A few questions on the content of the previous lecture

slido

A plane separating the brain into dorsal and ventral parts is called...

ⓘ Start presenting to display the poll results on this slide.

slido

The process through which the neural plate folds into a neural groove and then a neural tube is called....

ⓘ Start presenting to display the poll results on this slide.

slido

The neural tube gives rise to the ..., while the neural crest gives rise to the ...

ⓘ Start presenting to display the poll results on this slide.

Any questions/remarks before we begin today’s lecture?

Nervous system anatomy

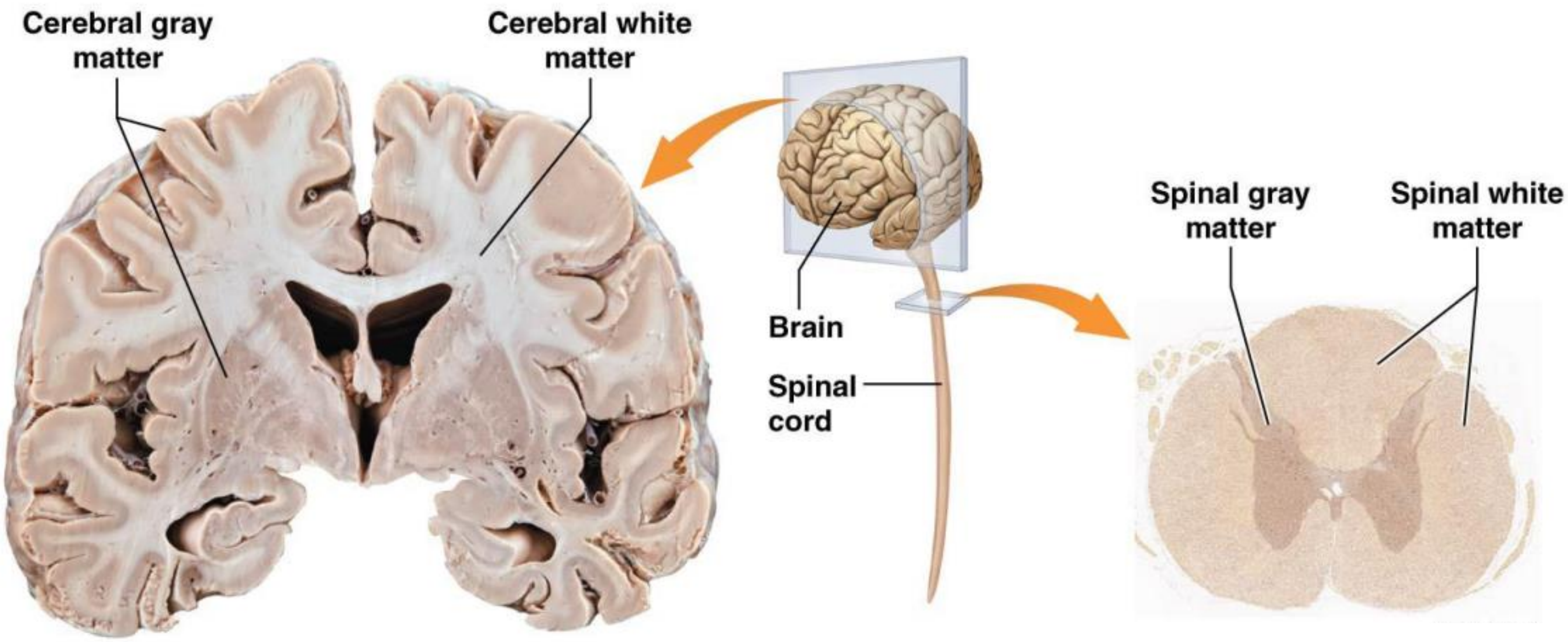
Dr. Lavinia Carmen Uscătescu

November 20th 2023

Outline

1. Central nervous system
    - Cortical and subcortical organisation
    - The cerebellum
    - Commissures
    - The ventricular system
    - Cerebral blood supply
    - The spinal cord
2. Peripheral nervous system

Gray and white matter distribution



https://tinyurl.com/mtkj5sap

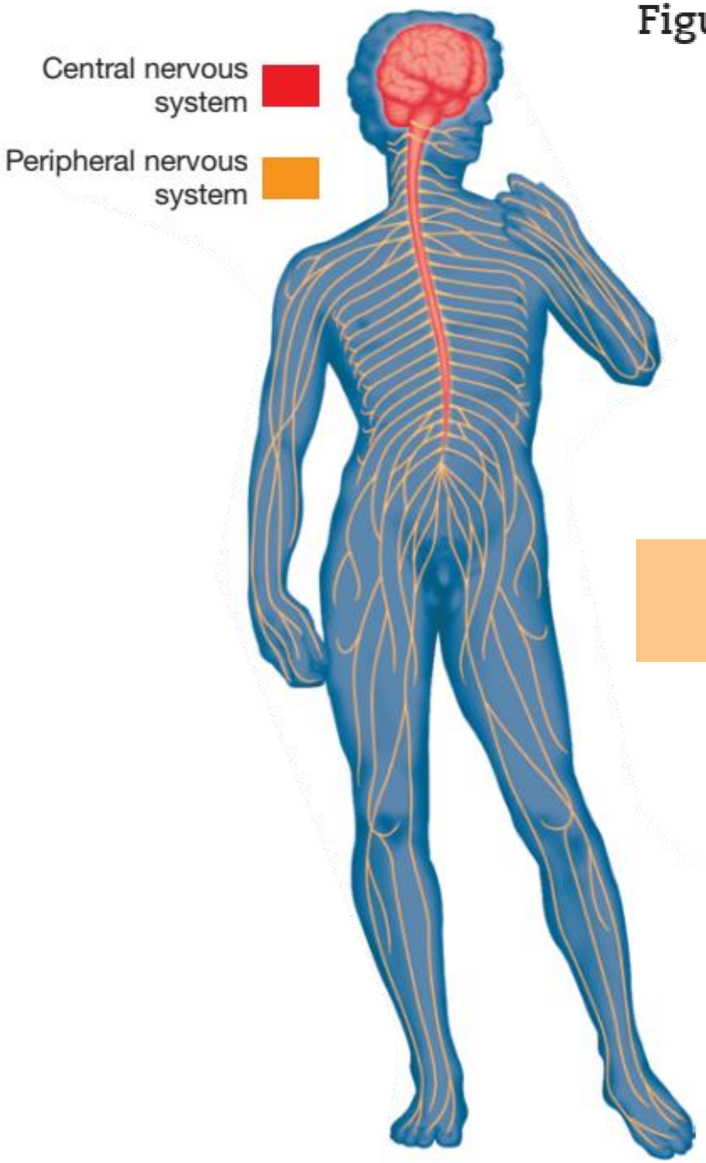
gray matter

composed largely of cell bodies and unmyelinated interneurons

white matter

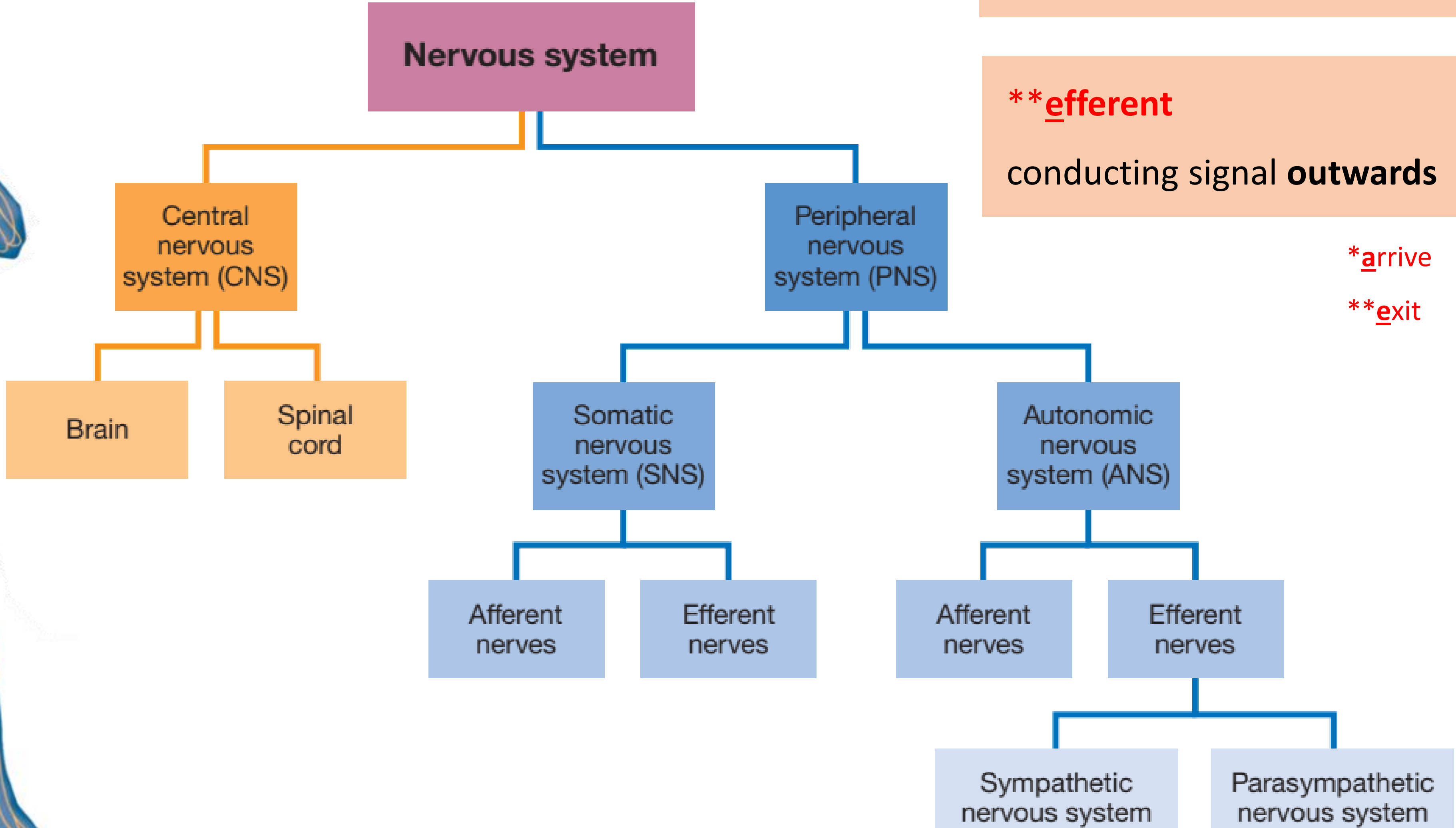
composed largely of myelinated axons

Nervous system subdivisions



Pinel & Barnes, (2021), p. 74

Figure 3.2 The major divisions of the nervous system.



Pinel & Barnes, (2021), p. 75

***afferent**

conducting signal **inwards**

****efferent**

conducting signal **outwards**

*arrive

**exit

Cortical and subcortical organisation

The meninges

meninges

(plural of "meninx")

The three membranes that envelop the brain and spinal cord

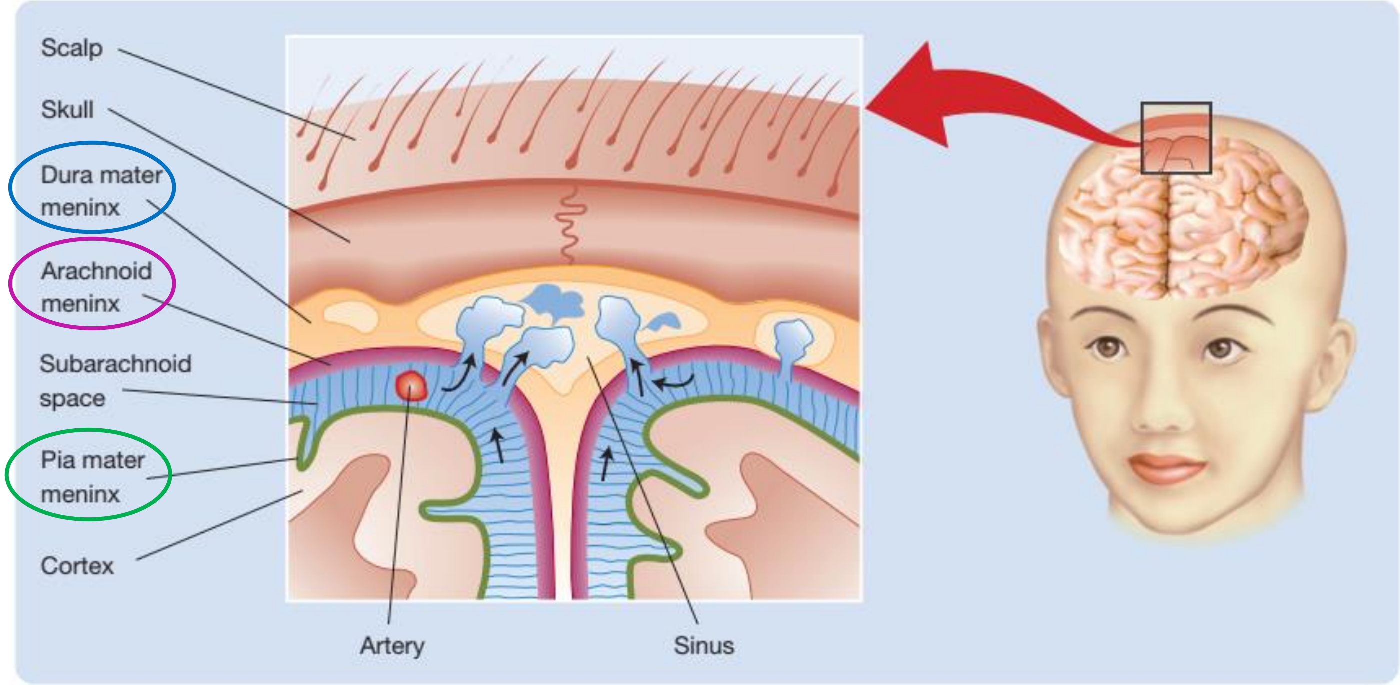
*from Latin and Greek ("meninx"): "**membrane, covering**"*

dura mater

*tough **outer membrane** surrounding the brain and the spinal cord*

*from Latin : "**hard mother**"*

Figure 3.4 The absorption of cerebrospinal fluid (CSF) from the subarachnoid space (blue) into a major sinus. Note the three meninges.



Pinel & Barnes, (2021), p. 76

arachnoid (mater)

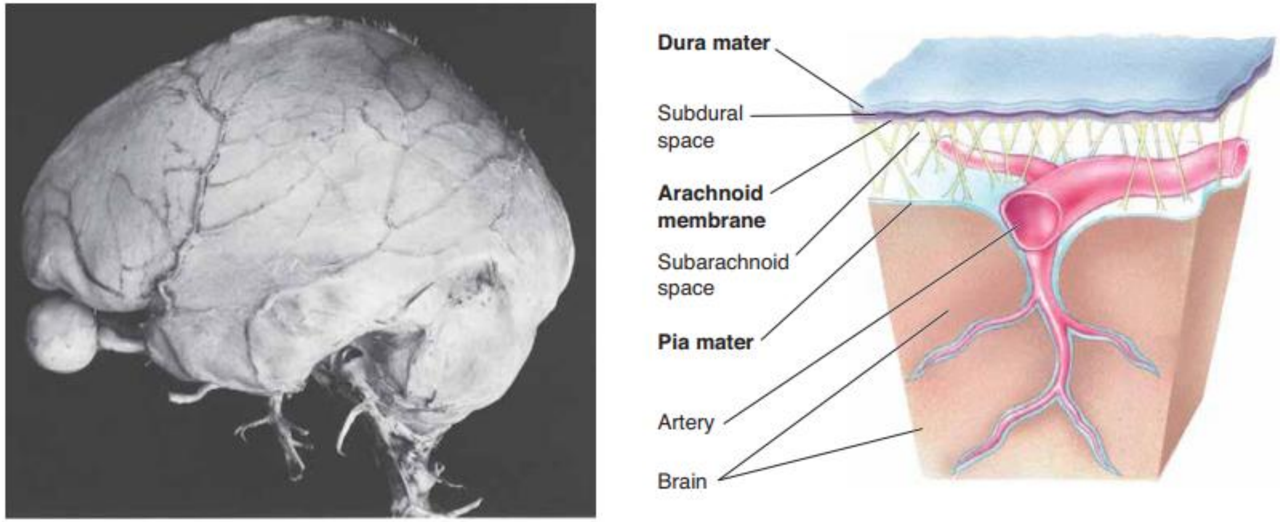
*the **middle membrane** surrounding the brain and spinal cord*

*from Latin ("arachnoides") and from Greek ("arakhnoeides"): "**cobweb-like**"*

pia mater

*the **innermost layer** of the meninges*

*from Latin : "**tender mother**"*



(a) (b)

▲ FIGURE 7.6
The meninges. (a) The skull has been removed to show the tough outer meningeal membrane, the dura mater. (Source: Gluhbegoric and Williams, 1980.)
(b) Illustrated in cross section, the three meningeal layers protecting the brain and spinal cord are the dura mater, the arachnoid membrane, and the pia mater.

Bear et al., (2015), p. 186

See the Munich Brain Course at:
https://www.intensivkurs-neuroanatomie.de/

The subarachnoid space is filled with a clear liquid called "**cerebrospinal fluid**" (CSF). It also contains **major blood vessels** and **cisterns** (enlarged pockets of CSF created due to the separation of the arachnoid from the pia mater)

did you know…?

Figure 10.1 A meningioma.

Living Art Enterprises/Science Source

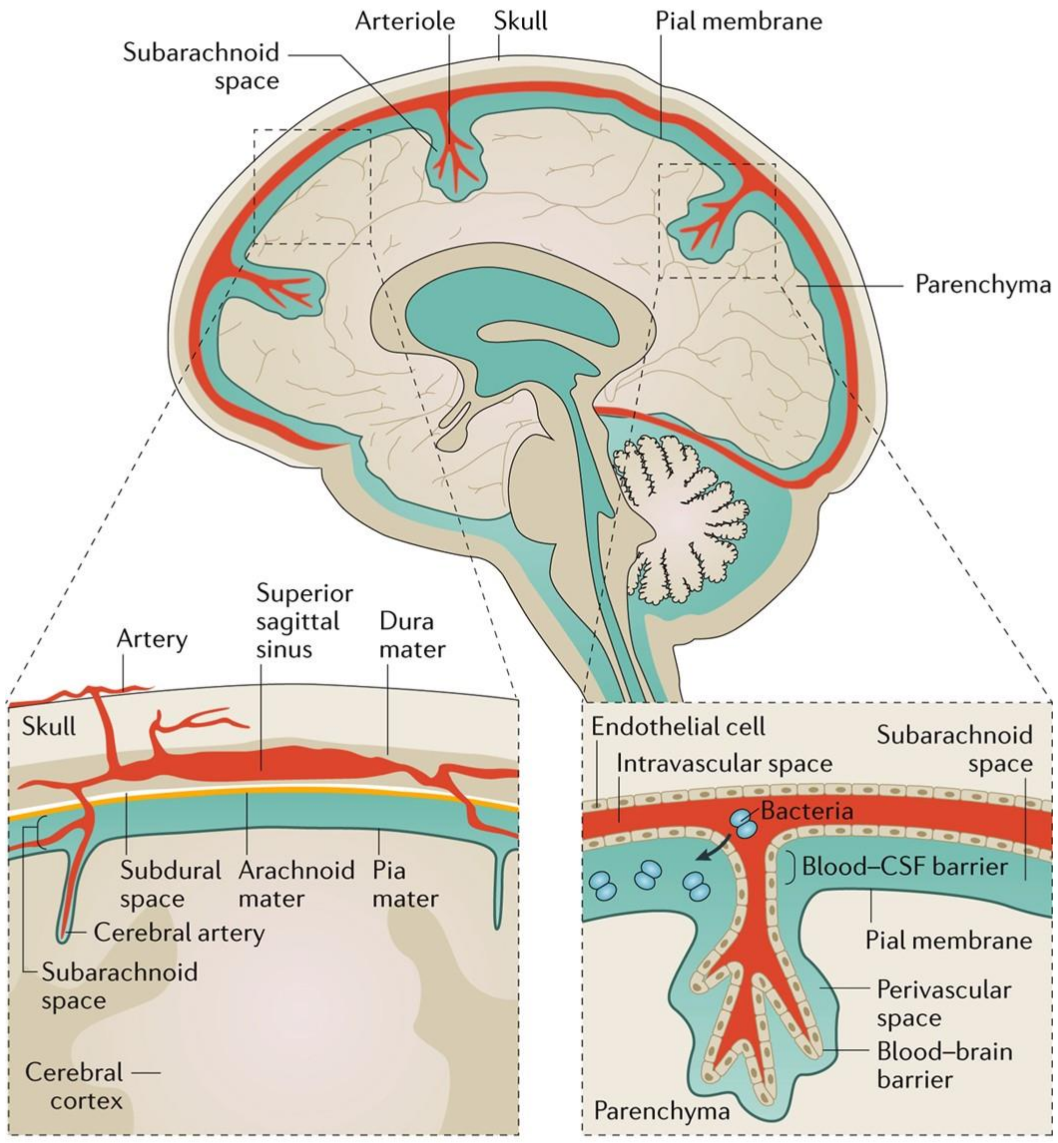
Pinel & Barnes, (2021), p. 260

~ 20% of tumors found in the human brain are **meningiomas** (tumors that grow between the layers of the meninges).

All meningiomas are **encapsulated** tumors (i.e., tumors that grow within their own membrane) => particularly easy to identify on a CT scan.

They can influence the function of the brain only by the **pressure** they exert on surrounding tissue, and they are almost always benign tumors => are surgically removable, with little risk of further growth in the body.

did you know…?



https://www.nature.com/articles/nrdp201674

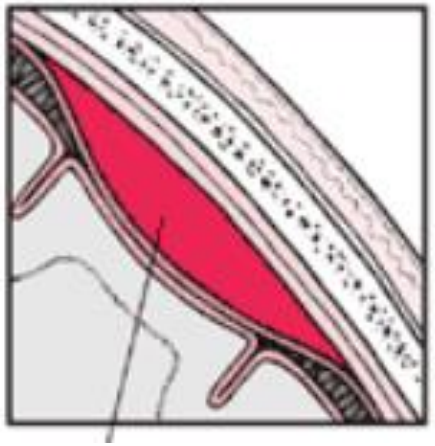
Meningitis is an <u>inflammation of the meninges</u> and <u>subarachnoid space</u> that can also involve the brain **cortex** and **parenchyma** owing to the close anatomical relationship between the cerebrospinal fluid (CSF) and the brain.

Per definition, **bacterial meningitis** is an <u>infection of the CSF-filled subarachnoid space</u>. Inflammation of the meninges and subarachnoid space leads to the classic triad of meningitis symptoms — **headache**, **fever**, and **neck stiffness**.

**__brain parenchyma__ refers to the functional tissue in the brain that is made up of the two types of brain cell, neurons and glial cells*

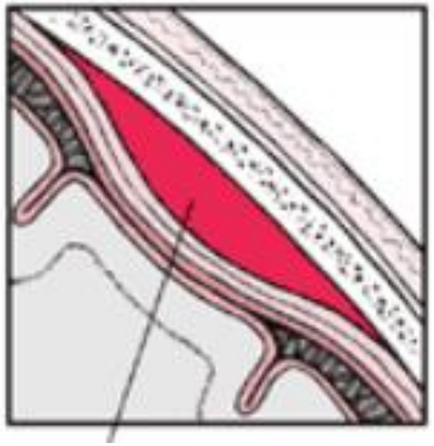
did you know…?

Subdural hemorrhage



Bleeding between the **arachnoid** mater and the **dura** mater

Epidural hemorrhage



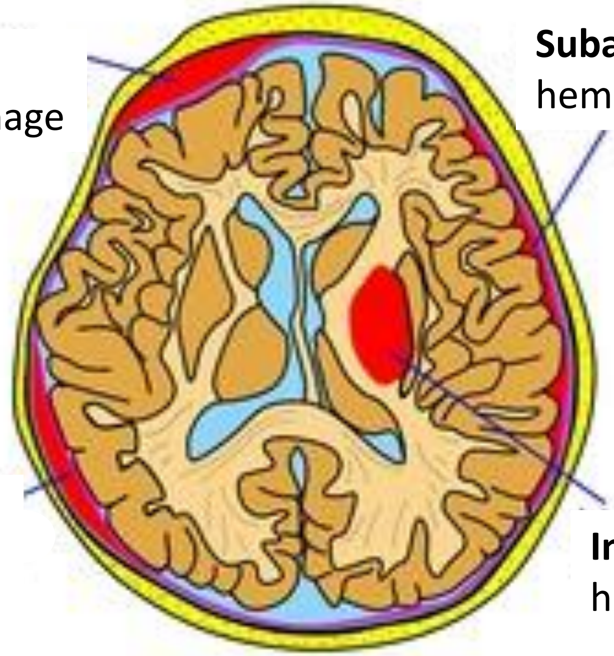
Bleeding between the **dura** mater and the **skull**

https://tinyurl.com/585p8xr7

Intracranial hemorrhage

Epidural hemorrhage

Subarachnoid hemorrhage



Subdural hemorrhage

Intracerebral hemorrhage

https://tinyurl.com/39vwz94k

The meninges in 3D

https://www.youtube.com/watch?v=UkffBv4sh4U&list=PLp9HSlEm97VXyQ32Uwjfz3dpmQ8nl63zJ&index=6

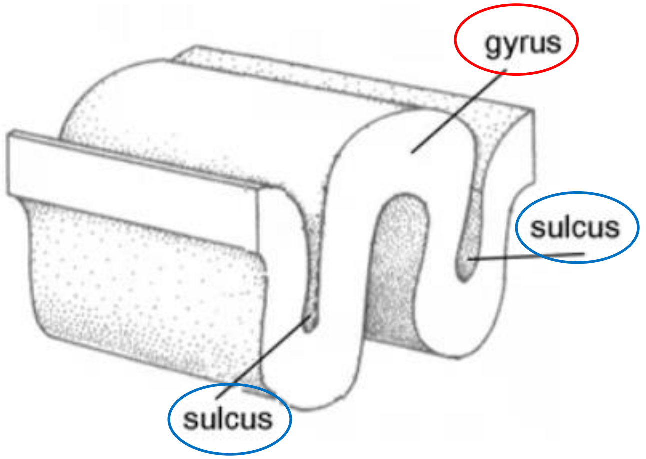
Major landmarks and structures

gyrus, (pl.) gyri

***convolution** between grooves of the brain*

from Latin (gyrus): "circle"

from Greek (gyros): "ring, circle"

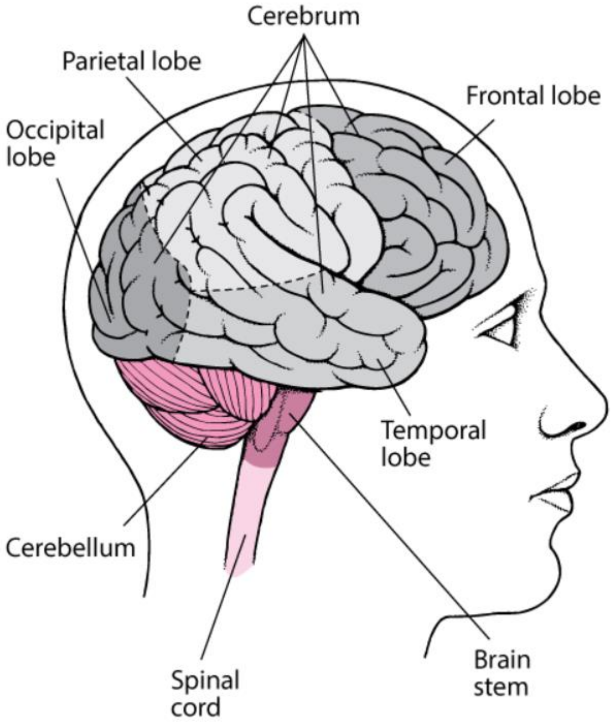


https://tinyurl.com/56h9byp6

sulcus, (pl.) sulci

***fissure** between convolutions of the brain*

from Latin (sulcus): "furrow, trench, ditch"



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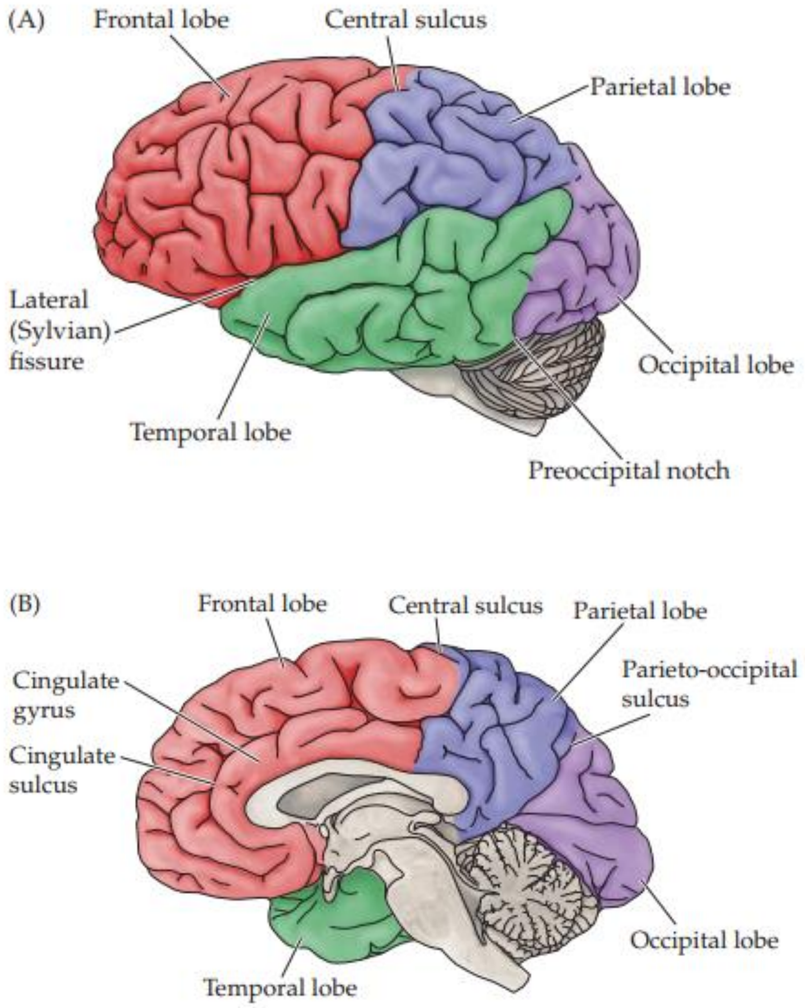


Purves et al., (2018), Appendix

The **central sulcus is also known as the **fissure of Rolando**, or the **Rolandic fissure***

Brief overview of cortical localisation

https://www.youtube.com/watch?v=akjdkBeFNLE

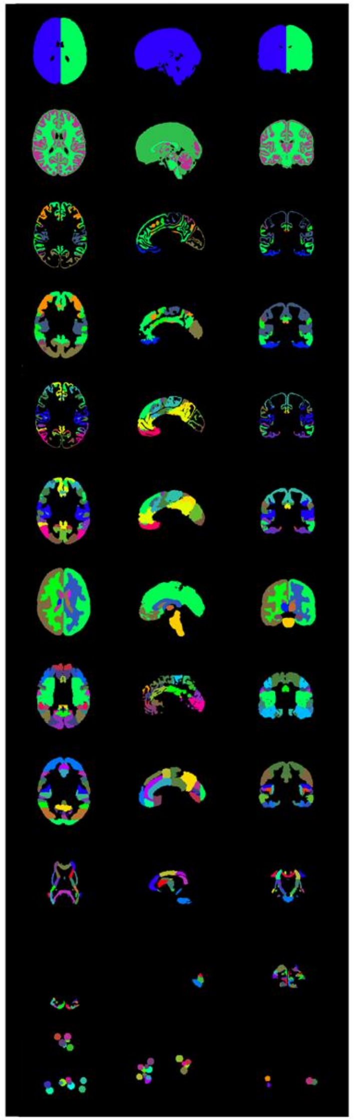
Neuroscientists use a wide array of **cortical** and/or **subcortical** atlases for **parcellation**, depending on which brain areas they are interested in and how fine-grained their analysis needs to be.

cytoarchitectonic atlas

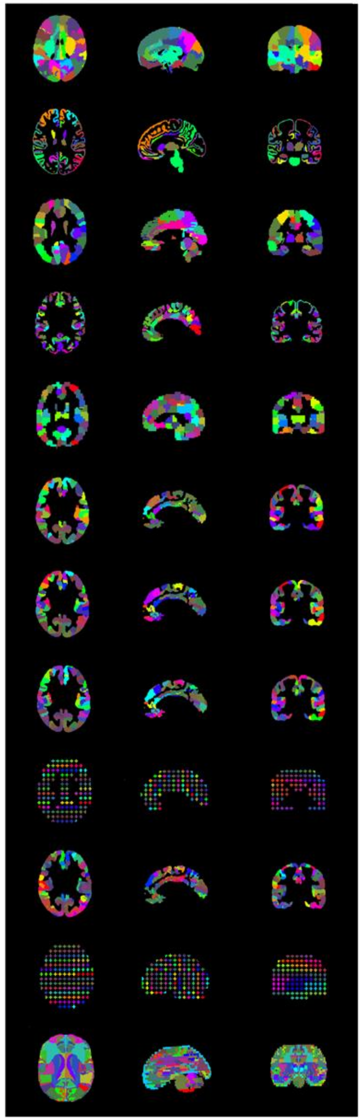
an atlas based on the **cellular composition** of the central nervous system's tissues under the **microscope**

There is considerable inter-individual neuroanatomical variability!

