Structure and functions of brain

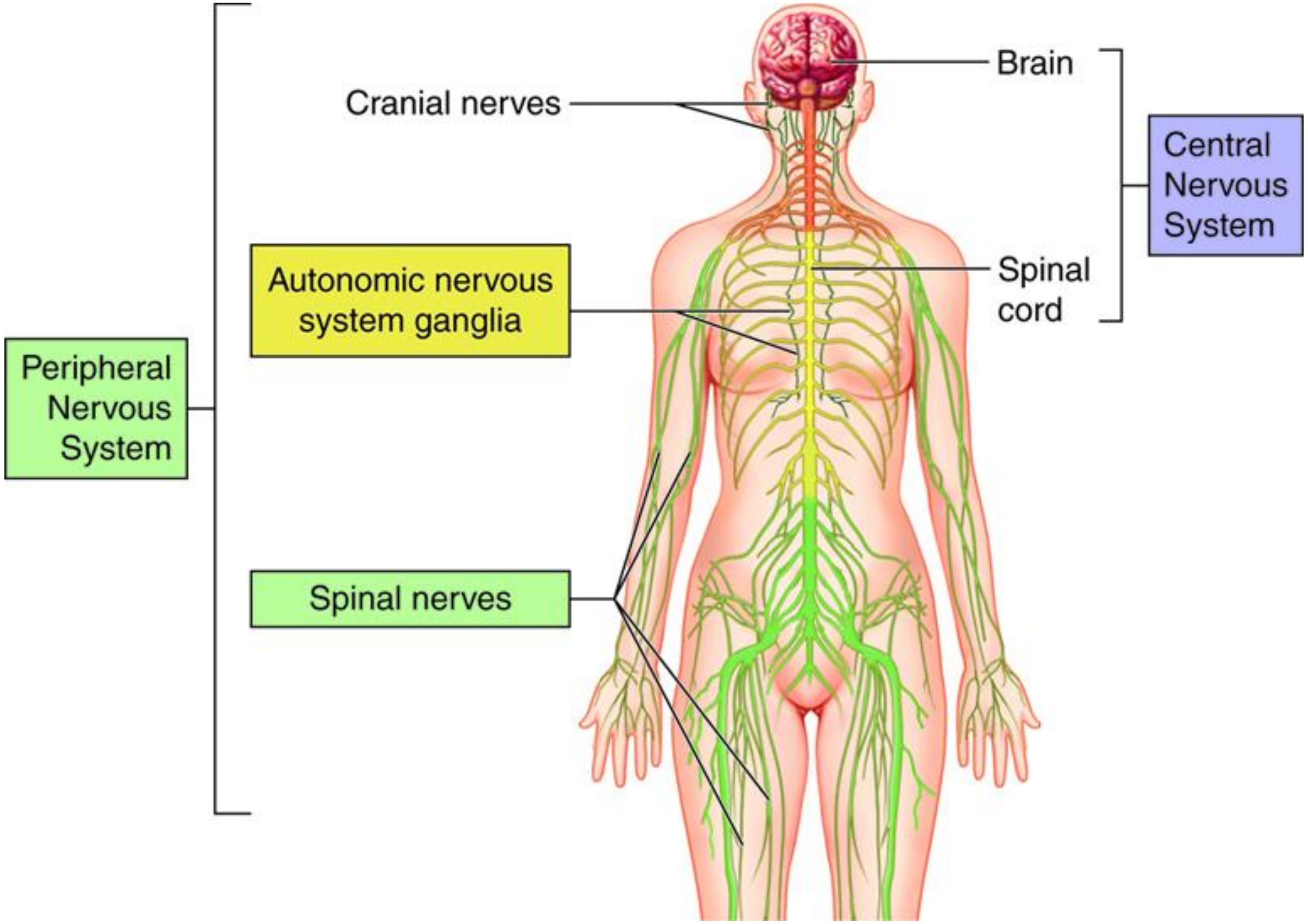
Lecture 5

Outline

- Nervous system:
  - CNS & PNS
- Autonomic Nervous System
  - Sympathetic Nervous System
  - Parasympathetic Nervous System
- Brain organization
  - General areas of brain
  - Brain hemispheres
  - Brain lobes
  - Brain mapping

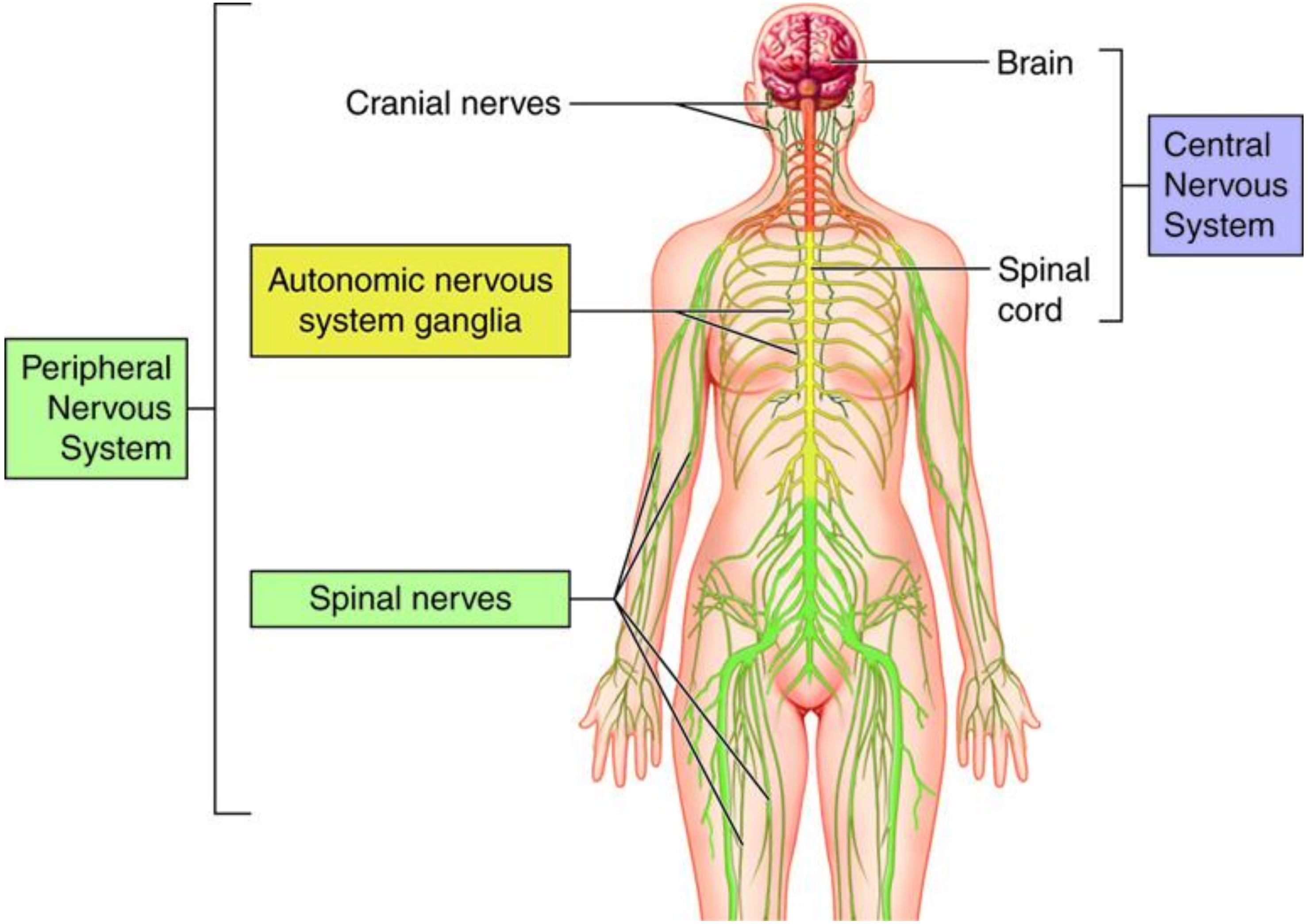
Description of nervous system

- Neurons are the main functional unit of this network. They can generate electrical signals to quickly transmit information over long distances and pass them on to many other neurons.
- Glial cells support this network by cleaning, regulating, protecting, healing and insulating the neurons and their connections.



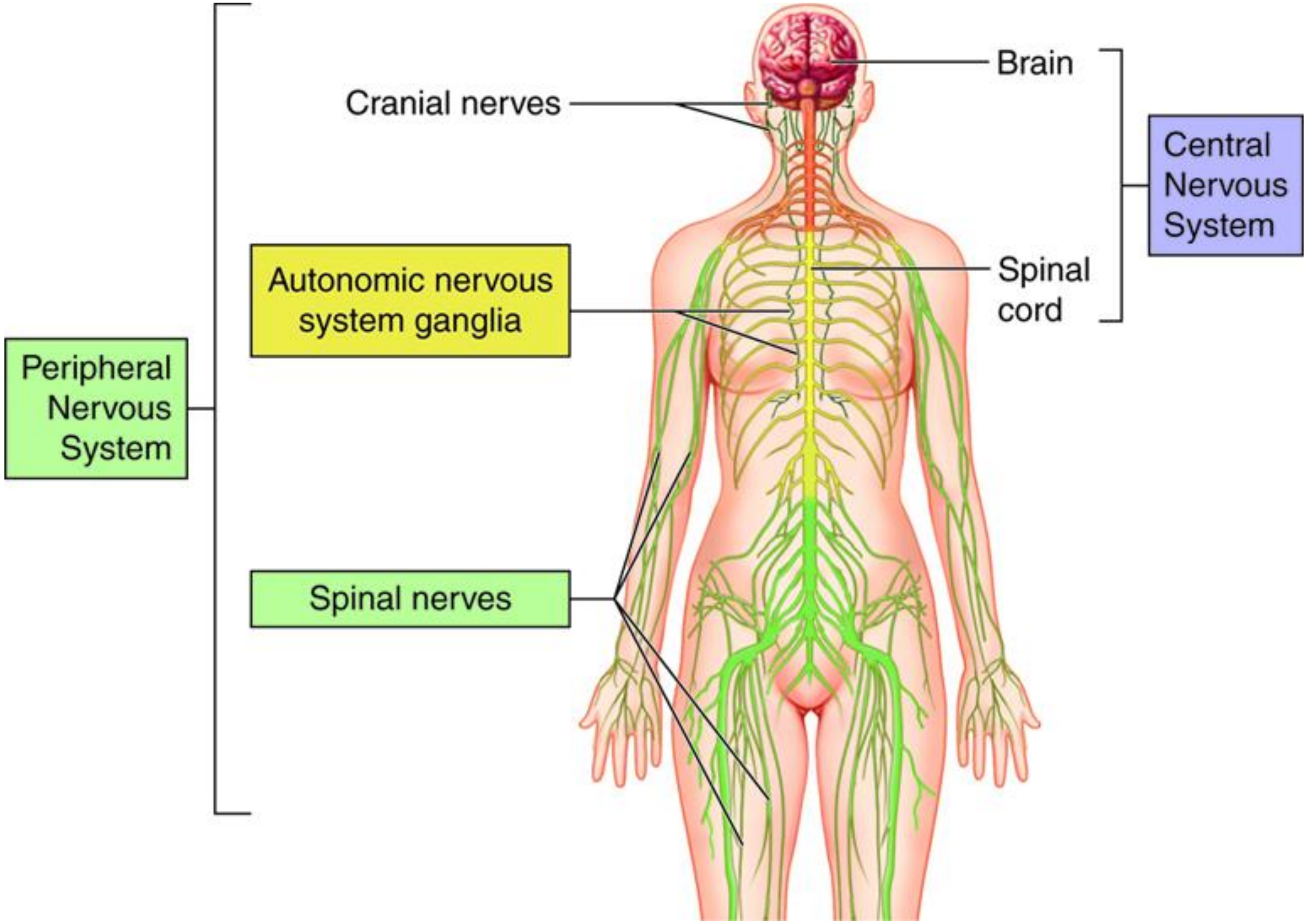
Nervous system

- The core of the nervous system, with over 100 trillion connections, is the human brain.
- Messages are relayed to the brain via the spinal cord, which runs down through the back and contains thread-like nerves that branch out to every organ and body part.



