

Week 2 (Ch04)

Neuromotor Basis for Motor Control

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Objectives

1. Describe the general structure of a neuron and the types and functions of neurons.
2. Identify and describe the structural components of the brain that are most directly involved in control of movement and describe their primary functions.
3. Identify and describe the neural pathways that make up the ascending and descending tracts.
4. Describe a motor unit, the recruitment of motor units, and their relationship to the control of movement.
5. Describe the basic components of a conceptual hierarchical model that describes the CNS structures and their functions in the control of movement.

Welcome everyone to our exploration of the neuromotor system, the amazing foundation for how we control our movements. This system is incredibly complex, yet it allows us to do everything from simple actions like picking up a pen to much more intricate tasks. Think about that example for a moment: deciding to pick up a pen is a cognitive act, but how does that thought turn into the actual movement of your hand and fingers? This chapter, and our discussion today, will dive into the neurophysiological basis of these actions, looking specifically at the central nervous system's structure and function as it relates to motor skills. Understanding this process is vital for anyone planning a career in physical rehabilitation or helping people learn and relearn motor skills. It truly provides a more comprehensive appreciation of human capabilities and limitations in movement.

Objective 1

Describe the general structure of a neuron and the types and functions of neurons.

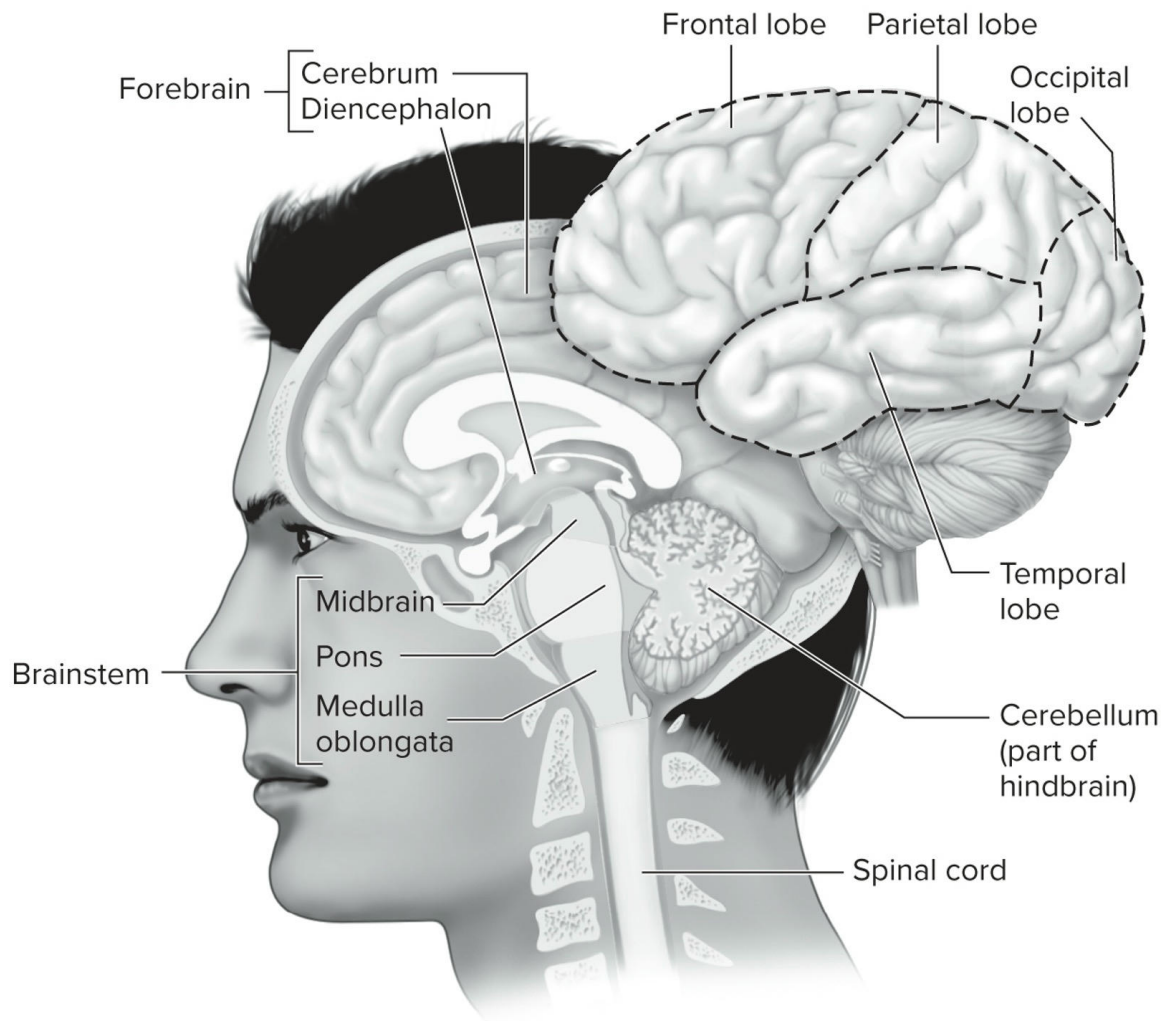
! Important

Intro Video: Take a few minutes to watch the intro video below on the neuron.

<https://youtu.be/HUuUUJktL6E>

The Neuromotor System: An Introduction

- Start by watching this brief video on the nervous system: Nervous System Overview.
- The **neuromotor system** is the amazing foundation for how we control our movements, from simple to intricate tasks.
- This discussion will dive into the **neurophysiological basis of actions**, specifically the **central nervous system's (CNS) structure and function** as it relates to motor skills.
- Understanding this process is **vital for anyone planning a career in physical rehabilitation** or helping people learn and relearn motor skills.
- It provides a comprehensive appreciation of **human capabilities and limitations in movement**.



(b) Major divisions of adult brain

The Neuron: Basic Building Block

- **Neurons** Nerve cells; the basic component of the nervous system that provide the means for receiving and sending information through the entire nervous system. are billions of functional units essential for sending and receiving information throughout the nervous system.
- Most neurons share a similar general three-part structure:
 - **Cell body (soma)**: Contains the nucleus and organelles, vital for neuron function and homeostasis.
 - **Dendrites** Extensions from a neuron's cell body that receive neural impulses from other neurons; a neuron may have none or as many as thousands of dendrites.: Tree-like branches primarily responsible for receiving signals from other neurons.
 - **Axon** Extensions from a neuron's cell body that transmit neural impulses to other neurons, structures in the CNS, or muscles; a neuron has only one axon, although most axons branch into many branches.: A long projection that transmits signals away from the cell body to other neurons, muscles, or glands.
- Many axons are covered by a **myelin sheath** A cellular membrane that speeds up the transmission of neural signals along the axon by acting as an electrical insulator., a fatty layer that acts as an electrical insulator and increases signal speed.
- **Axon terminals**: Serve as signal transmission relay stations for neurotransmitters Chemical signals passed on to other neurons or to muscles in the specific case of movement control., which are chemical messengers.
- **Synapse** The junction between the axon of a neuron and another neuron where the passing on of neural signals from one neuron to another occurs.: The specific junction where one neuron communicates with another.

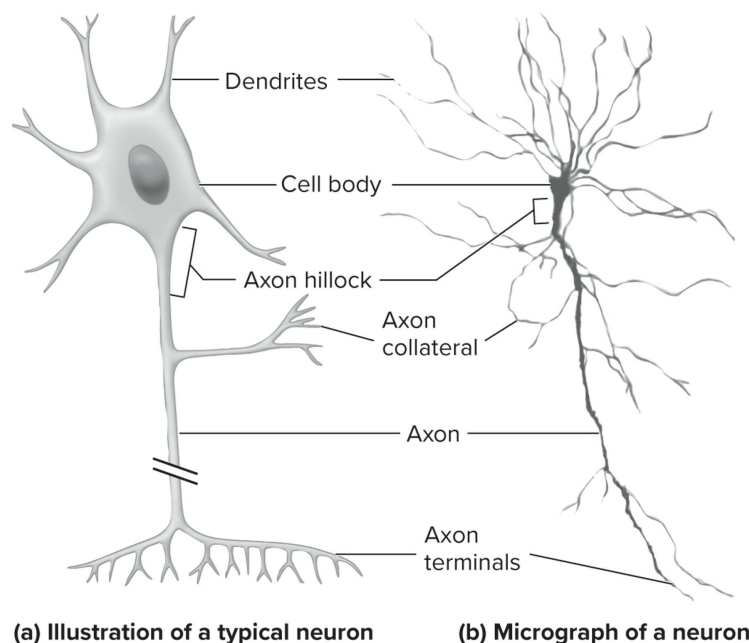


Figure 1: Figure 1.1: Neuron Structure

Let's start with the basic building block of our nervous system: the neuron. Neurons are functional units that number in the billions and are essential for sending and receiving information throughout the nervous system. Most neurons share a similar general three-part structure, as you can see illustrated in Figure 4.1. This figure shows both a diagrammatic illustration and a microscopic view of a neuron, highlighting its key components. The central part is the cell body, also known as the soma, which contains the nucleus and other organelles vital for the neuron's function and regulates its homeostasis. Extending from the cell body are dendrites, which are tree-like branches primarily responsible for receiving signals or information from other neurons. A neuron can have anywhere from none to thousands of dendrites. Then we have the axon, a long, slender projection, often called a nerve fiber, that transmits signals away from the cell body to other neurons, muscles, or glands. Unlike dendrites, there's only one axon per neuron, though it often has many branches called collaterals. Many axons are also covered by a fatty layer called the myelin sheath, which acts as an electrical insulator and significantly increases the speed at which neural signals travel along the axon. At the very ends of the axons, we find axon terminals, which serve as signal transmission relay stations for neurotransmitters, the chemical messengers that pass signals to other neurons or muscles, especially for movement control. The specific junction where one neuron communicates with another, often between an axon terminal and a dendrite or cell body, is called a synapse.

Neural Communication: The Electrochemical Process

- Neurons communicate through a fascinating **electrochemical process**.
- When sufficiently stimulated, a neuron generates an electrical impulse called an **action potential**. **A rapid, all-or-nothing electrical signal that travels quickly down the axon once a threshold charge is reached.**
- This **rapid, all-or-nothing electrical signal** travels quickly down the axon once a threshold charge is reached.
- At the axon terminals, the action potential triggers the release of **neurotransmitters** (chemical messengers stored in vesicles) into the **synapse** (the tiny gap between neurons).
- Neurotransmitters diffuse across the synapse and bind to specific **receptors** on the next (post-synaptic) neuron.
- This binding can either **excite** (making it more likely to fire) or **inhibit** (making it less likely to fire) the next neuron, ensuring precise information transmission.

