

Introduction to Neurophysiology 1

Organization and functions of the nervous system

Fatima Ryalat, MD, PhD

Assistant Professor, Physiology and Biochemistry Department,
School of Medicine, The University of Jordan



Edited by: Abdelhadi
Okasha



Overview of the nervous system

- The nervous system is composed of two divisions:
- The central nervous system (CNS), which includes the brain and the spinal cord.
- The peripheral nervous system (PNS), which includes sensory receptors, nerves, and ganglia.

Organization of the nervous system

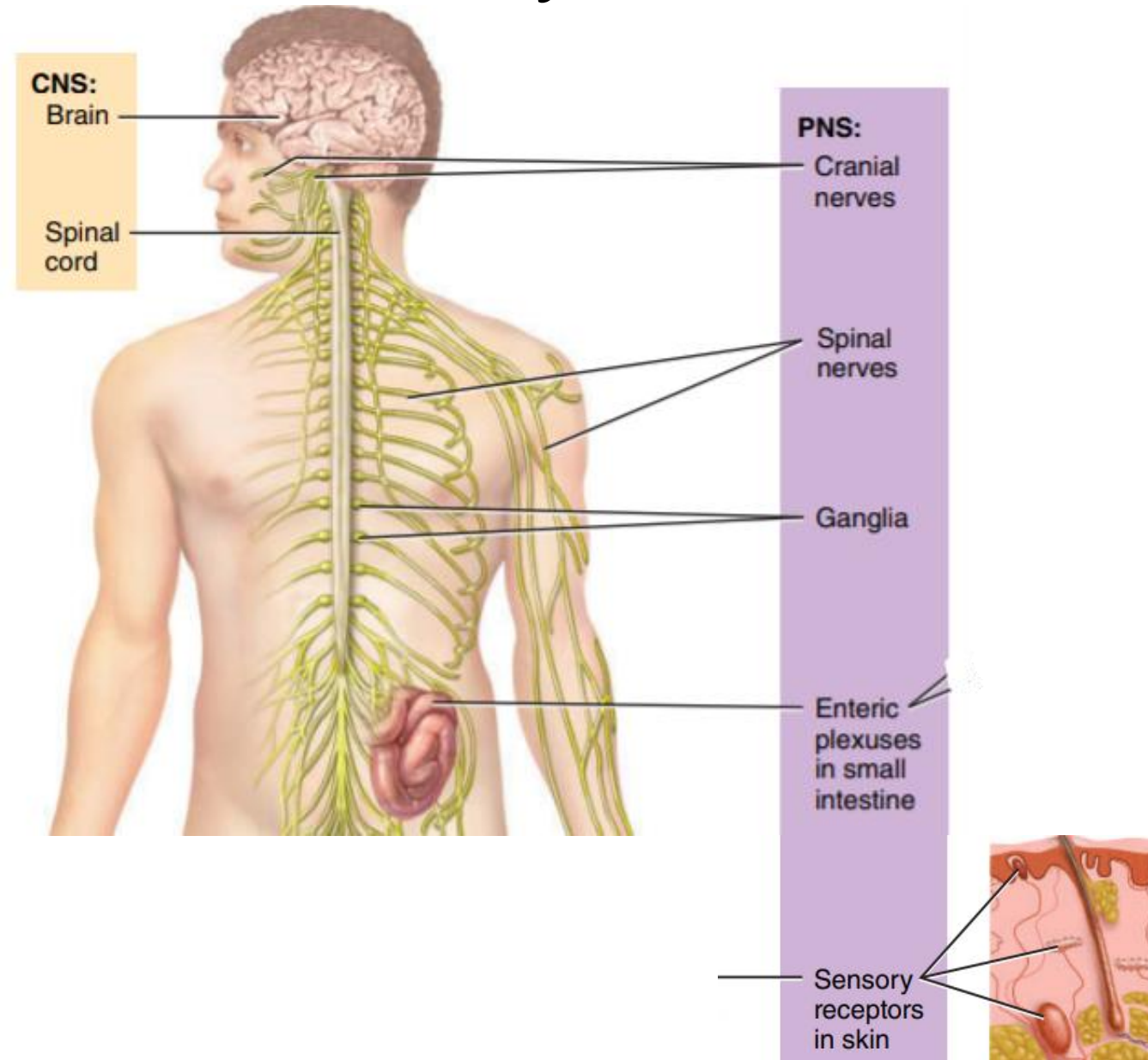
The nervous system is subdivided into two main components:

1. Central Nervous System (CNS)

- Composed of the **brain** and **spinal cord**.

2. Peripheral Nervous System (PNS)

- Includes **spinal nerves** and **ganglia**.



Functions of the nervous system

- **Sensory function:** sensory receptors detect internal or external stimuli. The sensory information is carried to the CNS through cranial and spinal nerves.
- **Integrative function:** process sensory information by analyzing it and making decision for appropriate responses.
- **Motor function:** activation of effectors (muscles and glands) through cranial and spinal nerves.

Functions of the nervous system

- **Sensory function:** sensory receptors detect internal or external stimuli. The sensory information is carried to the CNS through cranial and spinal nerves.
- **Sensation** is the process of becoming aware of changes in the environment. It's important to understand that the term “environment” refers to both:
 - The **external environment** around the body, and
 - The **internal environment** inside the body.
- Changes may occur in either domain. For example:
 - **External changes** might include:
 - Temperature fluctuations
 - Touch or pressure on the skin
 - Light entering the eye

- Each type of change—called a **stimulus**—has a specific **modality** (e.g., light, temperature, pressure).

To detect each specific modality, the body uses specialized **sensory receptors**:

- **Thermoreceptors** detect temperature changes, but they do **not** respond to mechanical pressure.
- **Photoreceptors** in the **retina of the eye** detect changes in light.
- **Baroreceptors** (e.g., in blood vessels) detect changes in **blood pressure**.
- These receptors send signals about internal and external changes to the **central nervous system** for processing.

Sensory function

- Most activities of the nervous system are initiated by sensory experiences that excite sensory receptors.
- These sensory experiences can either cause immediate reactions from the brain, or memories of the experiences can be stored in the brain for minutes, weeks, or years and determine bodily reactions at some future date.

Functions of the nervous system

- **Integrative function:** processes sensory information by analyzing it and making decision for appropriate responses.
- Integration occurs **exclusively in the central nervous system**—specifically in the **brain** or **spinal cord**.
- This processing determines:
 - **Whether or not we become consciously aware** of the stimulus.
 - If we **do** become aware of it, this is called **perception**.
- **Perception** = Conscious awareness of a sensation
This function is typically associated with the **cerebral cortex**.
- Examples:
 - We are **consciously aware** of changes like:
 - Ambient temperature
 - Physical touch
 - We are **not consciously aware** of internal changes like:
 - Fluctuations in blood pressure
(because this integration happens in the **brainstem**, below the level of the cerebral cortex)

- responsible for:
 - . Processing **sensory information**
 - . Comparing **new inputs** with **previously stored information** (past experiences and memories)
 - . Making appropriate **decisions**

- The **central nervous system** can make **three types of decisions** based on how it perceives the incoming sensory information:

1. Immediate Response

- If the input is **urgent or important**, an **immediate motor response** is triggered.
- This involves sending signals to **muscles** or **glands** to:
 - Contract
 - Secrete substances

2. Information Storage

- If the input is **not immediately important**, the CNS might **store** it for **future use**.
- This is related to **memory**, so the information can be retrieved later if needed.

3. Information Discarding

- If the input is **irrelevant or unimportant**, the CNS will **discard** it.
- In fact, **more than 90%** of all sensory information received is discarded!

- **Why So Much Information is Discarded**

- Think about the **enormous amount of sensory input** you're experiencing right now — just while listening to this lecture:

- **Auditory** inputs (the lecture itself)
- **Tactile** inputs (pressure, touch, vibration, tickling)
- **Thermal** inputs (changes in temperature)
- **Internal** changes (like fluctuations in blood chemistry, pressure, etc.)
- It would overwhelm the brain to consciously process all of it. That's why:
- The CNS acts as a filter, choosing **what matters** and **what doesn't** at any given moment.
- Again, for each input, the CNS must **integrate** the information and make **one of three decisions**:
 - Act **immediately** via **motor output**
 - **Store** the information for **later use**
 - **Discard** it entirely

Integrative function

- More than 99 percent of the sensory information is discarded by the brain as irrelevant and unimportant.
- However, when important sensory information excites the mind, it is immediately channeled into proper integrative and motor regions of the brain to cause desired responses.
- This channeling and processing of information is called the integrative function of the nervous system.

Storage of information: memory

- Only a small fraction of even the most important sensory information usually causes immediate motor response.
- Much of the information is stored for future control of motor activities and for use in the thinking processes.
- Most storage occurs in the cerebral cortex, but even the basal regions of the brain and the spinal cord can store small amounts of information.

