L2 – PNS

PNS is defined as the nerves connecting the CNS to the body, and includes a number of ganglia.

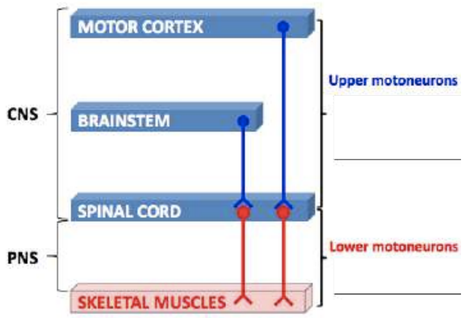
MOVEMENT TYPES

Simple Pattern Reflexes	• Involve only spinal cord circuits • Automatic • Unlearned • Stereotyped/predictable reflexes • Don't require cortical input
Complex Postural Adjustments	• Reflexive movements • Involve the spinal cord and supra-spinal centres (brain stem and cerebellum) • Controlled by the extrapyramidal system in the brain stem • Not stereotyped reflexes, but instead flexible, goal-oriented, adaptive reflexes • Mostly coordinate their action with voluntary movements • Require cortical input for coordination
Voluntary Movements	• Involve the spinal cord, brain stem and motor cortex

MOTOR NEURONS

2 motor neurons involved in the voluntary pathway:

Upper Motor Neurons	• 1st order motor neurons • Cortical motor neurons in the motor cortex (pyramidal tract) • Motor neurons of brainstem nuclei (extrapyramidal tract) • Only in the CNS (their axons don't project into the PNS)
Lower Motor Neurons	• 2nd order motor neurons • Cell bodies in the CNS (anterior horn of the spinal cord, or in the brain stem for motor cranial nerves) • Axons project into the PNS to skeletal muscles they innervate • Nerves in the periphery contain lower motor neuron axons



MOTOR UNIT

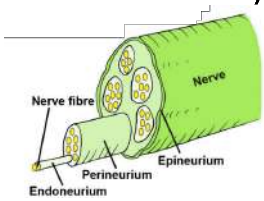
- A single lower motor neuron and the muscle fibres it innervates
- Muscles with precise contraction have smaller motor units (a single motor neuron controls fewer muscle fibres)
- Power-generating muscles have large motor units (a single motor neuron controls more muscle fibres)

NEUROMUSCULAR JUNCTION

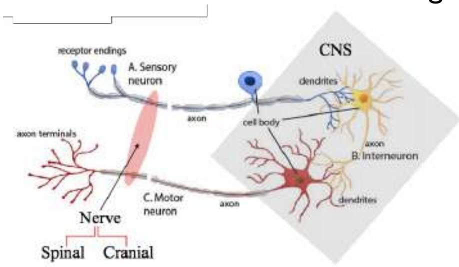
Synapse/junction between terminals of a motor neuron and the muscle fibres it innervates.

NERVES

- Axons in the periphery cluster to form nerves
- Axons in the CNS cluster to form tracts
- Nerves are collections of 1000s of axons surrounded by epineurium
- Individual axons are surrounded by endoneurium
- These are then bundled into fascicles and surrounded by perineurium



- Contain sensory and motor neurons
- Cell bodies of sensory neurons are in the PNS in dorsal root ganglia

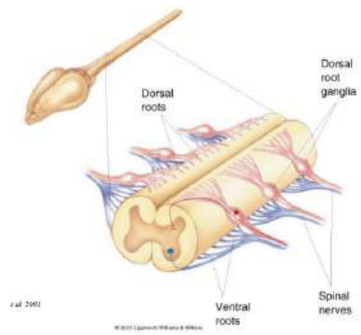


SPINAL NERVES

- Emerge from the spinal cord
- 31 pairs of spinal nerves:
    - 8 cervical (C1-C8)
    - 12 thoracic (T1-T12)
    - 5 lumbar (L1-L5)
    - 5 sacral (S1-S5)
    - 1 coccygeal (Co1)
- Each vertebrae has a pair of spinal nerves emerging from it
- 7 cervical vertebrae but 8 cervical spinal nerves
    - C1 spinal nerve emerges above C1 vertebrae
    - T1 spinal nerve emerges below T1 vertebrae
- Cell bodies of motor neurons are located between C1 and L2
- Spinal cord terminates at L2

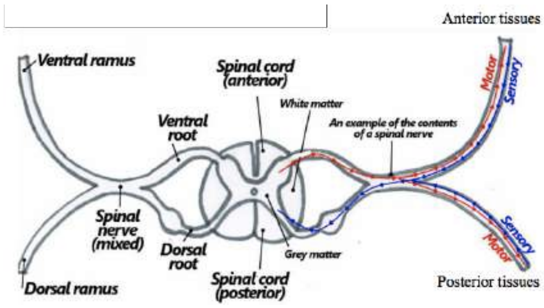
Spinal Roots

- Separate spinal roots connect efferent (motor) and afferent (sensory) neurons to the CNS
- Lower motor neurons cell bodies are in the anterior horn of the spinal cord and exit the spinal cord via the anterior roots
- Sensory neurons exit the spinal cord via posterior roots and have their cell bodies in the DRG



Rami

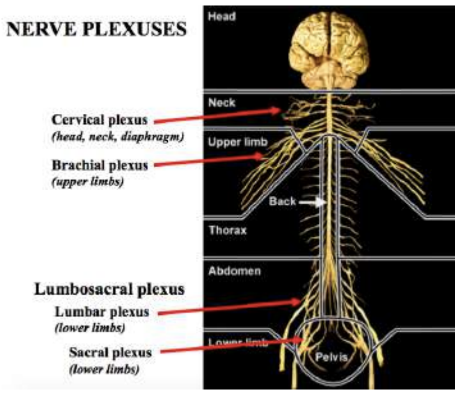
- Spinal nerves then separate into anterior and posterior rami
- Anterior rami innervate anterior tissues and go on to form plexi
- Posterior rami innervate posterior tissues