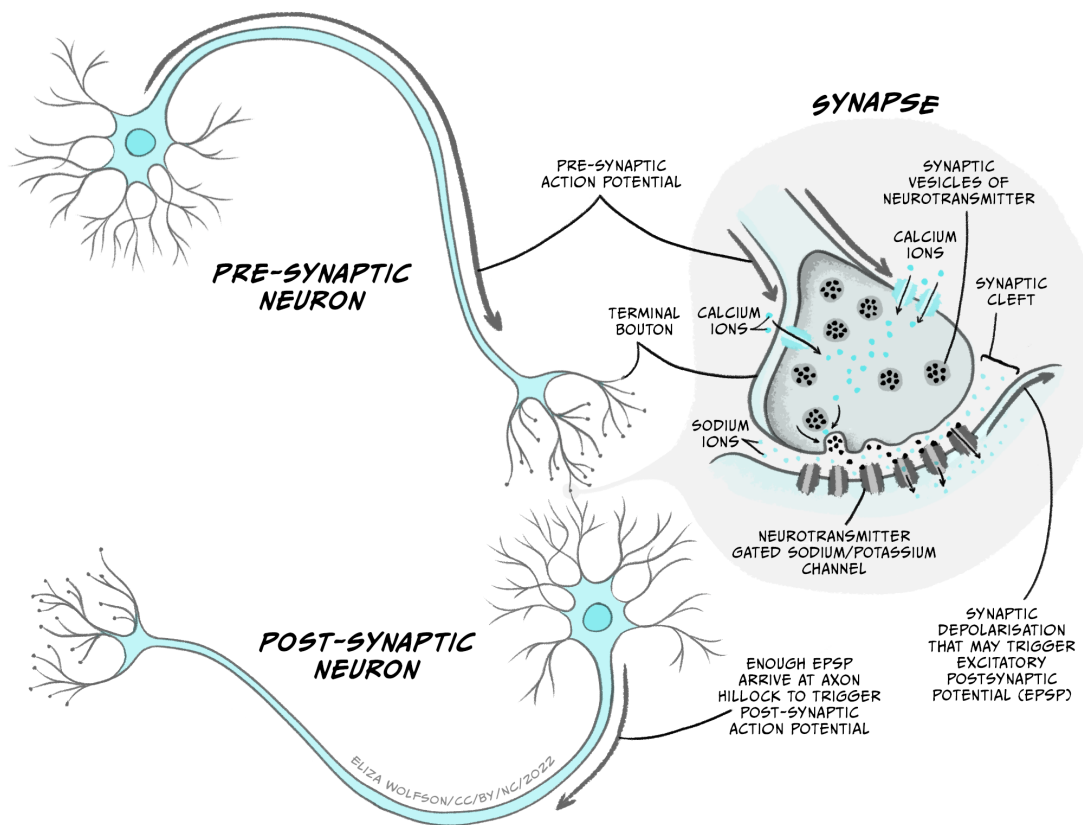


Figure 2: Neural Communication

Image credit: <https://doi.org/10.20919/ZDGF9829/5>

So, how do these incredible neurons actually communicate with each other? It's a fascinating electrochemical process. When a neuron receives enough stimulation, it generates an electrical impulse called an action potential. Think of it as a rapid, all-or-nothing electrical signal that travels quickly down the axon. This impulse is generated when the neuron's internal electrical charge reaches a specific threshold, causing a quick depolarization and then repolarization. Once the action potential reaches the axon terminals, it triggers the release of those chemical messengers we just mentioned, the neurotransmitters. These neurotransmitters are stored in tiny sacs called vesicles within the axon terminals. They are then released into the synapse, that tiny gap between neurons. Once in the synapse, they diffuse across and bind to specific receptors on the dendrites or cell body of the next neuron, the post-synaptic neuron. This binding can either excite that next neuron, making it more likely to fire its own action potential, or inhibit it, making it less likely to fire. This precise chemical signaling ensures information is transmitted efficiently across the nervous system.

Functional Classes of Neurons

- There are three main functional classes of neurons based on their role in the **Central Nervous System (CNS)** The central nervous system functions as the 'command center' for human behavior, comprising the brain and spinal cord, and forms the center of activity for the integration and organization of sensory and motor information.:
- **1. Sensory Neurons (Afferent Neurons)** Nerve cells that send neural impulses to the CNS. They receive information from sensory receptors and convert signals into electrical impulses. They are unipolar with one axon and no dendrites.):
 - Send neural impulses **to the CNS**.
 - Receive information from sensory receptors, converting signals into electrical impulses.
 - Are unipolar Having one axon and no dendrites; characteristic structure of sensory neurons. (one axon, no dendrites); cell body mostly in the peripheral nervous system.
 - **Helpful Tip:** Afferent neurons Arrive at the CNS.

Types of neurons

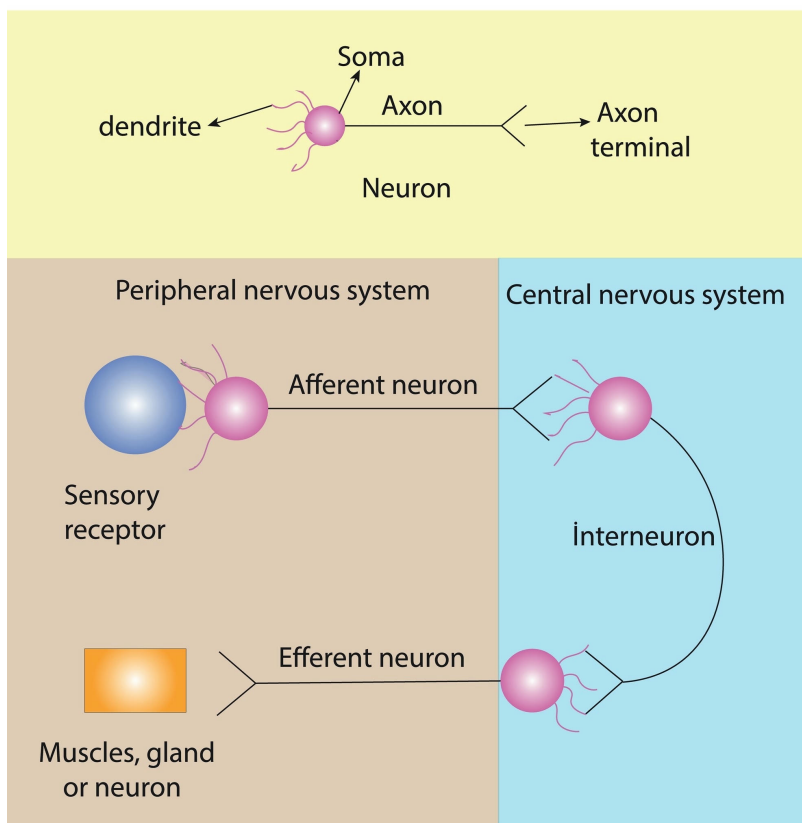


Figure 3: Functional Classes of Neurons

Now, let's talk about the different kinds of neurons, which we can classify based on their function in sending and receiving information to, from, and within the central nervous system, or CNS. As you can see illustrated in Figure 4.2, there are three main functional classes of neurons.

First, sensory neurons, also known as afferent neurons, are responsible for sending neural impulses to the CNS. They receive information from various sensory receptors throughout the

body, acting almost like transducers, converting sensory signals into electrical signals for transmission along neural pathways. A unique structural feature of sensory neurons is that they are unipolar, meaning they have only one axon and no dendrites, with their cell body and most of the axon located in the peripheral nervous system before entering the CNS.

Functional Classes of Neurons (continued)

- There are three main functional classes of neurons based on their role in the **Central Nervous System (CNS)**:

- **2. Motor Neurons (Efferent Neurons)** Nerve cells that send neural impulses from the CNS to skeletal muscle fibers, crucial for movement control.):

- Send neural impulses *from* the CNS to skeletal muscle fibers, crucial for movement control.
- **Alpha motor neurons** Motor neurons found predominantly in the spinal cord that connect directly with skeletal muscle fibers and serve as the functional unit of motor control.: Found mostly in the spinal cord, directly connect to skeletal muscle fibers.
- **Gamma motor neurons**: Supply intrafusal fibers Specialized muscle fibers within skeletal muscles that are supplied by gamma motor neurons and are important for muscle spindle function. within skeletal muscles.
- **Helpful Tip**: Efferent neurons Exit the CNS.

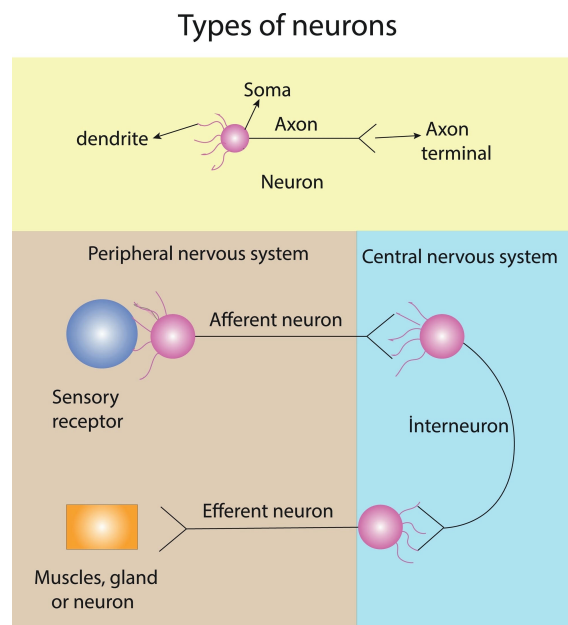


Figure 4: Functional Classes of Neurons

Second, we have motor neurons, also called efferent neurons, which send neural impulses from the CNS to skeletal muscle fibers. This is crucial for movement control. There are two types of motor neurons that influence movement: alpha motor neurons, found mostly in the spinal cord, have many branching dendrites and long axons that directly connect with skeletal muscle fibers.

Gamma motor neurons supply intrafusal fibers within skeletal muscles. A helpful tip to remember the difference: afferent neurons arrive at the CNS, while efferent neurons exit the CNS.

Functional Classes of Neurons (continued)

- There are three main functional classes of neurons based on their role in the **Central Nervous System (CNS)**:
 - **3. Interneurons** Specialized nerve cells that originate and terminate in the brain or spinal cord; they function between axons descending from the brain and synapse on motor neurons, and between the axons from sensory nerves and the spinal nerves ascending to the brain.:
 - Function entirely **within the CNS** (brain or spinal cord).
 - Act as **connections** between descending axons from the brain to motor neurons, and between sensory nerves and ascending spinal nerves.
 - Critical for **integrating signals** within the CNS.
 - Vastly numerous, with an estimated 200,000 interneurons for every sensory neuron.