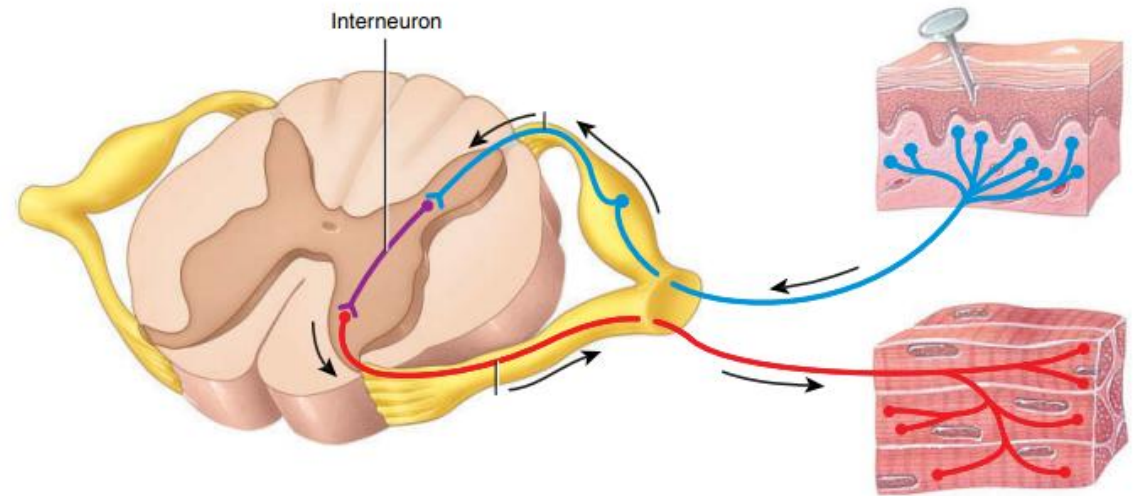
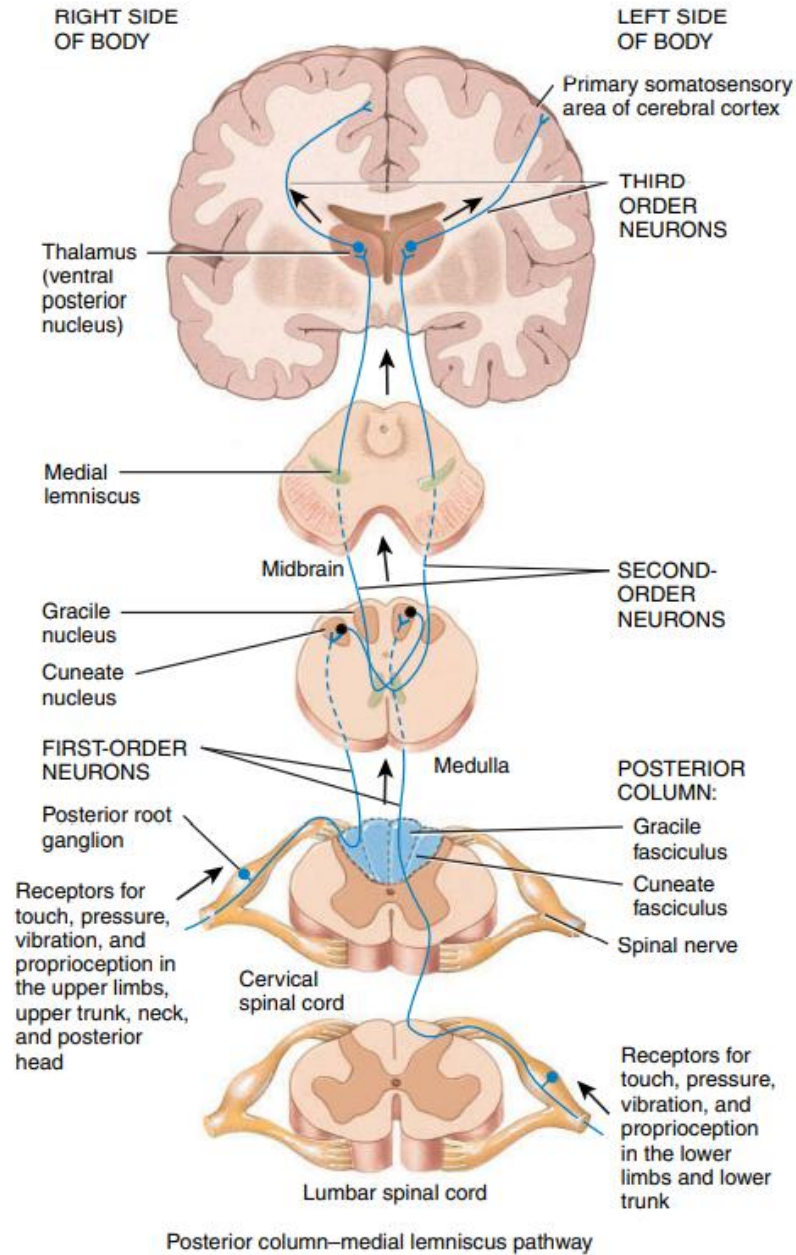
Storage of information: memory

- Once memories have been stored in the nervous system, they become part of the brain processing mechanism for future “thinking.”
- The thinking processes of the brain compare new sensory experiences with stored memories; the memories then help to select the important new sensory information and to channel this into appropriate memory storage areas for future use or into motor areas to cause immediate bodily responses.

- **The Central Nervous System: Decision-Making at Different Levels**
- We previously defined the **central nervous system (CNS)** as being composed of:
 - . The **brain**
 - . The **spinal cord**
- These represent **different anatomical levels** of the CNS, and **any part** of the CNS can participate in **decision-making**, not just the brain.

Spinal cord

- The spinal cord has two main functions:
- 1- nerve impulse propagation (sensory and motor tracts): transmits signals from the periphery of the body to the brain, or in the opposite direction from the brain back to the body.
- 2- integration of information (such as in spinal reflexes).



The **spinal cord** is **not only** responsible for **nerve impulse propagation** — i.e., simply transmitting signals between the **peripheral nervous system (PNS)** and the **brain**. It also plays an active role in **decision-making**, particularly in situations involving **spinal reflexes**.

What is a Reflex?

A **reflex** is an **automatic, rapid, and involuntary response** to a stimulus. It involves a specific **neural pathway** known as the **reflex arc**, which is composed of **five key components**:

- 1.Sensory receptor** – Detects a stimulus (e.g., pain).
- 2.Sensory (afferent) neuron** – Carries the impulse to the spinal cord.
- 3.Integration center** – Located in the **gray matter** of the spinal cord, where a decision is made.
- 4.Motor (efferent) neuron** – Transmits the command from the CNS to the effector.
- 5.Effector** – The **muscle** or **gland** that responds (e.g., by contracting or secreting).

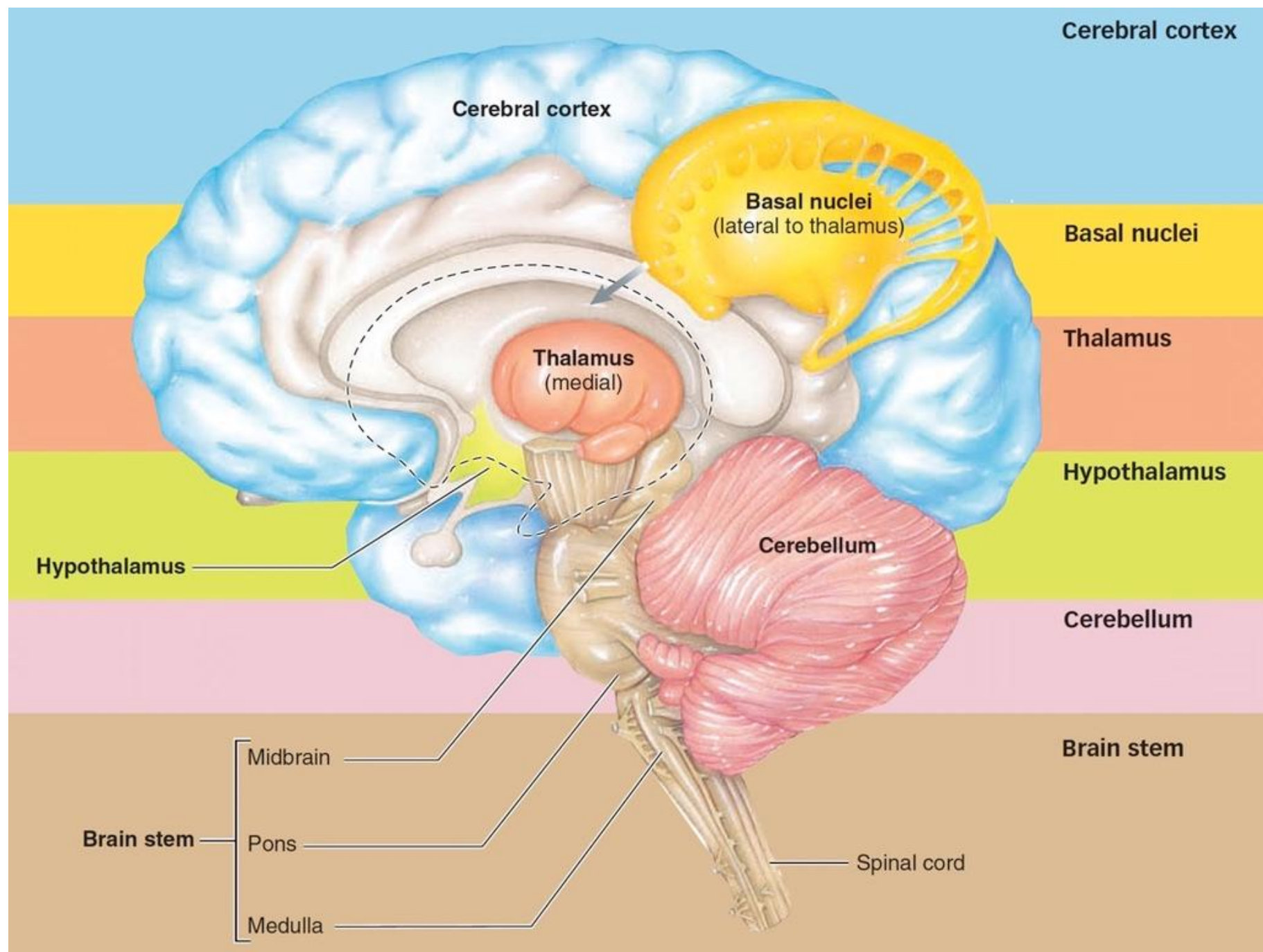
Example: Pain Withdrawal Reflex

Let's say you touch something painful:

- **Pain receptors** in the skin are activated.
- A **sensory neuron** transmits this signal via spinal nerves to the **spinal cord**.
- The **spinal cord** itself (specifically, the **integration center**) analyzes the situation **without sending the information to the brain first**.
- A decision is made **immediately** to protect the body.
- A **motor neuron** carries the command to muscles, causing:
 - **Flexion** or **withdrawal** of the limb **away** from the painful stimulus.

This process is:

- **Fast**, because it bypasses the brain.
- A prime example of how the **spinal cord can make decisions independently** in critical situations.



1. Brainstem

After the spinal cord, the first major structure encountered is the **brainstem**.

The **brainstem** includes three key regions:

- **Medulla oblongata**
- **Pons**
- **Midbrain**

These areas collectively perform **vital regulatory functions**, such as:

- **Cardiovascular center:**
 - Controls **heart rate** and **blood pressure**
- **Respiratory centers:**
 - Regulate **breathing patterns**

In addition, the brainstem:

- Sends **feedback** to different parts of the CNS involved in **motor control**
- Contains **multiple nuclei**, which are involved in **integrating sensory and motor functions**

2. Hypothalamus

The **hypothalamus** is a key regulatory center that controls:

- **Vegetative states** (like sleep, hunger, thirst, body temperature)
- The **autonomic nervous system (ANS)**
 - Controls involuntary body functions (e.g., heart rate, digestion, pupil dilation)
- **Hormone release** from various glands, especially via the **pituitary gland**

3. Basal Nuclei (Basal Ganglia)

Within the deeper parts of the brain are **nuclei** (clusters of neurons), many of which are involved in **motor control**.

- These nuclei can send **inhibitory** or **excitatory** signals to other parts of the brain, including the **cerebrum** (cerebral cortex).

4. Cerebral Cortex

The **cerebral cortex** is the **outermost layer** of the brain and is responsible for the **highest levels of processing** in the human nervous system.

It plays a major role in:

- **Higher intellectual functions**
- **Precise motor control**
- **Fine-tuned sensory awareness**
- **Perception** — the **conscious awareness of sensation**

The **cerebral cortex** is **where most of our memories are stored**, and where sophisticated decision-making occurs.

Key Points:

- It is **divided into lobes** (frontal, parietal, temporal, occipital), each associated with different functions.
- The **cerebral cortex** is often referred to as the **higher brain**.
- Structures below the cortex are part of the **subcortical** or **lower brain**.

Lower brain (subcortical regions)

- Many, if not most, of the subconscious activities of the body are controlled in the lower areas of the brain.
- Examples of subcortical structures are brain stem, cerebellum, diencephalon, basal nuclei, hippocampus, and amygdala.

