurotransmitters

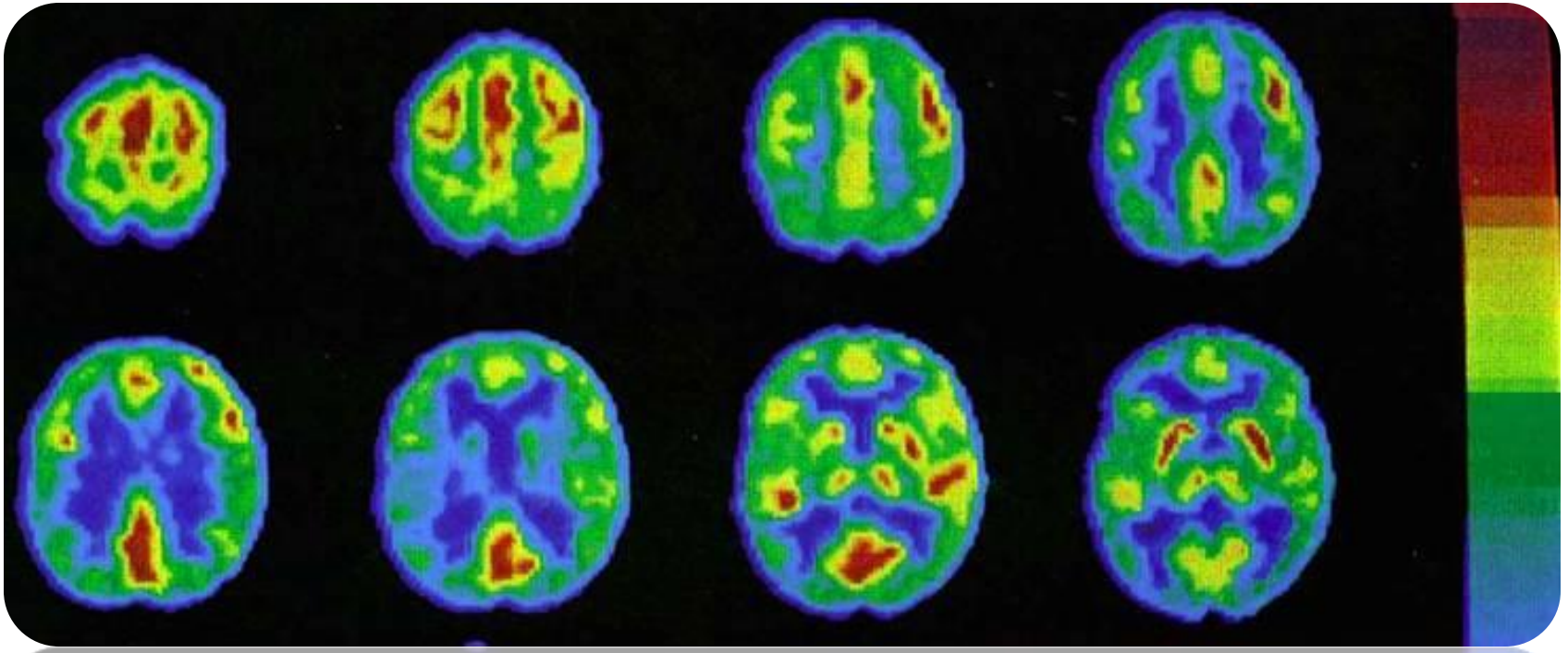
Released during exercise, excitement, & sex, producing well-being & euphoria, reducing pain. Biologically active section shown.

Cerebral metabolism of glucose

- Brain tissue includes neurons and glia cells
- In physiological conditions, glucose oxydation to CO_2 and H_2O is the unique metabolic pathway to produce ATP
- Glucose and oxygen supplies strictly rely on cerebral blood flow
- Human brain:
  - ~2% of total body weight
  - receives 15% basal cardiac output and consumes 20% of O_2
  - extracts about 10% blood glucose
  - limited glycogen storage
  - Blood supply increases in 'activated' brain regions

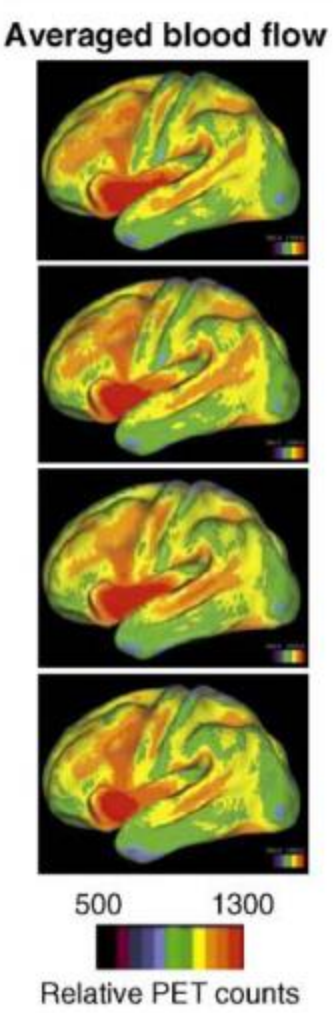


Our brain never rests…



Glucose consumption at rest as measured by PET

Our brain never rests…



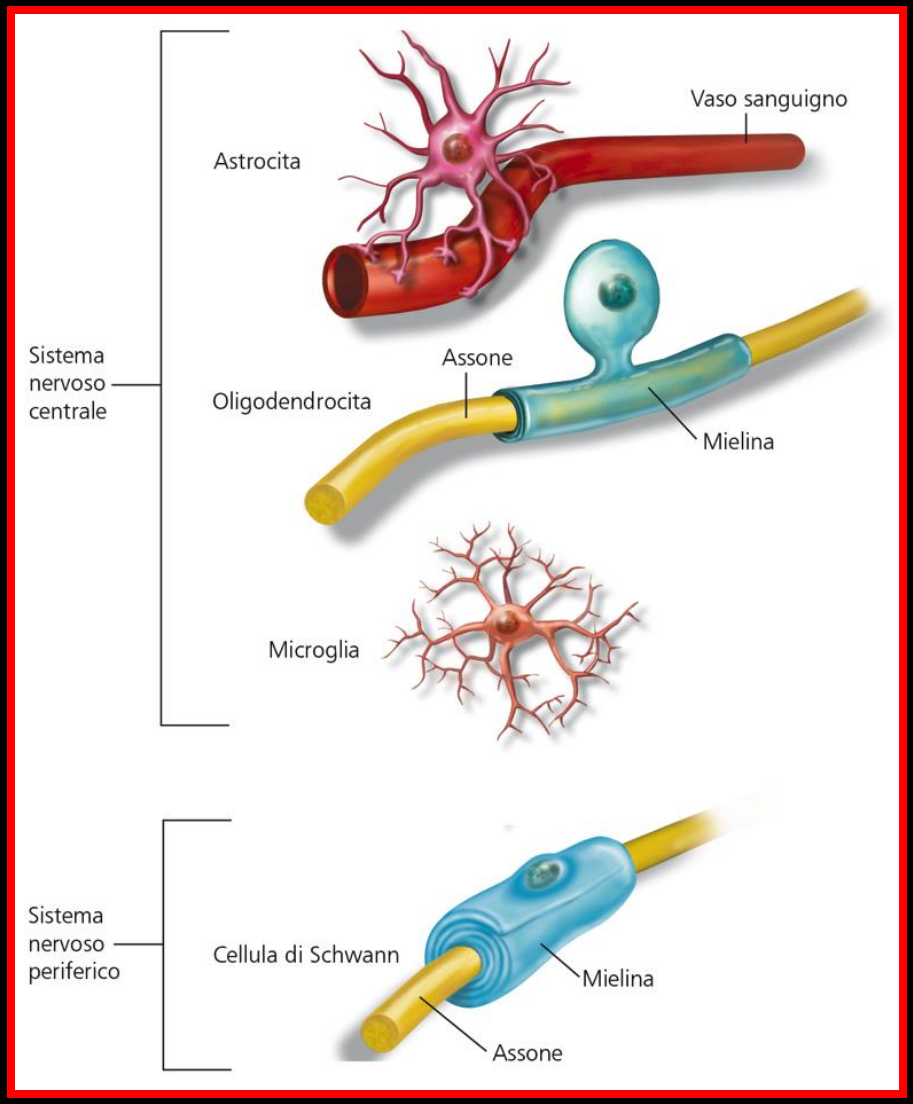
Which are the resting state or task-dependent responses?

Neurovascular coupling

- Increases in neuronal synaptic activity are accompanied by increases in regional blood flow supply (coupling)
- Bloof flow supplies glucose and oxygen to neurons
- In healthy conditions, glucose oxydation is the only metabolic pathway to produce ATP in the neuron
- ATP restores neuron membrane potential
- ATP consumption is located at a synaptic level
- Glucose consumption represents an indirect parameter to assess synaptic neuronal activity

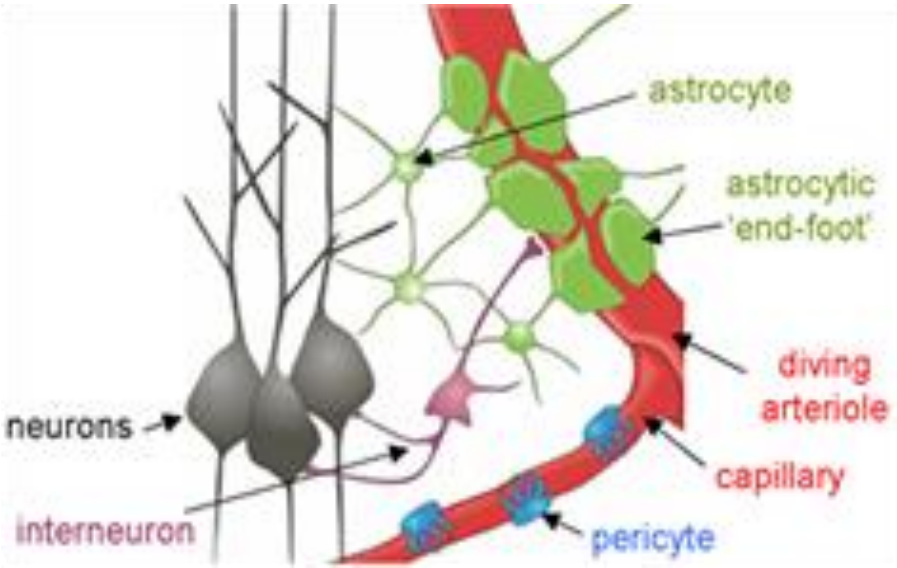
Neurovascular coupling

- Brain tissue includes neurons and glia cells



Neurovascular coupling (functional hyperemia)

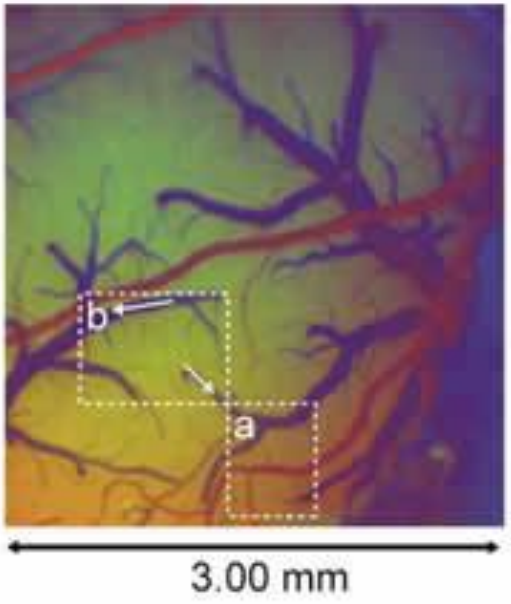
- A local increase in cortical blood flow accompanies almost all neuronal responses to stimulus in the brain
- However, little is understood about the interrelation between blood flow and the neuronal activity that underlies it
- More importantly, normal functioning of the brain depends critically on the integrity of neurovascular coupling (e.g., Alzheimer's and age related neurodegeneration)

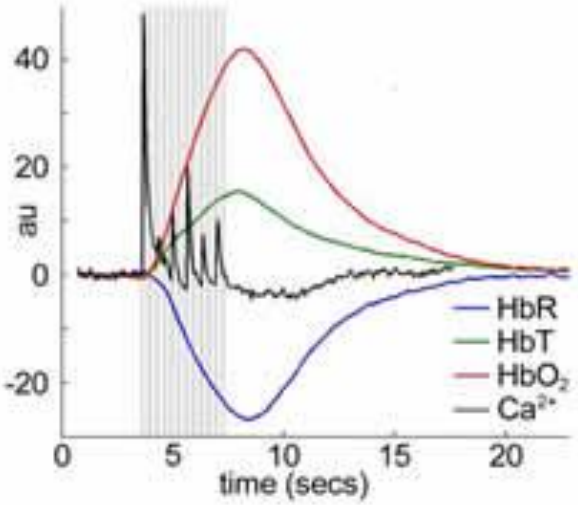


http://orion.bme.columbia.edu/~hillman/Brain_Imaging.html

Neurovascular coupling

- The typical hemodynamic response consists of a rapid increase in HbT and HbO with a concomitant decrease in HbR.
- This response corresponds to a local increase in blood flow and in the amount of oxygenated blood present in the region, due to rapid dilation of the pial arterioles and little or no dilation (passive or active) of pial veins (so far, fMRI models assumed that the majority of HbT changes occurred in the venous compartment!)

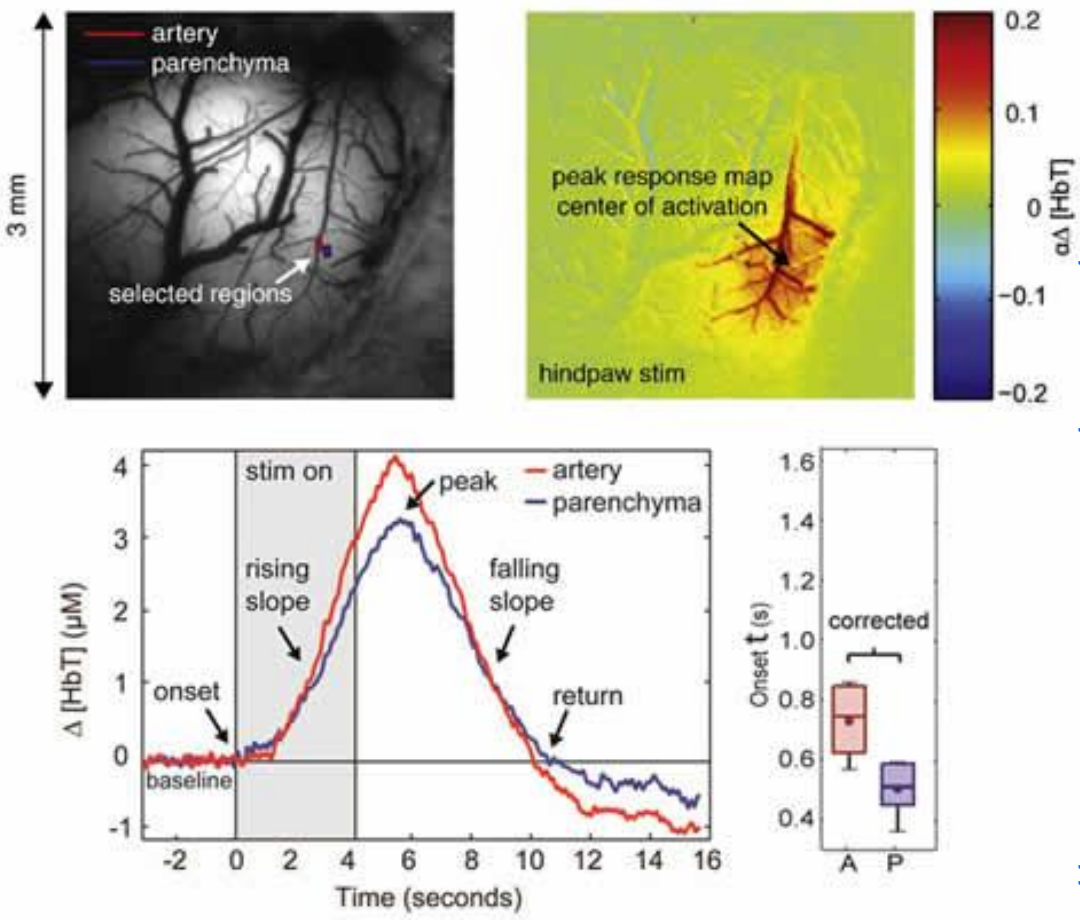




http://orion.bme.columbia.edu/~hillman/Brain_Imaging.html

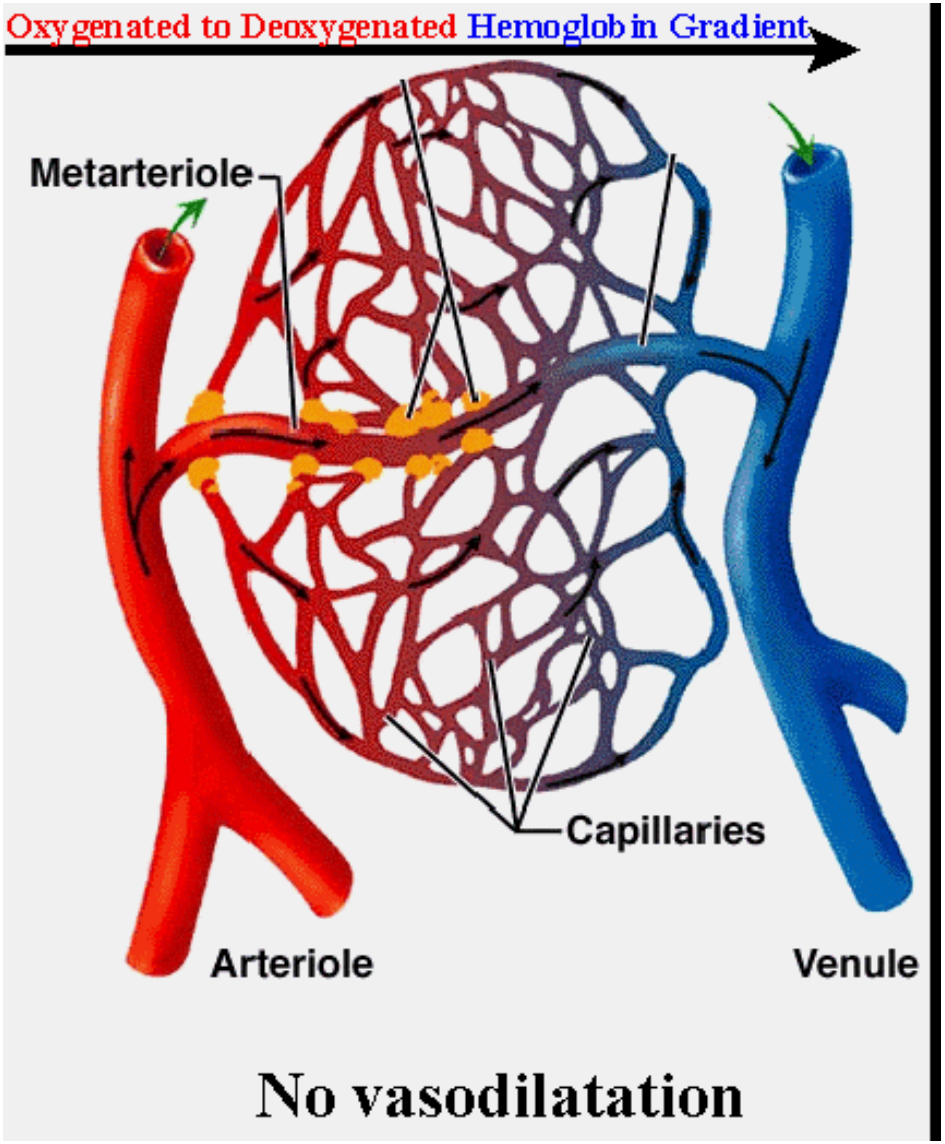
Neurovascular coupling

- HbT changes in the parenchyma originating from the capillary bed precede dilation of pial arterioles by a few hundred milliseconds
- We observed high speed (2-4 mm/s) retrograde propagation of vasodilation
- Dilations over 1mm away were seen within 400 milliseconds of stimulus onset



http://orion.bme.columbia.edu/~hillman/Brain_Imaging.html

Neurovascular coupling

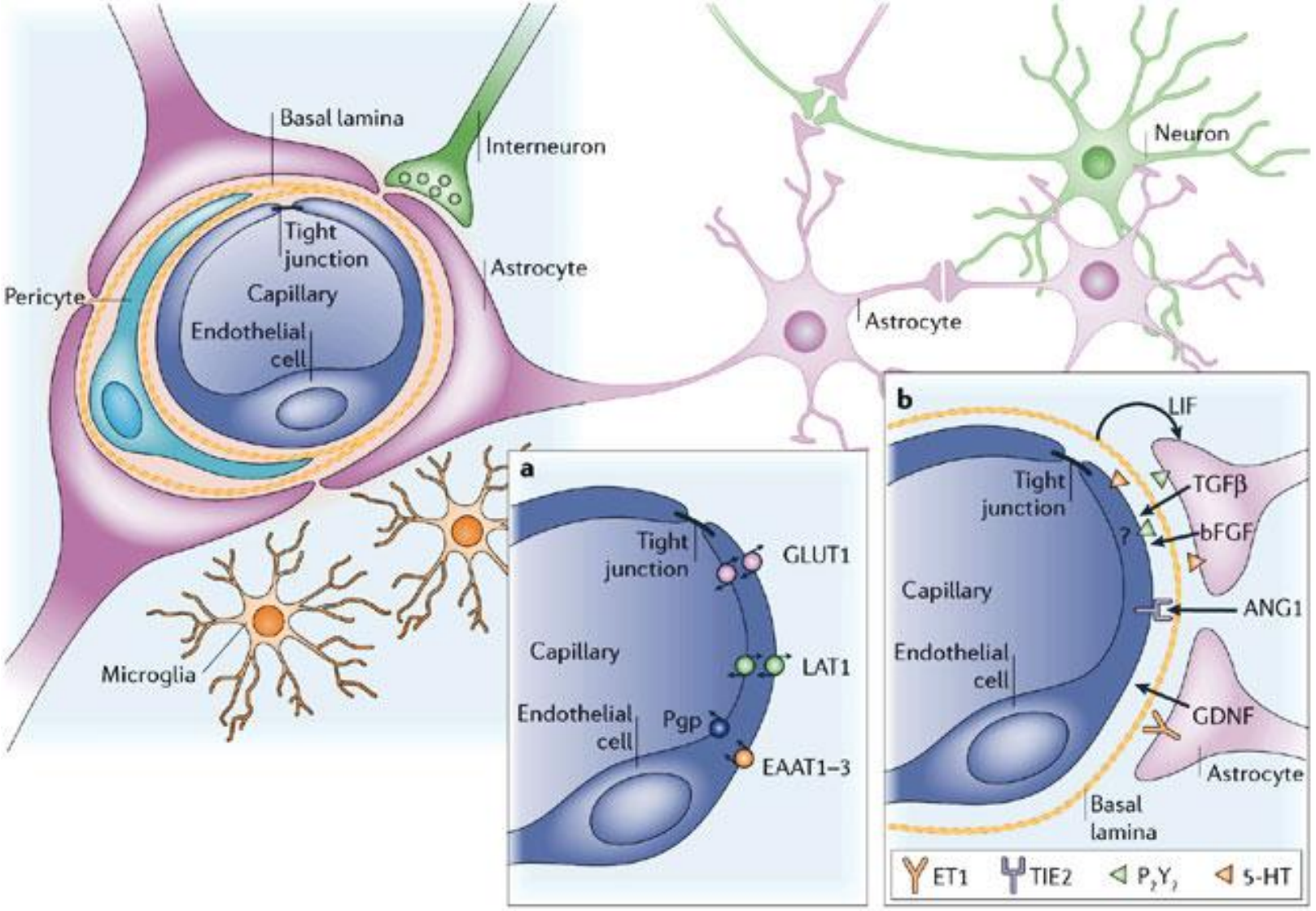


Neurovascular coupling

- Astrocytes possess many properties that make them attractive candidates for involvement in neurovascular coupling:
  - can sense the presence of local glutamate release via their metabotropic glutamate receptors
  - can release a range of vasoactive products including prostaglandins and potassium ions
  - are present around vessels in the brain
  - exhibit transient increases in intracellular calcium during stimulation
- Astrocytes enstheath all sub-pial vessels; diving arterioles, capillaries and ascending veins, but that they do not exhibit preferential relationships with diving arterioles and seem unlikely to be the primary mediators of long-distance, rapid dilation of pial arteriole branches… what about *endothelium*?

http://orion.bme.columbia.edu/~hillman/Brain_Imaging.html

Neurovascular coupling

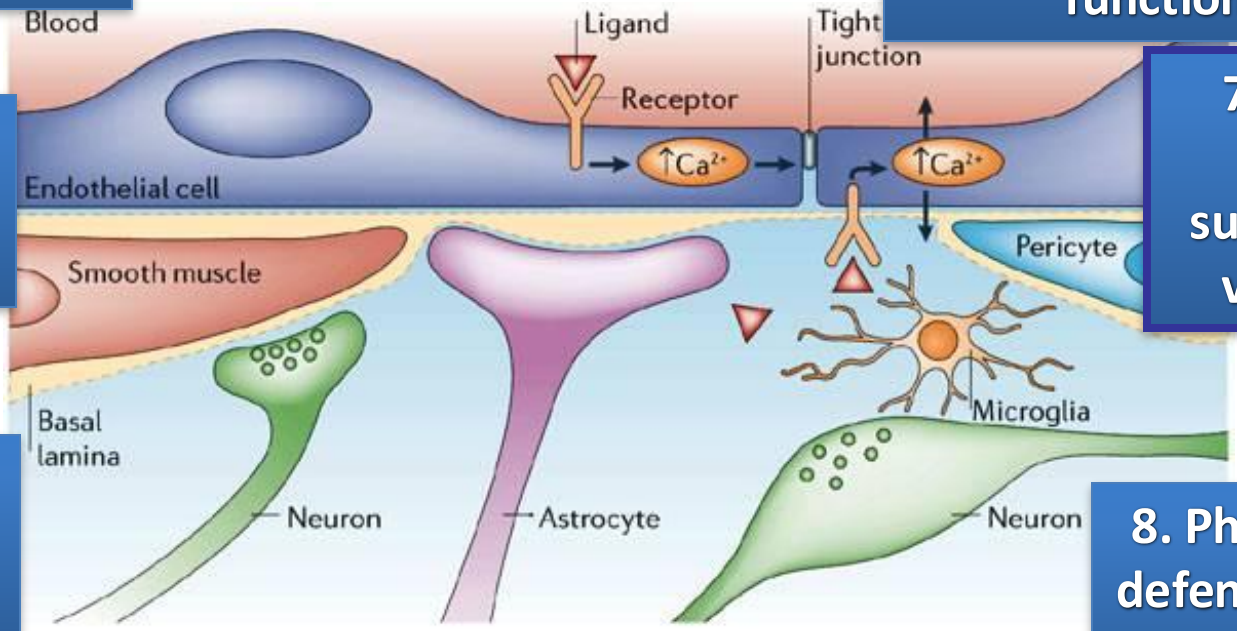


The homeostatic role of the BBB

4. Provides nutrients and removes catabolites

5. Selects the transport of substances to neurons

6. Modulates the release of molecules with hormonal function



3. Regulates the neuronal architecture

7. Regulates blood flow supply through vasodilation

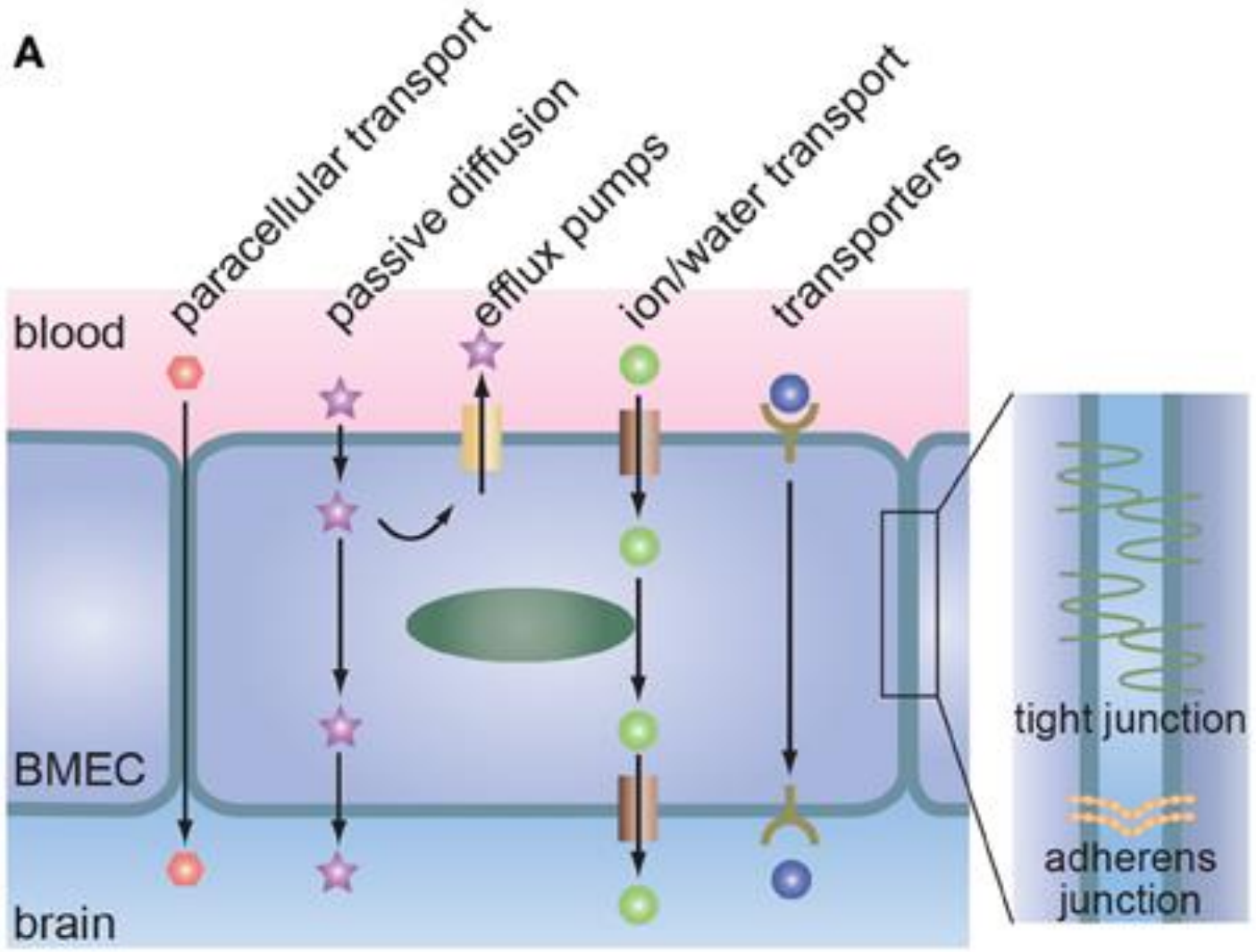
2. Regulates the vascular scaffold

8. Phagocytic and defense properties

1. Regulates ion and fluid exchange

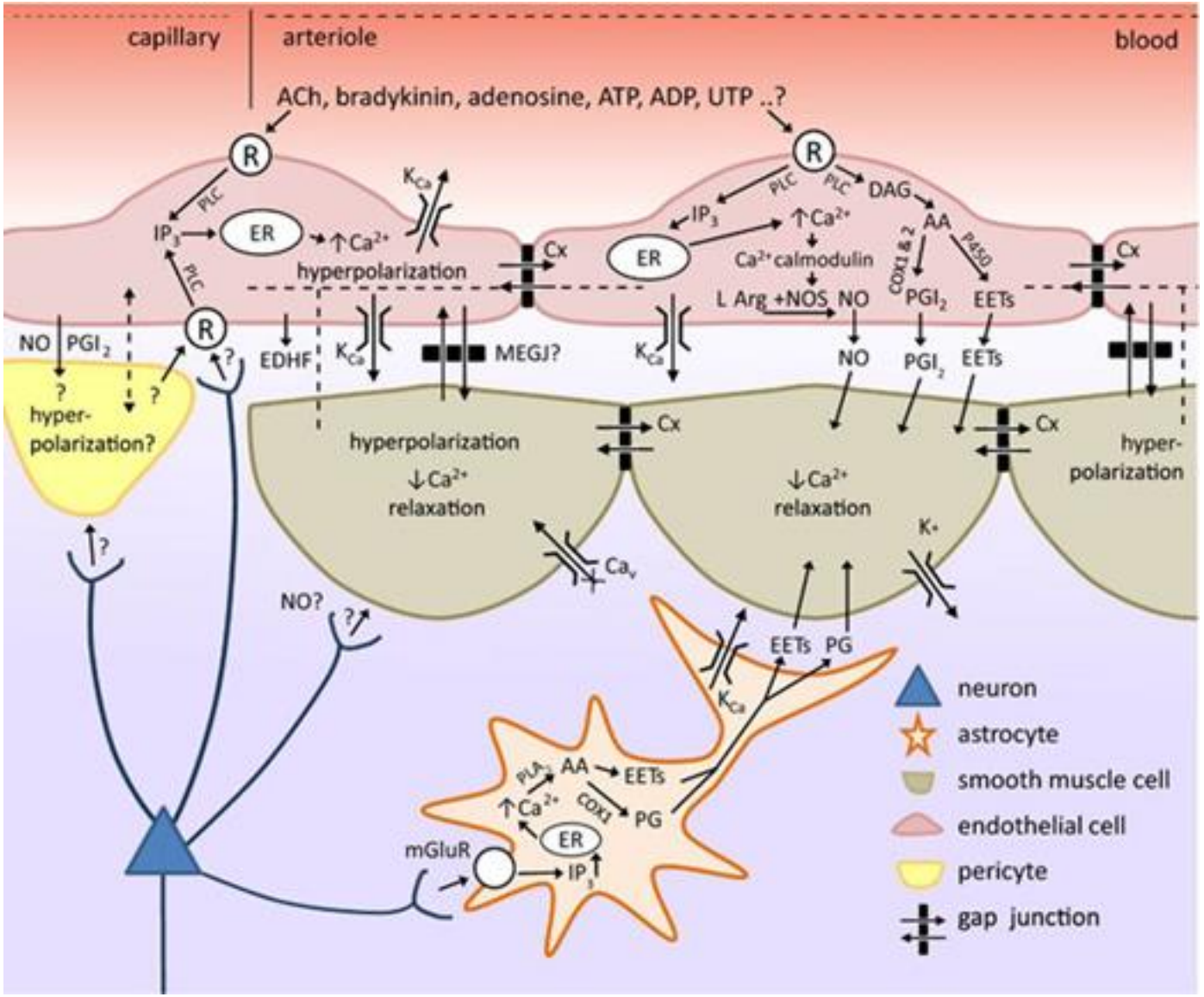
~20 m² per 1.3 kg of nervous tissue!

