Motor System

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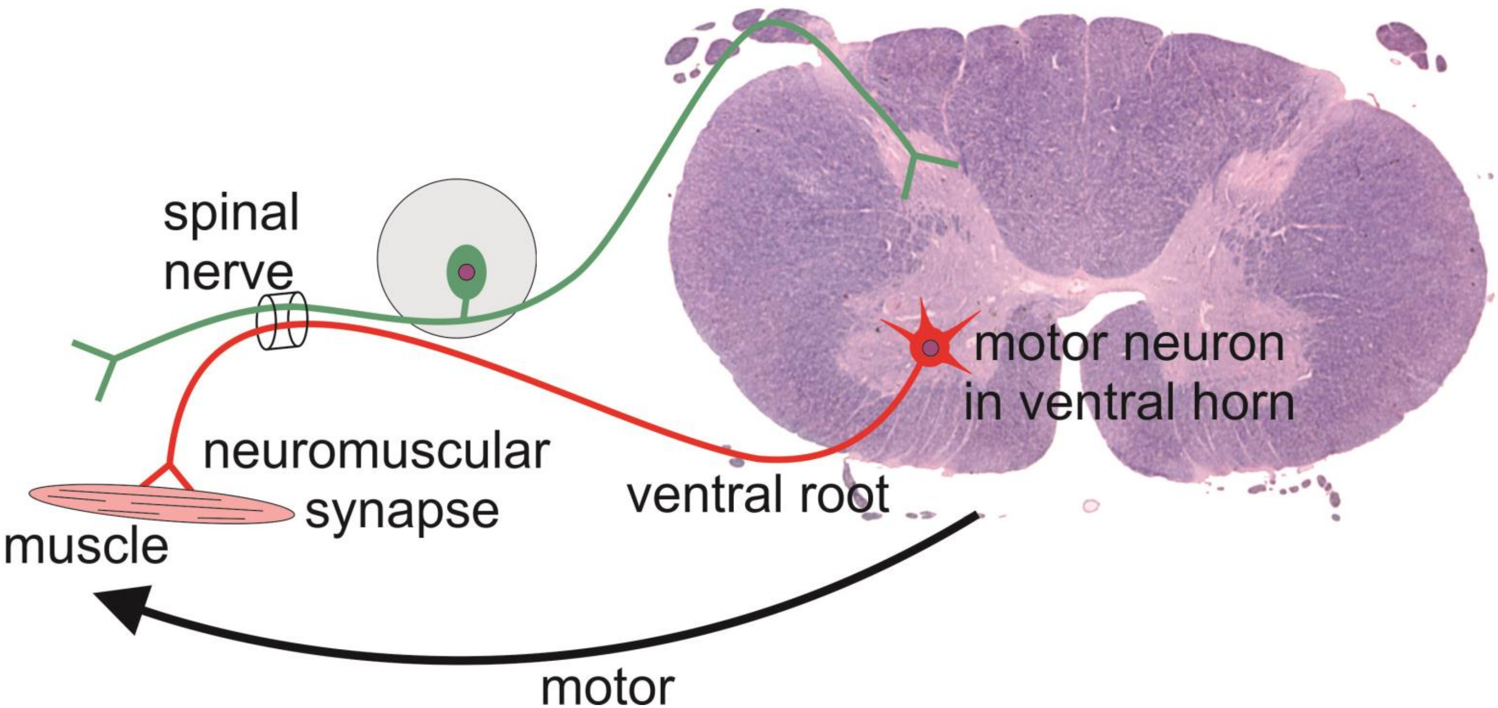
Output Systems of the CNS

- Somatomotor system – controls striated skeletal muscles
- Autonomic motor system – sympathetic and parasympathetic control of smooth muscles and other tissues
- Neuroendocrine system – hormones from hypothalamus (via the pituitary gland), pineal gland and adrenal medulla