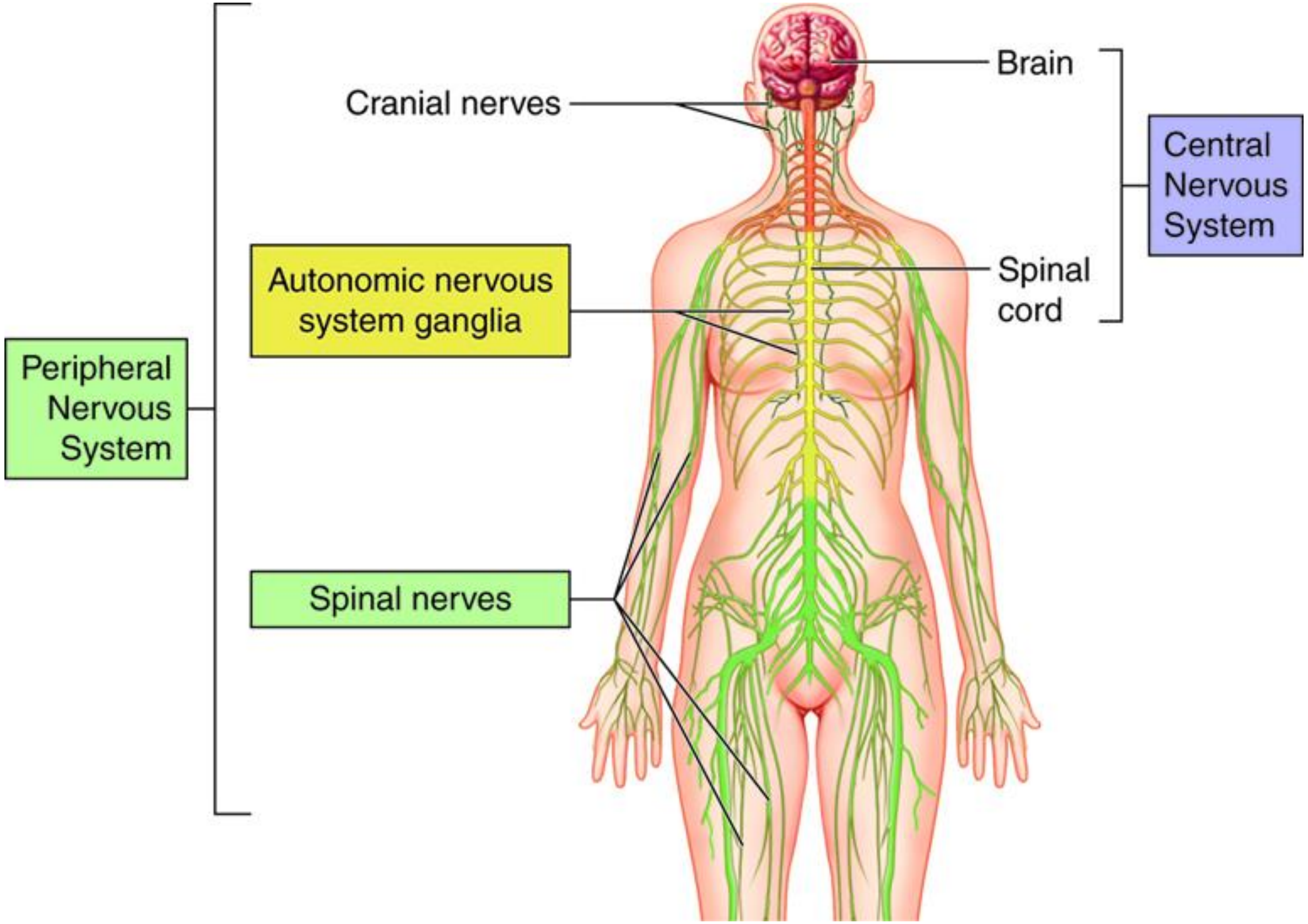
Central Nervous System (CNS)

- CNS is made of soft delicate tissue but it's well protected by the skull and spinal vertebrae.
- The blood-brain barrier also prevents many toxins from entering the brain.
- CNS acts as the control center, sending and receiving information to and from muscles, glands, organs and others systems in the body through the Peripheral Nervous System (PNS).



Peripheral Nervous System (PNS)

- PNS acts as a relay, transmitting information between the CNS and the rest of the body.
- Unlike the CNS, PNS is not protected by the vertebral column and skull, or by the blood–brain barrier, which leaves it exposed to toxins and mechanical injuries.



Peripheral Nervous System (PNS)

Sensory Division

- Also known as the afferent (conducting inwards) division, the sensory division receives sensory information from the body and sends it inwards to the CNS.

Motor Division

- Also knows as the efferent (conducting outwards) division, the motor division receives information from the CNS and sends it out to the body.

Somatic nervous system

- The somatic system relays information about most of the body’s conscious activity to and from the CNS.
- The somatic sensory receptors receive information from the senses and send it to the CNS while the somatic motor division sends information from the CNS to control the actions of the skeletal muscles.

Autonomic nervous system

- The autonomic nervous system primarily regulates involuntary or unconscious activity such as heart rate, breathing, pupil dilation, regulating glands and internal organs, blood pressure, digestion, and many other chemical processes that keep our body working.
- The autonomic sensory receptors receive information from these systems and send it to the CNS while the autonomic motor division sends information from the CNS to these systems.

Autonomic Nervous System

Sympathetic Nervous System

Parasympathetic Nervous System

Sympathetic nervous system (SNS)

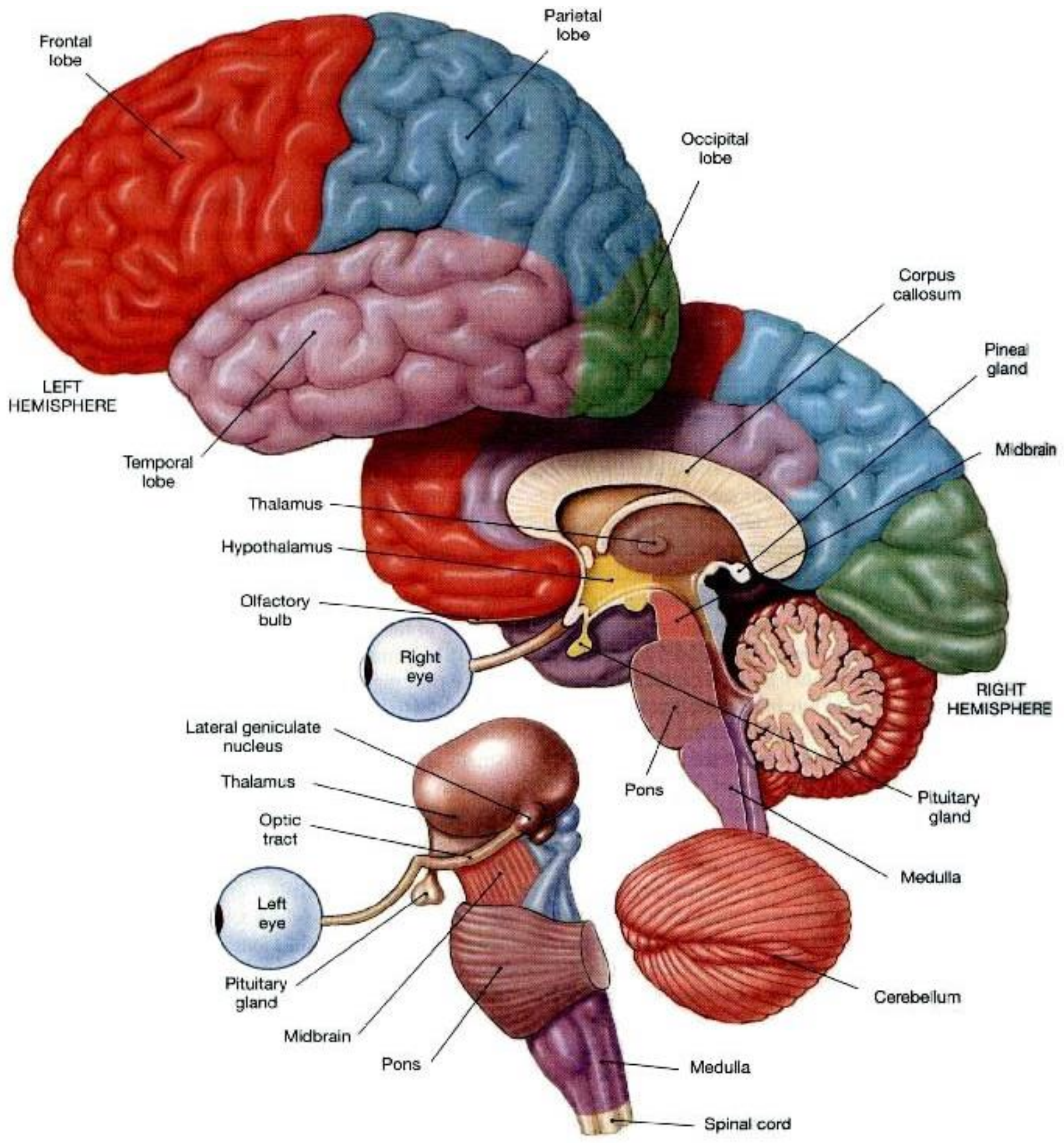
- SNS prepares the body to react and expend energy in times of stress.
- When a potentially threatening experience occurs, the body reacts with what has been called the “fight-or-flight” phenomenon.
- SNS quickens the heart rate and breathing to increase oxygen, dilates pupils for better vision, reduces digestion to conserve energy, and prepares the muscles of the body to either defend or escape.
- SNS is not only active for life-threatening situations; **a project deadline or an urgent email might be stressful enough to trigger it**.

Parasympathetic nervous system (PSNS)

- PSNS helps the body “rest-and-digest”, conserving energy and maintaining functions under ordinary conditions.
- PSNS slows the heart rate, stimulates digestion and other metabolic processes.
- PSNS is slow acting, unlike its counterpart, and may take several minutes or even longer to get the body back to a relaxed state after a stressful situation.