The homeostatic role of the BBB



http://journal.frontiersin.org/article/10.3389/fneng.2013.00007/full

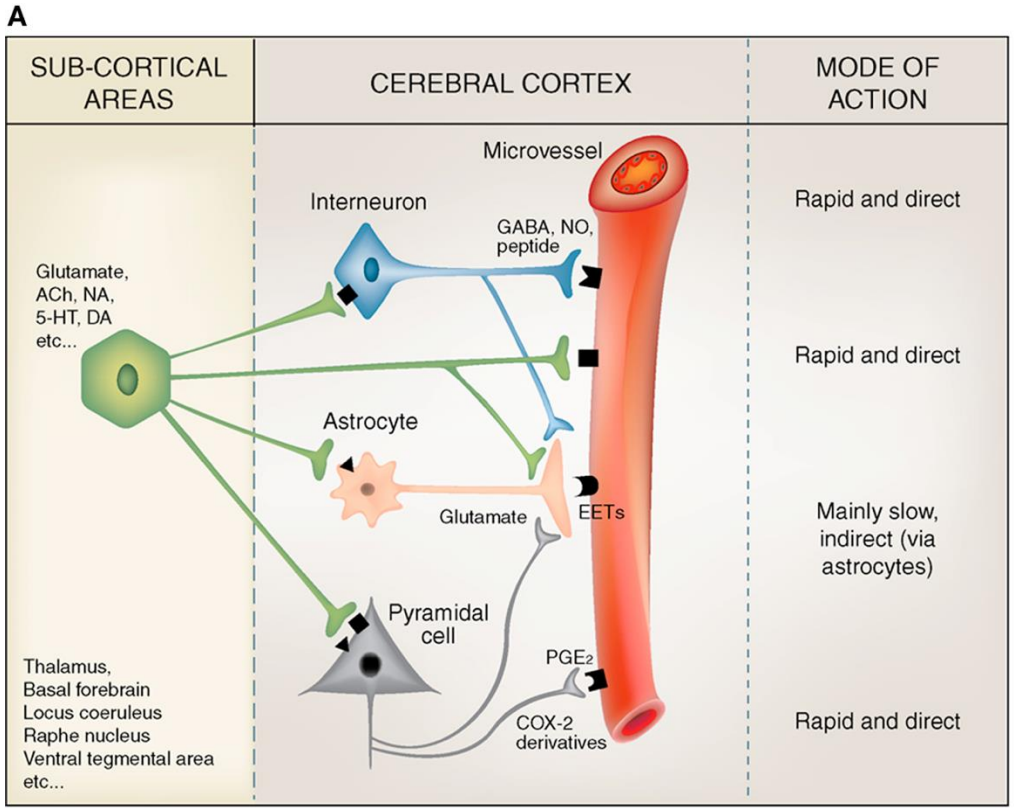
Neurovascular coupling: endothelium

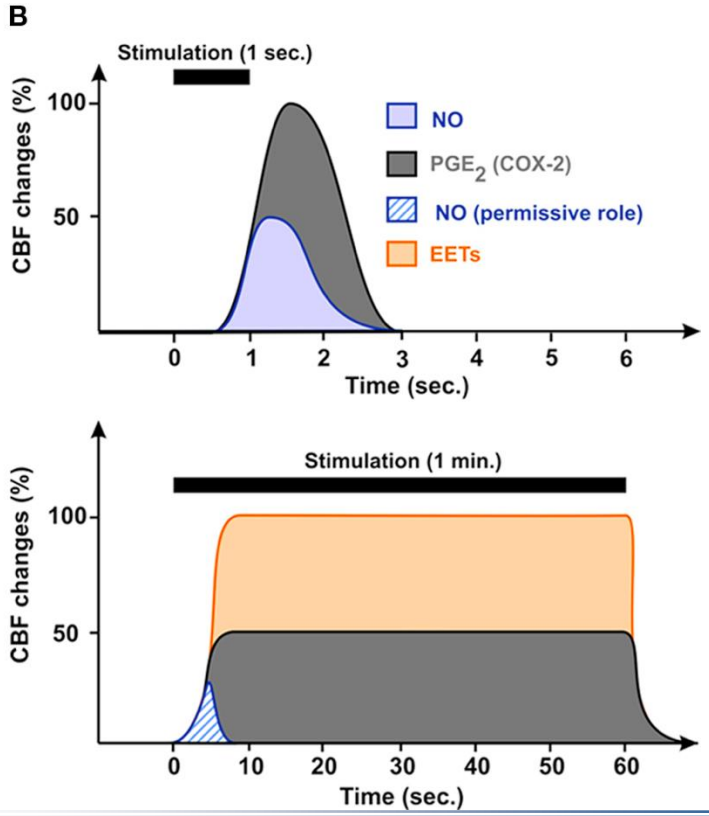


http://orion.bme.columbia.edu/~hillman/Brain_Imaging.html

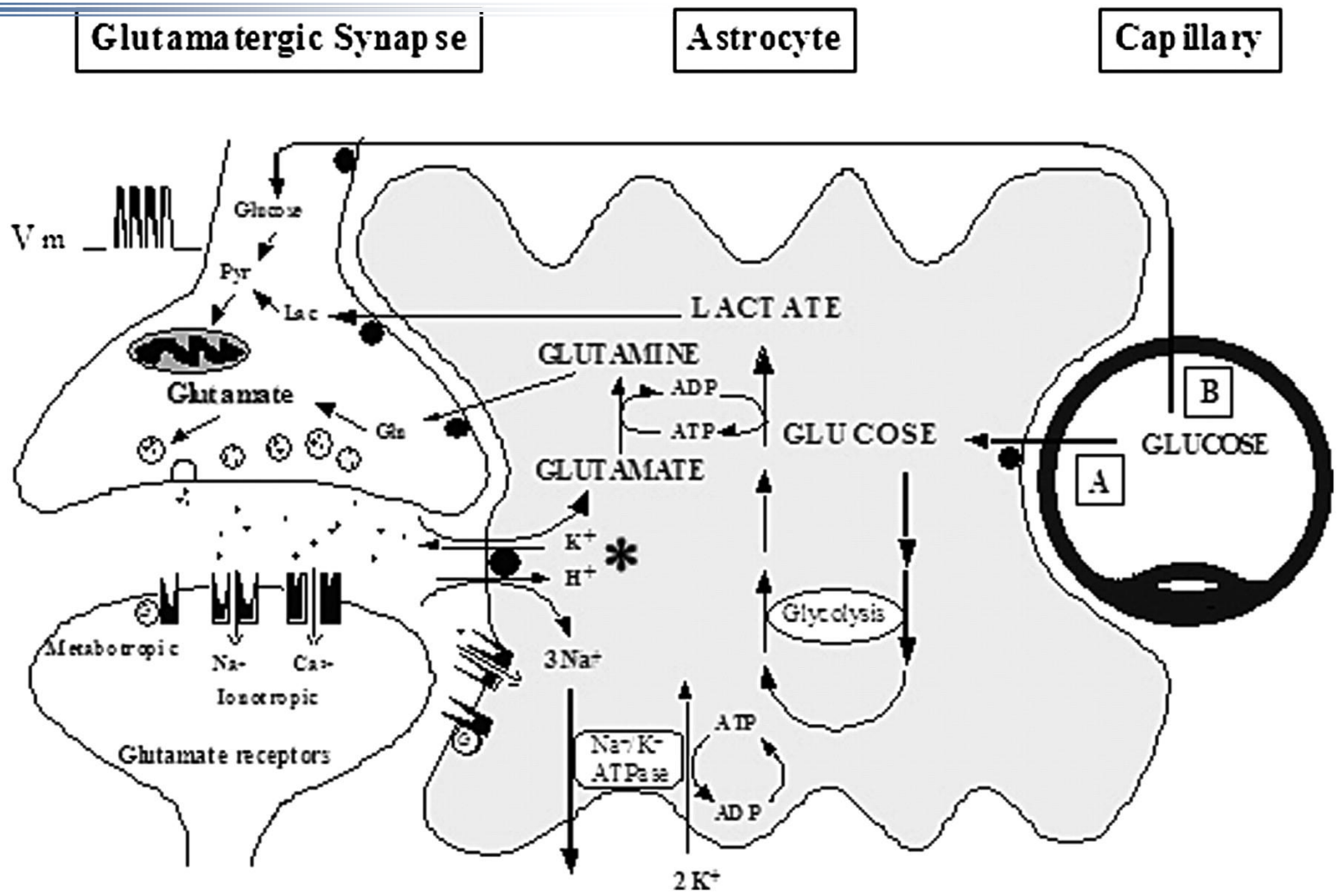
Neurovascular coupling: where are the neurons?

- Regulation of microvessels by pyramidal cells, GABA interneurons and astrocytes, and their effects to temporally regulate CBF changes
- Brief stimulations (1 s) are more likely to involve neurally-derived mediators whereas sustained stimulation (1 min) are more susceptible to recruit astrocyte-derived messengers



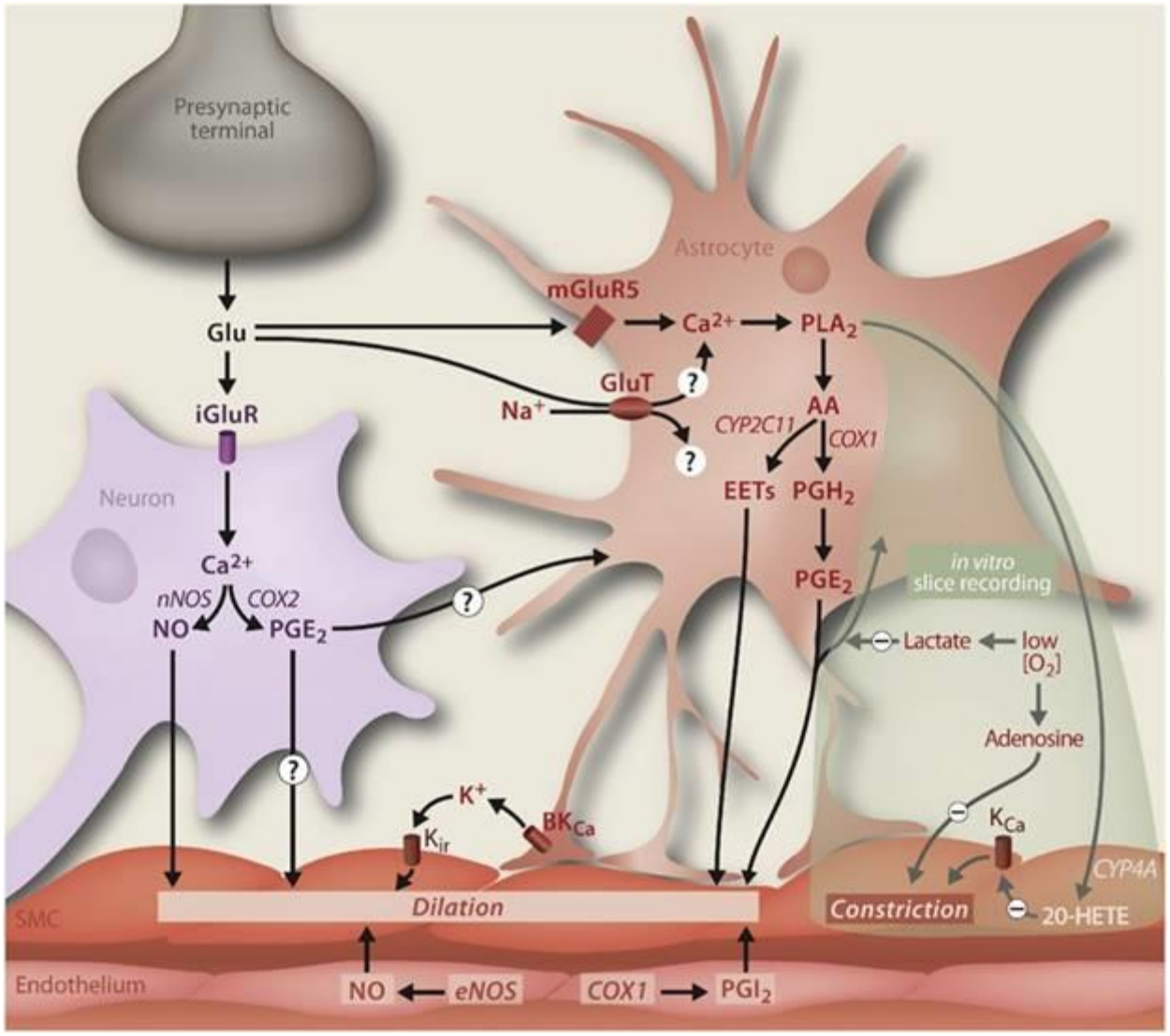


Neurovascular coupling: where are the neurons?



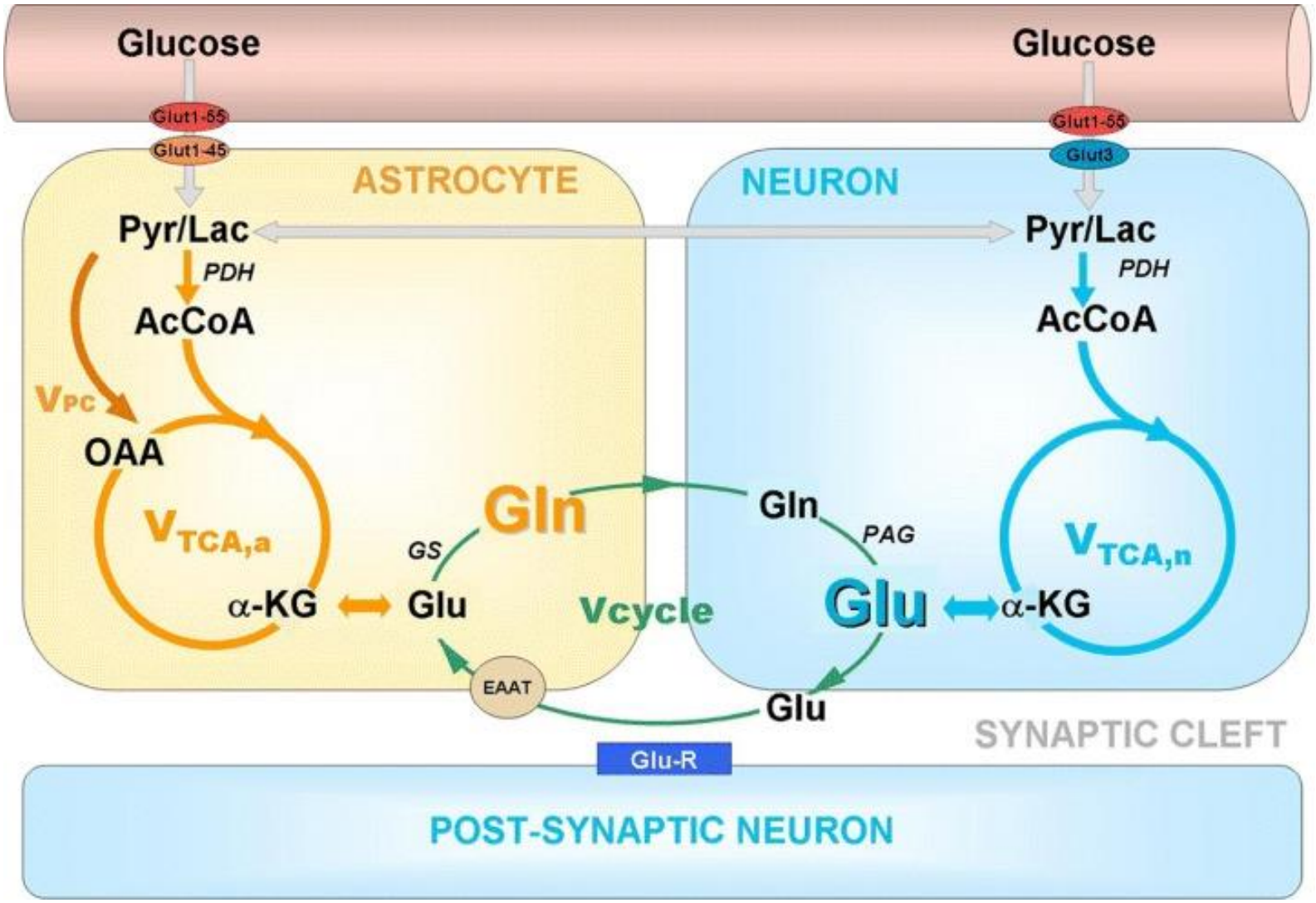
Pierre J Magistretti Am J Clin Nutr 2009;90:875S-880S

The cerebrovascular unit: where the 'signal' comes from

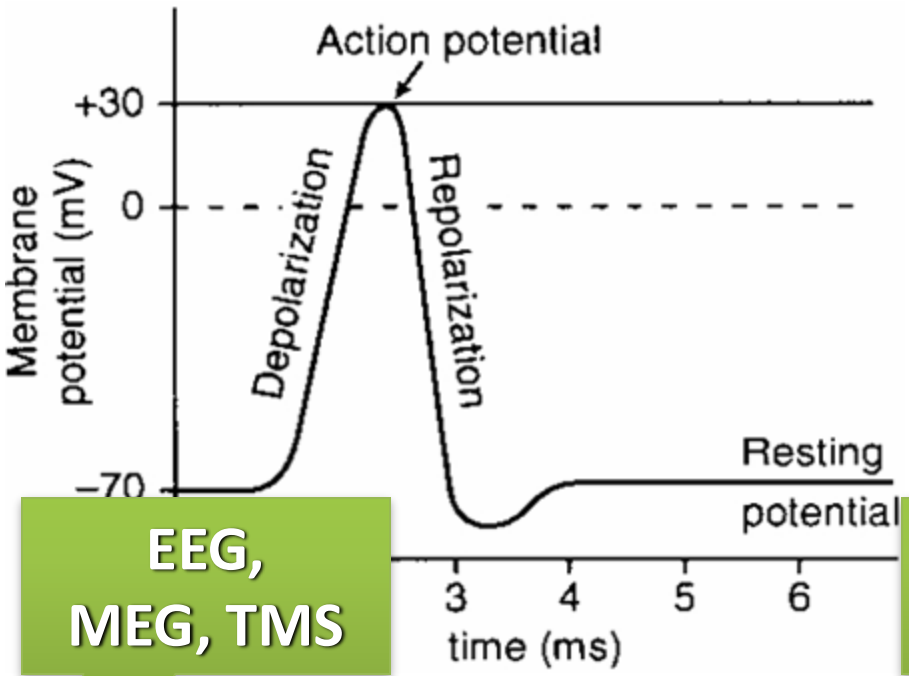


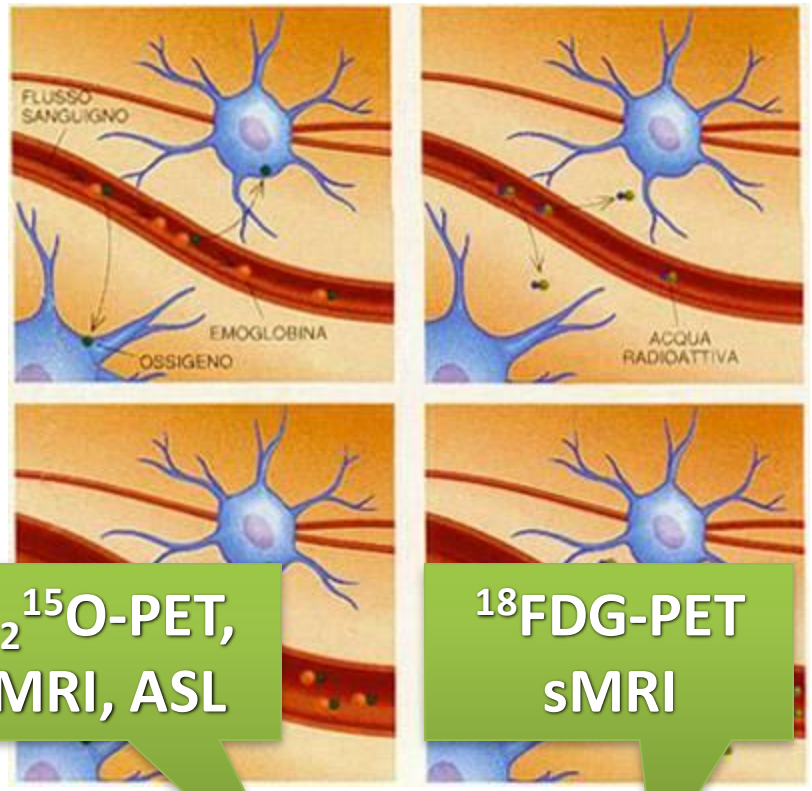
Petzold and Murthy, Neuron 2011

Neurovascular coupling: where are the neurons?



The cerebrovascular unit: where the 'signal' comes from



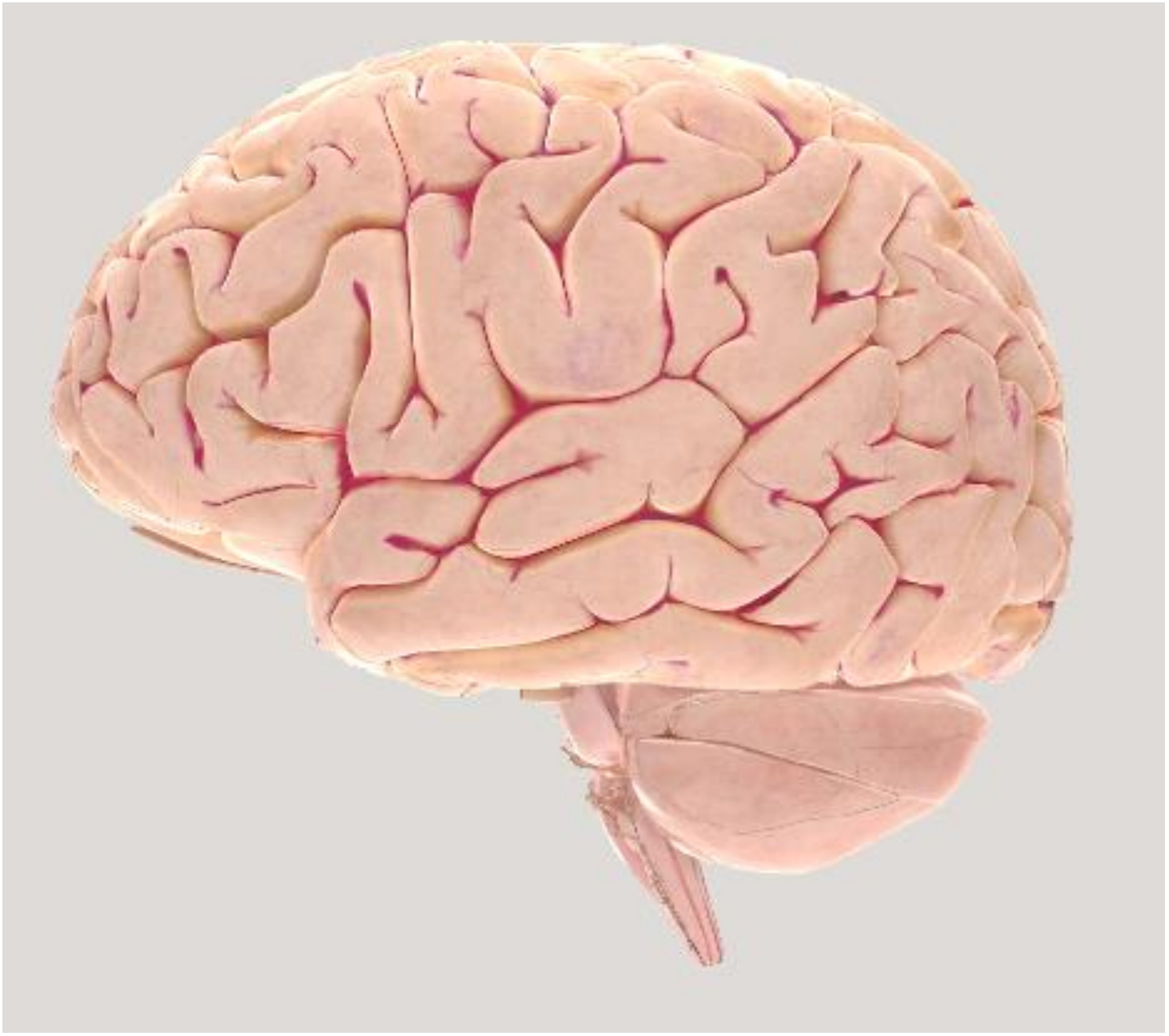


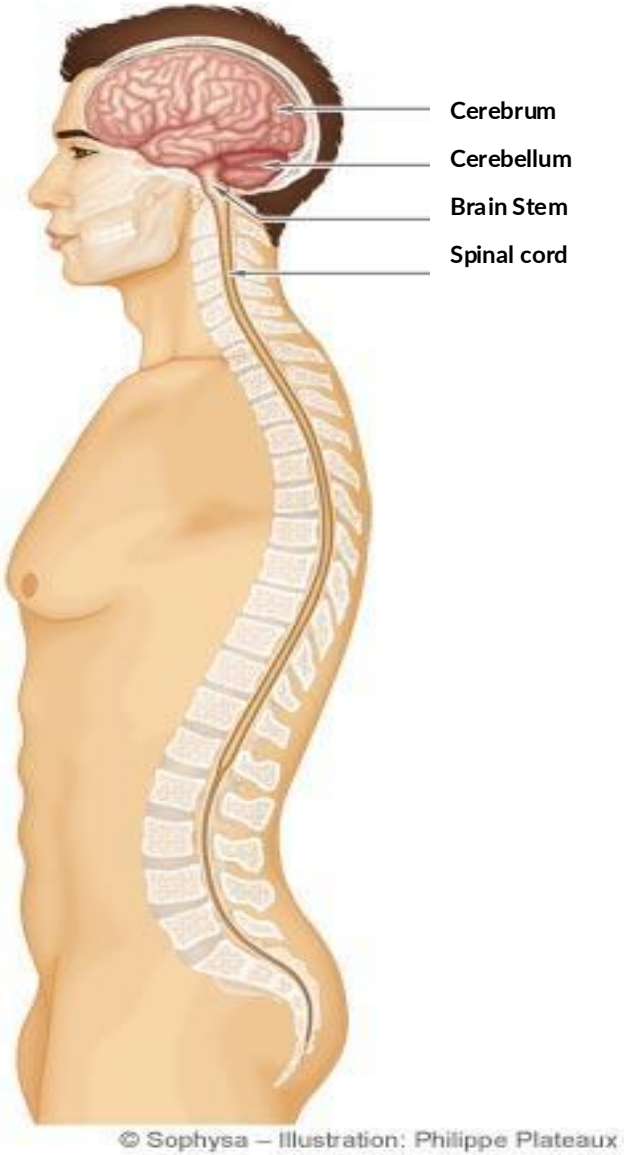
EEG, MEG, TMS

$H_2{}^{15}O$-PET, fMRI, ASL

^{18}FDG-PET sMRI

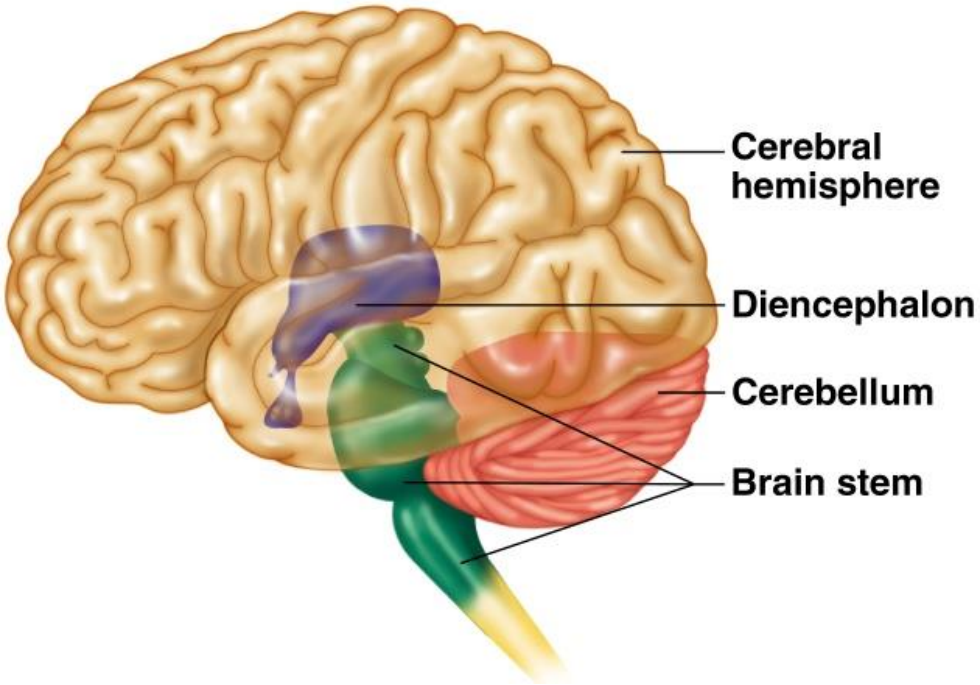
↑ Neuronal synaptic activity → ↑ Activity Na^+/K^+ pump → ↑ ATP Request → ↑ Glucose and oxygen request → ↑ Cerebral blood flow sypply → ↑ Glucose oxydative metabolism and ATP production



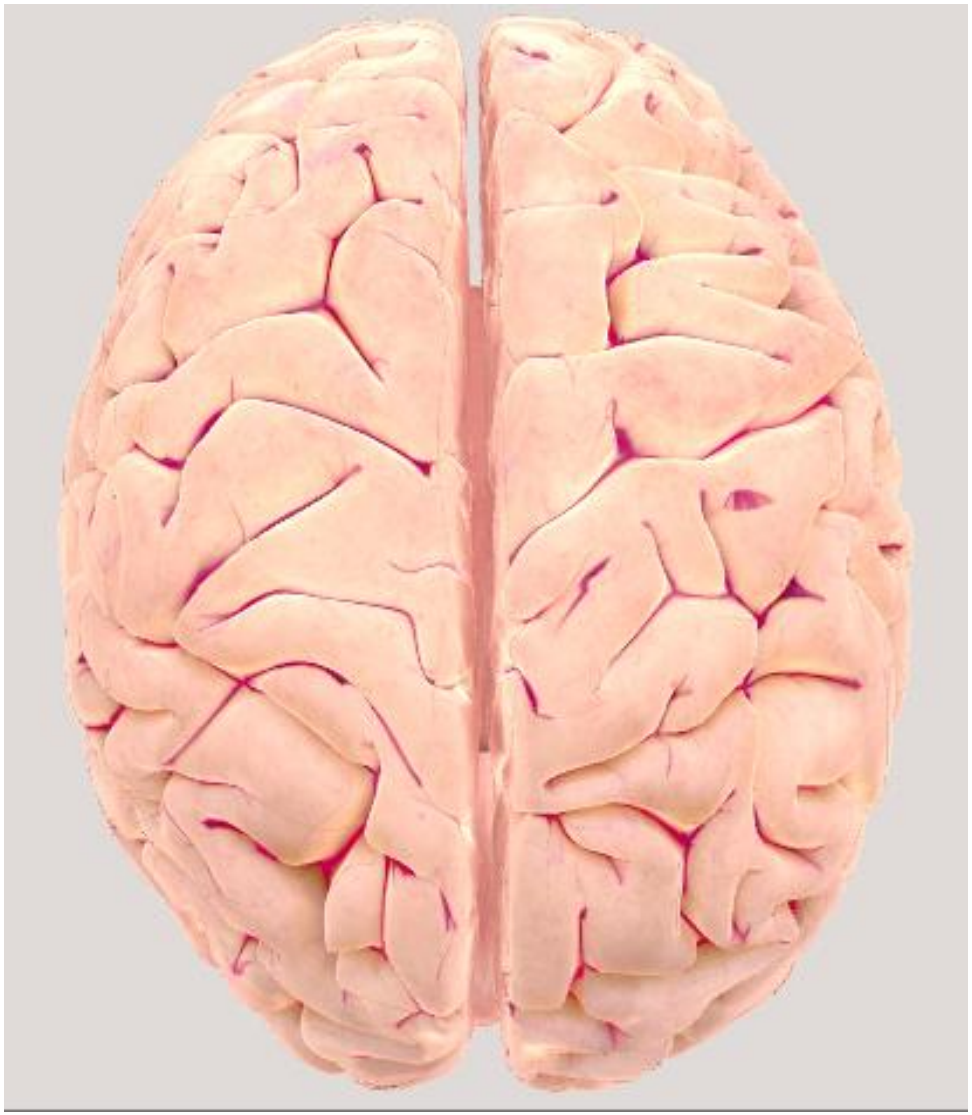


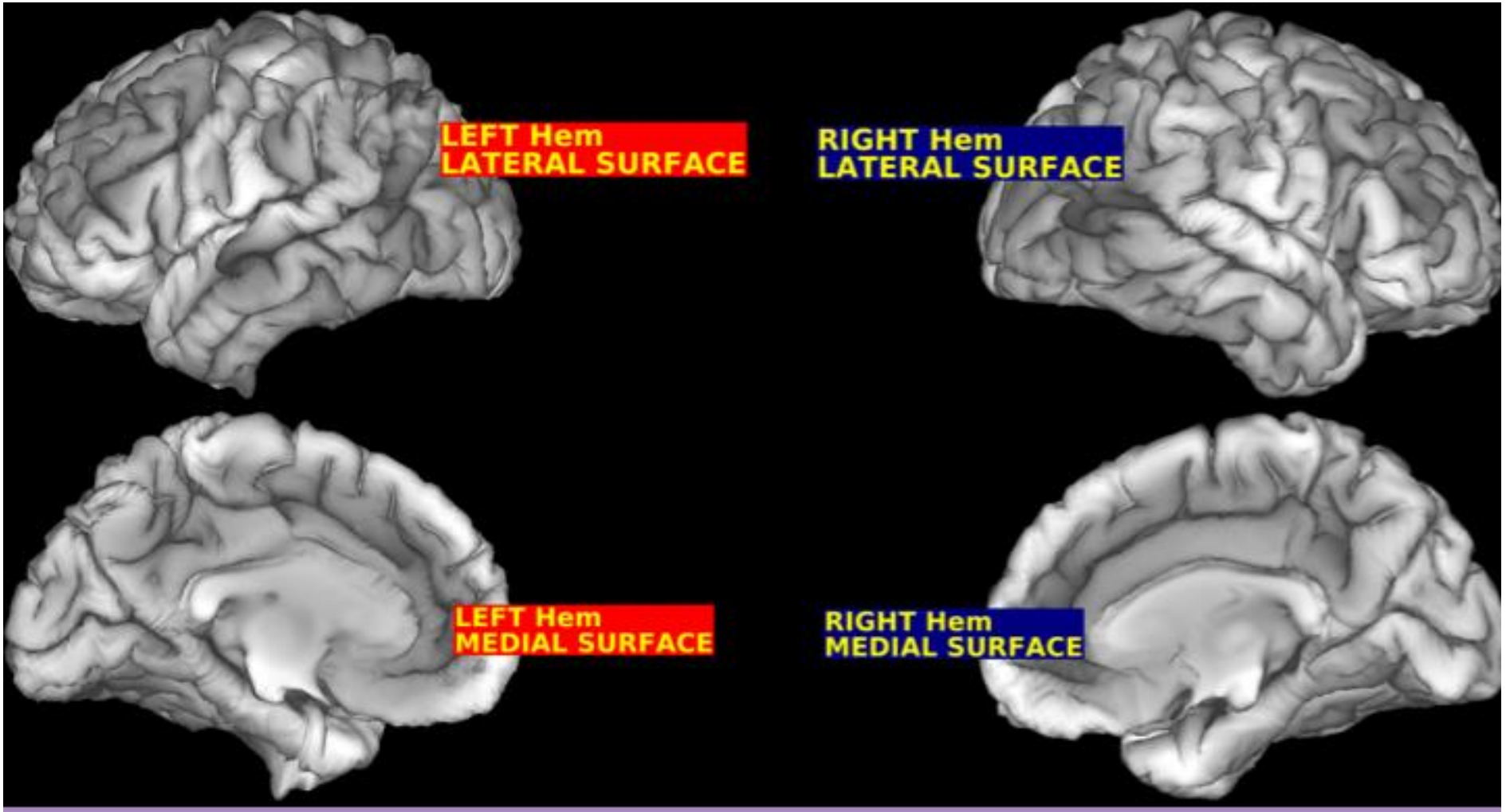
Regions of the Brain

- Cerebral hemispheres
- Diencephalon
- Brain stem
- Cerebellum



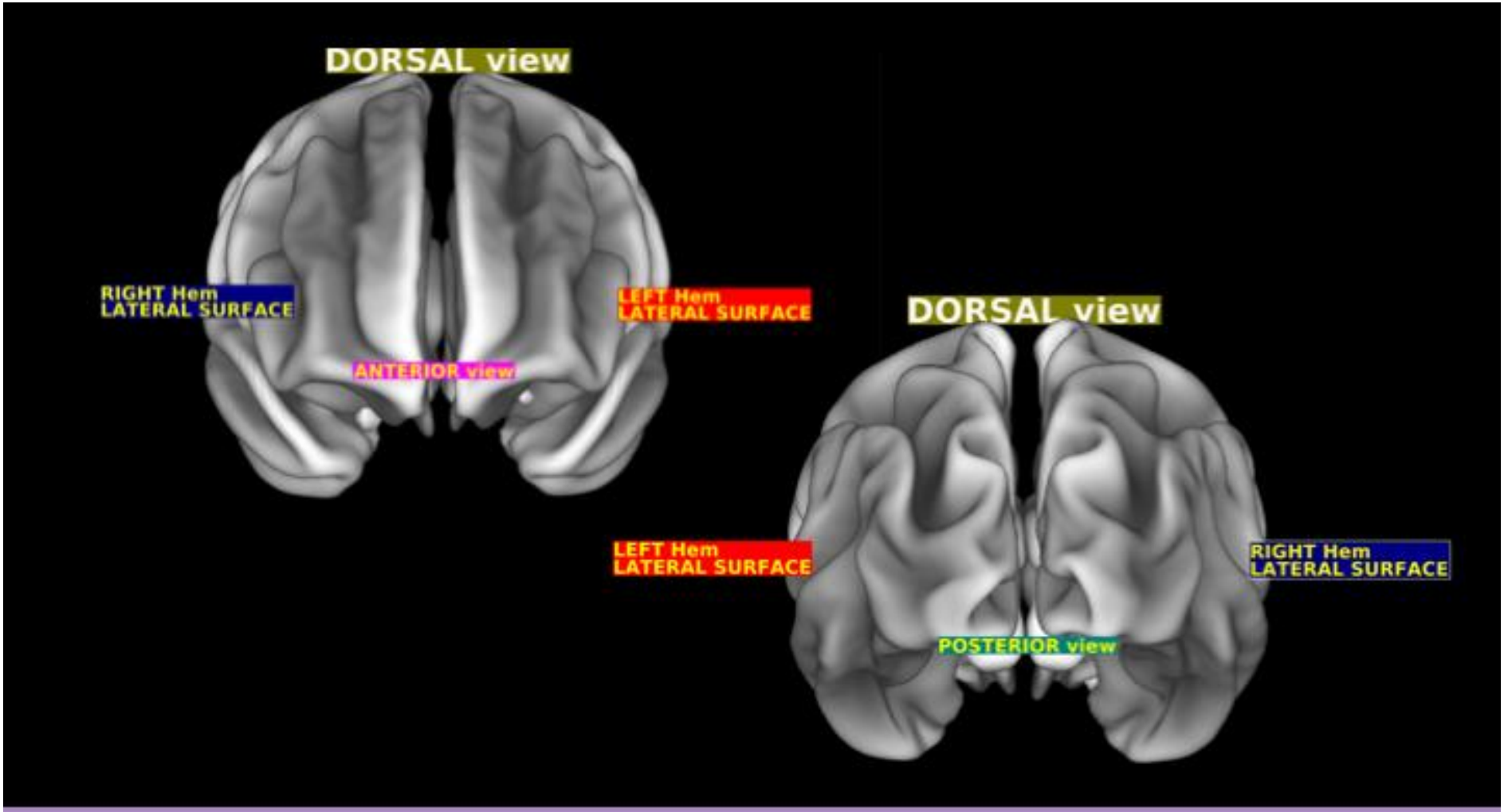
The *cerebrum*, divided into 2 hemispheres