(Lower) Motor Neuron

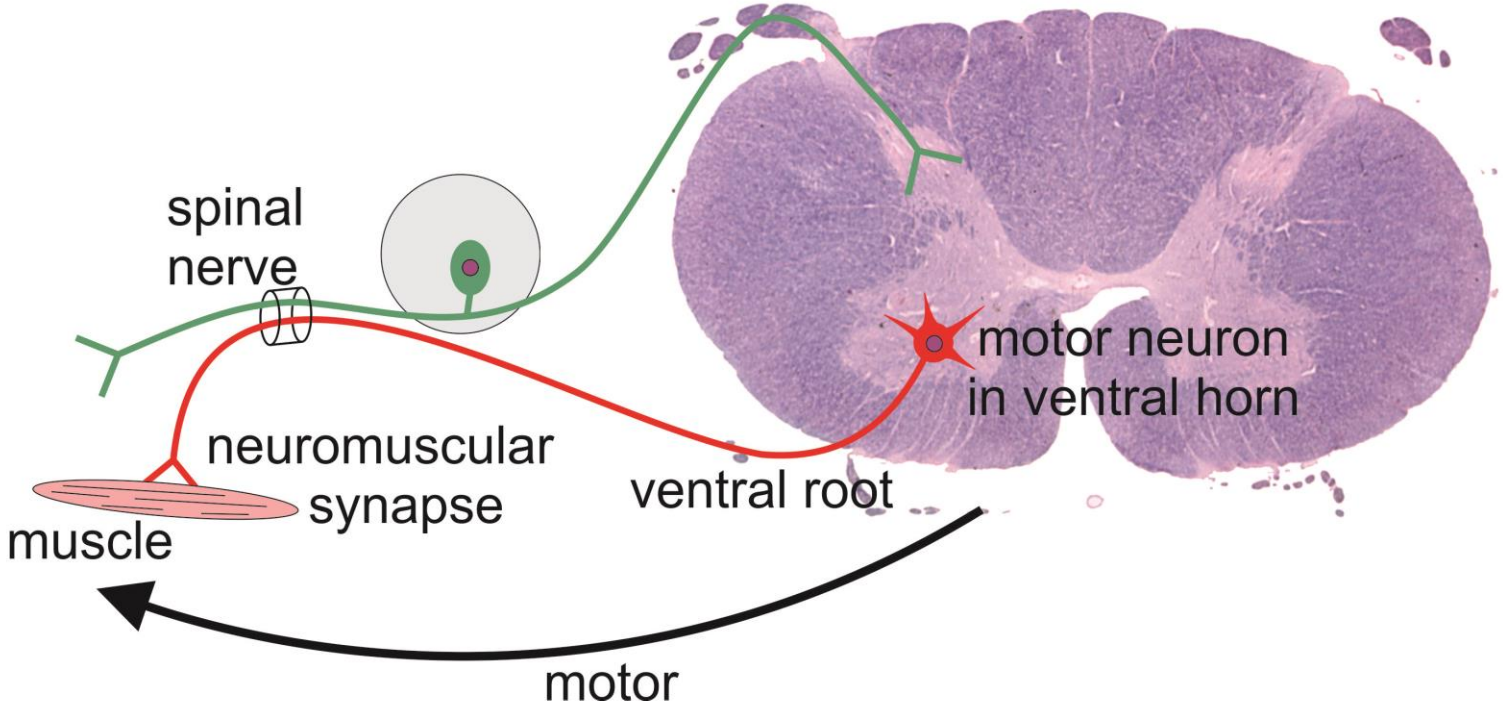
- Motor neurons are the only cells to synapse with and control skeletal muscles.

- The somas of motor neurons are in the ventral horn of the spinal cord and in brainstem cranial nerve motor nuclei.