Types of neurons

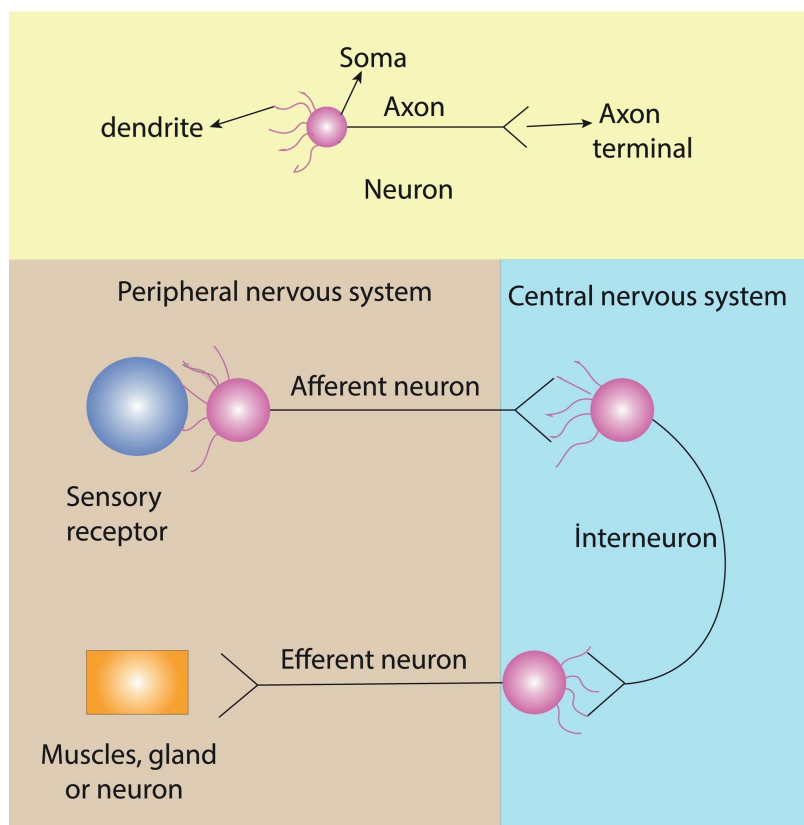


Figure 5: Functional Classes of Neurons

Finally, there are interneurons, which function entirely within the CNS, meaning they originate and terminate in the brain or spinal cord. They act as connections between axons descending

from the brain, synapsing on motor neurons, and between axons from sensory nerves and the spinal nerves ascending to the brain. These interneurons are critical for integrating signals within the CNS. In fact, for every sensory neuron, there are estimated to be ten motor neurons and a staggering 200,000 interneurons, highlighting their vast network.

StudyApp

I encourage you to stop and study the material just covered by visiting our StudyApp.

The StudyApp will open in a new window; once done, close and go back to the main presentation.

Objective Two

Identify and describe the structural components of the brain that are most directly involved in control of movement and describe their primary functions.

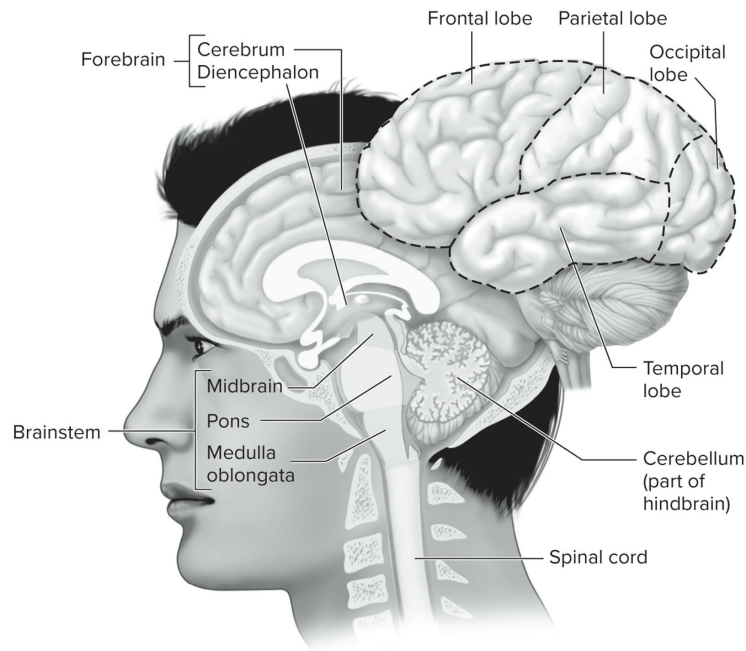
The Central Nervous System (CNS)

- The **Central Nervous System (CNS)** is an incredibly complex system comprising the **brain** and the **spinal cord**.
- It functions as the “**command center**” for **human behavior**.
- The CNS is the **central hub for integrating and organizing all sensory and motor information** that controls our movements.
- Our focus is on the specific CNS parts most directly related to **motor control**, especially **voluntary, coordinated movement**.

Moving on from the individual neurons, let’s look at the bigger picture: the Central Nervous System, or CNS. This incredibly complex system, comprising the brain and the spinal cord, functions as the “command center” for human behavior. It’s the central hub for integrating and organizing all the sensory and motor information that controls our movements. While the CNS is involved in countless processes, our focus today will be on the specific parts most directly related to motor control, especially voluntary, coordinated movement.

Major Structural Components of the Brain

- The brain’s major structural components most directly involved in controlling movement are:
 - The **Cerebrum**
 - The **Diencephalon**
 - The **Cerebellum**
 - The **Brainstem**
- The **cerebrum and diencephalon** are sometimes collectively referred to as the **forebrain**.
- Figure 4.3 illustrates these major divisions and their subcomponents, helping visualize their location within the brain.



(b) Major divisions of adult brain

Figure 6: Major Structural Components of the Brain

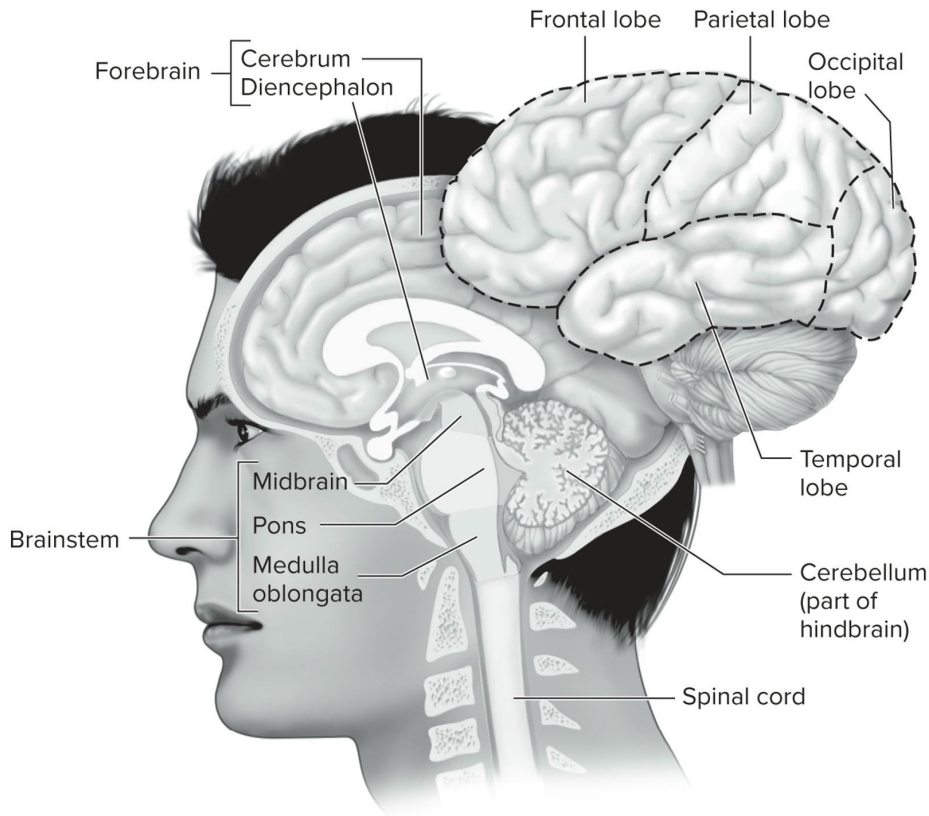
Image credit: (Magill & Anderson, 2016)

Now, let's explore the major structural components of the brain that are most directly involved in controlling movement. As you can see in Figure 4.3, the brain is quite complex, but we'll focus on four key areas: the cerebrum, the diencephalon, the cerebellum, and the brainstem. The cerebrum and diencephalon are sometimes collectively referred to as the forebrain. Figure 4.3 specifically illustrates these major divisions, along with their subcomponents, helping us visualize where each part is located within the brain. We will explore each of these components in more detail, understanding their unique contributions to how we move.

The Cerebrum

- The **cerebrum** is a brain structure in the forebrain that consists of two halves, known as the **right and left cerebral hemispheres**, connected by the **corpus callosum**. is divided into two halves: the **right and left cerebral hemispheres**.
- These hemispheres communicate via the **corpus callosum**, a thick band of nerve fibers that connects the right and left cerebral hemispheres, allowing communication between them., a thick band of nerve fibers.
- The **cerebral cortex** is the distinctive undulating, wrinkly, gray-colored surface covering both hemispheres.
 - It's a thin tissue (2-5 mm thick) made up of nerve cell bodies, referred to as **gray matter**.
 - Its folding creates **gyri** (ridges) and **sulci** (grooves), vastly increasing its surface area.

- Cortical neurons are primarily **pyramidal cells** **Primary cells for sending neural signals from the cortex to other parts of the CNS, named for the pyramid shape of their cell body.**, which send neural signals from the cortex to other CNS parts.
- Underneath the gray matter is **white matter**, an inner layer of myelinated nerve fibers that helps in **rapid signal transmission**.



(b) Major divisions of adult brain

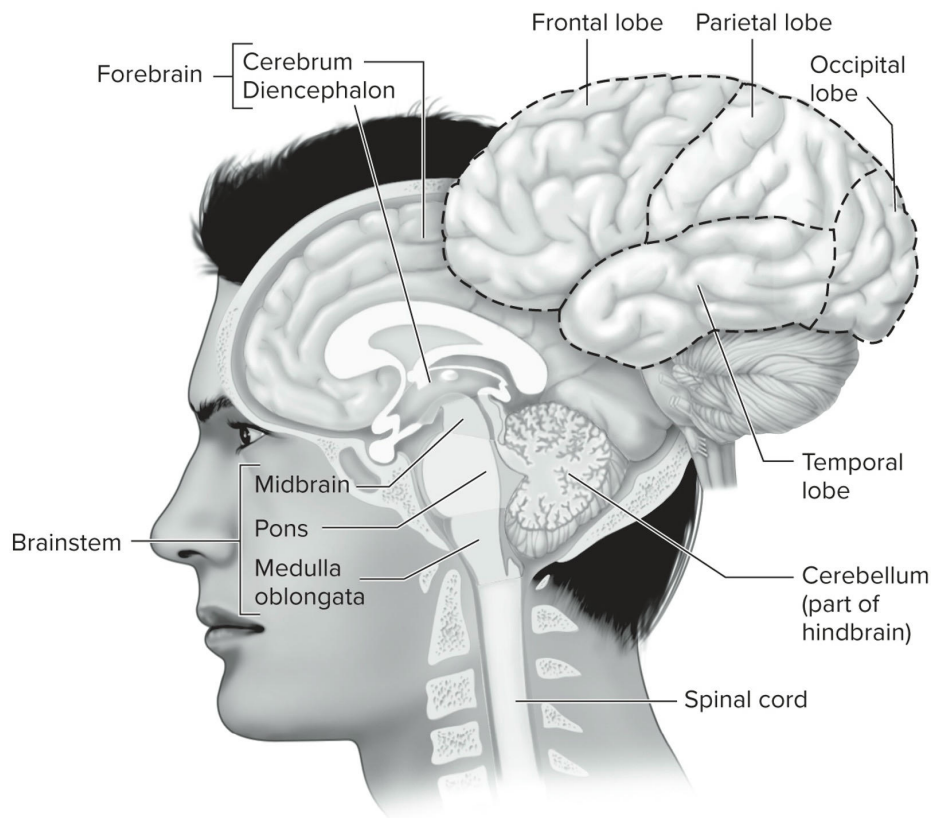
Figure 7: Major Structural Components of the Brain

Image credit: (Magill & Anderson, 2016)

Let's begin with the cerebrum, which is perhaps the most recognizable part of the brain. It's divided into two halves, the right and left cerebral hemispheres, which communicate with each other through a thick band of nerve fibers called the corpus callosum. Covering both hemispheres is the cerebral cortex, which is that distinctive undulating, wrinkly, gray-colored surface you often see in brain images. This cortex is actually a thin tissue, only about two to five millimeters thick, made up of nerve cell bodies and referred to as gray matter. The folding of this tissue creates ridges, called gyri, and grooves, called sulci, which vastly increase its surface area. Cortical neurons within the gray matter are primarily either pyramidal cells, which are the main cells for sending neural signals from the cortex to other CNS parts, or nonpyramidal cells. Underneath this gray matter cortex lies an inner layer of myelinated nerve fibers, known as the white matter, which helps in rapid signal transmission.