Brain organization

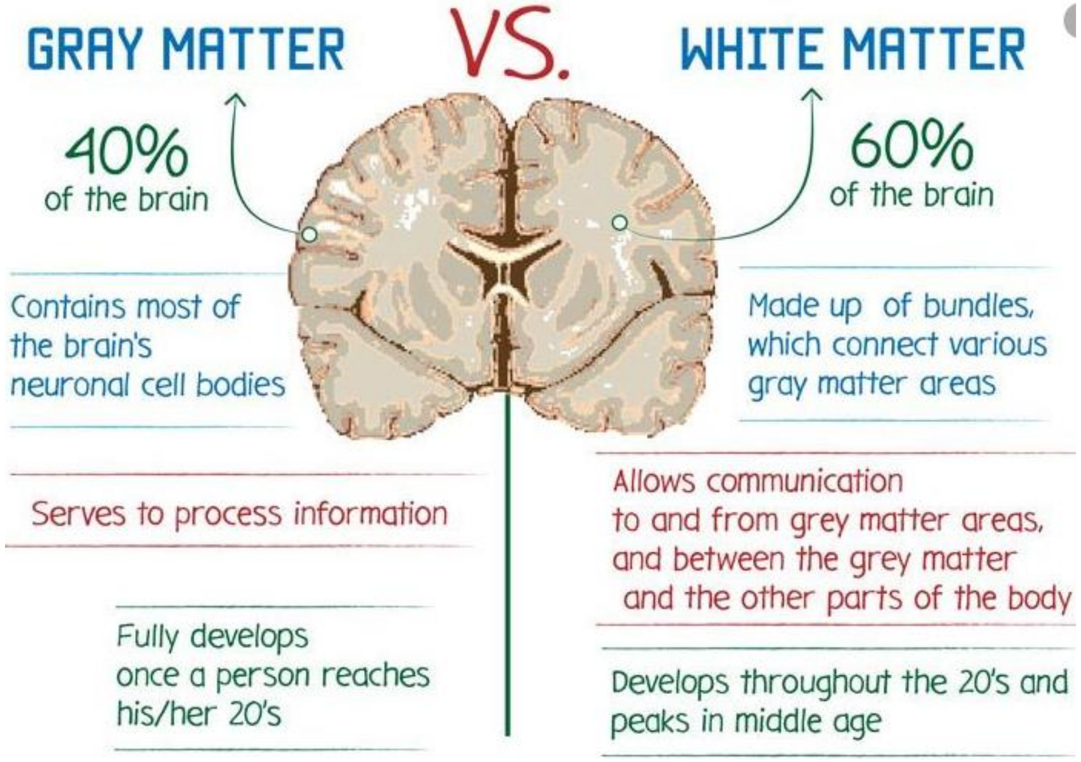
- One of the most fascinating and wondrous things in the universe exists within each of us: our brain.
- Our brain is uniquely structured with many sections and folds that provide it with enough surface area necessary to process and store all of the body’s important information.



The brain

- soma = cell body = grey matter
- axon = output = white matter

- collection of cell bodies = nucleus
- collection of axons = tract

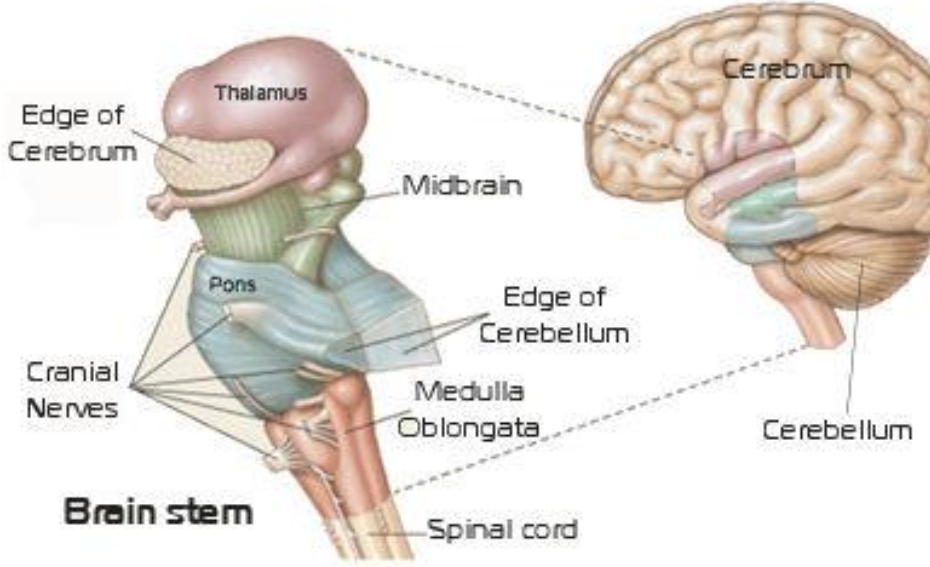


The brain

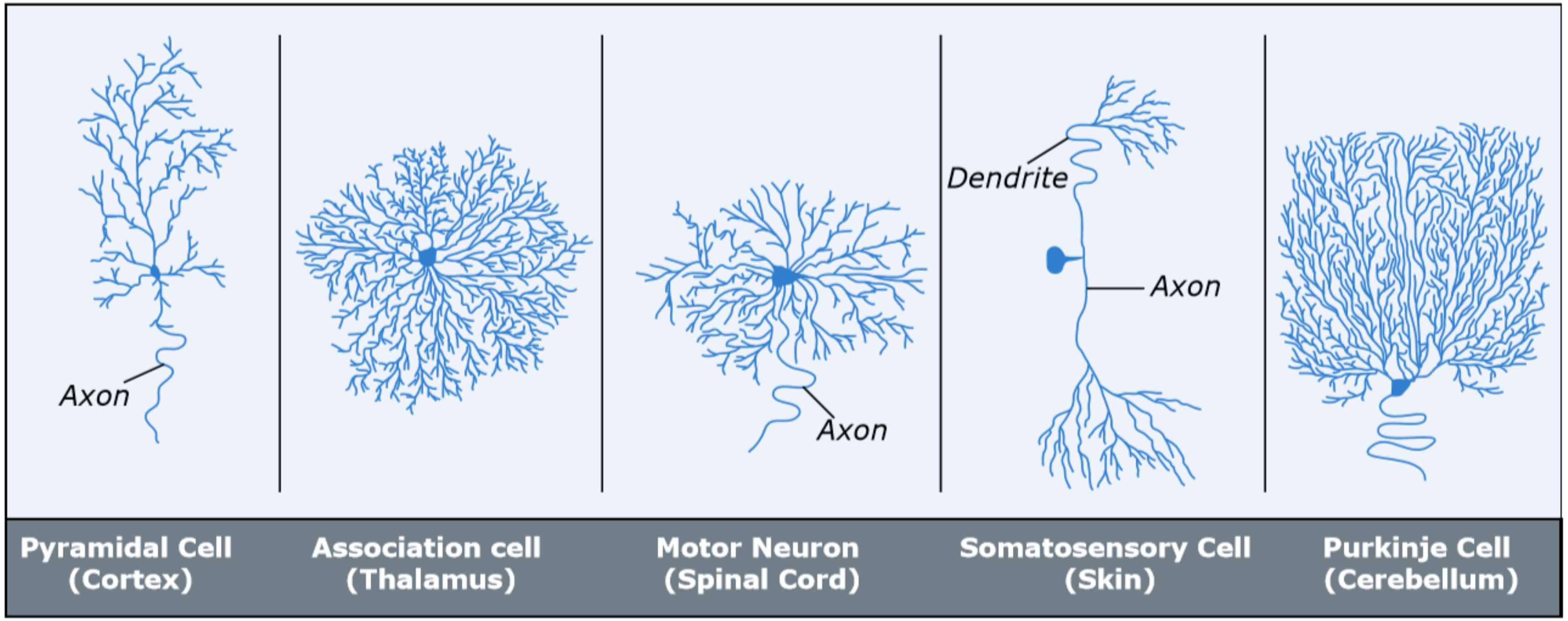
- CNS has about 1,000,000,000,000 (”Trillion”) neurons and 1,000,000,000,000,000 (“Quadrillion”) synapses; 62,000 miles of myelinated axons; 100,000 miles of dendrites
- Up to 15,000 connections per cell
  - average neuron may have about 1,000 synapses
  - average axon may synapse on about 1,000 neurons
- Each of the 100 billion neurons may have the processing capacity of a medium-sized computer - computes about 1000 multiplications and additions every 10 msec
- Time for information to go from one neuron to another about 10 msec - slower than millions of operations per second by fast computers - but billions of such neuronal computers yields massively parallel processing in the brain

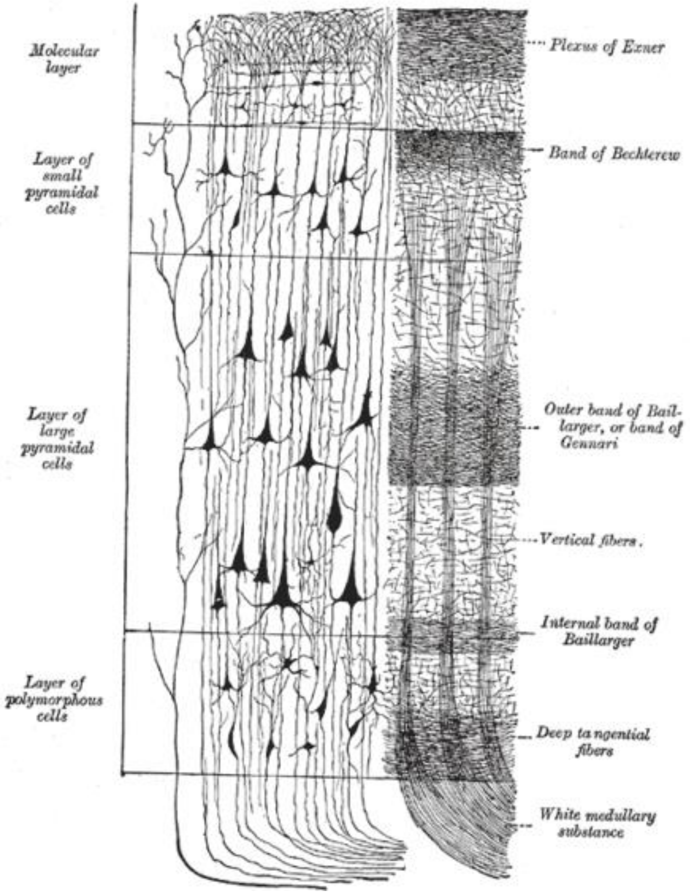
General areas of brain

- **The brainstem** is involved with autonomic control of processes like breathing and heart rate as well as conduction of information to and from the peripheral nervous system, the nerves and ganglia found outside the brain and spinal cord.
- **The cerebellum**, adjacent to the brainstem, is responsible for balance and coordination of movement.
- **The cerebral cortex** quickly perceives, analyzes, and responds to information from the world around us. It handles sensory perception and processing as well as higher-level cognitive functions like perception, memory, and decision-making.