Segmental Innervation

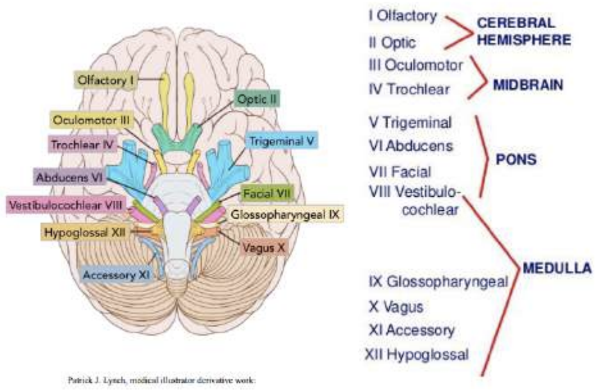
- Each spinal cord segment and its corresponding spinal nerves innervate specific and separate body segments
- Dermatome = area of skin supplied by a single spinal nerve
- Myotome = group of muscles innervated by a single spinal nerve
- Damage to a spinal nerve causes dysfunction in its dermatome/myotome
- Damage to a peripheral nerve, which contains axons of multiple spinal nerves, will cause dysfunction across multiple dermatomes/myotomes
- Peripheral nerves contain axons of many spinal nerves so that in the event of spinal nerve damage, organ function can be maintained by other spinal nerves innervating it

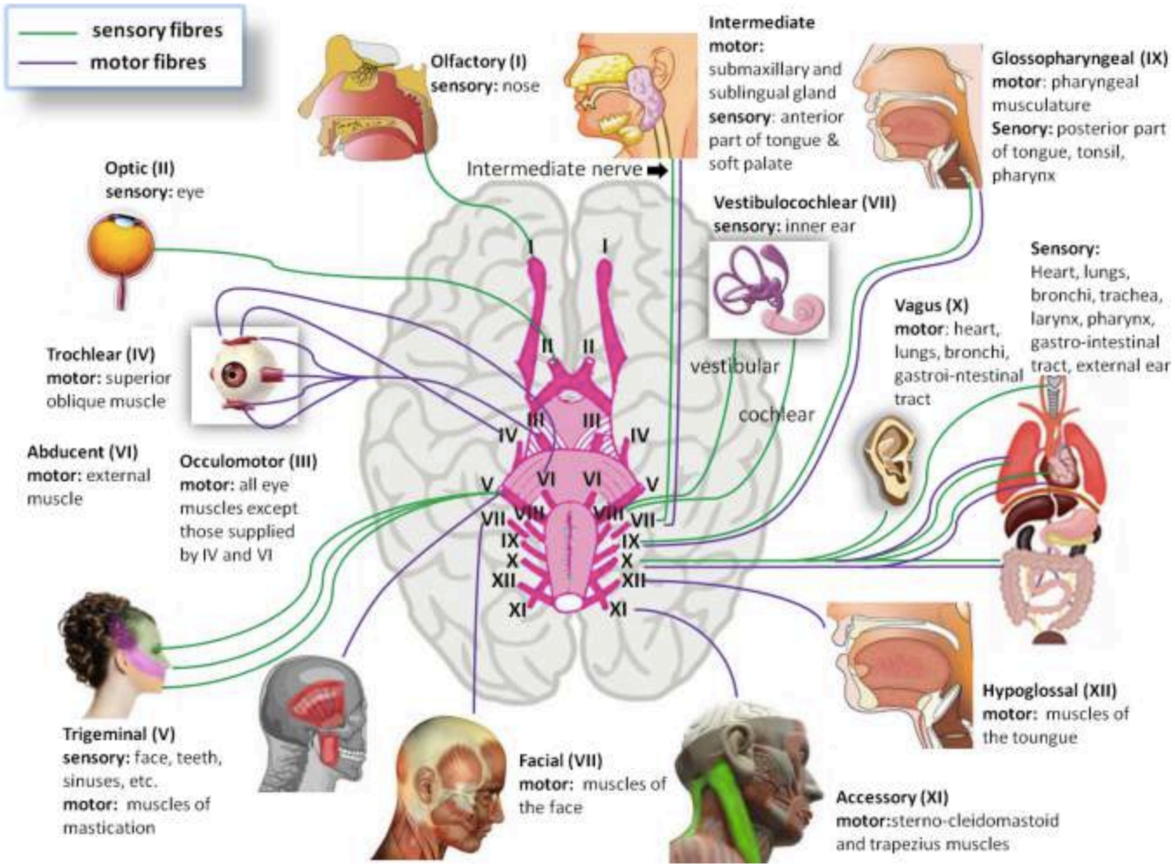
Nerve Plexi



CRANIAL NERVES

- Emerge from brain or brainstem
- Some have motor control, therefore there are upper and motor neurons in cranial nerves



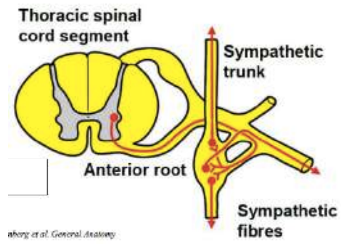


AUTONOMIC NS

- Effector system in the CNS and PNS
- Mediates unconscious homeostatic control of organs and body physiology
- 2 main divisions:
  - Sympathetic NS (thoracolumbar outflow)
  - Parasympathetic NS (craniosacral outflow)

Sympathetic Outflow

- Cell bodies of sympathetic motor neurons in the lateral horns of the spinal cord
- Axons exit via the anterior root
- Pre-ganglionic sympathetic neurons synapse with post-ganglionic sympathetic neurons in the sympathetic trunk
- The post-ganglionic neuron then goes on to innervate the effector
- Sympathetic trunk located bilaterally on either side of the vertebral column
- White communicating ramus links pre-ganglionic neuron to the sympathetic trunk → preganglionic neuron is myelinated
- Grey communicating ramus links post-ganglionic neuron from sympathetic trunk → post-ganglionic neuron is unmyelinated

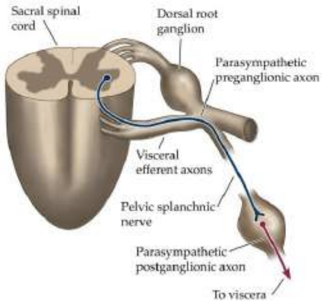


Parasympathetic Outflow

Sacral Segment:

- Cell bodies of parasympathetic motor neurons are in the lateral horns of the spinal cord
- Axons exit via the anterior root

- Pre-ganglionic parasympathetic neurons synapse with parasympathetic post-ganglionic neurons in ganglia located close to, or in the target tissue



Cranial Nerves with Parasympathetic Output:

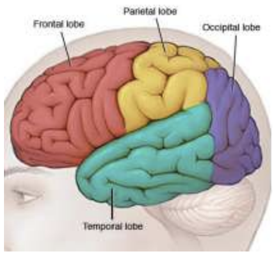
- Oculomotor nerve (III) – narrows pupil, focuses lens
- Facial nerve (VII) – innervates tear, nasal and salivary glands
- Glossopharyngeal nerve (IX) – innervates salivary glands
- Vagus nerve (X) – innervates viscera up to the proximal ½ of the colon, and forms cardiac, pulmonary and oesophageal plexi

L3 and 4 – CNS AND MOTOR CONTROL

Comprised of the brain and spinal cord.