Lobes of the Cerebral Cortex

- The cerebral cortex of each hemisphere is divided into four distinct **lobes**, named for the skull bones closest to them:
 - The **Frontal Lobe**: Located at the front of the brain, anterior to the central sulcus. It is incredibly important for the control of **voluntary movement**, including planning and executing actions.
 - The **Parietal Lobe**: Situated just behind the central fissure. It is a key brain center for **perception** and for **integrating sensory information** from different parts of the body.
 - The **Occipital Lobe**: The most posterior lobe of the cortex. It contains areas vital for **visual perception**.
 - The **Temporal Lobe**: Located just below the lateral fissure. It plays important roles in **memory, abstract thought, and judgment**.



(b) Major divisions of adult brain

Figure 8: Major Structural Components of the Brain

Image credit: (Magill & Anderson, 2016)

The cerebral cortex of each hemisphere is further divided into four distinct lobes, named for the skull bones closest to them. Looking at Figure 4.3 again, you can clearly see these divisions. The frontal lobe is located at the front of the brain, anterior to the central sulcus. This area is incredibly important for the control of voluntary movement, including planning and executing actions. Next,

we have the parietal lobe, situated just behind the central fissure. This lobe is a key brain center for perception and for integrating sensory information from different parts of the body. Moving to the back of the brain, the occipital lobe is the most posterior lobe of the cortex. As you might guess, this lobe contains areas vital for visual perception. Finally, located just below the lateral fissure, the temporal lobe plays important roles in memory, abstract thought, and judgment. Each of these lobes contributes uniquely to our overall brain function, particularly in how we perceive and interact with our environment through movement.

Sensory Cortex and Association Areas

- **Sensory Cortex Areas:**

- Located posterior to the central sulcus, receiving specific types of sensory information via sensory nerves.
- Includes a **somatic sensory area** processing pain, temperature, and pressure from the body.
- Due to proximity and interconnectedness with motor areas, often referred to as the **sensori-motor cortex**.

- **Association Areas:**

- Crucial for **higher-level processing**, lying adjacent to specific sensory areas (parietal, temporal, occipital lobes).
- They “**associate**” or **connect information from different sensory cortex areas**, integrating various types of sensory input.
- Connect with other cortex regions for seamless interaction between perception and **higher-order cognitive functions**.
- Vital for **complex decision-making related to movement**, such as in choice reaction time situations.

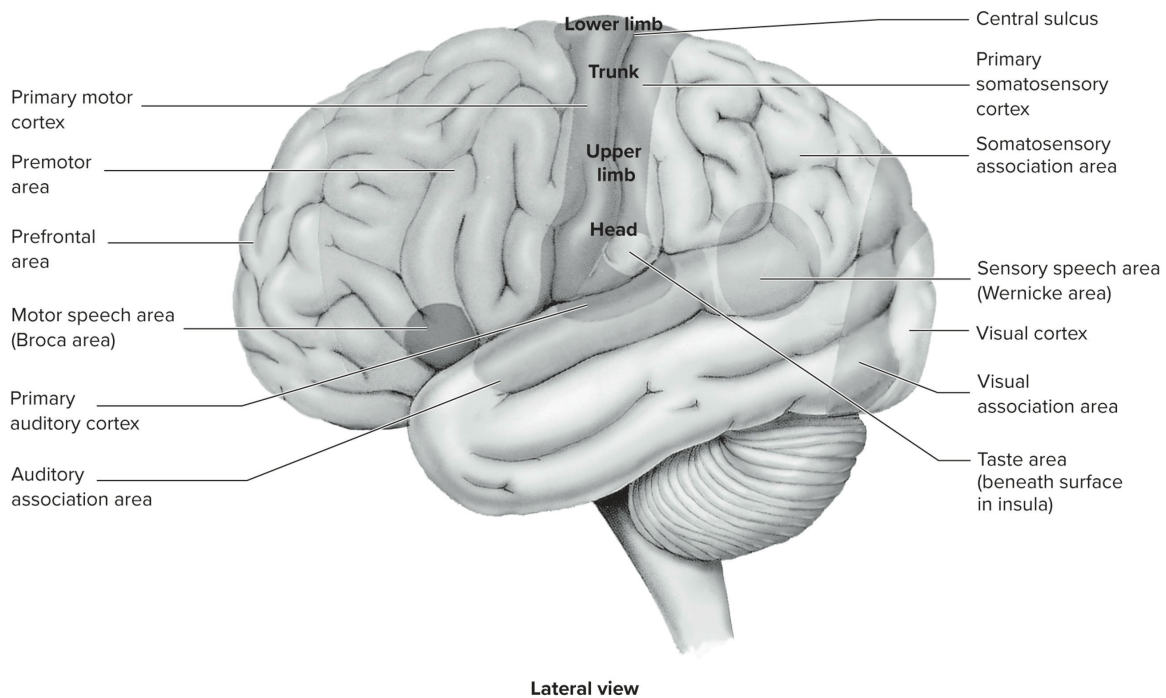


Figure 9: Sensory Cortex and Association Areas

Image credit: (Magill & Anderson, 2016)

Beyond the basic lobes, the cerebral cortex has specific areas dedicated to sensory processing. As shown in Figure 4.4, the sensory cortex areas are located posterior to the central sulcus. Each of these areas receives specific types of sensory information transmitted via sensory nerves. For instance, Figure 4.4 highlights sensory-specific regions for vision, taste, and speech. It also shows a somatic sensory area which processes information like pain, temperature, and pressure from the body. Notice how closely these sensory areas are situated to the motor areas of the cortex. Because of this proximity and their interconnected functions, these areas are often referred to as the sensorimotor cortex. Additionally, association areas are crucial for higher-level processing. These areas lie adjacent to each specific sensory area, primarily in the parietal, temporal, and occipital lobes. The term “association” perfectly describes their function: they “associate” or connect information from different sensory cortex areas. This means they integrate various types of sensory input, even from different parts of the body. Furthermore, these association areas connect with other cortex regions, allowing for a seamless interaction between perception and higher-order cognitive functions. For example, in a choice reaction time situation, these areas are where your brain might transition from perceiving the options to initiating the appropriate action. This makes them vital for complex decision-making related to movement.

Motor Control Areas of the Cerebral Cortex

- Several areas within the cerebral cortex are particularly active in the control of movement:

- **Primary Motor Cortex:** Found in the frontal lobe, anterior to the central sulcus. Critical for **initiating movements** and **coordinating fine motor skills** (e.g., typing) and postural coordination.
- **Premotor Area:** Anterior to the primary motor cortex. Essential for **organizing movements before they are initiated** and maintaining **rhythmic coordination during movement**. Also plays a role in benefits from observing actions.
- **Supplementary Motor Area (SMA):** On the medial surface of the frontal lobe. Vital for controlling **sequential movements** and for the overall **preparation and organization of movement**.
- **Parietal Lobe:** A critical cortical area for **voluntary movement control**. Integrates movement preparation and execution processes by interacting with premotor cortex, primary motor cortex, and SMA before and during movement (e.g., visual attention, grasping).

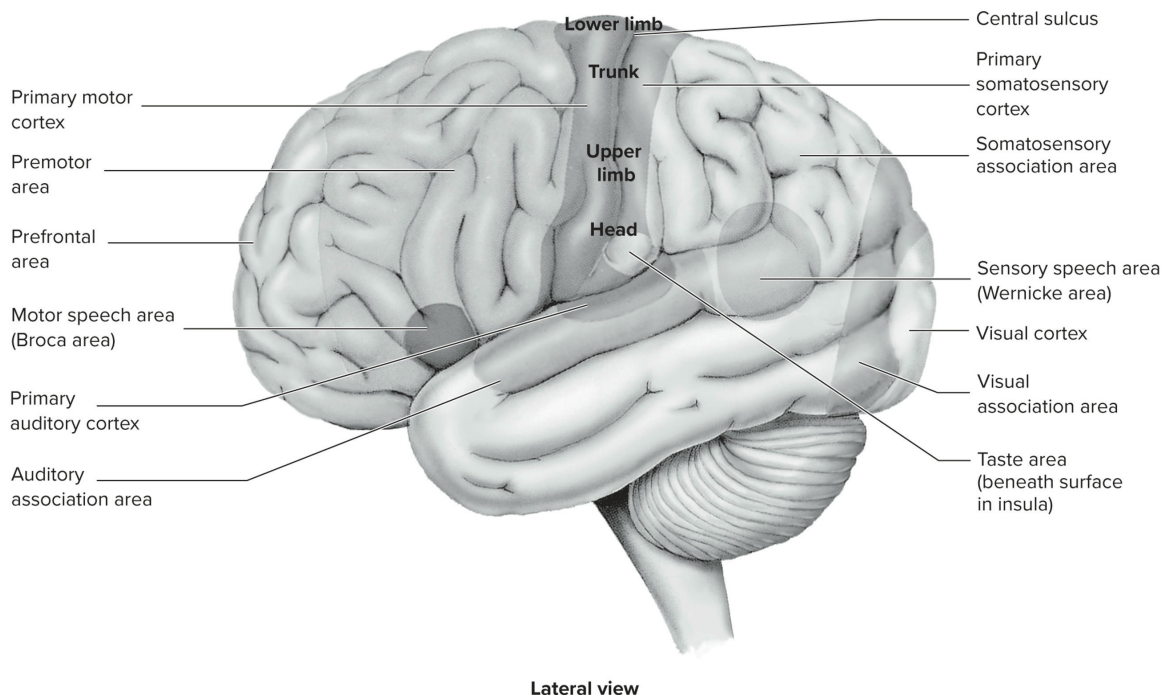


Figure 10: Sensory Cortex and Association Areas

Image credit: (Magill & Anderson, 2016)

Within the cerebral cortex, several areas are particularly active in the control of movement. We can see these areas highlighted in Figure 4.4, alongside the sensory functions we just discussed. First, the primary motor cortex is found in the frontal lobe, just anterior to the central sulcus. This area contains motor neurons that send axons directly to specific skeletal muscles throughout the body. It is absolutely critical for initiating movements and for coordinating movements required for fine motor skills, like the precise finger movements needed for typing or playing the piano. It also helps control and learn postural coordination. Second, located anterior to the primary motor cortex, is the premotor area. This region is essential for organizing movements before they are initiated and for maintaining rhythmic coordination during movement. This allows for smooth

transitions between movements in sequential skills, such as typing or piano playing. Interestingly, the premotor cortex also plays a key role in the benefits we get from observing someone else perform an action. Third, the supplementary motor area (SMA) is situated on the medial surface of the frontal lobe. The SMA is vital for controlling sequential movements and for the preparation and organization of movement overall. Finally, the parietal lobe, which we discussed earlier for its sensory integration role, has also been identified as a critical cortical area for voluntary movement control. It plays a significant role in integrating movement preparation and execution processes by interacting with the premotor cortex, primary motor cortex, and SMA both before and during movement. For example, it's involved in visual attention, tracking moving targets, and grasping. So, you can see how these areas work together in a complex network to allow for coordinated and intentional movement.