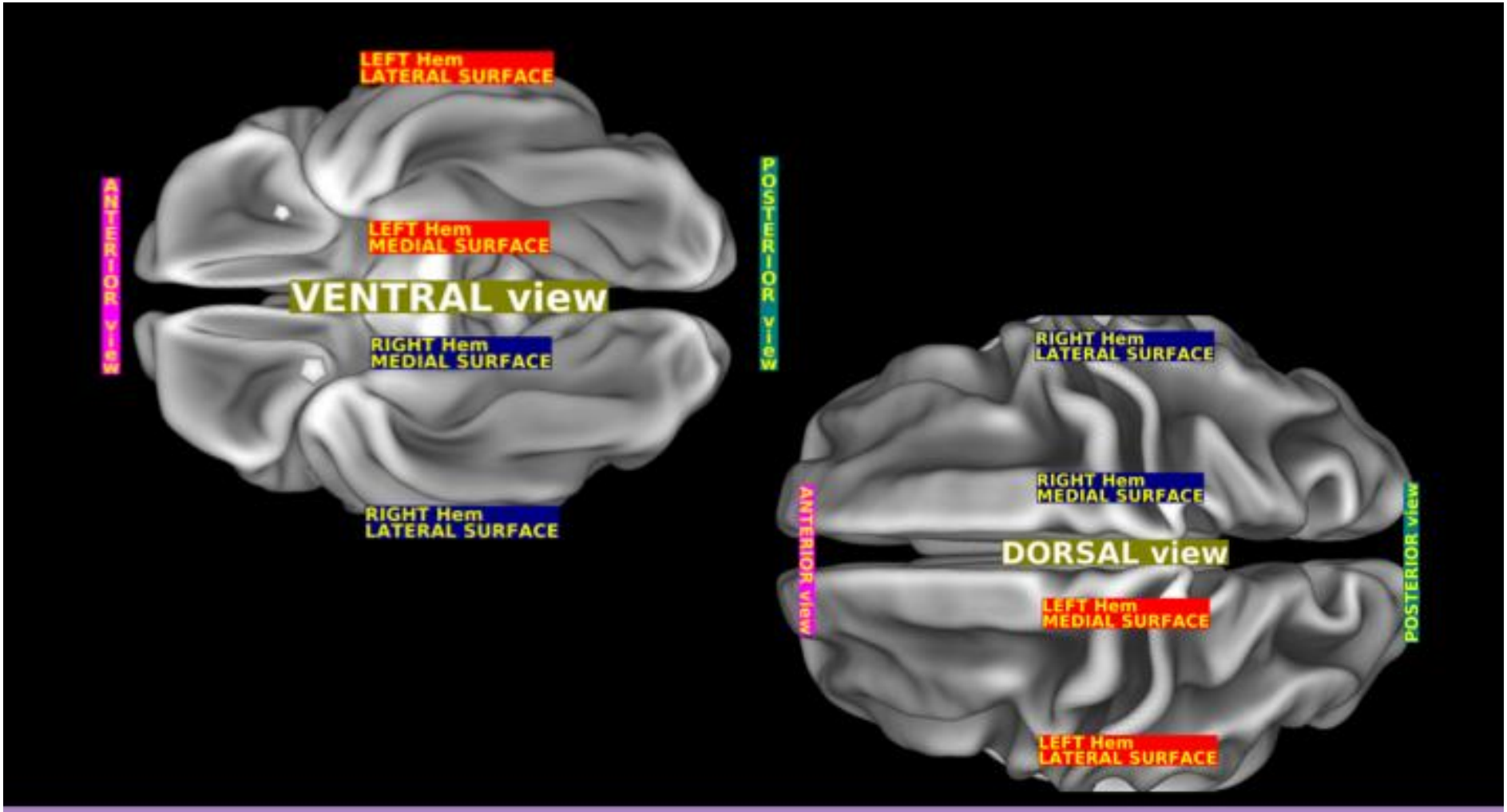
CEREBRAL HEMISPHERES

a first subdivision



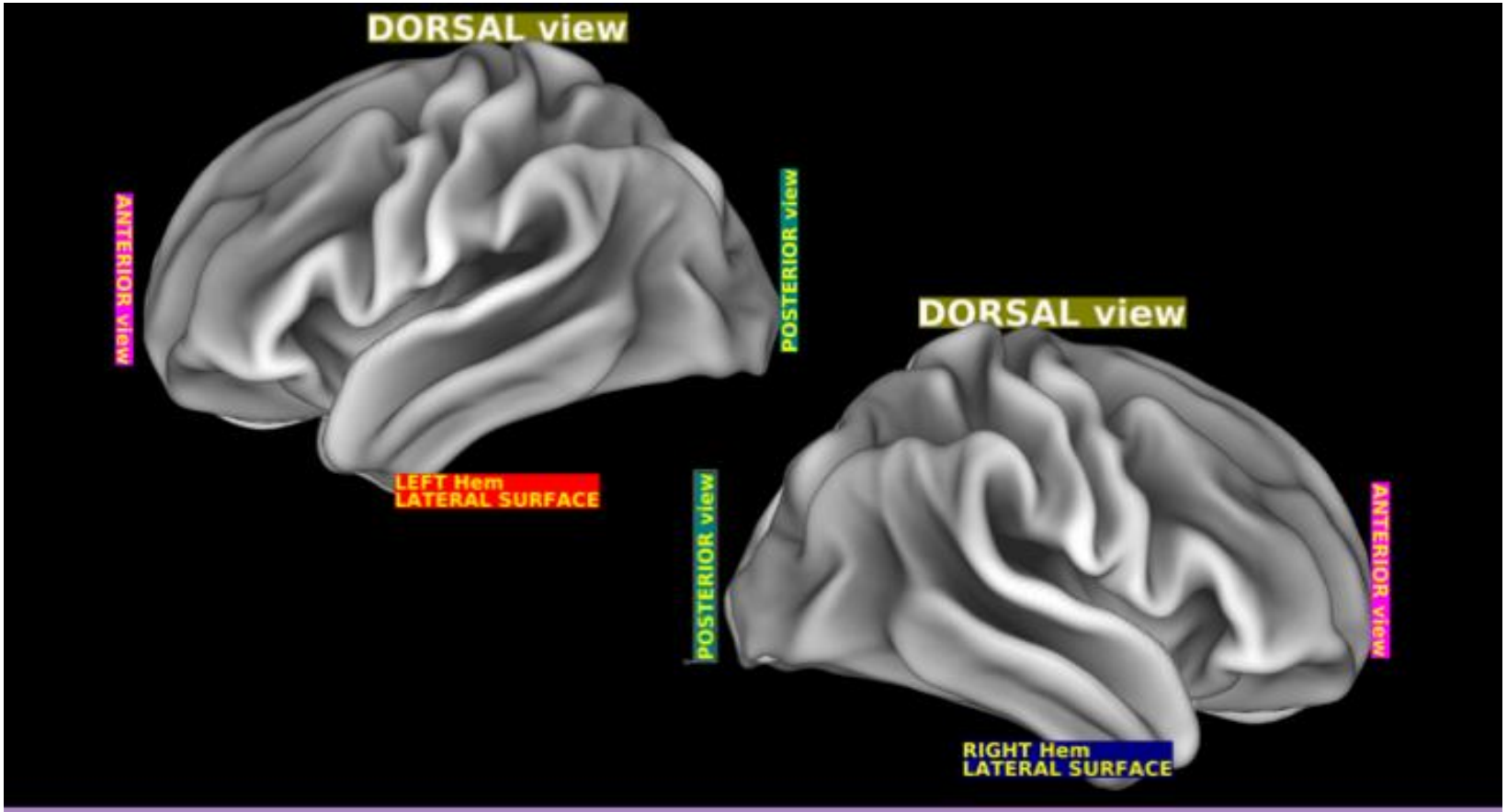
CEREBRAL HEMISPHERES

a first subdivision



CEREBRAL HEMISPHERES

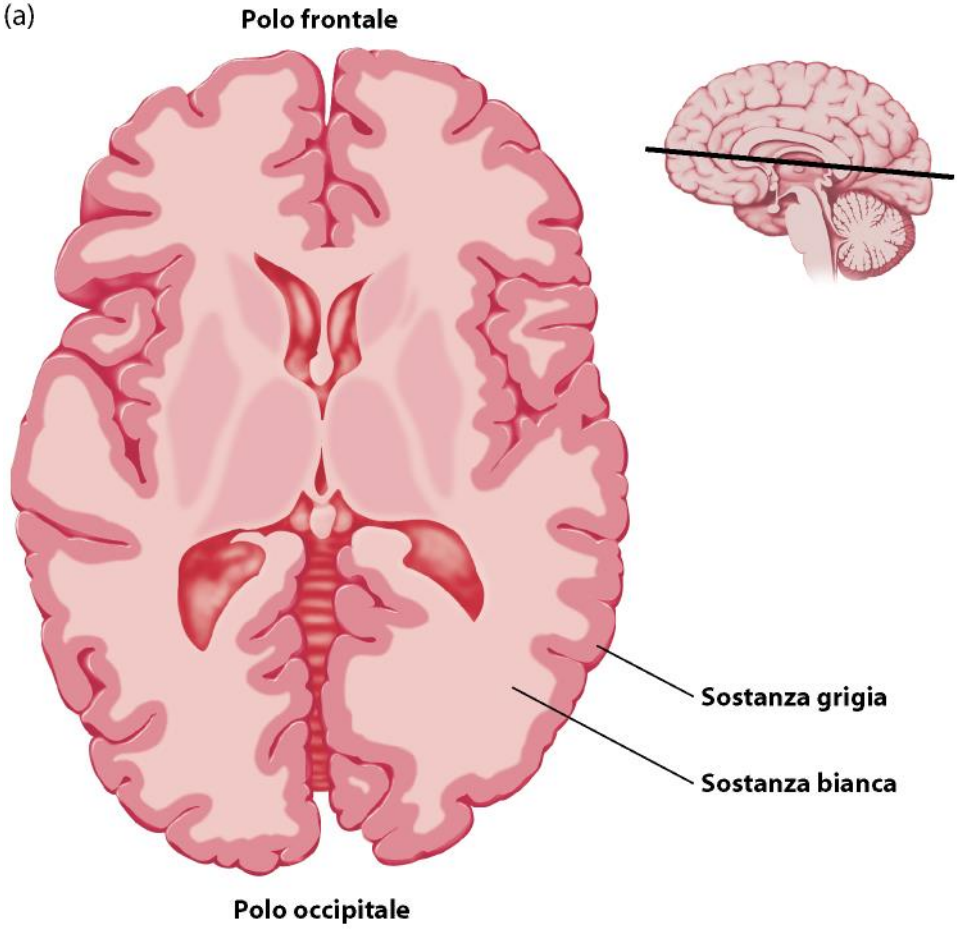
a first subdivision



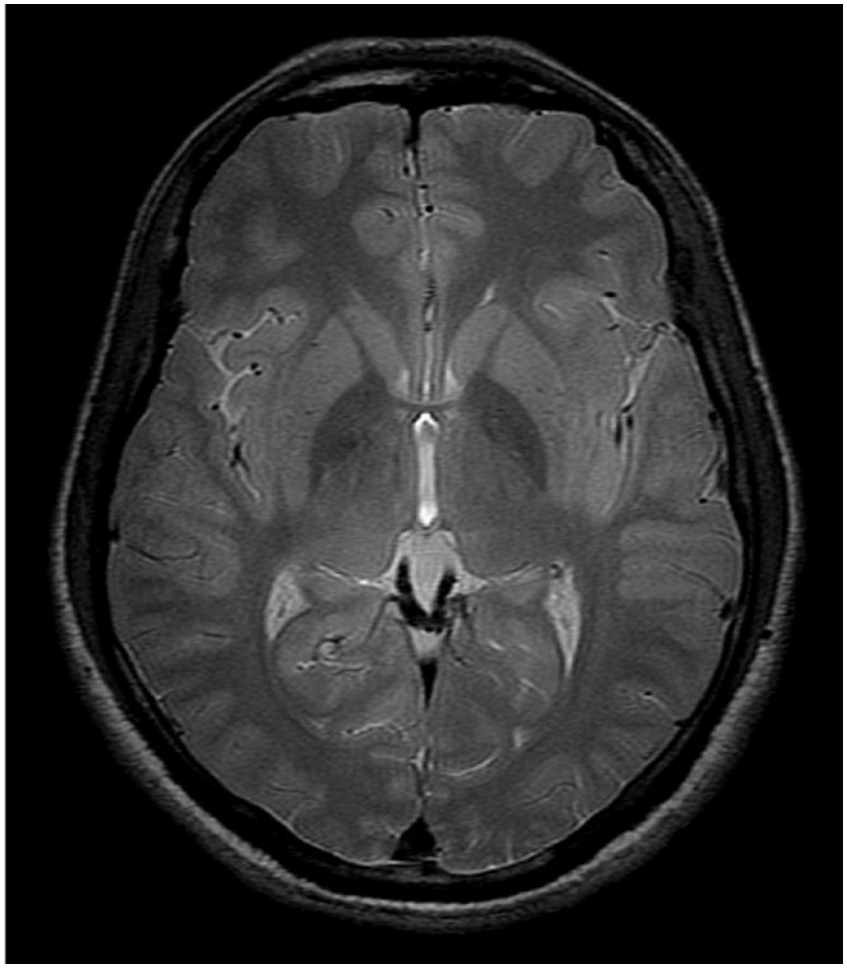
CEREBRAL HEMISPHERES

a first subdivision

(a)

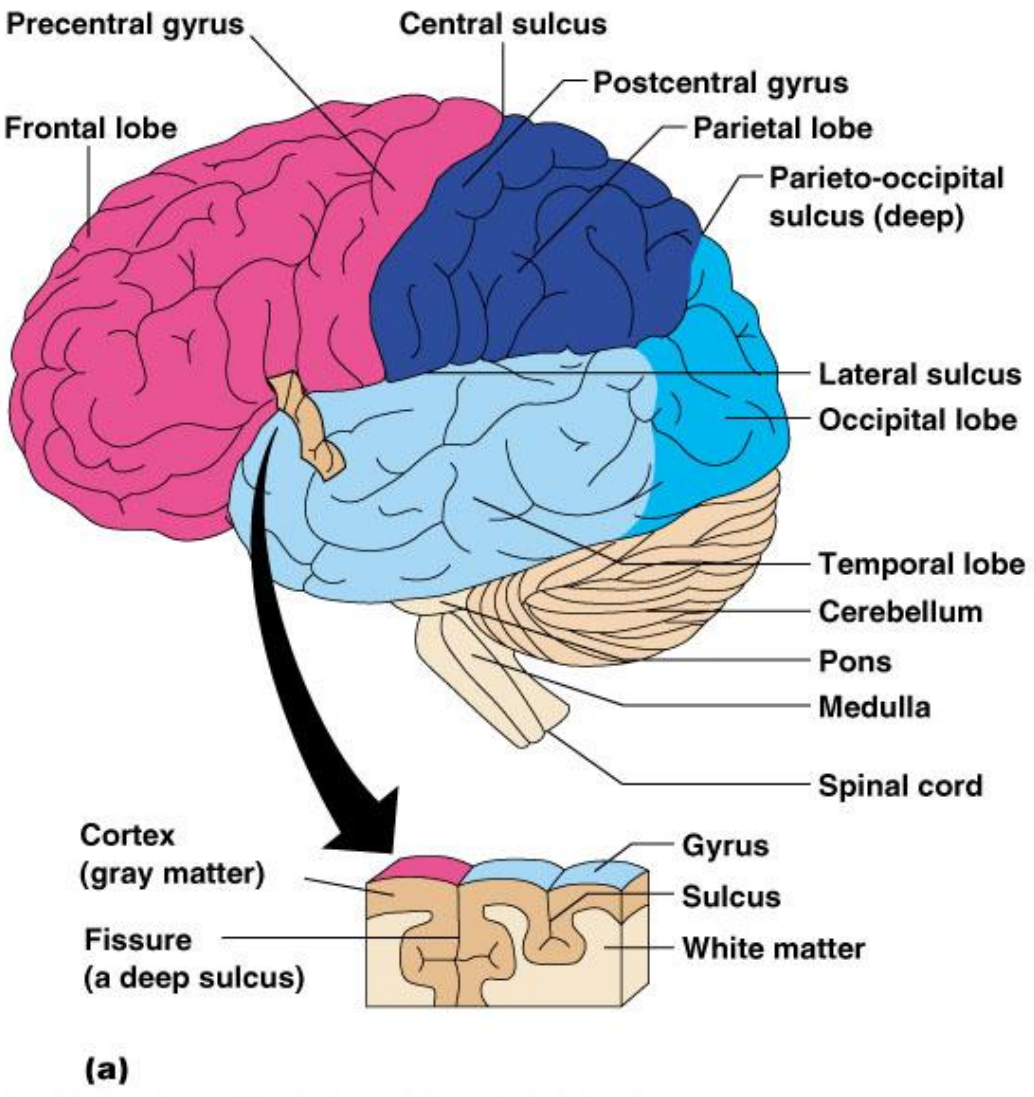


(b)



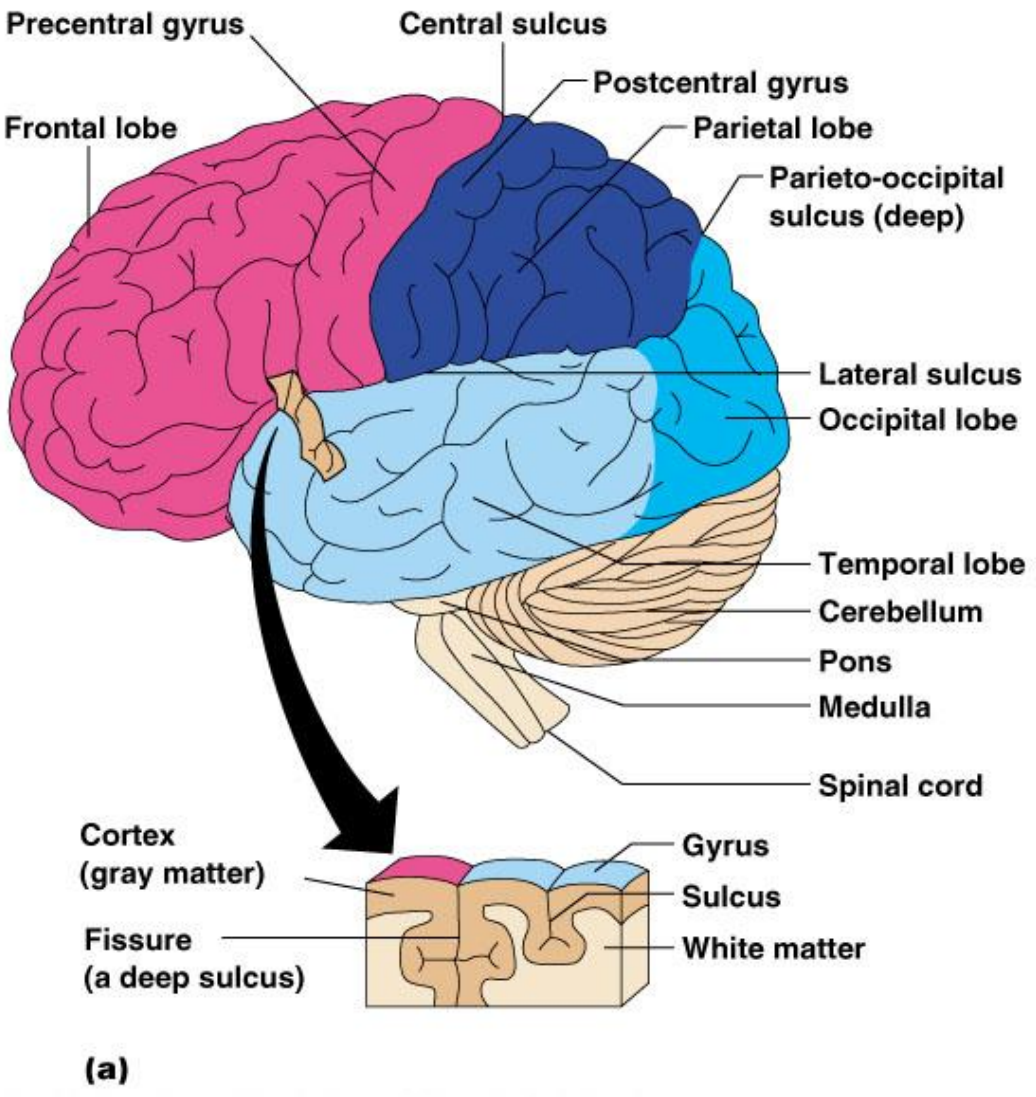
Cerebral Hemispheres (Cerebrum)

- Paired (left and right) superior parts of the brain
- Include more than half of the brain mass

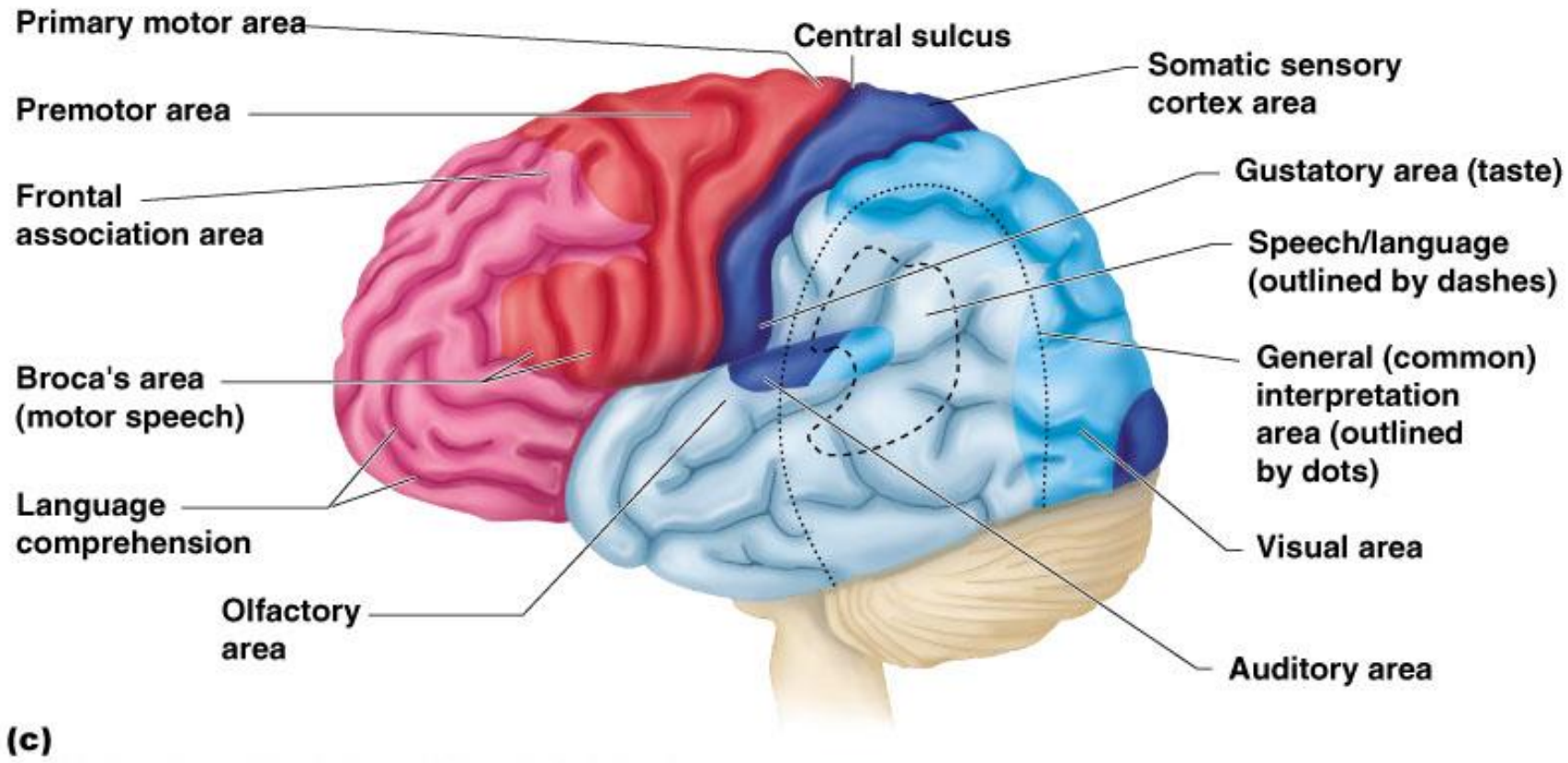


Cerebral Hemispheres (Cerebrum)

- The surface is made of ridges (gyri) and grooves (sulci)

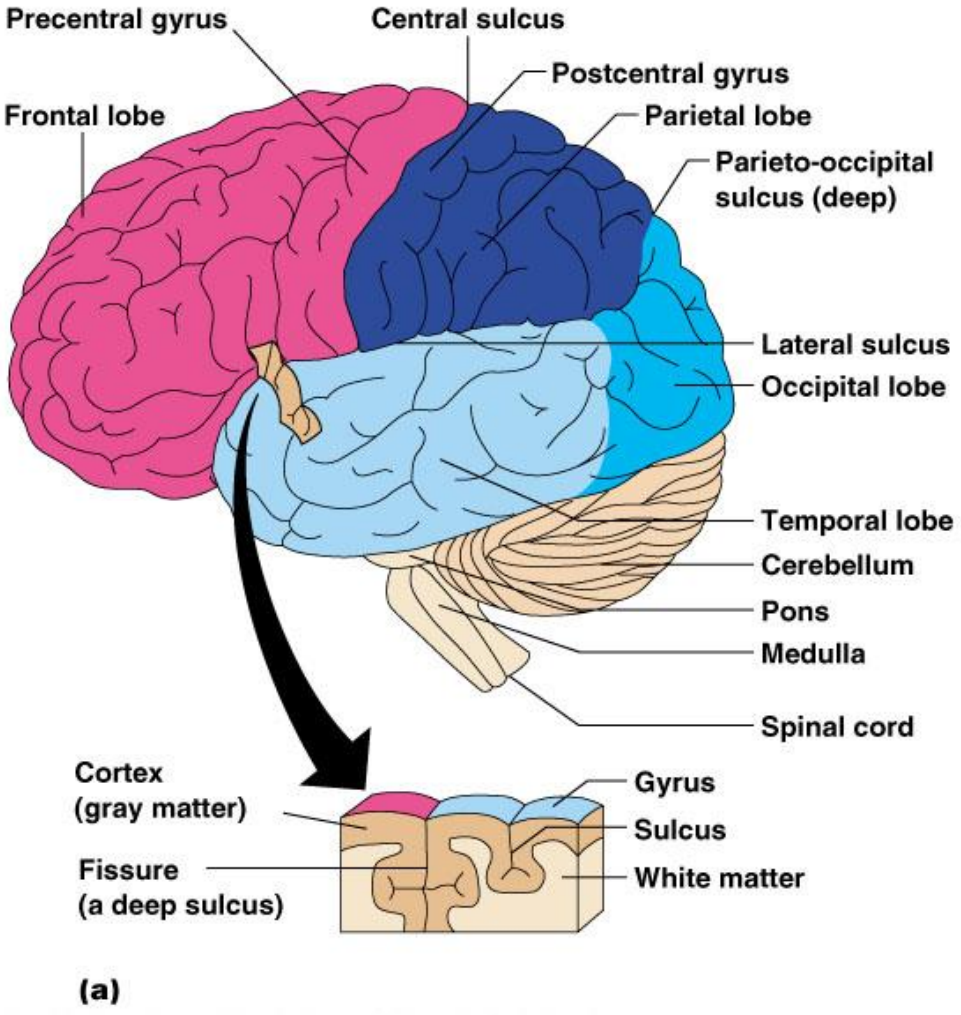


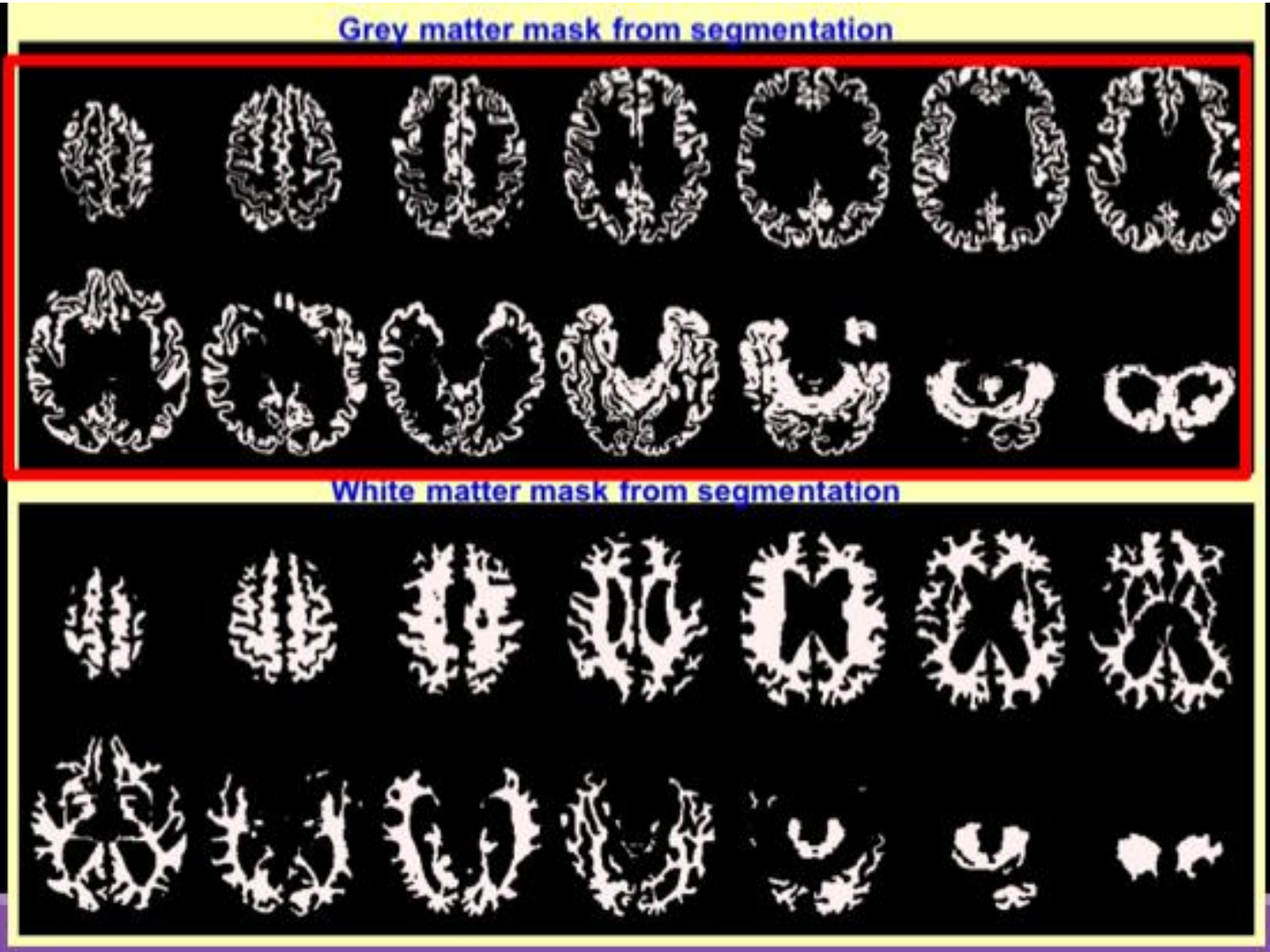
Specialized Area of the Cerebrum



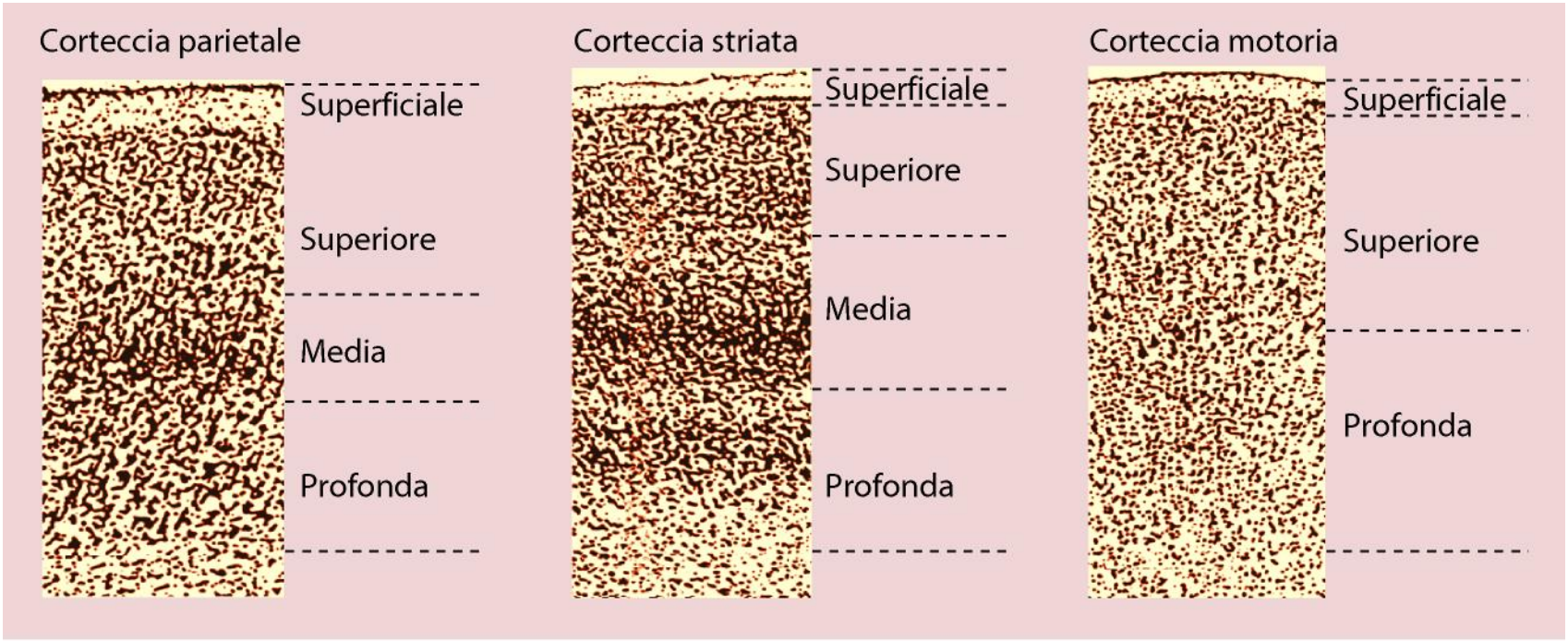
Layers of the Cerebrum

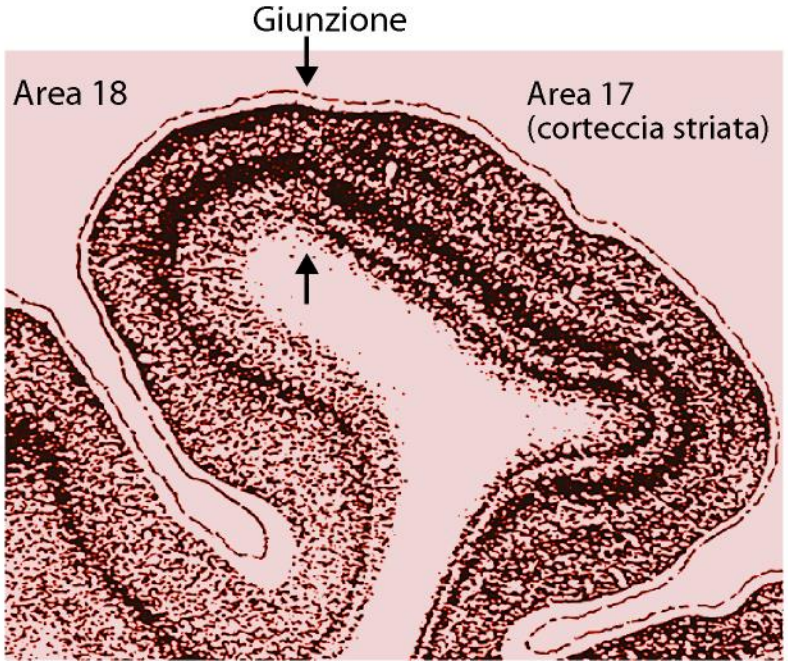
- **Gray matter**
  - **Outer layer**
  - **Composed mostly of neuron cell bodies**





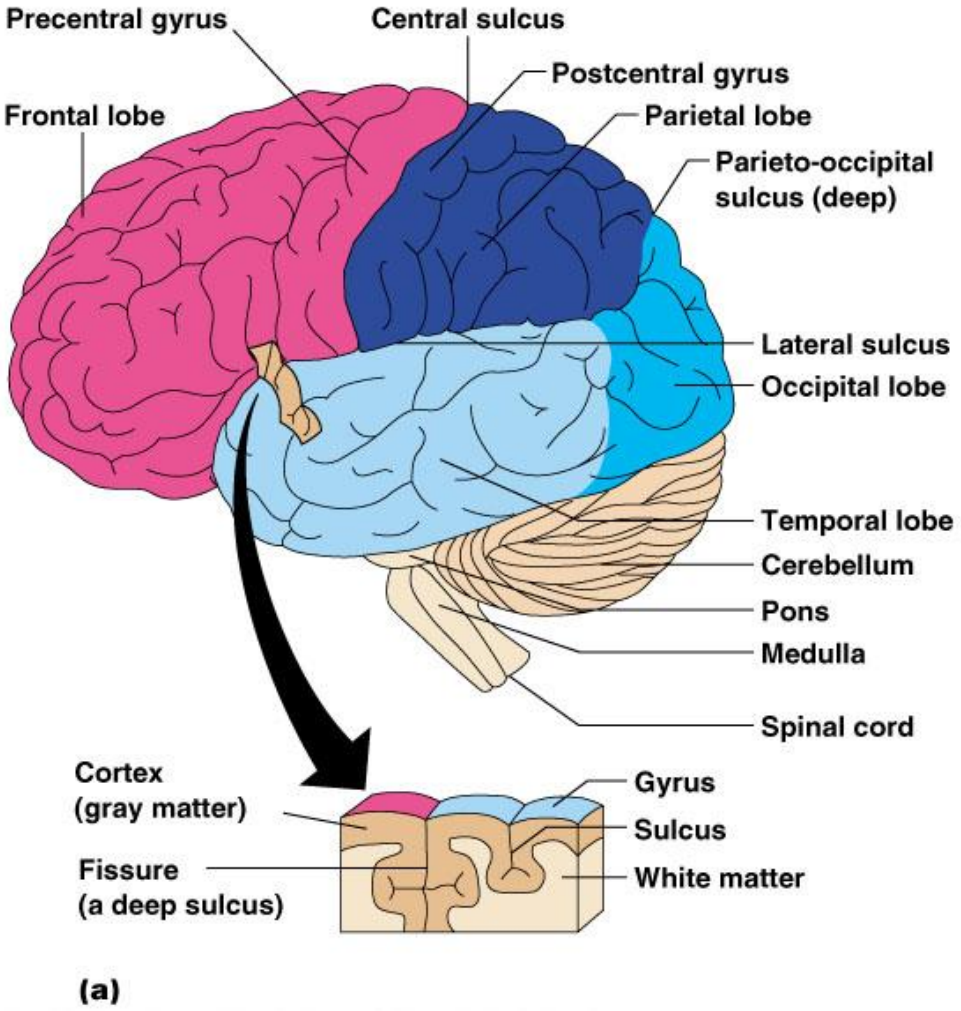
Gray matter contains neurons (top). That is where synapses do happen!
White matter is made up of all the axons departing from neurons (bottom)