BRAIN ANATOMY

- Gyri = folds on the surface
- Sulci = grooves
- Grey matter deep in the brain are termed basal ganglia/nuclei



Brodmann Areas

- Result from microscopic analysis of the brain, looking for differences in organization
- Based on cellular differences
- Brodmann Area 4 = Precentral Gyrus/Primary Motor Cortex
- Brodmann Area 6 = Premotor Cortex

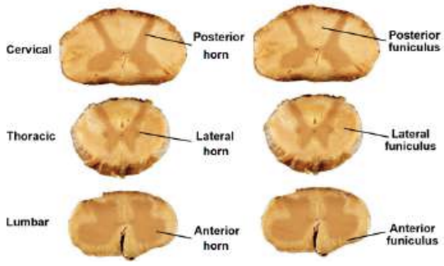
Brainstem

- Located between the diencephalon and the spinal cord
- 3 major divisions:
  - Midbrain
  - Pons
  - Medulla Oblongata
- Medullary pyramids (which axons of upper motor neurons pass through) are located on the ventral surface of the medulla

SPINAL CORD ANATOMY

Enlargements

- Spinal cord is enlarged in the cervical and lumbar regions
- This is due to increased numbers of lower motor neurons in the cervical and lumbar regions
- These lower motor neurons innervate the arms and legs

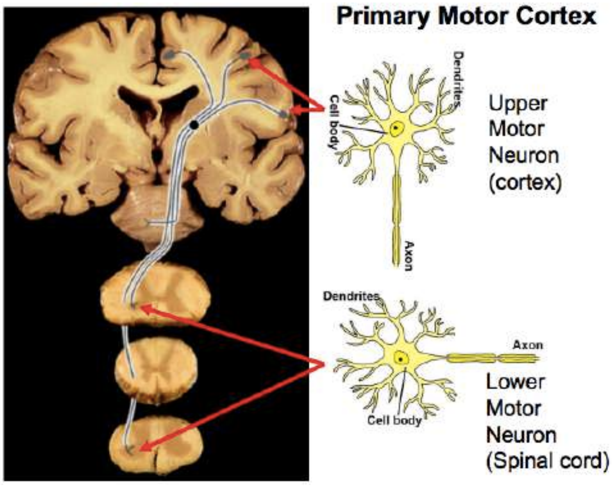


Cauda Equina

- Spinal cord ends at L2 in a cone-like tip called conus medullaris
- Nerve fibres continue down and exit the vertebral column at their corresponding level
- These nerve fibres have a horse-tail appearance, and is hence called the cauda equina
- A continuation of dura-mater goes from conus medullaris to the coccyx bone

UPPER MOTOR NEURON PATHWAY

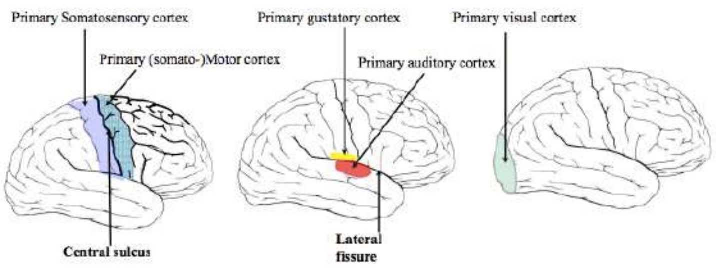
- Cell bodies of upper motor neurons are located in the primary motor cortex (representation of each body part on the motor cortex corresponds with the degree of motor innervation → motor homunculus)
- Axons of these upper motor neurons travel through the internal capsule, then continue down through the brainstem
- Some upper motor neurons terminate in the brainstem and synapse with a cranial nerve
- Other upper motor neuron axons continue down the white matter tracts of the spinal cord
- The upper motor neuron will then synapse with a lower motor neuron in the anterior horn of the spinal cord



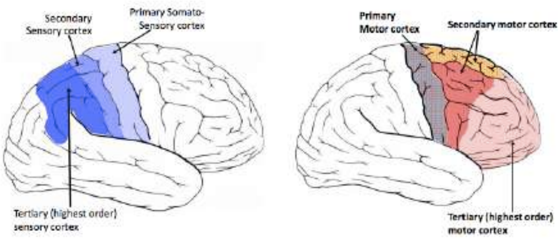
ORGANISATION OF THE CEREBRAL CORTEX

Primary and Secondary Cortices

- Each lobe is composed of functional cortical areas (primary, secondary and tertiary cortices)
- Primary cortices are located around the deepest sulci/fissures:
  - Central sulcus is surrounded by the primary motor cortex and primary somatosensory cortex
  - Lateral fissure is surrounded by the primary auditory cortex and primary gustatory cortex
  - Calcerine sulcus is surrounded by the primary visual cortex