Higher brain (cerebral cortex)

- Cerebral cortex is an extremely large **memory storehouse**.
- Without the cerebral cortex, the functions of the lower brain centers are often imprecise. Cortical information usually converts these functions to determinative and **precise operations**.
- The cerebral cortex is essential for most of our **thought processes**.

Functions of the nervous system

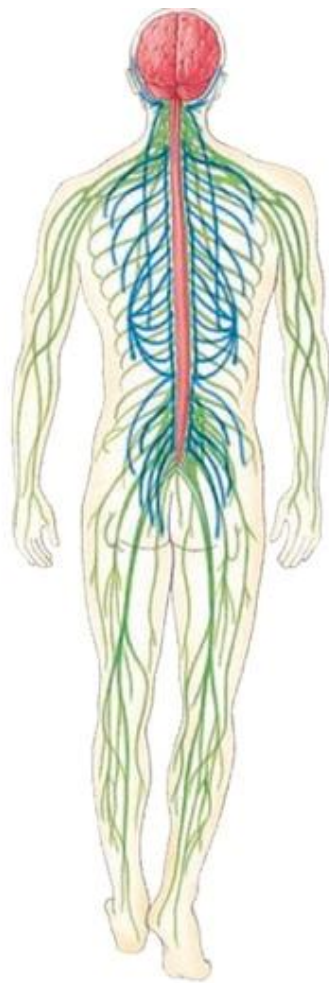
- **Sensory function:** sensory receptors detect internal or external stimuli. The sensory information is carried to the CNS through cranial and spinal nerves.
- **Integrative function:** process sensory information by analyzing it and making decision for appropriate responses.
- **Motor function:** activation of effectors (muscles and glands) through cranial and spinal nerves.

Motor function

- The most important eventual role of the nervous system is to **control the various bodily activities.**
- This task is achieved by controlling:
 - (1) contraction of appropriate skeletal muscles throughout the body.
 - (2) contraction of smooth muscle in the internal organs.
 - (3) secretion of active chemical substances by both exocrine and endocrine glands in many parts of the body.

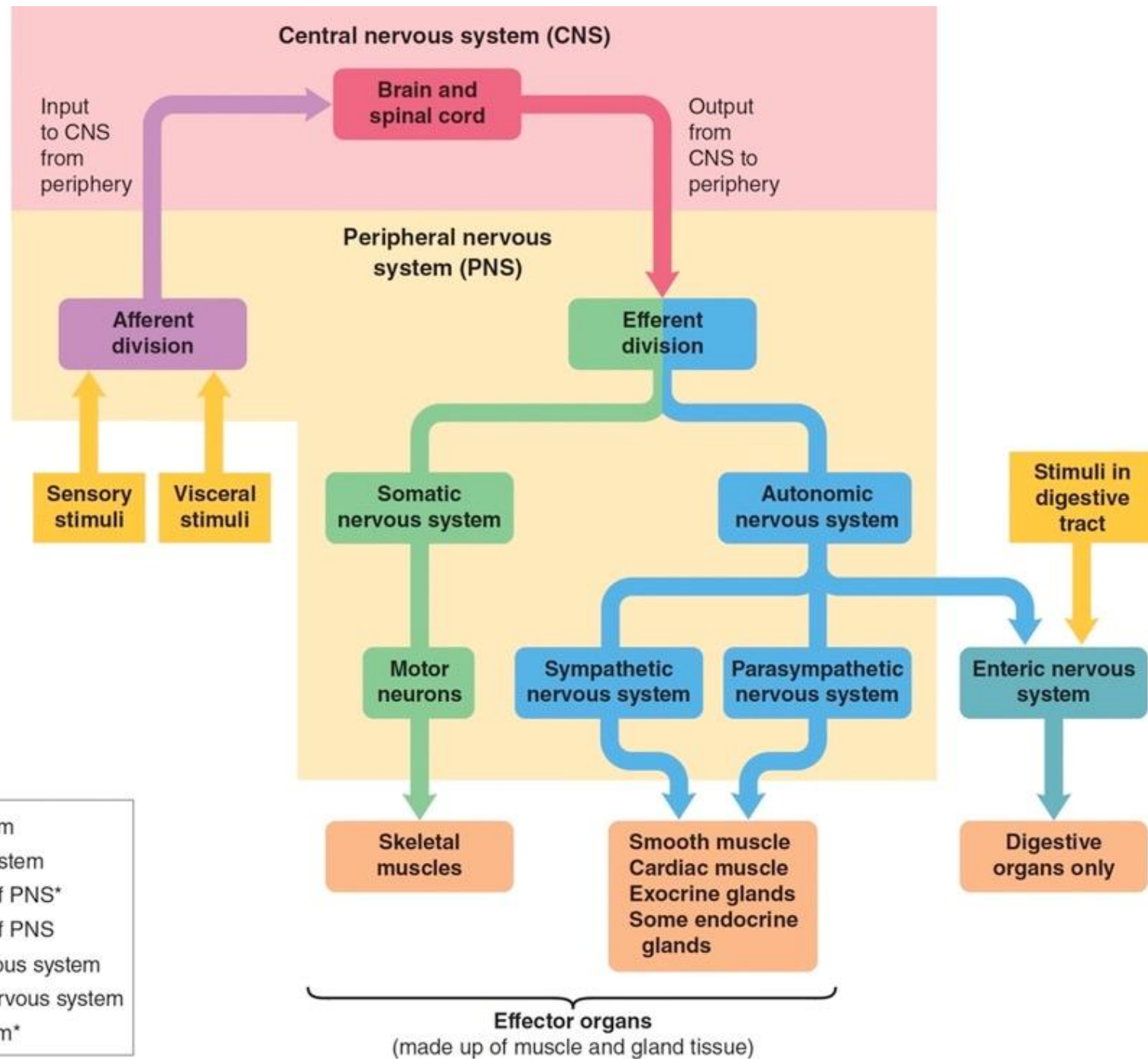
Motor function

- These activities are collectively called motor functions of the nervous system.
- The muscles and glands are called **effectors** because they are the actual anatomical structures that perform the functions dictated by the nerve signals.



KEY

- Central nervous system
- Peripheral nervous system
- Afferent division of PNS*
- Efferent division of PNS
- Somatic nervous system
- Autonomic nervous system
- Enteric nervous system*



1. Sensory Function

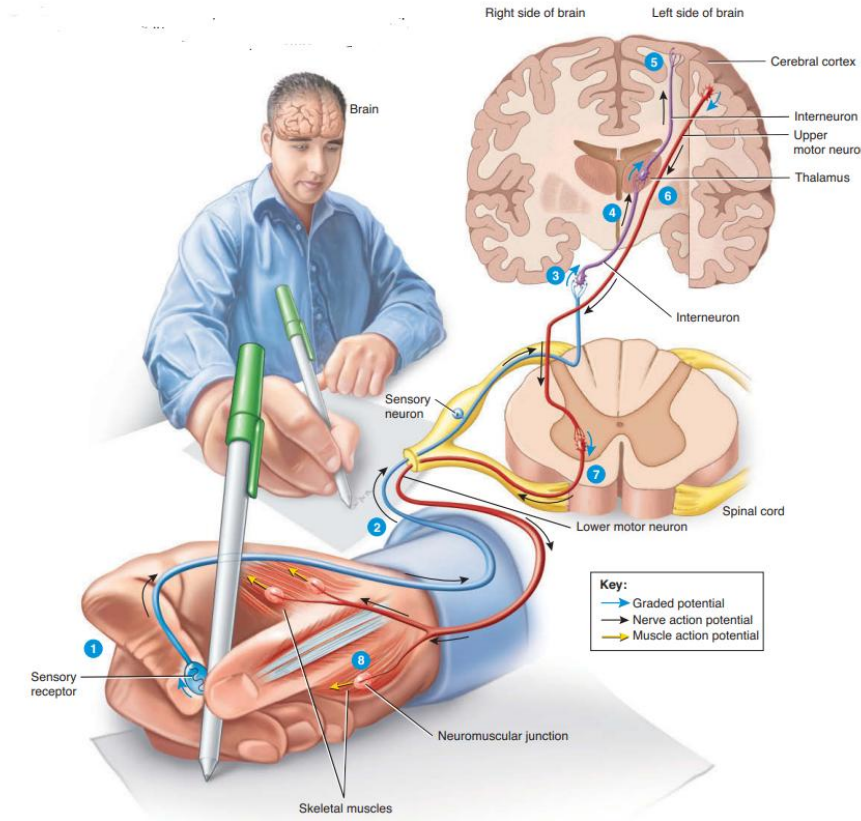
- When you **grip the pen**, the **skin on your fingers** experiences **pressure and touch**.
- This **mechanical stimulus** is detected by **specialized sensory receptors** (specifically, **mechanoreceptors**) located in the **skin**.
- These receptors convert the stimulus into **electrical signals** (nerve impulses).
- The impulses travel via **sensory (afferent) neurons** through **ascending pathways** in the spinal cord to reach the **central nervous system**.