Brain-Computer Interfaces (BCIs)

- **Brain-Computer Interfaces (BCIs)** offer incredible potential for individuals with neurological disorders who are unable to move physically .
- BCIs work by reading the **electrical activity (brain waves)** that occurs in the brain when a person ***imagines moving*** a body part .
- They can be part of an EEG skull cap or, in more advanced versions, implanted directly inside the brain .
- With training, BCIs can enable individuals to perform functional activities such as:
 - Typing or manipulating small robots .
 - Moving a cursor to communicate phrases.
 - Maneuvering a prosthetic hand to grasp objects .
 - Driving real and simulated wheelchairs .
- The success of BCI research demonstrates its strong potential to benefit a wide range of **physical disabilities** in the future.

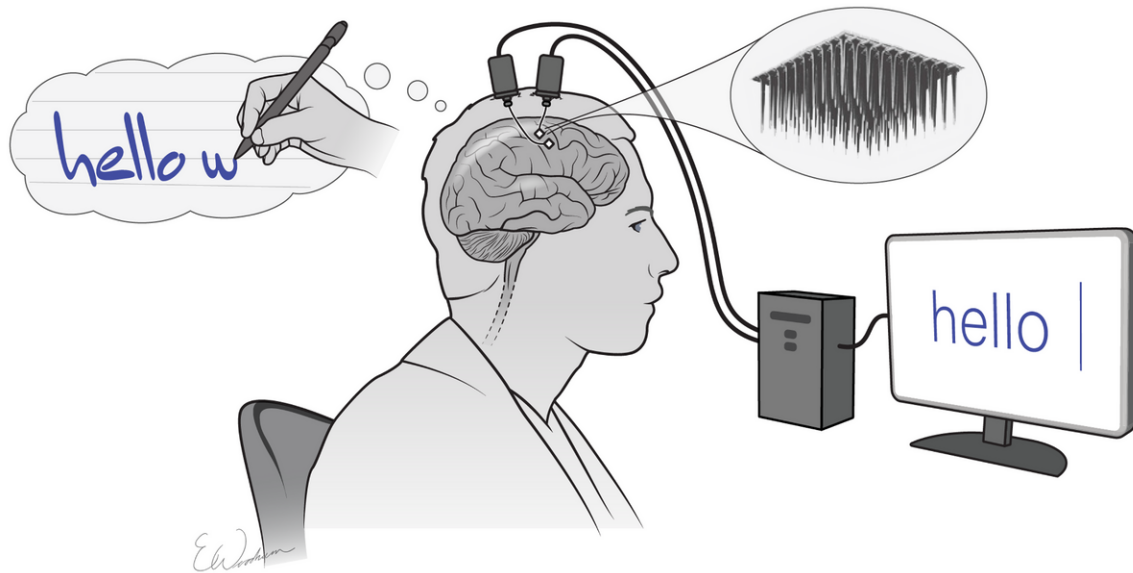


Figure 11: Brain-Computer Interface

Image credit: <https://bit.ly/4fQ9BVK>

Building on our understanding of brain activity, let's look at an exciting technological advancement: Brain-Computer Interfaces, or BCIs. This technology offers incredible potential for individuals with neurological disorders who are unable to move physically. BCIs work by taking advantage of the electrical activity that occurs in the brain when a person imagines moving a body part. Essentially, they read these brain waves. Some BCIs are part of an EEG skull cap, while more advanced versions can actually be implanted directly inside the brain. With training, these devices can provide a means for individuals to perform certain functional activities. For example, there have been success stories where patients with paralysis were trained to use a BCI to type, manipulate a small robot, or even move a cursor on a computer screen to communicate phrases like "I'm hungry". More recent research has shown patients using implanted BCIs to maneuver a prosthetic hand to grasp and move objects. Others have successfully used EEG-based BCIs to drive real and simulated wheelchairs. The continued success of BCI research demonstrates its strong potential to benefit a wide range of physical disabilities in the future. It's a truly remarkable example of how understanding brain function can lead to innovative solutions.

Subcortical Components: The Basal Ganglia

- The **basal ganglia**, also known as the basal nuclei, are collections of four large nuclei buried deep within the cerebral hemispheres: the caudate nucleus, the putamen, the substantia nigra, and the globus pallidus.
- They receive neural information from the cerebral cortex and brainstem, with motor neural output primarily to the brainstem.
- The basal ganglia play critical roles in the **planning and initiation of movement**, the **control of antagonist muscles during movement**, and the **control of force**.
- Much is known about their role from studying **Parkinson's disease** A **basal ganglia disorder caused by a lack of dopamine production due to degeneration of neurons in the substantia nigra, leading to bradykinesia (slow movements), akinesia (reduced movement), tremor, and muscular rigidity.**, a basal ganglia disorder caused by a **lack of dopamine production** due to degeneration of neurons in the substantia nigra.
- This leads to movement difficulties including **bradykinesia** Slow movements, a characteristic symptom of Parkinson's disease resulting from basal ganglia dysfunction. (slow movements), **akinesia** Reduced amount of movement, a characteristic symptom of Parkinson's disease resulting from basal ganglia dysfunction. (reduced movement), **tremor**, and **muscular rigidity**.