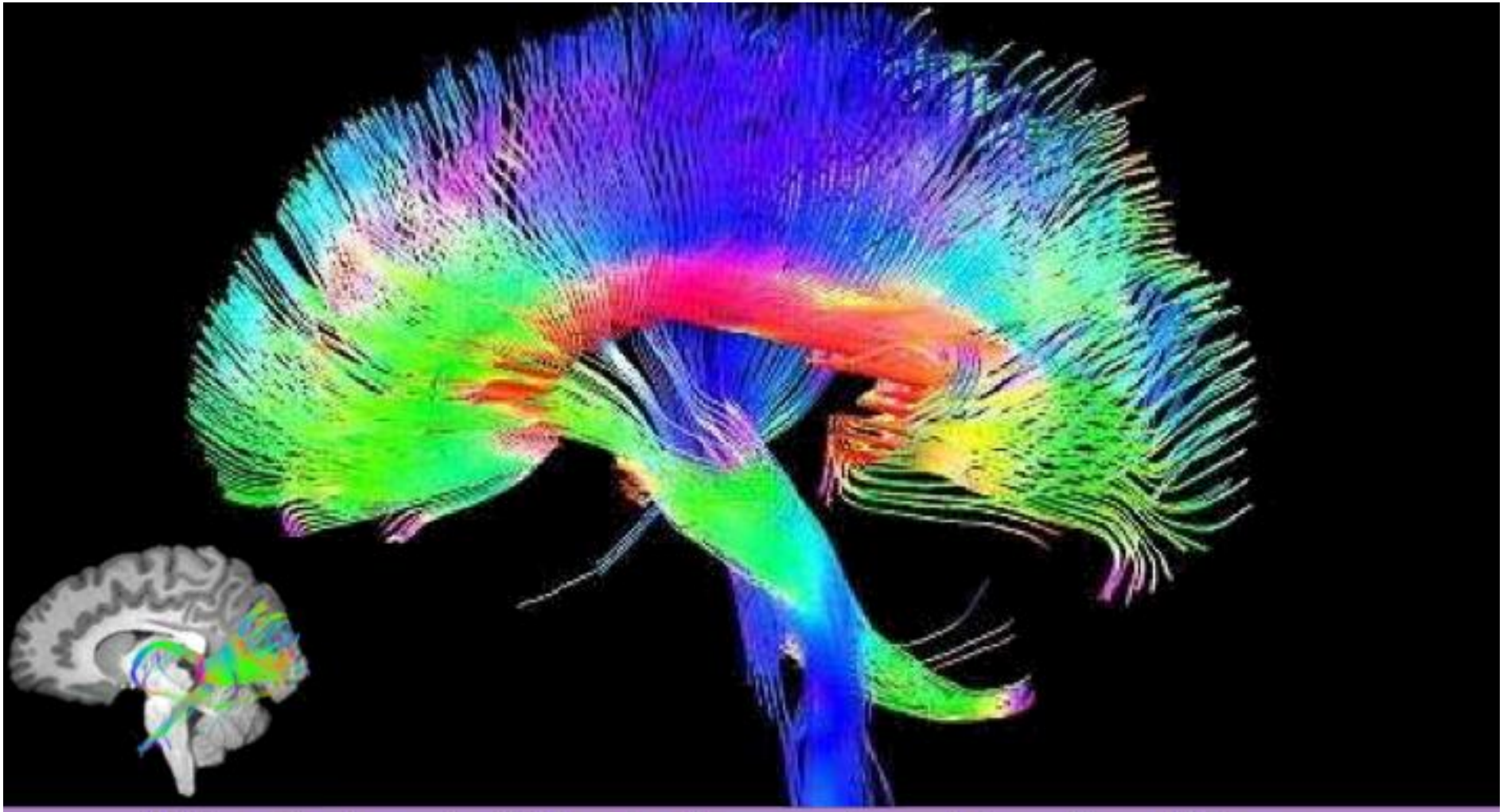

Corteccia parietale
Superficiale
Superiore
Media
Profonda
Corteccia striata
Superficiale
Superiore
Media
Profonda
Corteccia motoria
Superficiale
Superiore
Profonda


Giunzione
Area 18
Area 17
(corteccia striata)

Layers of the Cerebrum

- White matter
  - Fiber tracts inside the gray matter
  - Example: corpus callosum connects hemispheres



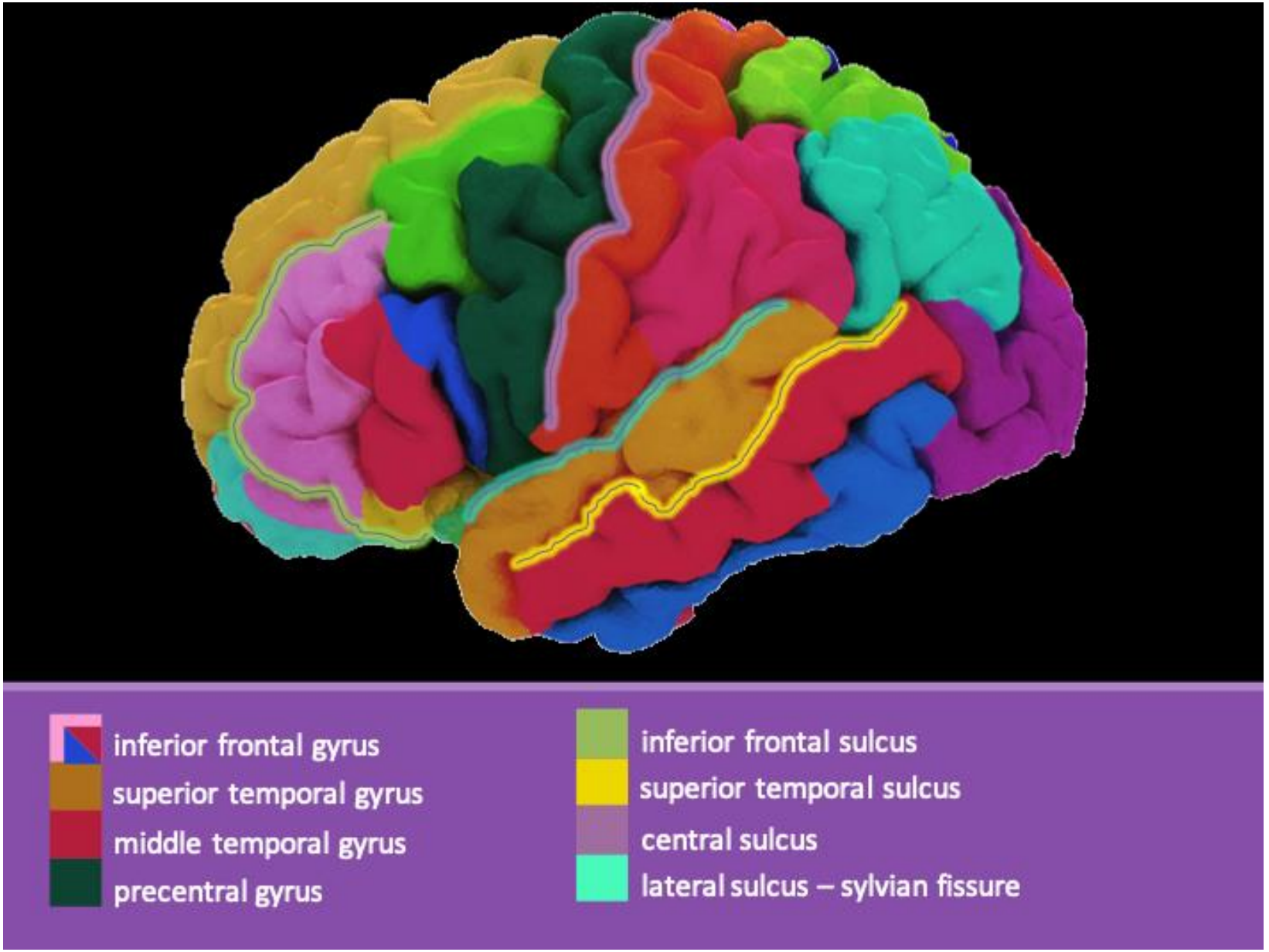


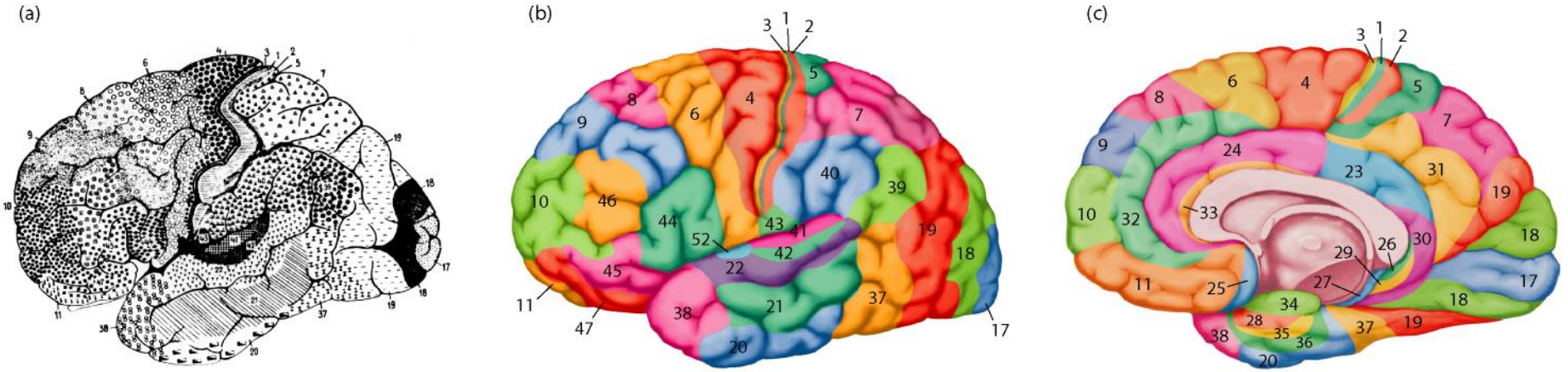
White matter is organized in fiber bundles, ascending and descending, which come and go to and from the brain and the spinal cord. White matter appears as white because of its covering made up of myelin, a fatty substance favoring the propagation of the electrical signal.

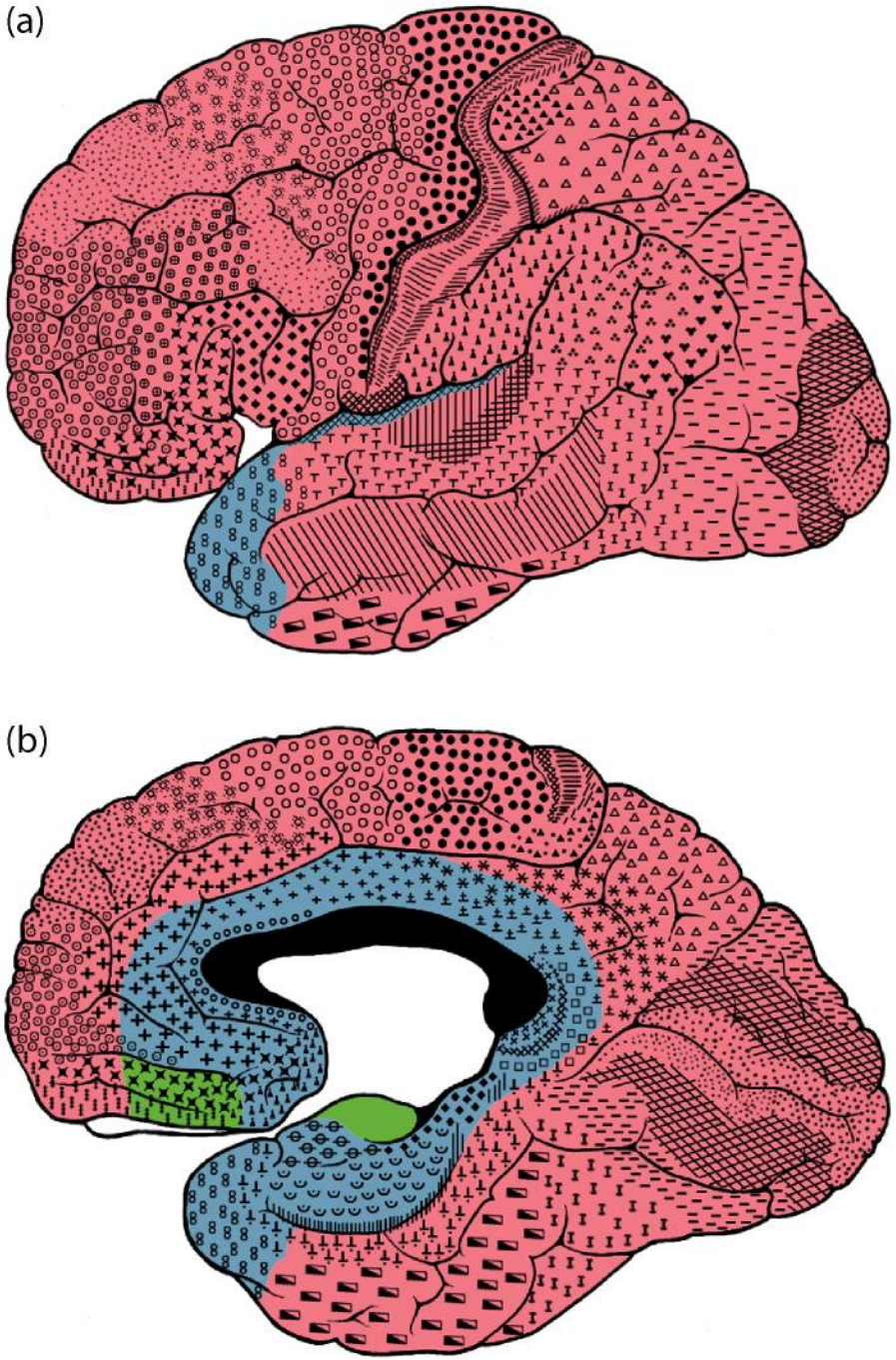
white matter is the highway for synapses

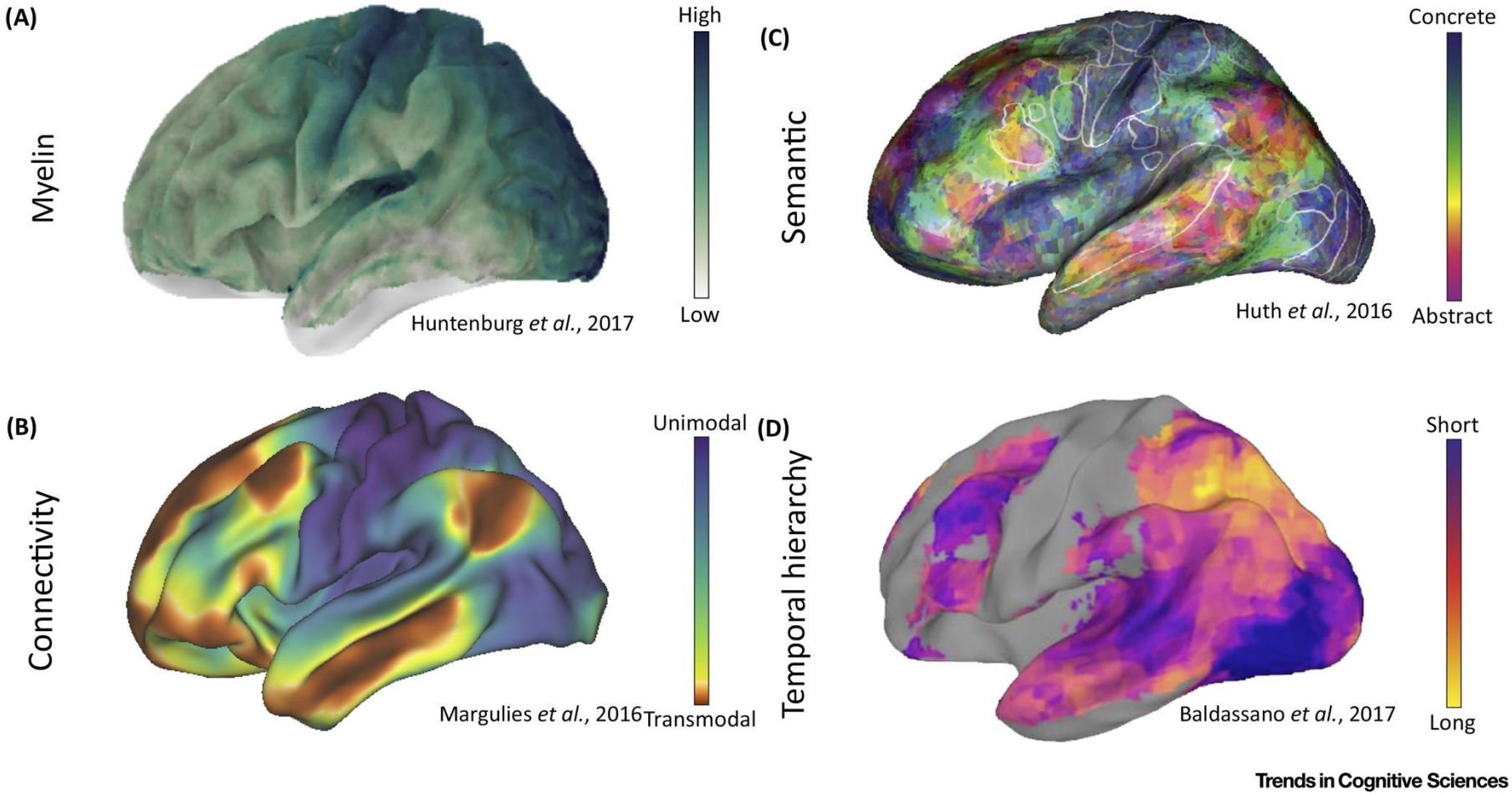
Lobes of the Cerebrum

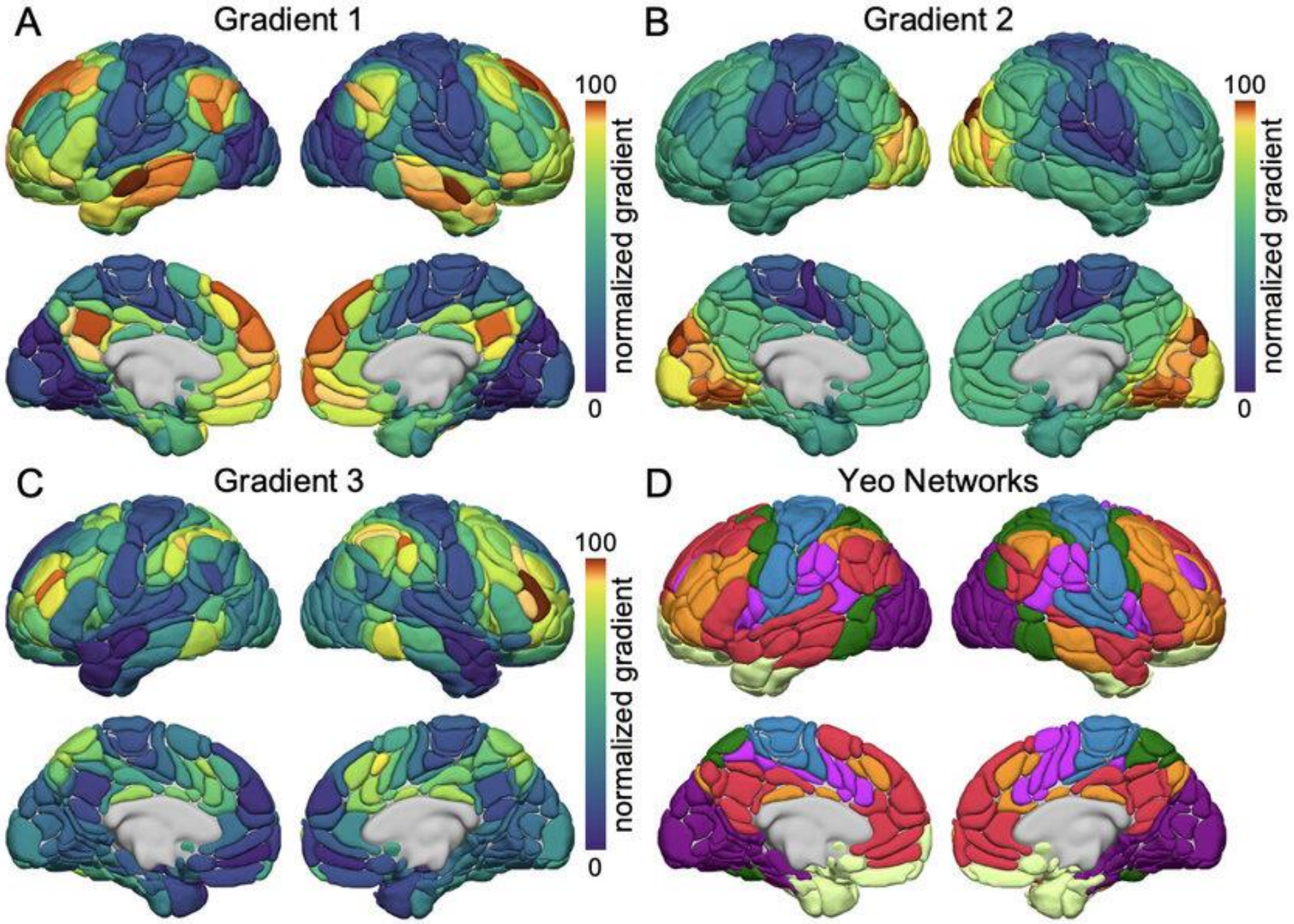
- Fissures (deep grooves) divide the cerebrum into lobes
- Surface lobes of the cerebrum
  - Frontal lobe
  - Parietal lobe
  - Occipital lobe
  - Temporal lobe


inferior frontal gyrus
superior temporal gyrus
middle temporal gyrus
precentral gyrus
inferior frontal sulcus
superior temporal sulcus
central sulcus
lateral sulcus – sylvian fissure

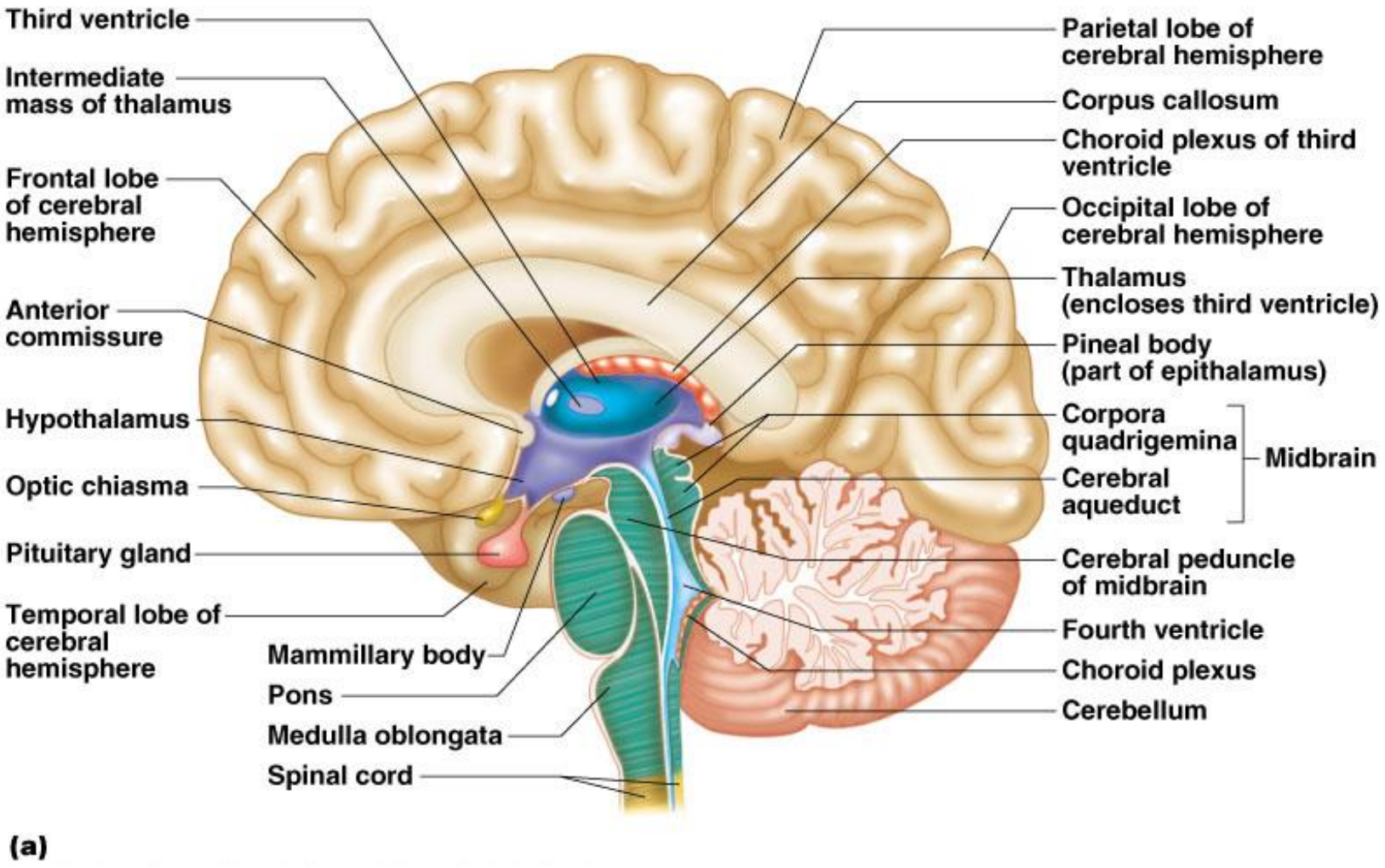




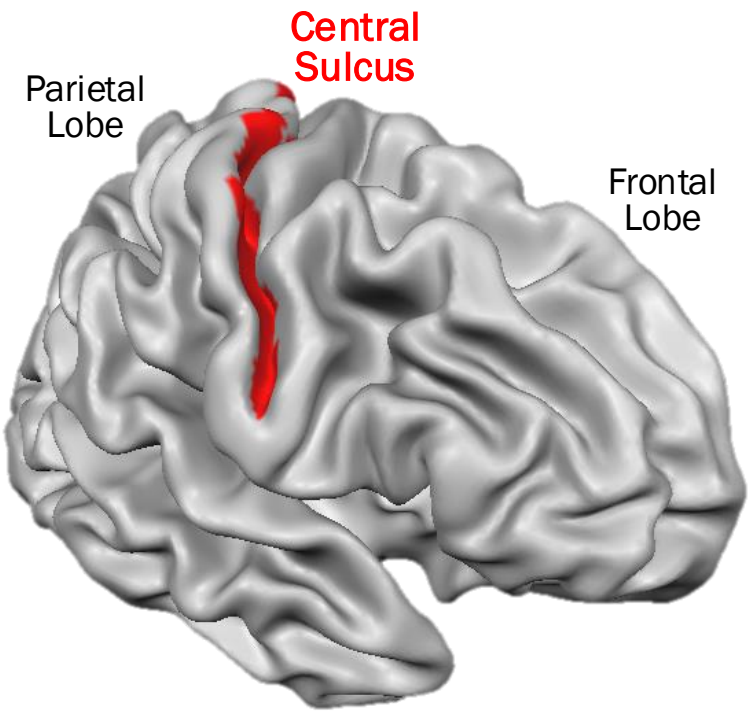

(A)
Myelin
High
Low
Huntenburg et al., 2017
(C)
Semantic
Concrete
Abstract
Huth et al., 2016
(B)
Connectivity
Unimodal
Transmodal
Margulies et al., 2016
(D)
Temporal hierarchy
Short
Long
Baldassano et al., 2017
Trends in Cognitive Sciences

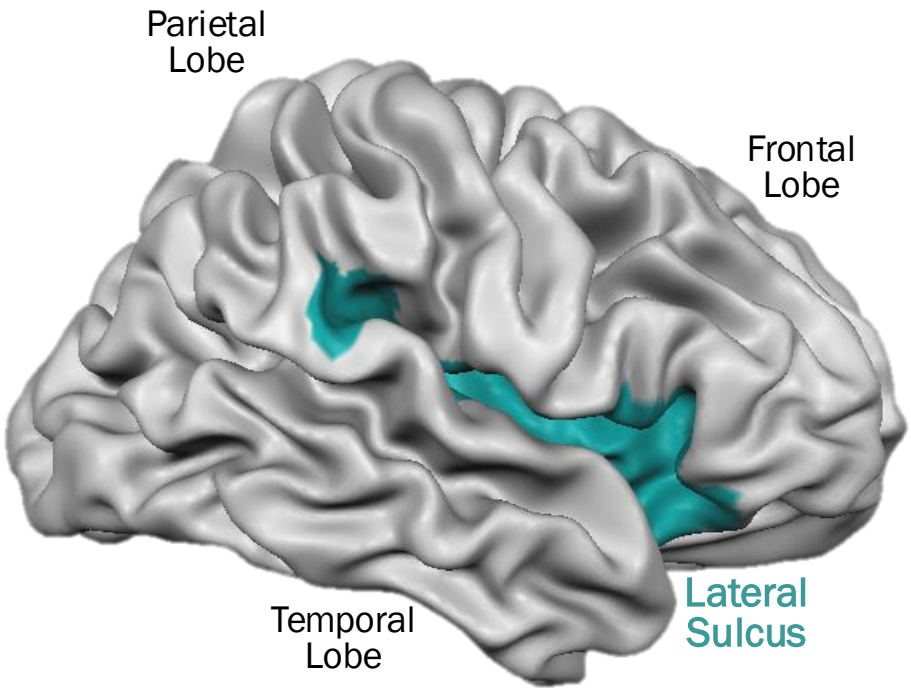

A
Gradient 1
100
normalized gradient
0
B
Gradient 2
100
normalized gradient
0
C
Gradient 3
100
normalized gradient
0
D
Yeo Networks

Lobes of the Cerebrum



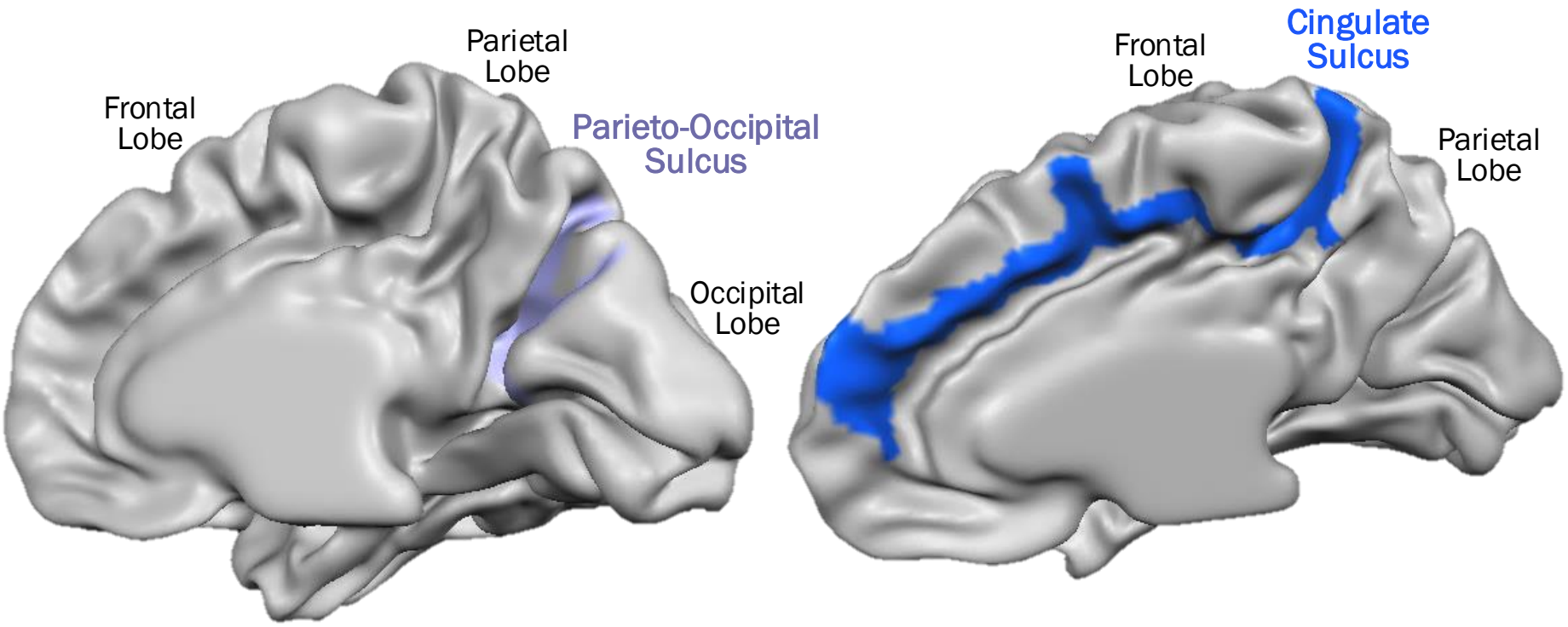
CENTRAL AND LATERAL SULCUS





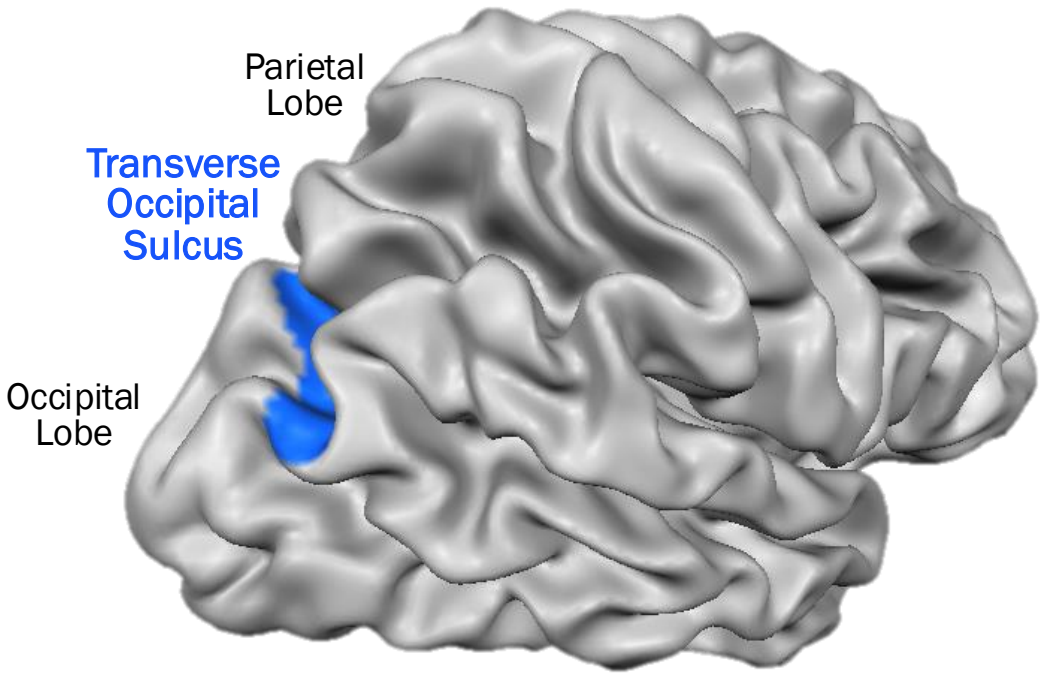
- These sulci are the most continuous fissures of the lateral surface of the brain and have an early ontogenetic development
- Morphology of CS and LS is similar between subjects and these sulci are a common landmark also in non-human primates' brain
- On the lateral surface of the brain, CS separates the frontal lobe from the parietal lobe, while LS separates the frontal and parietal lobes from the temporal lobe (below)

PARIETO-OCCIPITAL AND CINGULATE SULCUS



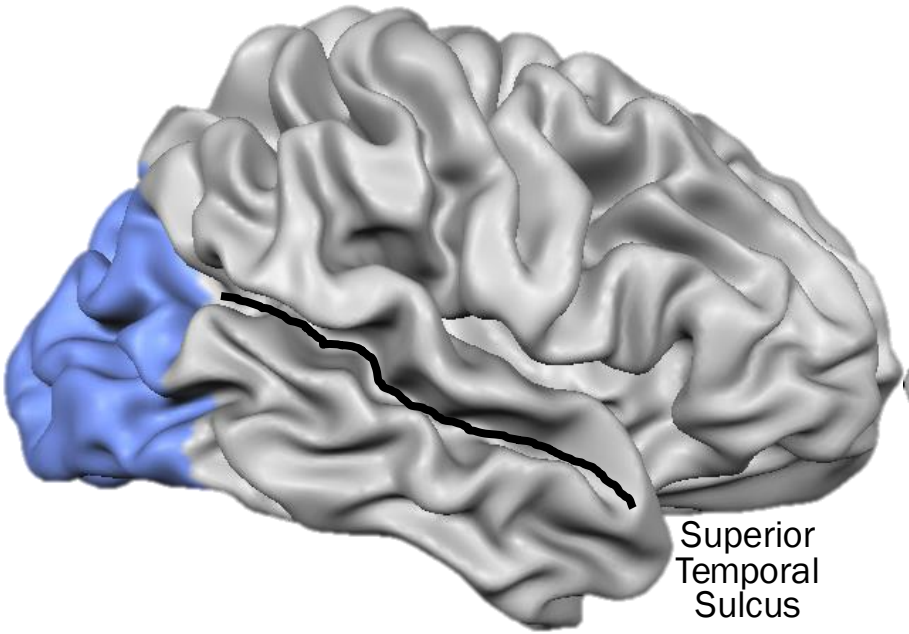
- These fissures are important landmarks on the medial surface of the brain: PO sulcus divides the medial regions of the parietal lobe from the occipital lobe. The ascending ramus of the CING sulcus separates the frontal from the parietal lobe on the medial surface of the brain
- Due to its shape, the part of parietal cortex lying between PO and CING is known as “precuneus”