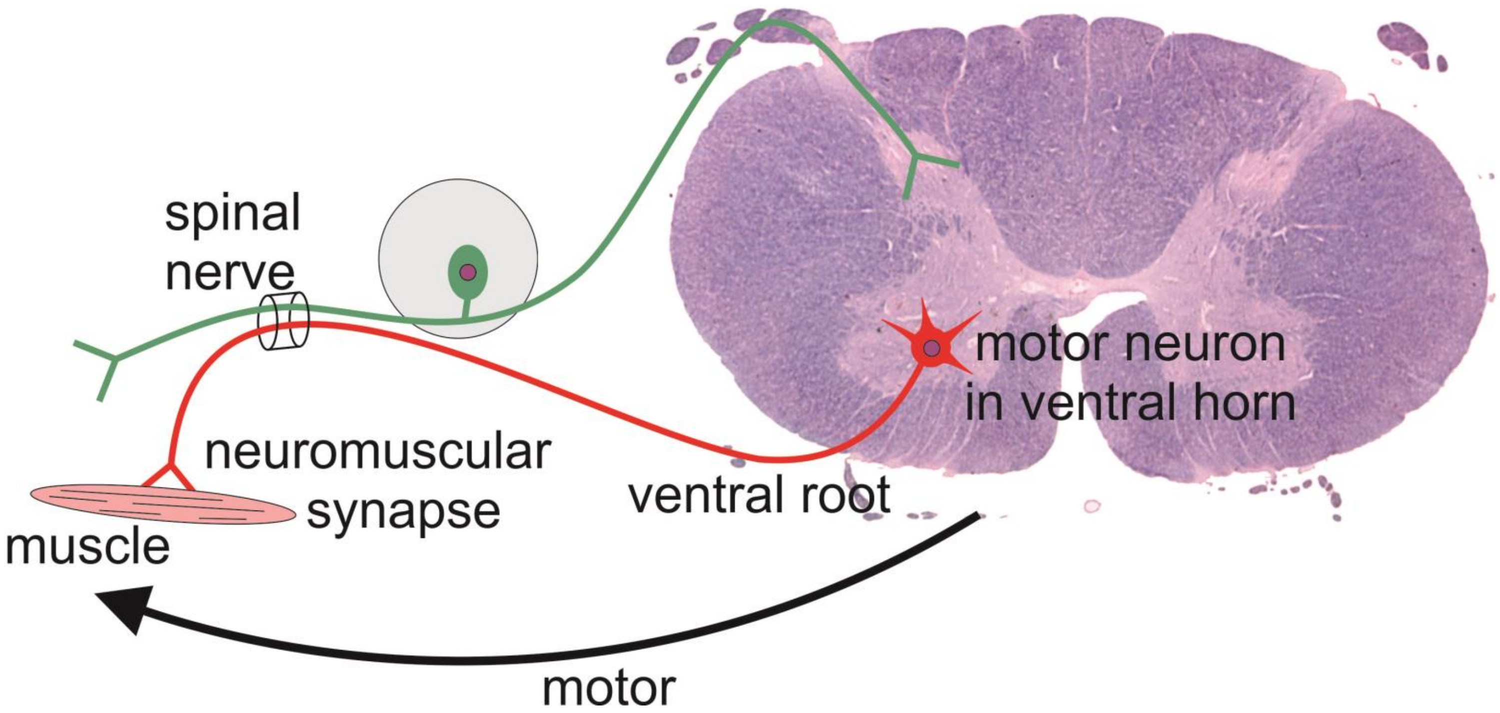
(Lower) Motor Neuron

- Axons of spinal motor neurons exit via ventral roots and join spinal nerves just after the dorsal root ganglion.
- Motor neuron axons course without interruption to muscles.