BASAL GANGLIA

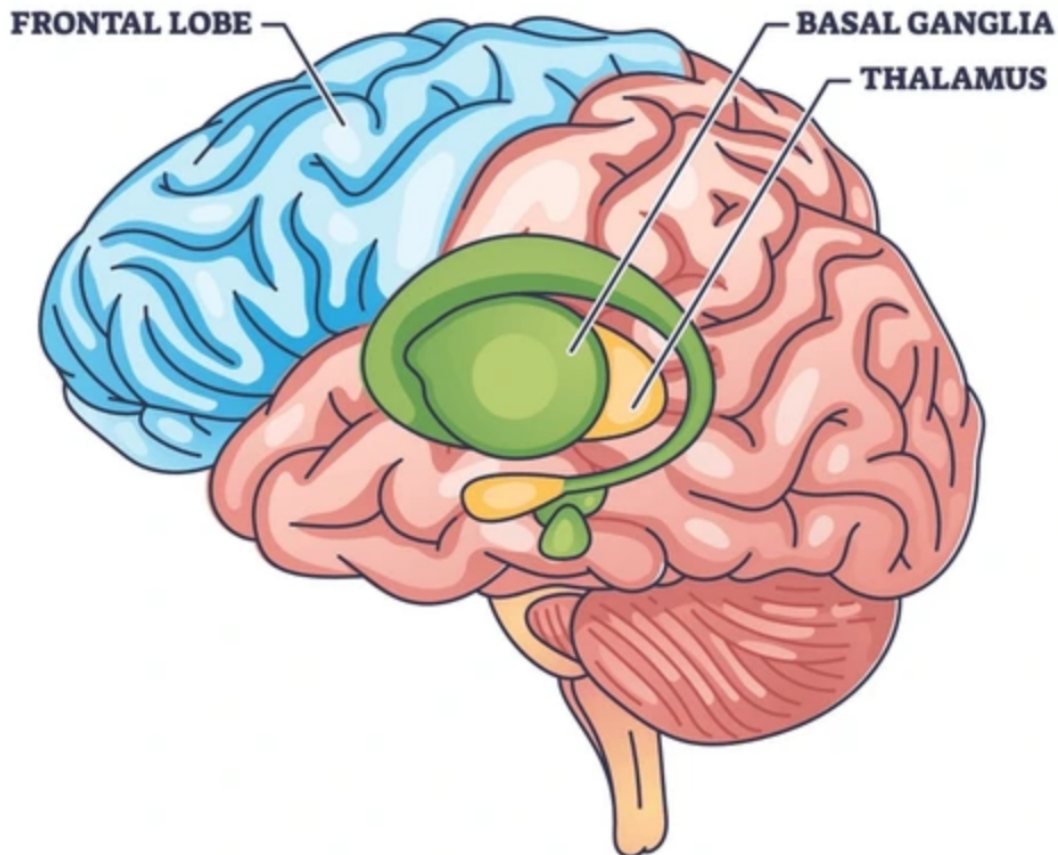


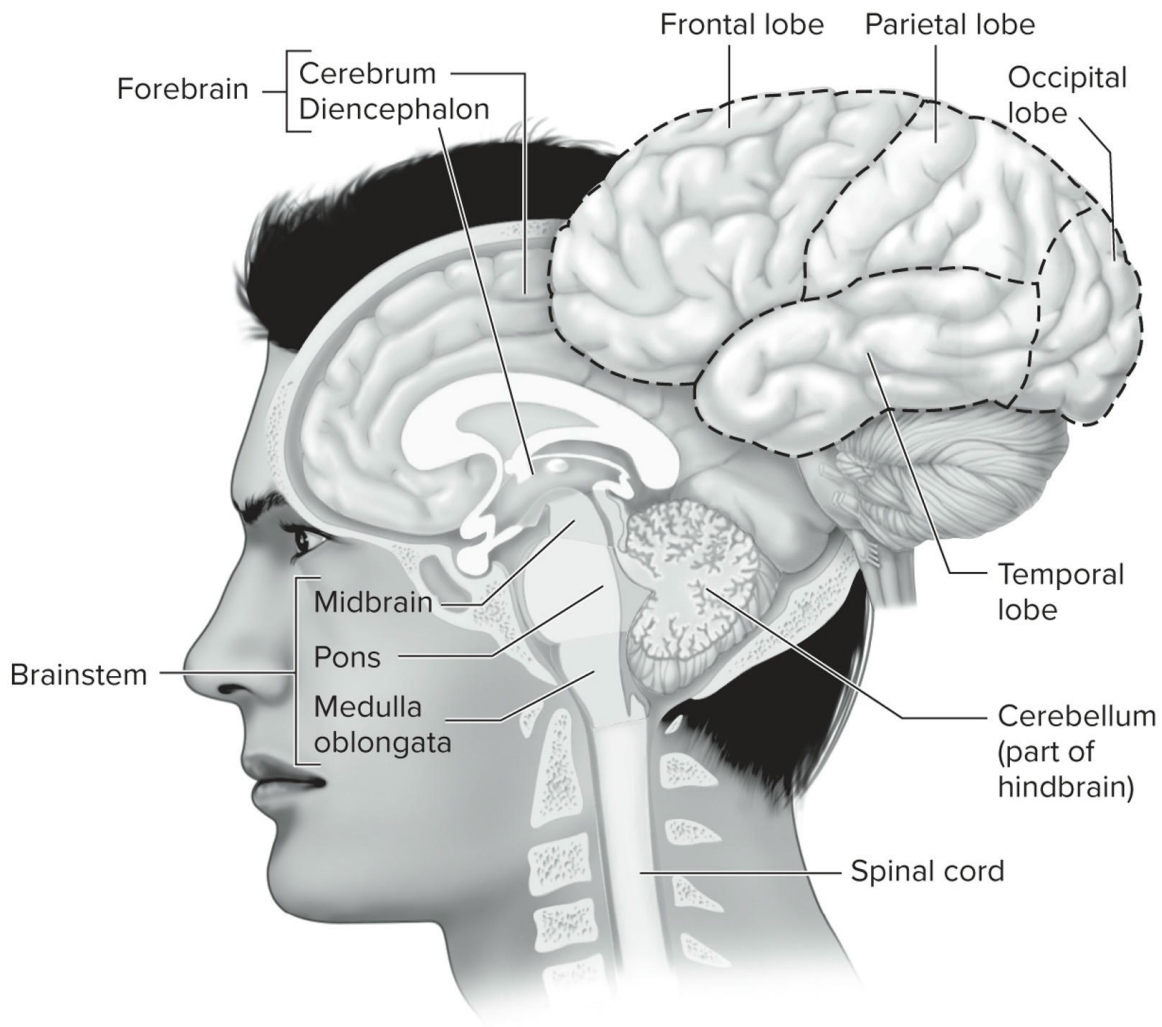
Figure 12: Basal Ganglia

Beyond the cerebral cortex, several important subcortical components also play crucial roles in movement control. One such component is the basal ganglia, also known as the basal nuclei. These are collections of four large nuclei buried deep within the cerebral hemispheres: the caudate nucleus, the putamen, the substantia nigra, and the globus pallidus. The basal ganglia receive neural information from both the cerebral cortex and the brainstem, and their motor neural output primarily goes to the brainstem. There's an important loop of information flow involving the basal ganglia, the thalamus, and the motor cortex that is essential for motor control. The basal ganglia play critical roles in the planning and initiation of movement, the control of antagonist muscles during movement, and the control of force. Much of what we know about the basal ganglia's role comes from studying conditions like Parkinson's disease. Parkinson's is a basal ganglia disorder primarily caused by a lack of dopamine production. Dopamine is a crucial neurotransmitter for normal basal ganglia function, and in Parkinson's, the neurons in the substantia nigra that produce dopamine degenerate, leading to reduced production. This results in several movement

difficulties, including bradykinesia (slow movements), akinesia (reduced movement), tremor, and muscular rigidity. Patients often struggle with initiating walking or writing, showing the direct impact of basal ganglia dysfunction.

Subcortical Components: The Diencephalon

- The **diencephalon** is strategically located between the cerebrum and the brainstem .
- It contains two important groups of nuclei :
 - The **Thalamus** A crucial relay station that receives and integrates most sensory neural inputs from the spinal cord and brainstem, then passes this information to the cerebral cortex. Also plays a significant role in controlling attention, mood, and pain perception.:
 - Acts as a crucial **relay station** .
 - Receives and integrates most sensory neural inputs from the spinal cord and brainstem, then passes this information to the cerebral cortex .
 - Also plays a significant role in controlling attention, mood, and pain perception .
 - The **Hypothalamus** Arguably the most critical brain center for controlling the endocrine system (hormone system), regulating overall body homeostasis including body temperature, hunger, thirst, and physiological responses to stress.:
 - Arguably the most critical brain center for controlling the **endocrine system** (hormone system) .
 - Regulates overall **body homeostasis**, including body temperature, hunger, thirst, and physiological responses to stress.



(b) Major divisions of adult brain

Figure 13: Diencephalon

Another key component of the forebrain is the diencephalon, which is strategically located between the cerebrum and the brainstem. It contains two important groups of nuclei: the thalamus and the hypothalamus. The thalamus acts as a crucial relay station. It receives and integrates most of the sensory neural inputs coming from the spinal cord and brainstem, and then passes this information along to the cerebral cortex for further processing. Beyond its relay function, the thalamus also plays a significant role in controlling attention, mood, and our perception of pain. Just below the thalamus lies the hypothalamus. This is arguably the most critical brain center for controlling the endocrine system—our hormone system—and for regulating overall body homeostasis. This includes essential functions like maintaining body temperature, regulating hunger and thirst, and controlling physiological responses to stress. Both the thalamus and hypothalamus are vital for various bodily functions, contributing to both conscious and unconscious processes.

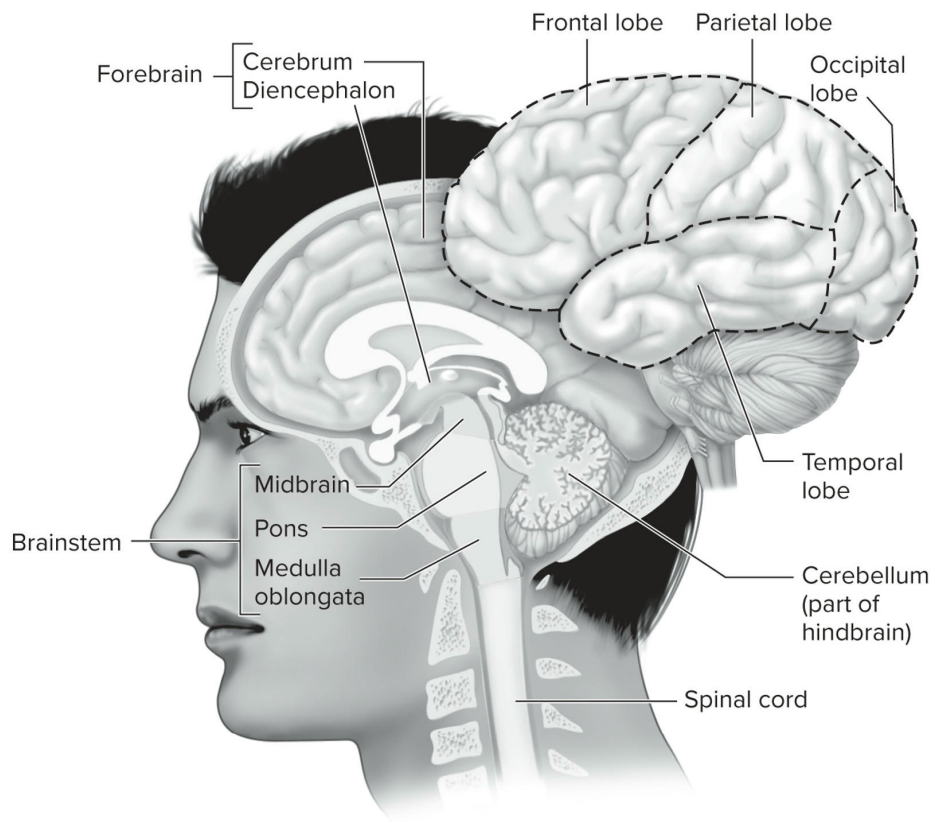
The Cerebellum

- The **cerebellum** is located behind the cerebral hemispheres and directly attached to the brainstem.
- It is covered by the **cerebellar cortex** (divided into two hemispheres) and contains deep cerebellar nuclei.
- It receives sensory neural pathways from the spinal cord, cerebral cortex, and brainstem.
- Its motor neural pathways connect to the spinal cord and send output to the motor cortex via the thalamus (cerebello-thalamo-cortico pathway).
- The cerebellum plays a **key role in the execution of smooth and accurate movements**; damage often results in clumsy movements.
- A major function is as a **movement error detection and correction system** :
 - Receives an “efference copy” a copy of intended movement signals that the cerebellum receives to compare with sensory information and signal needed adjustments to movements in progress.” of intended movement signals.
 - Compares this with sensory information to signal needed adjustments to movements in progress.
- It is also active in **eye-hand coordination, movement timing, force control, and posture**.
- Critically involved in the **learning of motor skills** through interaction with the cerebral cortex.

Next, let's explore the cerebellum, a fascinating brain structure located behind the cerebral hemispheres and directly attached to the brainstem. The cerebellum is covered by the cerebellar cortex, which, like the cerebral cortex, is divided into two hemispheres. Beneath this cortex, you'll find white matter embedded with deep cerebellar nuclei, including the red nucleus and the oculomotor nucleus. The cerebellum receives sensory neural pathways from three main regions: the spinal cord, the cerebral cortex, and the brainstem. Its motor neural pathways connect to the spinal cord via the red nucleus and the descending reticular formation. There's also an important pathway, the cerebello-thalamo-cortico (CTC) pathway, which sends output to the motor cortex via the thalamus. The cerebellum plays a key role in the execution of smooth and accurate movements. Damage to this area often results in clumsy movements, highlighting its importance. A major function of the cerebellum in motor control is acting as a movement error detection and correction system. It receives a copy of the intended movement signals sent from the motor cortex to the muscles—often called an “efference copy”. It then compares this motor information with sensory information it receives. This comparison allows the cerebellum to signal any needed adjustments to movements already in progress, helping us achieve our intended movement goals accurately. Furthermore, the cerebellum is active in controlling various other movement activities, such as eye-hand coordination, movement timing, force control, and posture. It is also very much involved in the learning of motor skills by interacting with areas of the cerebral cortex. While its specific role in cognition is still being understood, increasing evidence suggests it's also involved in language, visual-spatial processes, and working memory.

The Brainstem

- The **brainstem** is located directly under the cerebral hemispheres and connects to the spinal cord.
- It contains three main areas involved in motor control :
 - **Pons**: Located at the top, acts as a “**bridge**” between the cerebral cortex and the cerebellum. Influences chewing, swallowing, salivating, breathing, and balance.
 - **Medulla (Medulla Oblongata)**: An extension of the spinal cord. Regulates crucial internal physiological processes like **respiration** and **heartbeat**. It is a critical site where sensory and motor corticospinal tracts **cross over the body’s midline**, meaning one side of the brain controls movements on the opposite side.
 - **Reticular Formation**: A complex network of nuclei and nerve fibers, serving as a vital link between sensory receptors and motor control centers. Its primary role is as an **integrator of sensory and motor neural impulses**, influencing CNS activity to affect skeletal muscle.



(b) Major divisions of adult brain

Figure 14: Brainstem

Continuing our tour of the brain, we arrive at the brainstem, which is located directly under the cerebral hemispheres and connects to the spinal cord. This vital structure contains three main areas significantly involved in motor control. First, the pons, located at the top of the brainstem, acts like a bridge between the cerebral cortex and the cerebellum. Various neural pathways pass through or terminate in the pons, influencing functions like chewing, swallowing, salivating, and

breathing. It also appears to play a role in maintaining balance. Second, the medulla, also known as the medulla oblongata, is essentially an extension of the spinal cord. It serves as a regulatory agent for crucial internal physiological processes, such as respiration—where it interacts with the pons—and heartbeat. In terms of voluntary movement, the medulla is a critical site where the corticospinal tracts of the sensory and motor neural pathways cross over the body’s midline. This means that information from one side of the brain controls movements on the opposite side of the body. Finally, the reticular formation is the third important area within the brainstem. This complex network of nuclei and nerve fibers is a vital link between sensory receptors throughout the body and the motor control centers of the cerebellum and cerebral cortex. Its primary role in movement control is as an integrator of sensory and motor neural impulses. The reticular formation can access all sensory information and directly influence the CNS to either inhibit or increase its activity, which in turn affects skeletal muscle activity.

The Limbic System

- Start by watching this brief video overview of the limbic system: [Limbic System Overview](#).
- The **limbic system** is not a single structure but an important group of interconnected brain structures.
- It includes parts of the frontal and temporal lobes of the cerebral cortex, as well as the thalamus and hypothalamus, and connecting nerve fibers.
- While often associated with emotions and visceral behaviors, the limbic system also plays **important roles in the learning of motor skills**.
- This highlights how various brain regions work together to support movement and learning, even those not traditionally thought of as “motor” centers.