TRANSVERSE OCCIPITAL SULCUS

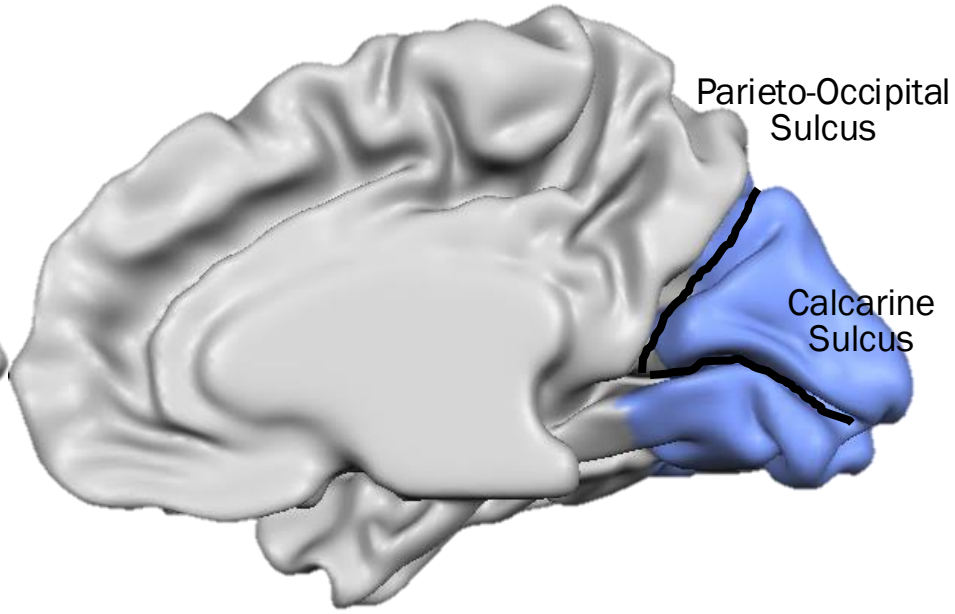


- The TO sulcus represents the boundary between parietal and occipital lobe on the lateral surface of the brain. Unlike other sulci that delineate lobes, TO is much more variable between individuals and it is not easy to identify
- The functional overlap between posterior temporal and occipital cortices is also reflected by the lack of one or more sulci that divide the temporal from the occipital lobe. This uncertainty also exists for the temporo-parietal junction on the lateral surface of the brain

OCCIPITAL LOBE



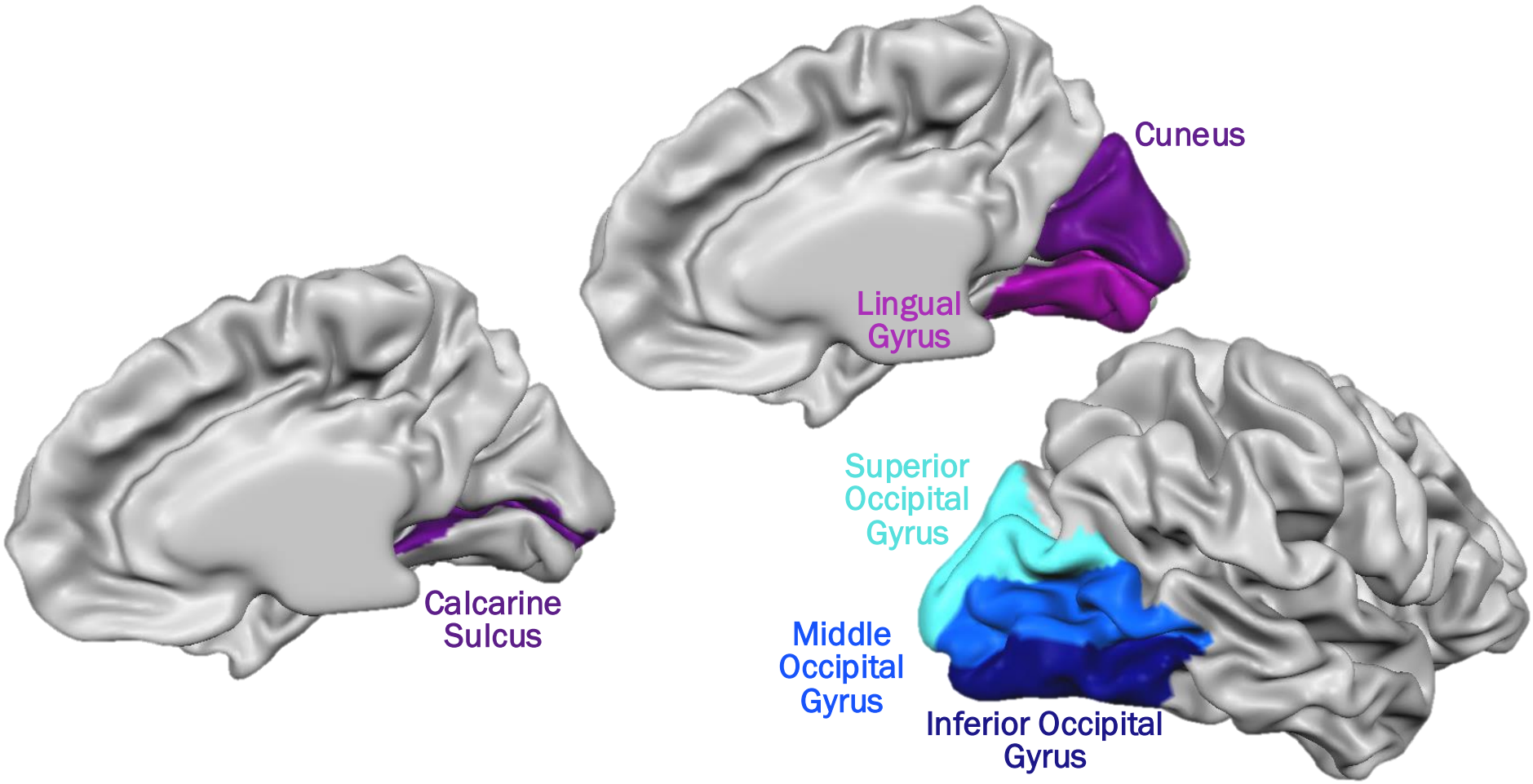
Lateral View



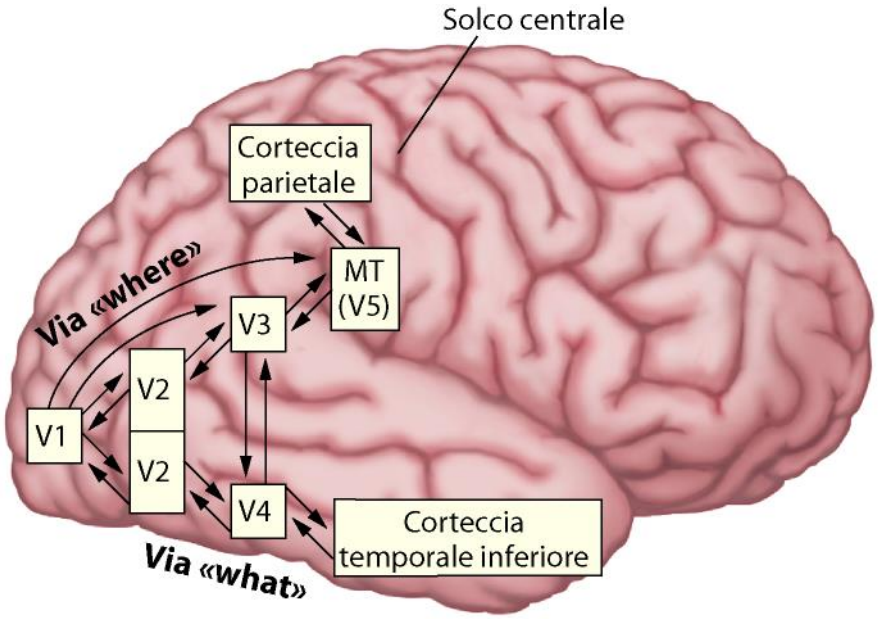
Medial View

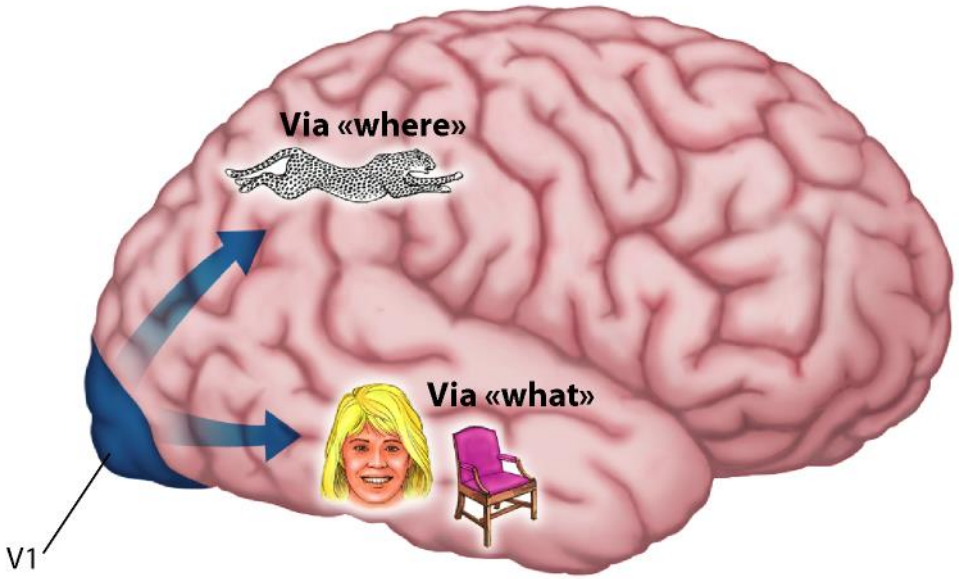
- The Occipital Lobe is entirely devoted to the analysis of visual stimuli and it comprises the primary visual cortex (lying along the calcarine sulcus) where the visual information is organized in a retinotopic manner
- Lesions produce selective impairment of the visual field (i.e., from scotoma to hemianopsia)

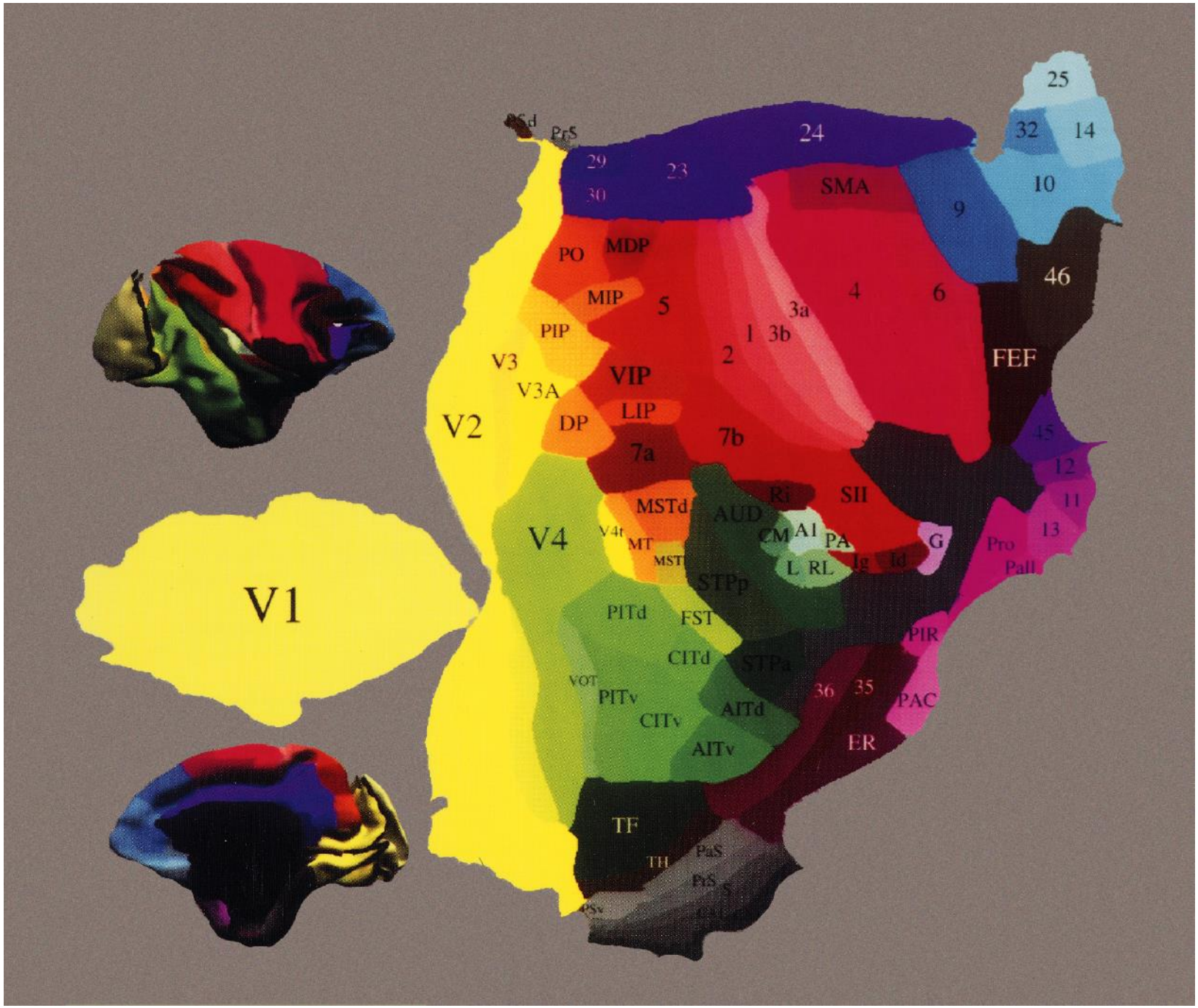
SULCI AND GYRI OF THE OCCIPITAL LOBE



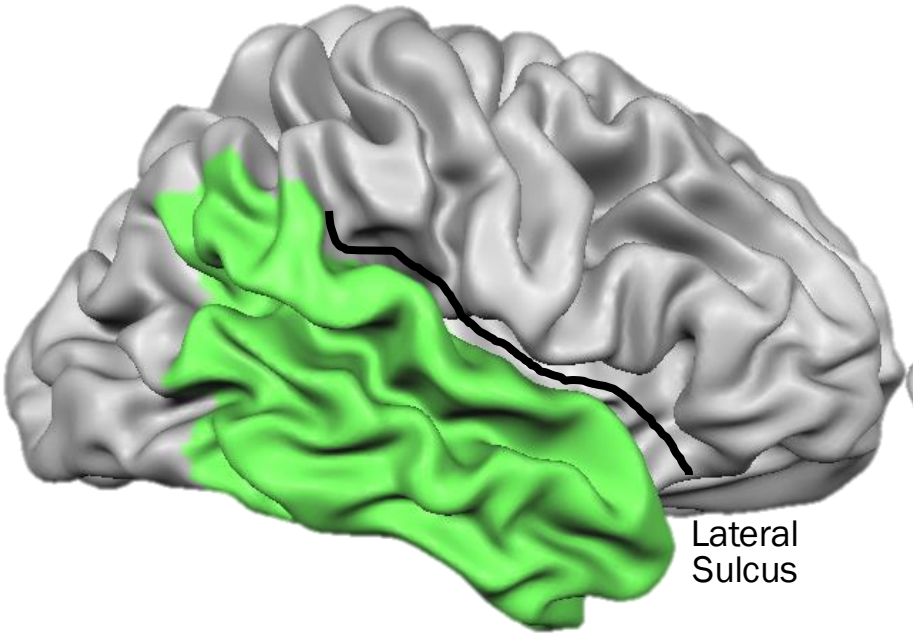
The primary visual cortex lies in the fold of the calcarine sulcus and receives retinotopic inputs from the retina. Higher order visual cortices, devoted to the analysis of specific characteristics of the retinal input (e.g., orientation, borders, etc), span across other occipital lobe structures (i.e., cuneus, linguagl gyrus, IOG, MOG, SOG).



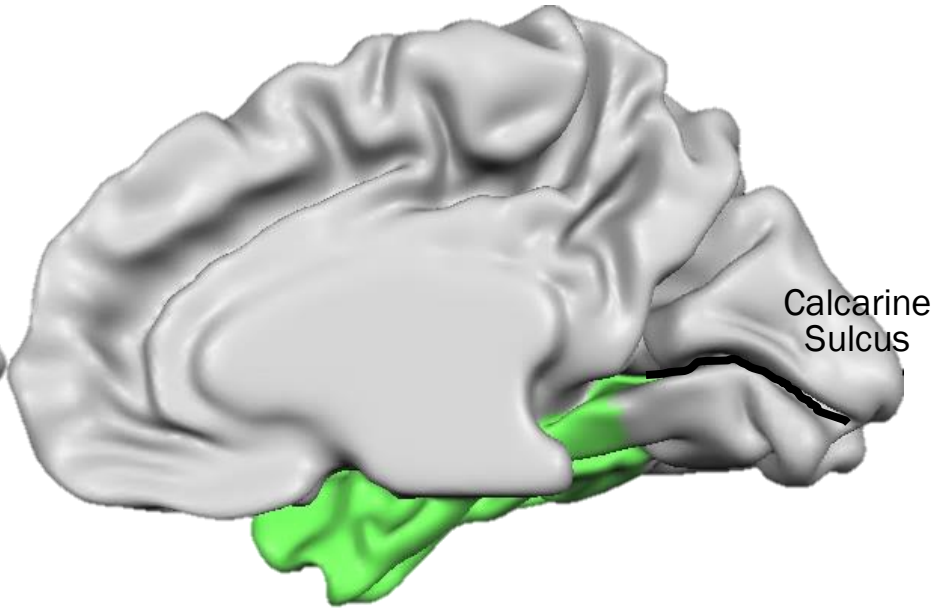




TEMPORAL LOBE



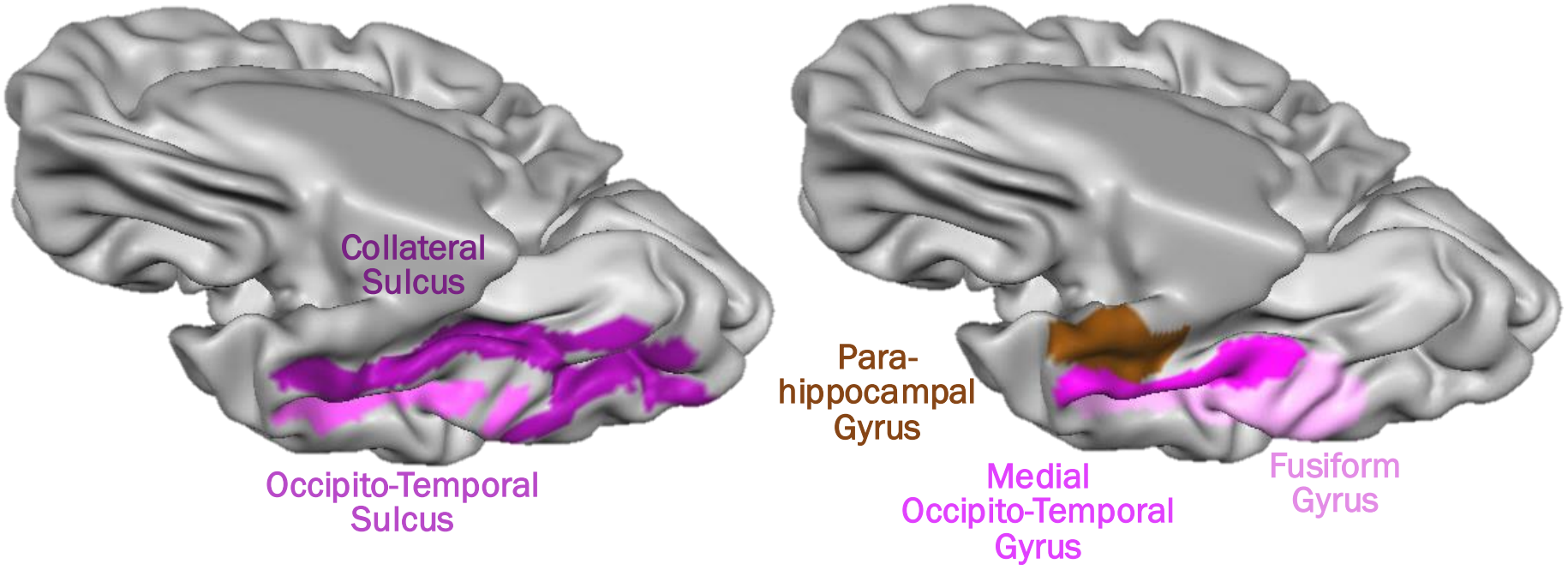
Lateral View



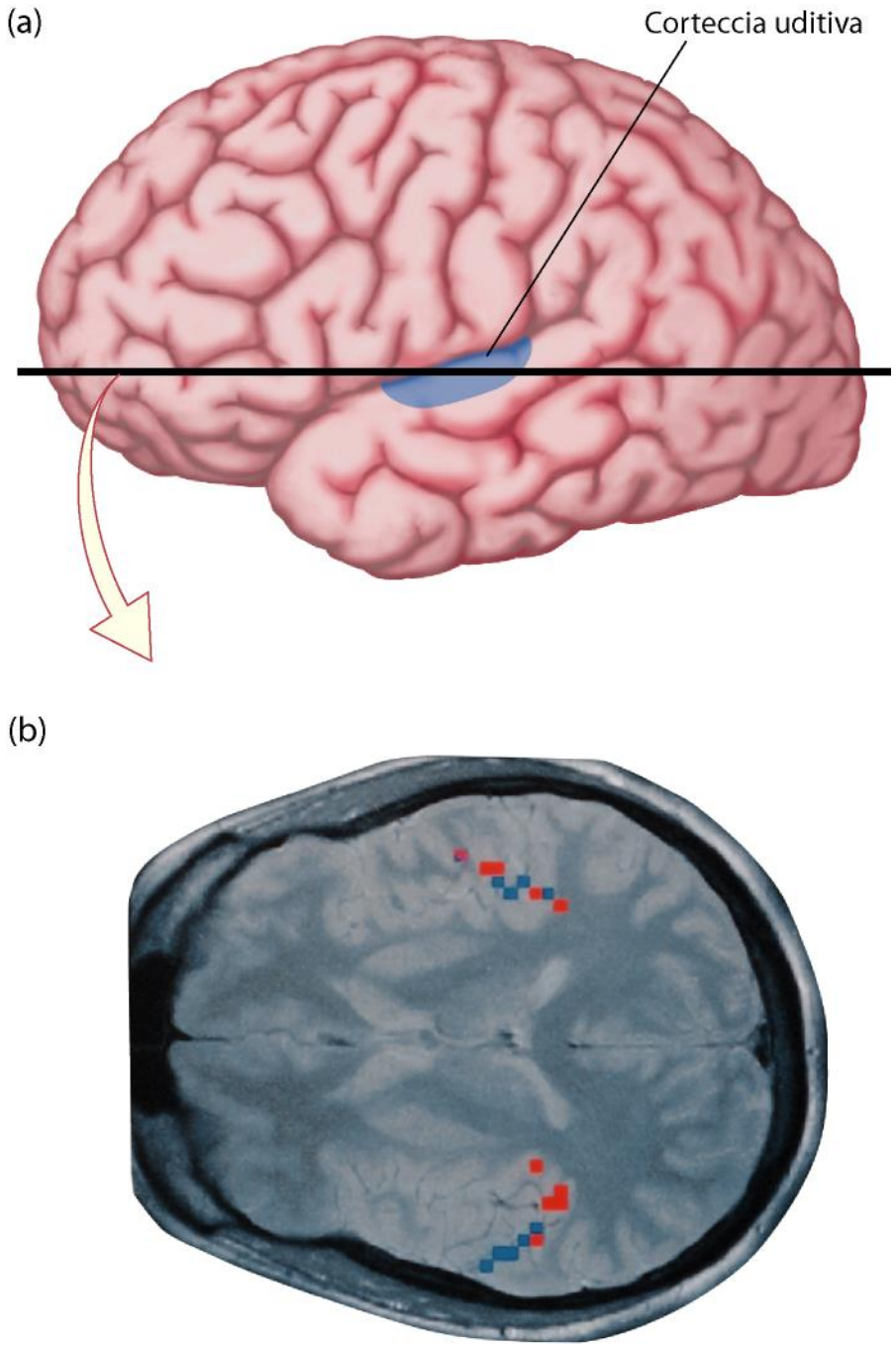
Medial View

- Processing of acoustic stimuli and language comprehension. Its ventral and posterior portions are involved in visual perception (e.g., motion discrimination, object recognition)
- Lesions of the superior part of the lateral temporal cortex lead to language comprehension deficits, while the disruption of ventral temporal regions produces object-specific agnosia (i.e., prosopagnosia = face blindness)

SULCI AND GYRI OF THE TEMPORAL LOBE (2)

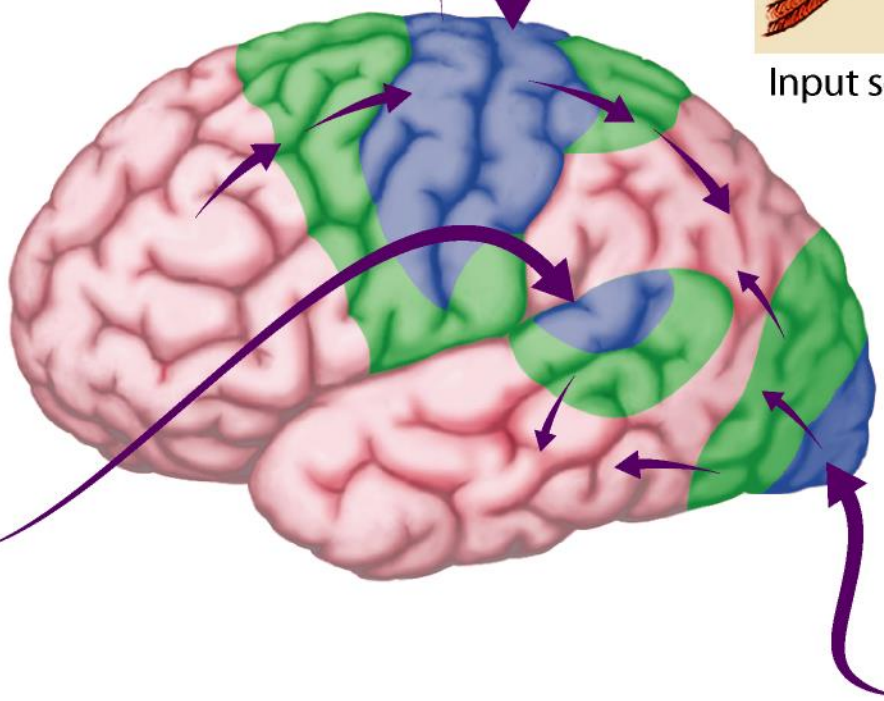


PHG: complex aspects of memory and learning, as well as processing of places and environments (PPA, parahippocampal place area); FG: higher-order processing of visual information (color discrimination within area V4, face processing within the FFA – fusiform face area)



Output motorio

Input somatosensoriale



Udito

Visione

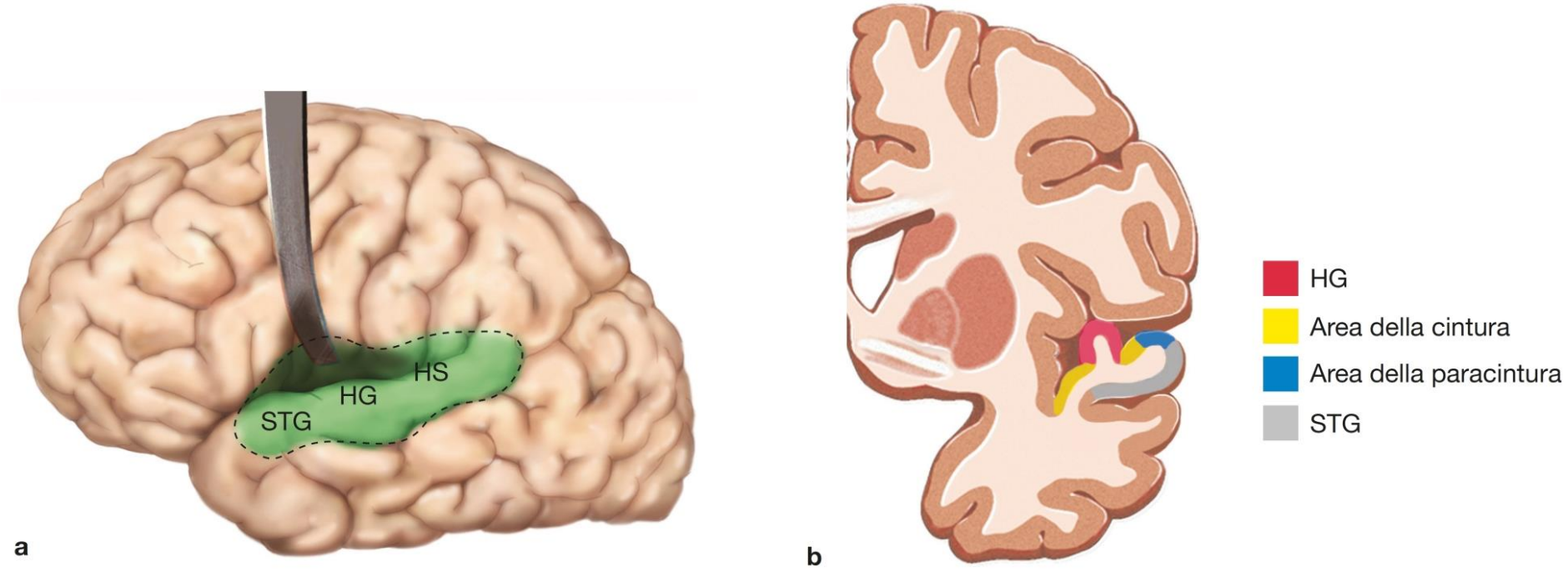
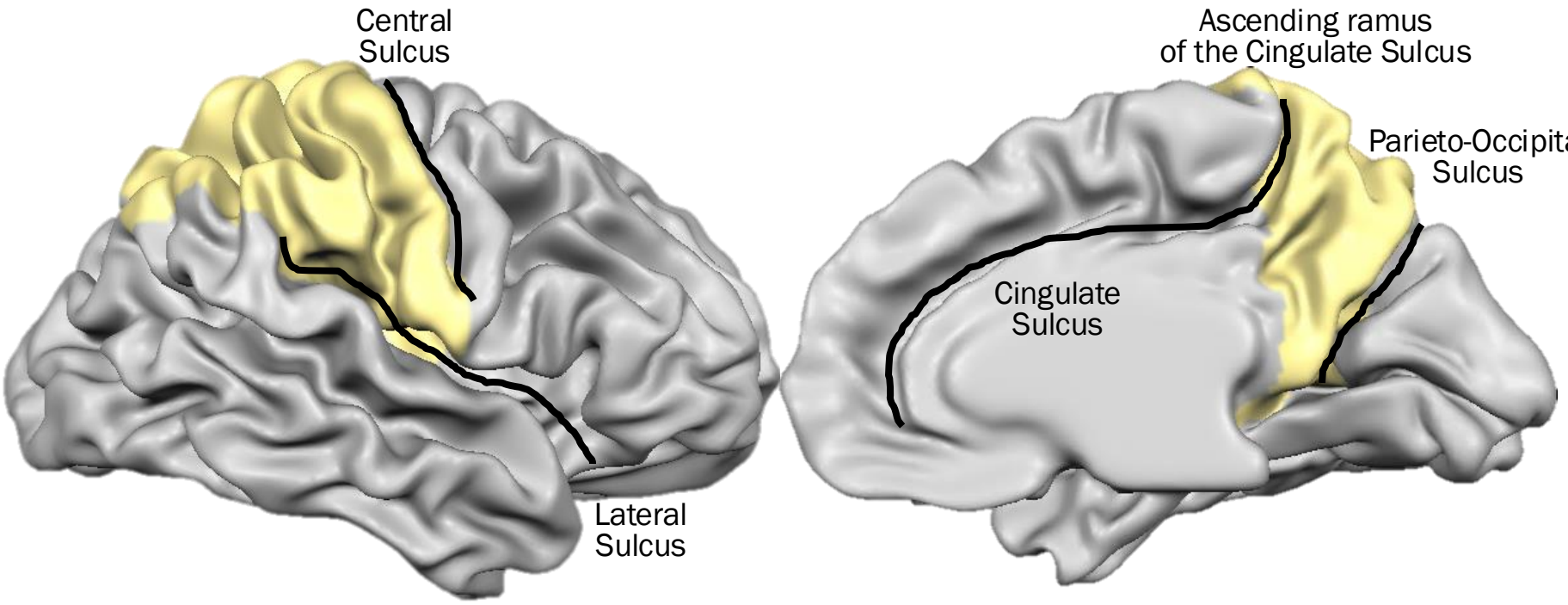


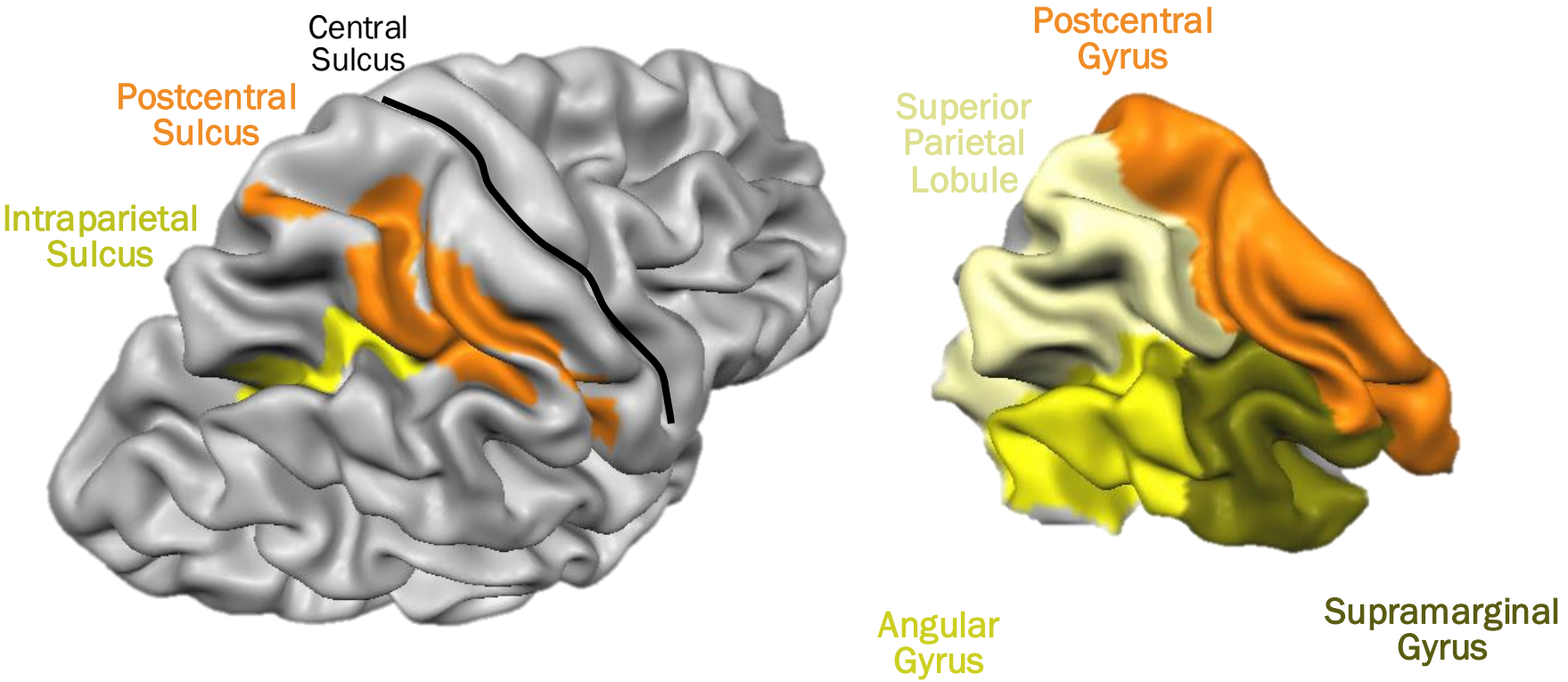
Figura 2.44 La corteccia uditiva umana.
(**a**) La corteccia uditiva primaria è situata nei giri temporali trasversi (giro di Heschl, HG), sepolti entro il solco laterale e inclusi nell'area di Brodmann 41 dei lobi temporali. Questa regione corticale e le circostanti aree uditive di associazione contengono rappresentazioni degli stimoli acustici. HS = solco di Heschl (*Heschl's sulcus*); STG = giro temporale superiore (*superior temporal gyrus*). (**b**) Vista coronale che mostra il giro di Heschl dentro il solco laterale.