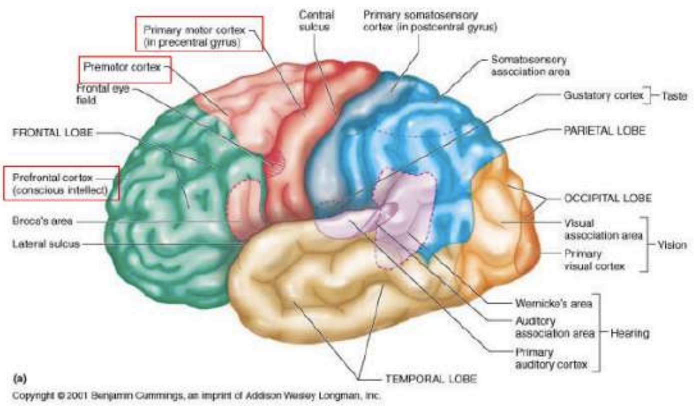


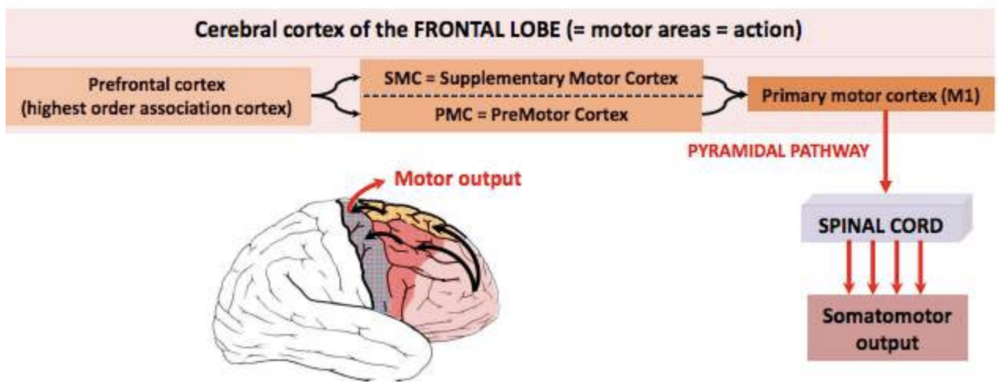
- Primary cortices are next to secondary cortices, which are next to tertiary cortices
- Tertiary cortices are the highest order cortices



Hierarchical Organisation of Motor Cortices

- Primary Motor Cortex is located next to the Secondary Motor Cortices (Premotor Cortex in orange and Supplementary Motor Area in yellow), which is located next to the Tertiary Motor Cortex (Prefrontal Cortex)
- Motor command is decided upon, planned and initiated by the Prefrontal Cortex
- This information is transferred to the Secondary Motor Cortices (PMC and SMC)
- This information is then transferred to the Primary Motor Cortex, and then exits the brain
- Motor Programs:
  - Stored in secondary motor areas
  - SMC and PMC contribute to learning sequences of movements and skills with sensory integration and bilateral coordination
- A decision to make a voluntary movement is made, then we engage a motor program, allowing us to initiate the upper motor neurons in the primary motor cortex to carry out the task





MOTOR PATHWAY LESIONS

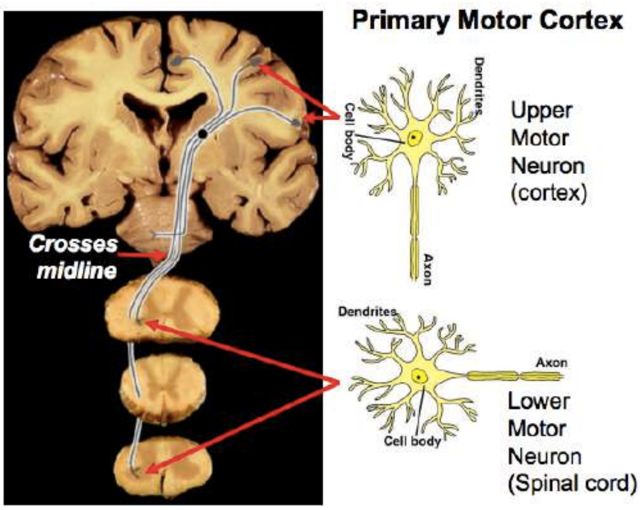
- Lesions to the primary motor cortex or upper motor neurons causes paresis or paralysis, characterized by hypertonia (rigidity) because voluntary motor output is blocked, but reflexive motor output to maintain muscle tone isn't
- Lesions to lower motor neurons causes paresis or paralysis, characterized by hypotonia (flaccidity) because voluntary motor output and reflexive motor output is blocked
- Lesions to the premotor cortex or supplementary motor area causes apraxia (inability to execute voluntary movement and imitate movement despite demonstrating normal muscle function)

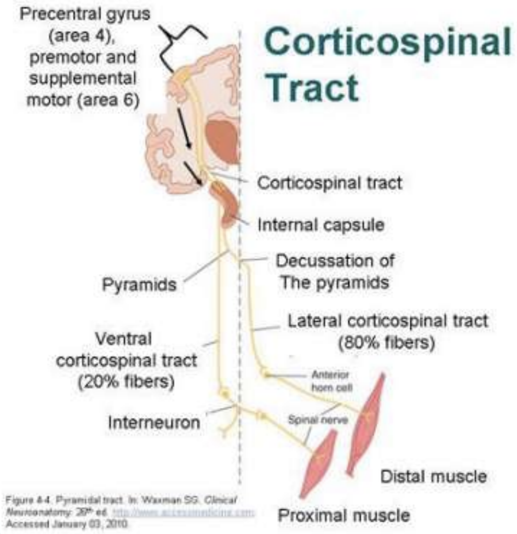
PYRAMIDAL SYSTEM

- Pathway for voluntary movement
- Upper motor neurons located in the primary motor cortex
- Direct pathway to influence lower motor neurons
- Consists of the lateral and anterior motor systems

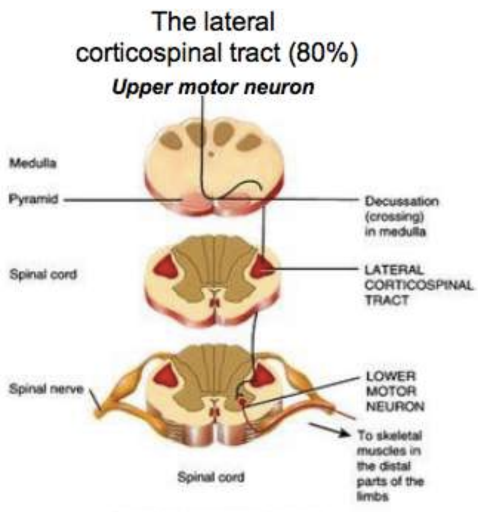
Lateral and Anterior Motor Systems

- Pathways an upper motor neuron can take as it passes into the spinal cord include the lateral and anterior motor systems
- Upper motor neurons whose cell bodies are on 1 side of the brain have their axons running down the spinal cord on the contralateral side
- 80% of upper motor neurons cross the midline at the decussation of the medullary pyramids in the brain stem
- 20% of upper motor neurons descend the spinal cord on the ipsilateral side and cross the midline at some level within the spinal cord