Atlas	# of regions	Horizontal	Sagittal	Coronal
Hemispheric	2			
Tissue	3			
Yeo-7	7			
Yeo-7-Lib	7			
Yeo-17	17			
Yeo-17-Lib	17			
HOS	21			
Brodmann	41			
HOC	48			
JHU	48			
PrincetonVis	49			
PP264	58			



Atlas	# of regions	Horizontal	Sagittal	Coronal
Desikan	70			
DKT	83			
AAL	116			
Glasser	360			
CPAC200	200			
Schaefer200	200			
Schaefer300	300			
Schaefer400	400			
Slab907	907			
Schaefer1000	1000			
Slab1068	1068			
Talairach	1105			



https://www.nature.com/articles/s41597-021-00849-3

… plus many more!

Cytoarchitectonics is <u>not the only way</u> in which the nervous system can be parcellated. **Functional parcels** are not necessarily strictly constrained to fixed anatomical boundaries.

> Neuroimage. 2020 Mar:208:116366. doi: 10.1016/j.neuroimage.2019.116366. Epub 2019 Nov 15.

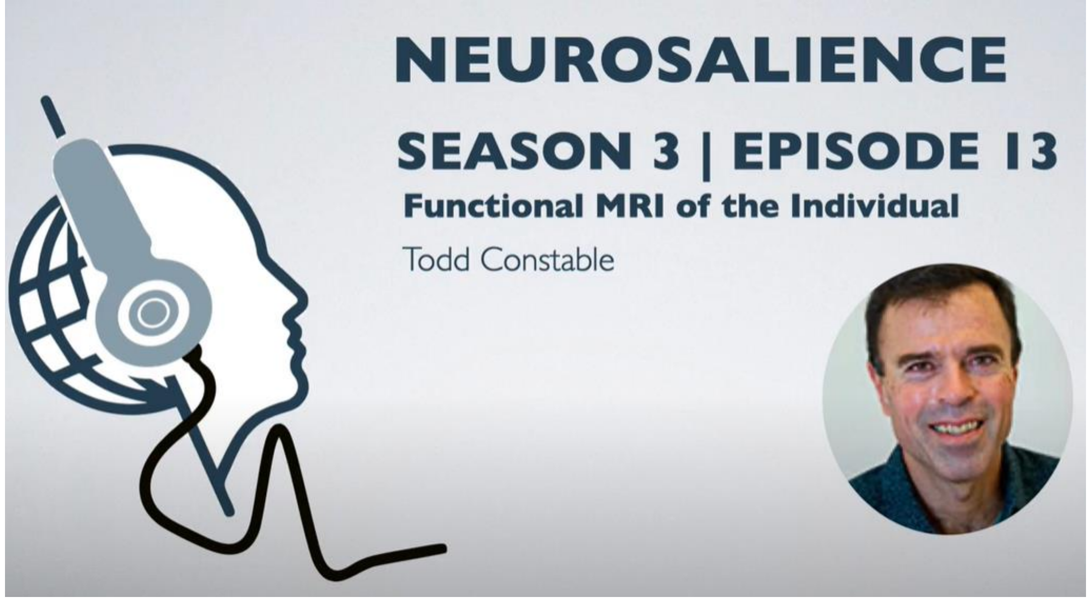
There is no single functional atlas even for a single individual: Functional parcel definitions change with task

Mehraveh Salehi [1], Abigail S Greene [2], Amin Karbasi [3], Xilin Shen [4], Dustin Scheinost [4], R Todd Constable [5]

Highlights

- Functional parcel boundaries reconfigure with cognitive state.
- Parcel reconfigurations are robust and reliable across sessions and subjects.
- Parcel sizes can significantly predict task condition and task performance.
- State-dependent functional atlases have implications for functional connectivity.

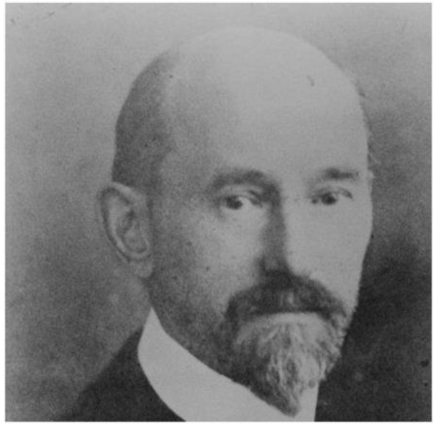
https://pubmed.ncbi.nlm.nih.gov/31740342/



https://www.youtube.com/watch?v=BiCOWD6iSdo

There are ways in which we can retain inter-individual variability in data analysis (more on this next semester, during our lecture on fMRI)

The **Brodmann** cytoarchitectonic atlas



Korbinian Brodmann

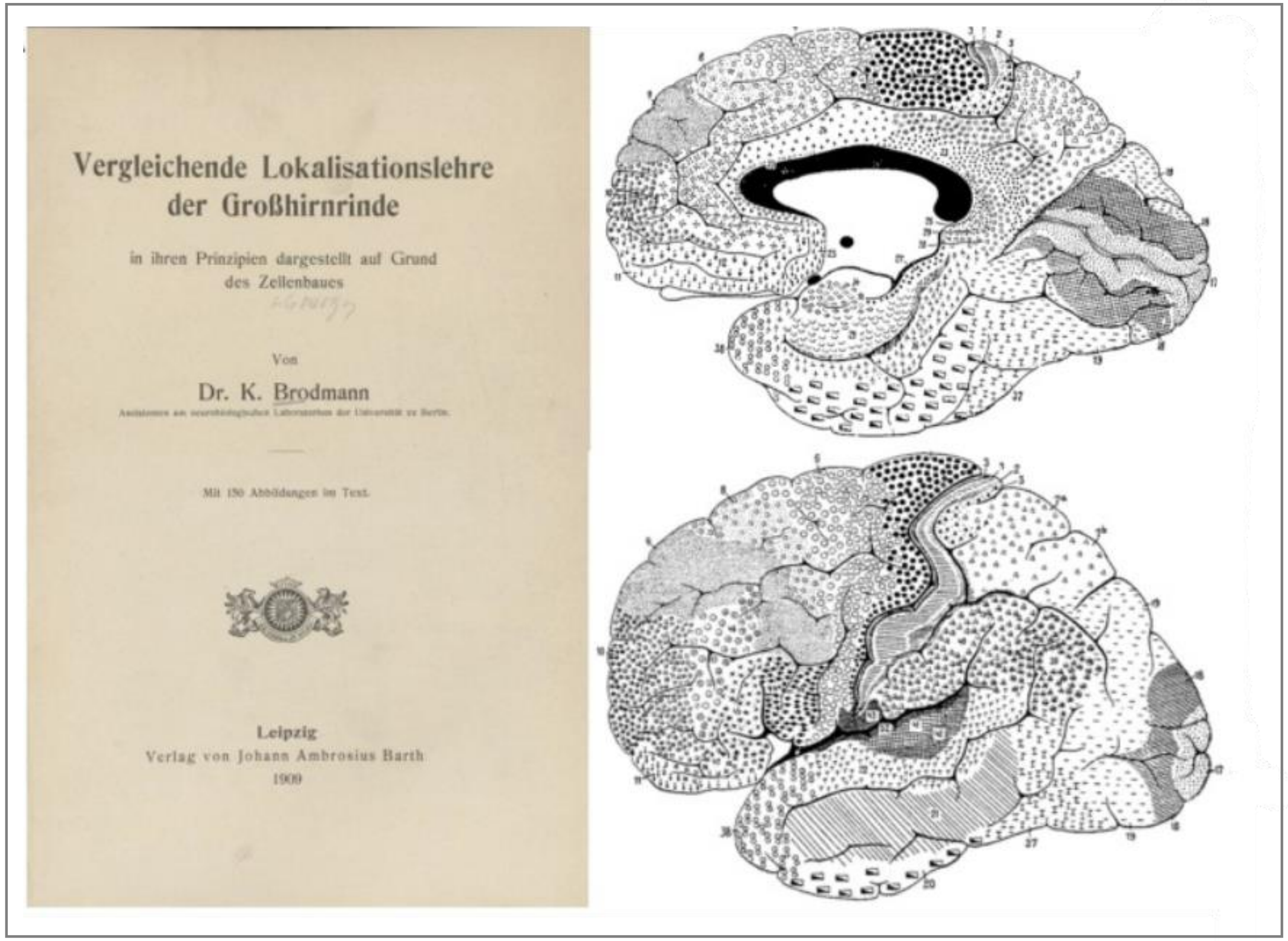
(1868 – 1918)

He distinguished **52** anatomically and functionally distinct areas in the human **cerebral cortex**, based on the shapes of cells and variations in their layered arrangement (**cytoarchitectonics**).

Brain. 2018 Nov; 141(11): 3262–3278.
Published online 2018 Oct 25. doi: 10.1093/brain/awy273
PMCID: PMC6202576
PMID: 30358817

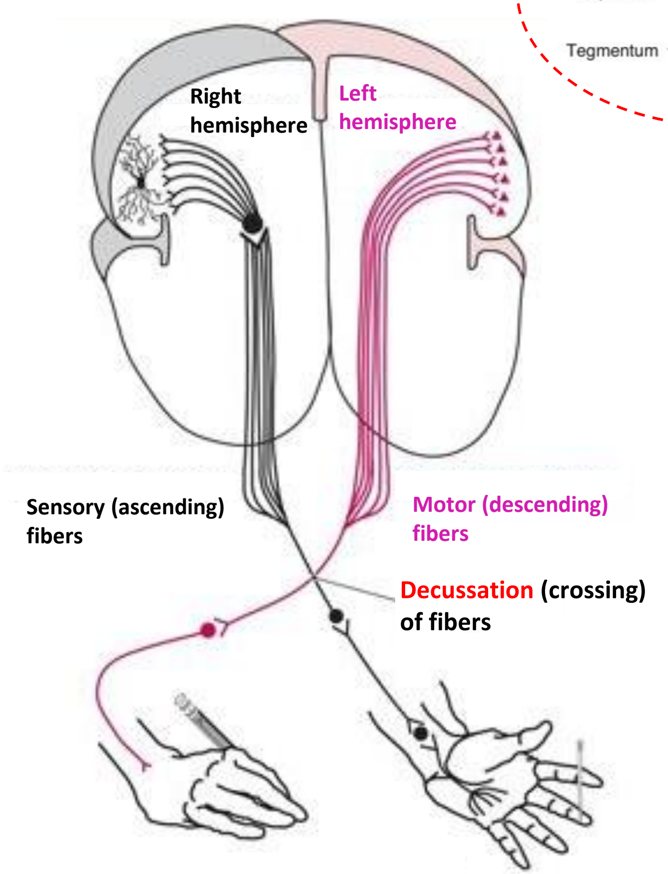
Brodmann: a pioneer of human brain mapping—his impact on concepts of cortical organization

Karl Zilles[1,2,3]



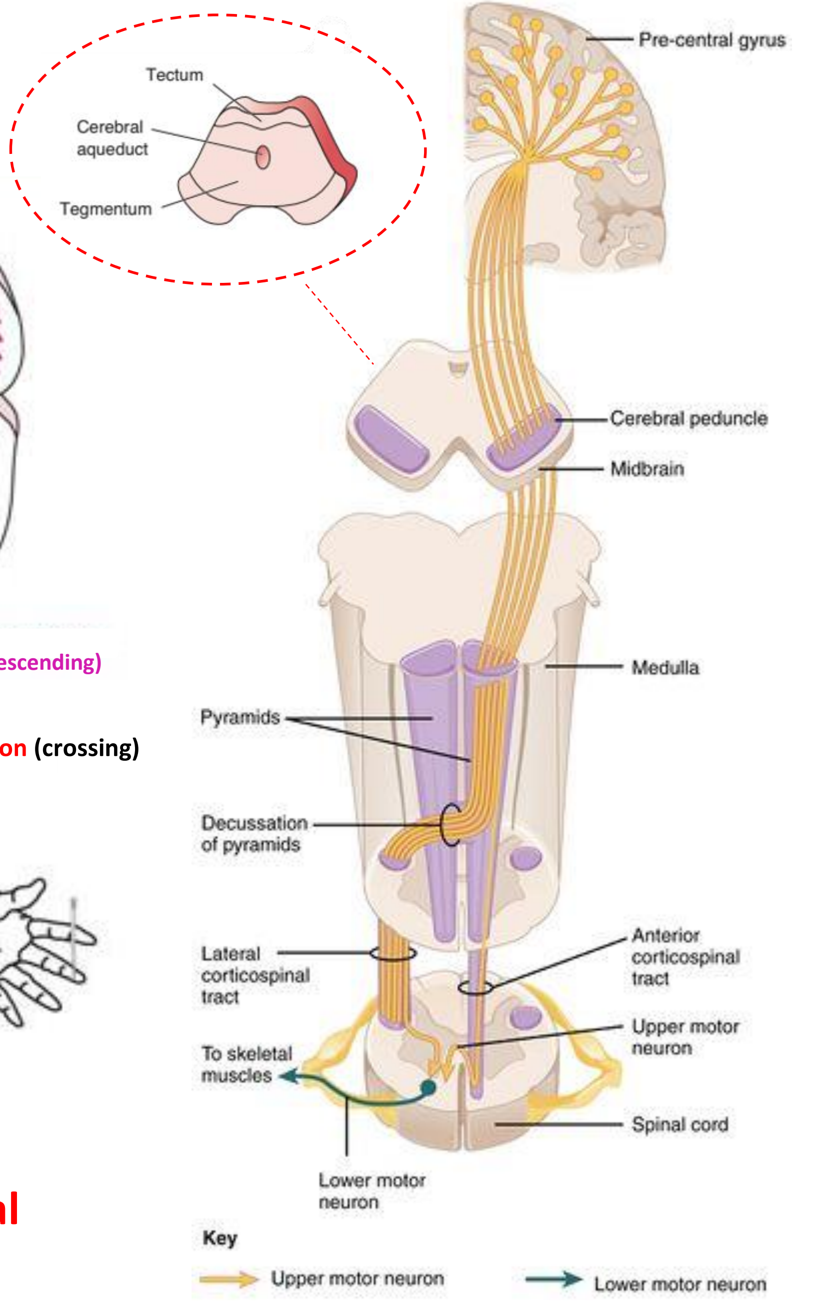
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6202576/

The hemispheres



https://tinyurl.com/3crybrm7

contralateral v. ipsilateral



https://www.physio-pedia.com/Corticospinal_Tract

Review > Lancet Neurol. 2005 Feb;4(2):87-99. doi: 10.1016/S1474-4422(05)00990-7.

Reaching beyond the midline: why are human brains cross wired?

Serge Vulliemoz [1], Olivier Raineteau, Denis Jabaudon

Affiliations + expand

PMID: 15664541 DOI: 10.1016/S1474-4422(05)00990-7

Abstract

The crossing of nerve tracts from one hemisphere in the brain to the contralateral sense organ or limb is a common pattern throughout the CNS, which occurs at specialised bridging points called decussations or commissures. Evolutionary and teleological arguments suggest that midline crossing emerged in response to distinct physiological and anatomical constraints. Several genetic and developmental disorders involve crossing defects or mirror movements, including Kallmann's and Klippel-Feil syndrome, and further defects can also result from injury. Crossed pathways are also involved in recovery after CNS lesions and may allow for compensation for damaged areas. The development of decussation is under the control of a host of signalling molecules. Growing understanding of the molecular processes underlying the formation of these structures offers hope for new diagnostic and therapeutic interventions.

https://pubmed.ncbi.nlm.nih.gov/15664541/

QUANTIZED COLUMNS

Why the Brain's Connections to the Body Are Crisscrossed

In all bilaterally symmetrical animals, from humans down to simple worms, nerves cross from one side of the body to the opposite side of the brain. Geometry may explain why.

https://tinyurl.com/c7u5s5v4

The lobes of the brain

Figure 3.18 The early development of the mammalian brain illustrated in schematic horizontal sections.

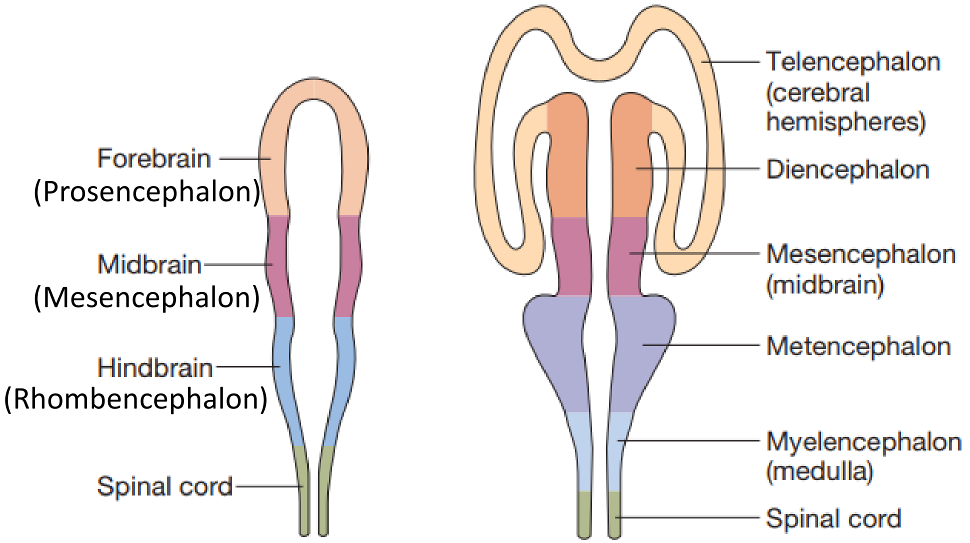
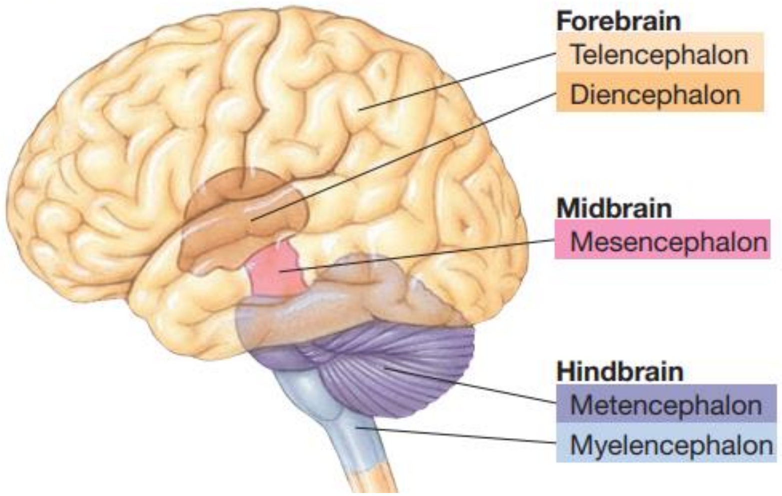
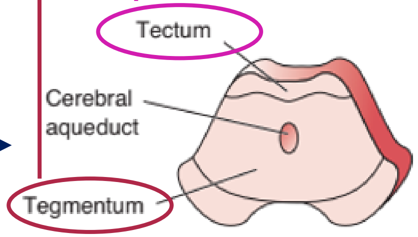


Figure 3.19 The five divisions of the adult human brain.



ascending **sensory** and
descending **motor** pathways

superior (vision) and
inferior (auditory) **colliculi**



pons and cerebellum

medulla

Pinel & Barnes, (2021), p. 87

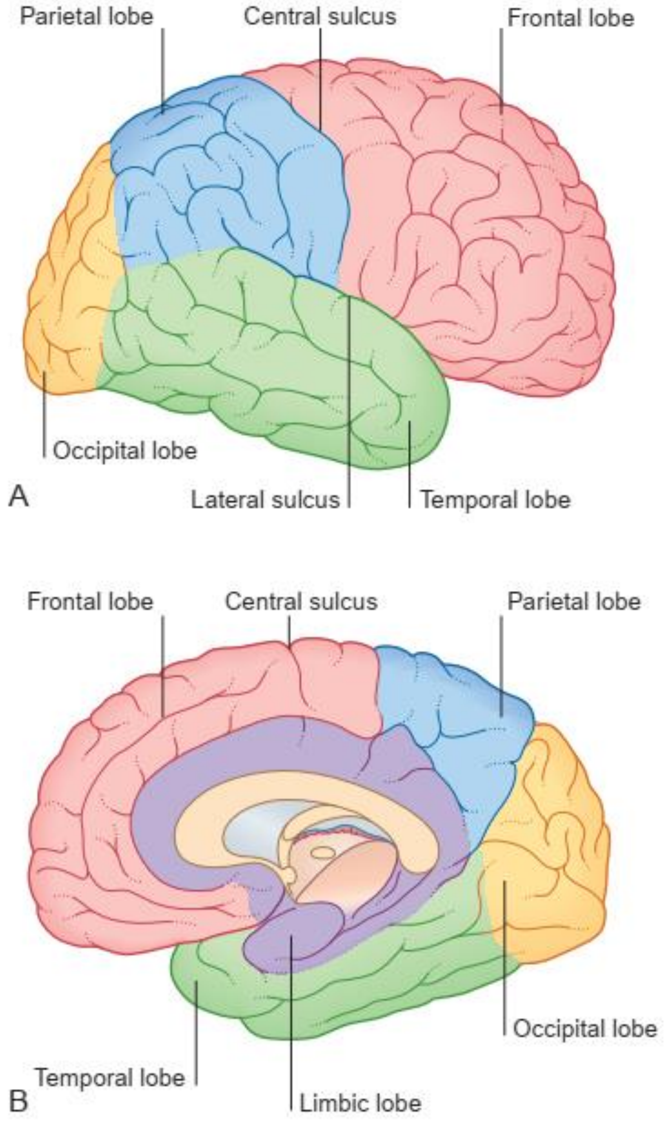
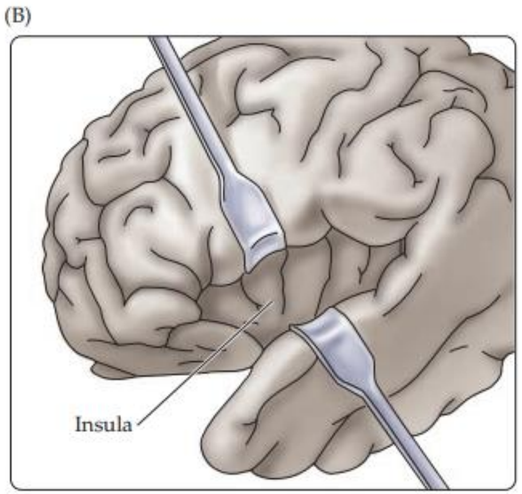


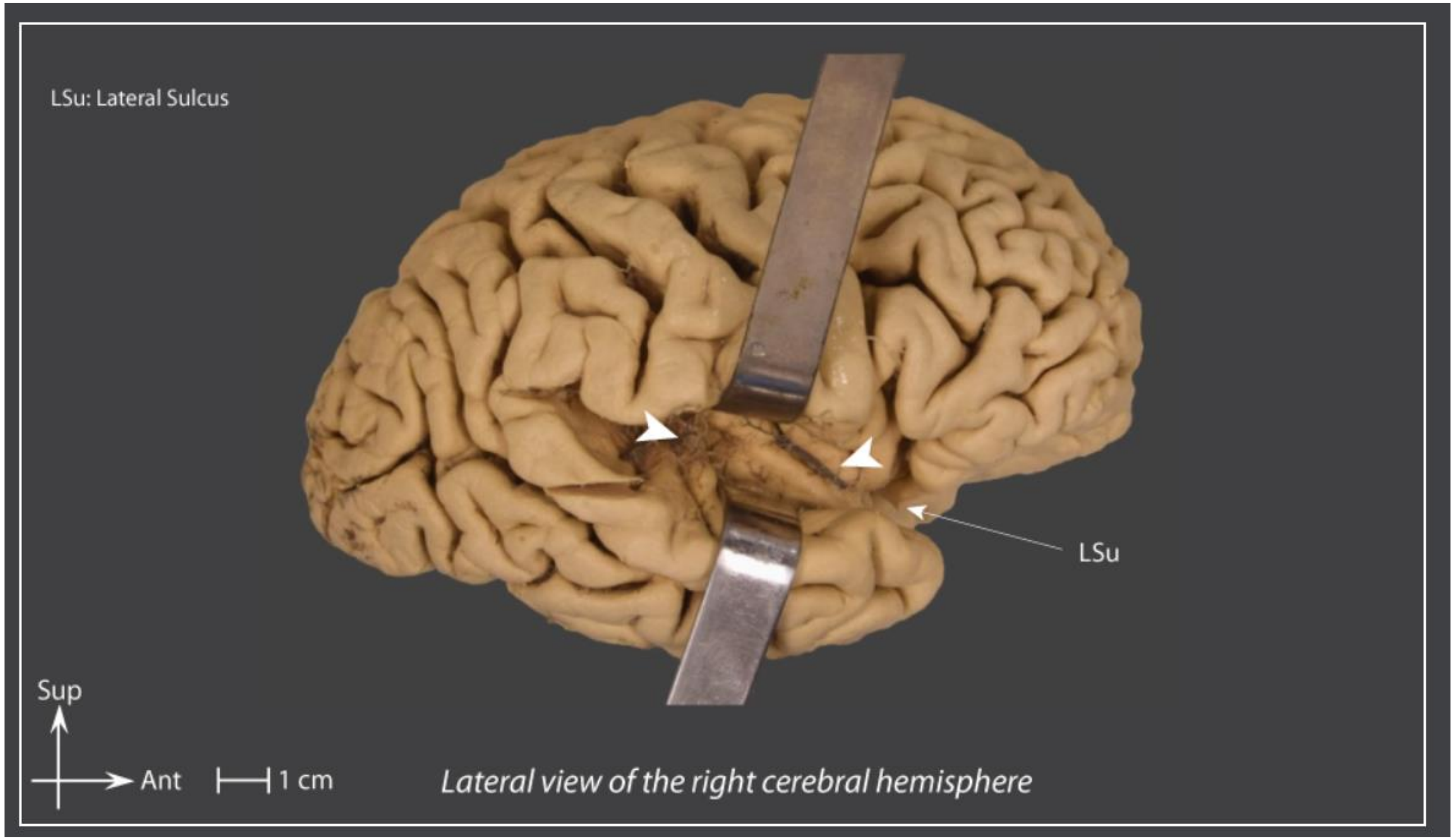
Fig. 2.1 The five lobes of the brain. (A) Lateral surface and (B) medial surface of the right cerebral hemisphere.