PARIETAL LOBE



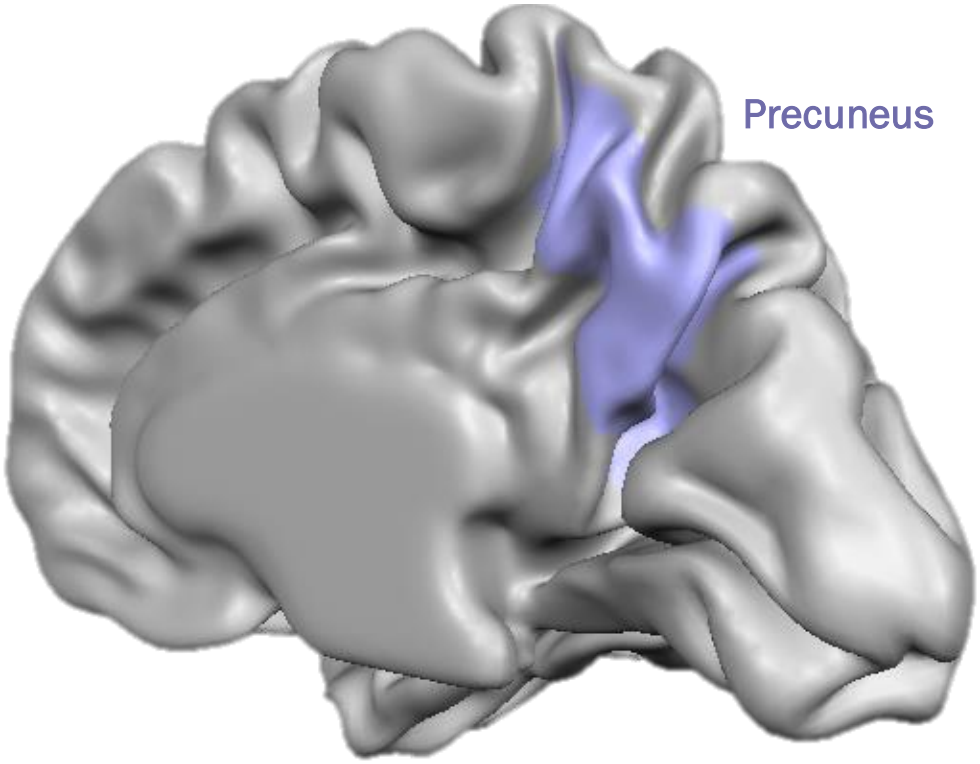
- Processing of somatosensory stimuli, spatial localization and action planning. Parietal lobe comprises also associative cortices that are involved in awareness and attention
- Lesions produce attention deficits and apraxia (i.e., inability to perform complex actions)

SULCI AND GYRI OF THE PARIETAL LOBE (1)



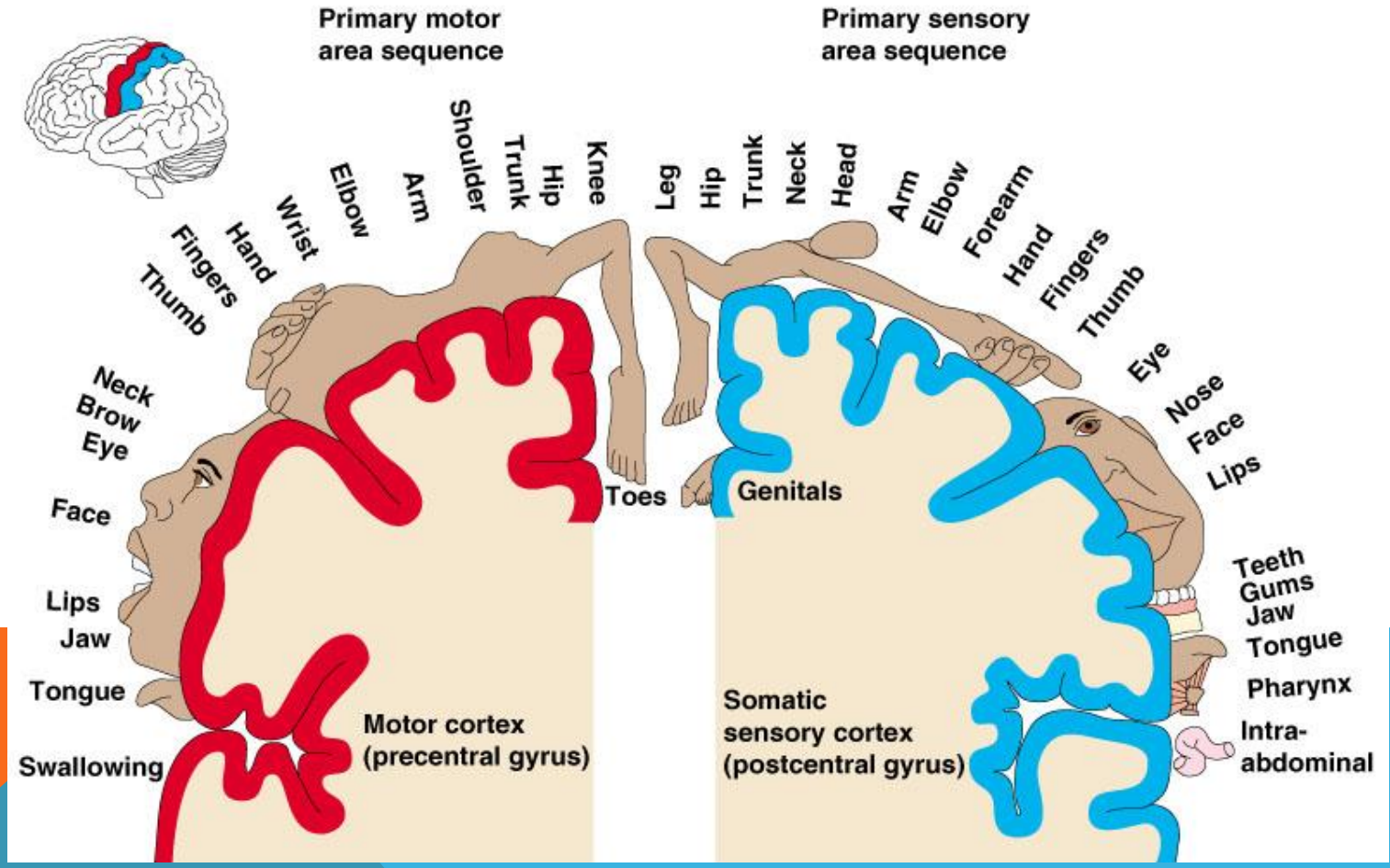
AG: semantic processing (speech comprehension) and numeric concepts (e.g., math); PostCG: primary somatosensory cortex responsible for the sense of touch, receives projections organized in a somatotopic manner; SMG: secondary somatosensory cortex; SPL: spatial attention, orientation, visuo-motor interaction during grasping and action execution

SULCI AND GYRI OF THE PARIETAL LOBE (2)

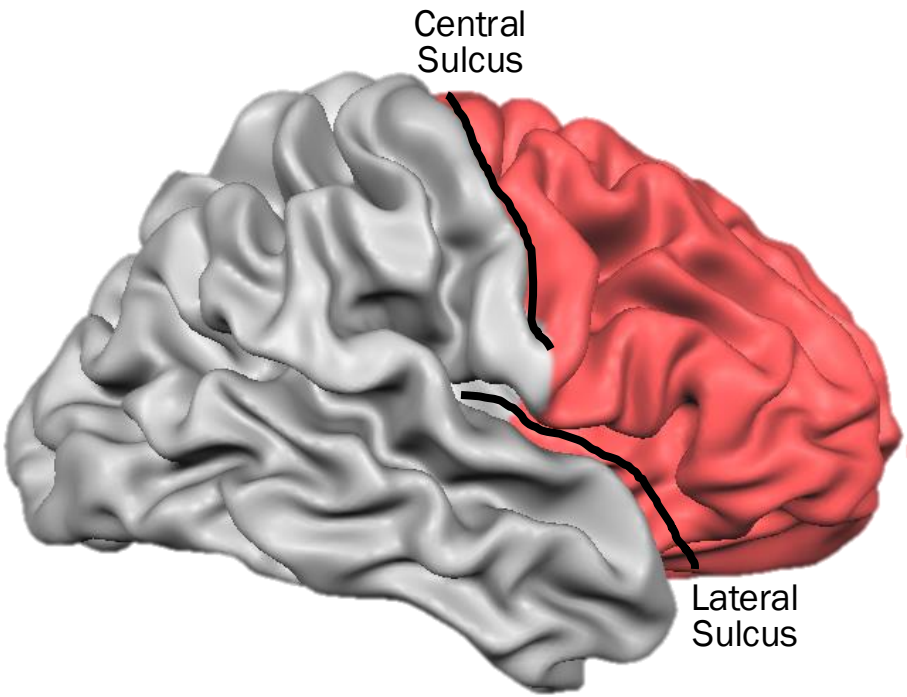


Precuneus is one of the most relevant nodes of the “default mode network” a set of brain regions that exhibit high metabolic consumption and it seems to be associated with conscious processing of stimuli and awareness

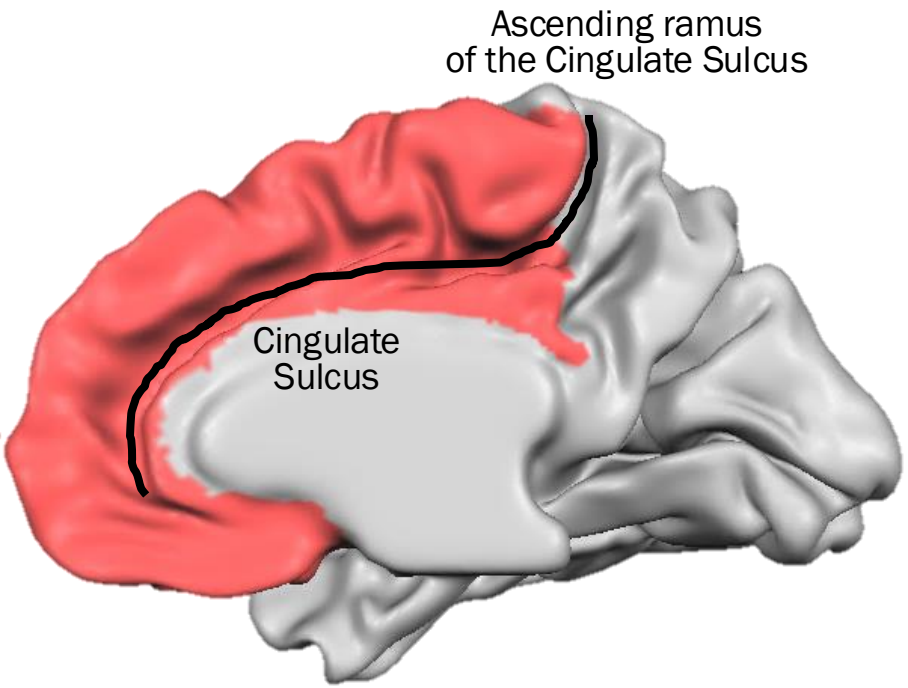
Sensory and Motor Areas of the Cerebral Cortex



FRONTAL LOBE



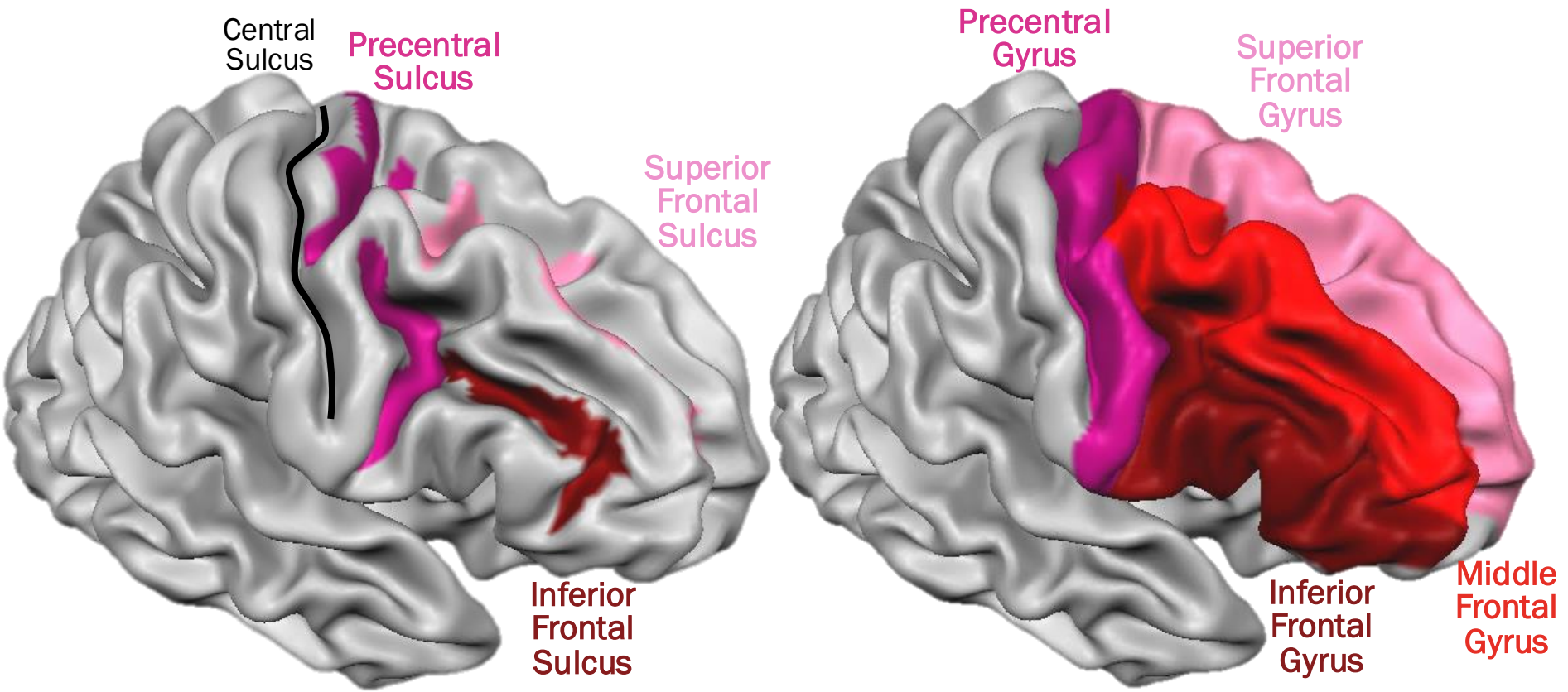
Lateral View



Medial View

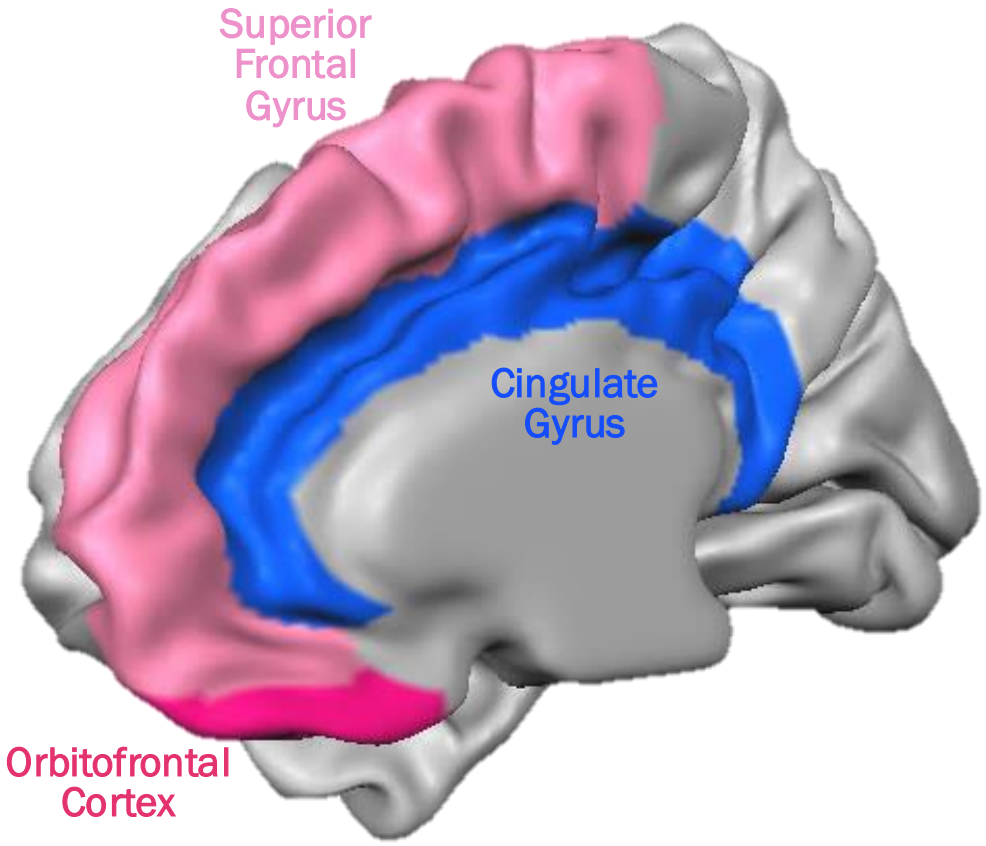
- Motor execution and higher cognitive functions (e.g., language production, impulse inhibition, reasoning and problem solving)
- Lesions mainly affect personality and behavior (e.g., Phineas Gage case), as well as the ability to speak (e.g., left hemisphere Broca's aphasia)

SULCI AND GYRI OF THE FRONTAL LOBE (1)

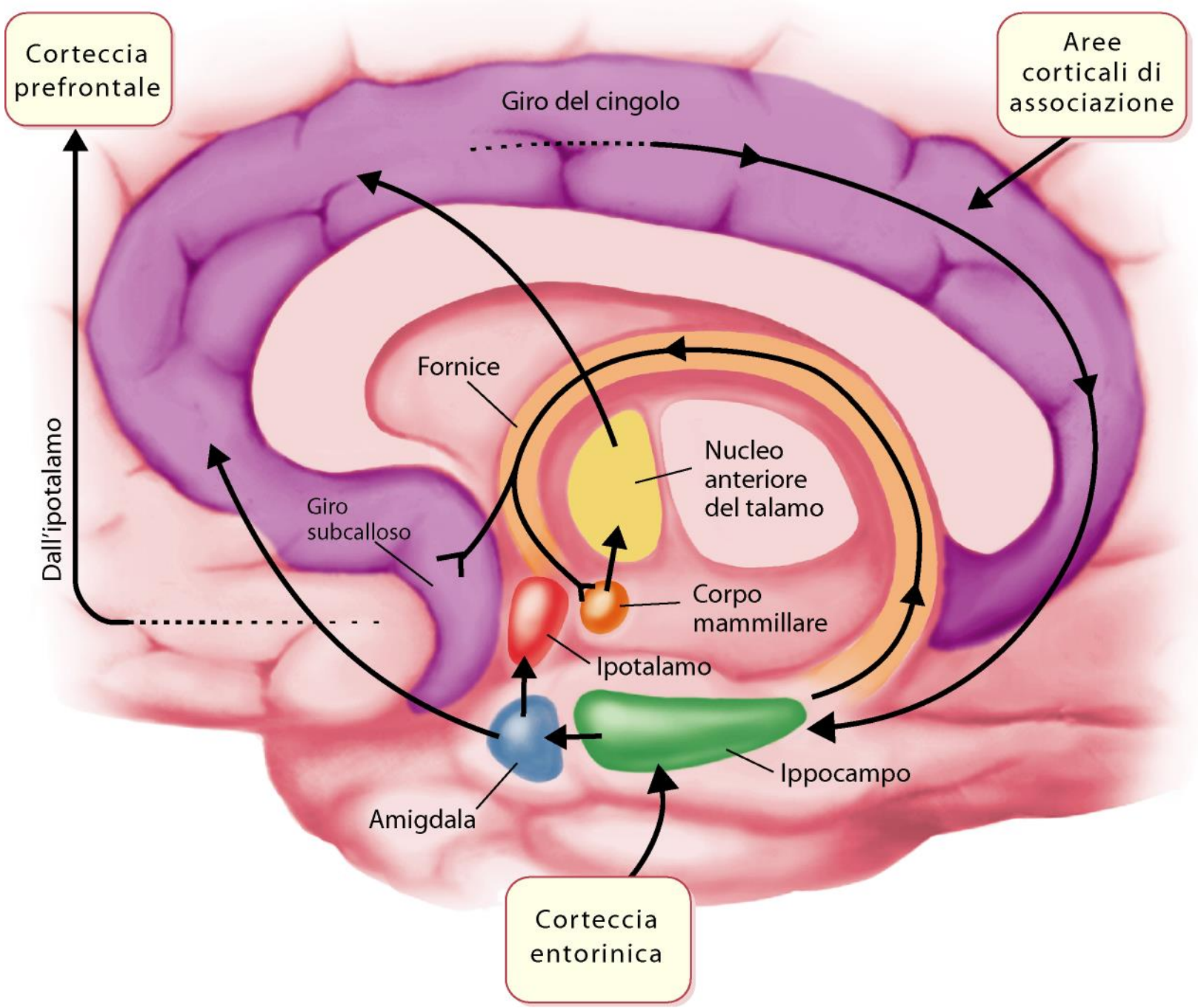


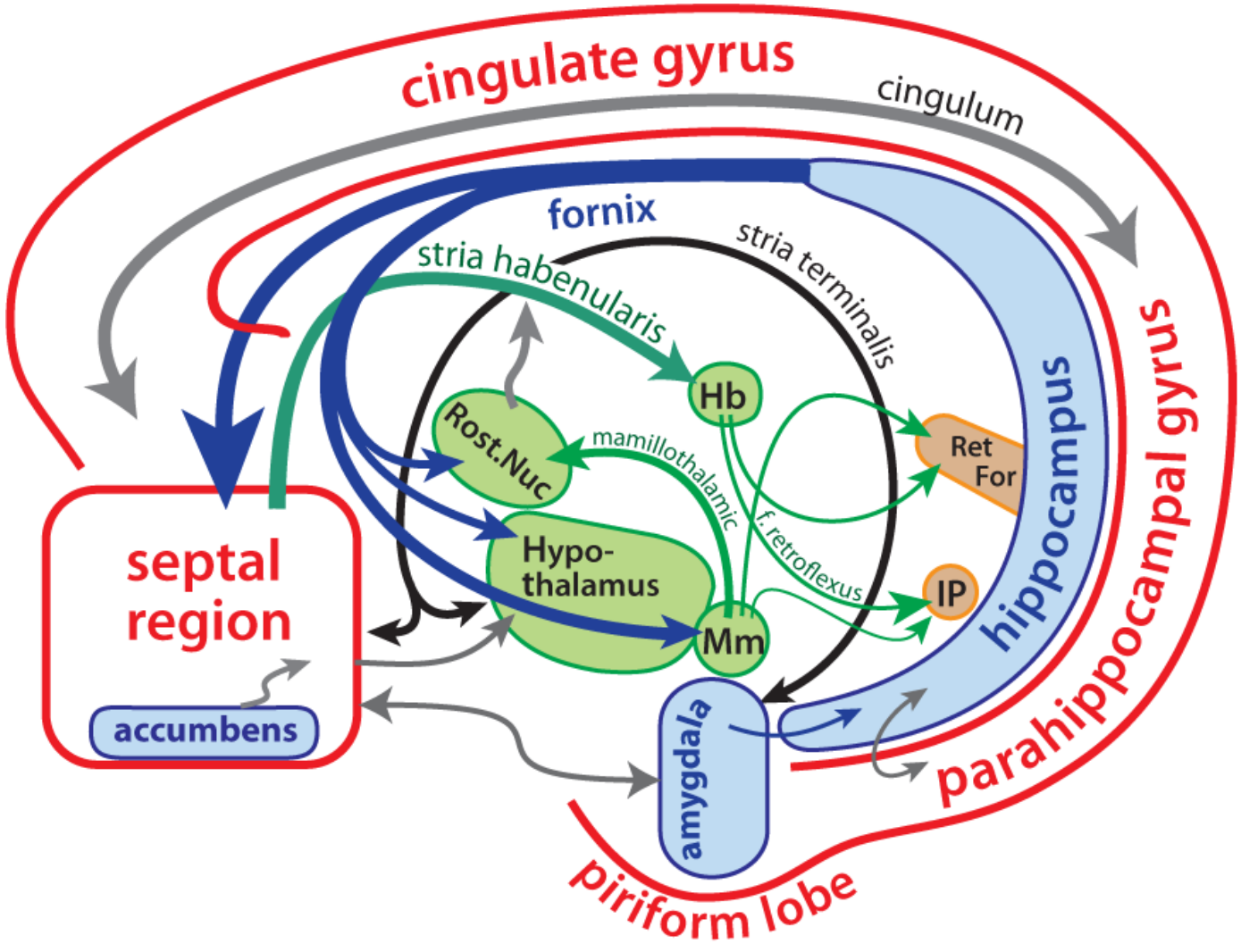
Left IFG: speech production; MFG: working memory, control and planning; SFG: premotor and supplementary motor cortex for motor planning and gaze control (frontal eye field); PreCG: primary motor cortex, somatotopic representation of muscles (i.e., Penfield homunculus)

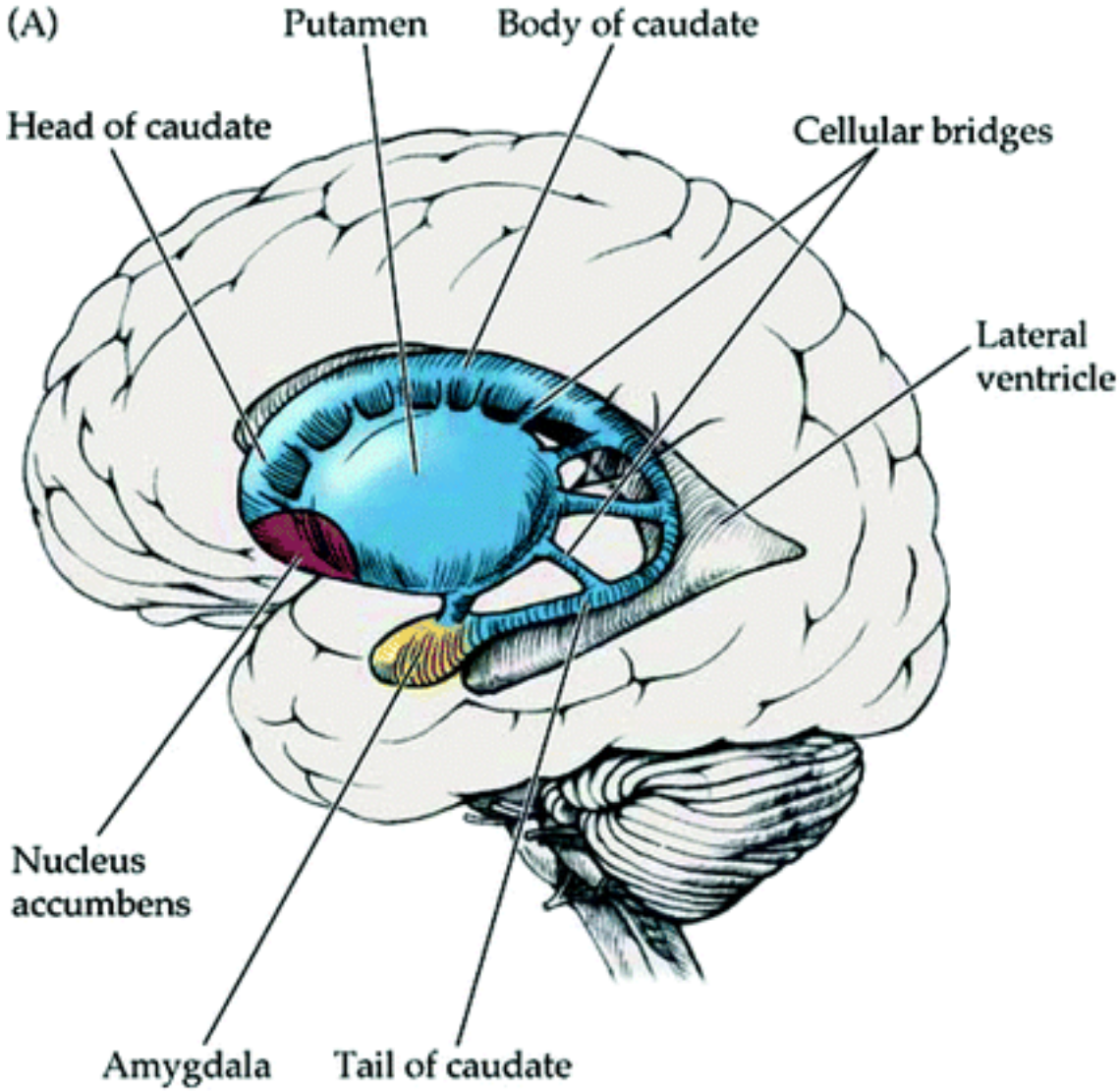
SULCI AND GYRI OF THE FRONTAL LOBE (2)

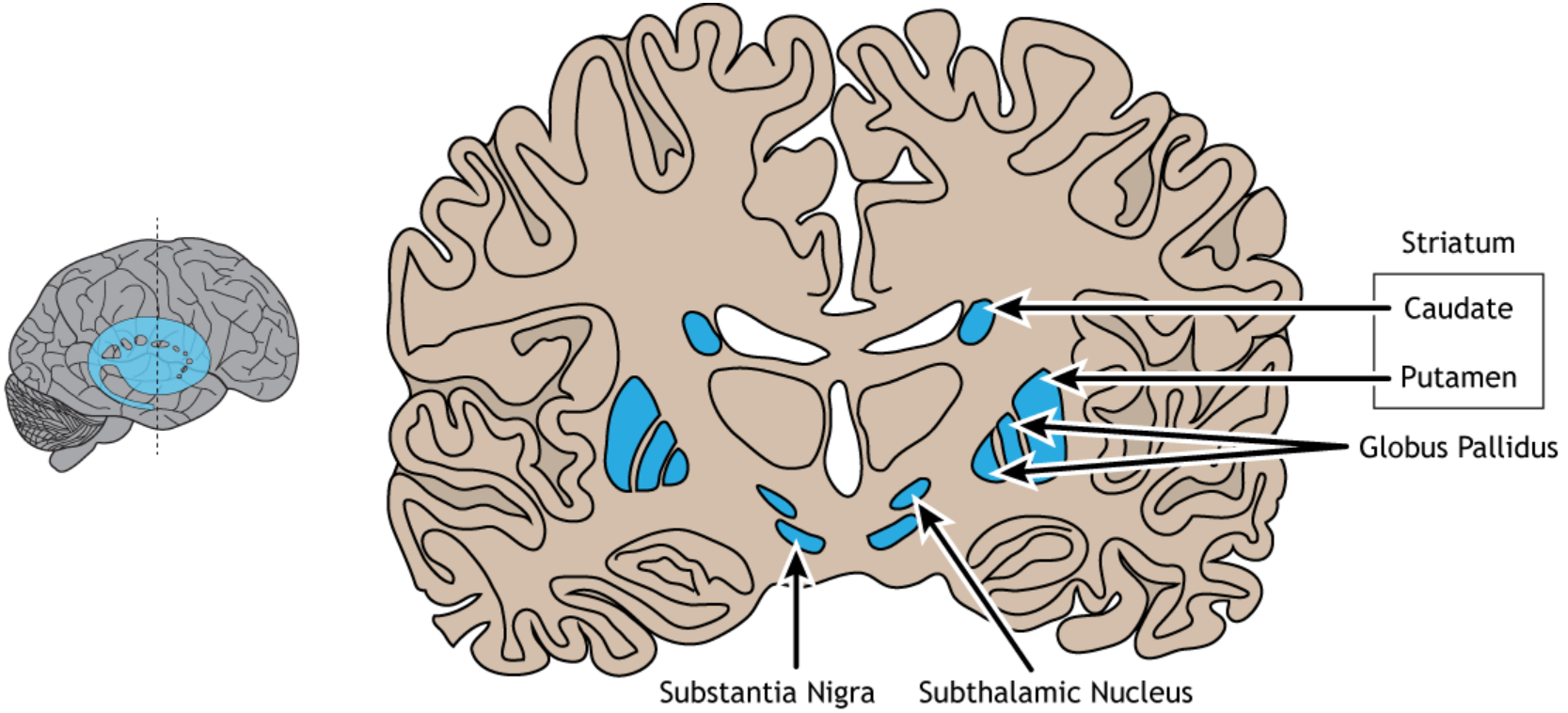


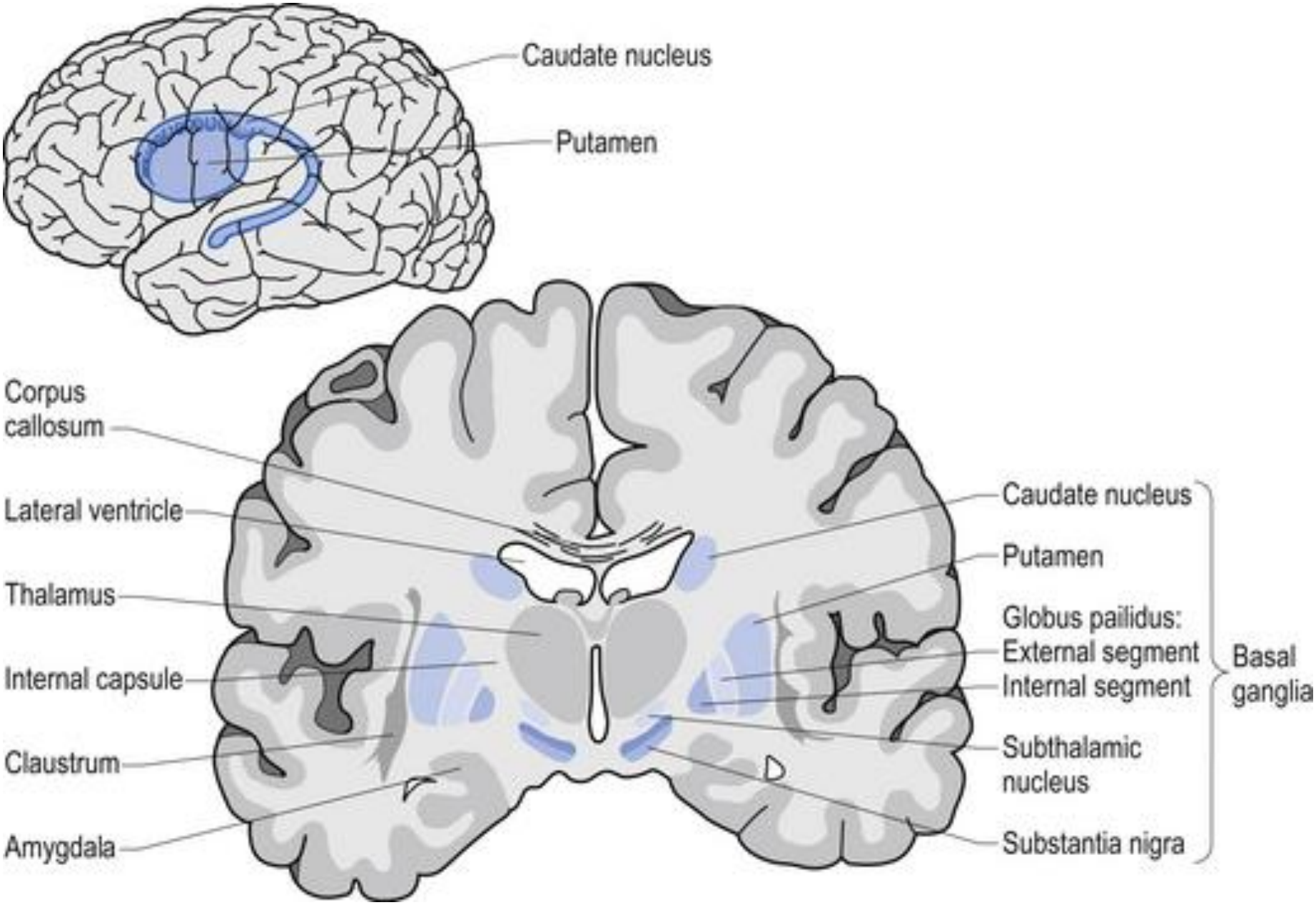
CingG: emotional response to pain, conflict and error monitoring;
OFC: decision-making, reward/punishment system

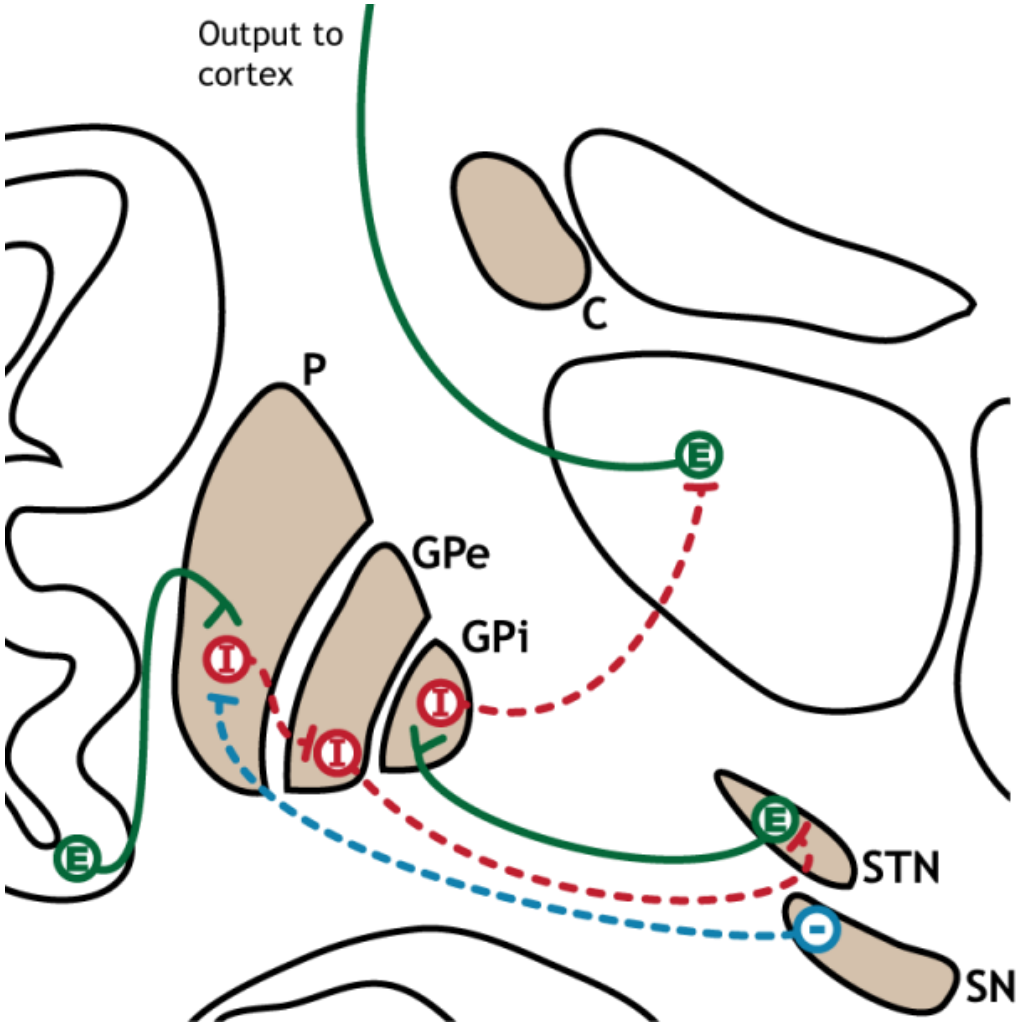







Striatum
Caudate
Putamen
Globus Pallidus
Substantia Nigra
Subthalamic Nucleus


Caudate nucleus
Putamen
Corpus callosum
Lateral ventricle
Thalamus
Internal capsule
Claustrum
Amygdala
Caudate nucleus
Putamen
Globus pallidus:
External segment
Internal segment
Subthalamic nucleus
Substantia nigra
Basal ganglia