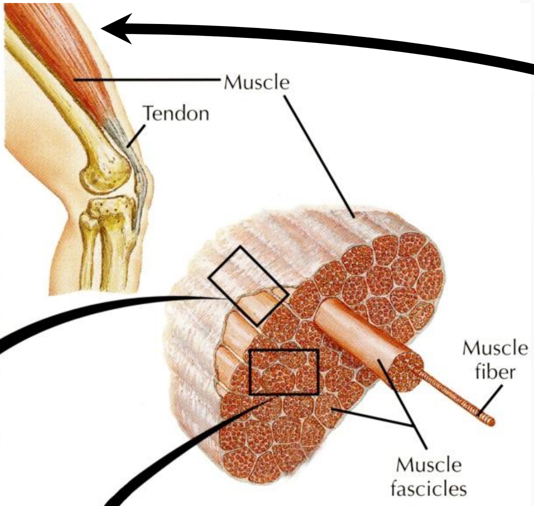
(Lower) Motor Neuron

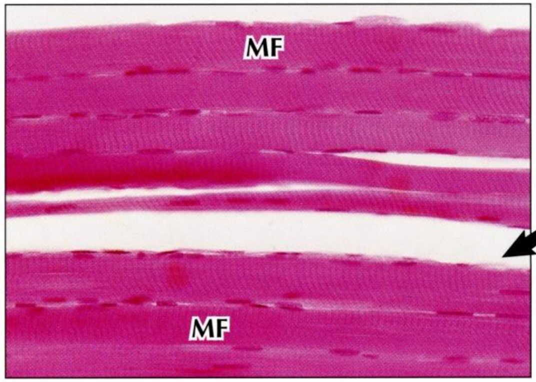
- Motor neuron axons synapse at neuromuscular junctions.
- The neurotransmitter used by motor neurons is acetylcholine.

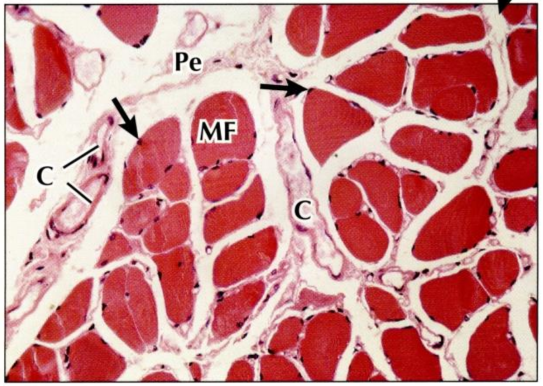


Muscle

- A muscle is a bundle of muscle fascicles.
- A fascicle is a bundle of muscle fibers.