Mtui et al., (2021), p. 8



Purves et al. (2018), Appendix

The banks of the lateral (Sylvian) fissure have been pulled apart to expose the **insula**



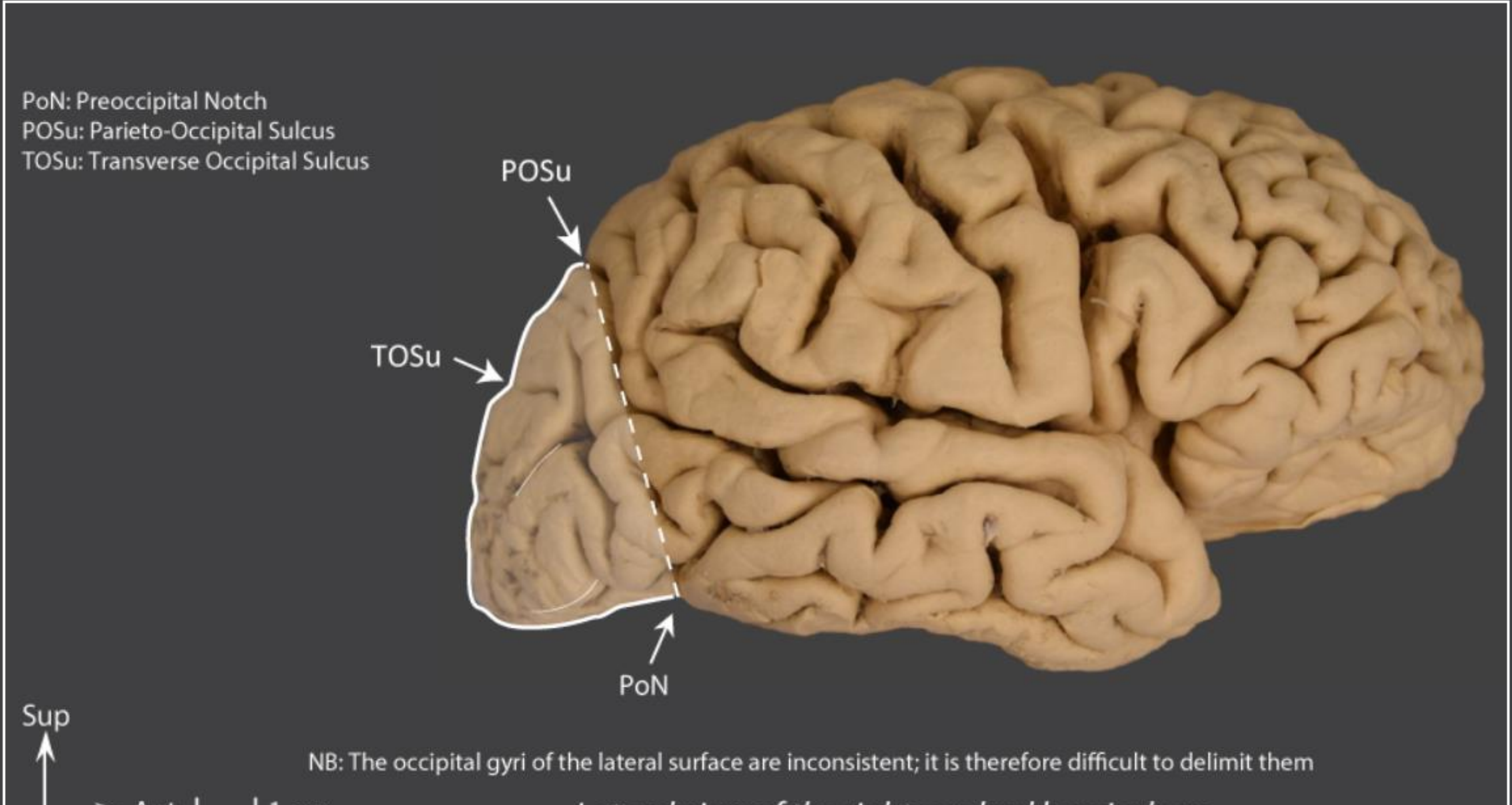
https://sites.uclouvain.be/braininteratlas/en/chapter/external-configuration

■ Six lobes

General view >

- Frontal lobe
  - Lateral view of the right cerebral hemisphere >
  - Medial view of the left cerebral hemisphere >
  - Inferior view of the forebrain >
- Parietal lobe
  - Lateral view of the right cerebral hemisphere >
  - Medial view of the left cerebral hemisphere >
- Temporal lobe
  - Lateral view of the right cerebral hemisphere >
  - Medial view of the left cerebral hemisphere >
  - Inferior view of the forebrain >
- Occipital lobe
  - Lateral view of the cerebral hemisphere >
  - Medial view of the cerebral hemisphere >
  - Inferior view of the forebrain >
- Insula (insular lobe) >
- Cingulate gyrus >

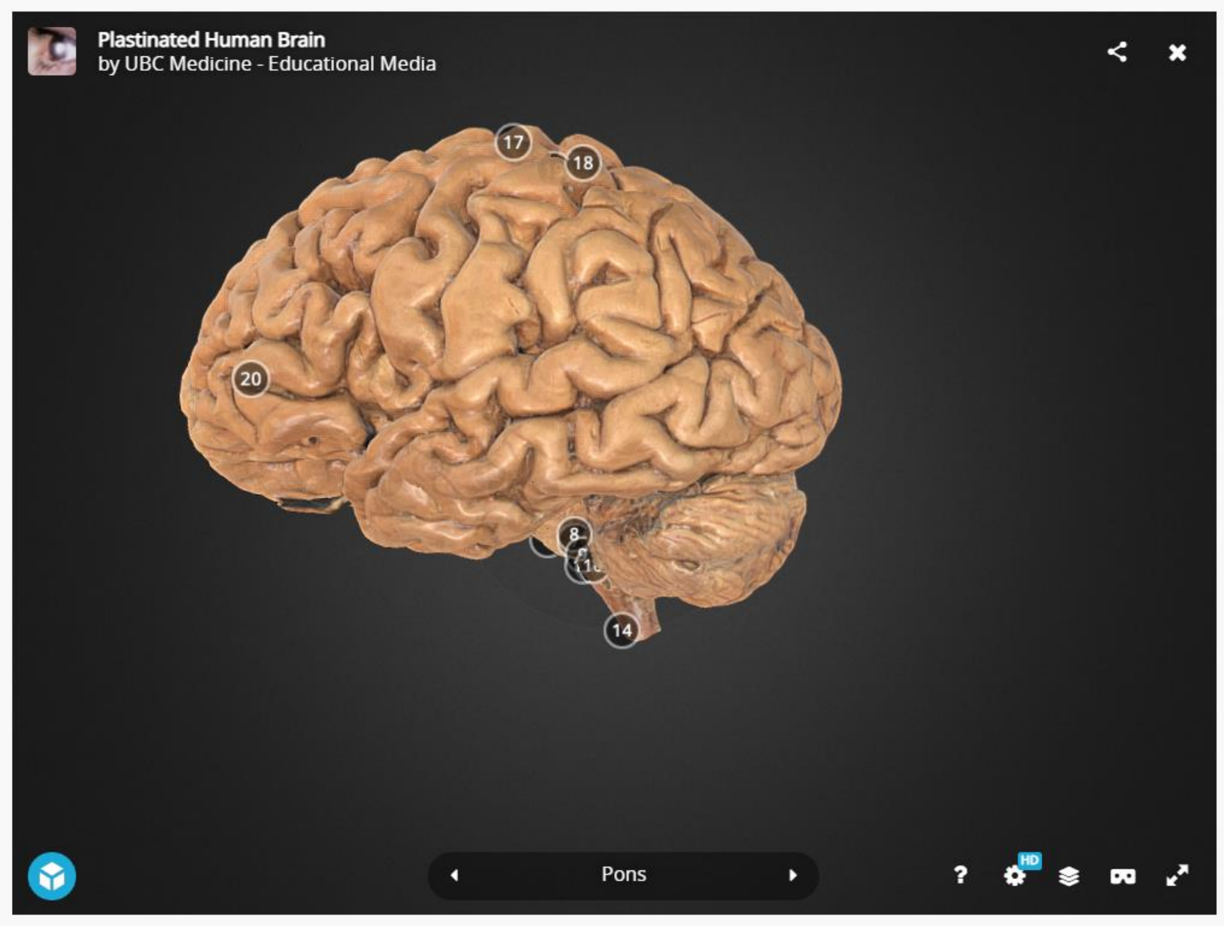
MENU



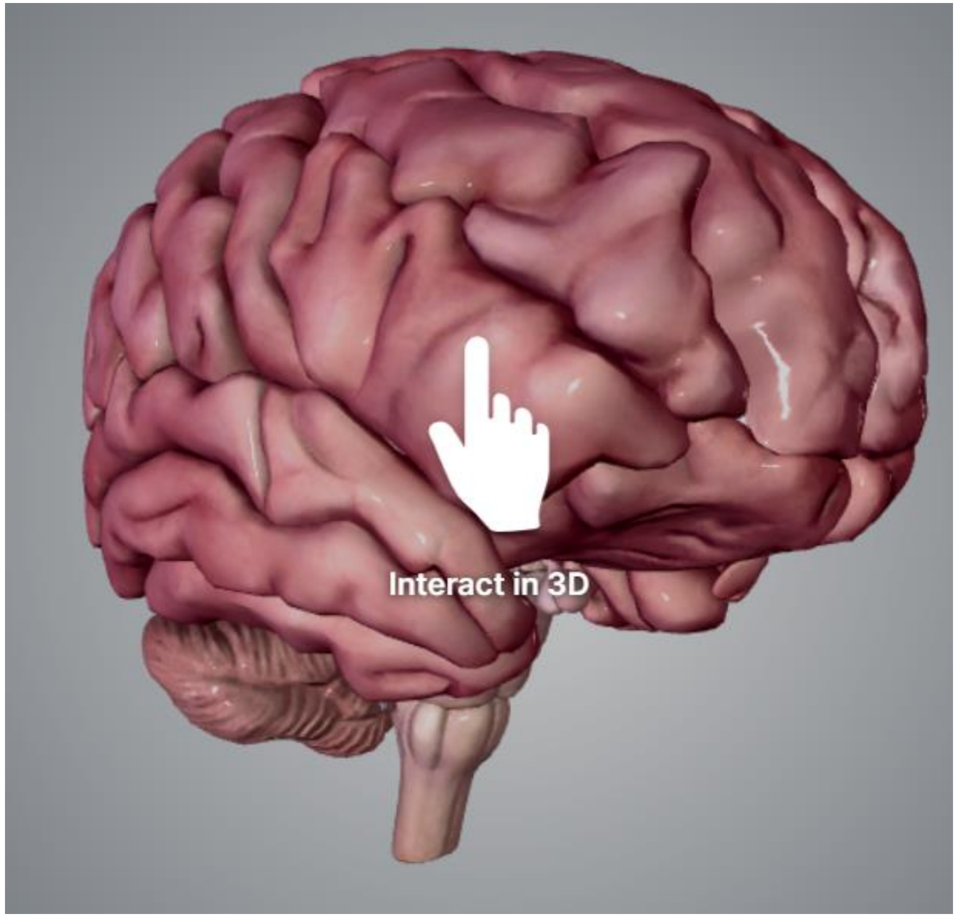
Lateral view of the right cerebral hemisphere

https://sites.uclouvain.be/braininteratlas/en/chapter/external-configuration

Let's explore all this in 3D



https://neuroanatomy.ca/3D/wholebrainPG.html



https://tinyurl.com/bdeuk3r8

Annotated surface neuroanatomical images

Neuroanatomy Tutorial - Labeled Images

Anatomy-Histology main menu

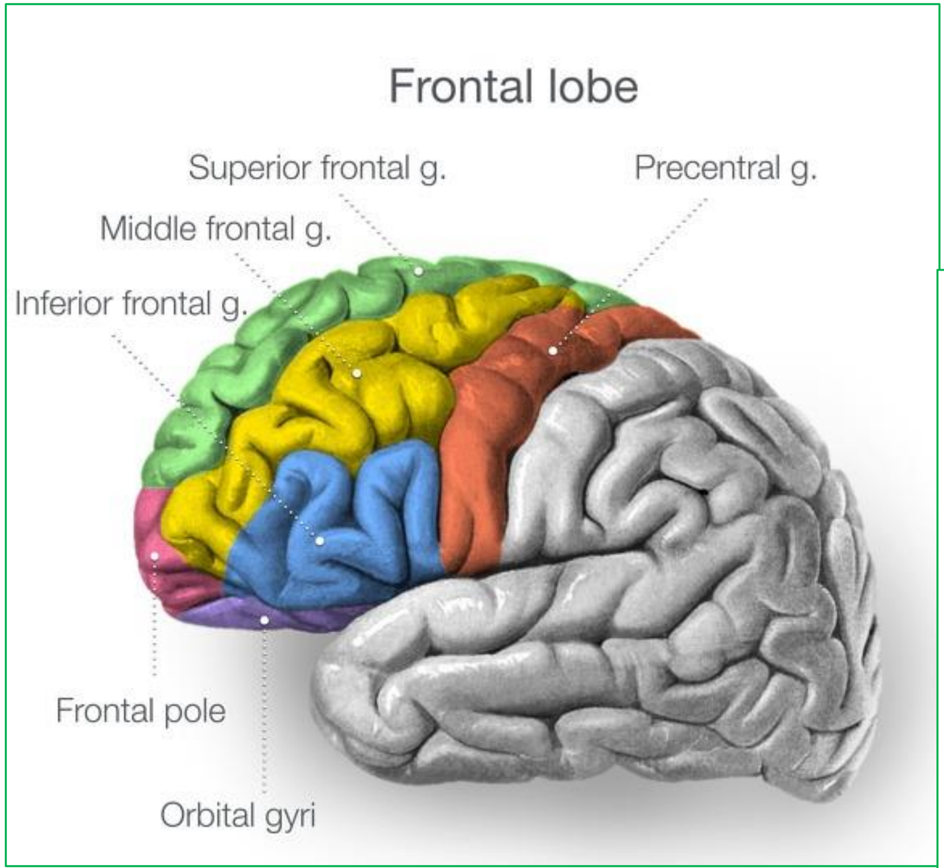
This tutorial has images in which the structures are labeled. You are to identify the structures by clicking on the name of the structure. The structure whose name is clicked will be identified in the image by an arrow.

External Views

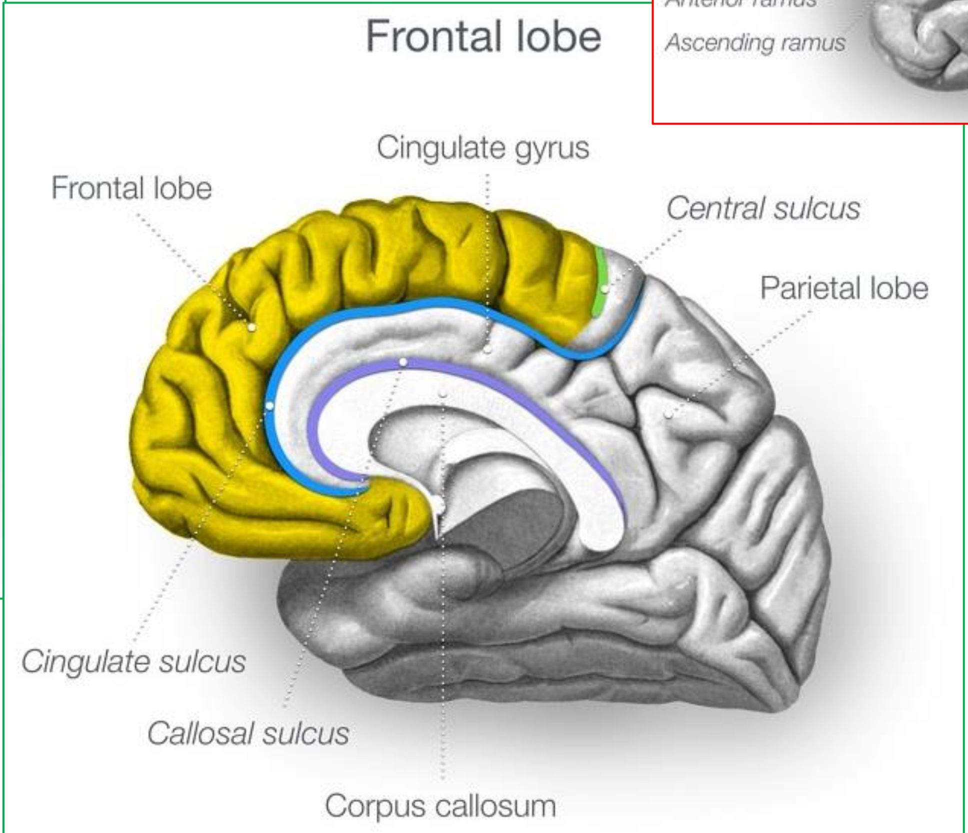
1. Brain and spinal cord, gross
2. Spinal cord nerve roots, gross
3. Brain, external view, vertex, gross
4. Brain, external view, vertex, Rolandic fissure, gross
5. Brain, external view, lateral, gross
6. Brain, external view, base of brain, gross
7. Brain, cranial nerves, base of brain, gross
8. Brain, 12th cranial nerves, base of brain, gross
9. Brain, cerebral arteries, base of brain, diagram
10. Brain, vertex, arachnoid granulations

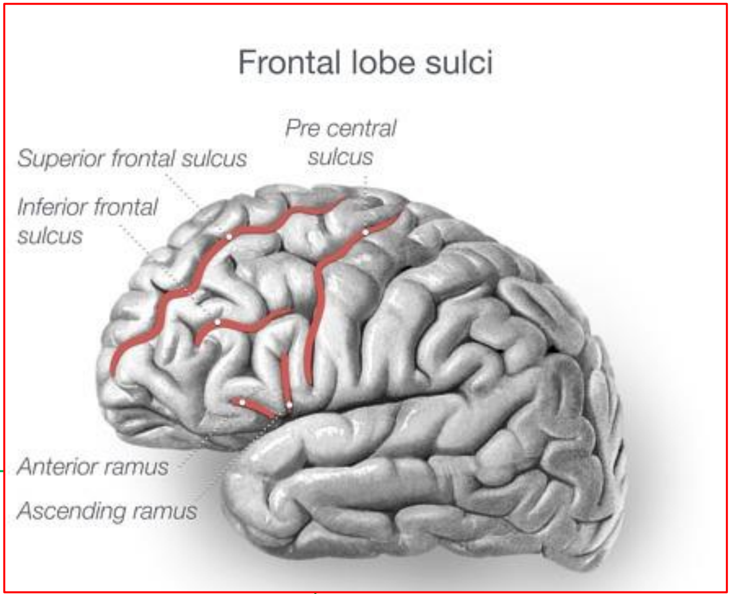
https://webpath.med.utah.edu/HISTHTML/NEURANAT/NEURANCA.html#1

Frontal lobe sulci and gyri: lateral and mid-sagittal view

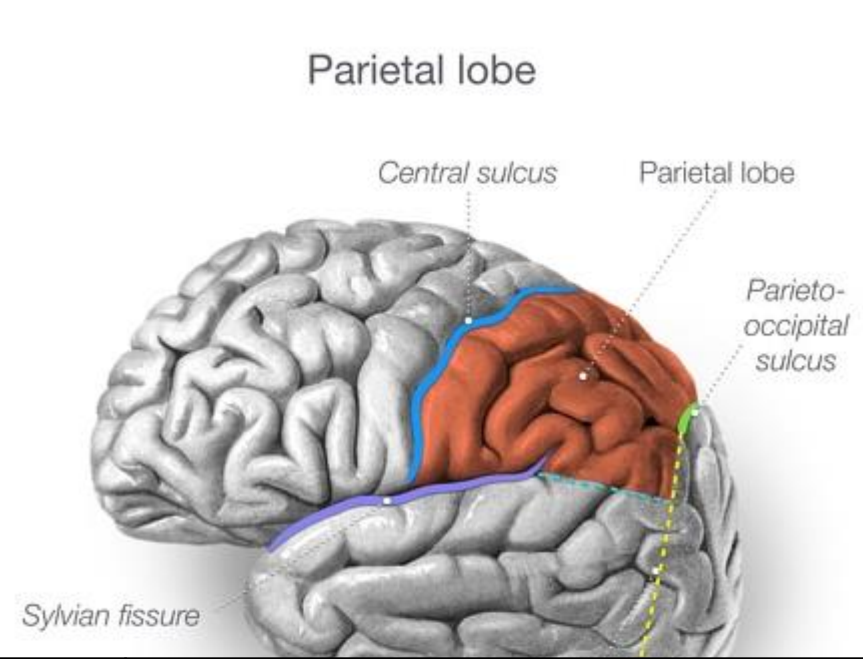


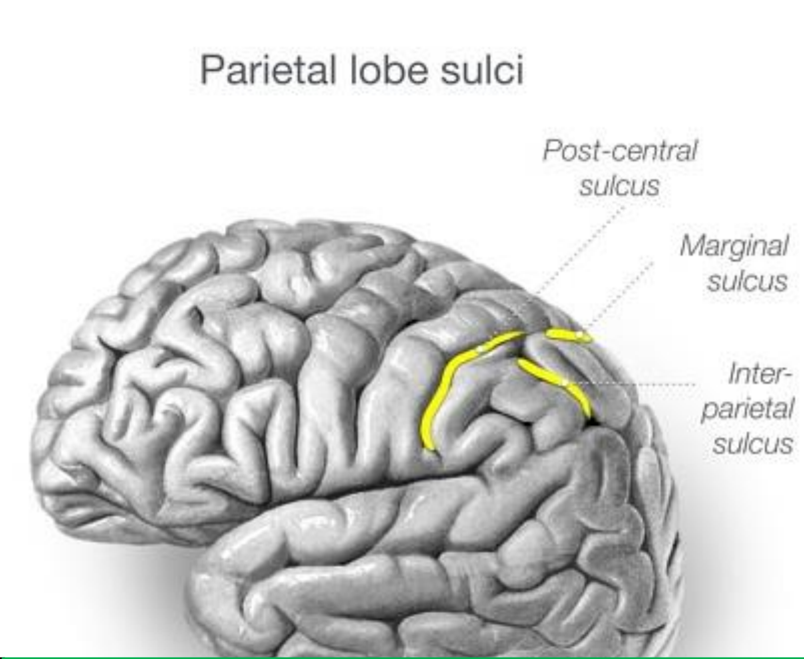
https://radiopaedia.org/articles/frontal-lobe

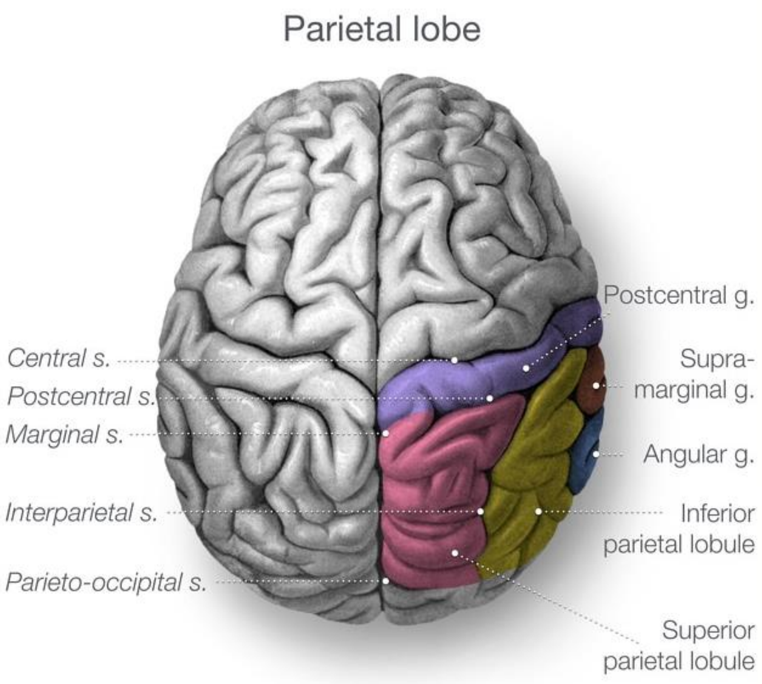


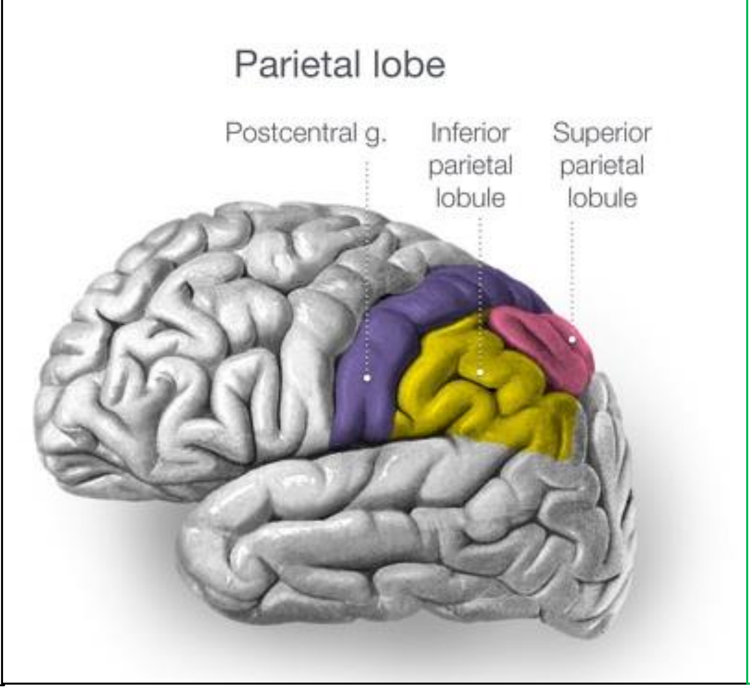


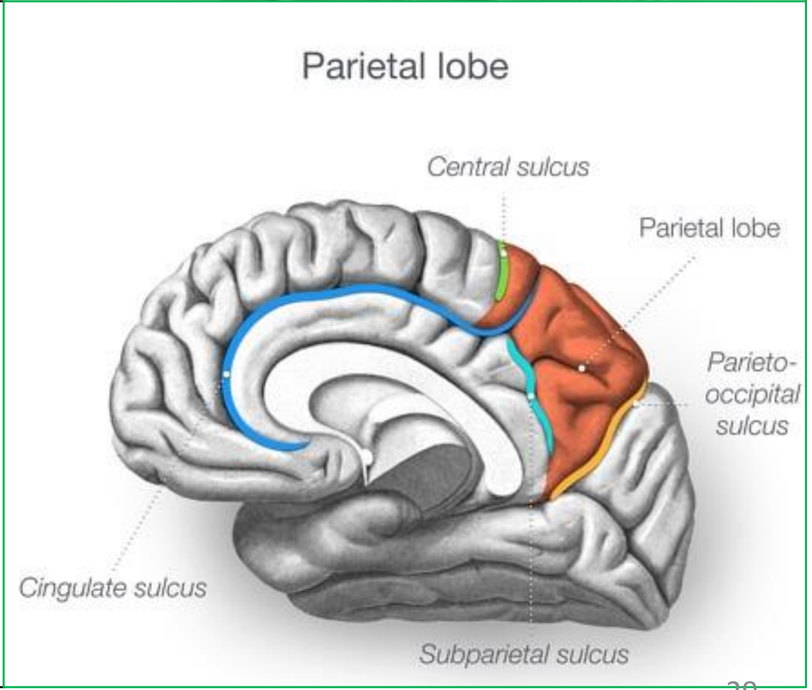
Parietal lobe sulci and gyri: lateral, dorsal, and mid-sagittal view