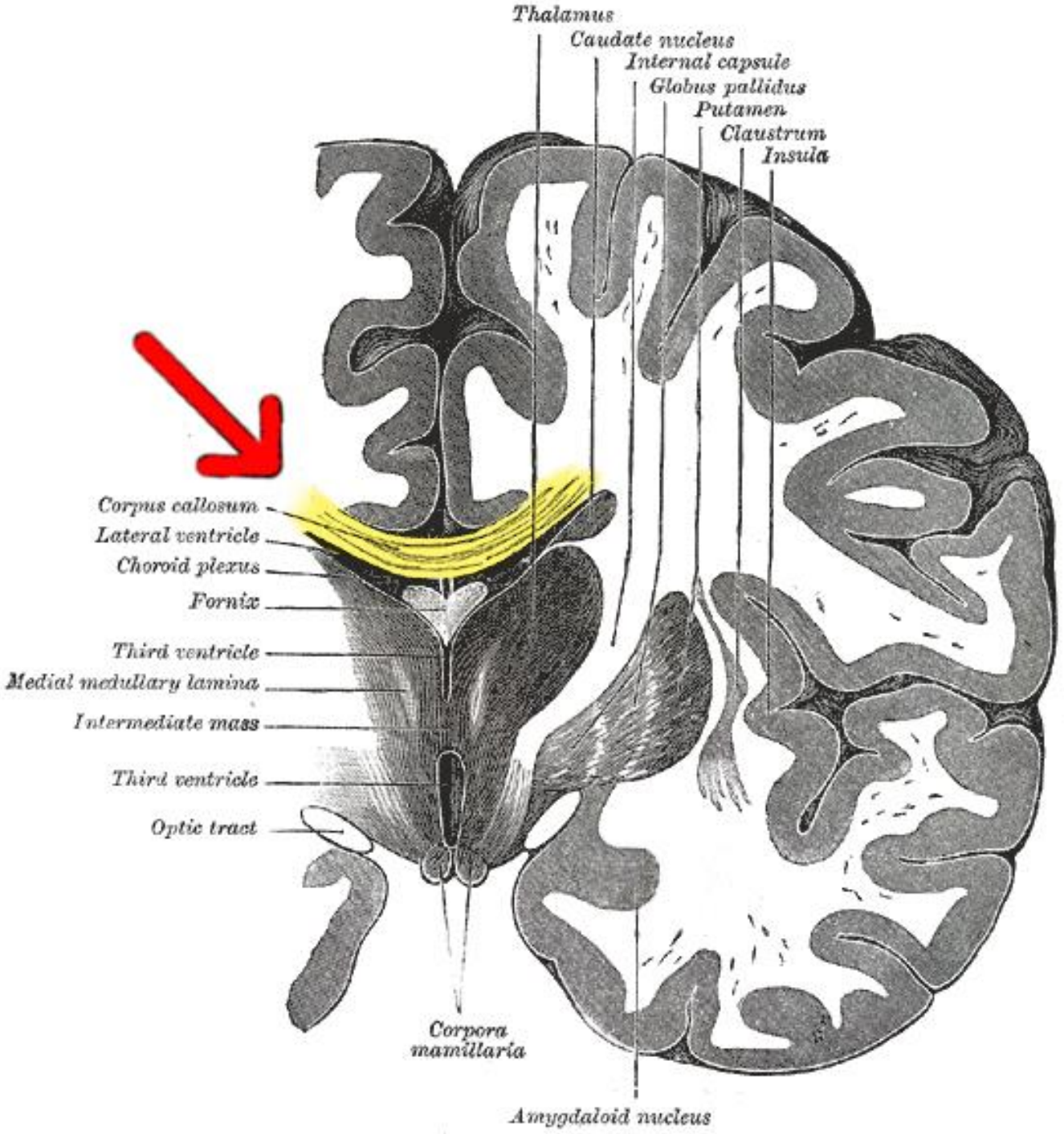


Excitatory glutamate projection

Inhibitory dopamine projection

Inhibitory GABA projection

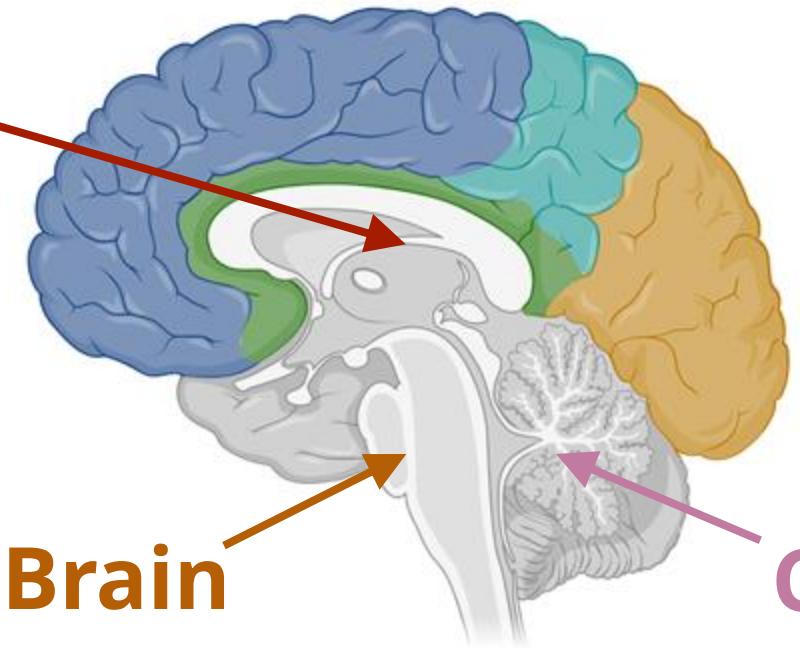
C	Caudate
P	Putamen
GPe	Globus pallidus, external segment
GPi	Globus pallidus, internal segment
STN	Subthalamic nucleus
SN	Substantia nigra


Thalamus
Caudate nucleus
Internal capsule
Globus pallidus
Putamen
Claustrum
Insula
Corpus callosum
Lateral ventricle
Choroid plexus
Fornix
Third ventricle
Medial medullary lamina
Intermediate mass
Third ventricle
Optic tract
Corpora mamillaria
Amygdaloid nucleus

Inner view of the brain: subcortical structures

Thalamus

Relay station for messages arriving from our senses in the body to the brain



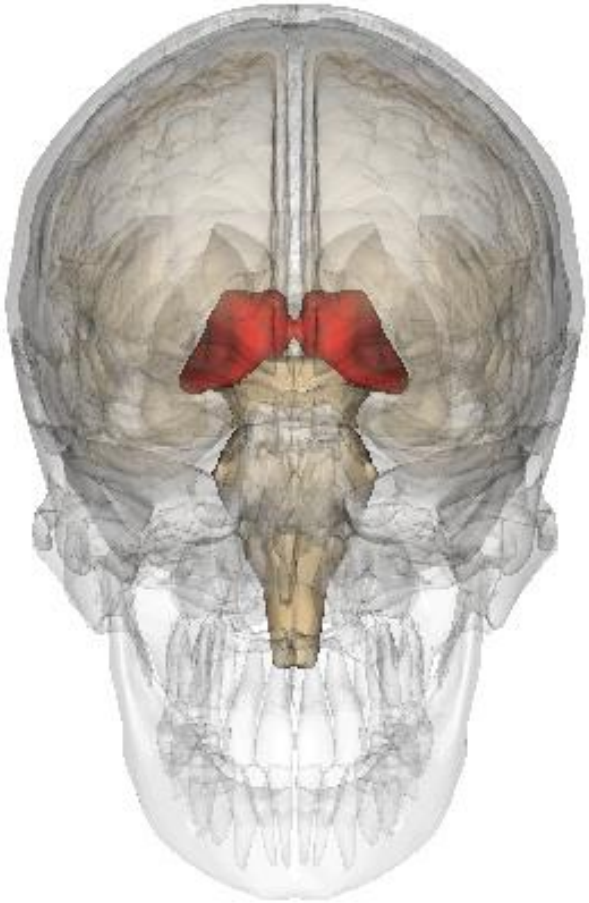
Brain stem

- Upper areas: basic functions (sleep, respiration, heart rate, blood pressure)
- Lower area: connects to spinal cord (sending and receiving messages from body)

Cerebellum

- "Little brain"
- Movement coordination
- Learning new motor skills / movements
- Making predictions

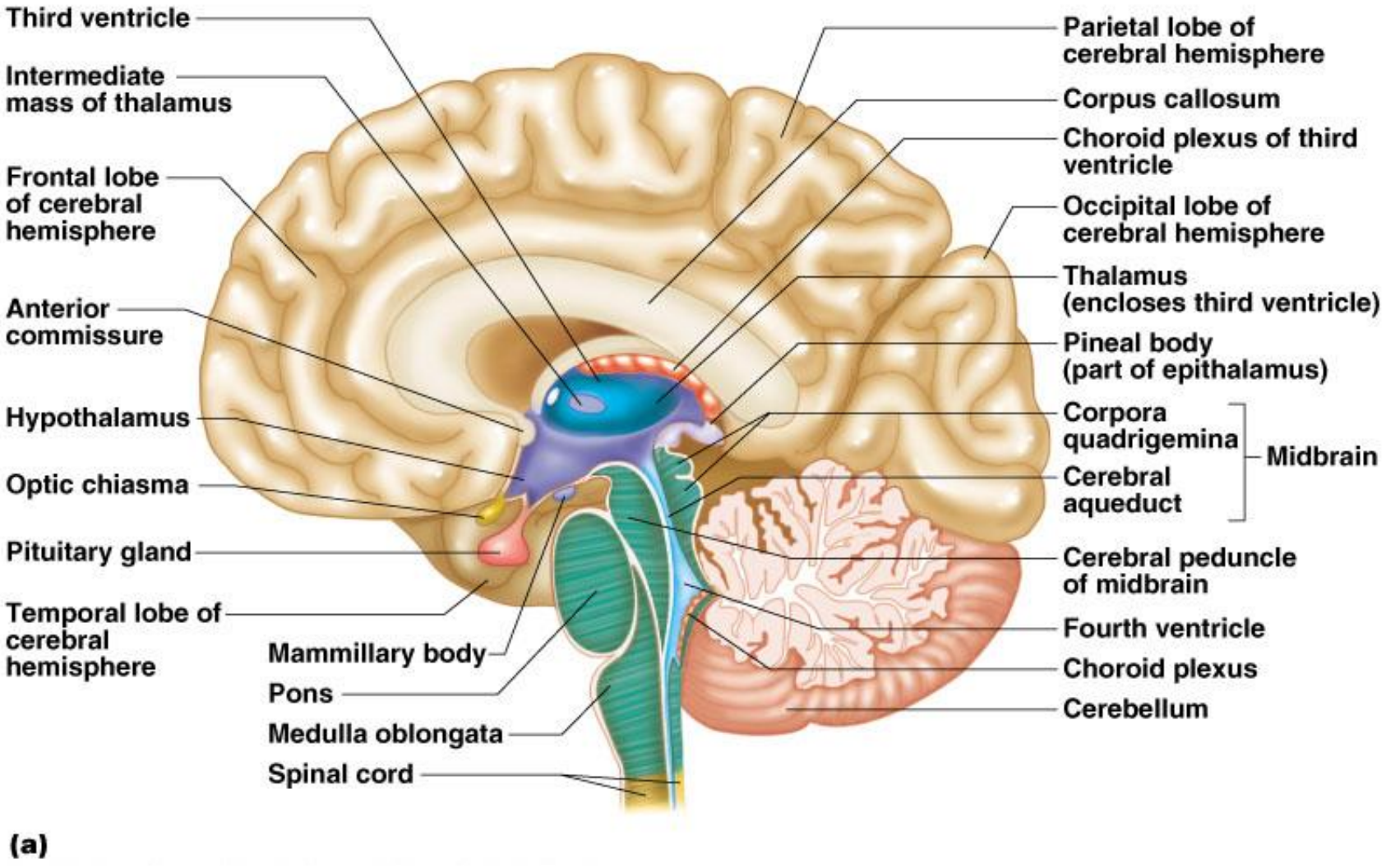
Thalamus



Diencephalon

- Sits on top of the brain stem
- Enclosed by the cerebral heispheres
- Made of three parts
  - Thalamus
  - Hypothalamus
  - Epithalamus

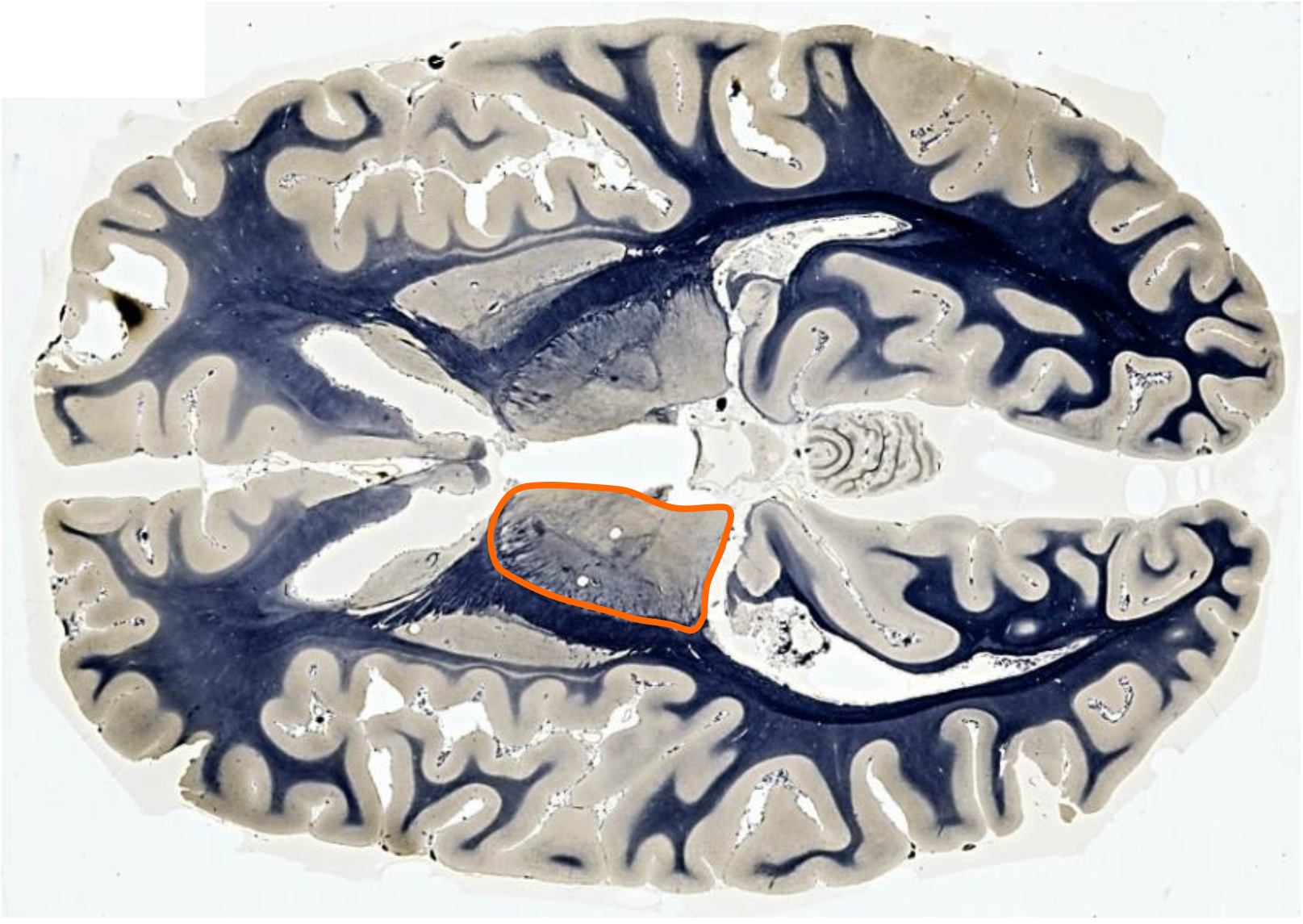
Diencephalon

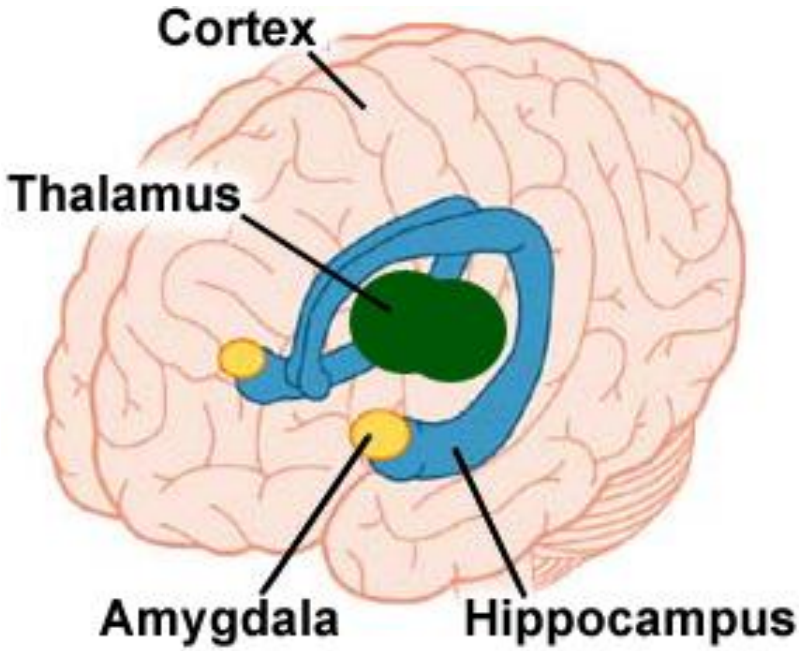


Thalamus

- Surrounds the third ventricle
- The relay station for sensory impulses
- Transfers impulses to the correct part of the cortex for localization and interpretation

Thalamus





- Emotions and emotion regulation
- Anxiety and Fear
- Combining memories with emotions

- Forming and retrieving memories
- Spatial navigation

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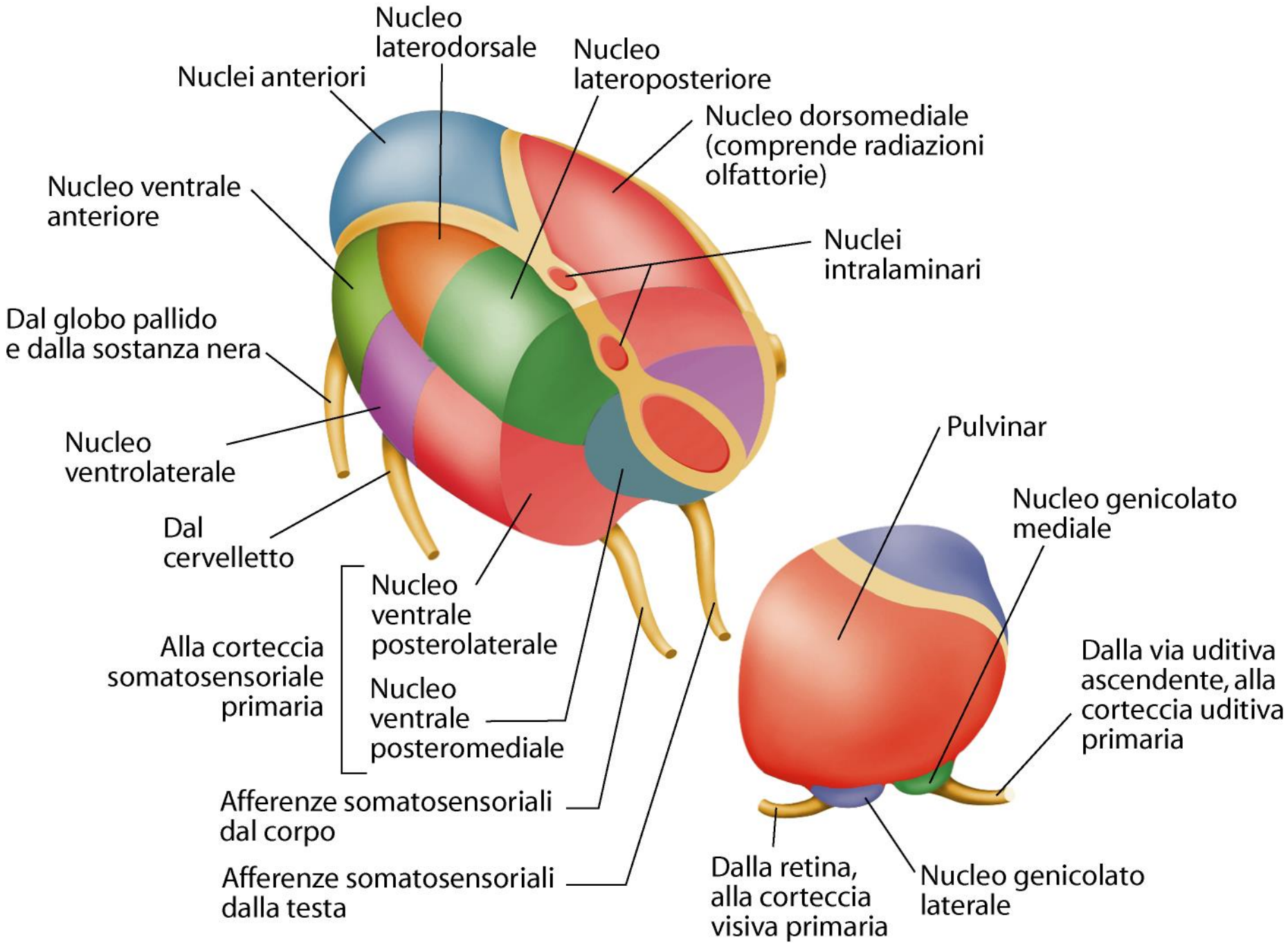
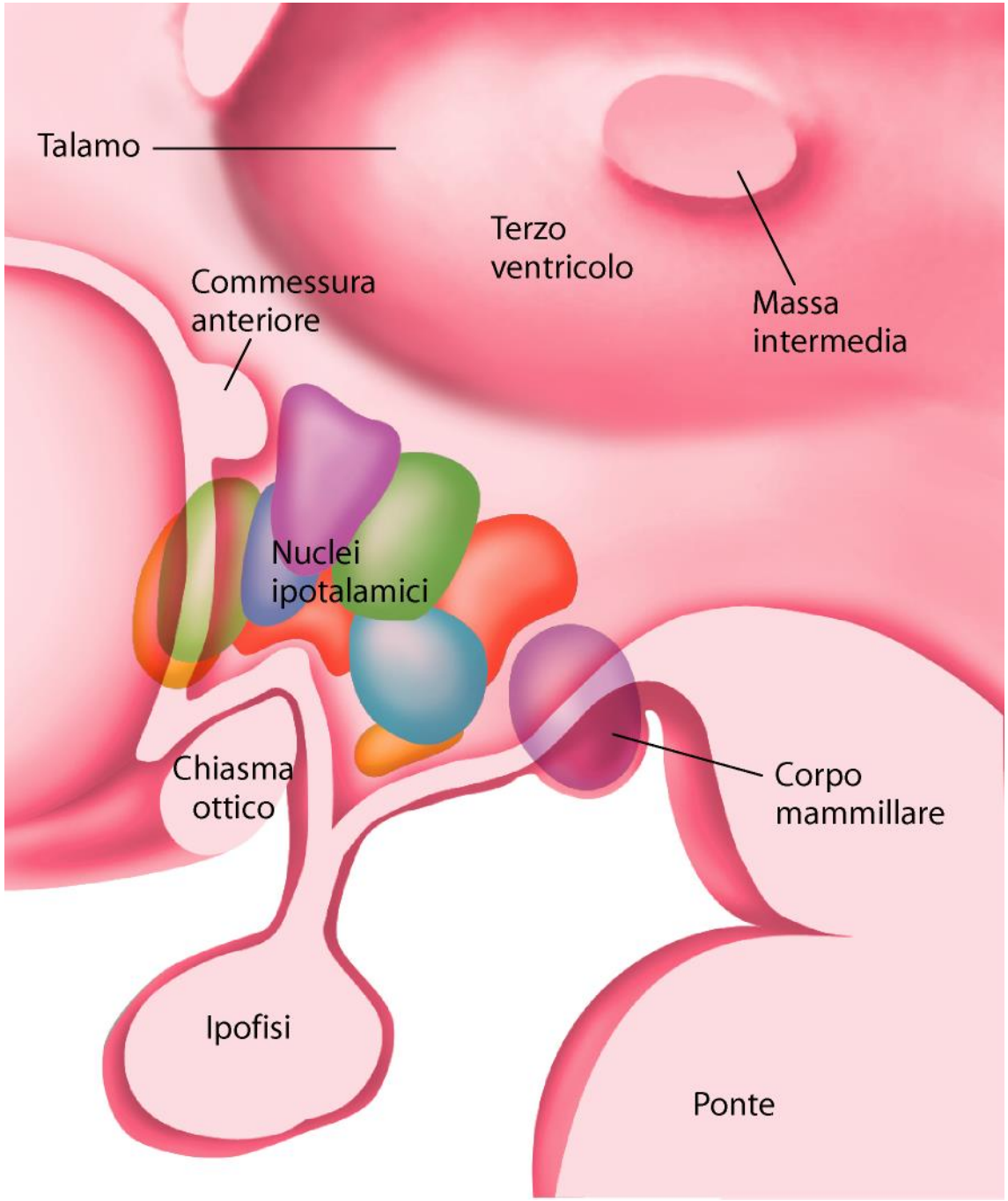


Hypothalamus

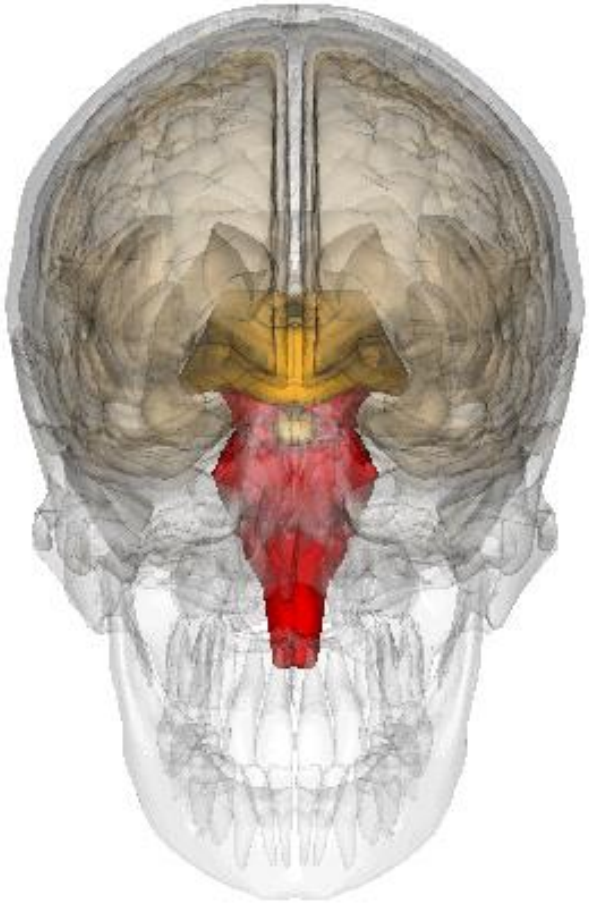
- Under the thalamus
- Important autonomic nervous system center
  - Helps regulate body temperature
  - Controls water balance
  - Regulates metabolism

Hypothalamus

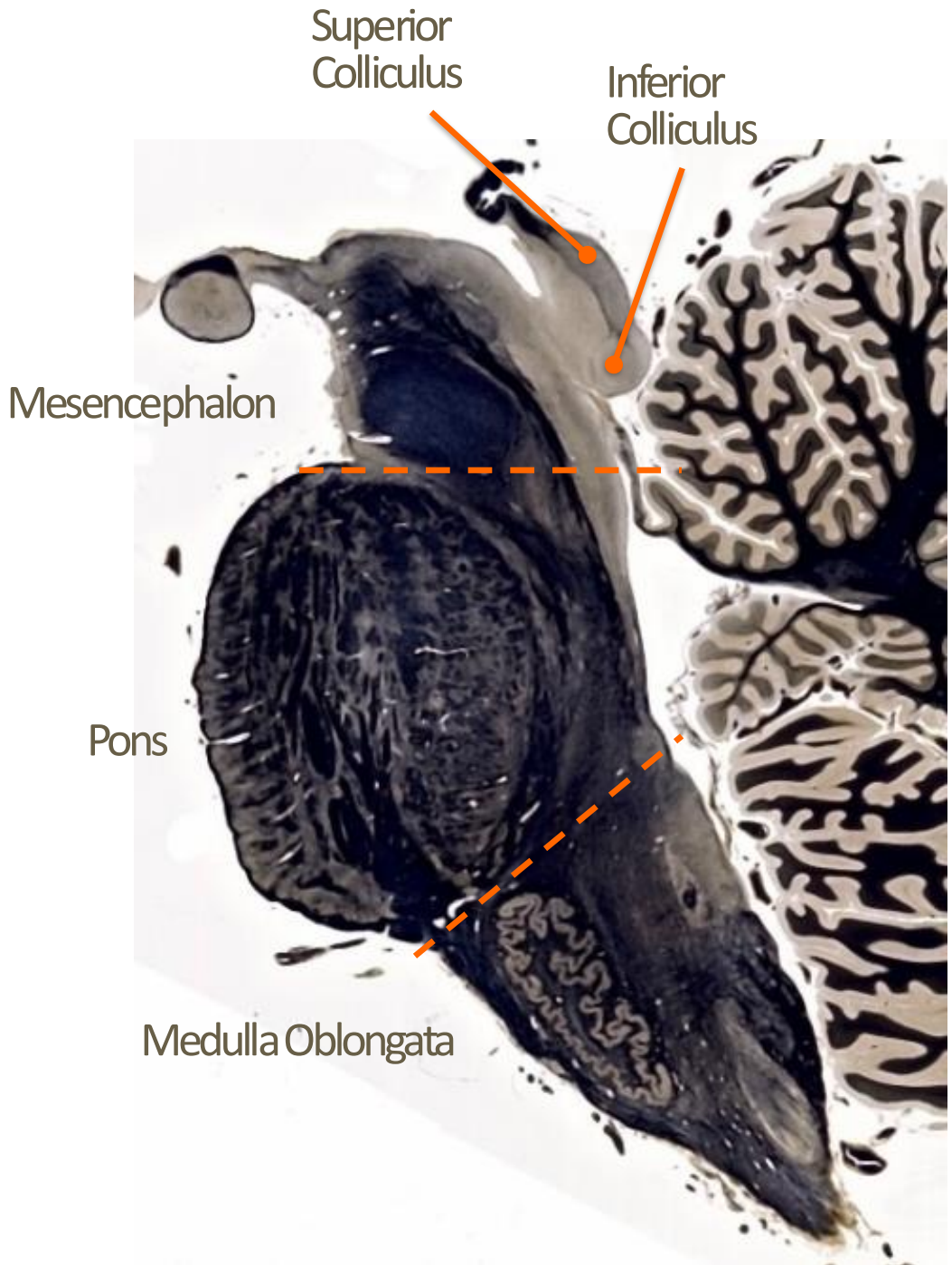
- An important part of the limbic system (emotions)
- The pituitary gland is attached to the hypothalamus



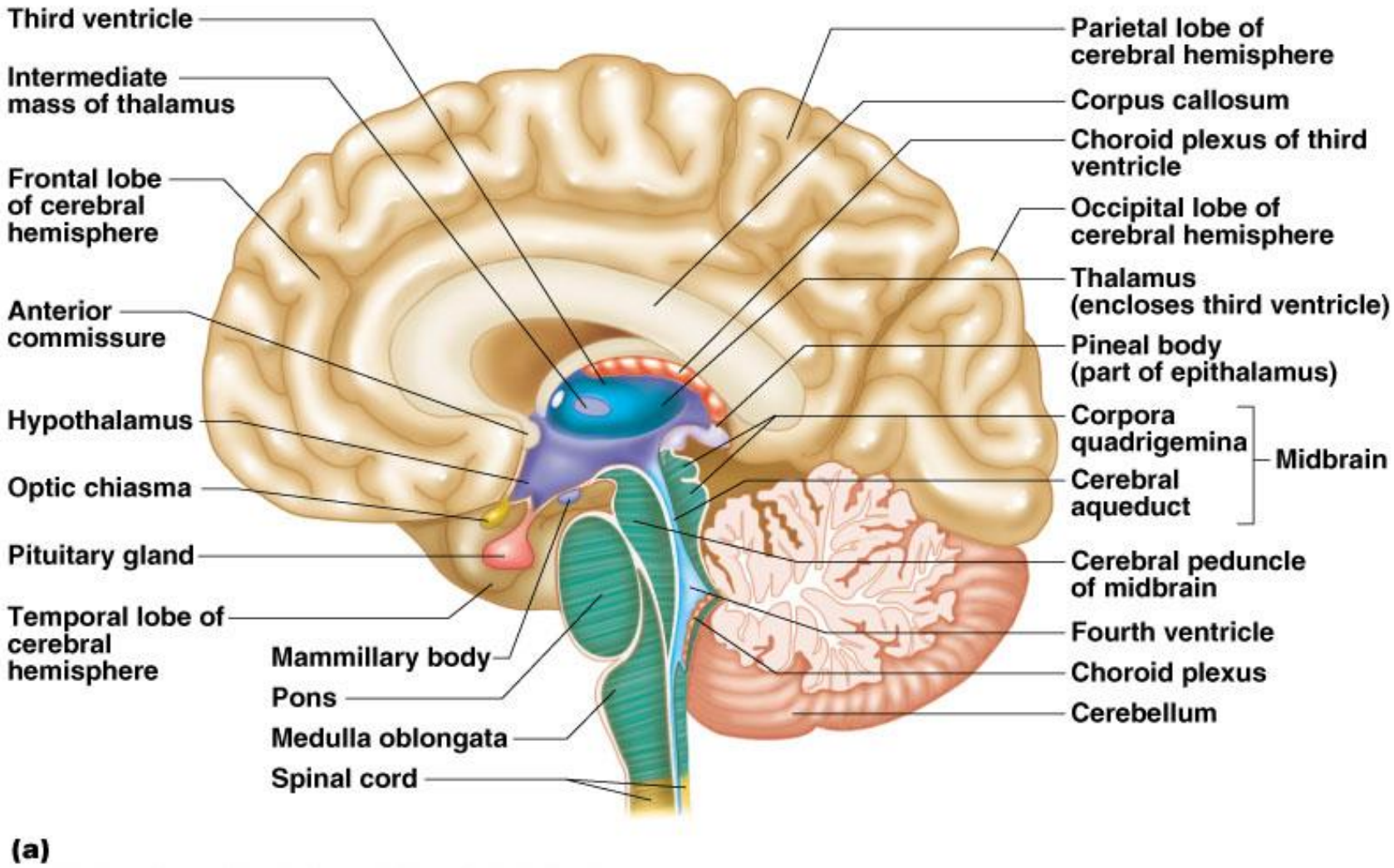
Brainstem

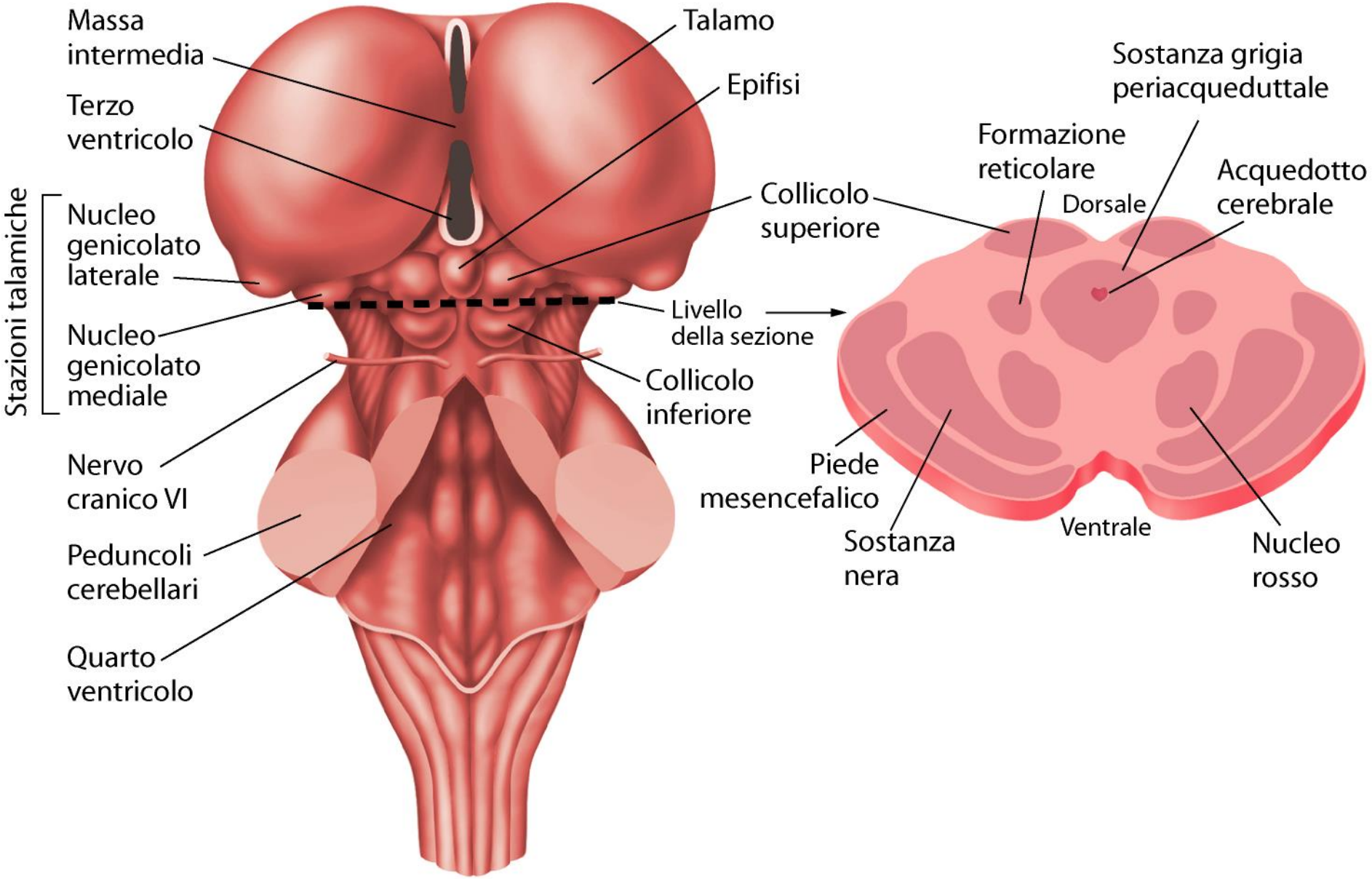


Brainstem


Superior Colliculus
Inferior Colliculus
Mesencephalon
Pons
Medulla Oblongata

Brain Stem


Third ventricle
Intermediate mass of thalamus
Frontal lobe of cerebral hemisphere
Anterior commissure
Hypothalamus
Optic chiasma
Pituitary gland
Temporal lobe of cerebral hemisphere
Mammillary body
Pons
Medulla oblongata
Spinal cord
Parietal lobe of cerebral hemisphere
Corpus callosum
Choroid plexus of third ventricle
Occipital lobe of cerebral hemisphere
Thalamus (encloses third ventricle)
Pineal body (part of epithalamus)
Corpora quadrigemina
Cerebral aqueduct
Midbrain
Cerebral peduncle of midbrain
Fourth ventricle
Choroid plexus
Cerebellum
(a)