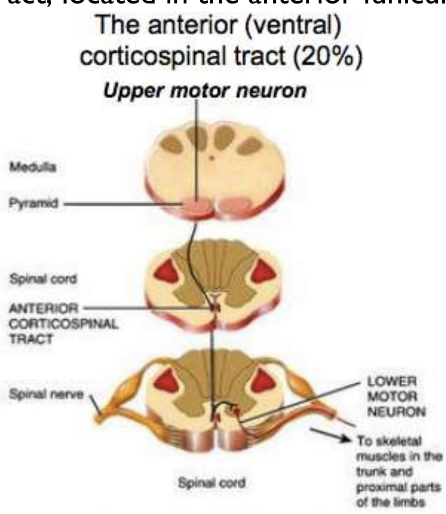


- Upper motor neurons that cross the midline at the decussation of the pyramids descend the spinal cord in the lateral corticospinal tract, located in the lateral funiculus



(a) The lateral corticospinal pathway

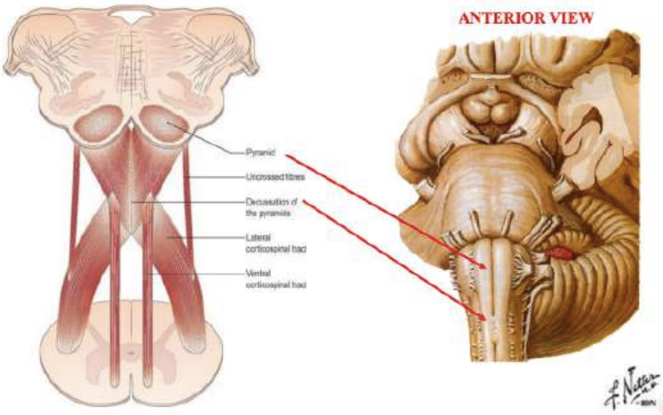
- Upper motor neurons which don't cross the midline at the pyramids, descend down the spinal cord in the anterior corticospinal tract, located in the anterior funiculus



(b) The anterior corticospinal pathway

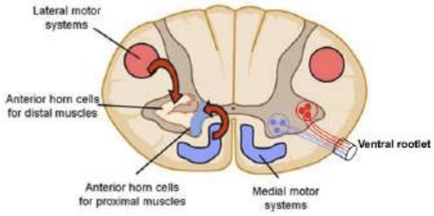
Medullary Pyramids

- Medullary pyramids are composed of all the fibres of the corticospinal tracts
- Anterior median fissure between the medullary pyramids
- Decussation of the pyramids is where the fibres of the lateral corticospinal tract cross the midline



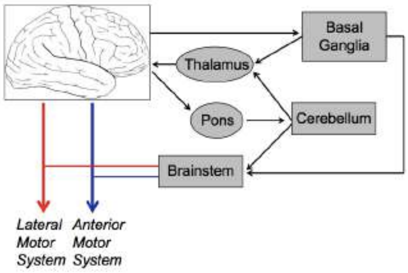
Topography of Pyramidal Tracts

- Anterior corticospinal tract lower motor neurons are located more medially in the anterior horn
- Lateral corticospinal tract lower motor neurons are located more laterally in the anterior horn



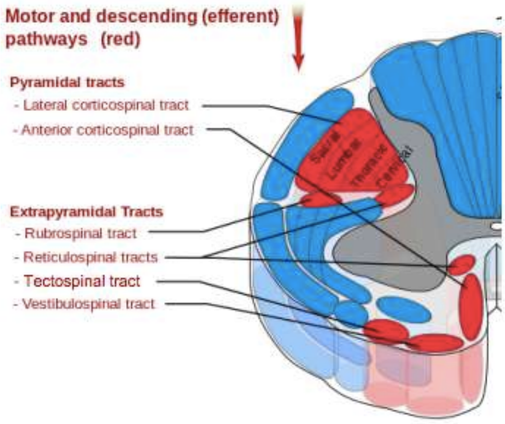
EXTRAPYRAMIDAL SYSTEM

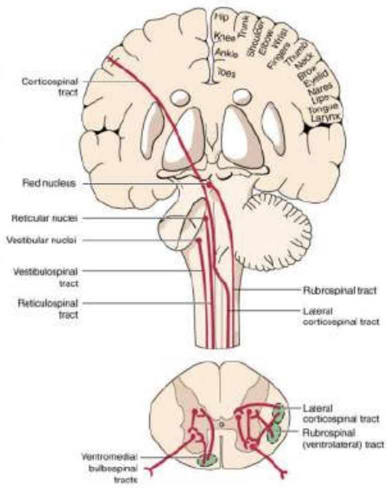
- Composed of descending fibre pathways, with their upper motor neurons originating in the brainstem
- Descend the spinal cord in the lateral and anterior funculi
- Controlled mostly by basal ganglia, midbrain nuclei and the cerebellum (and some cortical systems)
- Involved in:
  - Control and refinement of movement (force, rate, regulation of antagonists)
  - Involuntary movements (posture, support)
- Indirect pathway to influence lower motor neurons
- Extrapyramidal tracts are found in the reticular formation of the pons and medulla



Tracts of the Extrapyramidal System

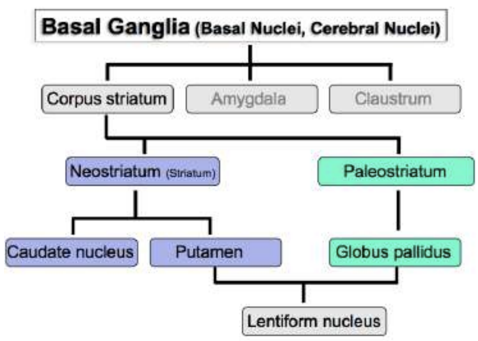
Rubrospinal Tract	• Originates in the red nucleus of the midbrain • Descends into the spinal cord in the lateral funiculus, mainly in the cervical region • Involved in upper limb control
Reticulospinal Tract	• Originates in the pons and medulla reticular formation • Descends into the spinal cord o Reticulospinal tracts originating in the medulla travel in the lateral funiculus o Reticulospinal tracts originating in the pons travel in the anterior funiculus • Involved in coordinating automatic movements and posture
Vestibulospinal Tract	• Originates in the vestibular nuclei of the medulla and pons • Descends into the spinal cord in the anterior funiculus • Involved in lower limb muscle tone control for posture and balance
Tectospinal Tract	• Originates in the midbrain colliculi • Descends into the spinal cord in the anterior funculus, mainly in the cervical region • Involved in automatic postural movements of the head in response to visual and auditory stimuli