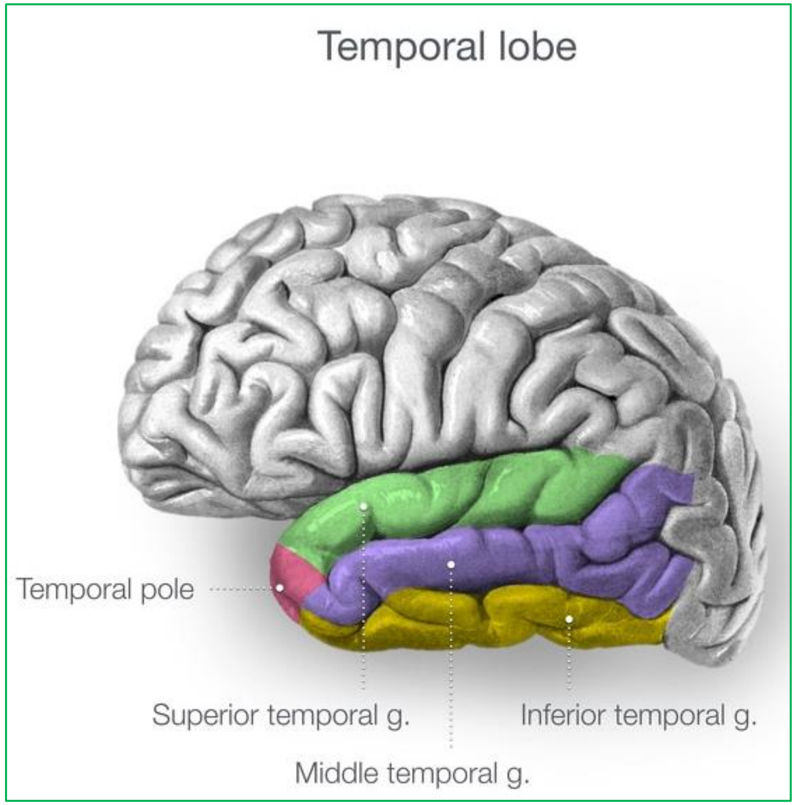


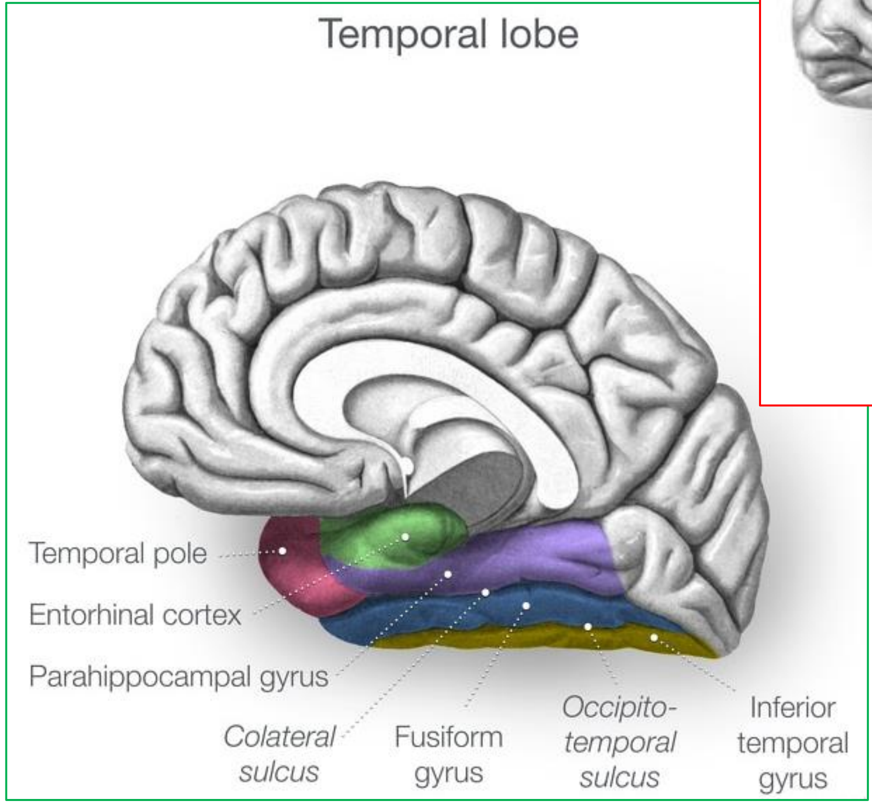


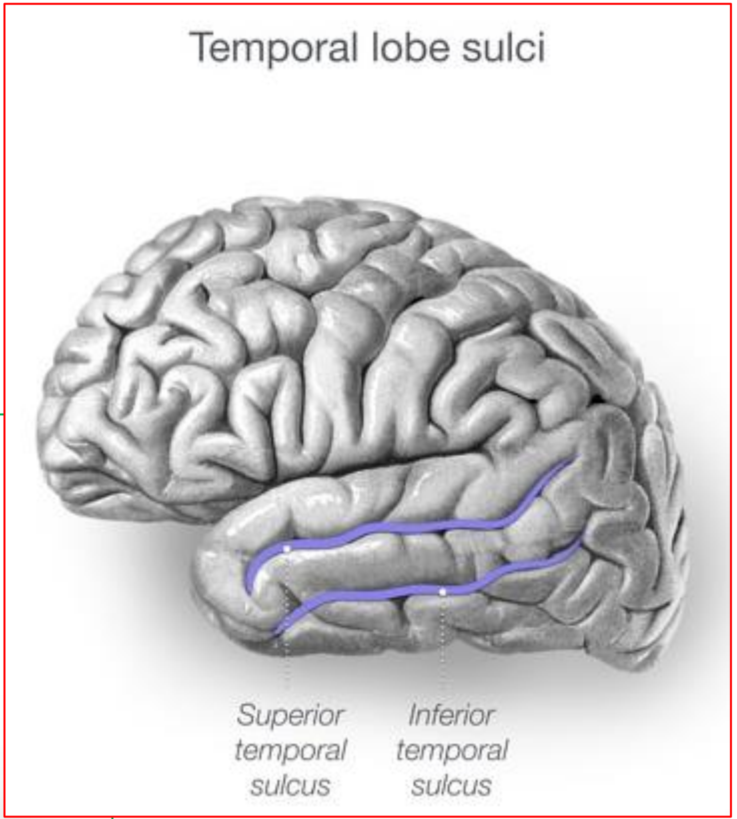


https://radiopaedia.org/articles/parietal-lobe

Temporal lobe sulci and gyri: lateral and mid-sagittal view

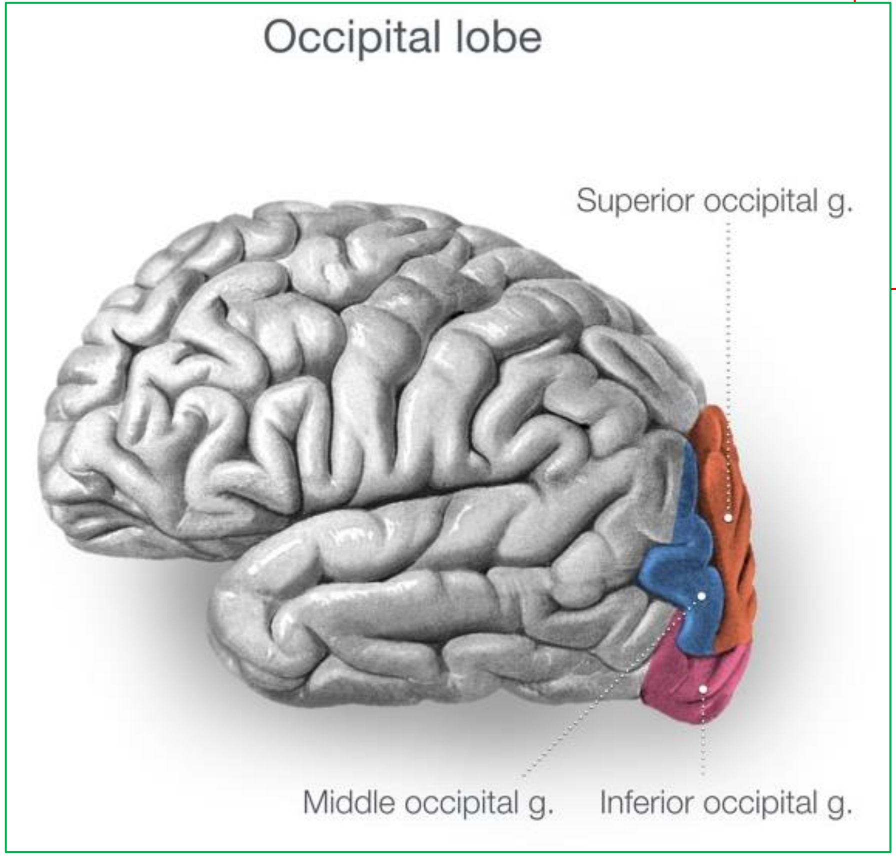


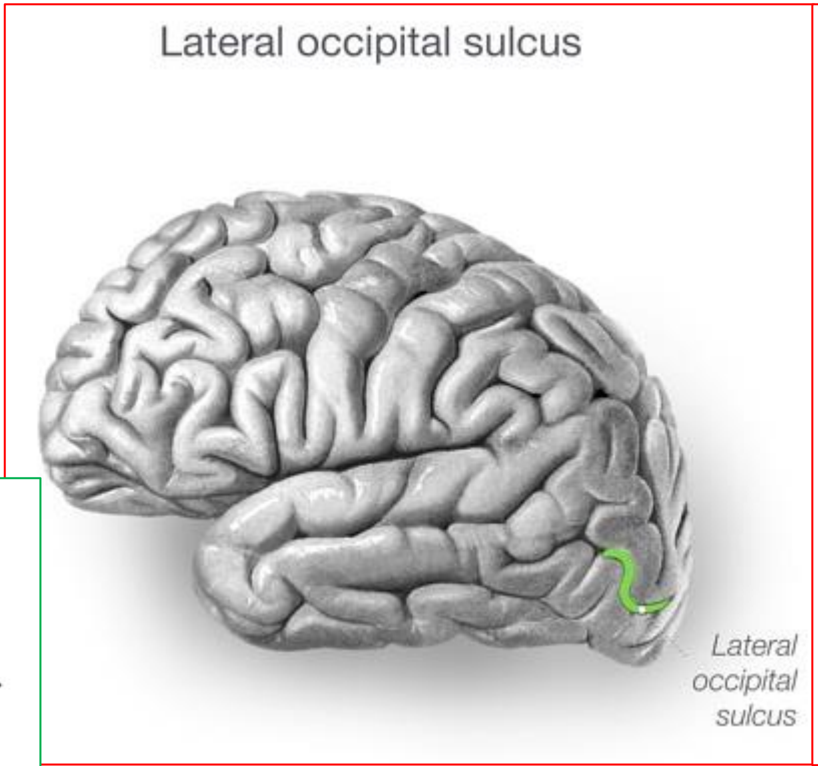


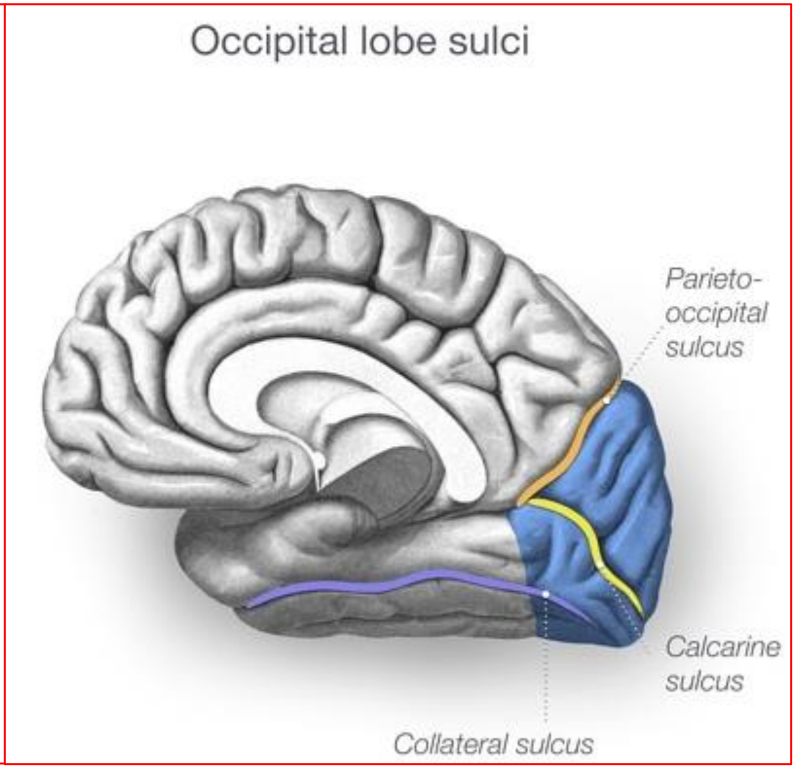


https://radiopaedia.org/articles/temporal-lobe

Occipital lobe: sulci and gyri: lateral and mid-sagittal view



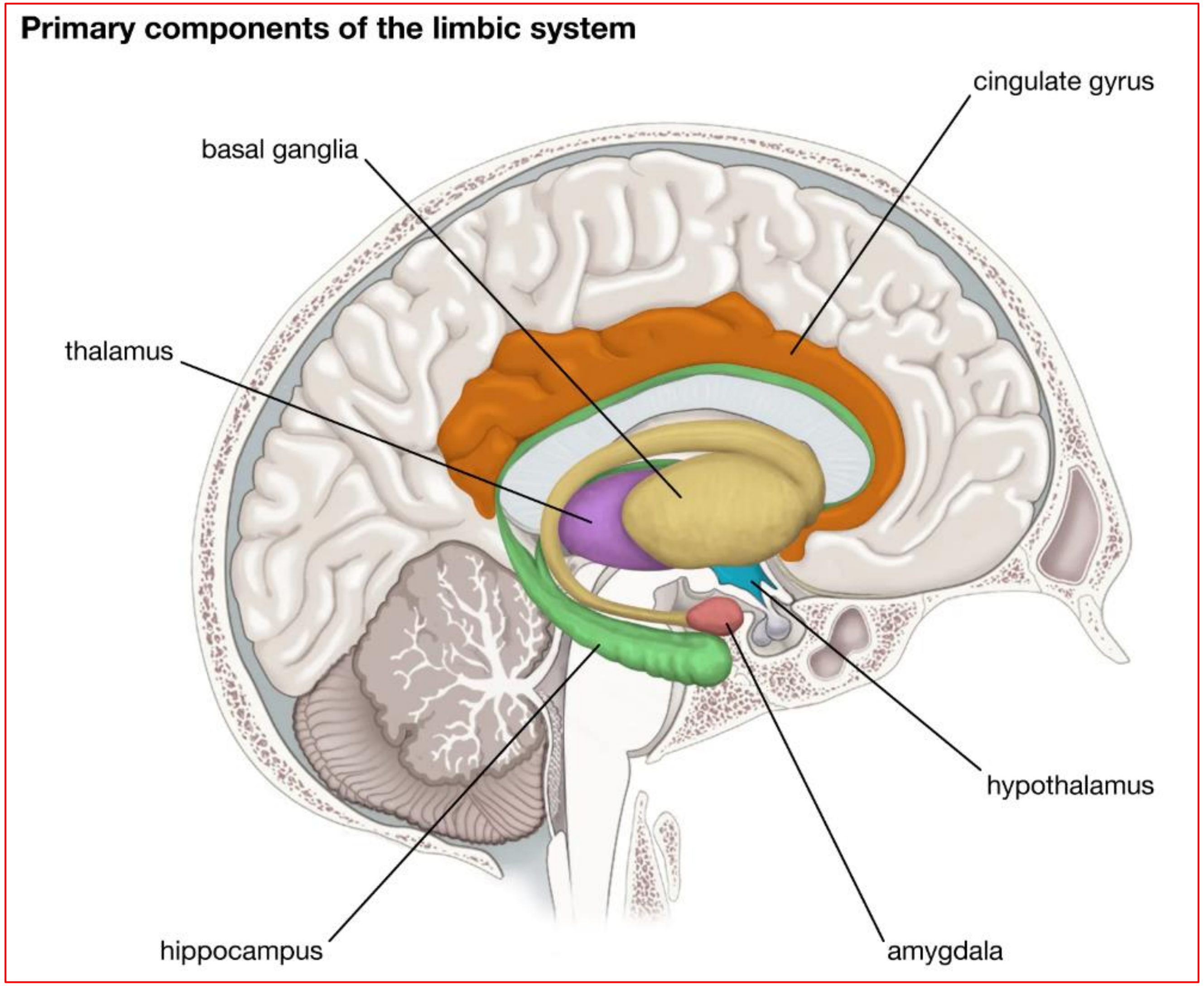




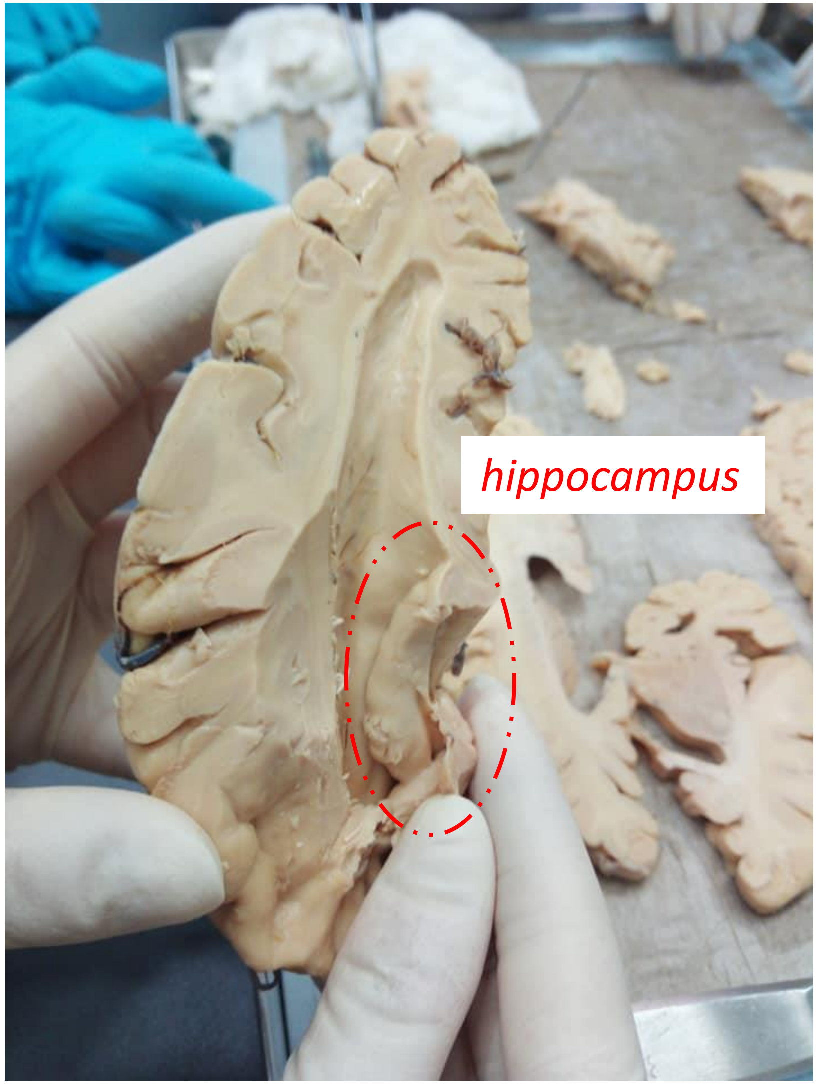
https://radiopaedia.org/articles/occipital-lobe

Limbic lobe/system: primary components

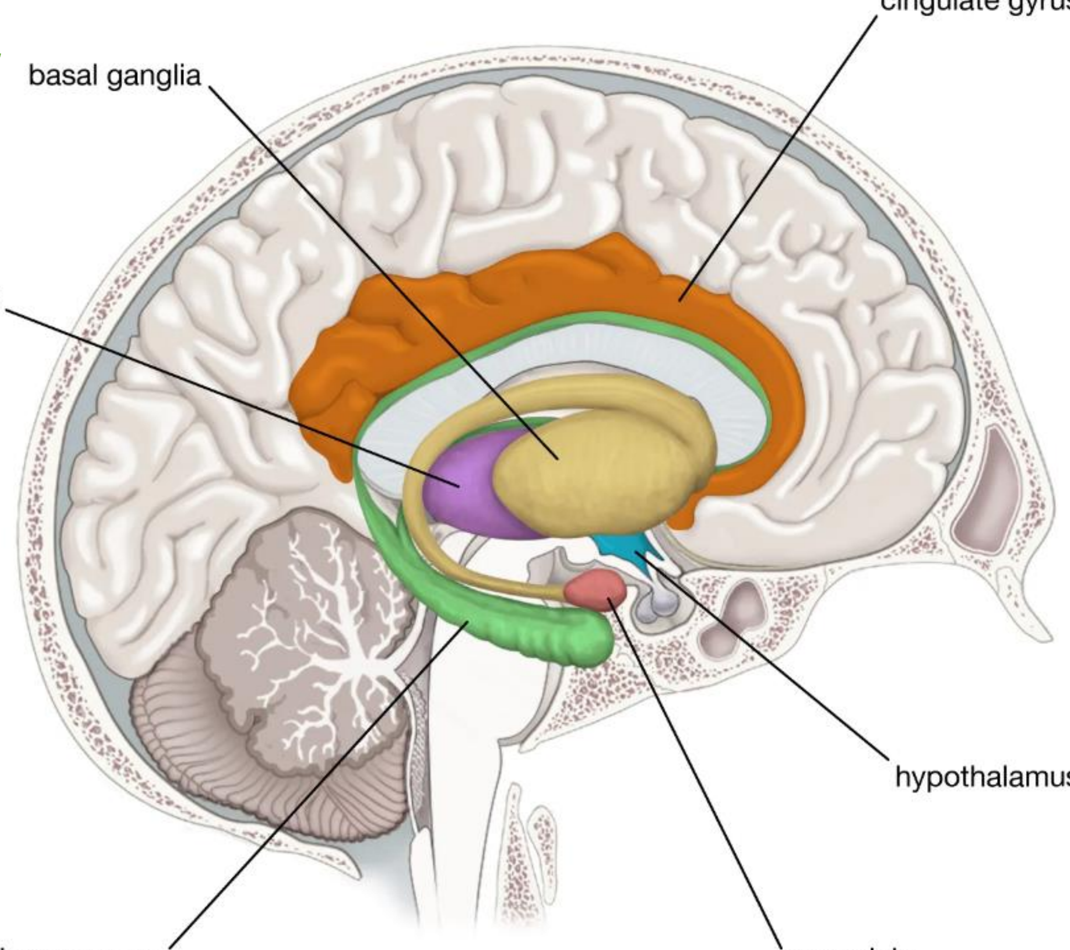
The **limbic system** => regulation of motivated behaviors (i.e., **fighting**, **fleeing**, **feeding**, and **mating**).



https://www.britannica.com/science/limbic-system



Limbic lobe/system: primary functions



collection of nuclei involved in **refining motor output** ← basal ganglia

cingulate gyrus → **emotion** and **pain** regulation

a **sensory relay** in visual, auditory, somatosensory, and gustatory systems; also significant roles in **motor activity**, **emotion**, **memory**, **arousal**, and other **sensorimotor association** functions ← thalamus

hypothalamus → contains a control centre for many functions of the **autonomic** nervous system, and it has effects on the **endocrine** system

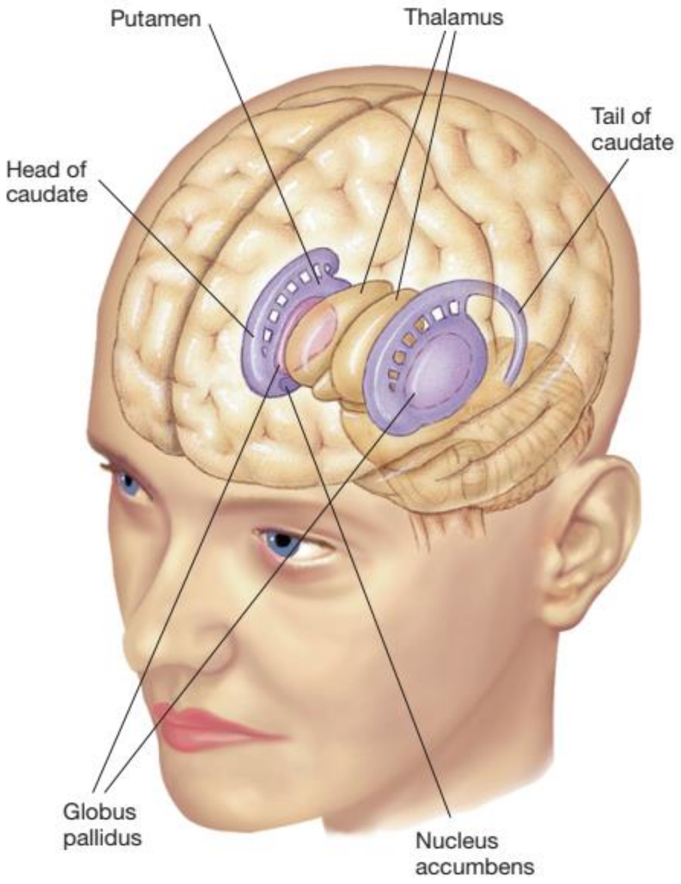
memory formation ← hippocampus

amygdala → **emotion** (primarily fear learning)

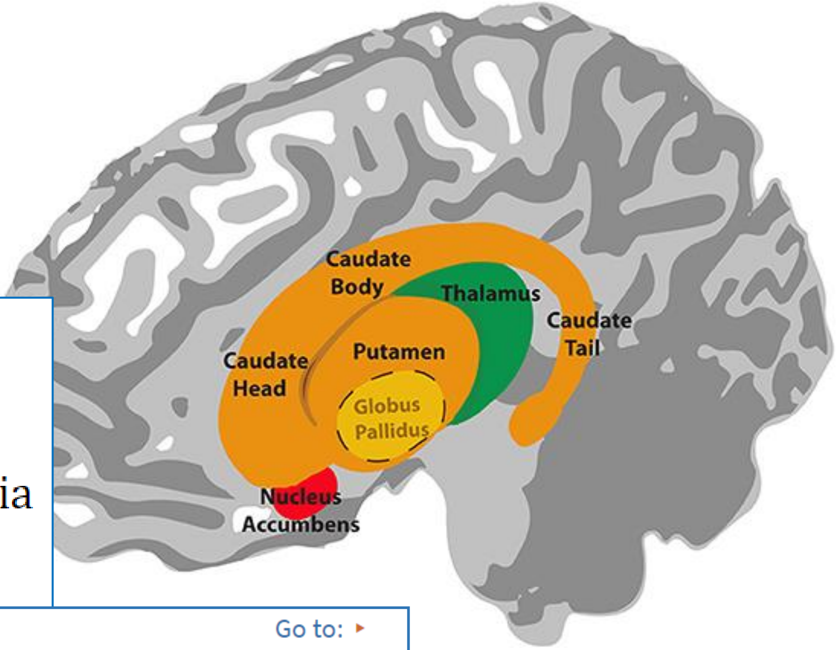
The basal ganglia

*The caudate and putamen are collectively know as **the striatum**.*

Figure 3.28 The basal ganglia: striatum (caudate plus putamen), and globus pallidus. Notice that, in this view, the right globus pallidus is largely hidden behind the right thalamus and the left globus pallidus is totally hidden behind the left putamen.



Pinel & Barnes, (2021), p. 93



https://tinyurl.com/395649ae

Cold Spring Harb Perspect Med. 2012 Dec; 2(12): a009621.

doi: 10.1101/cshperspect.a009621

Functional Neuroanatomy of the Basal Ganglia

José L. Lanciego, Natasha Luquin, and José A. Obeso

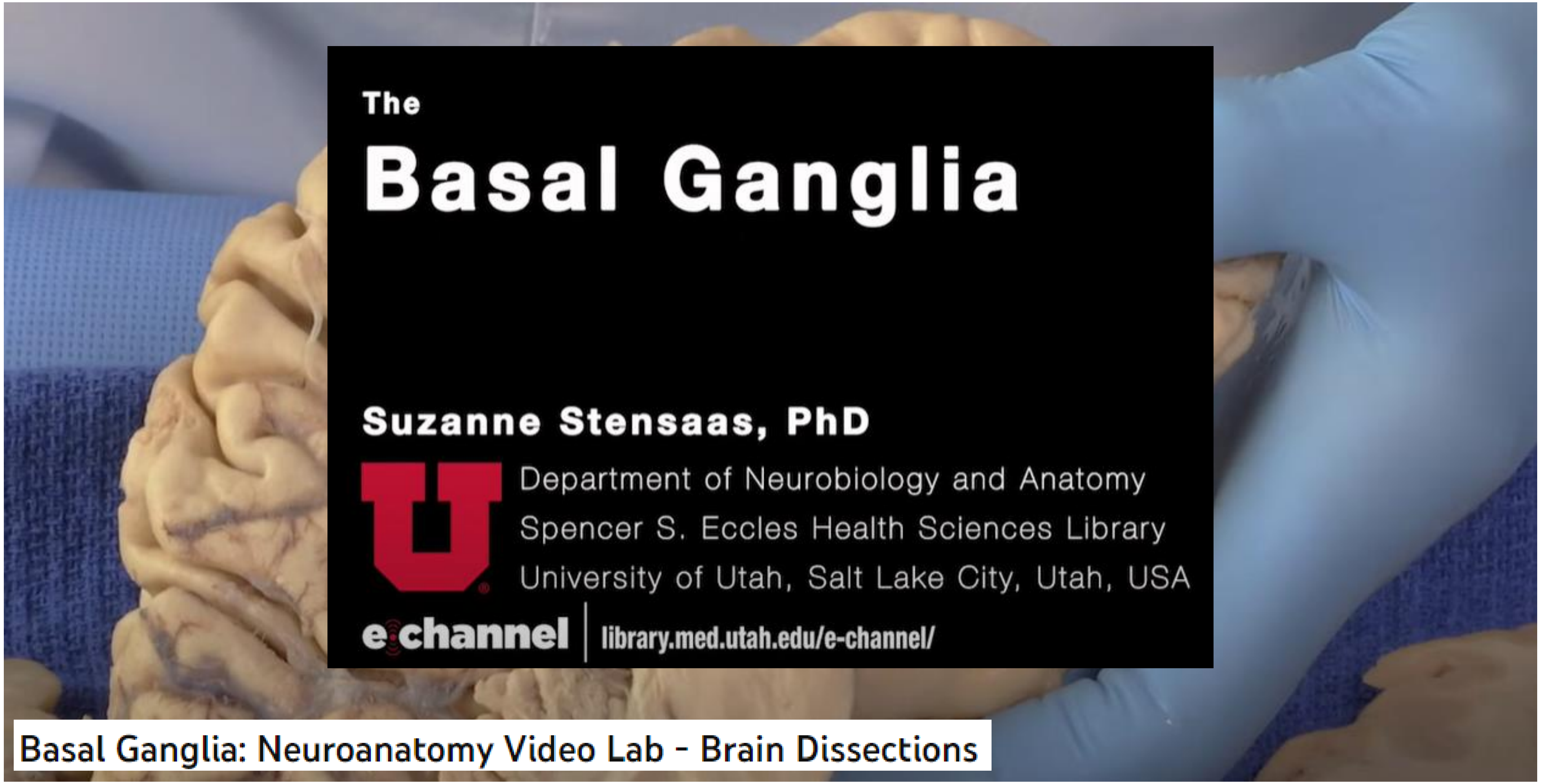
Abstract

Go to: ▸

The “basal ganglia” refers to a group of subcortical nuclei responsible primarily for motor control, as well as other roles such as motor learning, executive functions and behaviors, and emotions. Proposed more than two decades ago, the classical basal ganglia model shows how information flows through the basal ganglia back to the cortex through two pathways with opposing effects for the proper execution of movement. Although much of the model has remained, the model has been modified and amplified with the emergence of new data. Furthermore, parallel circuits subserve the other functions of the basal ganglia engaging associative and limbic territories. Disruption of the basal ganglia network forms the basis for several movement disorders. This article provides a comprehensive account of basal ganglia functional anatomy and chemistry and the major pathophysiological changes underlying disorders of movement. We try to answer three key questions related to the basal ganglia, as follows: What are the basal ganglia? What are they made of? How do they work? Some insight on the canonical basal ganglia model is provided, together with a selection of paradoxes and some views over the horizon in the field.

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3543080/

The basal ganglia in 3D



https://www.youtube.com/watch?v=JBuAFWKWxDQ

The cerebellum

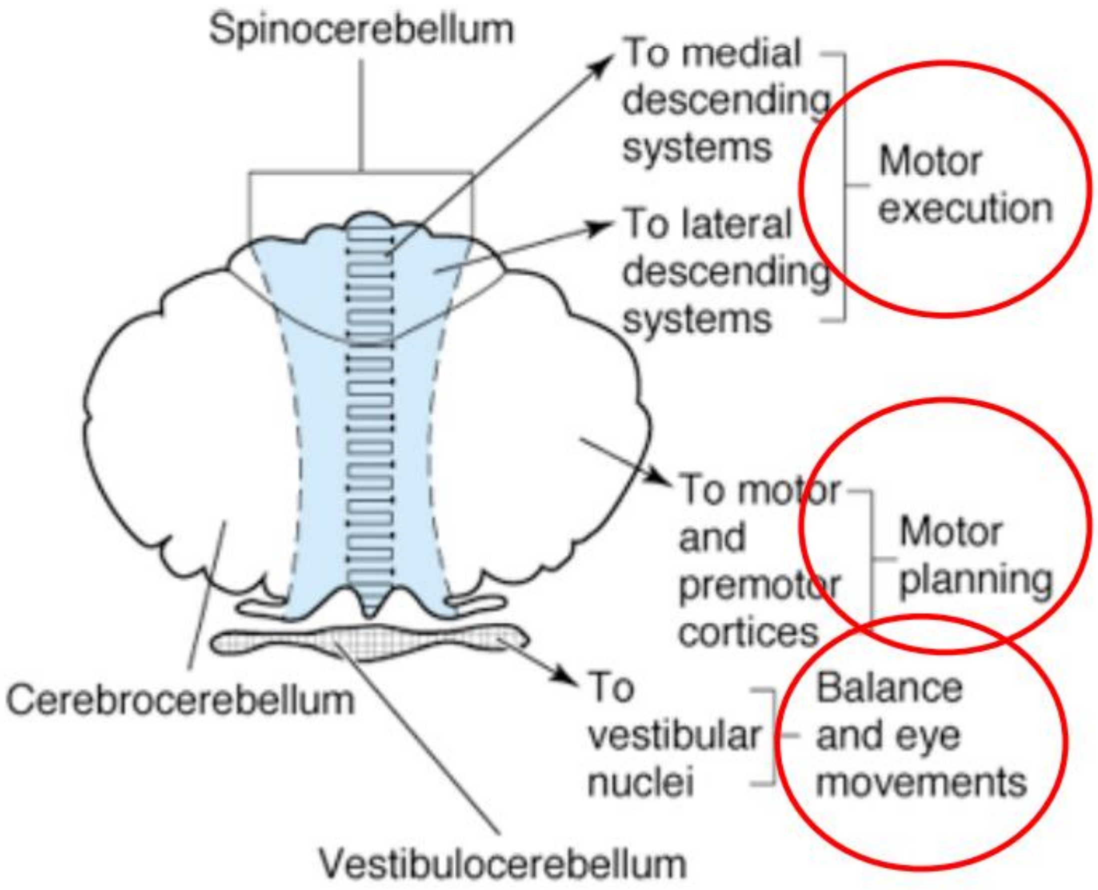
The cerebellum accounts for only **10%** of total brain volume, but contains **more than one-half** of its neurons.

It is composed a series of highly regular, repeating **units**, each containing the same basic microcircuit.

Different regions of the cerebellum **receive projections** from distinct brain and spinal structures and then **project back** to the brain.

The similarity of the architecture and physiology in all regions of the cerebellum implies that **different regions of the cerebellum perform similar computational operations on different inputs**.