Different kinds of neurons



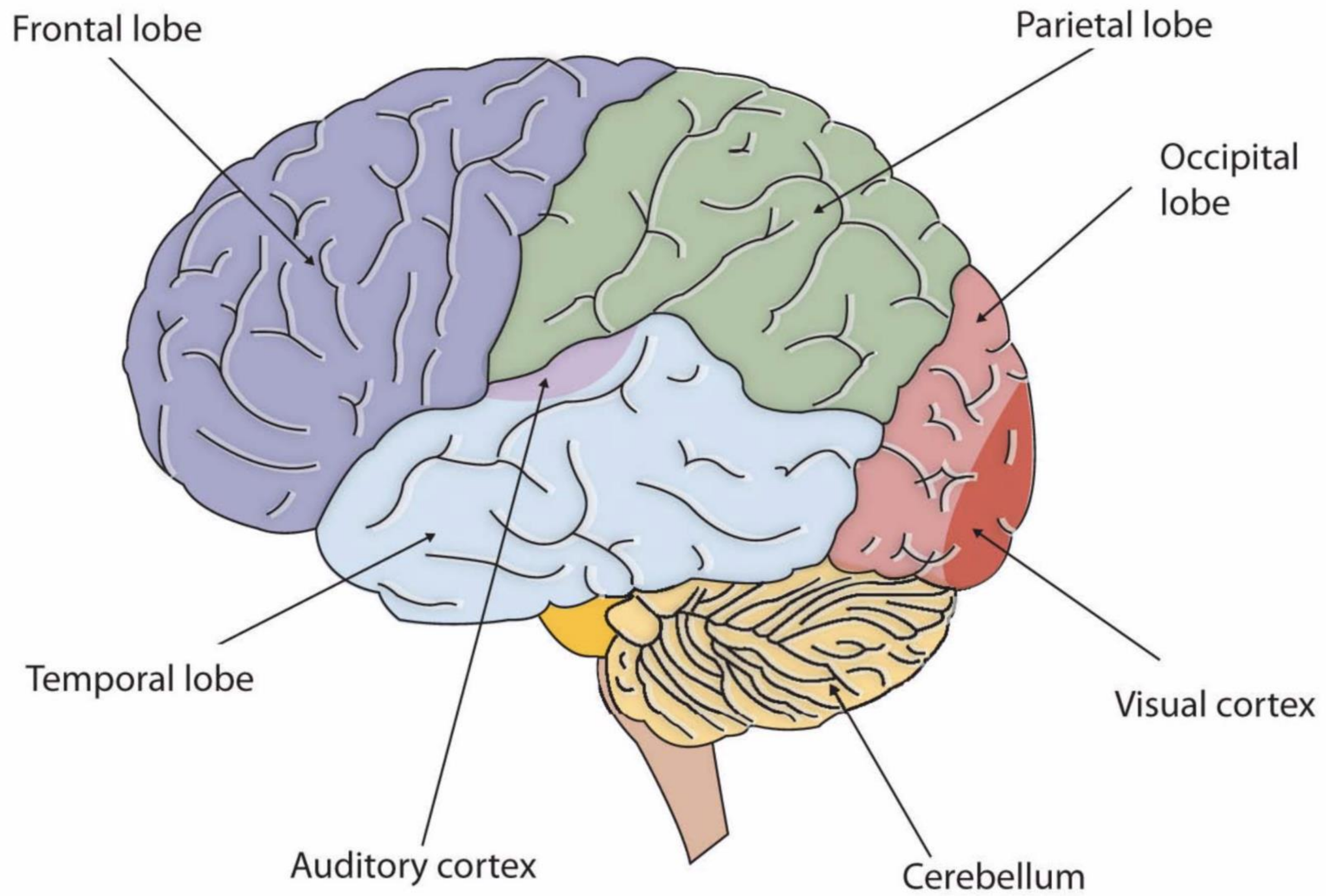


Brain hemispheres

- The cerebral cortex is divided into two hemispheres connected by the **corpus callosum**, a bridge of wide, flat neural fibers that act as communication relays between the two sides.
- The exception is language - both **Broca’s Area**, an area important to language syntax, and **Wernicke’s Area**, a region critical to language content, reside on the left side of the brain.
- Otherwise, the most cognitive processes are represented by activation in both hemispheres.

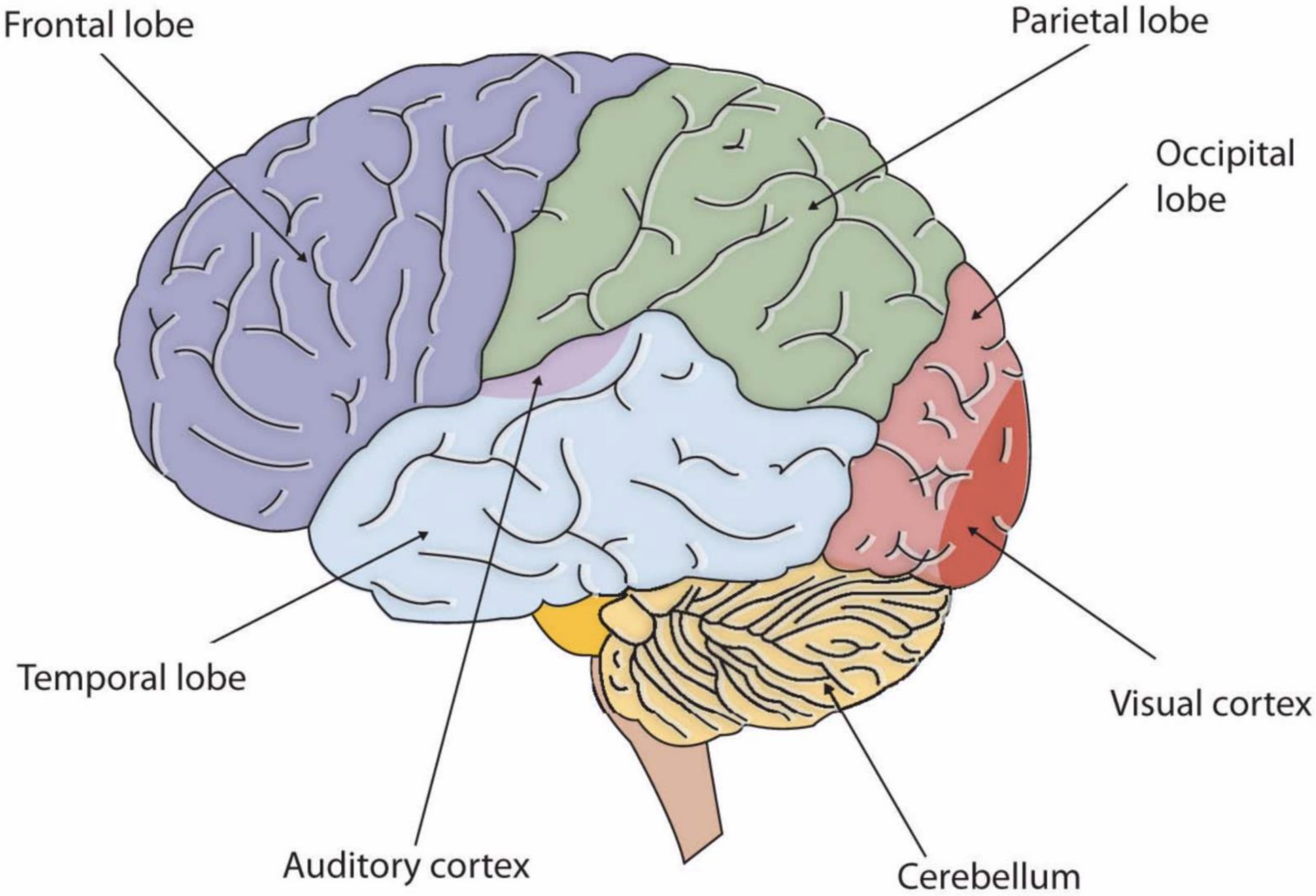
Brain lobes

- Four lobes are used to denote specific anatomical locations within the brain: Frontal Lobe, Occipital Lobe, Parietal Lobe, and Temporal Lobe.
- These lobes, or anatomical locations of the brain, are referred to when examining different brain functions.



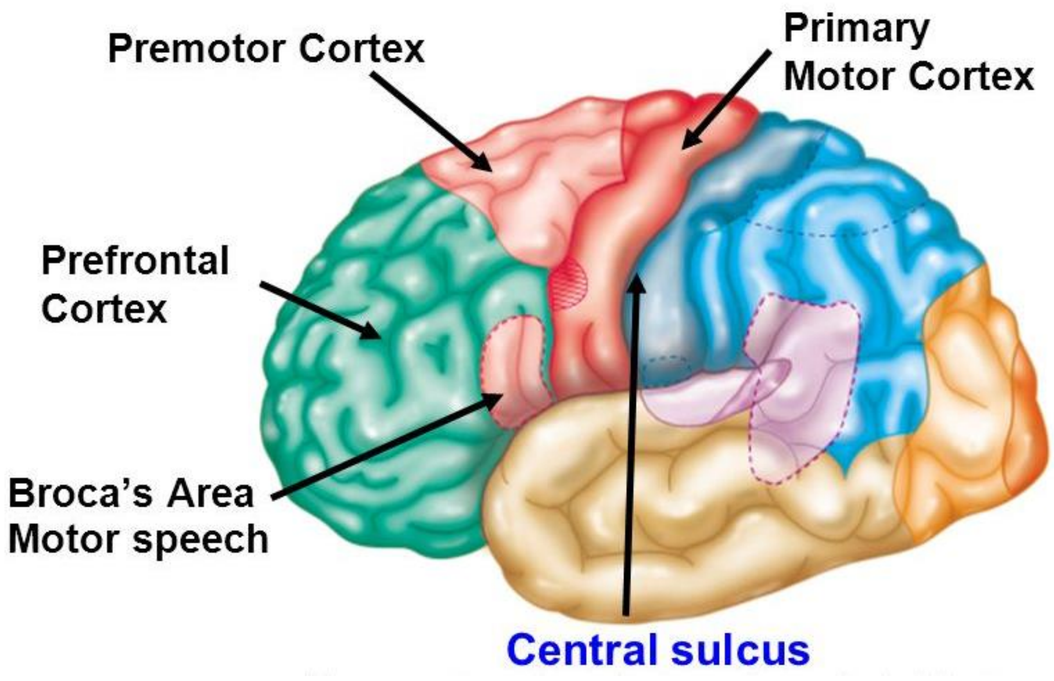
Frontal lobe

- It is the control center for executive functions including reasoning, decision-making, expressive language, higher level cognitive processes, orientation (person, place, time, and situation integration of sensory information), and the planning and execution of movement, or motor behavior



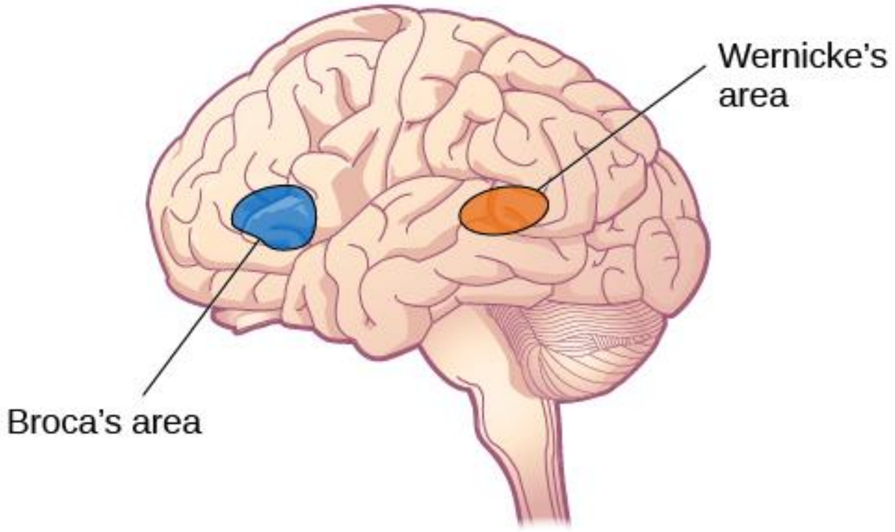
Frontal lobe

- It contains the **motor cortex**, which is involved in planning and coordinating movement;
  the **prefrontal cortex**, which is responsible for higher-level cognitive functioning; and **Broca's area**, which is important for language production.



Broca’s and Wernicke’s areas

- **Broca’s area** is essential for language production.
- **Wernicke’s area** is important for speech comprehension
- Whereas subjects with damage to Broca’s area have difficulty producing language, those with damage to Wernicke’s area can produce sensible language, but they are unable to understand it.