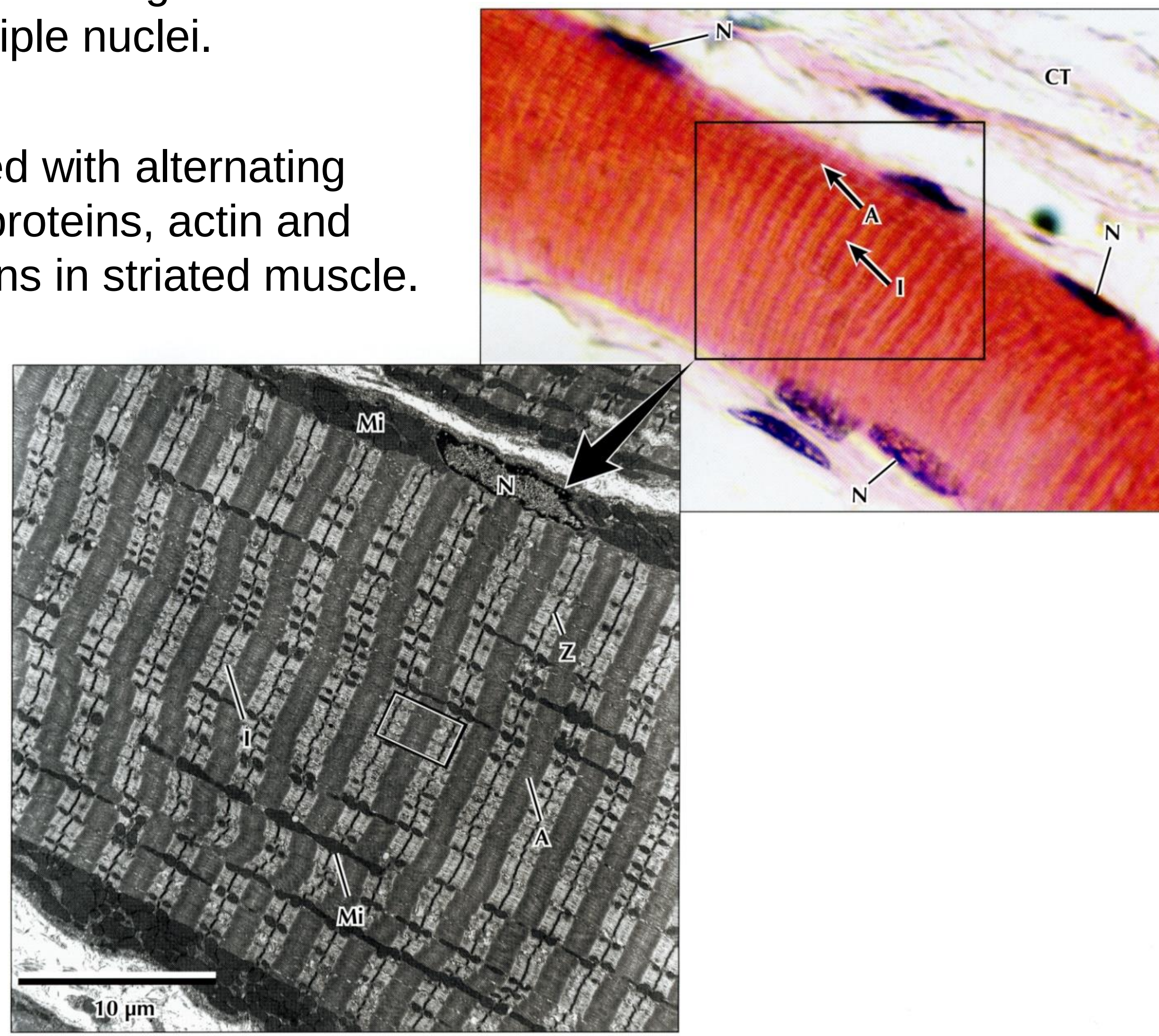




Muscle

- Each muscle fiber has a single cell membrane with multiple nuclei.

- A muscle fiber is filled with alternating bands of the motor proteins, actin and myosin – the striations in striated muscle.