Functional subdivisions



https://tinyurl.com/35j2snvh

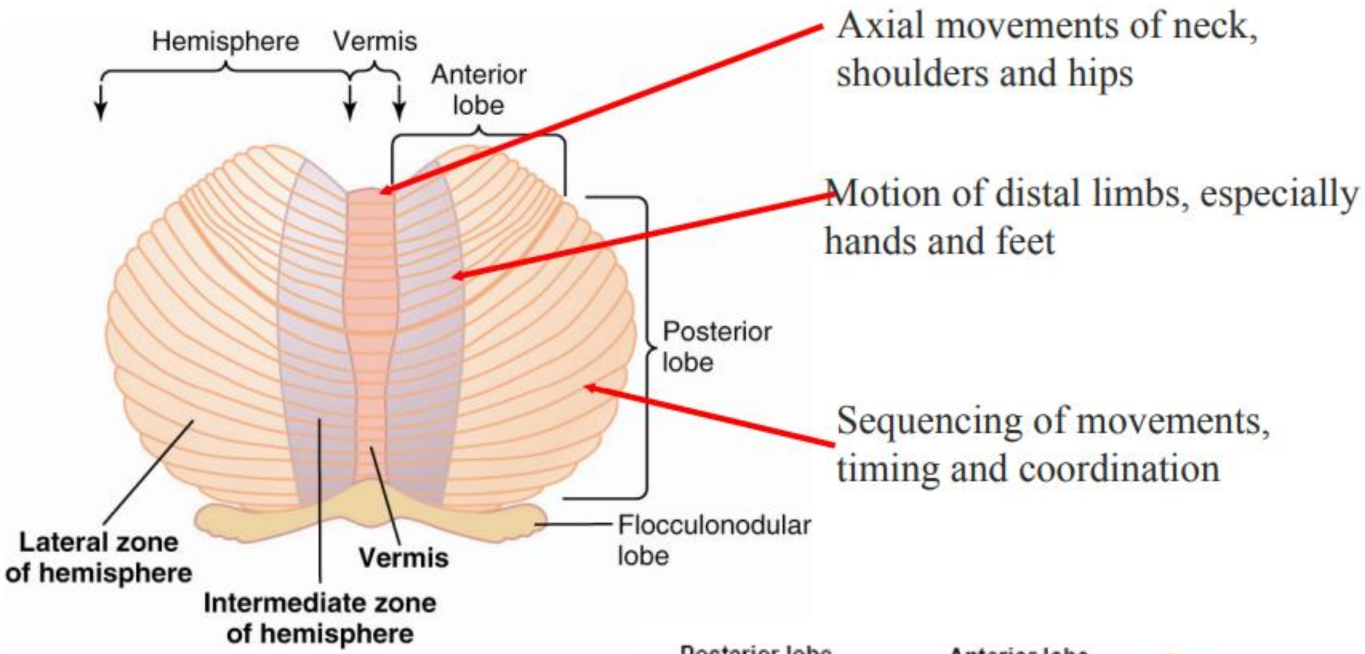
It is divided into 3 major functional divisions;

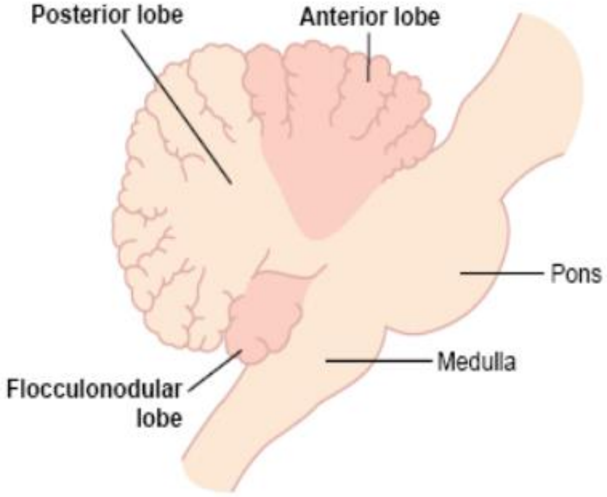
(1) **Vestibulocerebellum**→ composed of the "**flocculonodular** lobe“ (Archicerebellum)

(2) **Spinocerebellum** → composed of the vermis and paravermal zone. (Paleocerebellum)

(3) **Cerebrocerebellum**→ composed of lateral zones of the cerebellar hemispheres. (Neocerebellum)

Functional organisation





https://tinyurl.com/35j2snvh

Functionally arranged along the longitudinal axis:

(1) **Vermis**, located at the center

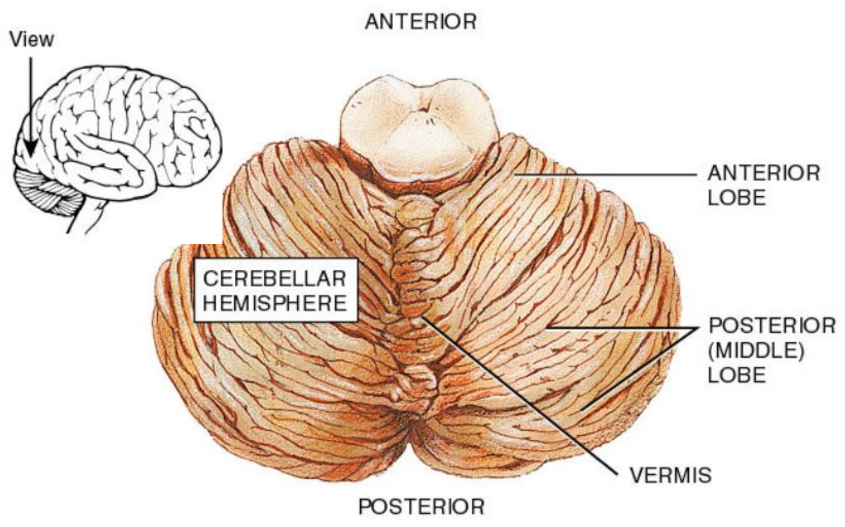
=> axial movements of the neck, shoulders, and hips

(2) **Intermediate zone**

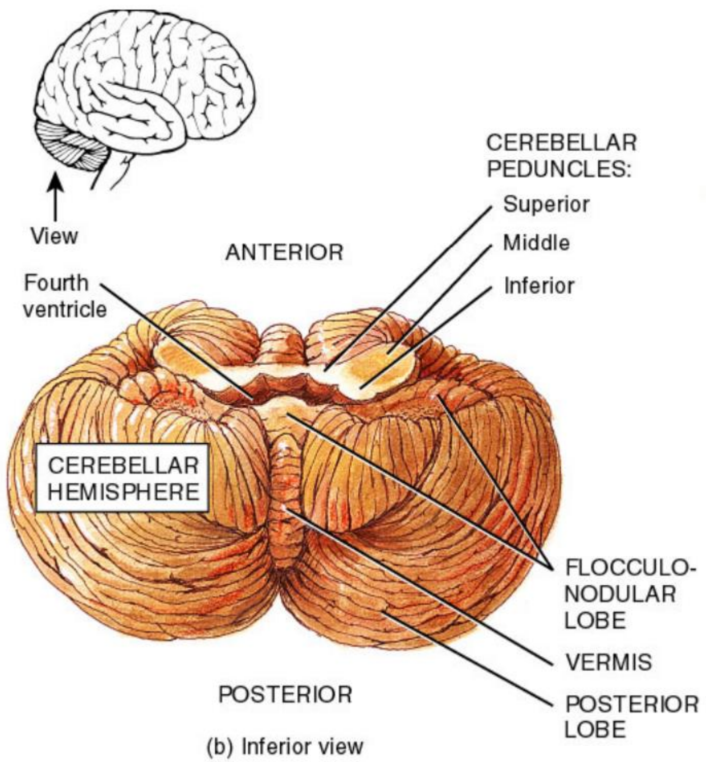
=> motion of distal portions of upper and lower limbs especially the hands and feet

(3) **Lateral zone**

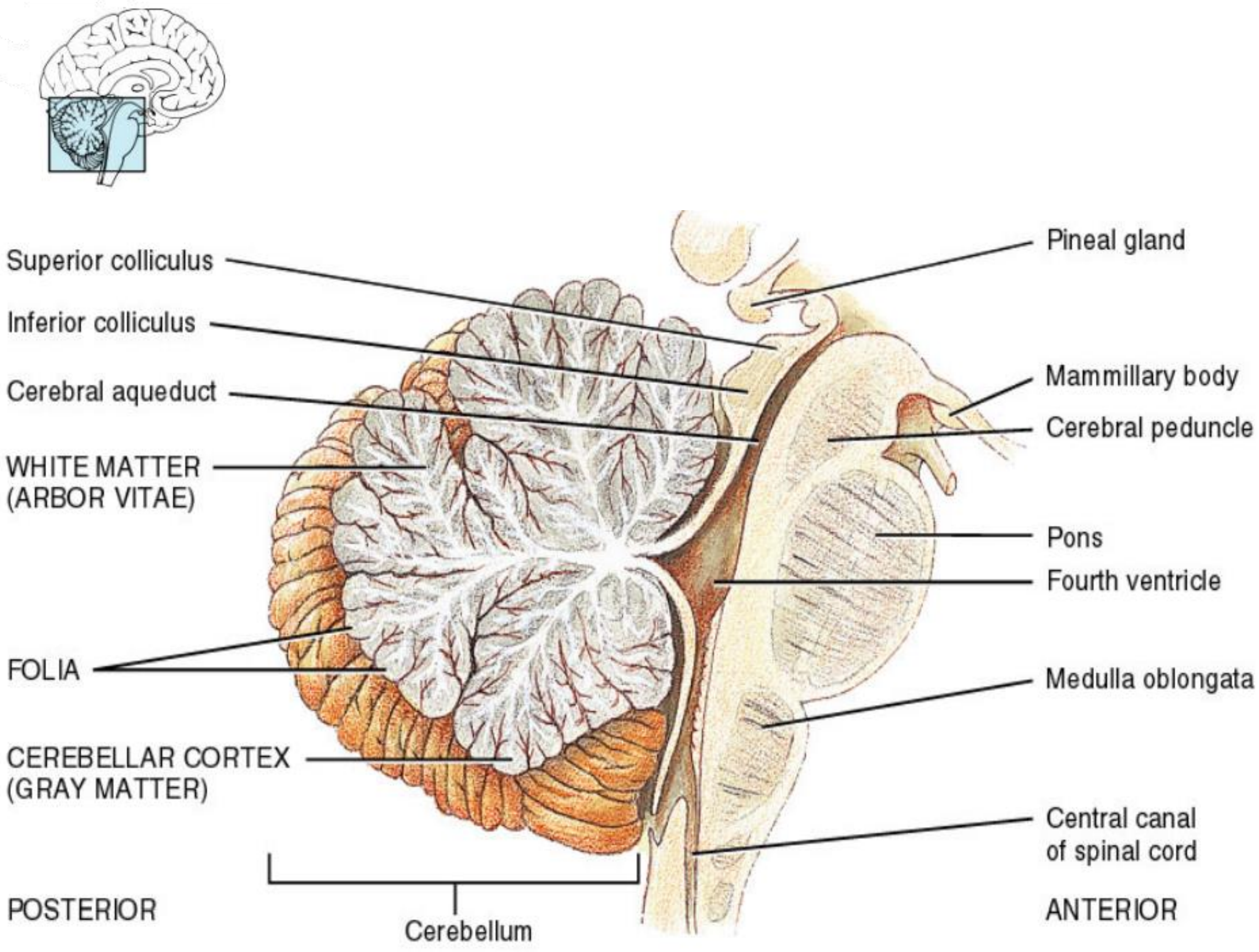
=> sequencing movements of the muscle. Important for timing and coordination of movement.



(a) Superior view



(b) Inferior view



https://tinyurl.com/35j2snvh

Functional diversity

Maintenance of balance and posture: important for making postural adjustments in order to maintain balance. Through its **input** from **vestibular** receptors and proprioceptors, it modulates **commands** to **motor neurons** to compensate for shifts in body position or changes in load upon muscles. Patients with cerebellar damage suffer from **balance disorders**, and they often develop stereotyped postural strategies to compensate for this problem (e.g., a wide-based stance).

Coordination of voluntary movements: most movements are composed of a number of different muscle groups acting together in a **temporally** coordinated fashion. One major function of the cerebellum is to **coordinate** the **timing** and **force** of these different muscle groups to produce fluid limb or body movements.

Motor learning: major role in **adapting** and **fine-tuning** motor programs to make **accurate movements** through a trial-and-error process (e.g., learning to hit a baseball).

Cognitive functions: also involved in certain cognitive functions, such as **language**. Thus, like the basal ganglia, the cerebellum is historically considered as part of the motor system, but its functions extend beyond motor control in ways that are not yet well understood.

https://nba.uth.tmc.edu/neuroscience/m/s3/chapter05.html

Review > Neurosci Lett. 2019 Jan 1:688:62-75. doi: 10.1016/j.neulet.2018.07.005. Epub 2018 Jul 8.

The cerebellum and cognition

Jeremy D Schmahmann [1]

Affiliations + expand

PMID: 29997061 DOI: 10.1016/j.neulet.2018.07.005

https://pubmed.ncbi.nlm.nih.gov/29997061/

***ataxia** = loss of muscle control in arms and legs*

=> lack of balance, coordination, and trouble walking

***dysmetria** = impaired judgment of distance*

=> impaired control of the range and direction of movement

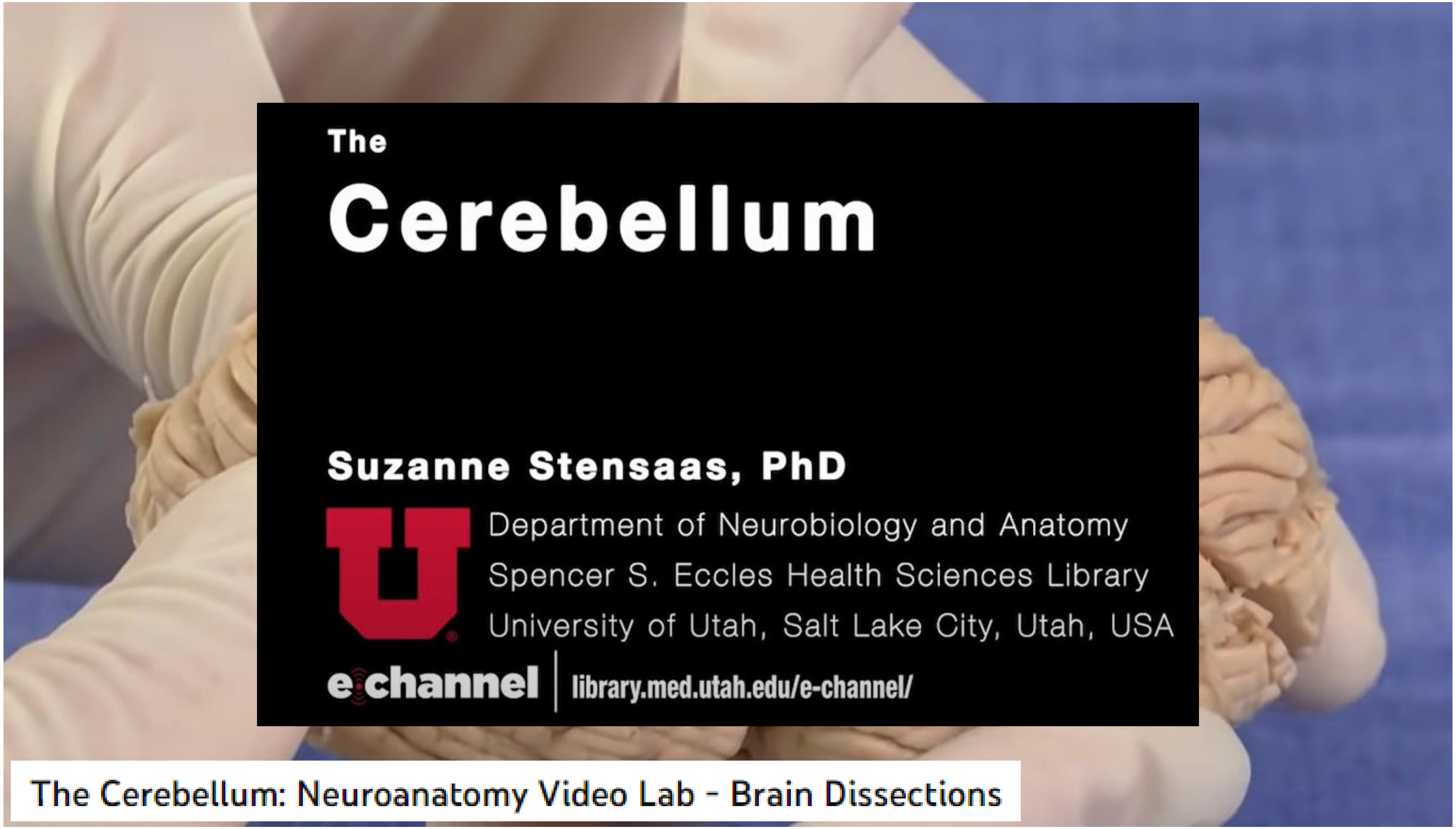
***dysarthria** = tongue or throat muscle weakness*

=> difficulty speaking

Abstract

What the cerebellum does to sensorimotor and vestibular control, it also does to cognition, emotion, and autonomic function. This hypothesis is based on the theories of dysmetria of thought and the universal cerebellar transform, which hold that the cerebellum maintains behavior around a homeostatic baseline, automatically, without conscious awareness, informed by implicit learning, and performed according to context. Functional topography within the cerebellum facilitates the modulation of distributed networks subserving multiple different functions. The sensorimotor cerebellum is represented in the anterior lobe with a second representation in lobule VIII, and lesions of these areas lead to the cerebellar motor syndrome of ataxia, dysmetria, dysarthria and impaired oculomotor control. The cognitive / limbic cerebellum is in the cerebellar posterior lobe, with current evidence pointing to three separate topographic representations, the nature of which remain to be determined. Posterior lobe lesions result in the cerebellar cognitive affective syndrome (CCAS), the hallmark features of which include deficits in executive function, visual spatial processing, linguistic skills and regulation of affect. The affective dyscontrol manifests in autism spectrum and psychosis spectrum disorders, and disorders of emotional control, attentional control, and social skill set. This report presents an overview of the rapidly growing field of the clinical cognitive neuroscience of the cerebellum. It commences with a brief historical background, then discusses tract tracing experiments in animal models and functional imaging observations in humans that subserve the cerebellar contribution to neurological function. Structure function correlation studies following focal cerebellar lesions in adults and children permit a finer appreciation of the functional topography and nature of the cerebellar motor syndrome, cerebellar vestibular syndrome, and the third cornerstone of clinical ataxiology - the cerebellar cognitive affective syndrome. The ability to detect the CCAS in real time in clinical neurology with a brief and validated scale should make it possible to develop a deeper understanding of the clinical consequences of cerebellar lesions in a wide range of neurological and neuropsychiatric disorders with a link to the cerebellum.

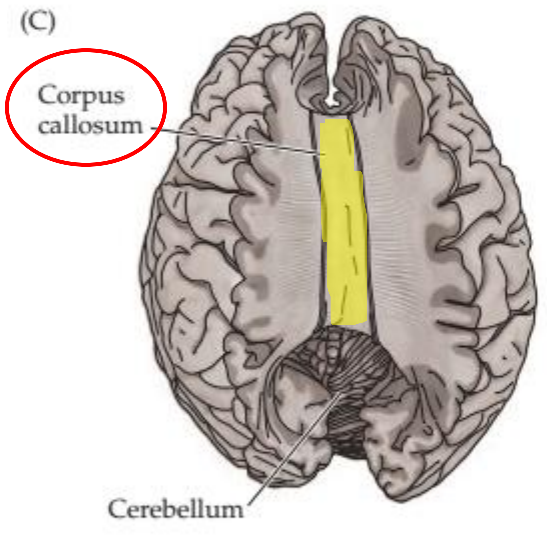
The cerebellum in 3D



https://www.youtube.com/watch?v=mpO4lTDr1to&t=379s

Commissures

Corpus callosum

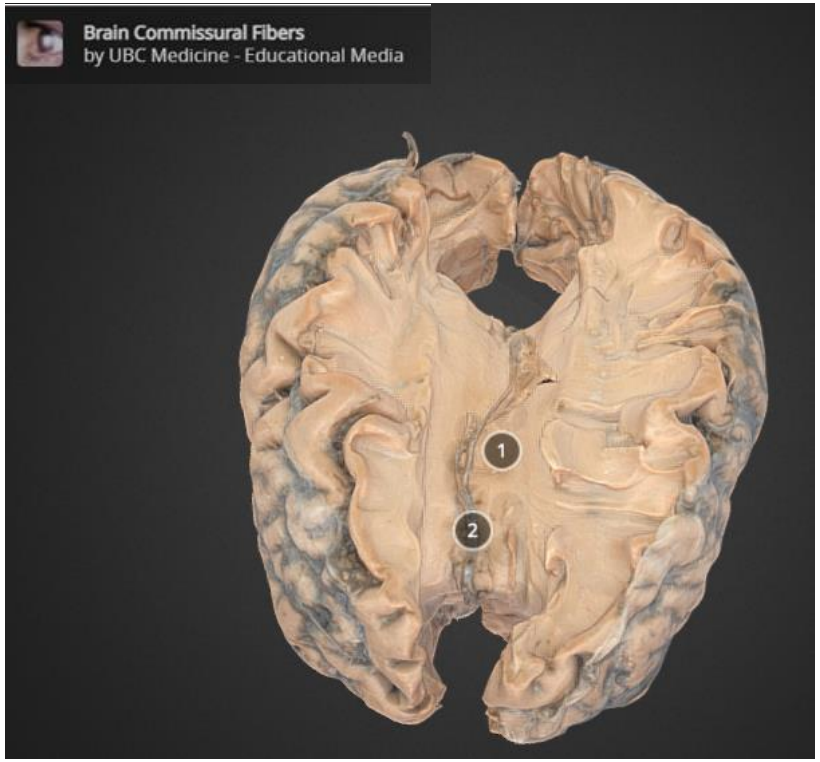


Purves et al., (2018), Appendix

medial view of the **corpus callosum**

https://neuroanatomy.ca/interactive/CortexMedial.html

3D rendering of the corpus callosum



https://neuroanatomy.ca/3D/3-4brainPG.html

commissure

*a **connecting** band of nerve tissue in the CNS*

from Latin ("commissura"): "joint, juncture"

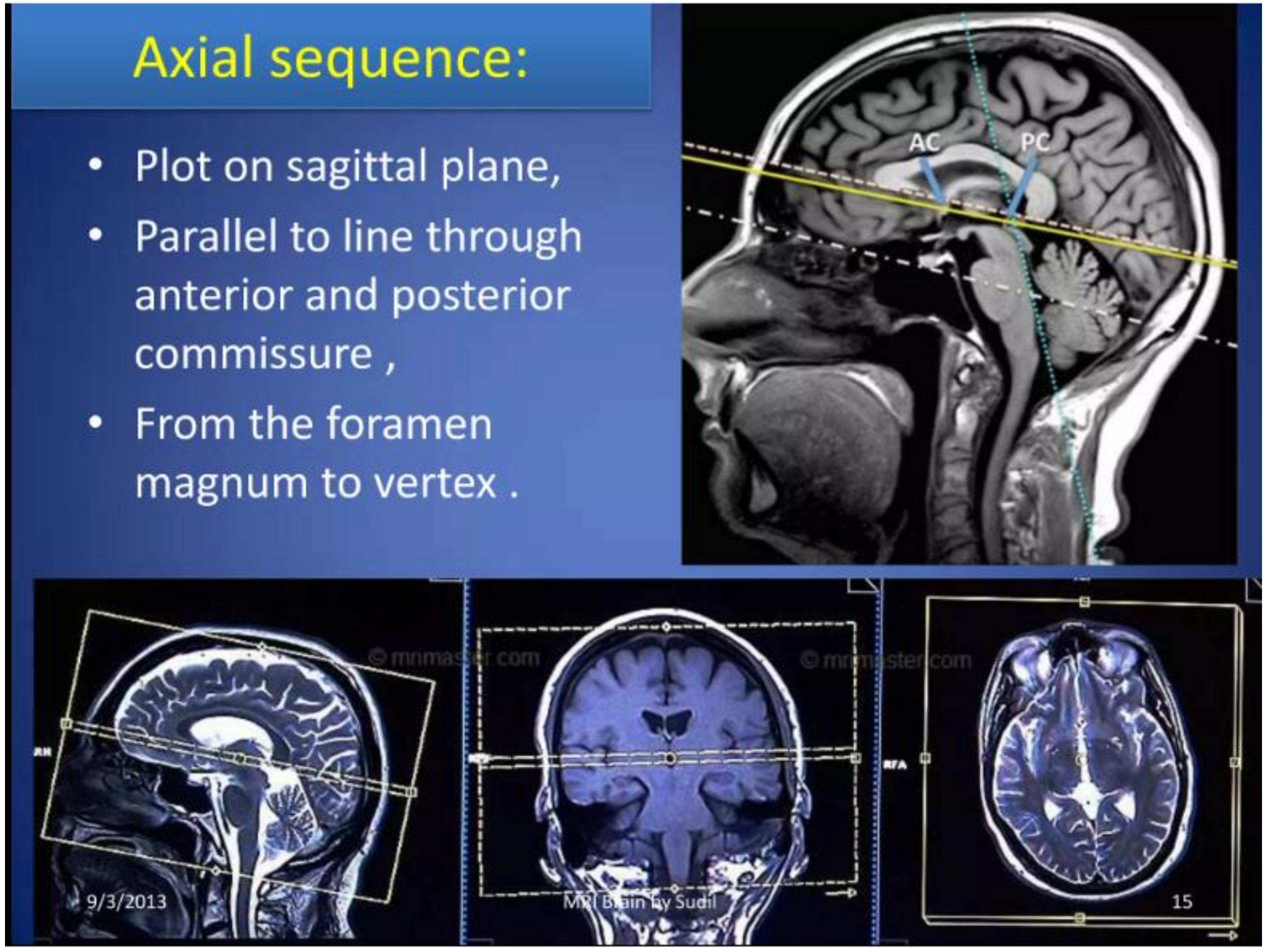
corpus callosum

*(callosal **commissure**)*

*a broad band of nerve fibres that **connects** the left and right **hemispheres** of the brain*

from Latin: "tough body"

Anterior and posterior commissure



https://www.slideshare.net/SudilPaudyal/mri-procedure-of-brain

The **anterior commissure (AC)** is transversely oriented and connects the two cerebral hemispheres along the midline => different parts of the **limbic system** on both sides => interhemispheric transfer of **visual, auditory**, and **olfactory** information between temporal lobes.

The **posterior commissure (PC)** is a transversely oriented and connects the two cerebral hemispheres along the midline. It is a very important anatomical landmark which is thought to play a role in the **visual** system, however its functions are still largely unknown.

The **anterior commissure - posterior commissure line (AC-PC line),** also known as the **bicommissural line**, has been adopted as a convenient standard by the neuroimaging community, and in most instances is the reference plane for axial imaging in everyday MRI scanning.

Commissurotomy and "split-brain"

The Nobel Prize in Physiology or Medicine 1981

Roger W. Sperry
David H. Hubel
Torsten N. Wiesel

Share this

Roger W. Sperry Facts

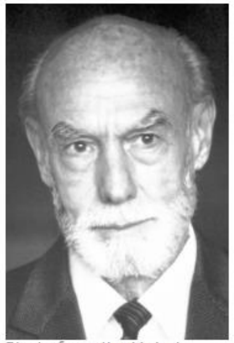


Photo from the Nobel Foundation archive.

Roger W. Sperry
The Nobel Prize in Physiology or Medicine 1981

Born: 20 August 1913, Hartford, CT, USA

Died: 17 April 1994, Pasadena, CA, USA

Affiliation at the time of the award: California Institute of Technology (Caltech), Pasadena, CA, USA

Prize motivation: "for his discoveries concerning the functional specialization of the cerebral hemispheres"

Prize share: 1/2

https://www.nobelprize.org/prizes/medicine/1981/sperry/facts/

https://www.youtube.com/watch?v=MZnyQewsB_Y

Review > World Neurosurg. 2021 Jan:145:455-461. doi: 10.1016/j.wneu.2020.08.178. Epub 2020 Sep 2.

The Evolution of Corpus Callosotomy for Epilepsy Management

Aparna Vaddiparti [1], Richard Huang [2], David Blihar [3], Maira Du Plessis [3], Michael J Montalbano [3], R Shane Tubbs [4], Marios Loukas [5]

Affiliations + expand

PMID: 32889189 DOI: 10.1016/j.wneu.2020.08.178

Abstract

Corpus callosotomy, first used in the management of epilepsy by William P. van Wagenen in 1940, was for years a contentious procedure. Two decades later, Nobel Laureate Roger W. Sperry's split-brain studies inspired surgeons to reexamine the role of corpus callosotomy in the control of epileptic seizures. In 1962, Joseph Bogen and Philip Vogel performed complete corpus callosotomies in patients with a history of generalized seizures. The identification of a set of postsurgical disconnection symptoms and other neurologic deficits begged the improvement of the surgical technique. Modifications to the operation, including anterior callosotomy, posterior callosotomy, partial callosotomy, staged callosotomy, microsurgical techniques, and radiosurgical techniques, continue to refine the procedure.

https://pubmed.ncbi.nlm.nih.gov/32889189/

Sperry moved on to human volunteers who had a severed corpus callosum. He showed a word to one of the eyes and found that split-brain people could only remember the word they saw with their right eye. Next, Sperry showed the participants two different objects, one to their left eye only and one to their right eye only and then asked them to draw what they saw. All participants drew what they saw with their left eye and described what they saw with their right eye. Sperry concluded that the left hemisphere of the brain could recognize and analyze speech, while the right hemisphere could not.

Lienhard, (2017): https://embryo.asu.edu/pages/roger-sperrys-split-brain-experiments-1959-1968-0

The ventricular system

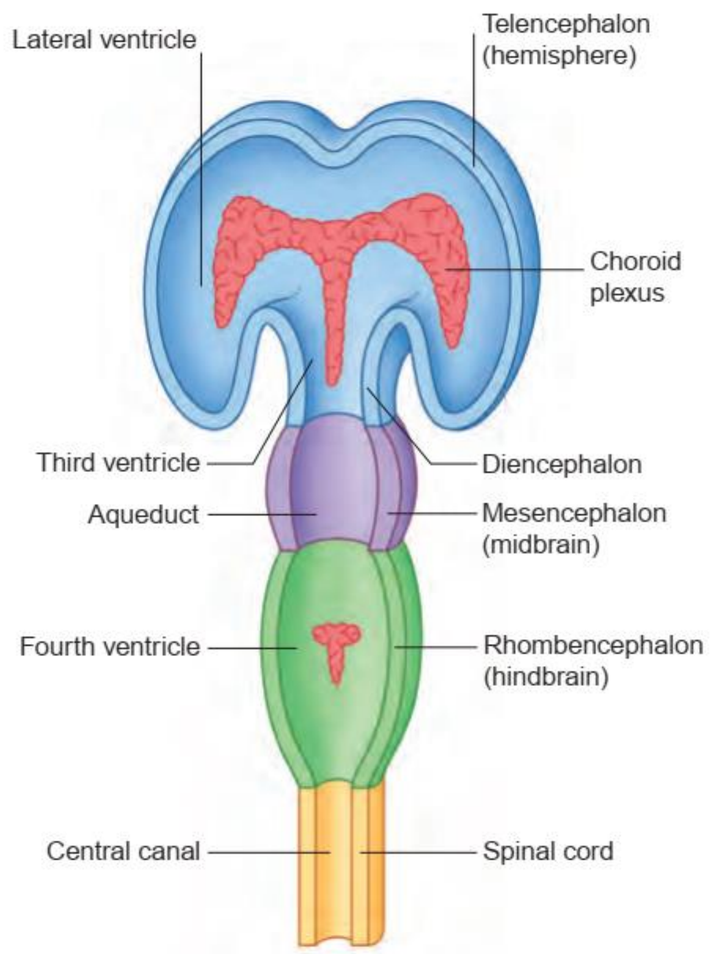


Fig. 1.5 The developing ventricular system. Choroid plexuses are shown in red.