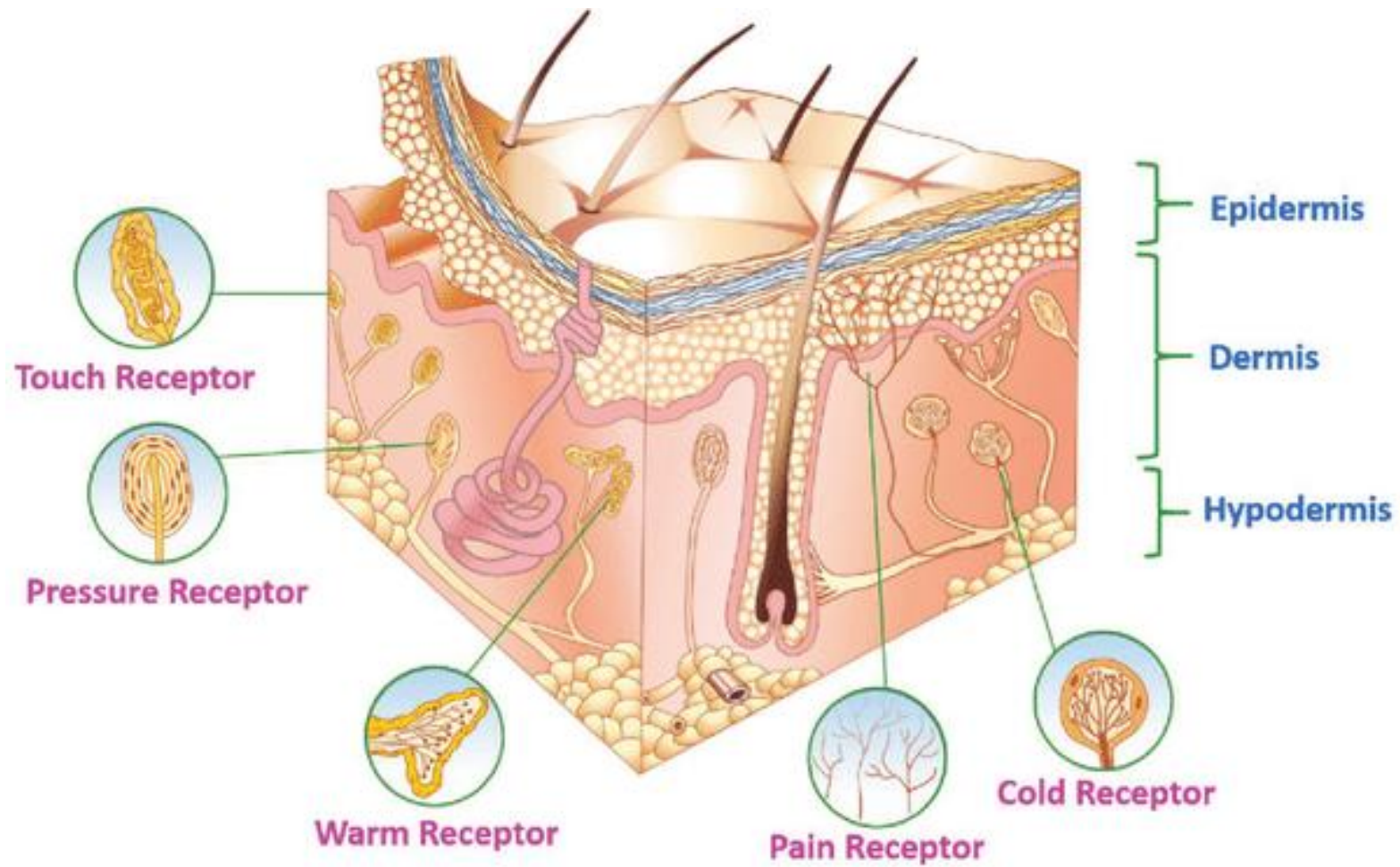
2. Integrative Function

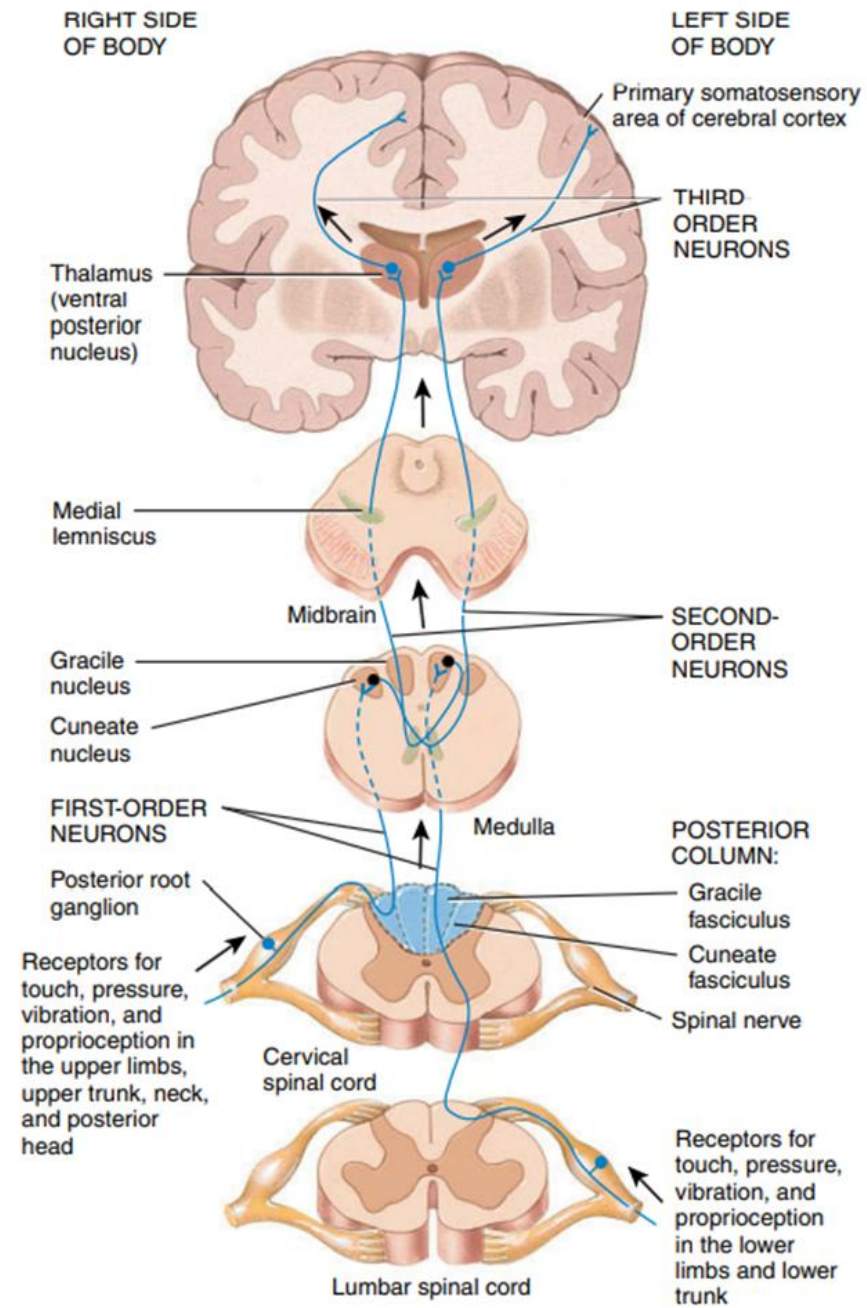
- Once the sensory information arrives in the CNS, it is **processed and interpreted**.
- The **brain**, particularly the **cerebral cortex**, determines:
 - The **location** and **intensity** of the touch
 - That you are holding a pen
 - That you intend to **write**
- Based on this analysis, the brain makes a **decision**: to **activate specific muscles in the hand and fingers** so you can write.

3. Motor Function

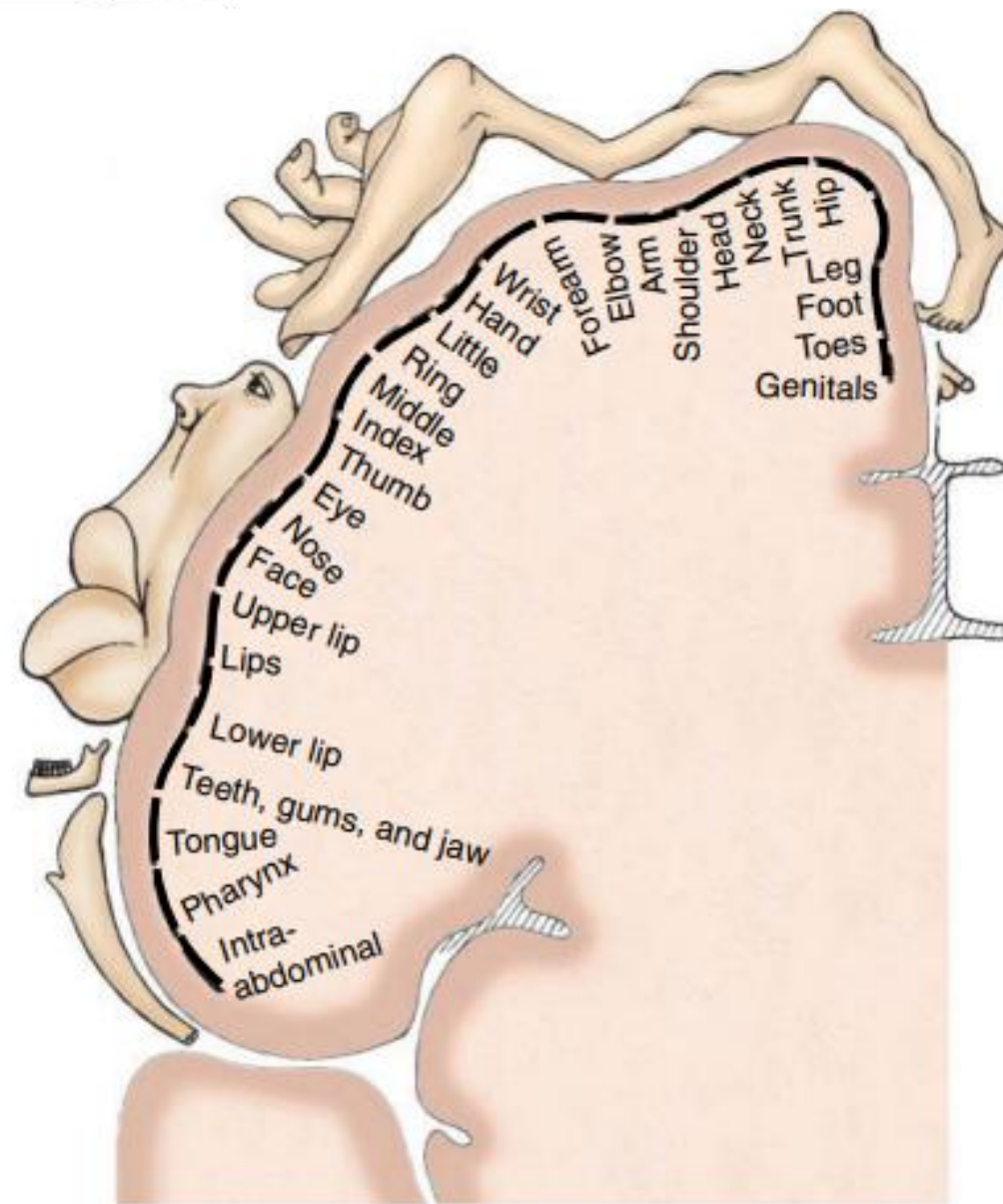
- The **decision** is converted into motor commands that travel from the **brain** to the **muscles** via **descending pathways**.
- These motor signals pass through a **series of motor neurons**:
 - **Upper motor neurons** (originating in the cortex)
 - **Lower motor neurons** (which exit the spinal cord and directly stimulate muscles)
- These neurons activate **specific skeletal muscles** in your **hand and fingers** (the **effectors**).
- The result is **coordinated movement** that allows you to **move your fingers** and **write on paper**.