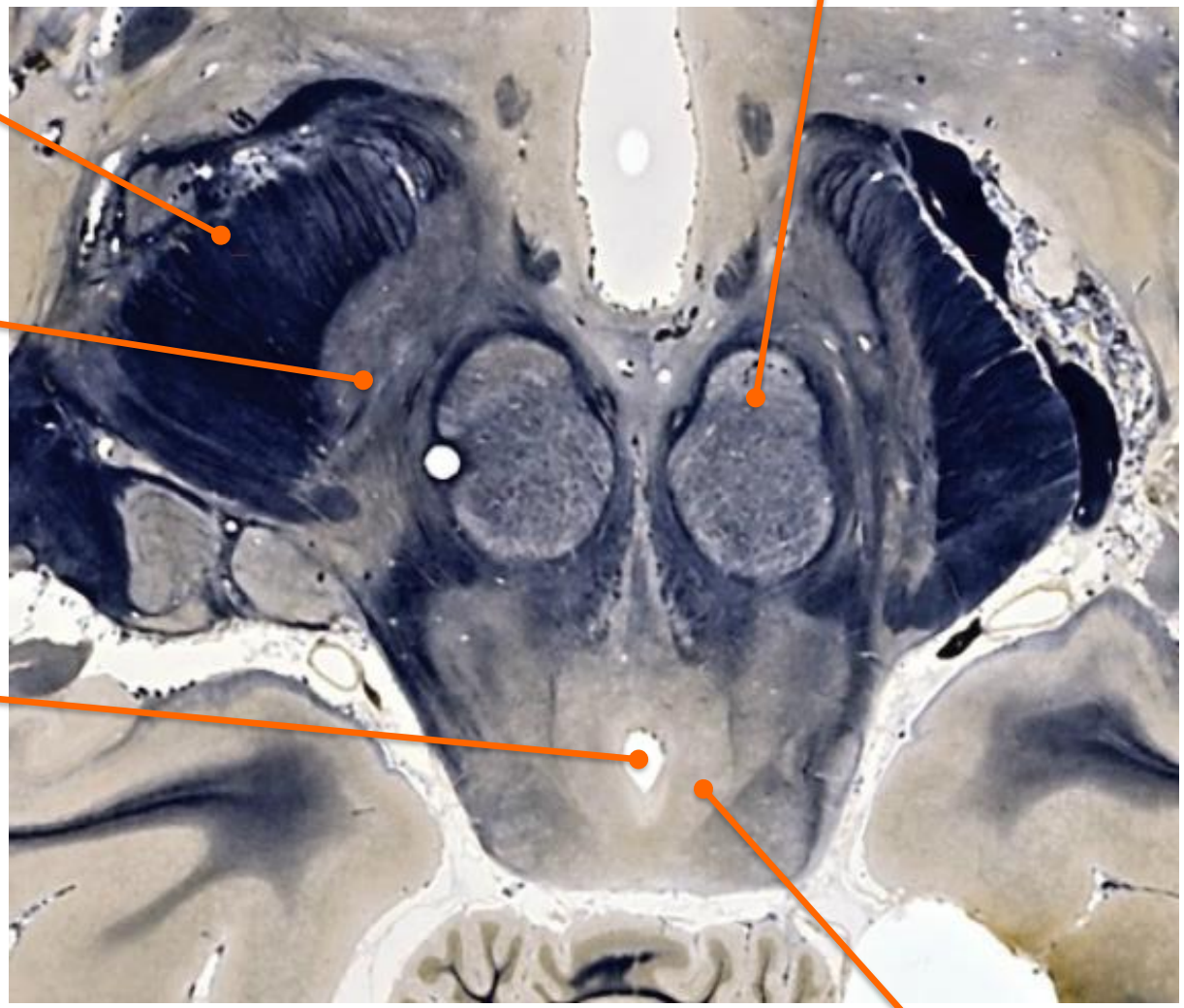
Brain Stem

- Attaches to the spinal cord
- Parts of the brain stem
  - Midbrain
  - Pons
  - Medulla oblongata

Midbrain

- Mostly composed of tracts of nerve fibers
  - Reflex centers for vision and hearing
  - Cerebral aquaduct – 3^{rd}-4^{th} ventricles

Mesencephalon



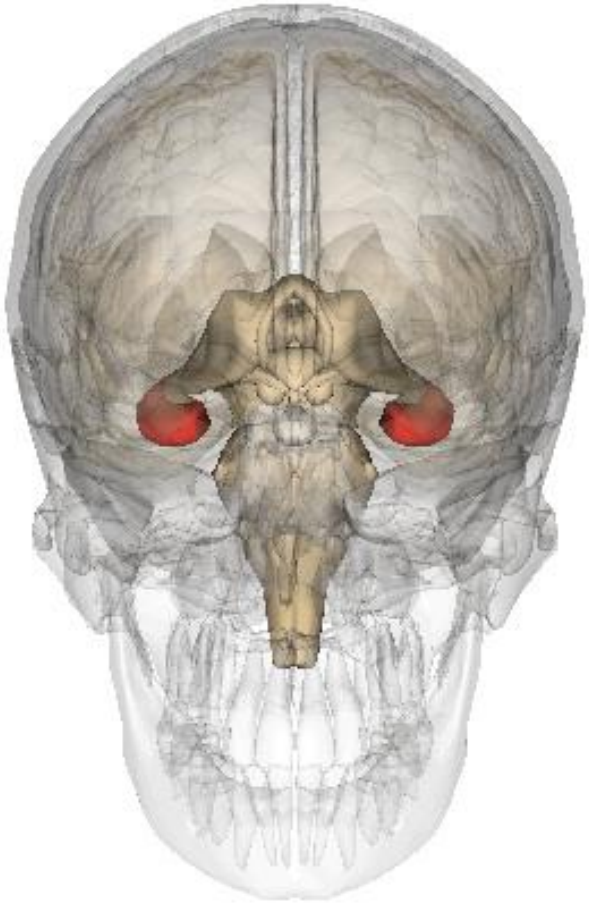
Pons

- The bulging center part of the brain stem
- Mostly composed of fiber tracts
- Includes nuclei involved in the control of breathing

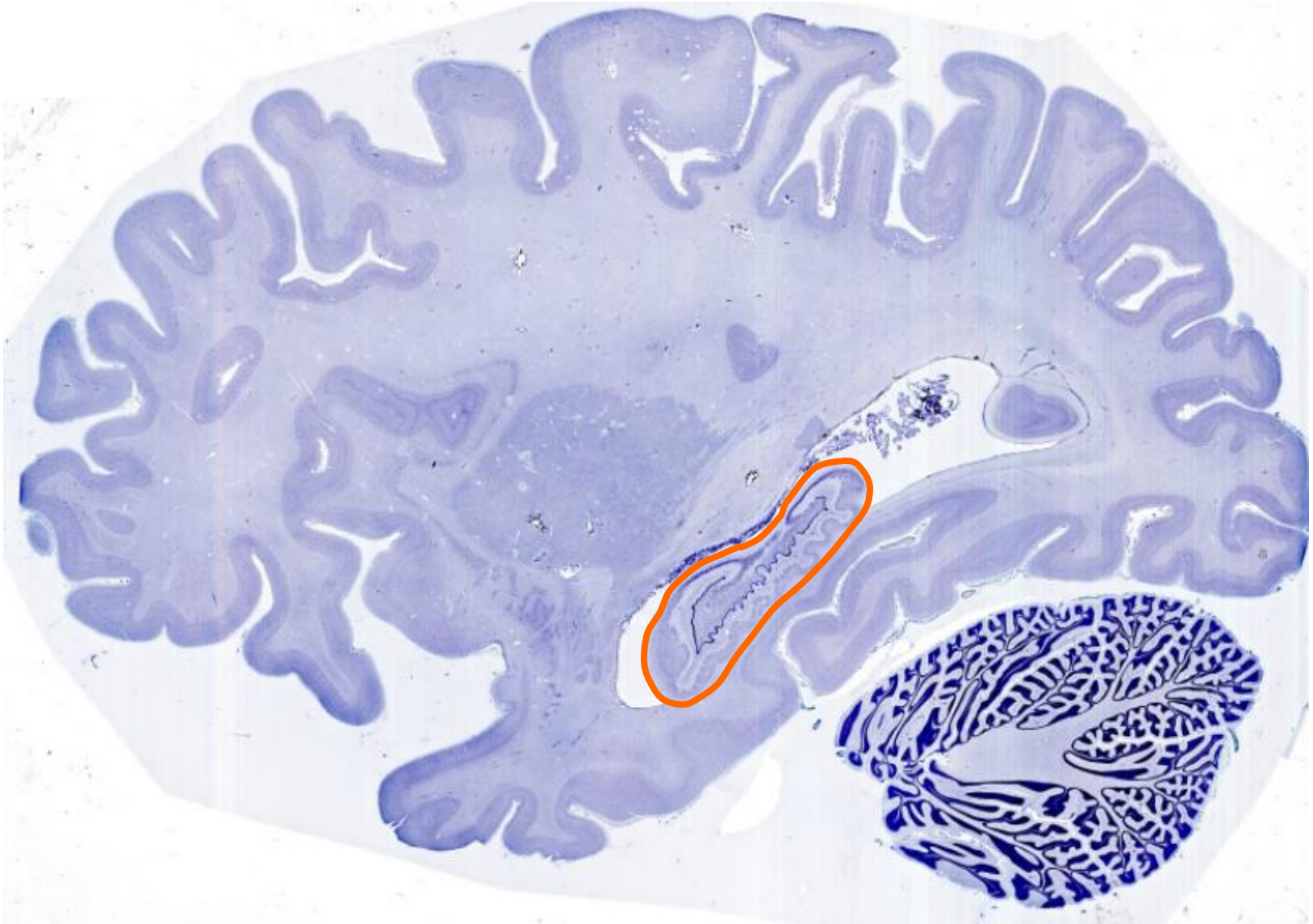
Medulla Oblongata

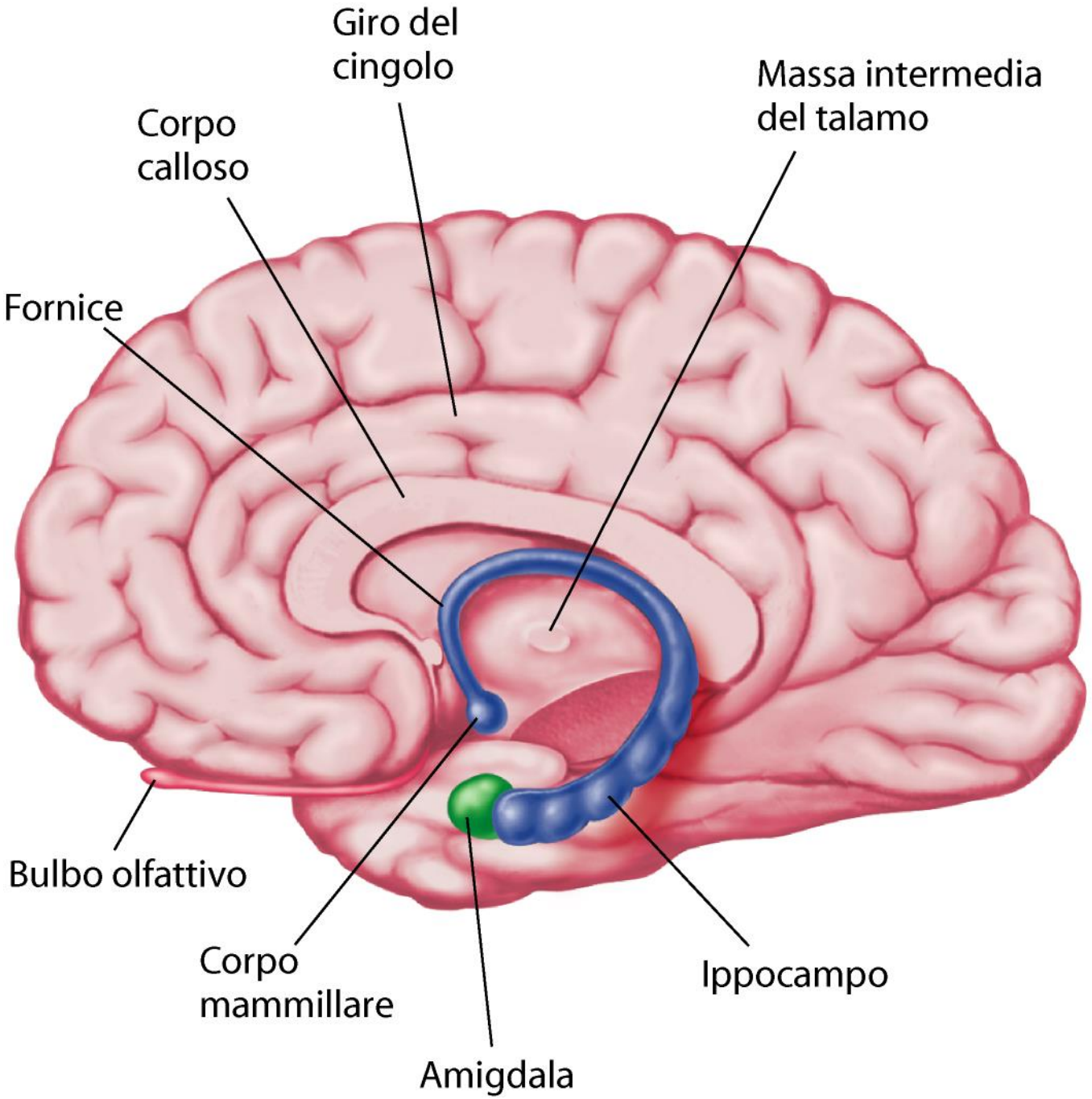
- The lowest part of the brain stem
- Merges into the spinal cord
- Includes important fiber tracts
- Contains important control centers
  - Heart rate control
  - Blood pressure regulation
  - Breathing
  - Swallowing
  - Vomiting

Hippocampus

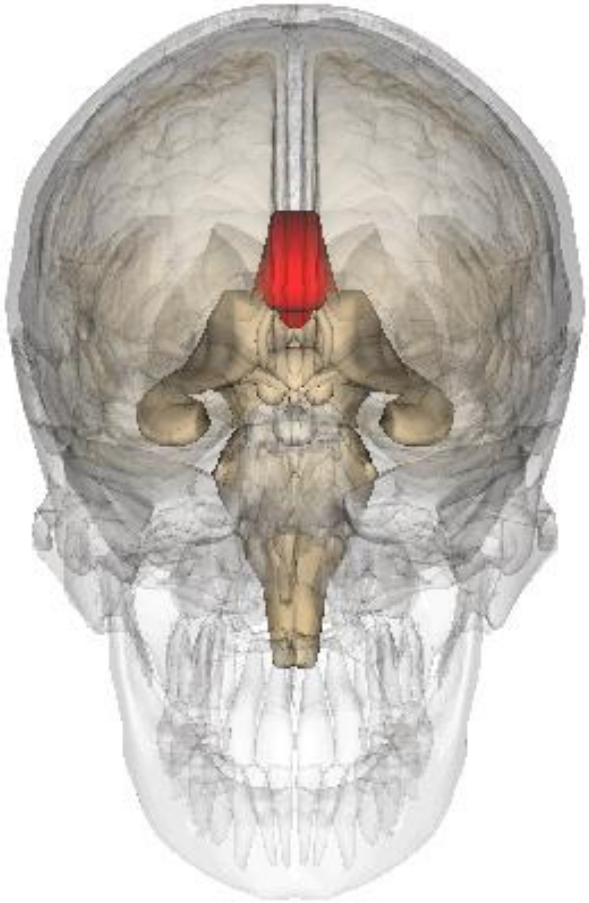


Hippocampus

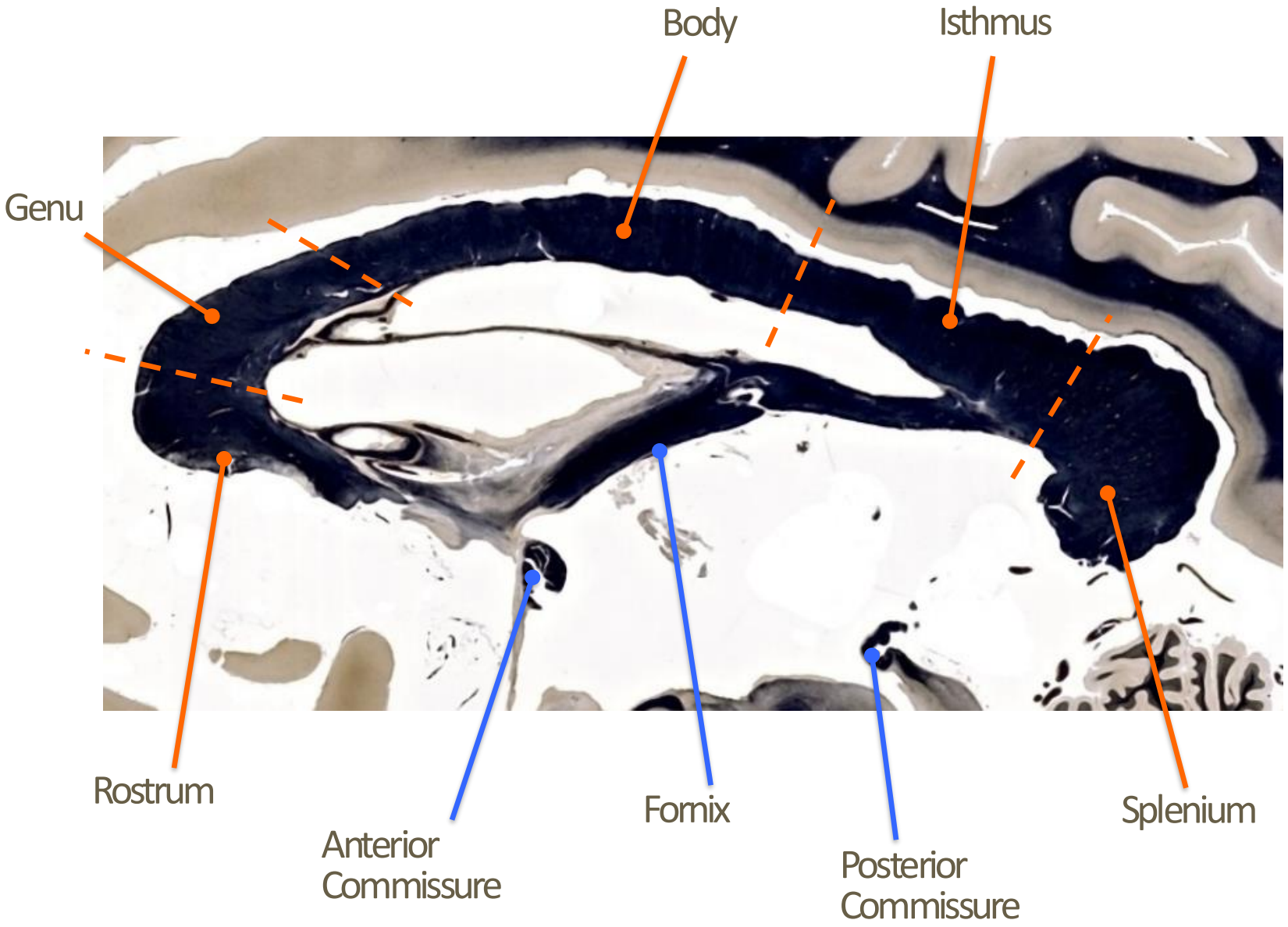




Corpus Callosum

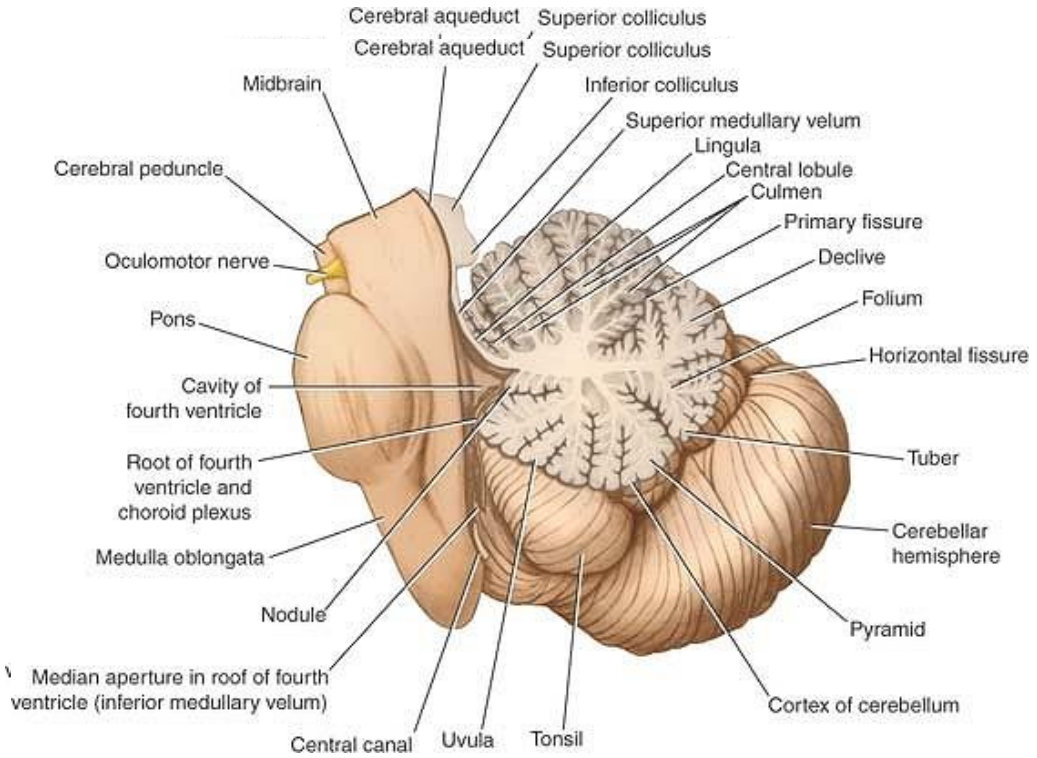


Corpus Callosum


Body
Isthmus
Genu
Rostrum
Anterior
Commissure
Fornix
Posterior
Commissure
Splenium

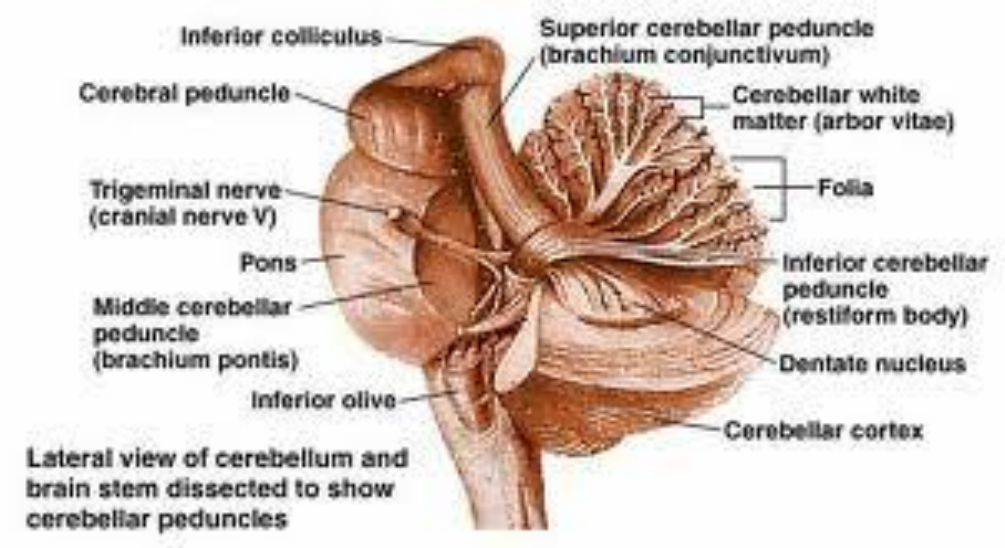
Cerebellum

- Situated in the posterior cranial fossa and is covered superiorly by the tentorium cerebelli.
- It is the largest part of the hindbrain (10% of total weight) and lies posterior to the fourth ventricle, the pons, and the medulla oblongata.
- It consists of two cerebellar hemispheres joined by a narrow median vermis.



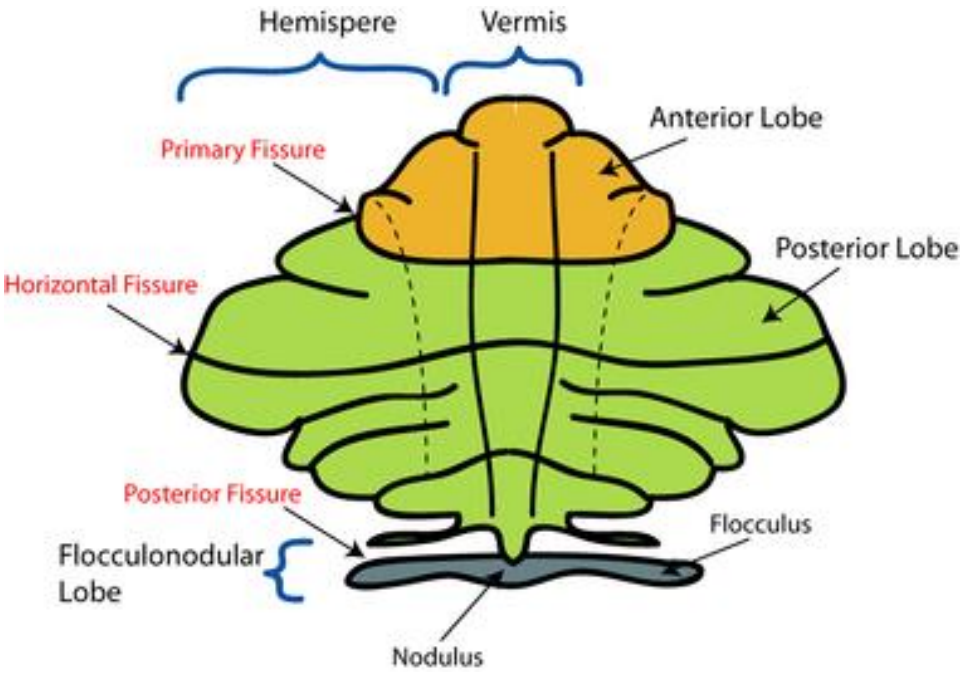
Cerebellum

- Three symmetrical bundles of nerve fibers called the superior, middle, and inferior cerebellar peduncles.
- Superior peduncle enters mid brain
- Middle peduncule consist of transverse fibres of pons
- Inferior peduncle connect with medulla



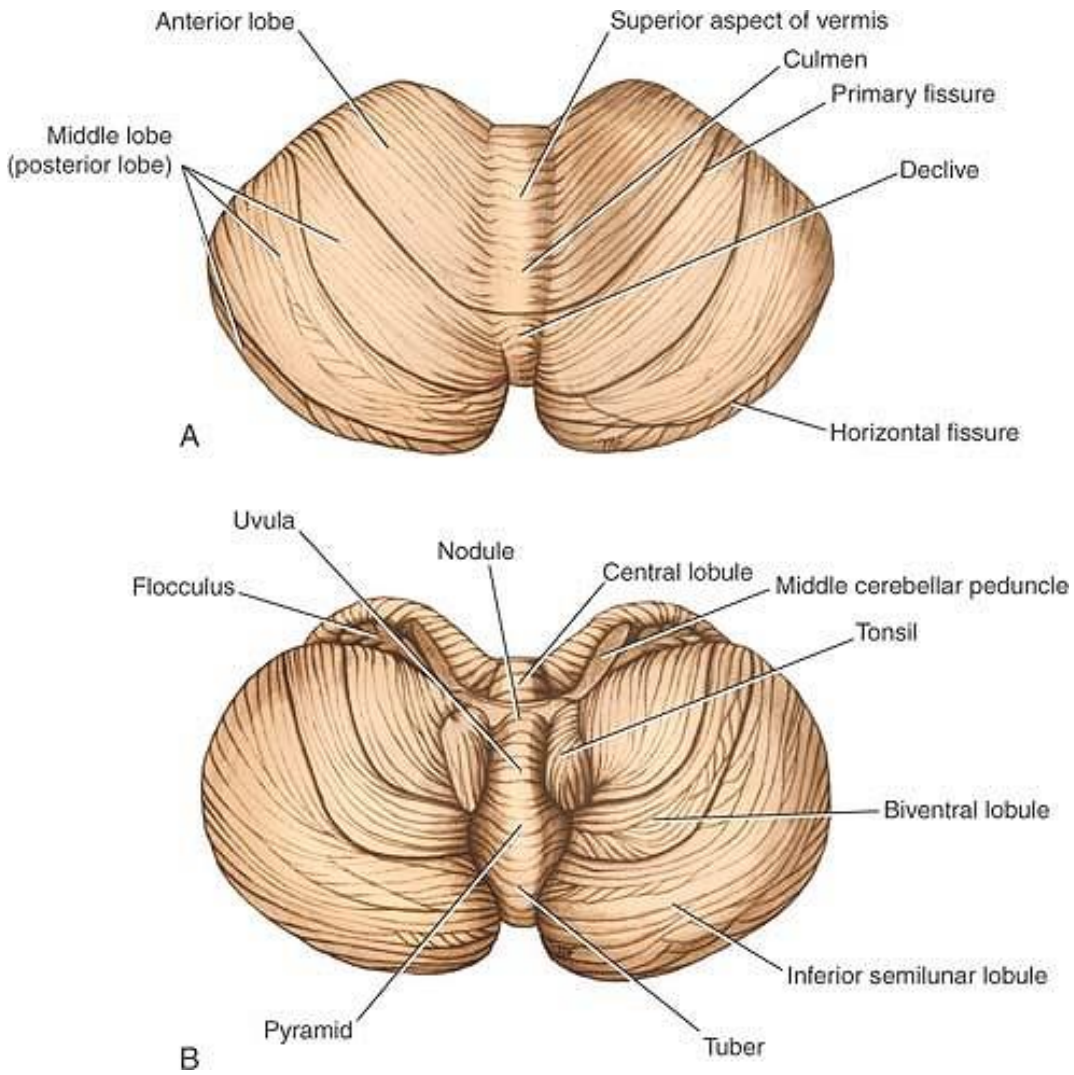
Cerebellum

- The cerebellum is divided into three main lobes: the anterior lobe, the middle lobe, and the flocculonodular lobe.
- The anterior lobe may be seen on the superior surface.
- It is separated from the middle lobe by a wide V-shaped fissure called the primary fissure.
- The middle lobe (sometimes called the posterior lobe), which is the largest part of the cerebellum, is situated between the primary and uvulonodular fissures.
- The flocculonodular lobe is situated posterior to the uvulonodular fissure.

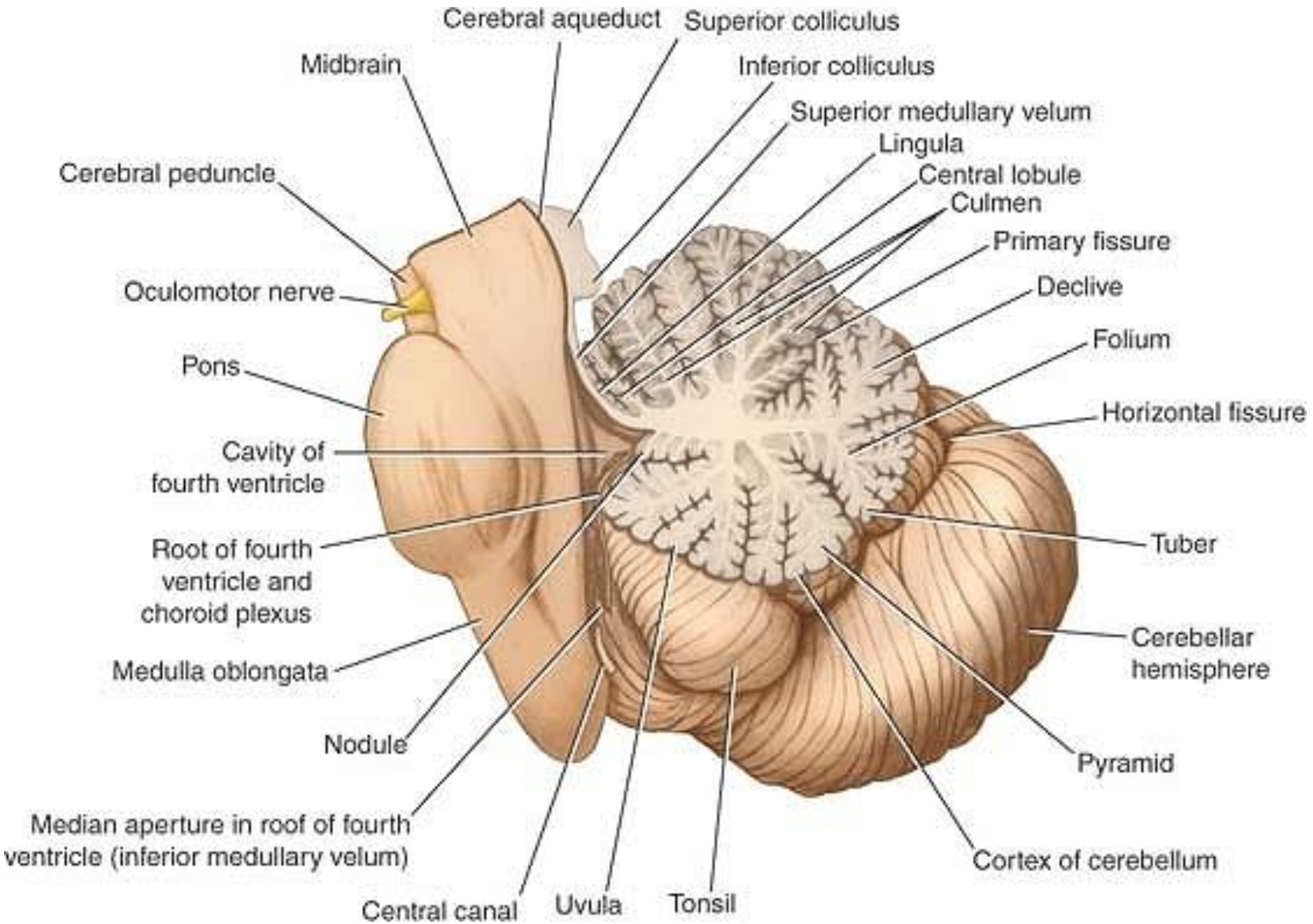


Cerebellum

- Sup part of vermis
- ✓ Lingula
- ✓ Culmen
- ✓ Declive
- ✓ Folium
- Inferior part of vermis
- ✓ Tuber
- ✓ Pyramid
- ✓ Uvula
- ✓ Nodule



Vermis


Cerebral aqueduct
Superior colliculus
Midbrain
Inferior colliculus
Superior medullary velum
Lingula
Cerebral peduncle
Central lobule
Culmen
Primary fissure
Oculomotor nerve
Declive
Folium
Pons
Horizontal fissure
Cavity of fourth ventricle
Tuber
Root of fourth ventricle and choroid plexus
Cerebellar hemisphere
Medulla oblongata
Nodule
Pyramid
Median aperture in roof of fourth ventricle (inferior medullary velum)
Cortex of cerebellum
Central canal
Uvula
Tonsil

Cerebellar nuclei

- Histologically made up of three layers
- Embedded in white matter are four paired nuclei
- Dentate is largest
- Main connection is cerebropontocerebellar
- Efferent fibres pass to contralateral red nucleus, thalamus, and cerebral cortex.