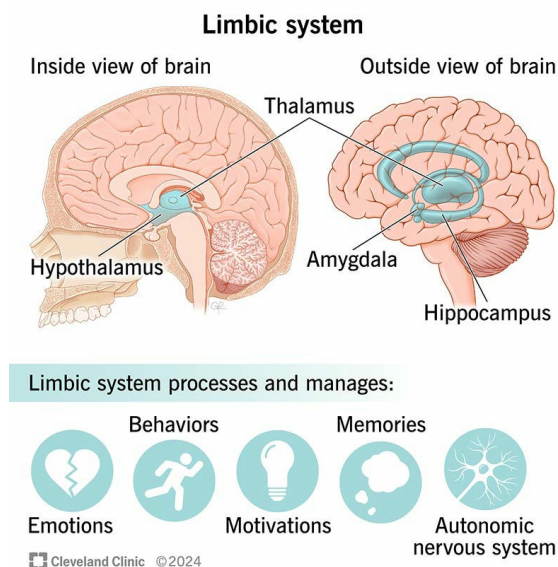


Figure 15: Limbic System

Before we move to the spinal cord, let’s briefly touch upon the limbic system. This isn’t a single structure, but rather an important group of interconnected brain structures. It includes parts of the

frontal and temporal lobes of the cerebral cortex, as well as the thalamus and hypothalamus, along with nerve fibers that connect these parts and other CNS structures. While often associated with emotions and visceral behaviors, the limbic system also plays important roles in the learning of motor skills. This highlights how various brain regions work together, even those not traditionally thought of as “motor” centers, to support our ability to move and learn.

We should also discuss the plasticity of the nervous system, which underlies recovery after injury and the improvements seen with training. Neuroplasticity refers to the brain and spinal cord’s ability to reorganize connections and change in response to experience, practice, or injury. This can involve sprouting of new connections, strengthening of existing synapses, or even recruitment of alternative neural pathways to perform lost functions. Plasticity is key to rehabilitation and motor learning, and deliberate, structured practice can harness this capacity to produce meaningful recovery.

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Objective Three

Identify and describe the neural pathways that make up the ascending and descending tracts

The Spinal Cord

- The **spinal cord** is a complex system critically involved in **motor control processes** and interacts with other systems.
- It is primarily composed of **gray matter** and **white matter**.
- The **gray matter** forms a distinctive butterfly- or H-shape in the central portion:
 - **Dorsal horns** (posterior pair): Contain cells involved in transmitting **sensory information** from sensory neurons.
 - **Ventral horns** (anterior pair): Contain cell bodies of **alpha motor neurons**, whose axons terminate on skeletal muscles to initiate movement.
 - Also contains **interneurons** (e.g., Renshaw cells) that can inhibit alpha motor neuron activity.
- The spinal cord also has **dorsal and ventral roots** where nerves enter and exit, forming spinal nerves.
- It is encased within a **vertebra** for protection.

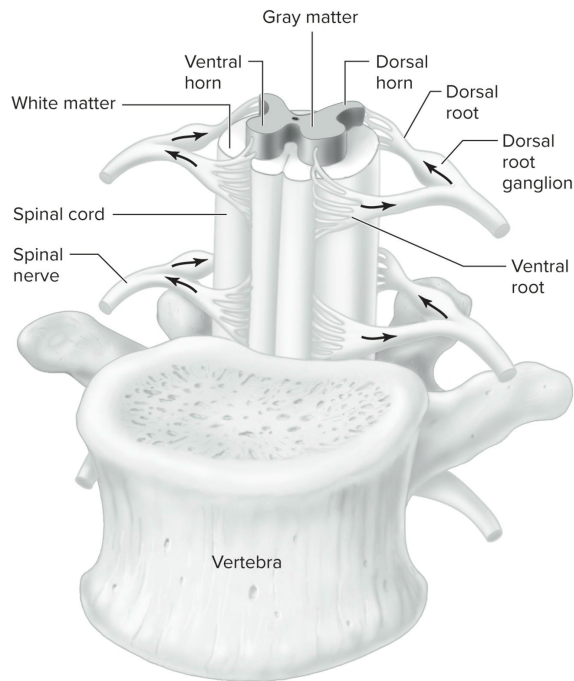


Figure 16: Spinal Cord

Now, let's explore the spinal cord, a complex system that is far more than just a simple relay cable for messages to and from the brain. It interacts with various other systems and is critically involved in motor control processes. The spinal cord is primarily composed of gray matter and white matter. As shown in Figure 4.5, the gray matter forms a distinctive butterfly- or H-shape in the central portion of the cord. This gray matter mainly consists of the cell bodies and axons of neurons that reside within the spinal cord. Protruding from the gray matter are two vital pairs of "horns". The posterior pair, known as the dorsal horns, contains cells involved in transmitting sensory information. Sensory neurons from various sensory receptors in the body synapse on these dorsal horn neurons. The anterior pair of horns, called the ventral horns, contains the cell bodies of alpha motor neurons, whose axons extend out to terminate on skeletal muscles, initiating movement. In addition to these, the spinal cord also contains interneurons, which are primarily located in the ventral horn. Some of these interneurons, known as Renshaw cells, can influence the neural activity of alpha motor neurons by inhibiting their activity, helping regulate when these motor neurons can fire again. Figure 4.5 also clearly illustrates the dorsal and ventral roots, which are where nerves enter and exit the spinal cord, forming spinal nerves. It also shows how the spinal cord is encased within a vertebra for protection.

Another important concept is the hierarchical control of movement, where higher centers plan and decide on actions and lower centers execute and refine them. In this model, cortical regions are responsible for planning and initiating voluntary actions while subcortical regions like the brainstem and spinal circuits implement routine or reflexive components. This hierarchy is flexible, however; with practice, some actions can shift toward more automatic control requiring less conscious attention.

Spinal Cord Pathways: Ascending (Sensory) Tracts

- **Sensory neural pathways**, also known as **ascending tracts** **Sensory neural pathways in the spinal cord and brainstem that connect with the various sensory areas of the cerebral cortex and cerebellum.**, transmit neural information from the body **to the brain**.
- They pass through the spinal cord and brainstem, connecting with sensory areas of the cerebral cortex and cerebellum.
- These tracts are specialized to carry signals from specific types of sensory receptors (e.g., proprioceptionThe sense of body position and movement in space, providing information about where body parts are located relative to each other and the environment., touch, pain).
- Two important ascending tracts for voluntary movement control are:
 - The **Dorsal Column**: Primarily carries information about **proprioception, touch, and pressure**.
 - The **Anterolateral System**: Transmits **pain and temperature** information, along with some touch and pressure.
- Both the dorsal column and anterolateral system tracts enter the thalamus before continuing to the cerebral cortex.
- **Spinocerebellar tracts** **Ascending tracts that are crucial for transmitting proprioception information specifically to the cerebellum.** are crucial for transmitting proprioception information specifically to the **cerebellum**.
- Most ascending tracts **cross over at the brainstem** (decussateTo cross over from one side of the body to the other, as nerve fibers do at the brainstem.), meaning sensory information from the right side of your body is processed in the left side of your brain, and vice versa.

The spinal cord is a highway for neural information, with pathways both ascending to the brain and descending from it. Let's first talk about sensory neural pathways, also called ascending tracts. These tracts pass through the spinal cord and brainstem, connecting with the various sensory areas of the cerebral cortex and cerebellum. These pathways are typically made up of a sequence of two or three neurons, with the first neuron in the chain synapsing with a sensory neuron outside the spinal cord. Most of these tracts are specialized to carry neural signals from specific types of sensory receptors, such as those for proprioception, touch, or pain. Two important ascending tracts that transmit sensory information to the sensory cortex for voluntary movement control are the dorsal column and the anterolateral system. The dorsal column primarily carries information about proprioception, touch, and pressure. In contrast, the anterolateral system transmits pain and temperature information, along with some touch and pressure. Both of these tracts enter the thalamus before continuing to the cerebral cortex. Additionally, several ascending tracts called the spinocerebellar tracts are crucial for transmitting proprioception information specifically to the cerebellum. Two of these tracts originate in the arms and neck, and two others originate in the trunk and legs. An important point to remember is that most ascending tracts cross over at the brainstem from one side of the body to the other. This means that sensory information from the right side of your body is received and processed in the left side of your brain, and vice versa.

Finally, let's connect these ideas to functional tasks and how understanding neuromotor control informs our approach to teaching and rehabilitation. For example, when teaching a patient to regain balance after a stroke, therapists emphasize task-specific practice, graded challenges, and

sensory feedback to drive plastic changes in the appropriate neural circuits. Similarly, in sports coaching, drills that mimic the sport context and provide immediate feedback accelerate learning by engaging the same neural systems used in actual performance.

Spinal Cord Pathways: Descending (Motor) Tracts

- **Motor neural pathways, called descending tracts** Motor neural pathways that descend from the brain through the spinal cord., originate in the brain and descend through the spinal cord.
- They are classified into two main groups that work together to control movement:
 - **Pyramidal Tract (Corticospinal Tract)** Motor pathways that originate in various parts of the cerebral cortex (60% from the primary motor cortex) and primarily transmit information for the control of fine motor skills. Most fibers cross over to the opposite side of the body at the medulla.:
 - Originates in various parts of the cerebral cortex (60% from the primary motor cortex).
 - Most fibers **cross over (decussate) to the opposite side of the body** at the medulla in the brainstem.
 - Primarily transmits information for the control of **fine motor skills**, like precise finger movements.
 - **Extrapyramidal Tracts (Brainstem Pathways):**
 - Have cell bodies in the brainstem, with axons descending into the spinal cord.
 - Most fibers **do not cross over** to the opposite side of the body.
 - Mainly involved in **postural control** and facilitating or inhibiting hand and finger flexion/extension muscles.

Now, let's discuss the motor neural pathways, which are called descending tracts because they descend from the brain through the spinal cord. These tracts can be broadly classified into two main groups: pyramidal tracts and extrapyramidal tracts. While anatomically distinct, it's important to remember that they are not functionally independent; they work together to control movement. The pyramidal tract, also known as the corticospinal tract, originates in various parts of the cerebral cortex and projects its axons down to the spinal cord. It gets its name from the pyramid shape of its nerve fiber collection as it travels from the cortex. About 60% of these fibers originate in the primary motor cortex. A key feature of the pyramidal tract is that most of its fibers cross over to the opposite side of the body—a process called decussation—at the medulla in the brainstem. This is why the muscles on one side of your body are controlled by the opposite cerebral hemisphere. This tract primarily transmits information involved in the control of fine motor skills, like precise finger movements. In contrast, the extrapyramidal tracts, sometimes referred to as brainstem pathways, have their cell bodies in the brainstem, with axons descending into the spinal cord. Unlike the pyramidal tract, most of these fibers do not cross over to the opposite side of the body. These neural pathways are mainly involved in postural control and in facilitating or inhibiting the muscles involved in the flexion and extension of the hands and fingers. So, while one focuses on fine, contralateral control, the other is more about general posture and ipsilateral coordination.

As a brief summary of the core ideas we've covered, remember that movement arises from interactions among neurons, motor units, the spinal cord, and brain structures such as the motor cortex, basal ganglia, and cerebellum, all coordinated through sensory feedback. These systems work together to plan, initiate, execute, and refine actions, and they are adaptable through mechanisms of plasticity and learning. Keeping these relationships in mind will help you connect basic neurophysiology with practical applications in movement science and rehabilitation.