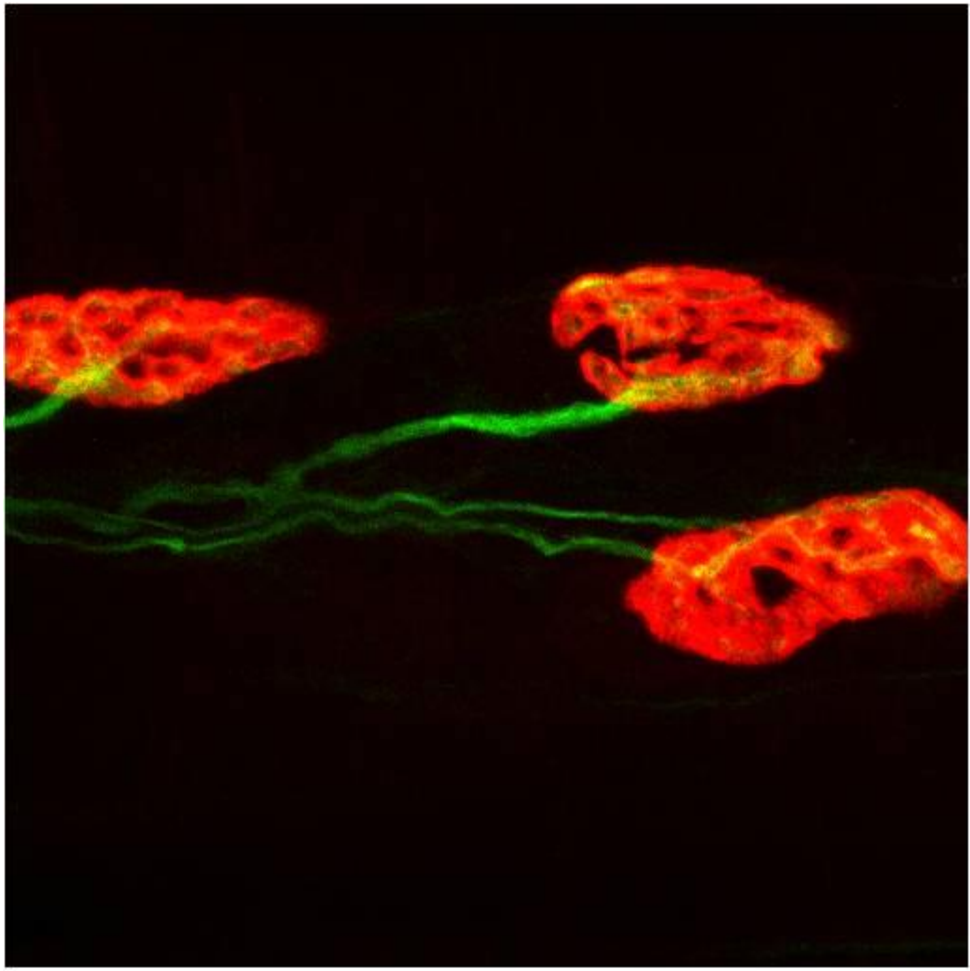
Muscle

- Each muscle fiber (myofiber) has only a single neuromuscular junction in the adult.

Muscle

- Acetylcholine receptors are concentrated in the myofiber membrane at the neuromuscular junction.
- Alpha-bungarotoxin is in the venom of the krait. α-bungarotoxin binds to the acetylcholine receptor and paralyzes the muscle.