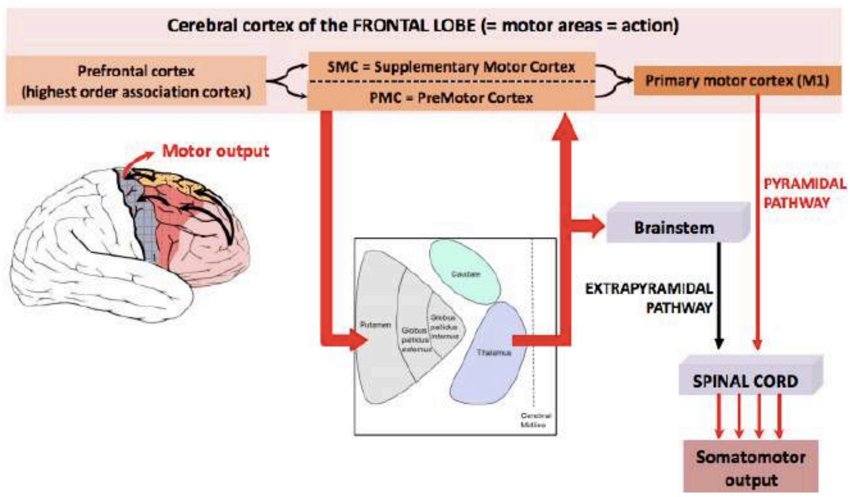




BASAL GANGLIA CONTROL SYSTEM

- Indirectly controls motor output
- Regulatory pathway involving communication with the brainstem (via extrapyramidal pathways) and circuits involving basal ganglia
- Basal ganglia include:
    - Cerebral Nuclei (Corpus Striatum)
        - Caudate Nucleus
        - Lentiform Nucleus:
            - Putamen
            - Globus Pallidus
    - Thalamus
    - Midbrain Nuclei
        - Subthalamic Nucleus
        - Substantia Nigra
- Extrapyramidal pathways and basal ganglia control system receives feedback via the cerebellum
- Anatomically, basal ganglia are collections of grey matter within the white matter of the cerebrum, but functionally, the basal ganglia also include nuclei in the diencephalon and brainstem





Anatomy of the Basal Ganglia

Cerebral Nuclei

Coronal Section	• Caudate nucleus is lateral to the lateral ventricle • Thalamus is inferior to the caudate nucleus • Internal capsule runs lateral to caudate nucleus and thalamus • Globus Pallidus is lateral to the internal capsule • Putamen is lateral to the Globus Pallidus

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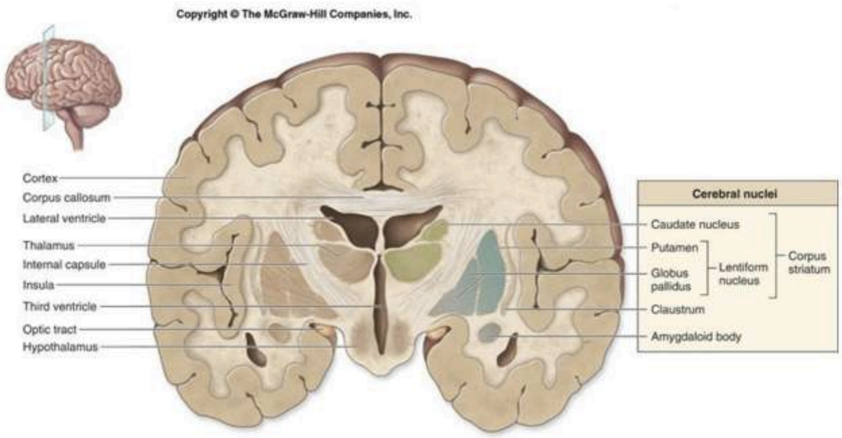

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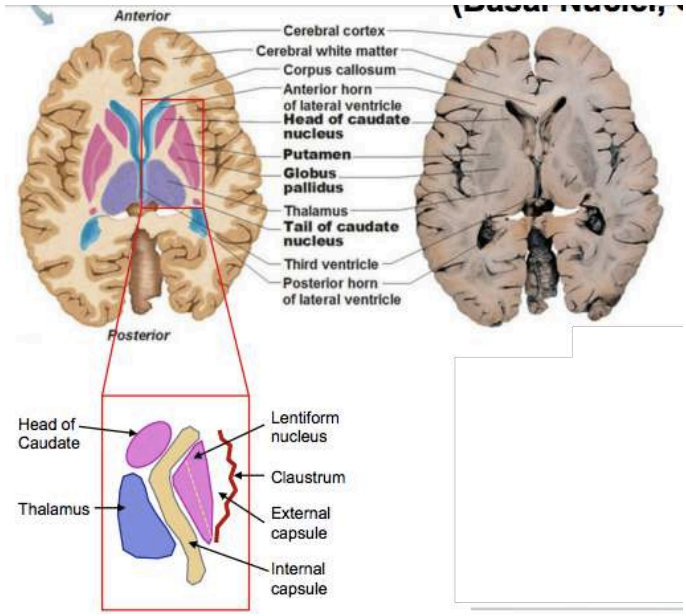
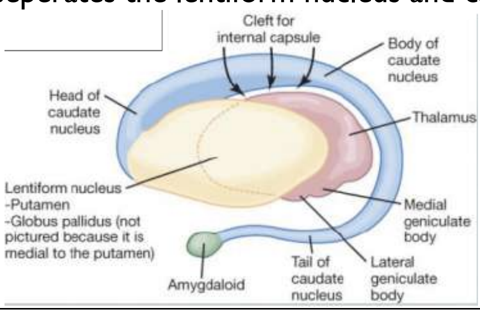
<tr><td>Transverse Section</td><td>

- Caudate nucleus is most anterior
- Thalamus is posterior to the caudate nucleus
- Internal capsule runs lateral to the caudate nucleus and thalamus
- Globus Pallidus is lateral to the internal capsule, and posteriolateral to the caudate nucleus
- Putamen is lateral to Globus Pallidus



- Caudate nucleus wraps around the lentiform nucleus
- Internal capsule seperates the lentiform nucleus and caudate nucleus



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<tr><td>Saggital Section</td><td>