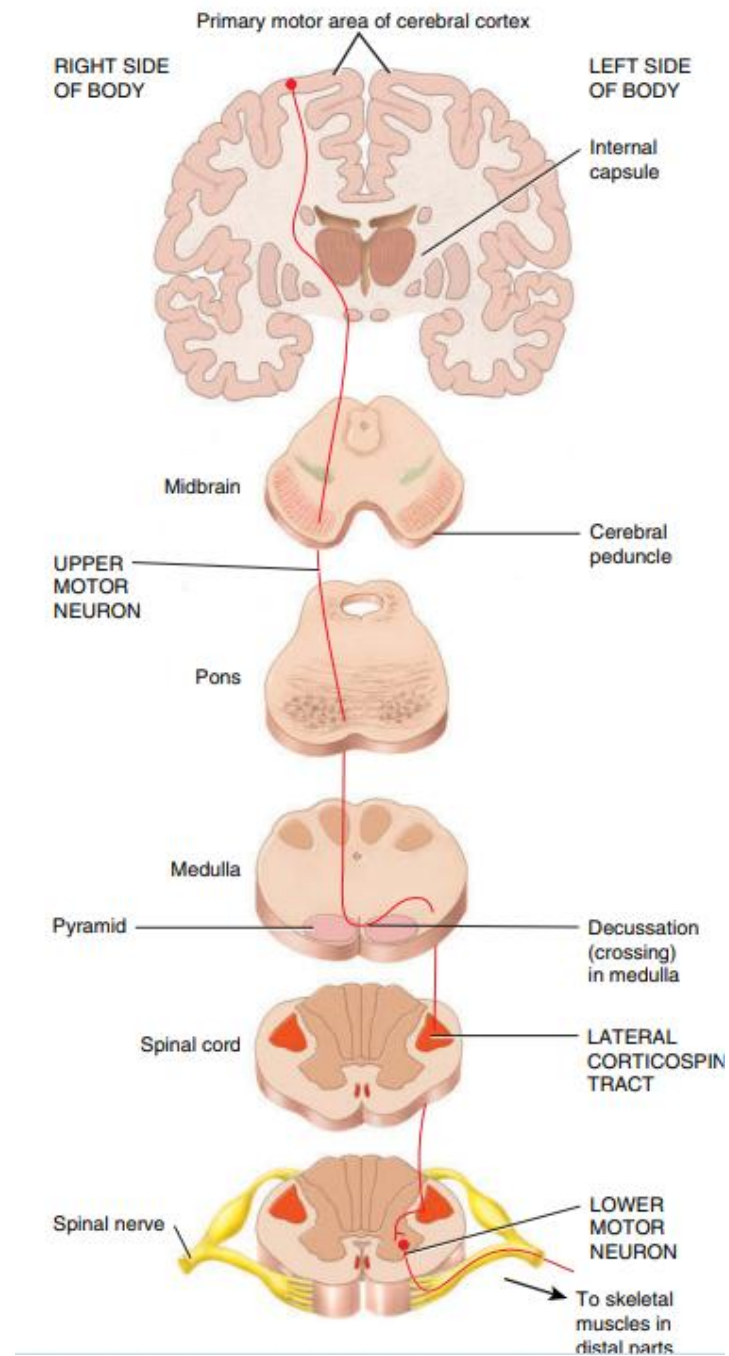


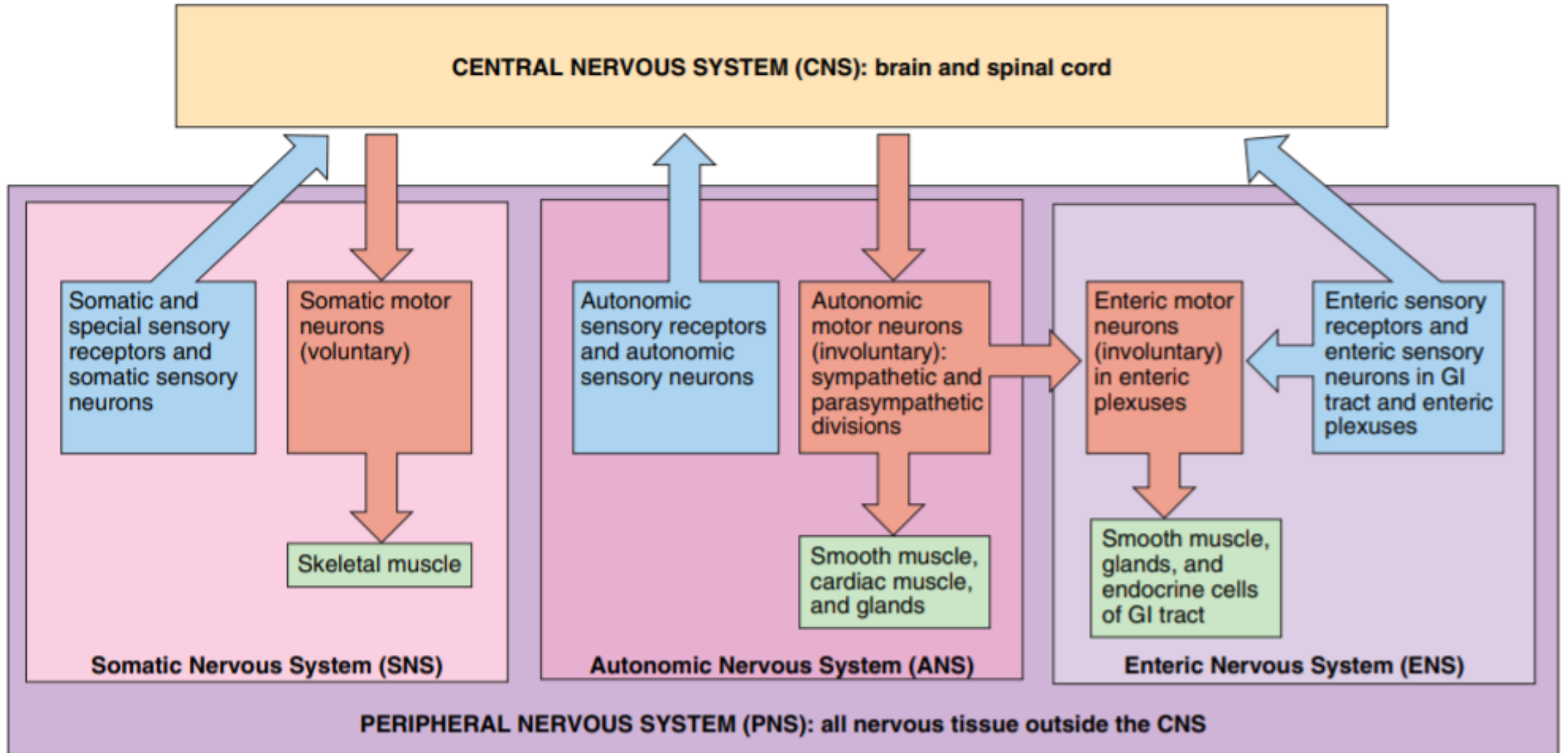


Posterior column–medial lemniscus pathway



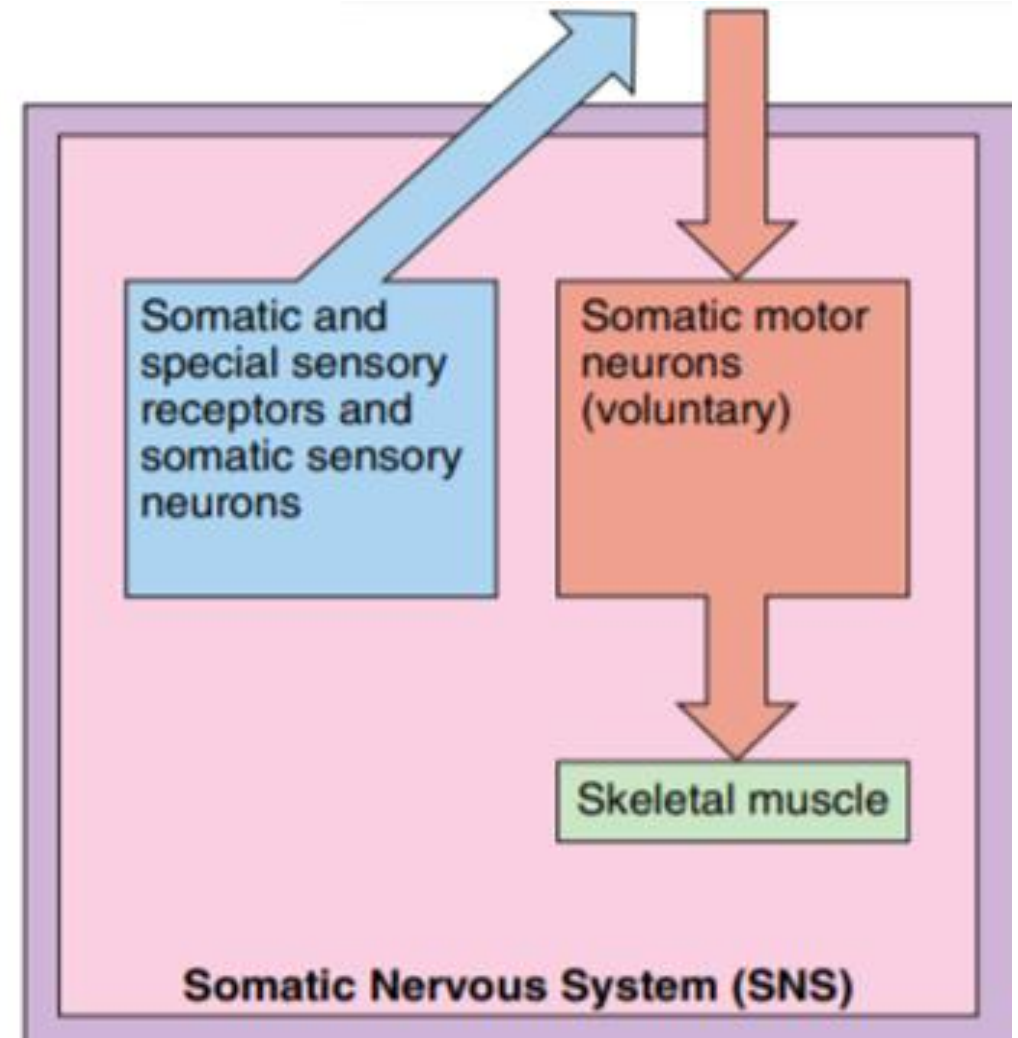
(a) Frontal section of primary somatosensory area in right cerebral hemisphere