red = fluorescently tagged α-bungarotoxin
green = motor neuron



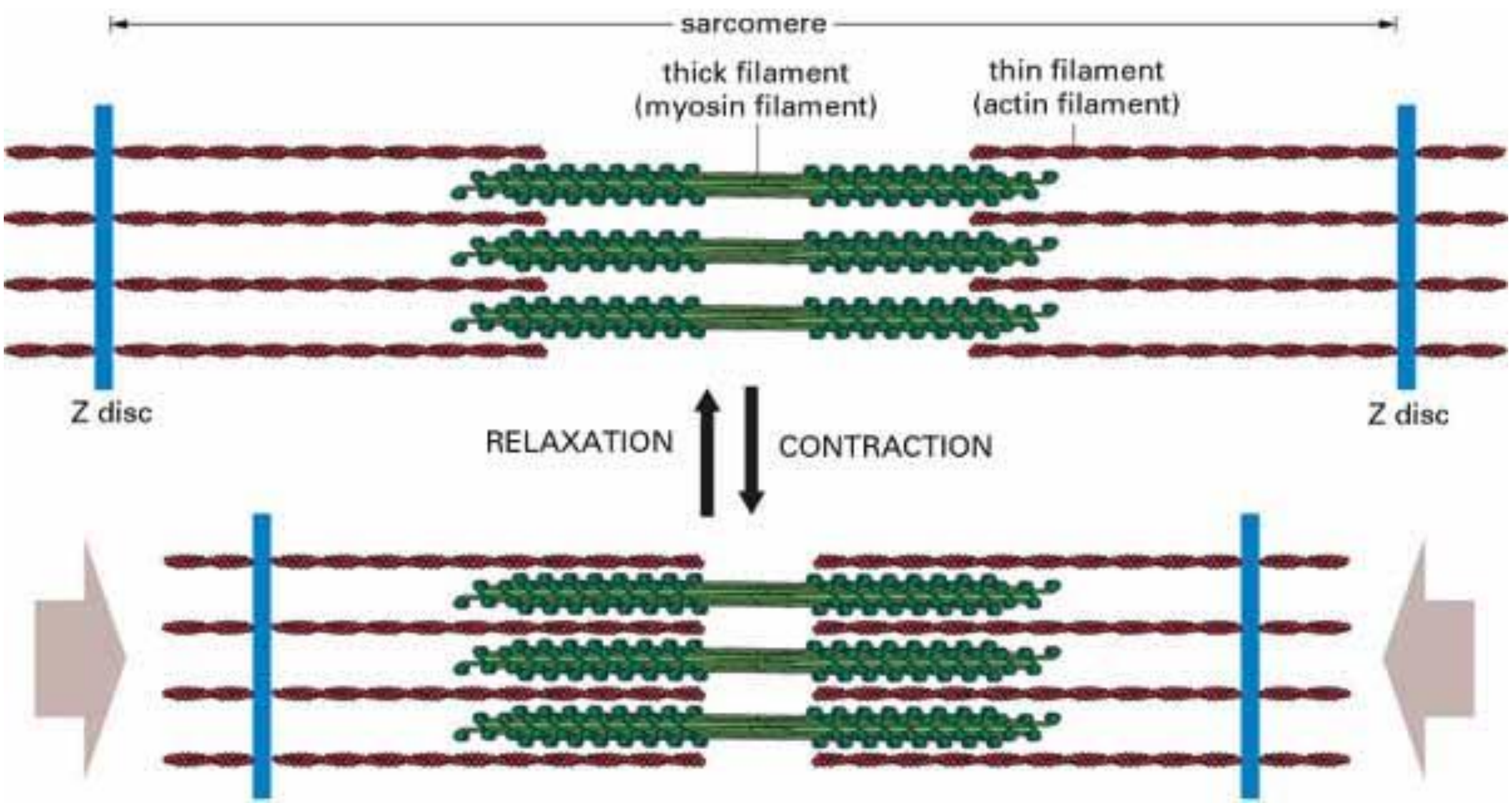
by Charlotte Sumner

Muscle

- Acetylcholine activates acetylcholine receptors.
- The receptors are ligand-gated ion channels; activation results in an influx of sodium (Na^+) into the muscle fiber and an outflow of potassium (K^+).
- Depolarization spreads along the muscle fiber like an action potential.
- Depolarization causes release of calcium (Ca^{++}) inside the muscle fiber.
- Calcium initiates sliding of myosin filaments on the actin filaments, i.e. a muscle contraction.

Muscle

- During muscle contraction, the myosin filaments ‘slide’ on the actin filaments along the length of the muscle fiber so that the fiber shortens.



Muscle

- Myosin requires energy in the form of ATP to generate a muscle contraction.

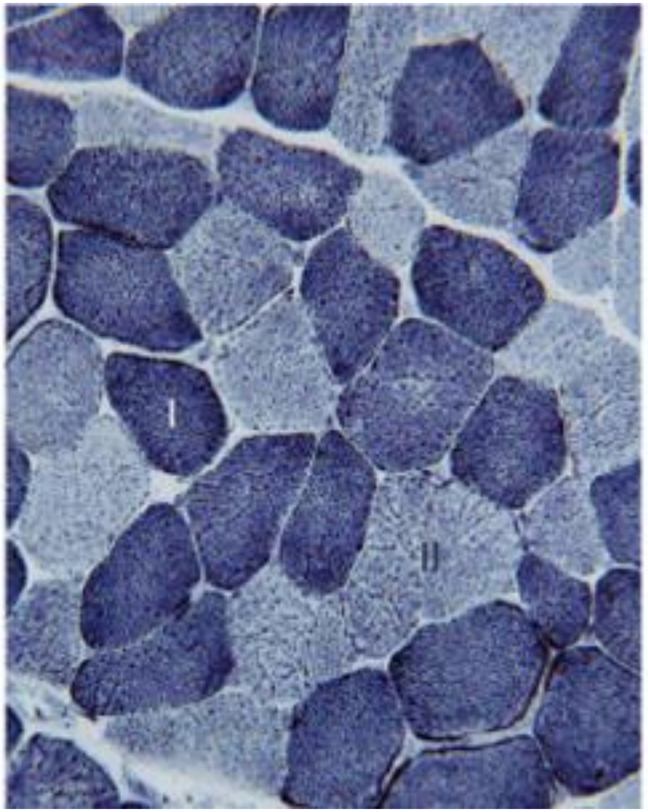
Muscle

- Muscle fibers are of three types:

type	***size***	***speed***	***force***	***fatigability***
I	thin	slow, long	low	slowly
IIa	thick	intermediate	intermediate	intermediate
IIb	thick	fast, short	high	rapidly

- Type I fibers have a higher density of mitochondria than type II fibers.

- A motor neuron innervates only one type of muscle fiber. A single motor neuron can innervate multiple fibers of the same type.



Muscle

- Exercise will increase the thickness of the muscle fibers.

- The nature of the exercise will influence the fiber types:
  - Sustained periods of exercise at low to moderate exertion increase the proportion of type I fibers and leads to long thin muscles that are slow to fatigue.

  - Short periods of high exertion increase the proportion of type II fibers and leads to short bulky muscles that can be very strong but fatigue quickly.

(Lower) Motor Neuron

- A motor neuron can synapse with one or more muscle fibers.