- Caudate nucleus is lateral to the midline and superiormost
- Thalamus is inferior to the caudate nucleus and lateral to the midline
- Globus Pallidus Internus is lateral to the caudate nucleus and thalamus
- Globus pallidus externus is lateral to globus pallidus internus
- Putamen is lateral to globus pallidus externus
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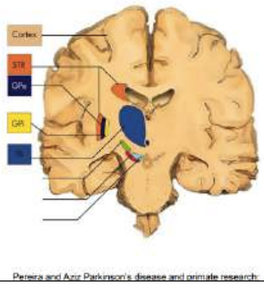
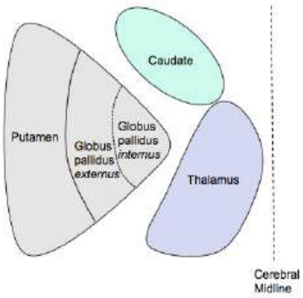


Pereira and Aziz Parkinson's disease and primate research


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Midbrain Nuclei

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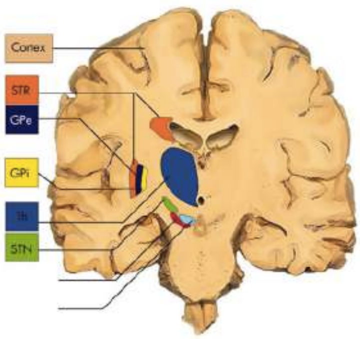
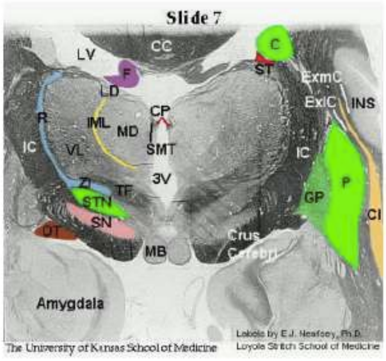
<tr><td>Subthamic Nucleus</td><td>

- Located inferior to the thalamus in the diencephalon
- Site of deep brain stimulation for Parkinson's disease
- Functionally part of the basal ganglia, but not anatomically
- Contains mostly glutamatergic neurons (excitatory nucleus)
- Has reciprocal connections with the basal ganglia, especially the globus pallidus





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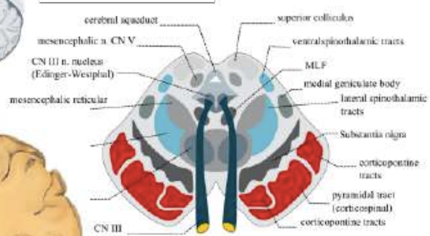
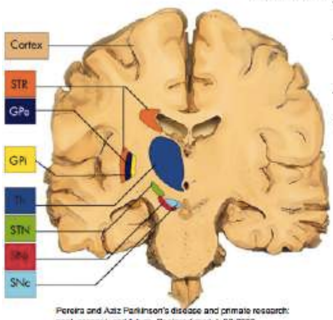
<tr><td>Substantia Nigra</td><td>

- Appears black as neurons of the SN contain pigment
- Located in the midbrain, below the subthalamic nucleus
- Involved in motor planning and movement
- 2 components of the SN:
  - Pars Compacta
    - Contains dopaminergic neurons
    - Appears black due to neuromelanin
    - Degenerated in Parkinson's disease
  - Pars Reticulata
    - Contains GABAergic neurons
    - Neurons less densly packed


https://en.wikipedia.org/wiki/Substantia_nigra#/media/File:Midbraincrosssection.png




Pereira and Aziz Parkinson's disease and primate research: past, present, and future. Postgrad med J. 82:2006

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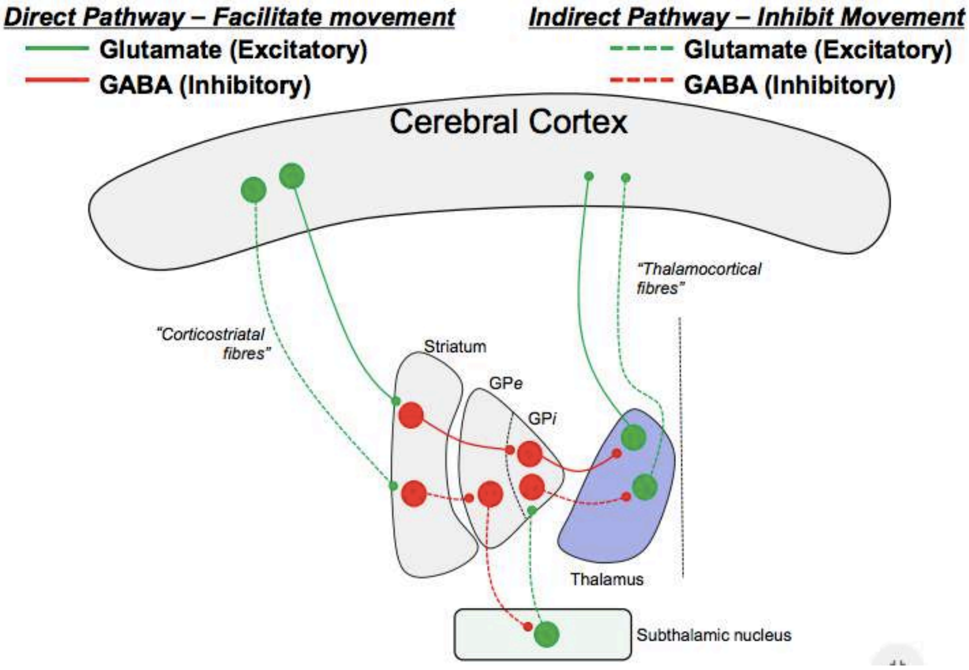
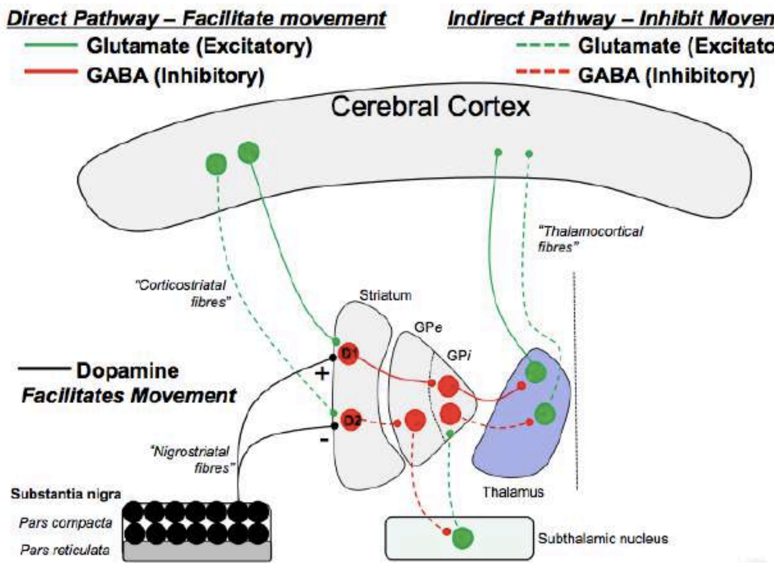
Basal Ganglia Circuits