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Objective Four

Describe a motor unit, the recruitment of motor units, and their relationship to the control of movement

The Motor Unit

- The **motor unit** **The alpha motor neuron and all the muscle fibers it innervates; it serves as the functional unit of motor control for the innervation of the muscles involved in a movement.** is defined as the **alpha motor neuron and all the muscle fibers it innervates.**
- It is the functional unit of motor control for innervating muscles involved in a movement.
- The connection between the alpha motor neuron and skeletal muscle fibers occurs at a specialized synapse called the **neuromuscular junction** **A specialized type of synapse located near the middle of muscle fibers that allows nerve impulses to be transmitted from the nerve fiber to the muscle fibers so that appropriate muscle contraction can occur.**, located near the middle of the muscle fibers.
- This synapse allows nerve impulses to be transmitted directly to muscle fibers, causing them to contract.
- The number of muscle fibers served by one alpha motor neuron varies significantly:
 - For **fine movements** (e.g., eye, larynx), a motor unit may innervate very few muscle fibers (sometimes just one).
 - For **large skeletal muscles** involved in gross motor skills or posture, one motor unit can innervate a large number (up to 700).
- When an alpha motor neuron activates, **all the muscle fibers it connects to will contract simultaneously.**

Bringing our discussion of neural pathways to its ultimate destination for movement, we arrive at the motor unit. This concept, first introduced in the early 20th century, defines the motor unit as the alpha motor neuron and all the muscle fibers it innervates. Essentially, it's the functional unit of motor control for innervating the muscles involved in a movement. As you can see in Figure 4.6, it clearly illustrates a single motor unit consisting of one motor neuron and the several muscle fibers it connects to. The connection between the alpha motor neuron and the skeletal muscle fibers occurs at a specialized synapse called the neuromuscular junction, located near the middle of the muscle fibers. This special synapse allows nerve impulses to be transmitted directly

to the muscle fibers, causing them to contract. The number of muscle fibers served by one alpha motor neuron axon can vary significantly. For fine movements, like those of the eye or larynx, a single motor unit might innervate very few muscle fibers—sometimes even just one per fiber. However, for large skeletal muscles involved in gross motor skills or posture, one motor unit can innervate a large number of muscle fibers, potentially as many as 700. An important principle is that when an alpha motor neuron activates, or “fires,” all the muscle fibers it connects to will contract simultaneously.

Before we finish, consider some broader implications for assessment and intervention. When evaluating motor problems, clinicians often look at patterns of weakness, changes in tone, reflexes, and coordination to infer the level of the nervous system that might be affected. Interventions should be tailored accordingly, using principles of motor learning and neuroplasticity: task specificity, appropriate intensity, meaningful feedback, and progressive challenge. These core ideas form the bridge between neuroscience and practical rehabilitation.

Motor Unit Recruitment and Force Control

- The amount of force a muscle exerts is controlled by **motor unit recruitment**.
- The number of active muscle fibers directly influences the amount of force produced.
- To increase force, the nervous system **increases the number of motor units activated**.
- This process follows the **Henneman size principle**The recruitment process that begins with the smallest, and therefore the weakest, motor units and systematically progresses to the largest, which are the most powerful motor units. Named after the initial reporting of this process by Henneman (1957).:
 - Recruitment begins with the **smallest (weakest) motor units**.
 - It systematically progresses to the **largest (most powerful) motor units** as more force is required.
- This systematic activation allows for precise and graded control over muscle force, whether for a gentle or heavy task.

So, how do we control the amount of force a muscle exerts, given that a motor unit fires all or nothing? The answer lies in motor unit recruitment. The number of muscle fibers active at any given time directly influences the amount of force a muscle can produce. To increase the force, the nervous system increases the number of motor units that are activated. This process of motor unit recruitment follows a very specific procedure known as the Henneman size principle. This principle states that recruitment begins with the smallest motor units, which are also the weakest, and then systematically progresses to the largest and most powerful motor units. This means that for light tasks, only a few small motor units are activated, but for tasks requiring more force, progressively larger and more numerous motor units are recruited. This systematic activation allows for precise and graded control over muscle force, whether you’re gently picking up a feather or lifting a heavy weight.

I encourage you to think about everyday examples that illustrate what we’ve discussed: how practicing a piano piece refines finger control through repeated activation of specific circuits, or how balance training after an injury restores coordinated muscle responses through repeated task

practice. These real-world examples highlight how the nervous system adapts with experience and how learning transfers to functional improvements.

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Objective Five

Describe the basic components of a conceptual hierarchical model that describes the CNS structures and their functions in the control of movement.

Neural Control of Voluntary Movement: A Hierarchical View

- Performing any motor skill begins with a **cognitively derived intent**.
- This intent is implemented into movement through a complex interplay of neurophysiological events and the cooperative interaction of many CNS structures and the peripheral nervous system.
- This interaction occurs both **hierarchically and in parallel**.
- The conceptual motor control hierarchy has three levels:
 - **1. Highest Level (“Higher Centers”)**: Responsible for forming **complex plans** based on intention. Includes areas for memory, emotions, supplementary motor area, and association cortex, integrating input from many brain structures.
 - **2. Middle Level**: Converts high-level plans into **smaller motor programs** that determine neural activation patterns and subprograms for individual joint movements. Involves the sensorimotor cortex, cerebellum, parts of the basal nuclei, and some brainstem nuclei.
 - **3. Lowest Level (“Local Level”)**: Executes specific details, specifying **muscle tension and joint angles** at precise times. Structures are the brainstem or spinal cord levels where motor neurons exit.
- This intricate, multi-level interaction underlies even the simplest behavioral activities.

Finally, let’s put it all together and consider the overall neural control of voluntary movement. Performing any motor skill, no matter how simple it seems, begins with a cognitively derived intent. For example, deciding to walk up a flight of stairs requires an intent based on your needs and the situation. The implementation of this intent into actual movement involves a complex interplay of numerous neurophysiological events and the cooperative interaction of many CNS structures, as well as sensory-perceptual components and the peripheral nervous system. This interaction happens both hierarchically and in parallel, as conceptually illustrated in Figure 4.7. While the diagram presents a hierarchical organization, many functions occur simultaneously rather than strictly sequentially. Figure 4.7 visually depicts the wide distribution of brain structures involved, from the initial intent to the neural innervation of muscles. Table 4.1 then breaks down this conceptual motor control hierarchy into three levels. At the highest level, we have the “higher centers,” which are responsible for forming complex plans based on your intention. These centers include areas involved with memory and emotions, the supplementary motor area, and the association cortex, all of which integrate input from many brain structures. The “command

neurons” then communicate these plans to the middle level. The middle level then converts these high-level plans into smaller motor programs that determine the pattern of neural activation needed for the movement. This level further breaks down programs into subprograms for individual joint movements. Structures at this level include the sensorimotor cortex, cerebellum, parts of the basal nuclei, and some brainstem nuclei. These programs are then sent down to the lowest control level. The lowest level, or “local level,” is where the specific details are executed. Its function is to specify the tension of particular muscles and the angles of specific joints at precise times to carry out the programs from the middle levels. The structures at this level are the brainstem or spinal cord levels from which motor neurons exit. This intricate, multi-level interaction truly underlies even the simplest behavioral activities. If you want to explore further, Chapter 4 in your textbook provides more detailed diagrams and examples that connect cellular mechanisms to system-level motor control. Pay attention to how structures like the cerebellum and basal ganglia interact with cortical areas, and to the role of sensory receptors in shaping motor output. As you study, try drawing simple diagrams linking components we discussed to make the relationships more concrete.

Cognitive Intent and Neural Activity

- Brain activity is influenced not just by the type of movement, but also by the **cognitive intent behind the movement**.
- Different patterns of activity can occur in the CNS even when the **same movement pattern** is used to achieve **different action goals**.
- For example, research with pianists showed distinct neural activity for the same finger flexion movement:
 - When the goal was **synchronization** with an auditory beat: Activation in contralateral sensorimotor cortex, supplementary motor area (SMA), and ipsilateral cerebellum.
 - When the goal was **syncopation** (off the beat): Additional brain areas were activated, including the premotor, prefrontal, and temporal association areas, along with the basal ganglia.
- This highlights how the brain dynamically adapts its network activity based on the subtle nuances of our intentions.

To further understand the complexity of neural control, it’s important to consider that brain activity isn’t just about the type of movement, but also about the cognitive intent behind the movement. This means that different patterns of activity can occur in the central nervous system even when the same movement pattern is used to achieve different action goals. A great example of this comes from research involving pianists. Researchers studied pianists playing music with two different action goals: synchronizing their finger flexion with an auditory beat, or performing it off the beat (syncopation). Even though the finger movement itself might appear similar, the neural activity in the brain differed significantly based on the pianist’s intent. When the goal was synchronization, activation occurred in the contralateral sensorimotor cortex, the supplementary motor area (SMA), and the ipsilateral cerebellum. However, when the goal was syncopation, additional brain areas were activated, including the premotor, prefrontal, and temporal association areas, along with the basal ganglia. This fascinating example highlights how our brain dynami-

cally adapts its network activity based on the subtle nuances of our intentions, even for what seems like a simple, repeated movement.

For our next class, we'll apply these ideas to specific movement examples and some simple case studies to practice localizing dysfunction and designing appropriate interventions. Bring questions about how particular injuries or diseases might affect movement patterns, and we'll work through how to assess and plan treatments that leverage motor learning principles.

Practical Implications for Practitioners

- Understanding the neuromotor system has practical implications for future practitioners:
 - **1. Clear Instructions:** Since action intent is critical, ensure clients have a **clear understanding of what they are supposed to do**. Clear communication significantly impacts skill performance.
 - **2. Know Damage Location:** For clients with neurological dysfunction, **knowing the specific location of damage** in their nervous system provides a comprehensive understanding of their capabilities and limitations in movement, allowing for tailored approaches.
 - **3. Check Medication:** If clients are taking medication for neurological dysfunction, always **check that they have taken their most recent dose** before rehabilitation sessions, as medication effectiveness impacts performance and participation.
- Applying these insights enables more **effective and informed support** for clients.

As future practitioners, understanding the neuromotor system has practical implications for your work. First, because the intent of an action is so critical to its planning, organization, and execution, it's vital to ensure that the people you work with have a clear understanding of what they are supposed to do when you give them instructions. Clear communication can significantly impact their ability to perform a skill. Second, if you are working with someone who has a neurological dysfunction, it is incredibly important to know the specific location of the damage in their nervous system. This knowledge will give you a comprehensive understanding of their capabilities and limitations in terms of planning, organizing, and executing movements. It helps you tailor your approach effectively. Finally, if your client is taking medication to help manage the limitations imposed by a neurological dysfunction, always check with them to ensure they have taken their most recent dose before beginning a rehabilitation session. The effectiveness of the medication can significantly impact their performance and participation in the session. By applying these insights, you can provide more effective and informed support to your clients.

To wrap up, remember that motor control is a distributed and interactive process. No single region acts alone; instead, networks across the neuraxis collaborate to produce behavior. Our goal in this course is to build an intuition for these networks so you can predict how changes at one level affect overall performance and how targeted practice can produce recovery and improvement.

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References

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