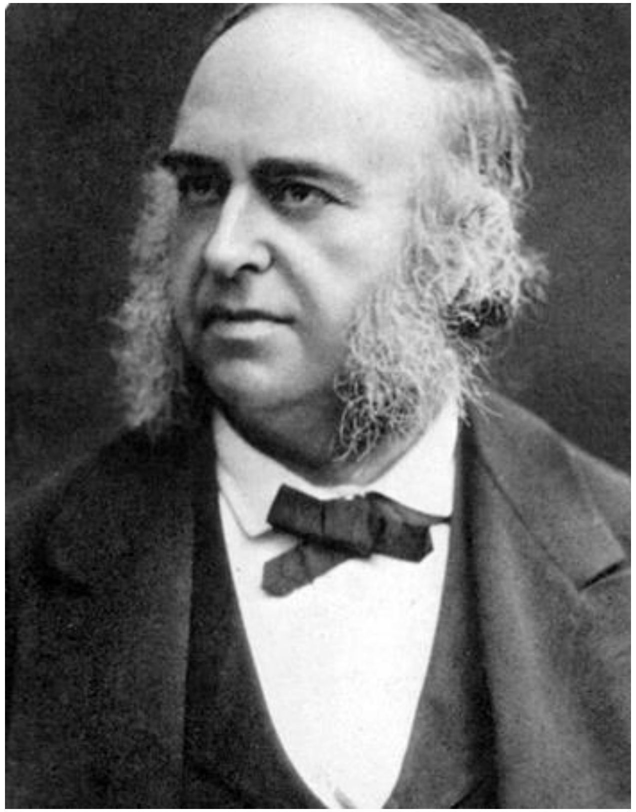


Damage to either Broca’s area or Wernicke’s area can result in language deficits. The types of deficits are very different, however, depending on which area is affected.

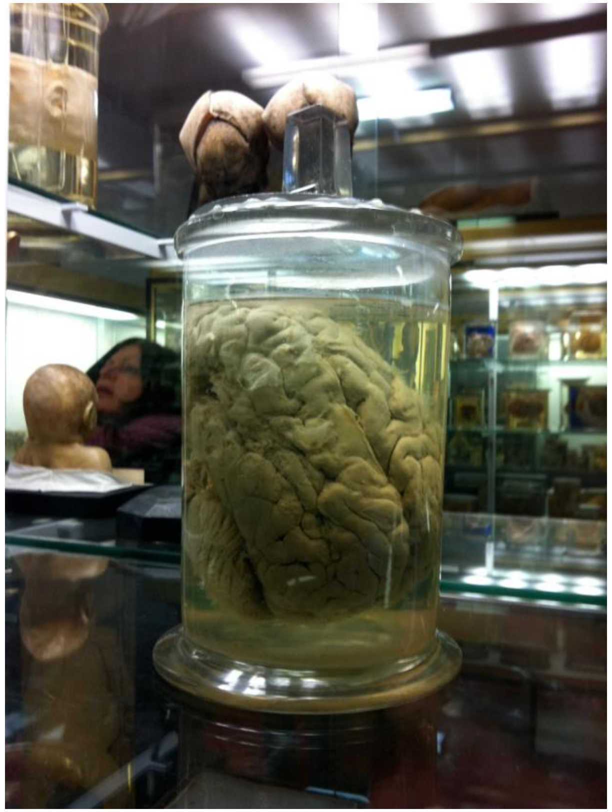
Brain mapping

- One of the first ways to map the brain is through natural injuries that allow you to compare different functions with areas of the brain.
- The loss of some function corresponds to damage to the corresponding part of the brain and vice versa
- **Jean Baptiste Bouillaud (1796-1881) argued for left-sided control of speech in 1825**
- **Marc Dax in 1836 reported that in a series of cases disorders of speech followed left hemisphere lesions - published by his son in 1865**
- **Ernest Auburtin reported to the Anthropological Society of Paris in 1861 a case "who had lost his speech but understood everything said to him . . . his intelligence is still unimpaired, and speech is wholly abolished... based on the symptoms that he presents, we have diagnosed softening of the anterior lobes**

Paul Broca (1824-1880)



Paul Broca was a French physician, anatomist and anthropologist



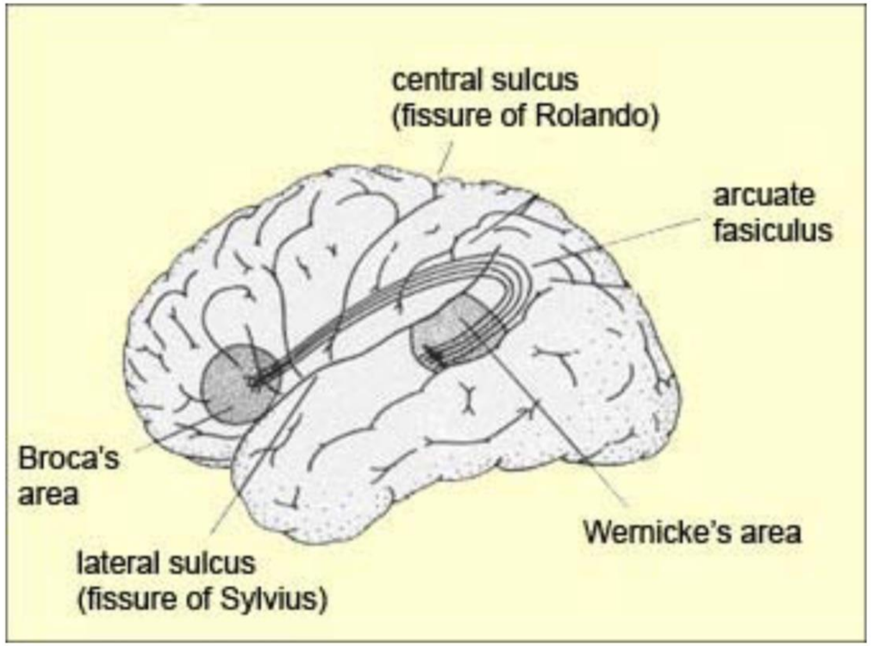
Mr. Tan's brain

Broca studied a patient, who had a 21-year progressive loss of speech and paralysis but not a loss of comprehension nor mental function

After his death, Broca performed an autopsy. He determined that, Mr Tan did in fact have a lesion in the frontal lobe in one of the cerebral hemispheres, which in this case turned out to be the left.

Broca’s aphasia

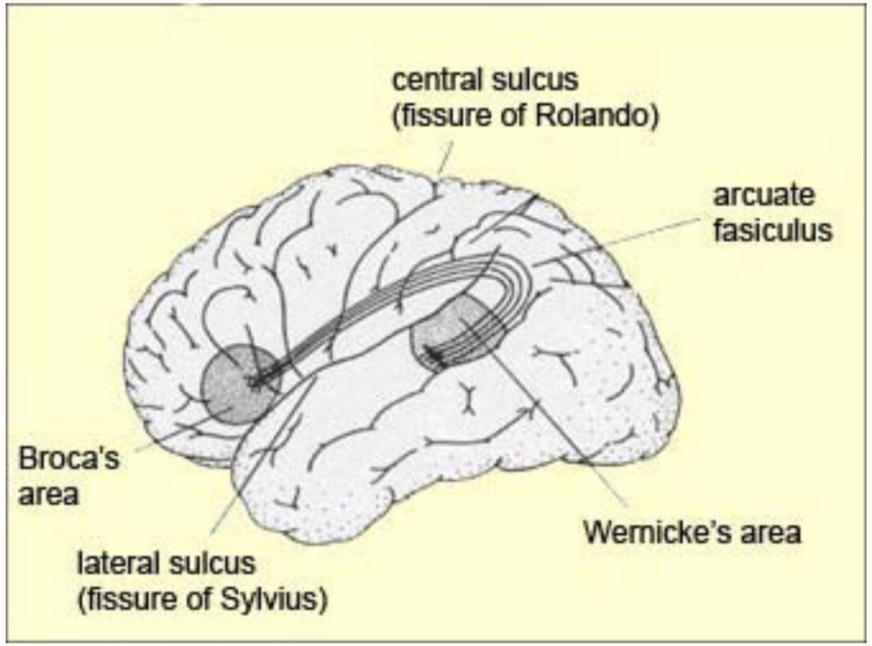
- **inabilty to speak despite presence of intact vocal mechanisms and normal comprehension**



Broca’s Area:

- **language processing**
- **speech production and comprehension**

Broca’s aphasia



- **results from damage to Broca’s Area (e.g., lesions)**
- **unable to create grammatically complex sentences**
- **speech described as telegraphic, contains content words only**
- **comprehension is relatively normal**

Frontal lobe damage

- The most famous case of frontal lobe damage is that of a man by the name of Phineas Gage.
- On September 13, 1848, Gage (age 25) was working as a railroad foreman in Vermont. He and his crew were using an iron rod to tamp explosives down into a blasting hole to remove rock along the railway’s path. Unfortunately, the iron rod created a spark and caused the rod to explode out of the blasting hole, into Gage’s face, and through his skull

Case of Phineas Gage

- Despite severe damage, Gage was conscious and able to get up, walk, and speak.
- But in the months following his accident, people noticed that his personality had changed. Many of his friends described him as no longer being himself. Before the accident, it was said that Gage was a well-mannered, soft-spoken man, but he began to behave in odd and inappropriate ways after the accident.
- Such changes in personality would be consistent with loss of impulse control—a frontal lobe function.

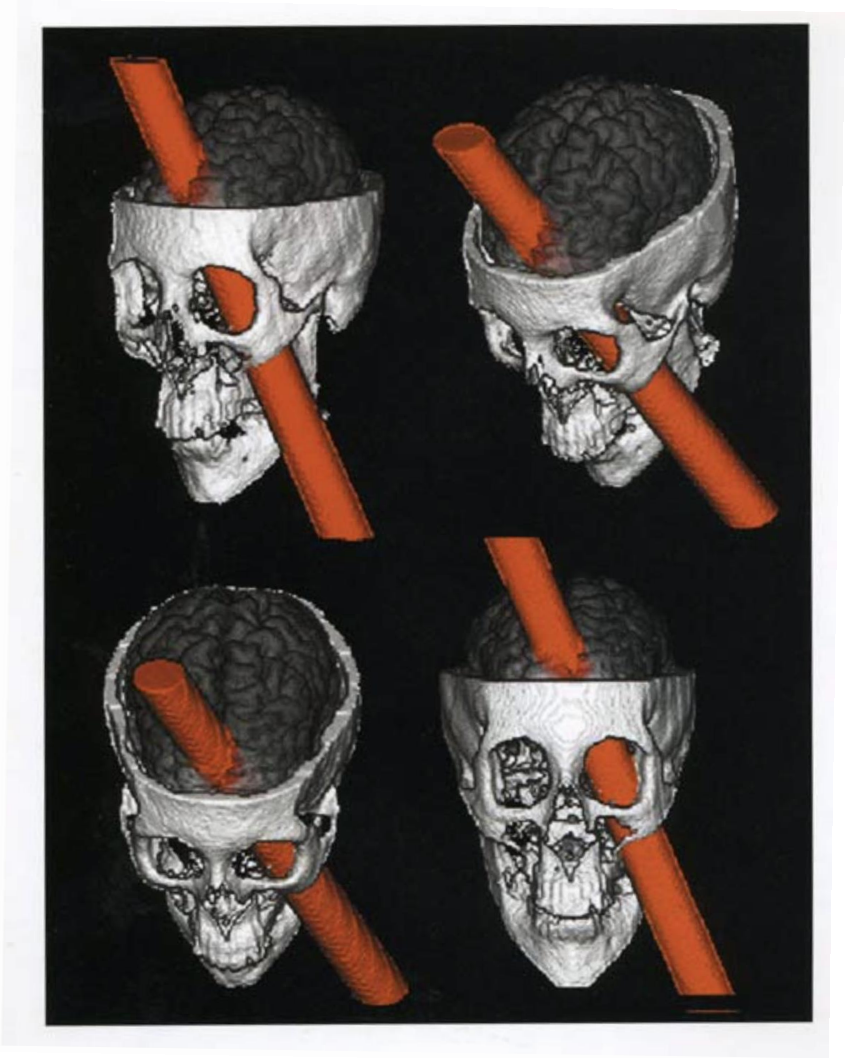
(a)

(b)

(a) Phineas Gage holds the iron rod that penetrated his skull in an 1848 railroad construction accident. (b) Gage's prefrontal cortex was severely damaged in the left hemisphere. The rod entered Gage's face on the left side, passed behind his eye, and exited through the top of his skull, before landing about 80 feet away

Case of Phineas Gage

- Beyond the damage to the frontal lobe itself, subsequent investigations into the rod’s path also identified probable damage to pathways between the frontal lobe and other brain structures, including the limbic system.
- With connections between the planning functions of the frontal lobe and the emotional processes of the limbic system severed, Gage had difficulty controlling his emotional impulses.