Mtui et al., (2021), p. 3

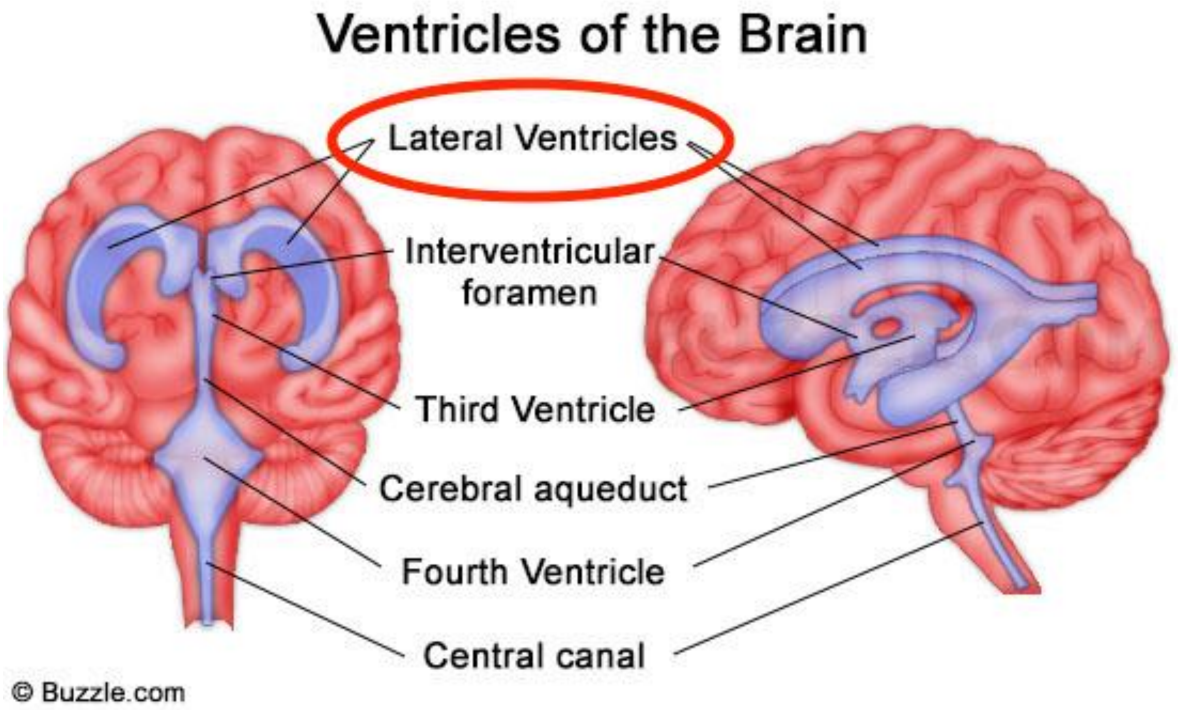
There are **four ventricles** within the brain, all of which developed from the original hollow space (lumen) within the neural tube.

The ventricles are lined by **ependymal cells**.
In some places the ependymal cells form specialized clusters with blood vessels called **choroid plexuses**, which secrete **cerebrospinal fluid** (CSF) into the ventricles.

Some ependymal cells have the ability to divide and produce new neurons (**neurogenesis**). Steady streams of developing neurons from the ependymal layer migrate to the **olfactory bulb** and the **dentate gyrus** of the **hippocampus**, where they replace old neurons, which may have died or become dysfunctional.

The **lateral ventricles** are the largest (one within each cerebral hemisphere).

CSF flows from the lateral ventricles through small openings (the **interventricular foramina**/ the **foramina of Monro**) into the **third ventricle** (a narrow midline space between the right and left diencephalon).

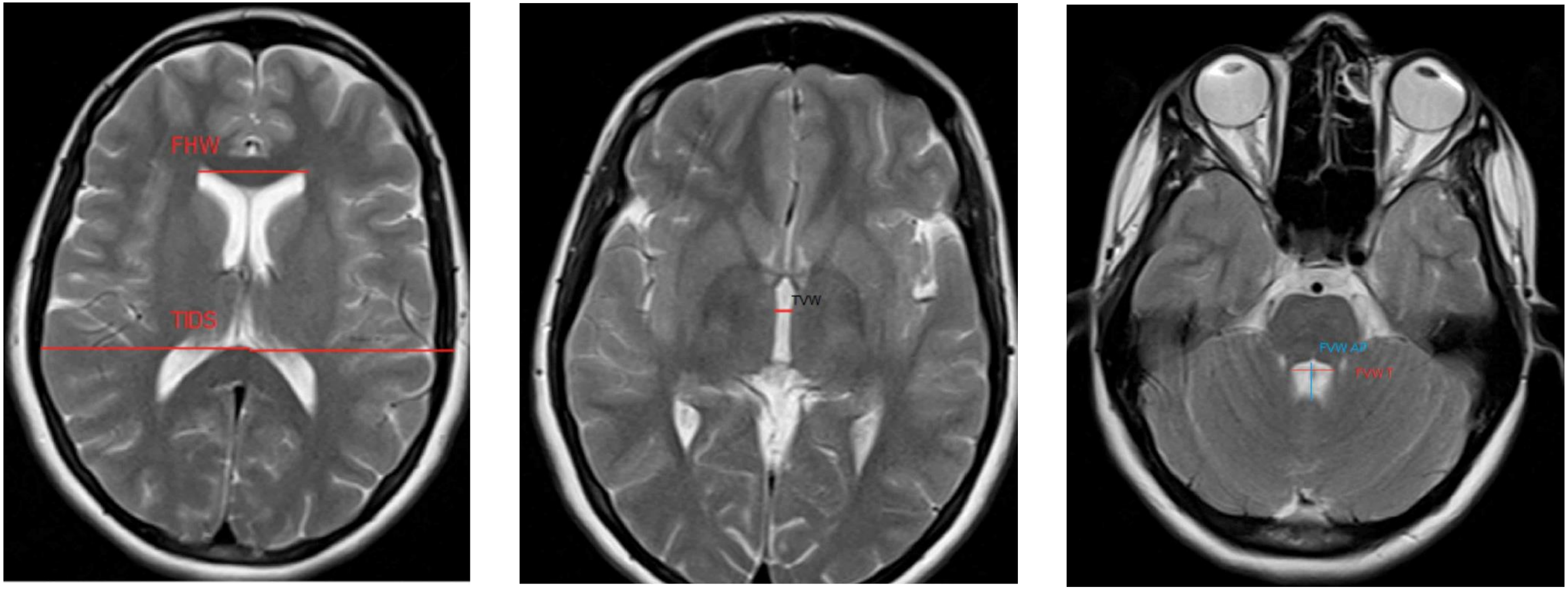


https://www.stepwards.com/?page_id=11243

The **third ventricle** is continuous caudally with the **cerebral aqueduct** (or **aqueduct of Sylvius**), which runs though the midbrain.

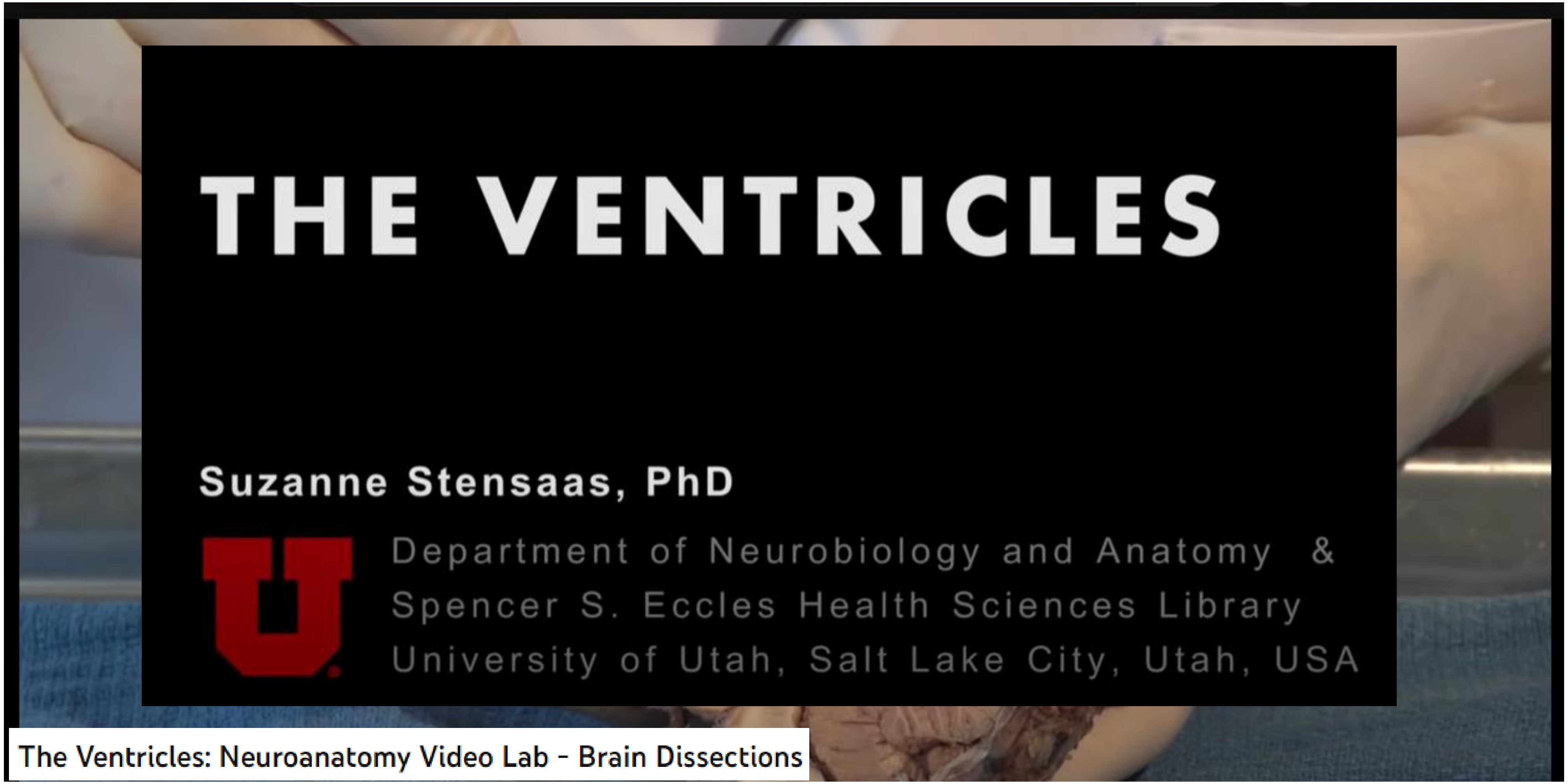
At its caudal end, the aqueduct opens into the **fourth ventricle**, a larger space dorsal to the pons and medulla. The **fourth ventricle**, covered on its dorsal aspect by the cerebellum, narrows caudally to form **the central canal** of the spinal cord.

Axial view of the lateral, third and fourth ventricles (T2W MRI)



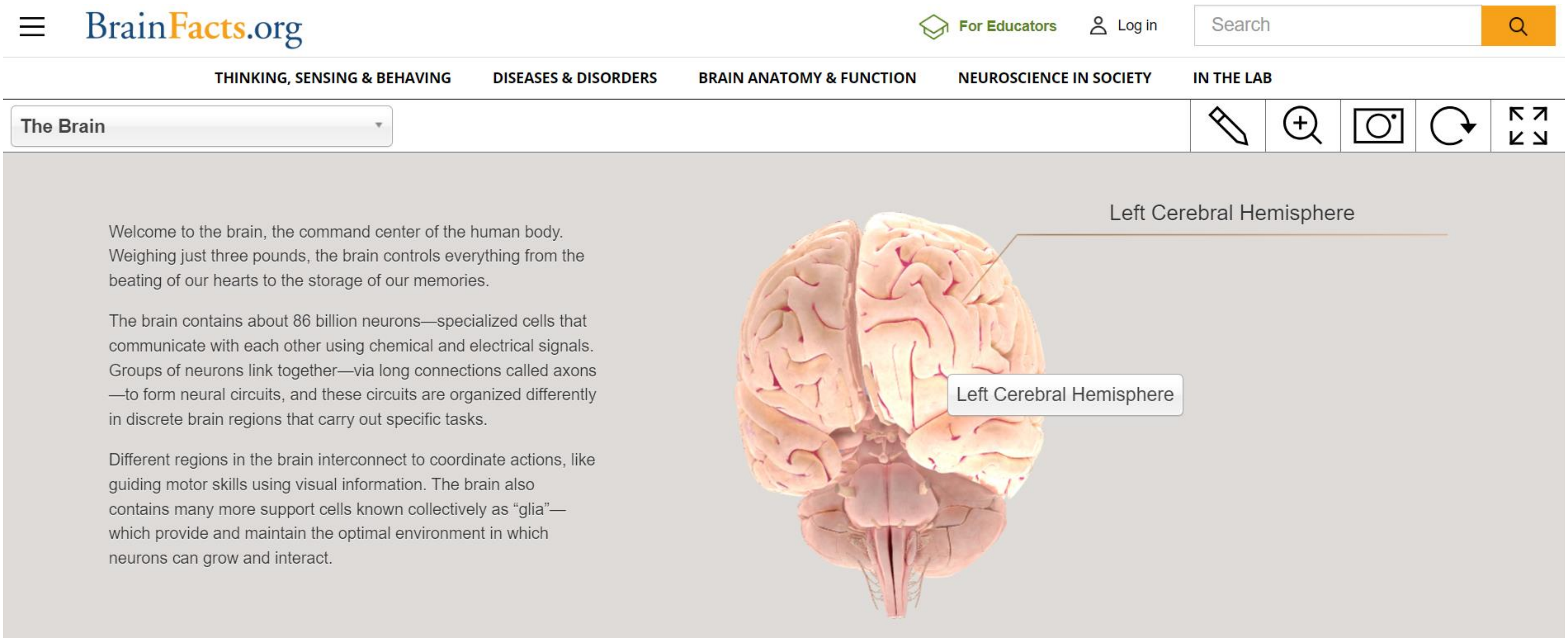
Polat et al., (2019)

Localisation of ventricles



https://www.youtube.com/watch?v=zqQ6iKw5DjY

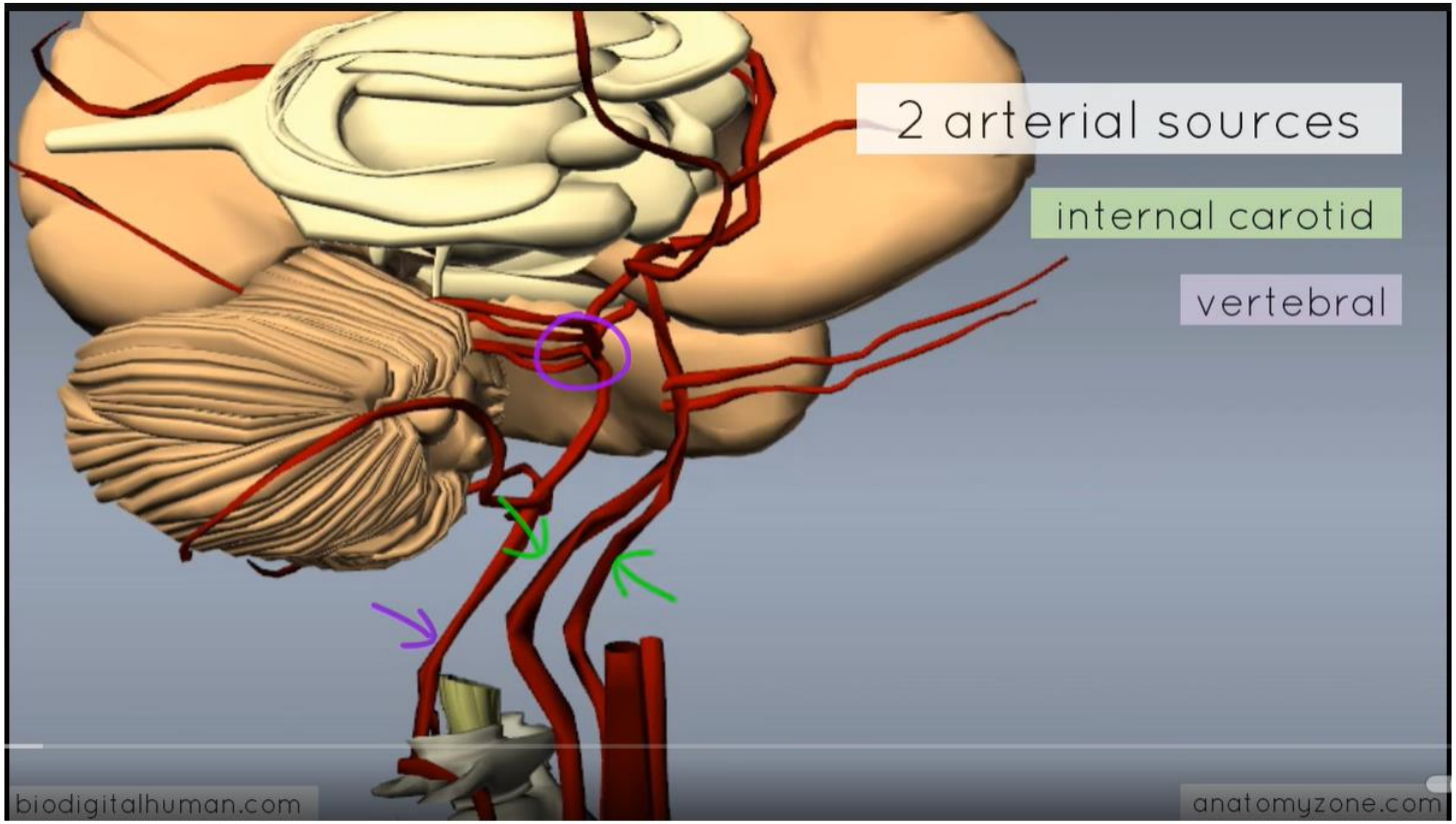
Now let's see everything we talked about until now, in 3D



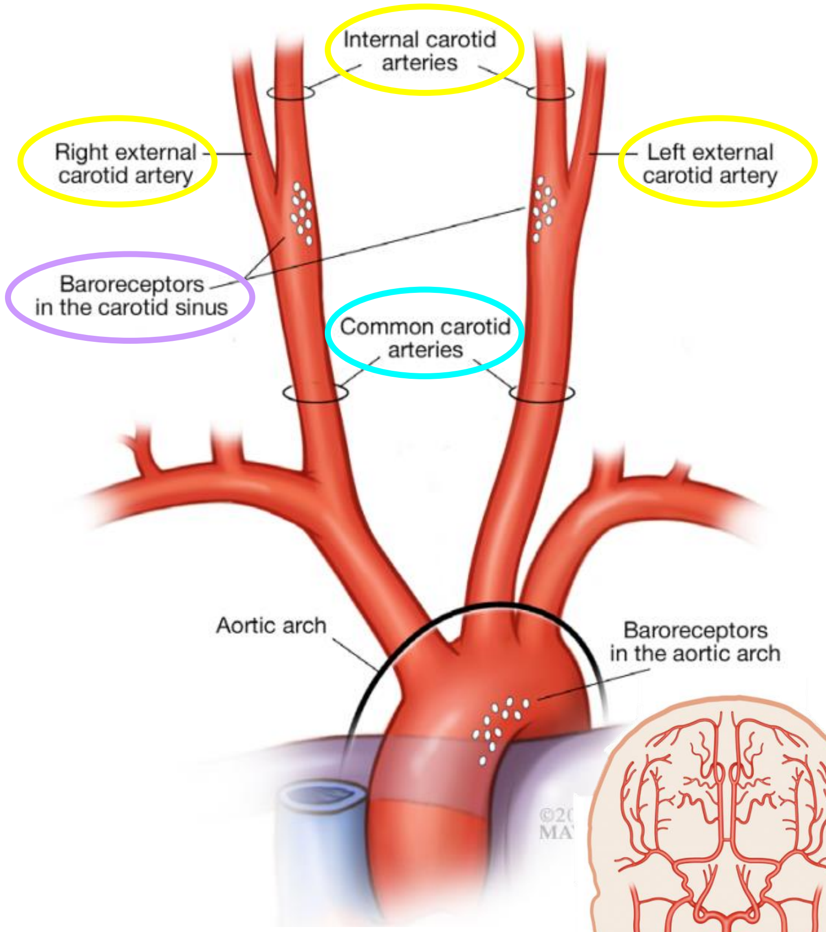
https://www.brainfacts.org/3D-Brain#intro=false&focus=Brain

Cerebral blood supply

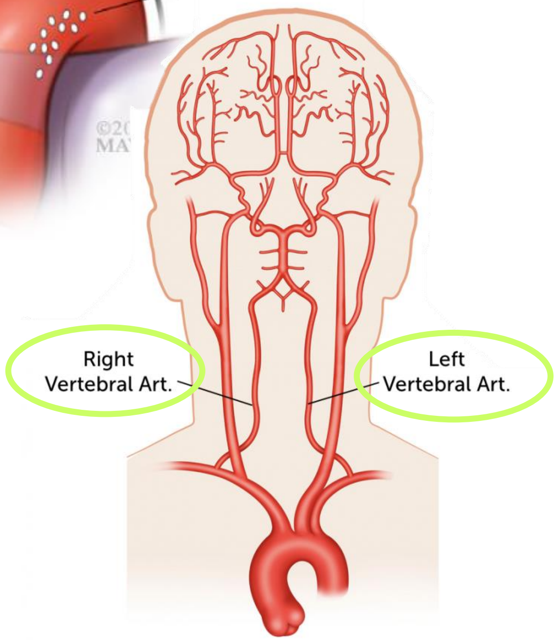
A 3D view of the Circle of Willis



https://www.youtube.com/watch?v=9hhfM7rQHiM



Welch et al., (2019)



https://tinyurl.com/47t7rna4

The major artery carrying oxygenated blood away from the heart is the aorta => **common carotid arteries**, which further branch into the **internal** and **external carotid arteries**.

The **external carotid arteries** => supplies blood to the tissues on the surface of the cranium.

The **internal carotid artery** enters the cranium through the **carotid canal** in the temporal bone.

The bases of the **common carotids** contain stretch receptors (**baroreceptors**) that immediately respond to the drop in blood pressure upon standing.

A second set of vessels that supply the CNS are the **vertebral arteries.** After they enter the cranium, they merge into the **anterior spinal artery** supplying the anterior aspect of the spinal cord.

The left and right **vertebral arteries** merge into the **anterior spinal artery**

They then merge into the **basilar artery**, which gives rise to branches to the brain stem and cerebellum.

The left and right internal carotid arteries and branches of the **basilar artery** all become the **circle of Willis.**

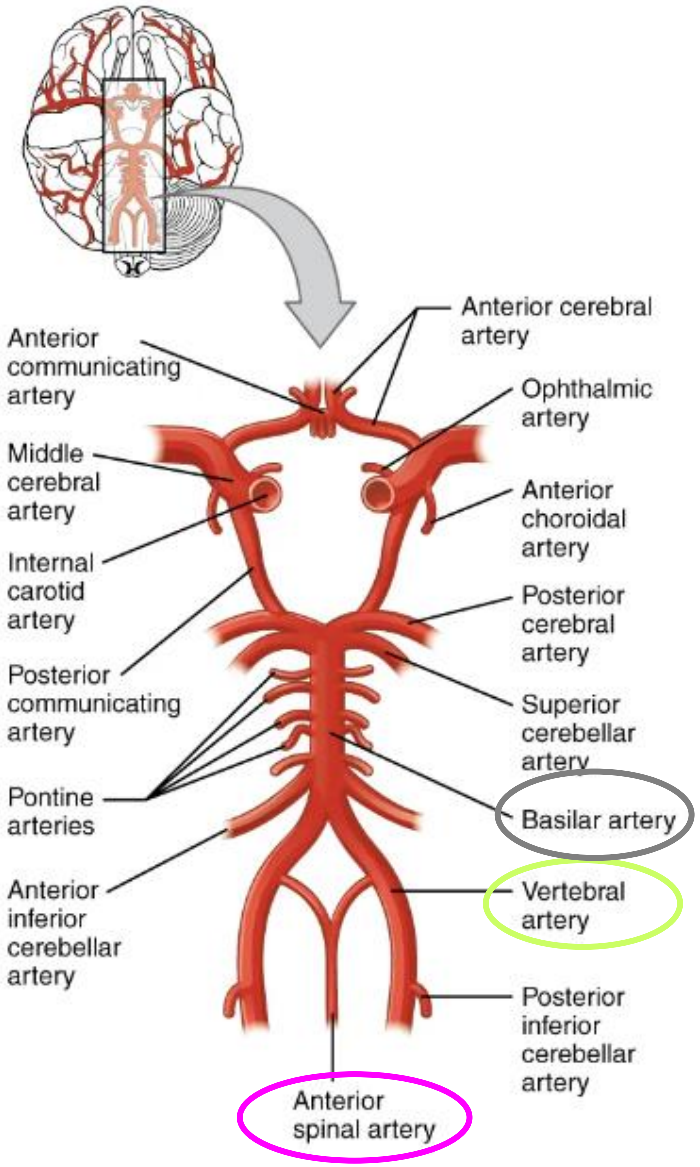


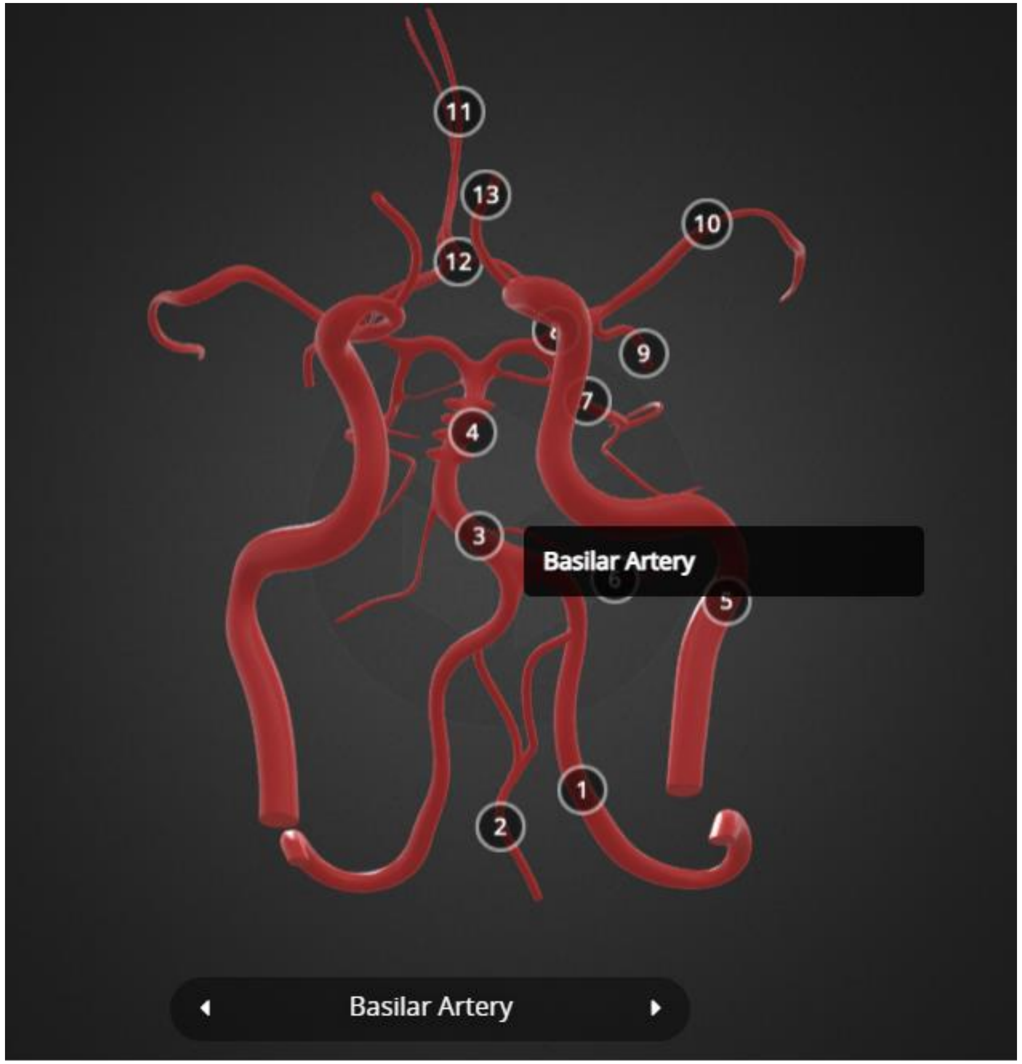
Figure 13.15 Circle of Willis The blood supply to the brain enters through the internal carotid arteries and the vertebral arteries, eventually giving rise to the circle of Willis.

https://tinyurl.com/5b6kzyk9

Arteriogram of the arterial supply to the CNS

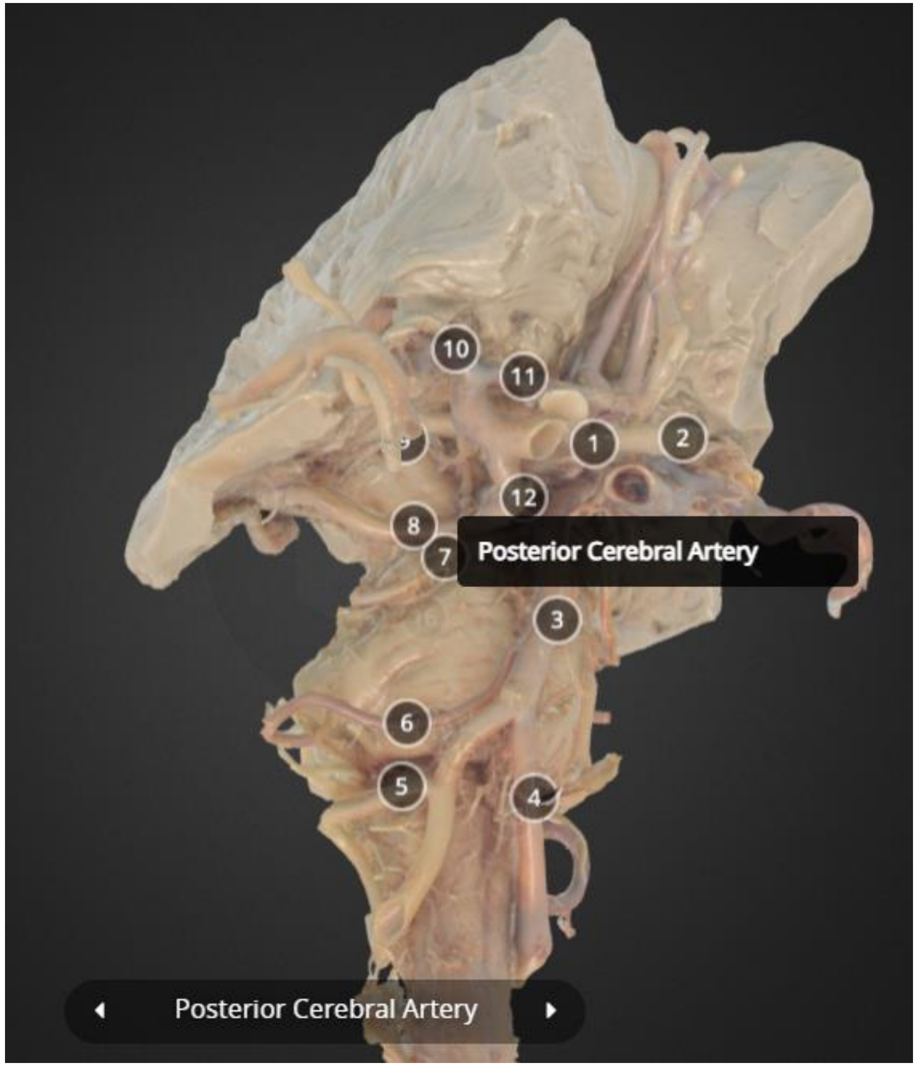
https://teachmeanatomy.info/neuroanatomy/vessels/arterial-supply/

3D rendering of the Circle of Willis



https://tinyurl.com/53fwsfj4

3D rendering of the brainstem plus the Circle of Willis



https://tinyurl.com/dsxzajwr

Venous return

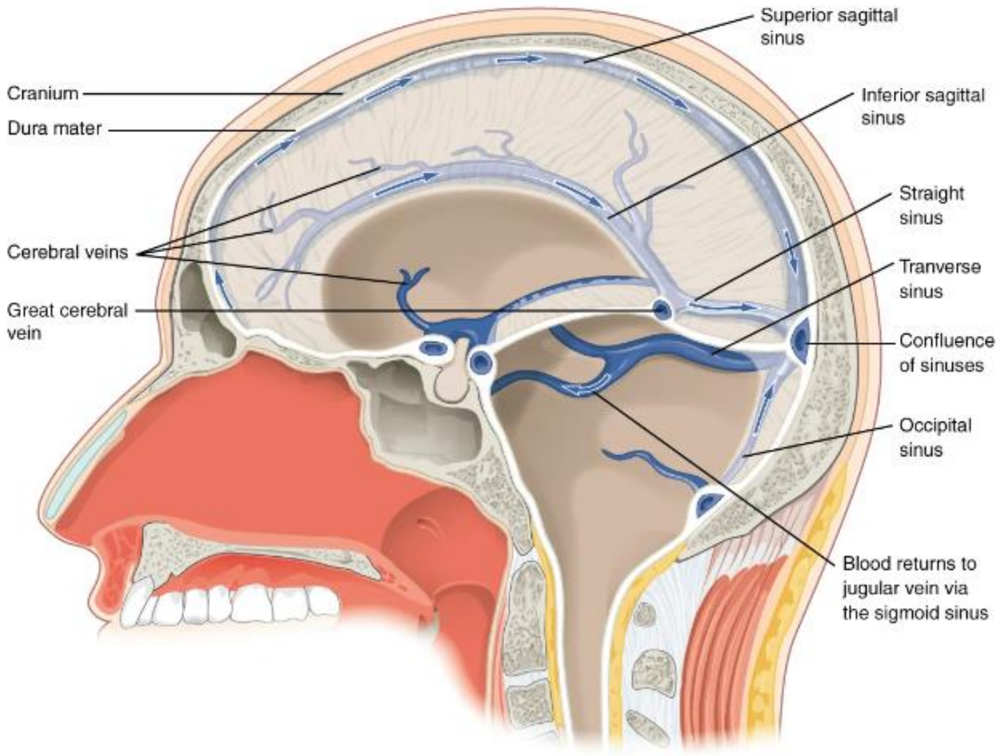


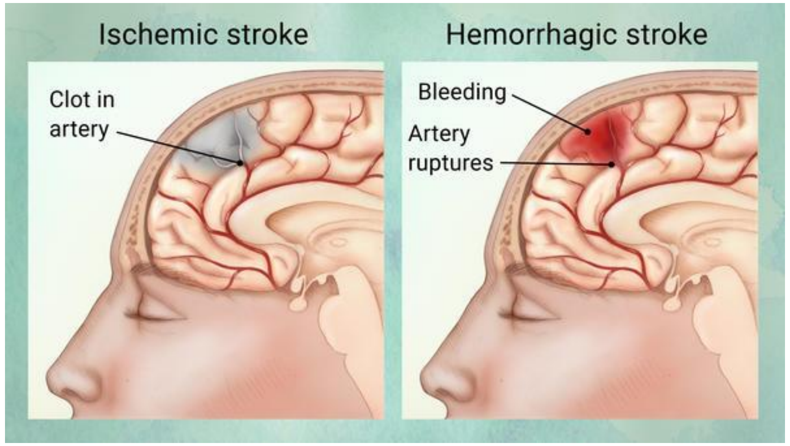
Figure 13.16 Dural Sinuses and Veins Blood drains from the brain through a series of sinuses that connect to the jugular veins.

https://tinyurl.com/5b6kzyk9

After passing through the CNS, blood returns to the circulation through a series of **dural sinuses** and **veins**.