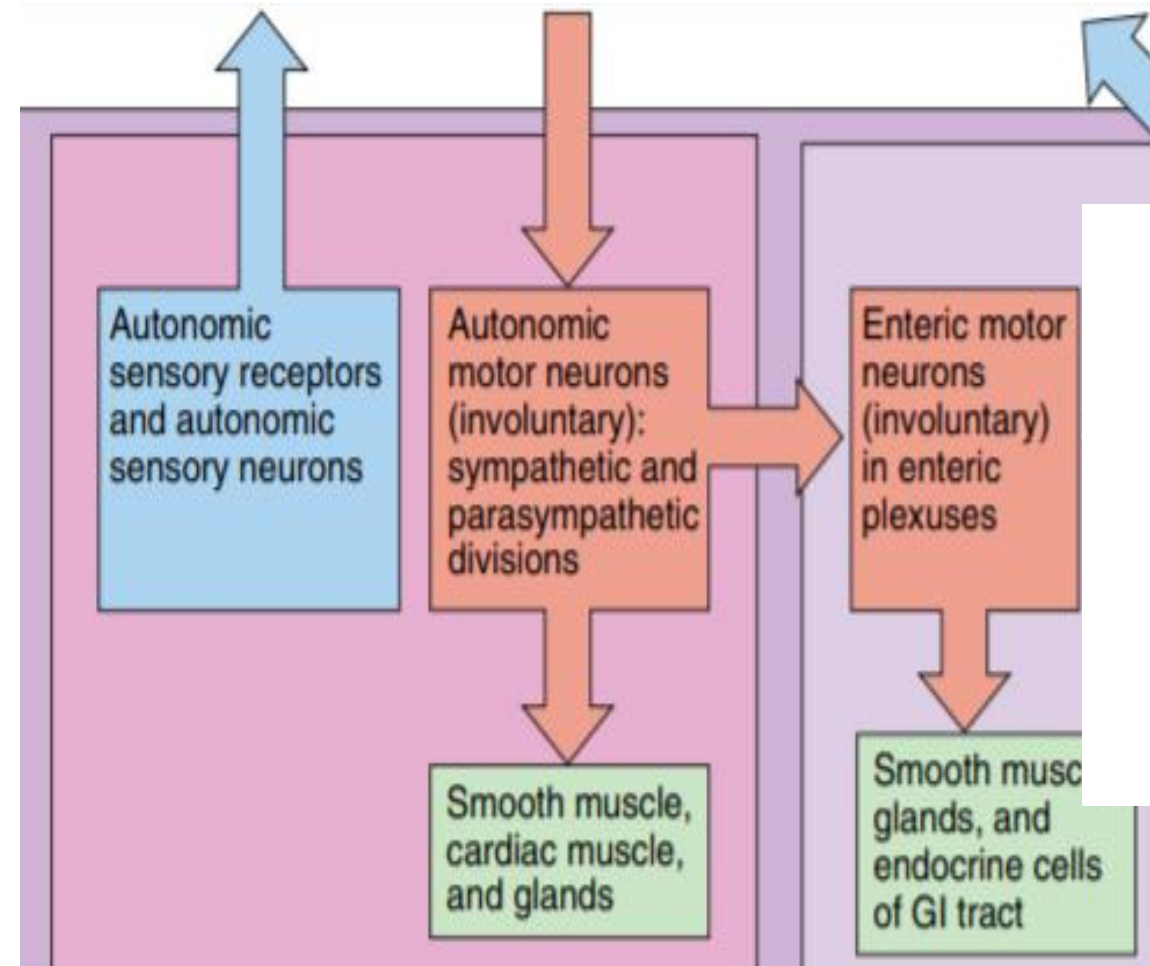
Somatic nervous system

- **sensory neurons:** convey information from somatic receptors (in the head, body wall and limbs) and from receptors of special senses: vision, hearing and taste to the CNS.
- **motor neurons:** conduct impulses from CNS to skeletal muscles only.
- It is the **voluntary** part of PNS because the motor response can be consciously controlled.



Autonomic nervous system

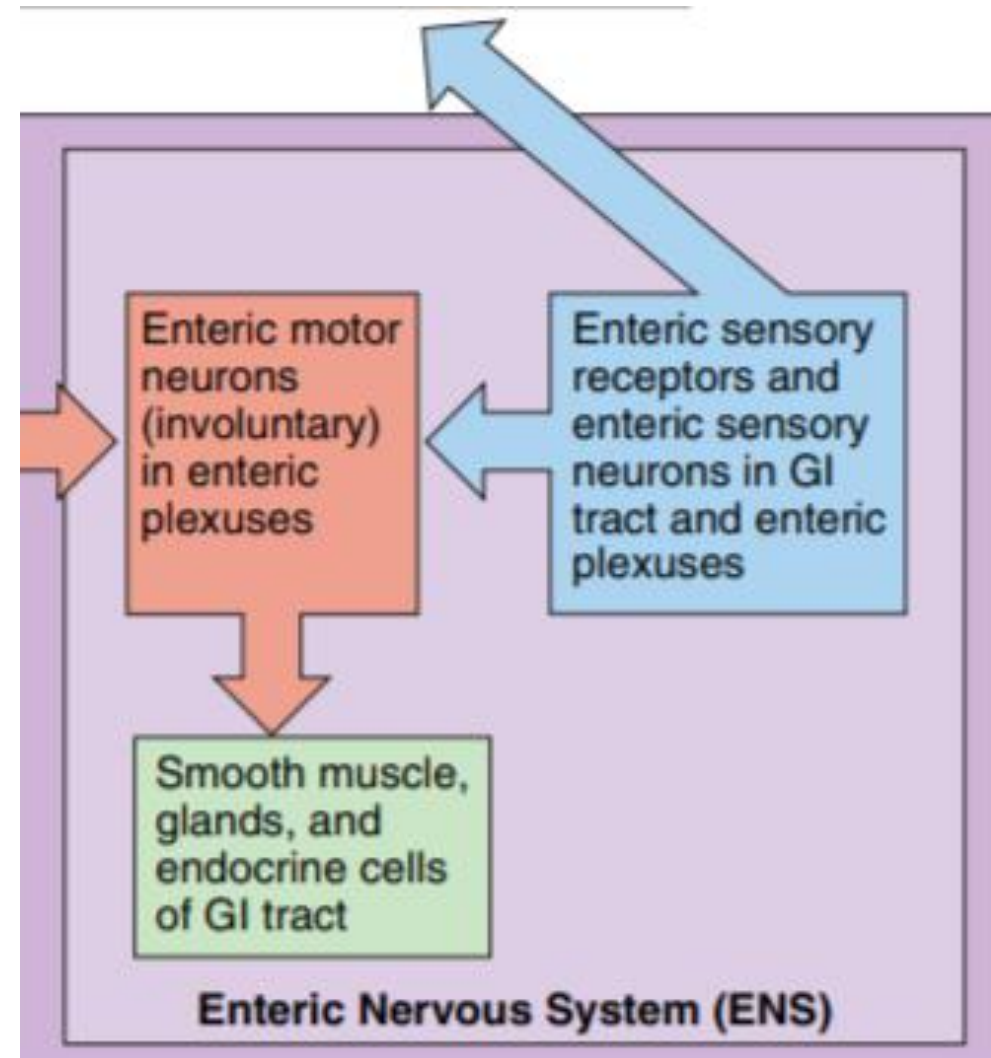
- **sensory neurons:** convey information from autonomic sensory receptors (located mainly in the visceral organs) to the CNS.
- **motor neurons:** conduct impulses from CNS to smooth muscles, cardiac muscles and glands. because the motor responses are not normally under conscious control, its action is involuntary.
- The motor part is divided into **sympathetic and parasympathetic** divisions.

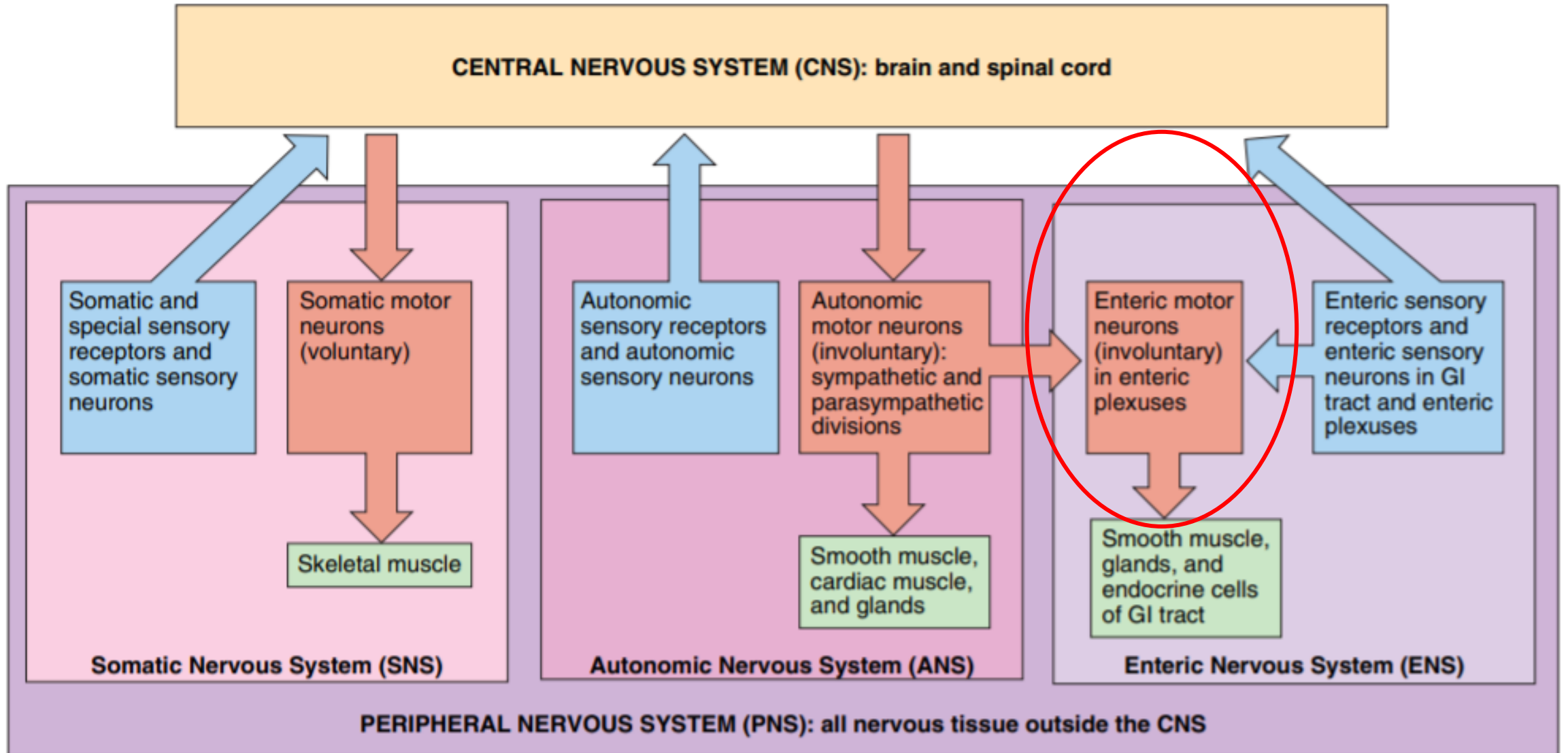


Most not all effectors receive nerves from both divisions, Usually they have opposing actions: sympathetic: fight or flight action, parasympathetic: rest and digest.