Computer generated model plotting path of tamping iron (shown in red) through Gage’s frontal cortex
FROM: Damasio, H., et al. "The Return of Phineas Gage: Clues About the Brain from the Skull of a Famous Patient." Science 264, no. 5162 (1994): 1102-5

Lobotomy

- A lobotomy is a form of psychosurgery, a neurosurgical treatment of a mental disorder that involves severing connections in the brain's prefrontal cortex.
- Most of the connections to and from the prefrontal cortex, the anterior part of the frontal lobes of the brain, are severed.
- It was used for psychiatric and occasionally other conditions as a mainstream procedure in some Western countries for more than two decades, despite general recognition of frequent and serious side effects.

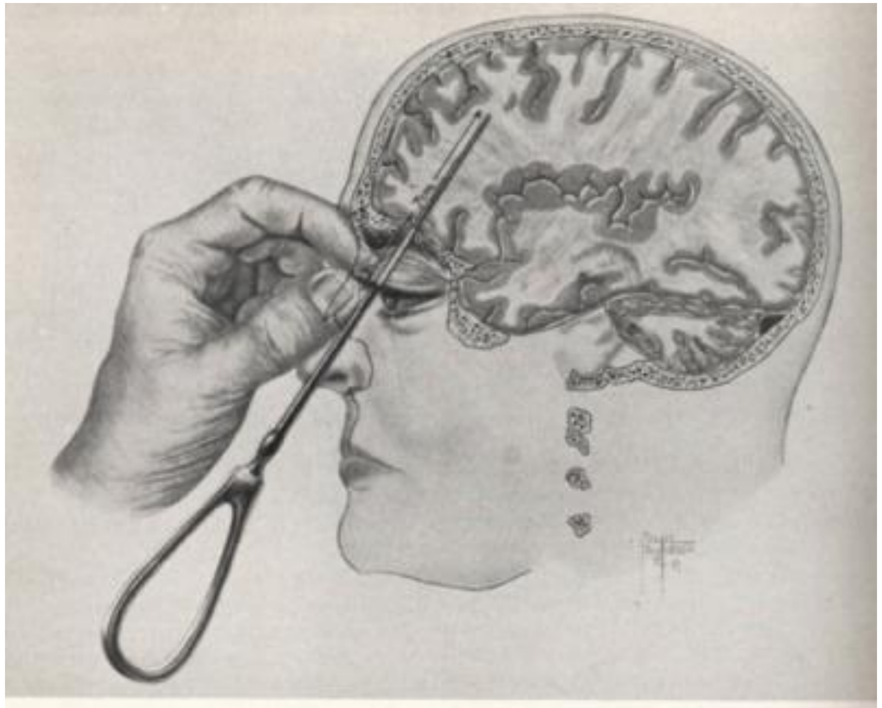
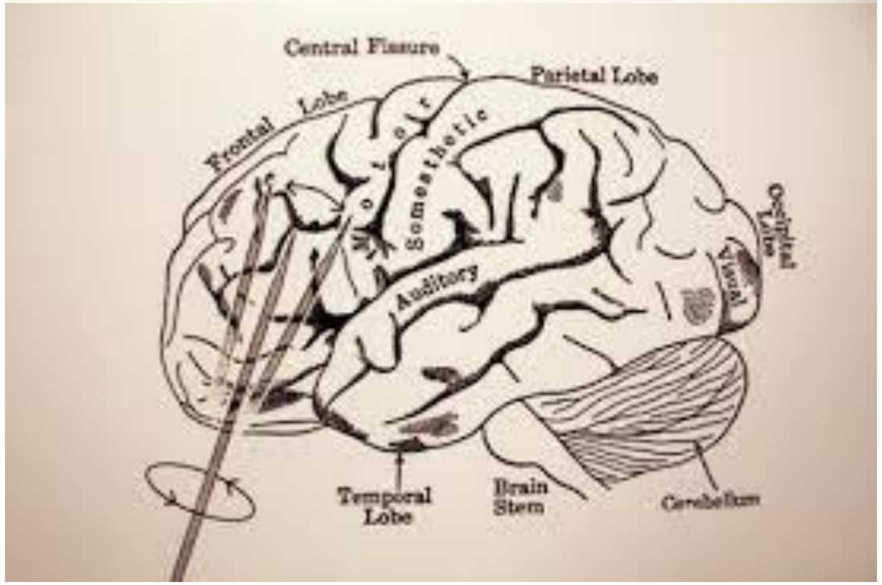
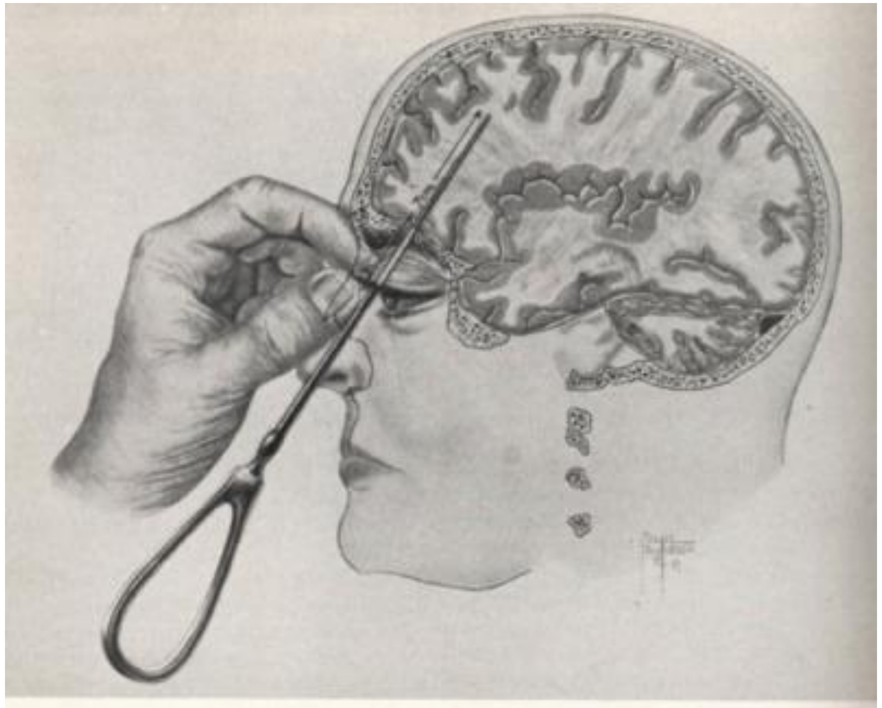


Fig. 4.—Phantom drawing showing instrument penetrating between eyeball and upper eyelid, through orbital plate into white matter in frontal lobe.



Lobotomy

- While some people experienced symptomatic improvement with the operation, the improvements were achieved at the cost of creating other impairments.
- The procedure was controversial from its initial use in part due to the balance between benefits and risks.
- Today, lobotomy has become a disparaged procedure, a byword for medical barbarism and an exemplary instance of the medical trampling of patients' rights.



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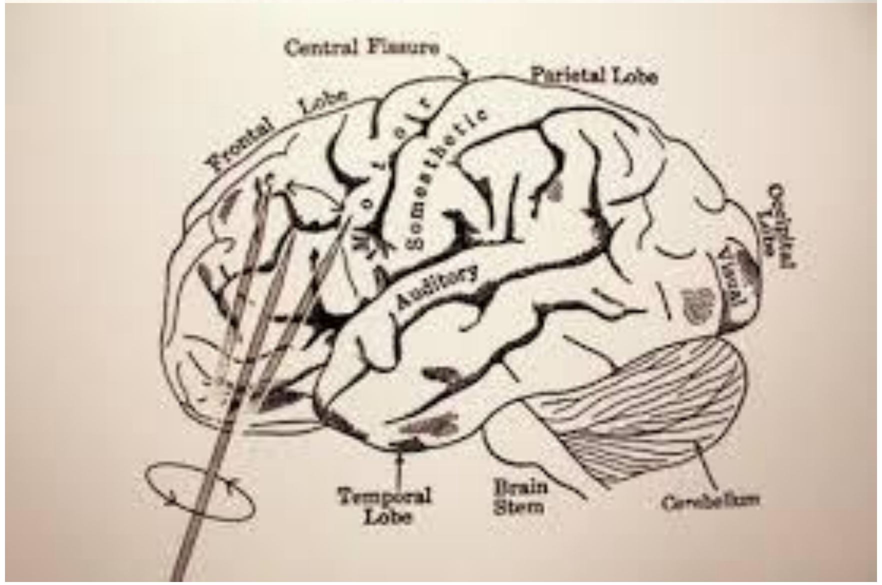


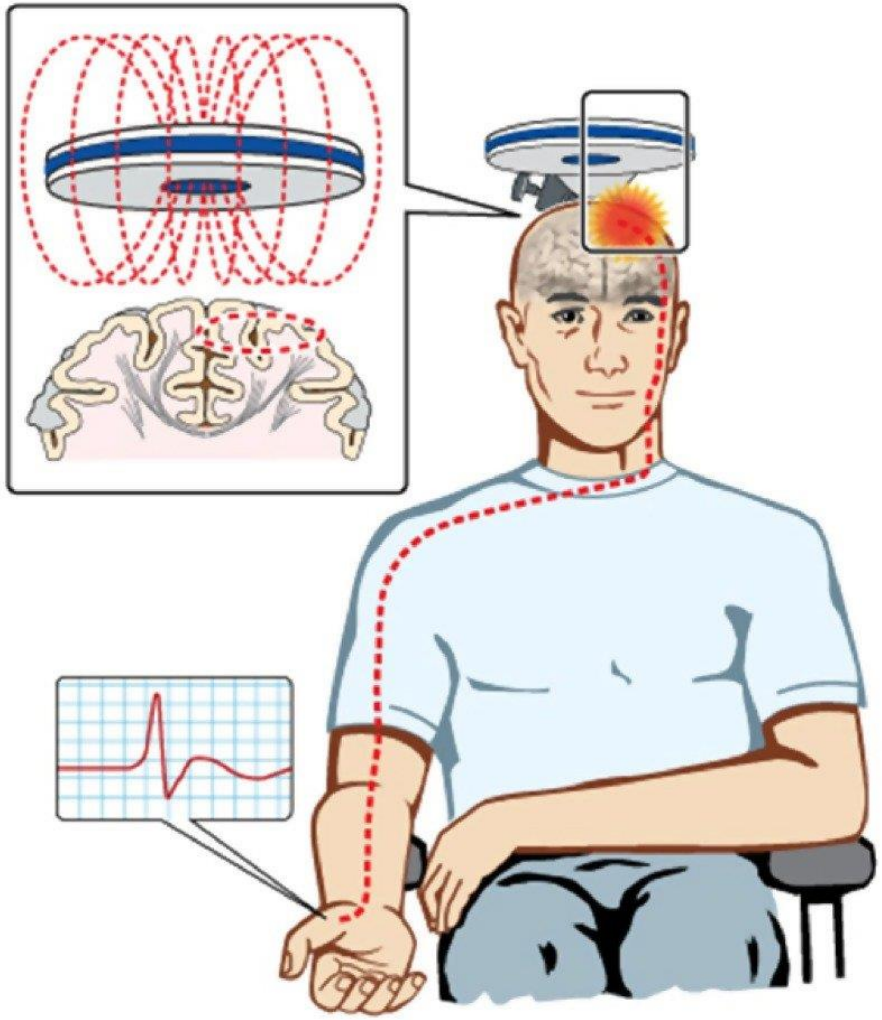
Lobotomy: Nobel Prize

- The originator of the procedure, Portuguese neurologist António Egas Moniz, shared the Nobel Prize for Physiology or Medicine of 1949 for the "discovery of the therapeutic value of leucotomy in certain psychoses", although the awarding of the prize has been subject to controversy.