The **superior sagittal sinus** runs in the groove of the **longitudinal fissure**, where it absorbs CSF from the meninges. The superior sagittal sinus drains to the **confluence of sinuses**, along with the **occipital sinuses** and **straight sinus**, to then drain into the **transverse sinuses**. The transverse sinuses connect to the **sigmoid sinuses**, which then connect to the **jugular veins**. From there, the blood continues toward the heart to be pumped to the lungs for reoxygenation.

The aftermath of a haemorrhagic stroke

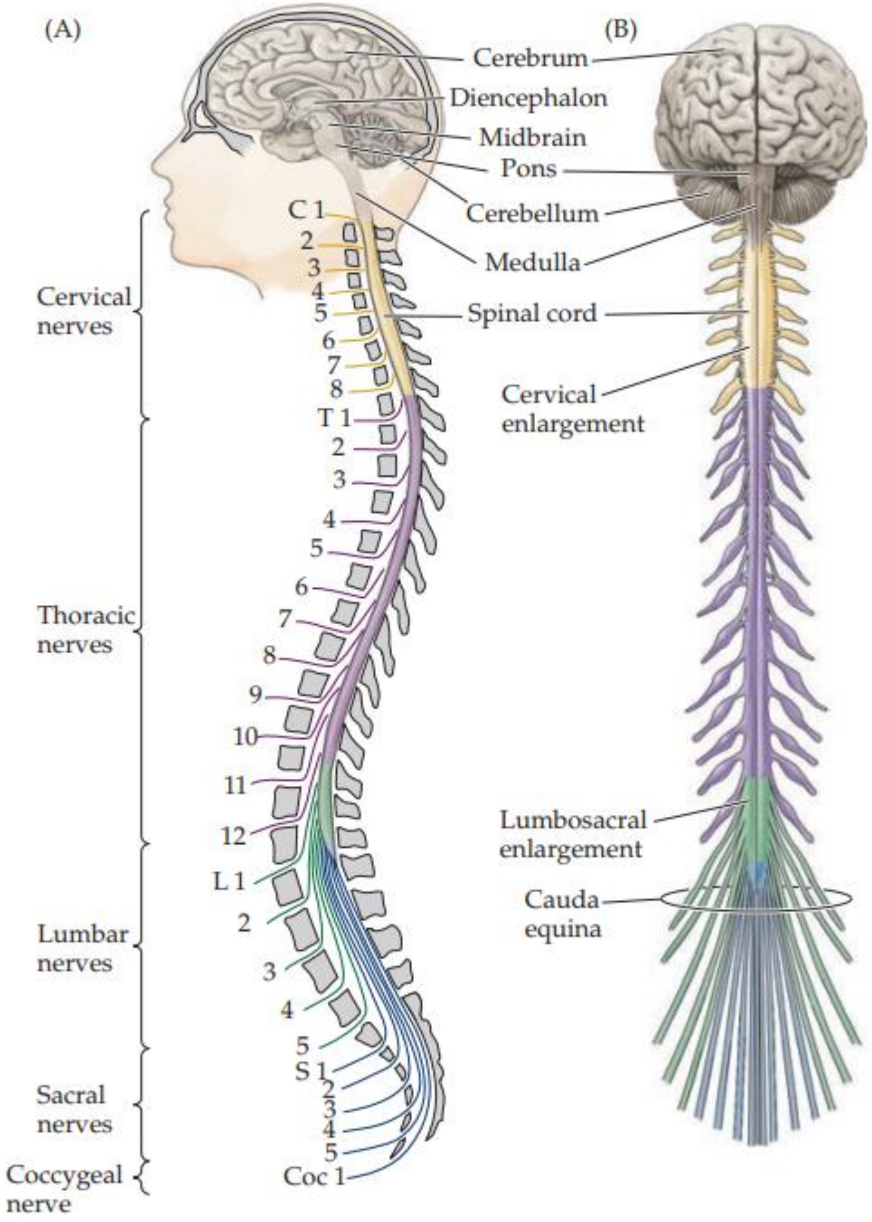


https://tinyurl.com/499ytr9e

The spinal cord

The vertebral column (and the spinal cord within it) is divided into **cervical**, **thoracic**, **lumbar**, **sacral**, and **coccygeal** regions. The peripheral nerves (spinal or segmental nerves) that innervate much of the body arise from the spinal cord's **31 pairs of spinal nerves**.

On each side of the midline, the cervical region of the cord gives rise to **8 cervical** nerves (C1–C8), the thoracic region to **12 thoracic** nerves (T1–T12), the lumbar region to **5 lumbar** nerves (L1–L5), the sacral region to **5 sacral** nerves (S1–S5), and the coccygeal region to **one coccygeal** nerve.

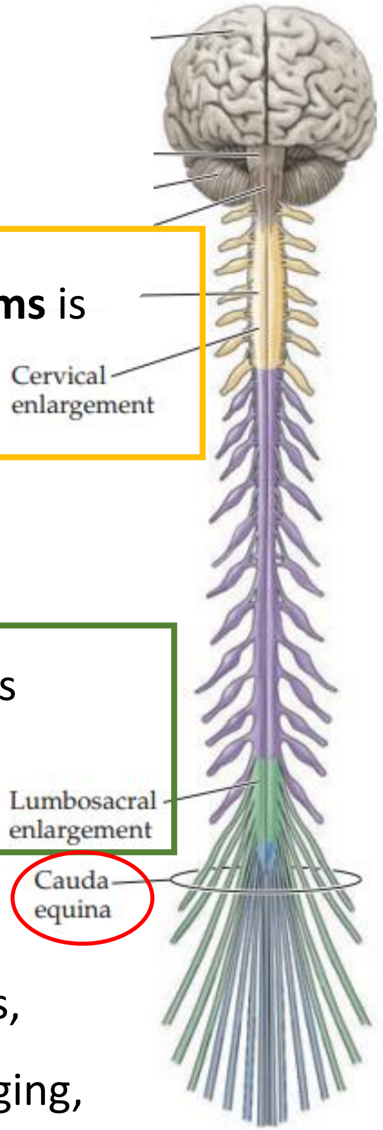


Purves et al. (2018), Appendix

Two regions of the spinal cord are **enlarged** to accommodate the **greater number of nerve cells** and connections needed to process information related to the **upper and lower limbs**.

The spinal cord expansion that corresponds to the **arms** is called the **cervical enlargement** (segments **C3–T1**).

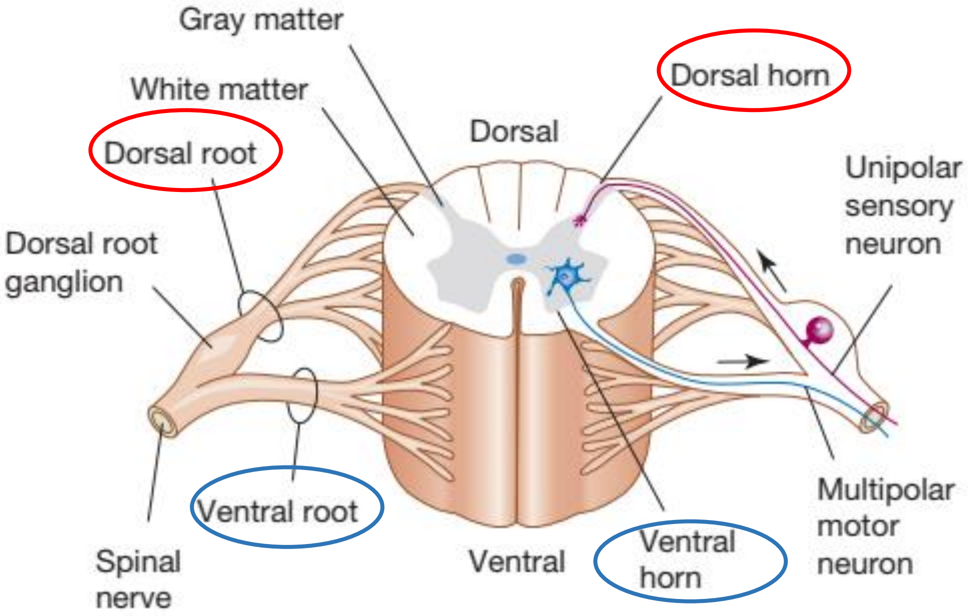
The spinal cord expansion that corresponds to the **legs** is called the **lumbosacral enlargement** (segments **L1–S2**).



Because the **spinal cord** is considerably **shorter than the vertebral column** in adults, **lumbar** and **sacral** nerves run for some distance in the vertebral canal before emerging,

=> collection of nerve roots known as the **cauda equina** *(from Latin: “horse’s tail”)*.

Figure 3.17 A schematic cross section of the spinal cord, and the dorsal and ventral roots.



Pinel & Barnes, (2021), p. 86

In transverse sections, the gray matter is conventionally divided into **dorsal (posterior)** and **ventral (anterior)** “horns.”

The neurons of the **dorsal horns** receive **sensory** information that enters the spinal cord **via the dorsal roots** of the spinal nerves.

The **ventral horns** contain the cell bodies of **motor** neurons that send axons via the **ventral roots** of the spinal nerves to terminate on *striated muscles.

*****striated muscles**: generate force and contract in order to support **respiration**, **locomotion**, and posture (**skeletal muscle**) and to pump blood throughout the body (**cardiac muscle**).*

The spinal cord in 3D: unfixed and cross-sectional

The Unfixed Spinal Cord: Neuroanatomy Video Lab - Brain Dissections

https://tinyurl.com/2ttsyuae

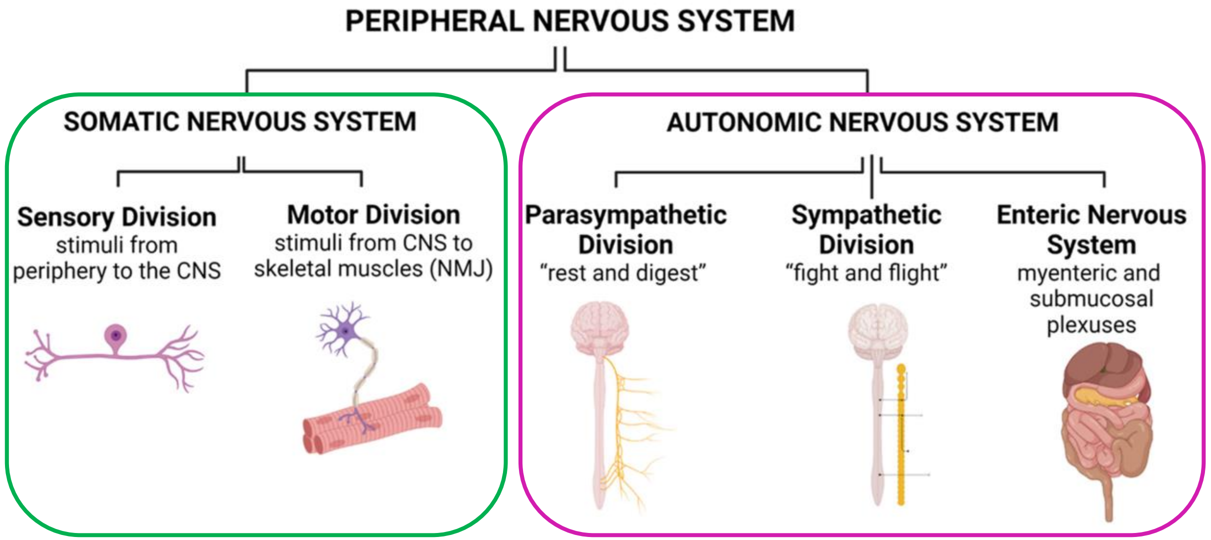
The Spinal Cord & Monosynaptic Reflex: Neuroanatomy Video Lab - Brain Dissections

https://tinyurl.com/bd228j3h

Peripheral nervous system

Peripheral nervous system (PNS)

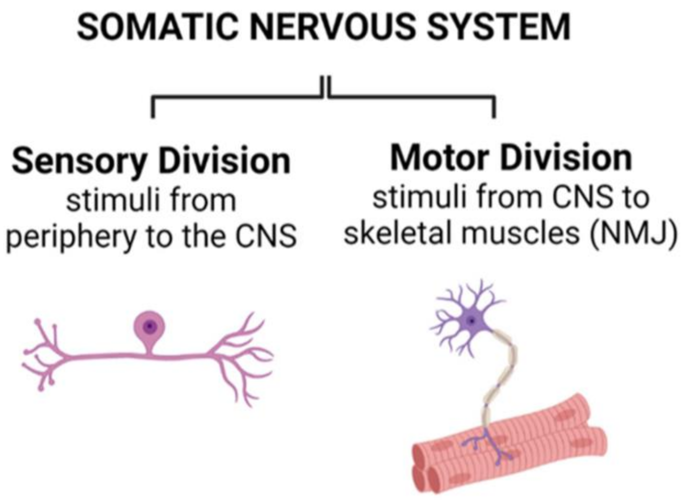
The **somatic nervous system (SNS)** is the part of the PNS that interacts with the **external environment**. It is composed of **afferent nerves** that carry **sensory signals** from the skin, skeletal muscles, joints, eyes, ears, and so on, to the central nervous system (CNS) and **efferent nerves** that carry **motor signals** from the CNS to the skeletal muscles.



https://tinyurl.com/2tjetjyb

The **autonomic nervous system (ANS)** is the part of the PNS that regulates the **body's internal environment**. It is composed of **afferent nerves** that carry **sensory signals** from internal organs to the CNS and **efferent nerves** that carry **motor signals** from the CNS to internal organs.

Somatic nervous system



pseudounipolar neuron

neuromuscular junction (NMJ)

Most sensory afferent neurons are pseudounipolar or bipolar. Pseudounipolar neurons have **one projection** from the cell body, which splits into **two axons** (no dendrites): one that extends **into the periphery**, and one that extends **into the CNS.**

(https://pittmedneuro.com/neuron.html)

Synaptic connection between the terminal end of a **motor nerve** and a **muscle** (skeletal/ smooth/ cardiac).

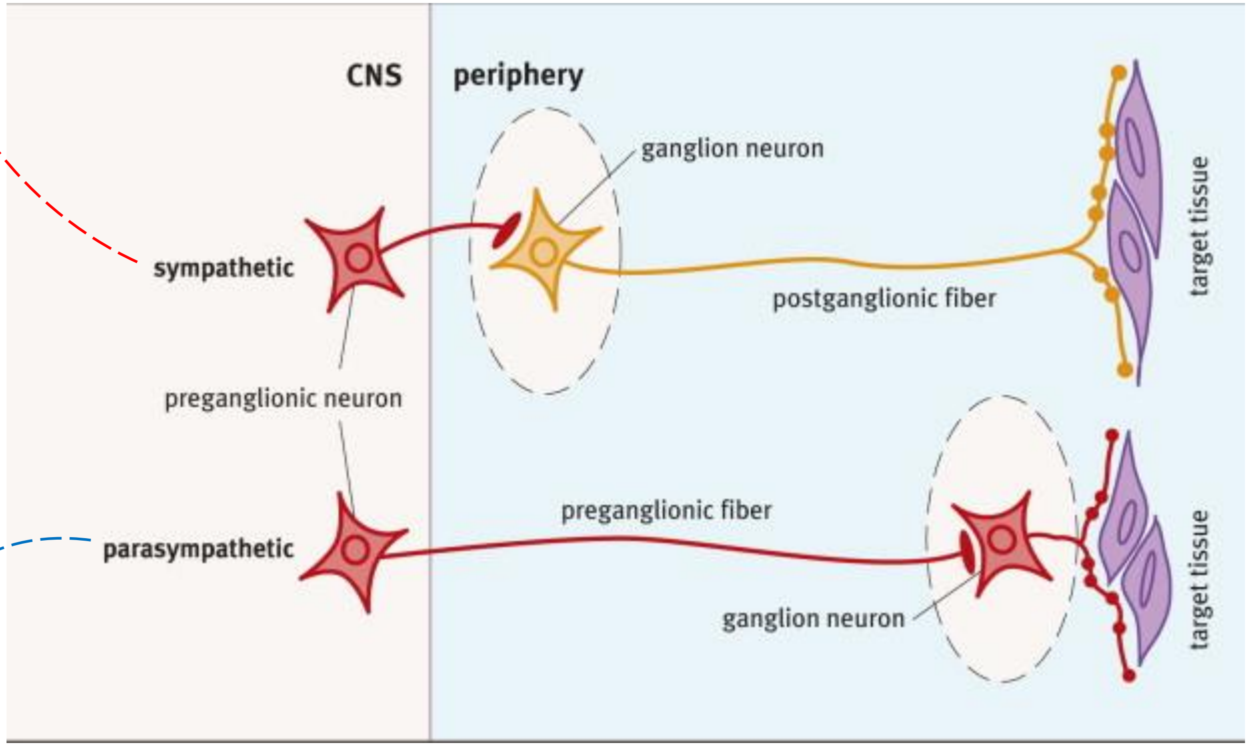
It is the site for the **transmission** of action potential from **nerve to the muscle.**

It is also a site for many diseases and a site of action for many pharmacological drugs.

(https://www.ncbi.nlm.nih.gov/books/NBK470413/)

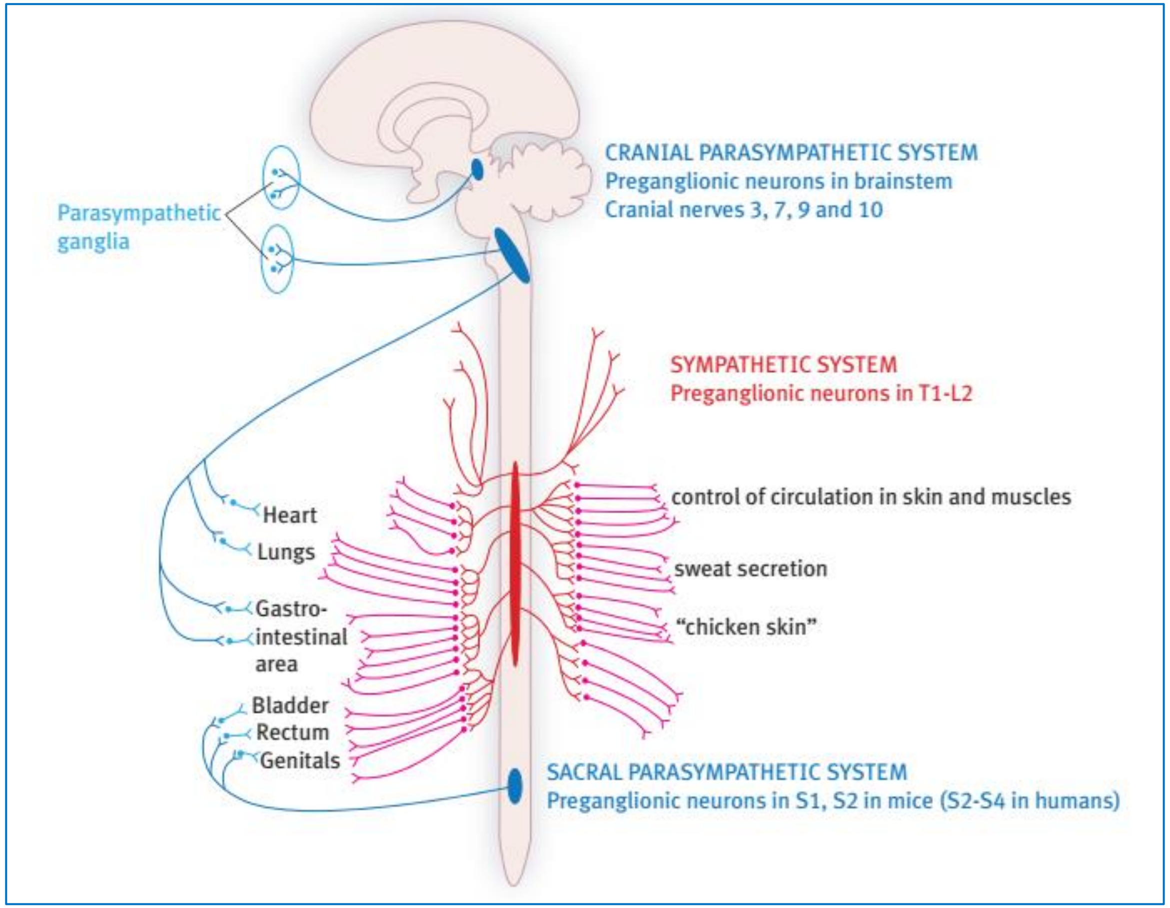
Autonomic nervous system

Sympathetic preganglionic neurons have short axons and synapse with ganglion cells close to the spinal cord.



Parasympathetic preganglionic neurons have long axons and synapse with ganglion cells close to the effector structure.

Watson et al., (2010), p. 53

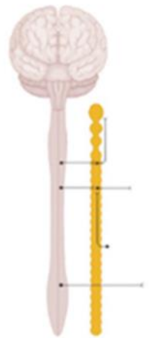


The origin and course of the **sympathetic preganglionic neurons** and **parasympathetic preganglionic neurons**. The **postganglionic neurons** are colored pink and pale blue.

The sympathetic preganglionic neurons are located in the thoracic and upper lumbar spinal cord. The parasympathetic preganglionic neurons are located in the midbrain and hindbrain, and in the sacral spinal cord.

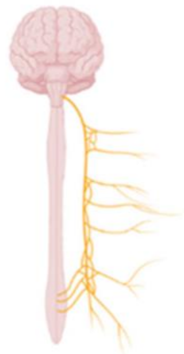
Watson et al., (2010), p. 52

Sympathetic Division
"fight and flight"



The **sympathetic nervous system** (*in 'sympathy*' with the needs of the body, e.g., in stressful situations the heart rate increases): **preganglionic sympathetic neurons** => only in the middle region of the spinal cord, from T2 to L1. The **sympathetic motor ganglia** are embedded in the **sympathetic chain** (a long system of ganglia and nerves that runs alongside the vertebrae), with approximately twenty ganglia on each side. From the ganglia, **postganglionic sympathetic fibers** => all levels of the **head, trunk, and limbs**.

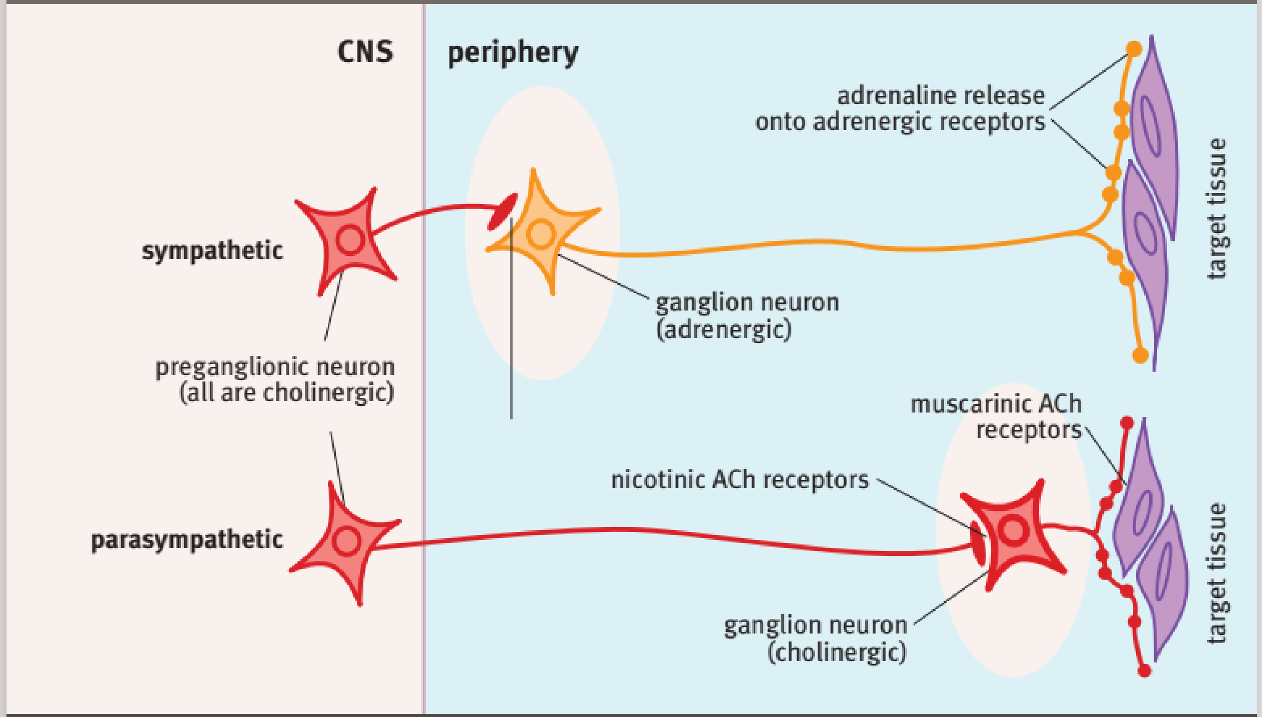
Parasympathetic Division
"rest and digest"



The **parasympathetic nervous system** is responsible for the normal day-to-day functions of the internal organs (*'rest and digest'*) => opposite effect compared to the sympathetic nervous system (e.g., the lower heart rate and blood pressure). The parasympathetic nervous system does not send nerves to the limbs; its role is restricted to the **glands and organs** of the head and trunk.

The **vagus nerve** (cranial nerve 10) conveys preganglionic parasympathetic axons from the brainstem and travels from the base of the skull to the pelvic brim. In between, it supplies the **larynx, oesophagus, lungs, heart, stomach, and the small and large intestines**.

Figure 5.14 Neurotransmitters in the autonomic nervous system



Sympathetic and parasympathetic preganglionic neurons are both cholinergic; they secrete acetylcholine (ACh) as a neurotransmitter. Postganglionic parasympathetic neurons are also cholinergic, however sympathetic postganglionic neurons are adrenergic; they secrete noradrenaline (NA). (Adapted from Brodal, 2004, p 372)

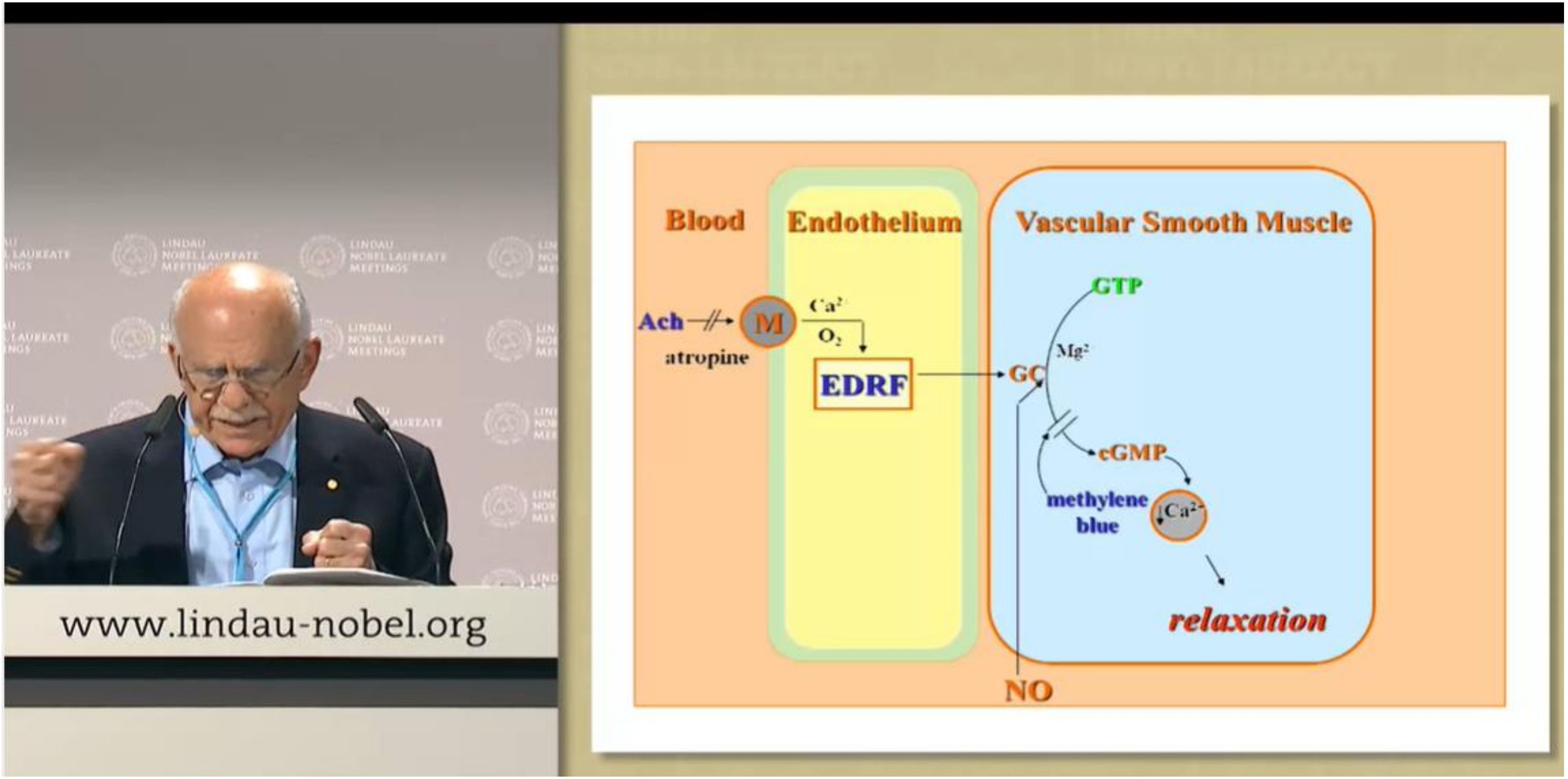
Watson et al., (2010), p. 71

Autonomic nervous system receptors are all **metabotropic**.