Direct Pathway	• Facilitates movement and promotes motor activity • Motor planning information from the cerebrum is sent to the striatum • These excitatory descending inputs activate inhibitory GABAergic neurons in the striatum • Inhibitory neurons from the striatum project to the globus pallidus internus, decreasing activity of globus pallidus internus neurons • Globus pallidus internus neurons are inhibitory, so we have disinhibition • Globus pallidus internus neurons project to the excitatory neurons of the thalamus, which are excited as a result of disinhibition • Thalamic neurons project to the cerebral cortex, providing feedback
Indirect Pathway	• Inhibits movement and opposes the direct pathway • Excitatory inputs from the cerebrum activate inhibitory neurons in the striatum • Inhibitory neurons of the striatum project to the globus pallidus externus, where they synapse with inhibitory neurons, resulting in disinhibition • Globus pallidus externus neurons project to the subthalamic nucleus, where they synapse with excitatory neurons, resulting in excitation due to disinhibition • Subthalamic neurons project to globus pallidus internus, where they synapse with inhibitory neurons • Globus pallidus internus inhibitory neurons project to the thalamus, where they inhibit thalamic excitatory neurons, inhibiting the final output to the cerebral cortex



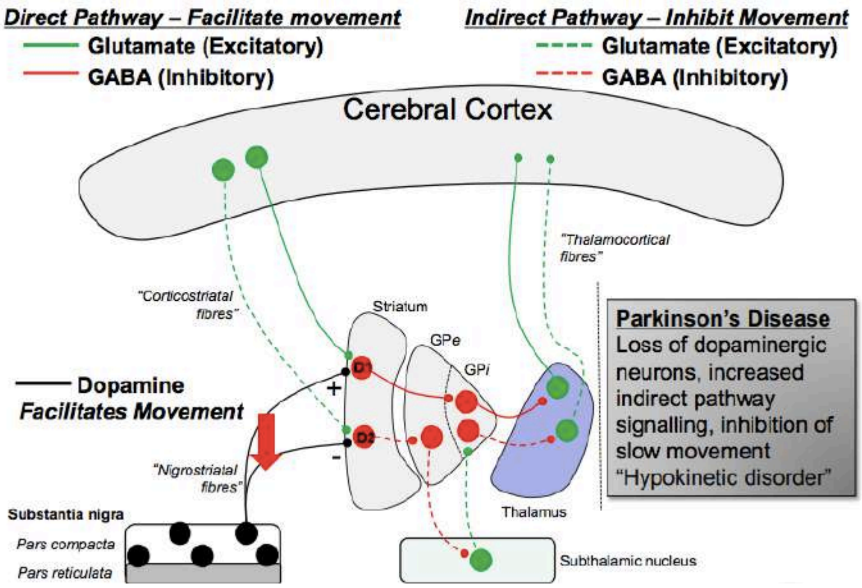
SN and Dopamine

- Dopaminergic neurons of the SN project to the striatum
- Neurons of the direct and indirect pathways project different DA receptors (D1 and D2 respectively)
- Effect of DA on D1 receptors is excitatory
- Effect of DA on D1 receptors is inhibitory
- This allows us to either further activate the direct pathway and further inhibit the indirect pathway



Parkinson's Disease

- Caused by degenerative changes in the globus pallidus and substantia nigra
- There is a reduction in DA in the SN
- Dopaminergic neurons would normally inhibit the indirect pathway, but in Parkinson's, DA input into the striatum is reduced
- This causes increased indirect pathway signaling, and hence increased inhibition of movement in those with Parkinson's

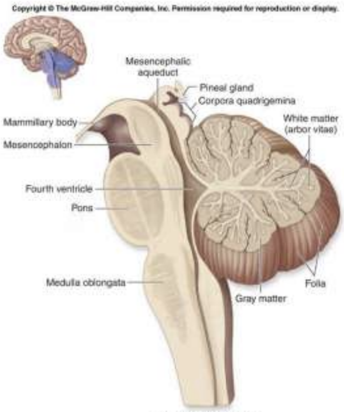


- Treated by:
  - L-Dopa (DA precursor)
  - Surgical destruction of globus pallidus and other basal ganglia that are inhibitory
  - Striatal implants of dopaminergic neurons of foetal origin
  - Deep brain stimulation of the subthalamic nuclei by inserting electrodes and inhibiting the STN neurons which drive inhibition in the direct pathway, reducing inhibition in the indirect pathway

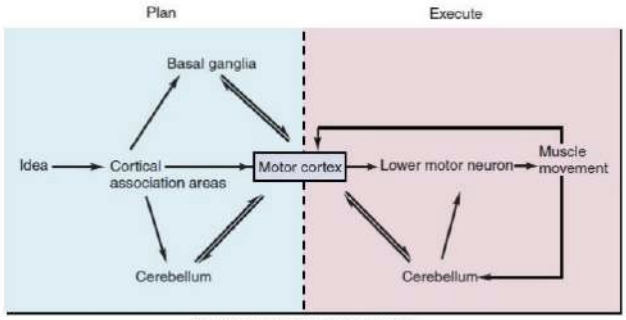
Cerebellum's regulation of the Basal Ganglia System

- Cerebellum is essential for fine movement, coordination, precision and timing
- Compares a motor plan from the cortex with the motor action and sensory feedback to refine movement
- As we execute a movement, sensory receptors (proprioceptors) provide feedback to the motor pathway
- This sensory information is received via the cerebellum

- The cerebellum then sends this information into the motor circuit, to the thalamus, and then other basal ganglia to affect the extrapyramidal pathways
- Damage to the cerebellum results in ataxia, where it appears as though we haven't learnt movements
- Therefore, without sensory feedback being relayed through the cerebellum, it appears as though we've never practiced movements



(a) Midsagittal section



Control of voluntary movement

FIGURE 5.44 Control of Voluntary Movement