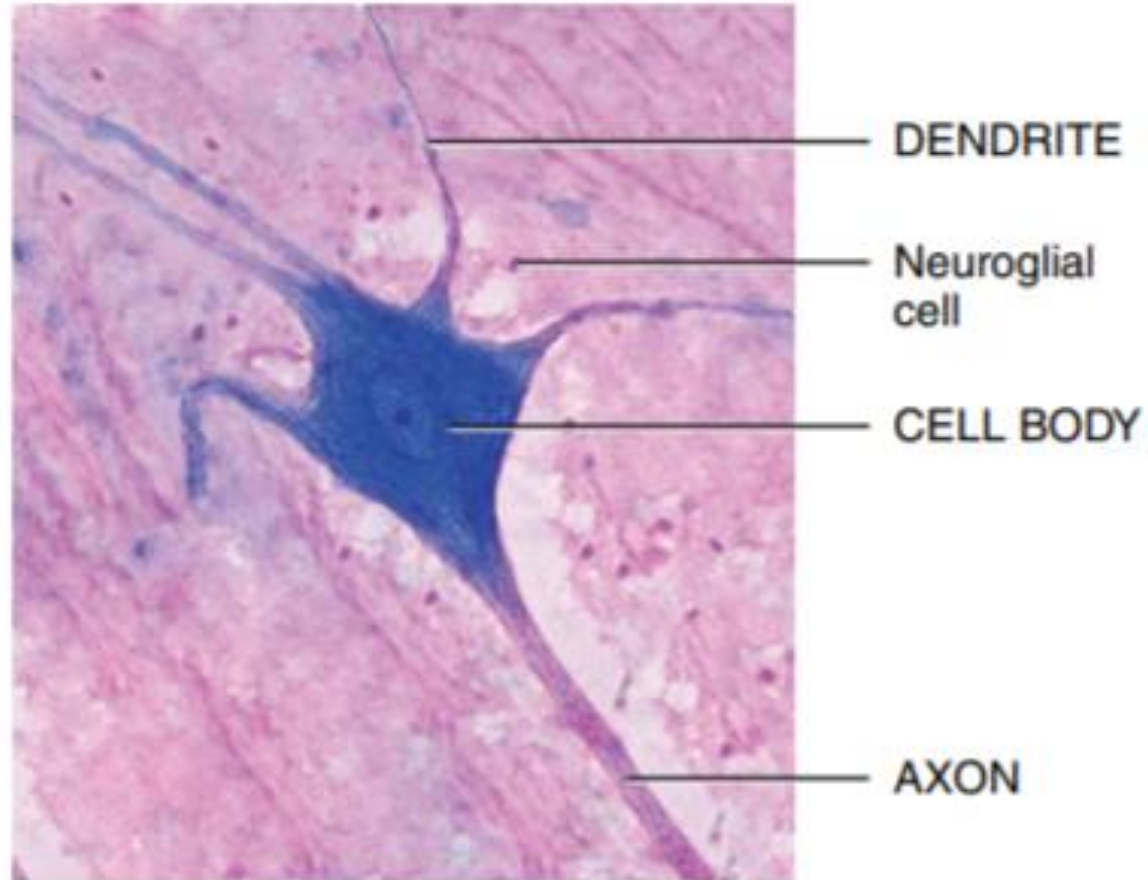
Enteric nervous system

- **Sensory neurons:** monitor changes within the digestive system (gastrointestinal: GI).
- **Motor neurons:** control the contraction of GI smooth muscles, the secretions of GI organs, and the activities of GI endocrine cells. It is called the brain of the gut.
- It is involuntary. Many of ENS neurons function independent of ANS or CNS, although they also communicate with the CNS via sympathetic and parasympathetic neurons.





The functional unit of the nervous system is the neuron



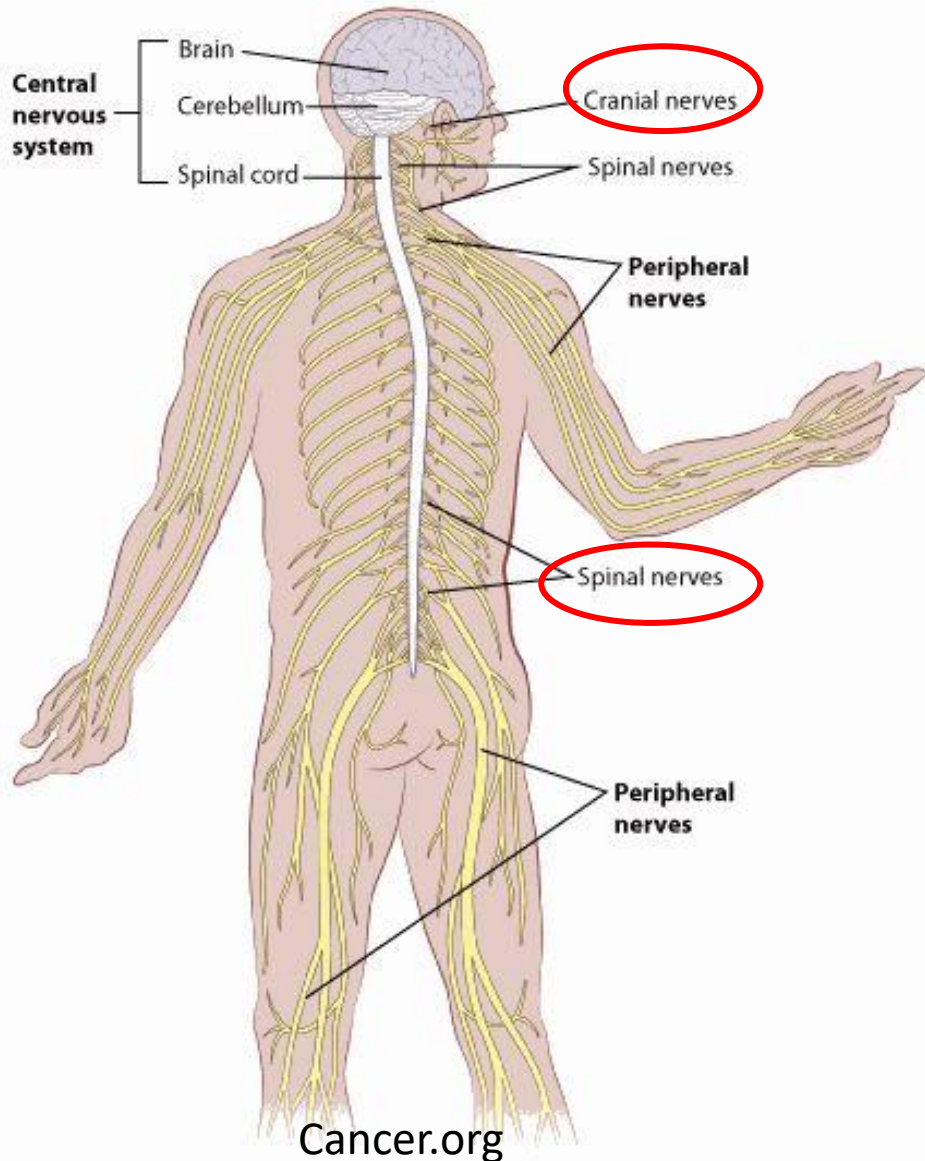
Collections of nervous tissue

- Components of nervous tissue are grouped together in a variety of ways.

Collections of axons

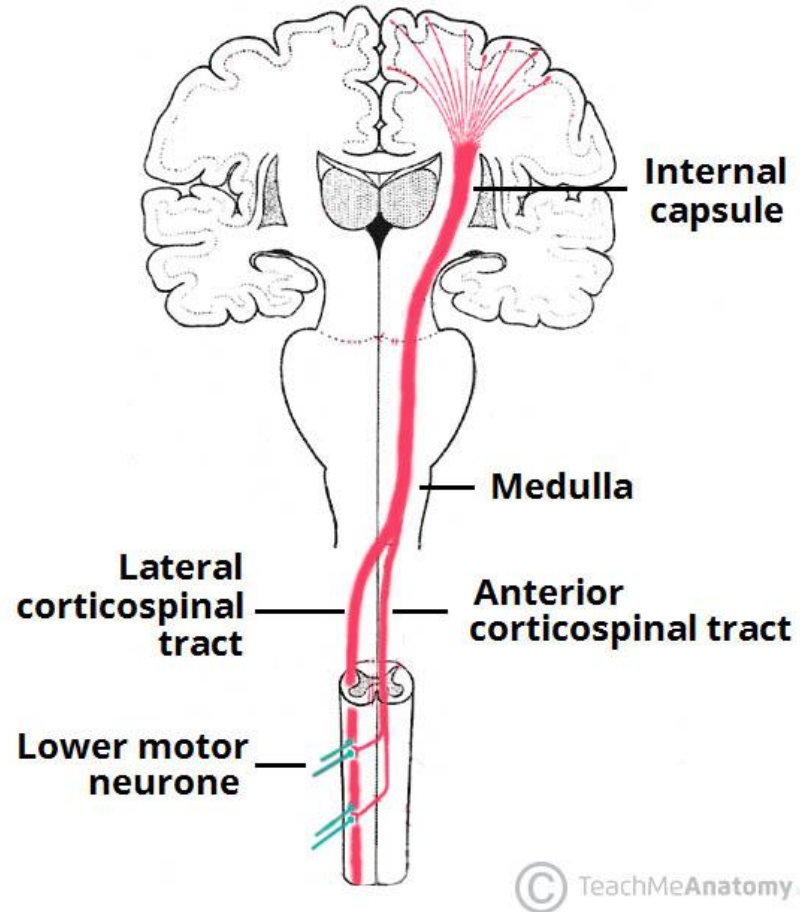
- The widespread collection of axons in the CNS is called **white matter**.
- A bundle of axons in the CNS is called **tract**.
- A bundle of axons in the PNS is called **nerve**.

Nerve



Nerves: a bundle of axons plus associated connective tissues and blood vessels outside the CNS. 12 cranial and 31 spinal. Each nerve follows a defined path and serve specific region of the body. What is the difference between nerves and tracts (nerves are outside CNS, and surrounded by schwan cells, but in tracts no schwan cells but oligodendrocytes.)

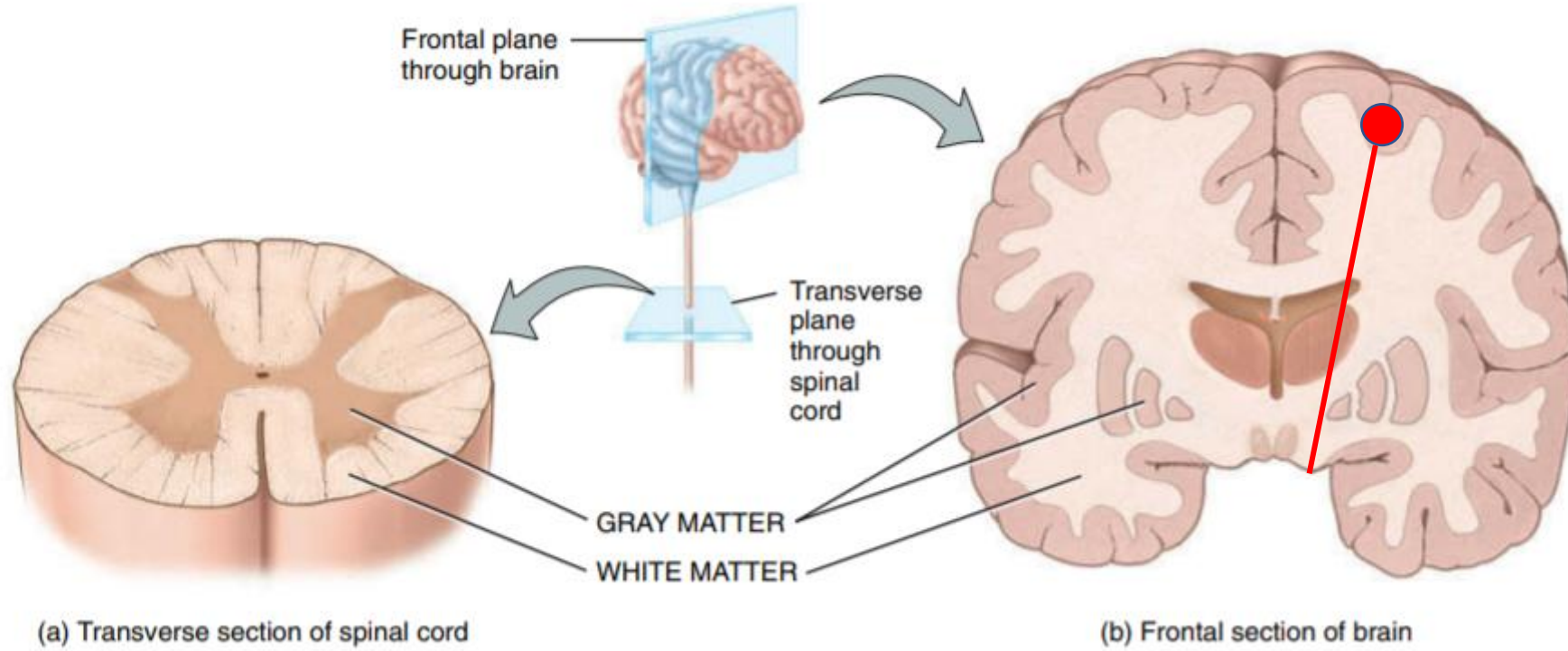
Tract



Can be classified according to the direction of information transmission by the neurons:
tracts (bundles of white matter transmitting signals up and down): ascending tracts(upward: cephalically), descending(downward: caudally)
Commisural fibers : Connect R to L or vice versa e.g. corpus callosum(the largest one).
Association fibers: connect antero-posterior (front to back) and vice versa.
Reticular formation: a deeper part of brain stem where grey matter and white matter mix. Like a network. Brain stem has many nuclei and reticular formation.