Noradrenergic and **cholinergic** receptors are **diverse** => various effects (e.g., sympathetic neurons that secrete noradrenaline trigger **different responses** in the smooth muscle cells of the gut because of **receptor differences**, i.e., the same neurotransmitter causes the gut walls to relax, but the gut sphincters to contract, because of their different adrenergic receptors).

The **enteric nervous system** makes use of about **20 different neurotransmitters**, the most important of which are **acetylcholine**, vasoactive intestinal polypeptide (VIP), **nitric oxide** (NO), **GABA**, and **serotonin**.

Watch this delightful lecture given by **Louis Ignarro** (awarded the Nobel Prize in Physiology or Medicine, in 1998, for his "discoveries concerning **nitric oxide** as a signalling molecule in the cardiovascular system") during the Lindau Nobel Meeting of 2018: https://mediatheque.lindau-nobel.org/recordings/37574



The **Enteric Nervous System** can control gastrointestinal behavior **independently of CNS input**. The notion that the gut was capable of generating **reflex responses** independent of the CNS was actually **first identified in 1755** by **Albrecht von Haller**, who stated that after removing the intestine from the body *"the intestines in this state after being deprived from all communication with the brain, preserve their peristaltic motion".*

Albrecht von Haller

(1708 – 1777)

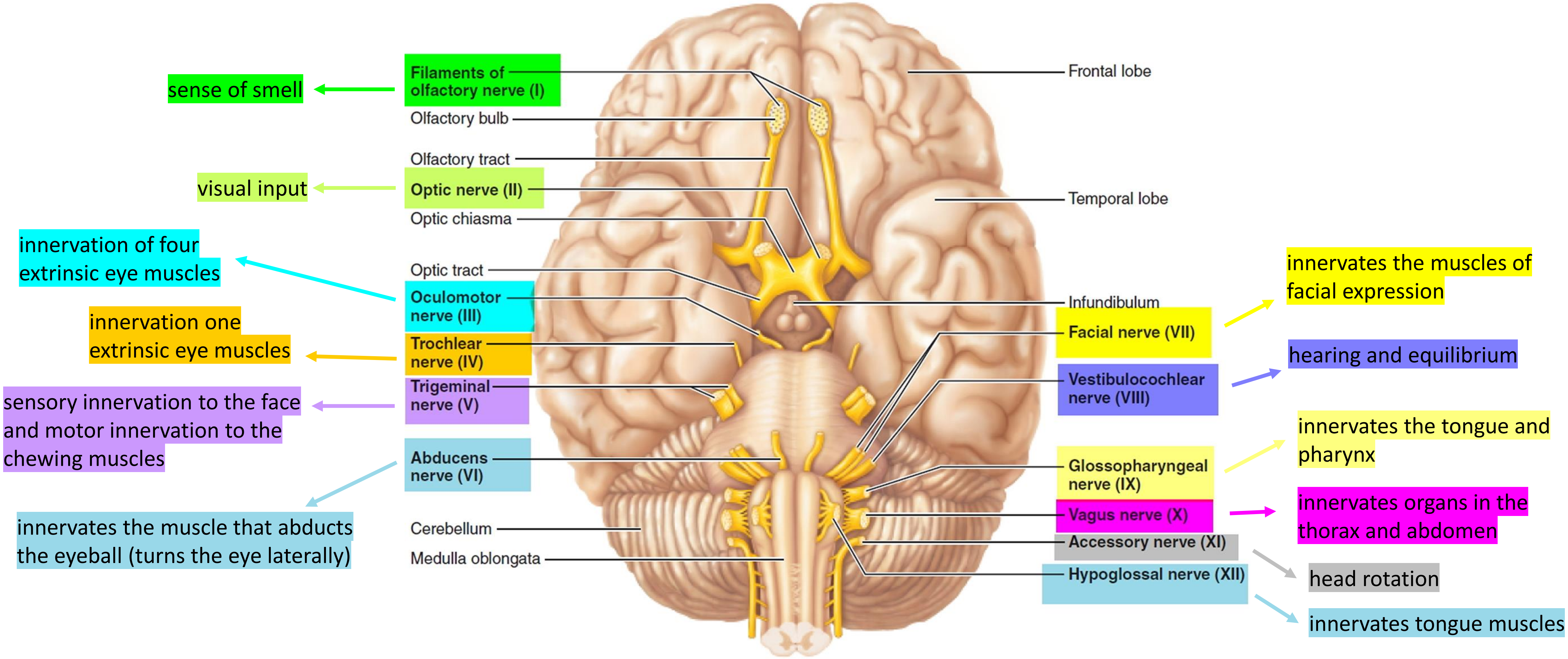
The **myenteric ganglia** are organised in a network around the gut, which spans the length between the **upper oesophagus and the internal anal sphincter** and contains mostly motor neurons.

The **submucosal ganglia** are localised in the **small and large intestine** with most of the primary afferent sensory neurons.

(https://qbi.uq.edu.au/brain/brain-anatomy/peripheral-nervous-system/enteric-nervous-system)

Cranial nerves

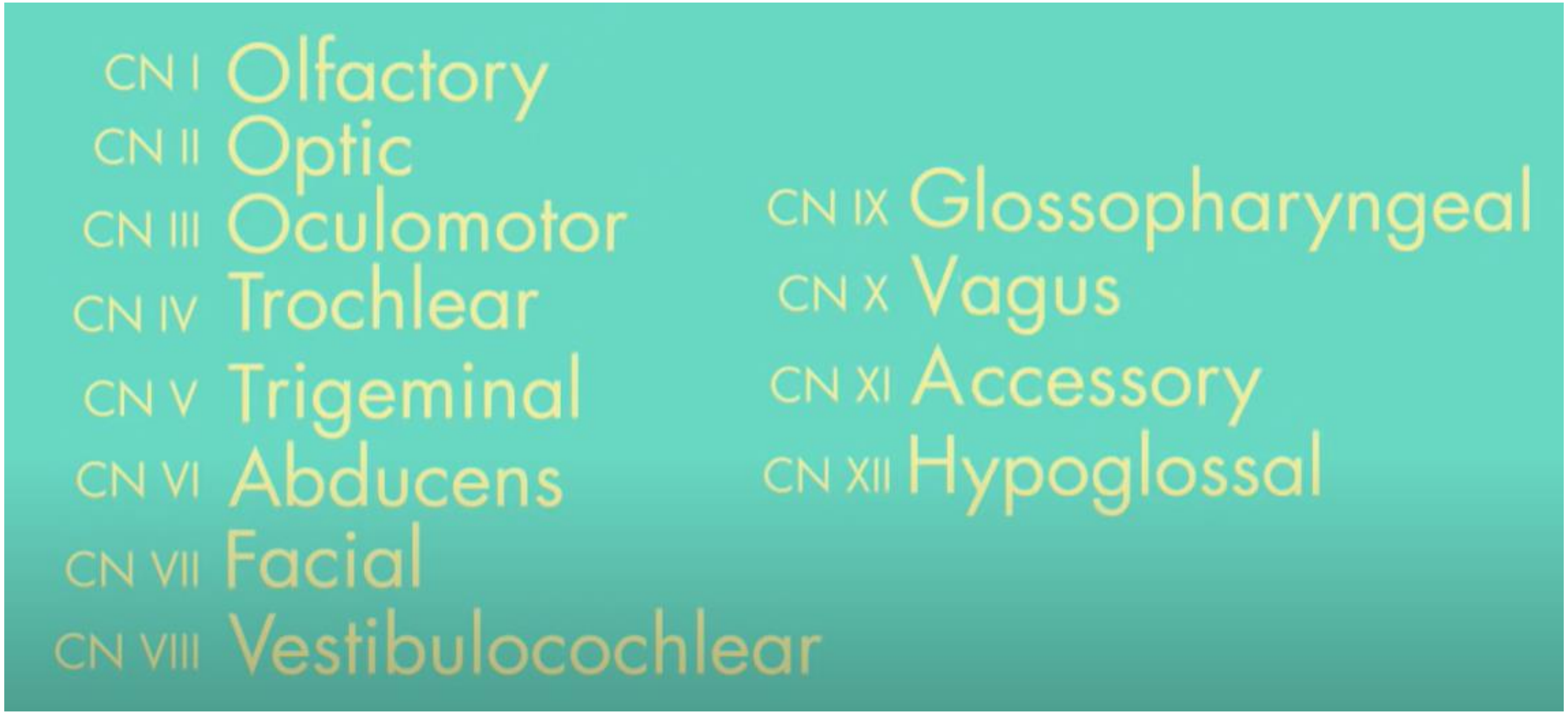
The 12 cranial nerves are generally considered to be components of the **PNS**. However, the **first** and **second** cranial nerves (**olfactory** and **optic** nerves, respectively) are considered to be extensions of the **CNS**, because they are myelinated by **oligodendrocytes**, whereas the 10 other cranial nerves are myelinated by **Schwann** cells.



https://tinyurl.com/wunzwj3c

Useful mnemonic: *“**O**n **o**ccasion, **o**ur **t**rusty **t**ruck **a**cts **f**unny. **V**ery **g**ood **v**ehicle **a**ny **h**ow”*

https://www.youtube.com/watch?v=6ENCJkXJvio



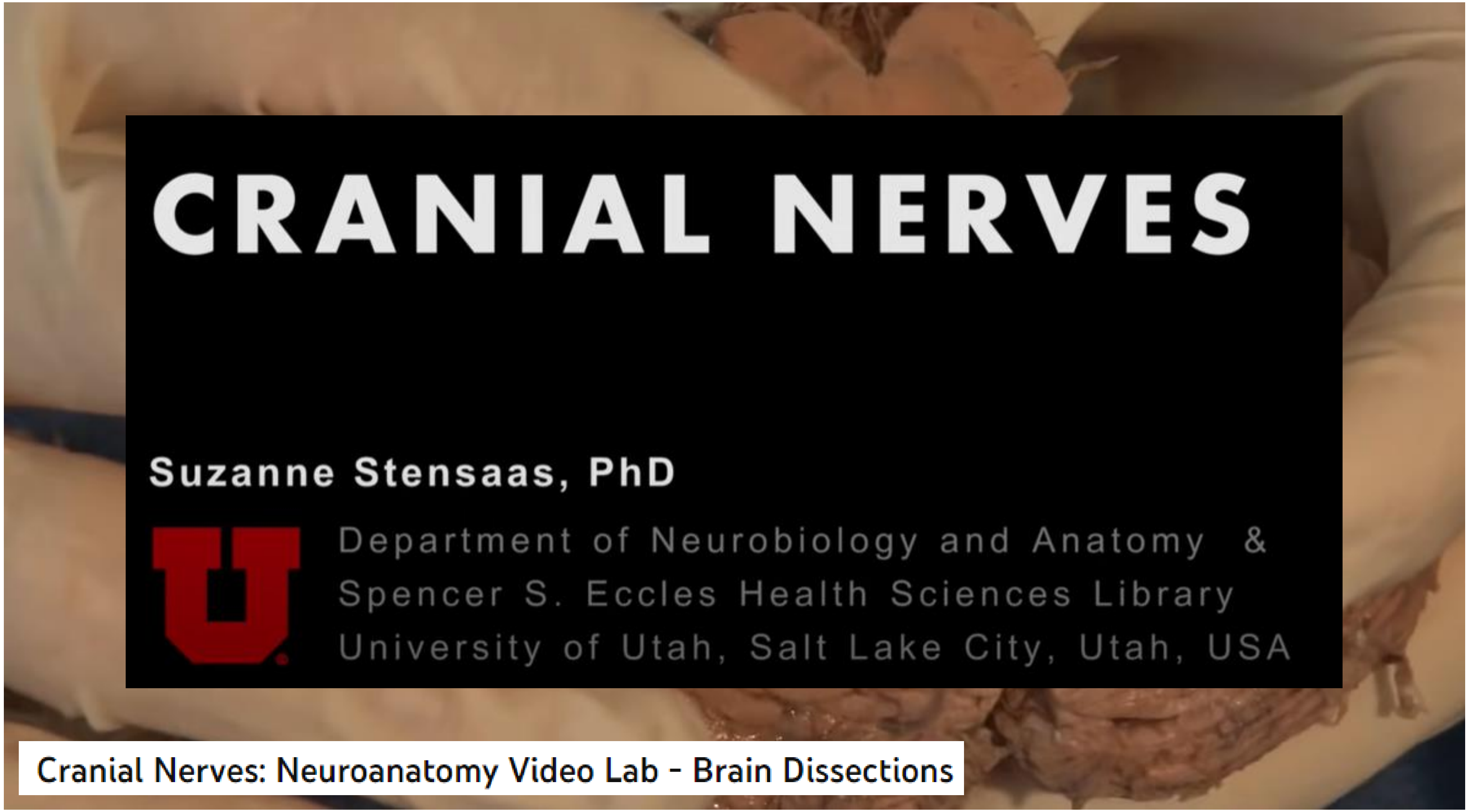
https://www.youtube.com/watch?v=6ENCJkXJvio

Cranial nerves: primary functions at a glance

TABLE A2 ■ The Cranial Nerves and Their Primary Functions

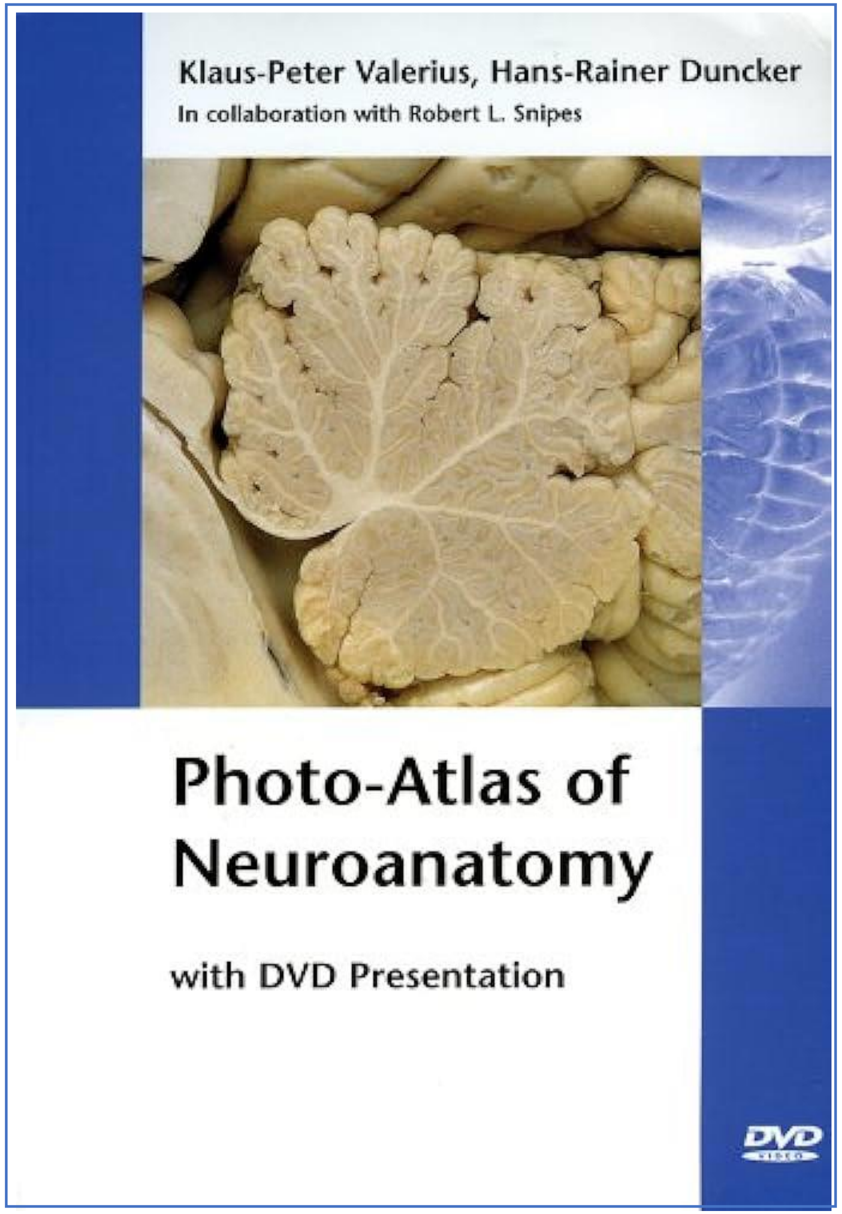
Cranial nerve	Name	Sensory and/or motor	Major function
I	Olfactory nerve	Sensory	Sense of smell
II	Optic nerve	Sensory	Vision
III	Oculomotor nerve	Motor	Eye movements; pupillary constriction and accommodation; muscle of upper eyelid
IV	Trochlear nerve	Motor	Eye movements (intorsion, downward gaze)
V	Trigeminal nerve	Sensory and motor	Somatic sensation from face, mouth, cornea; muscles of mastication
VI	Abducens nerve	Motor	Eye movements (abduction or lateral movements)
VII	Facial nerve	Sensory and motor	Controls the muscles of facial expression; taste from anterior tongue; lacrimal and salivary glands
VIII	Vestibulocochlear (auditory) nerve	Sensory	Hearing; sense of balance
IX	Glossopharyngeal nerve	Sensory and motor	Sensation from posterior tongue and pharynx; taste from posterior tongue; carotid baroreceptors and chemoreceptors; salivary gland
X	Vagus nerve	Sensory and motor	Autonomic functions of gut; cardiac inhibition; sensation from larynx and pharynx; muscles of vocal cords; swallowing
XI	Spinal accessory nerve	Motor	Shoulder and neck muscles
XII	Hypoglossal nerve	Motor	Movements of tongue

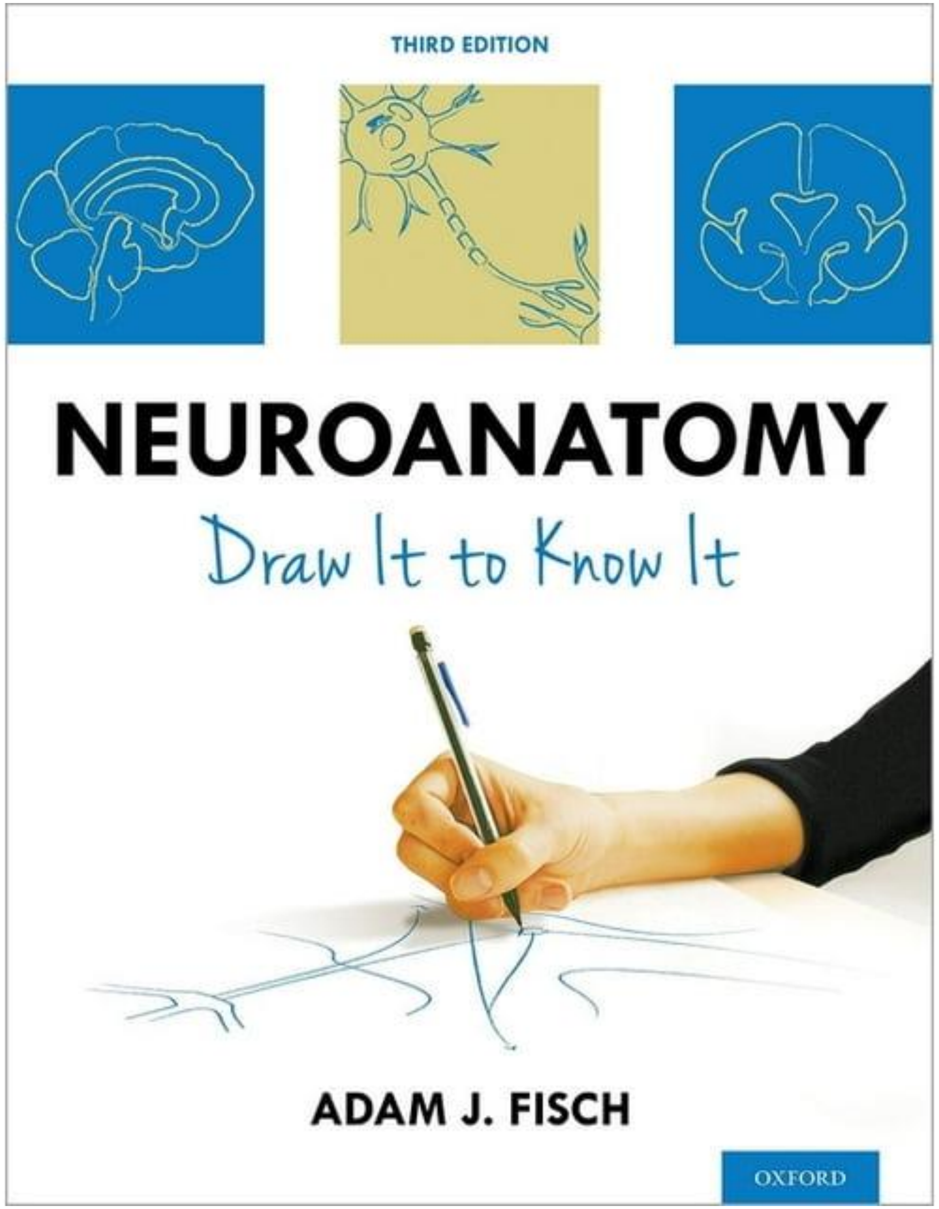
Purves et al. (2018), Appendix



https://www.youtube.com/watch?v=i8OHZ8t6vg0&list=PLp9HSlEm97VXyQ32Uwjfz3dpmQ8nl63zJ&index=9

Further reading





Further resources

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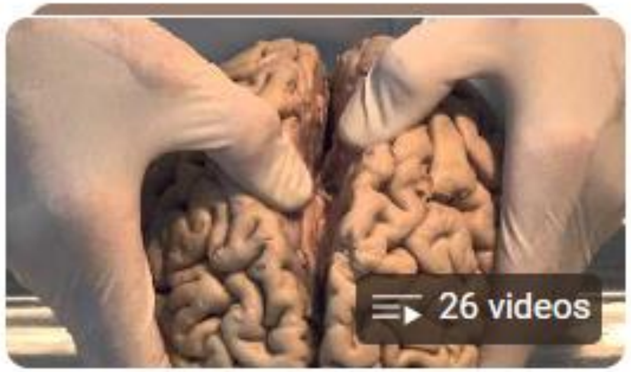
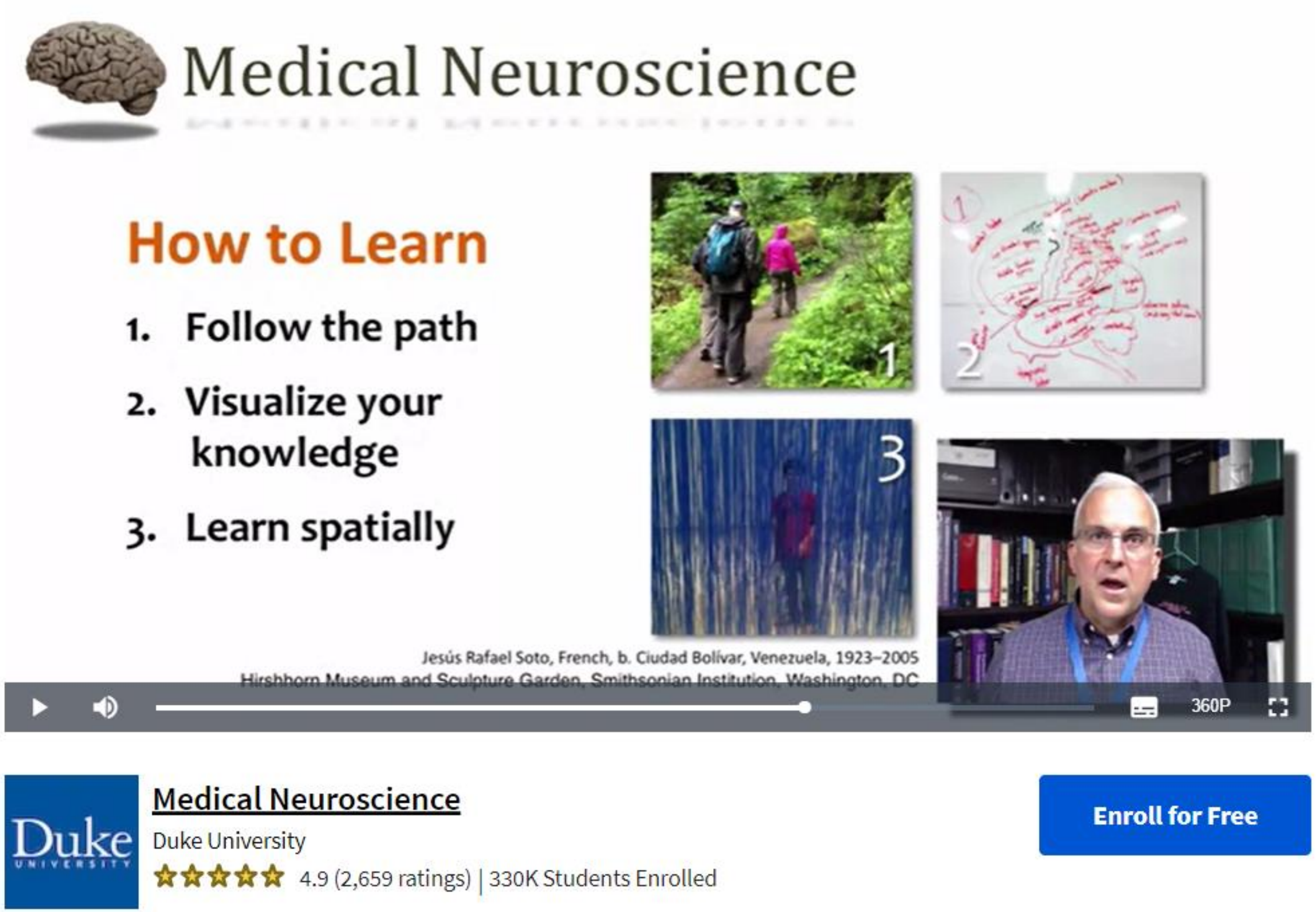


Brain Anatomy for Health Professionals

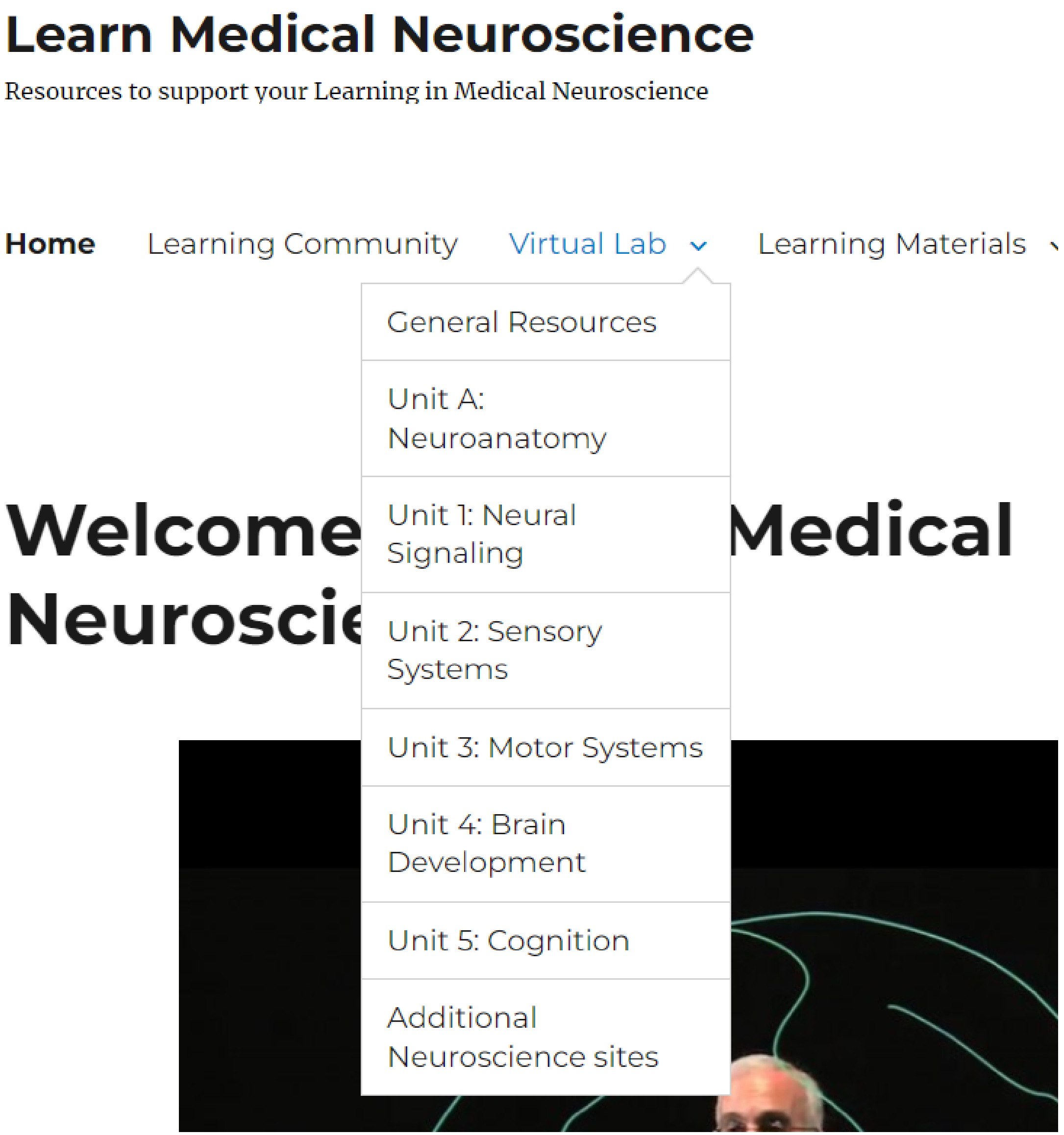
View full playlist

https://www.youtube.com/@EHSLDigitalPublishing/featured

A free Coursera course given by Duke university professor Leonard White



https://www.coursera.org/learn/medical-neuroscience



A wonderful collection of resources and visualization tools for neuroscience and neuroanatomy, associated with the Coursera course (see previous slide)

https://www.learnmedicalneuroscience.nl/