Transcranial magnetic stimulation

- Transcranial magnetic stimulation (TMS) is a noninvasive procedure that uses magnetic fields to stimulate nerve cells in the brain

- The human motor cortex can be mapped safely and painlessly with transcranial magnetic stimulation (TMS)



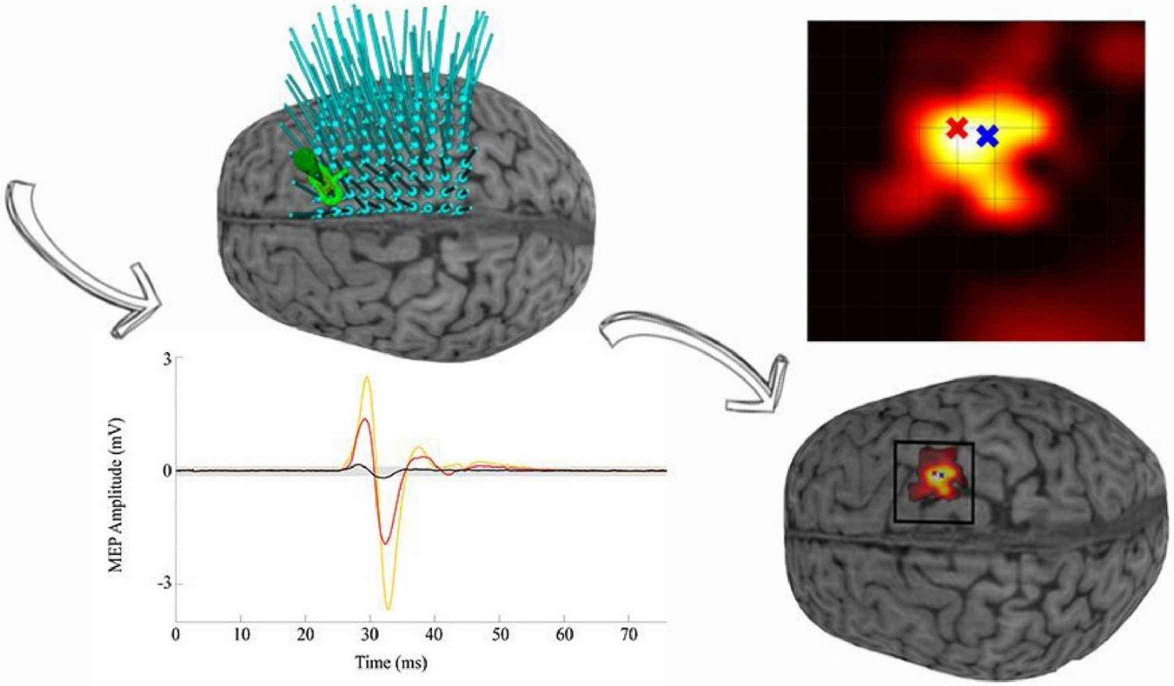
TMS coil placed over the vertex activates the primary motor cortex and the response (motor evoked potential, MEP) is recorded from the contralateral abductor muscle.

Robotic transcranial magnetic stimulation

The system automatically aligned the TMS coil to target sites in 3 dimensions with near-perfect coil orientation and real-time head motion correction. Motor maps of 4 forelimb muscles were derived bilaterally by delivering single-pulse TMS at predefined, uniformly spaced trajectories across a 10 × 10 grid (7 mm spacing) customized to the participant’s MRI.

Magnetic resonance imaging was performed and brain reconstructions were paired with the robotic TMS system

FROM: Journal of Neuroscience Methods, 309 (2018) 41-54

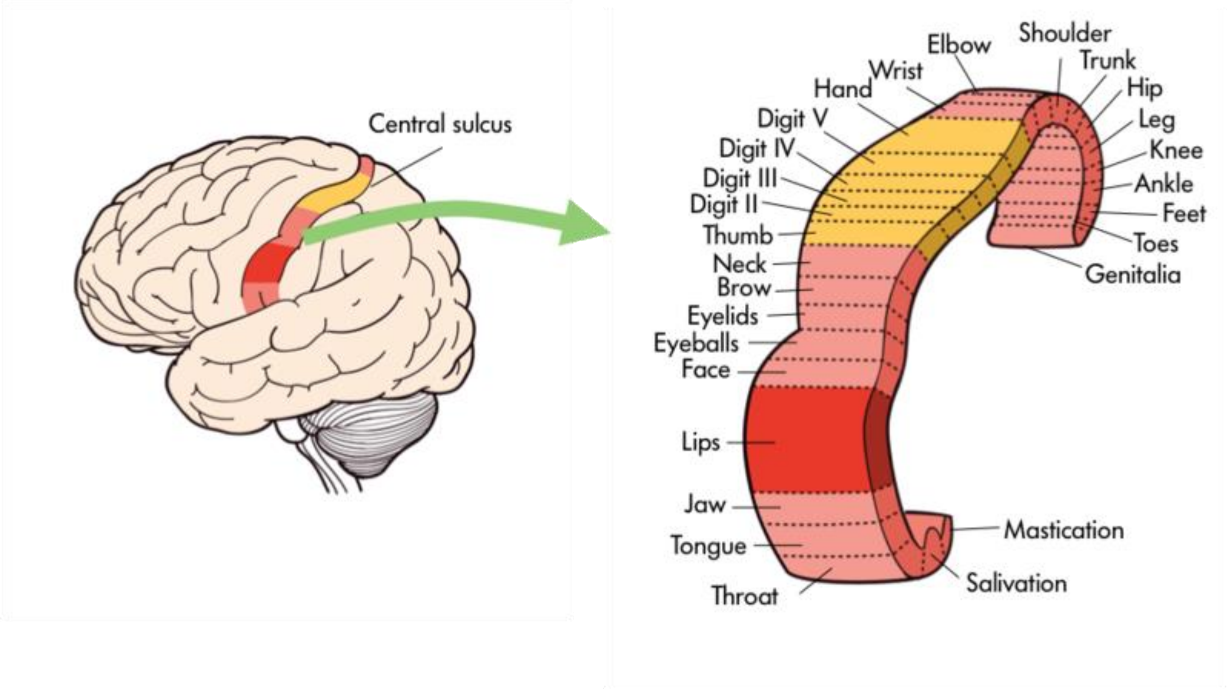


Cerebral cortex development

- Because the cerebral cortex in general, and the frontal lobe in particular, are associated with such sophisticated functions as planning and being self-aware they are often thought of as a higher, less primal portion of the brain.
- Other animals such as rodents while they do have frontal regions of their brain do not have the same level of development in the cerebral cortices.
- The closer an animal is to humans on the evolutionary tree — the more developed is this portion of their brain.

Primary motor cortex

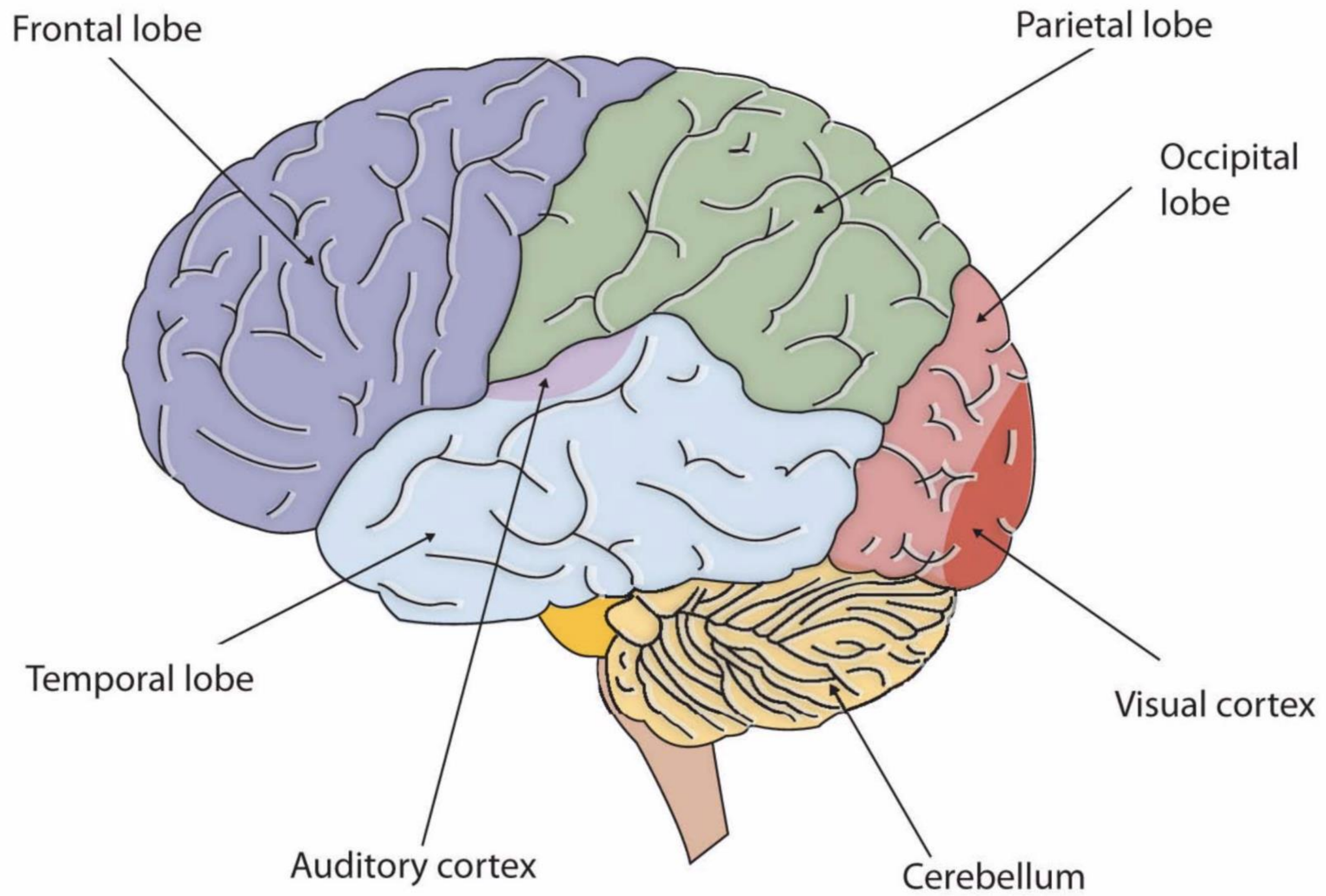
- This strip running along the side of the brain is in charge of voluntary movements like waving goodbye, wiggling your eyebrows, and kissing.
- The various regions of the brain are highly specialized.
- Each of our various body parts has a unique portion of the primary motor cortex devoted to it.
- Each individual finger has about as much dedicated brain space as your entire leg.