Descending pathway

White matter



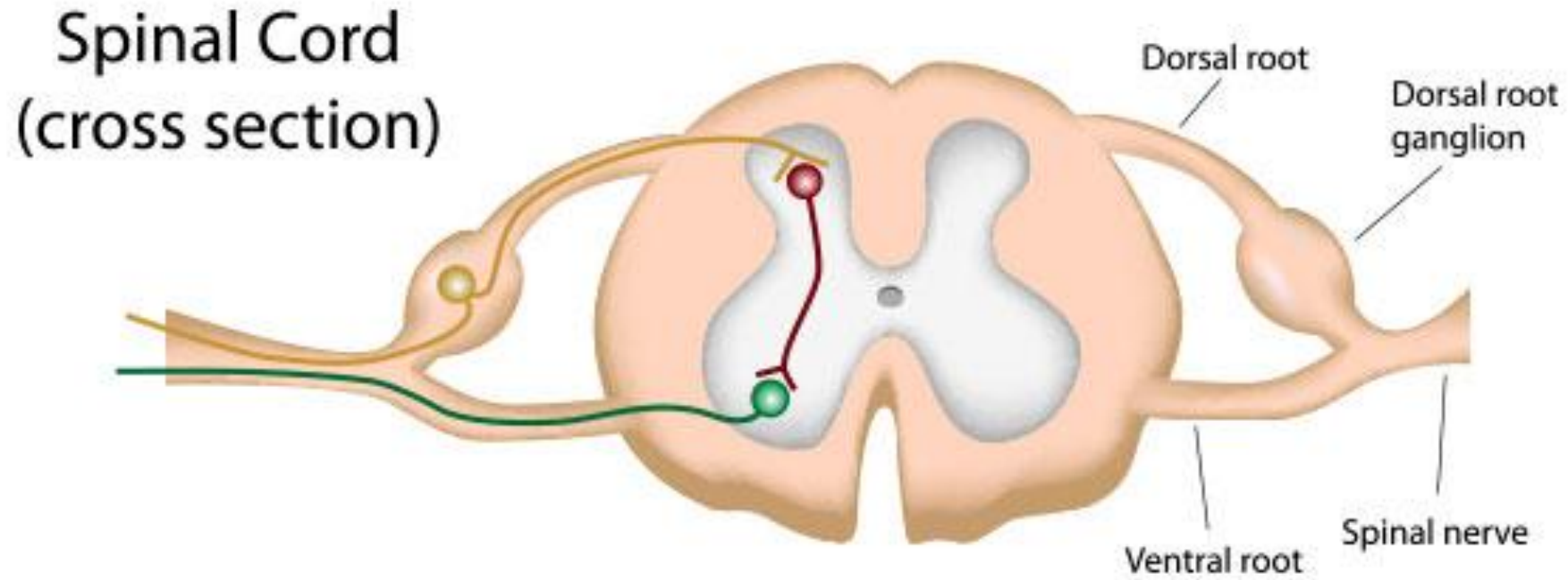
Collections of neuronal cell bodies

A widespread collection of neuronal cell bodies is called **gray matter**.

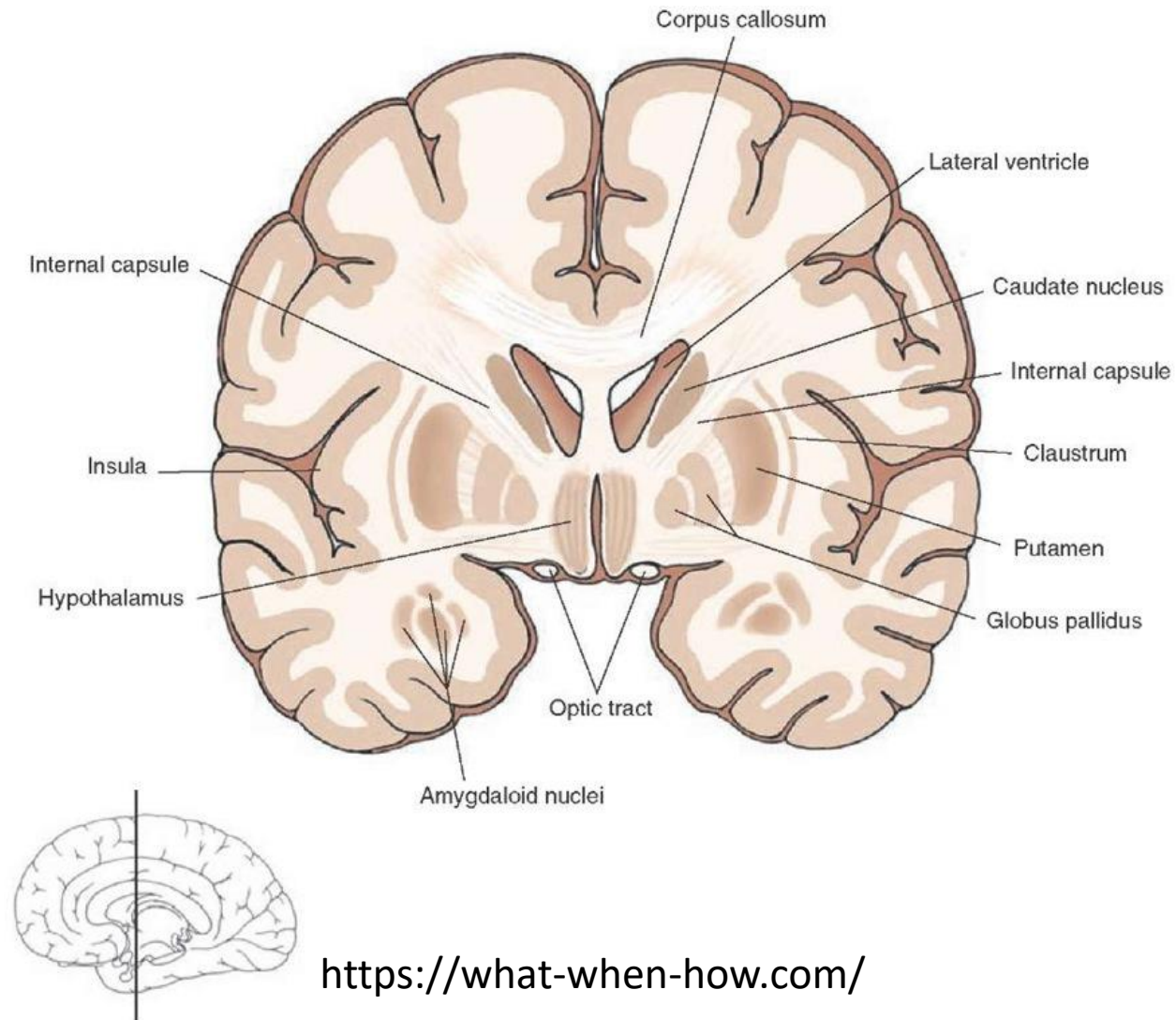
A cluster of neuronal cell bodies in the CNS is called **nucleus**.

A cluster of neuronal cell bodies in the PNS is called **ganglion**.

Ganglion

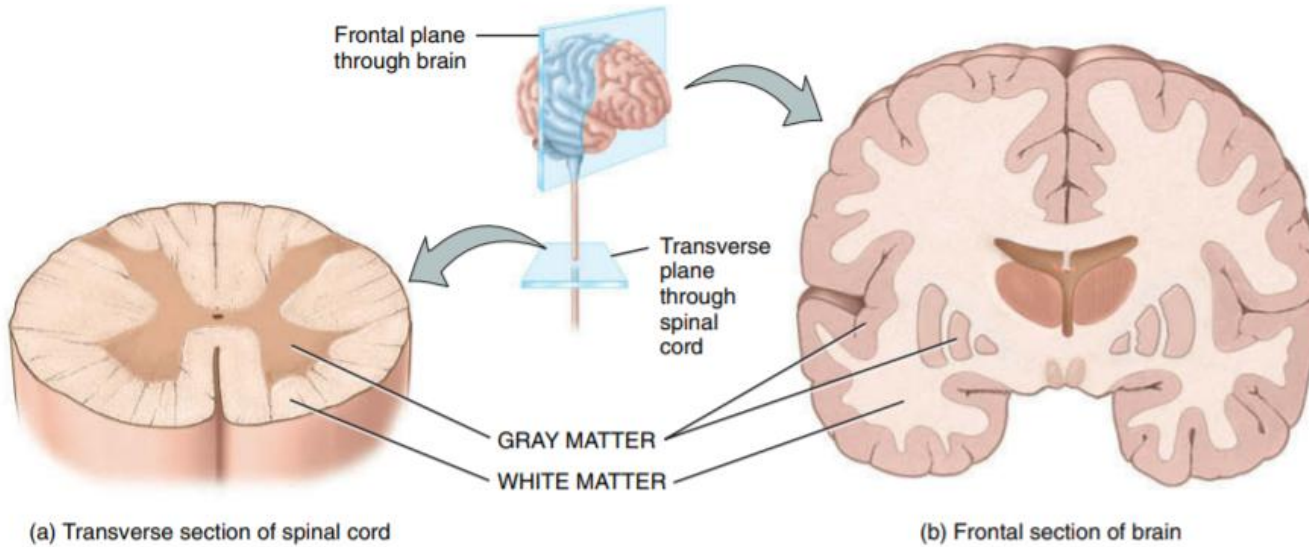


Nucleus



<https://what-when-how.com/>

Gray matter



Gray matter is composed of neuronal cell bodies in the CNS: cortex (grey matter on the surface of brain: cerebral and cerebellar) vs nuclei (collection of cell bodies (pieces of grey matter surrounded by white matter: deep):