Specific body parts like the tongue or fingers are mapped onto certain areas of the brain including the primary motor cortex.

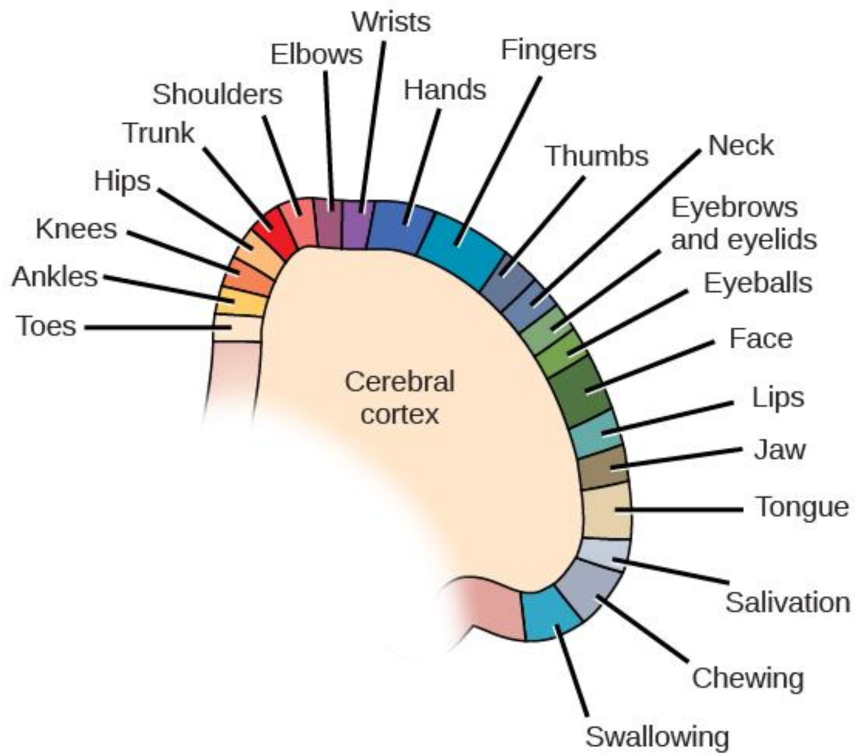
Parietal lobe

- The parietal lobe houses the somatosensory cortex and plays an important role in touch and spatial navigation, including the processing of touch, pressure, temperature, and pain.



Somatosensory cortex

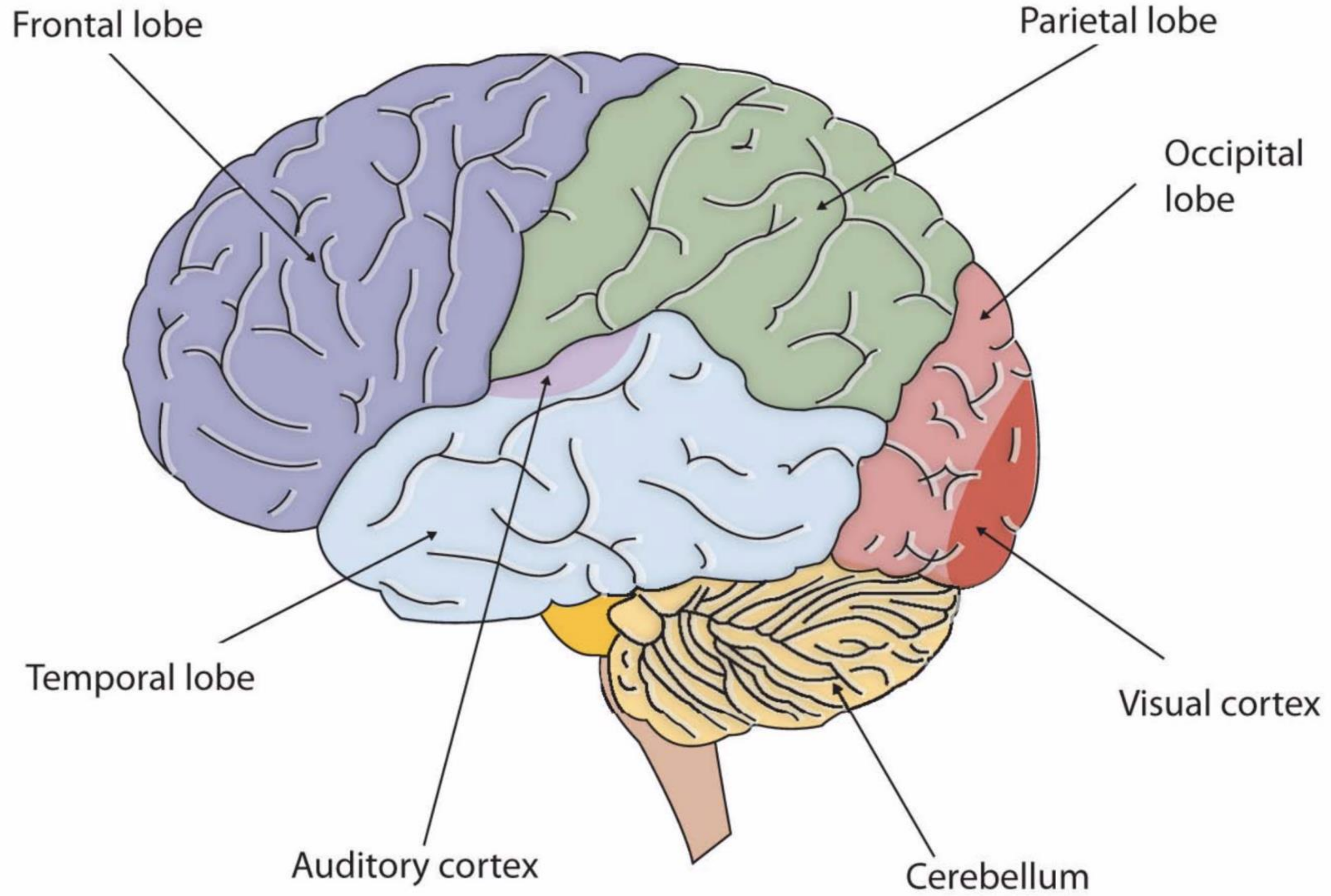
- Parietal lobe contains the **somatosensory cortex**, which is essential for processing sensory information from across the body, such as touch, temperature, and pain.
- The somatosensory cortex is organized topographically, which means that spatial relationships that exist in the body are maintained on the surface of the somatosensory cortex.



Spatial relationships in the body are mirrored in the organization of the somatosensory cortex.

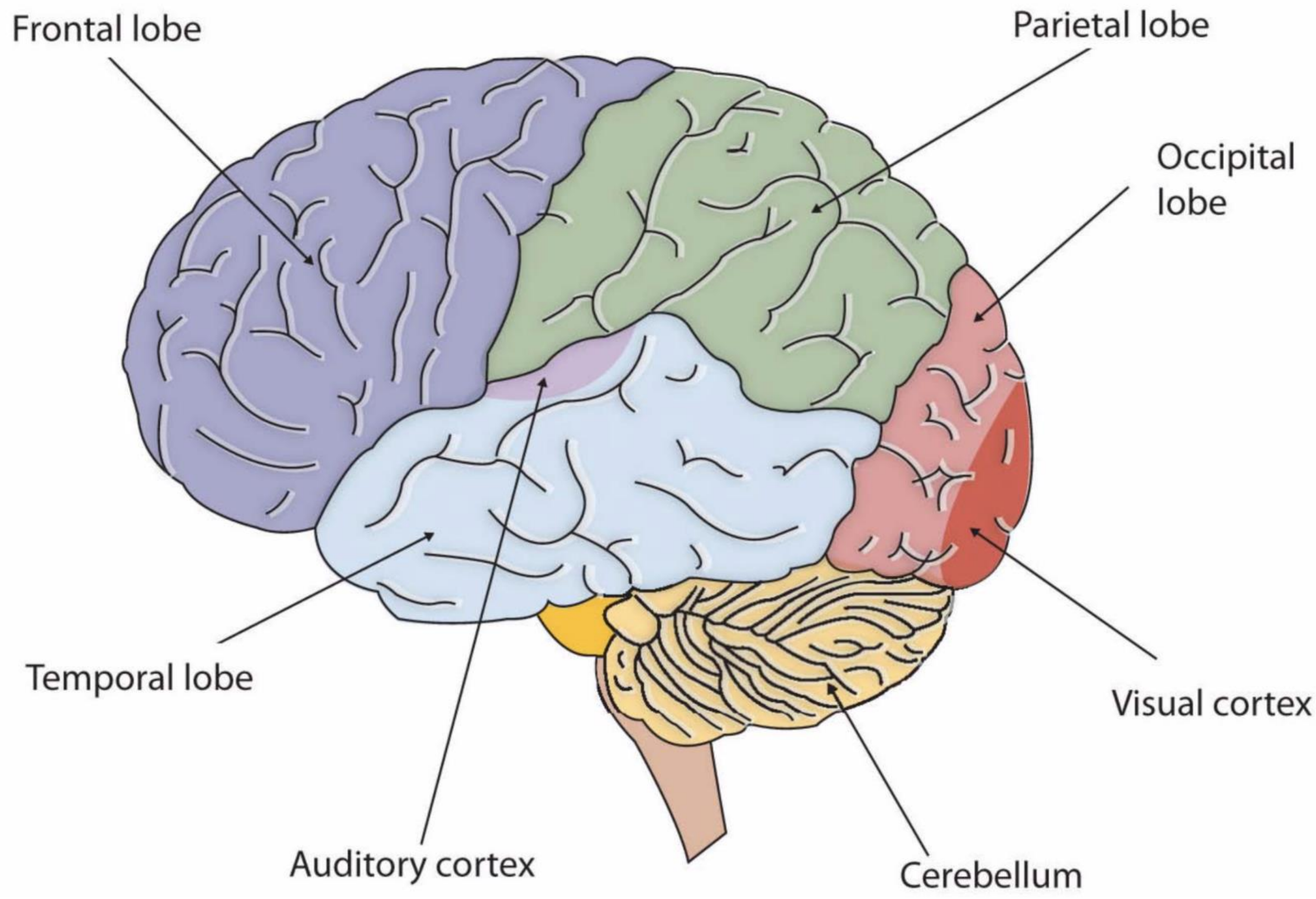
Temporal lobe

- The temporal lobe is a major processing center for receptive language, memory and emotion.
- For example, language processing areas - both Broca's Area, an area important to language syntax, and Wernicke's Area, a region critical to language content - reside on the left side of the brain in parietal lobe.



Occipital lobe

- The occipital lobe, located at the back of the brain, is the control center for the primary visual cortex, the brain region responsible for processing and interpreting visual information.



Example: visual system

- The lateral geniculate nucleus (LGN) is a relay center in the thalamus for the visual pathway.
- It receives a major sensory input from the retina. The LGN is the main central connection for the optic nerve to the occipital lobe, particularly the primary visual cortex.
- In humans, each LGN has six layers of neurons (grey matter) alternating with optic fibers (white matter).