- One motor neuron and all the fibers with which it synapses is a <u>motor unit</u>.
  - Muscles with fine control have small motor units (e.g. finger muscles).

  - Muscles with only course control have large motor units (e.g. gluteus maximus muscle in your butt).

Motor Control

Motor neuron firing is determined by inputs from several main sources:

- Local circuits:
  - sensory neurons (reflexes)
  - interneurons
- Descending projections from:
  - cortex (upper motor neuron)
  - red nucleus
  - superior colliculus
  - reticular formation of pons and medulla
  - vestibular nuclei

Motor Control

Basal ganglia and cerebellum have a major influence on movement; however, they function by altering the output of these other units of the nervous system.

Motor Control

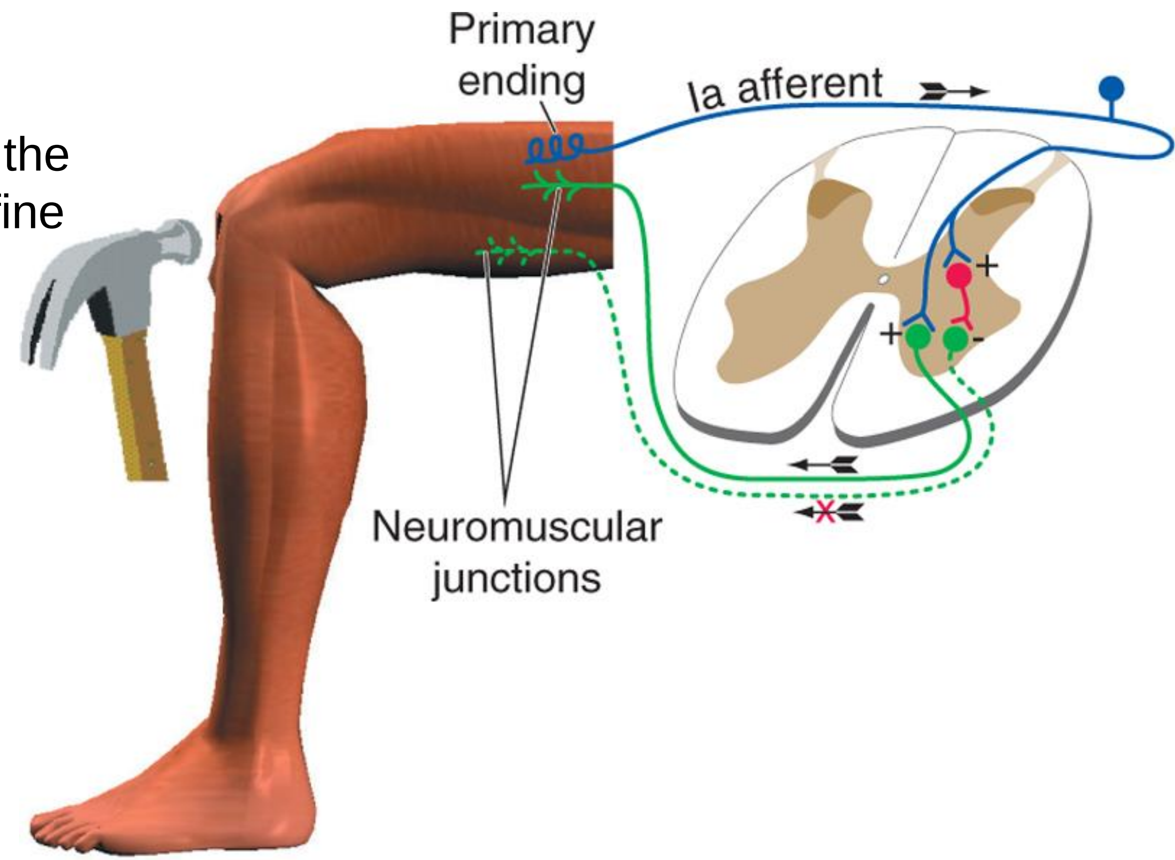
Descending projections are to motor neurons and to interneurons that synapse with motor neurons.

Motor Control

Reflex circuits:

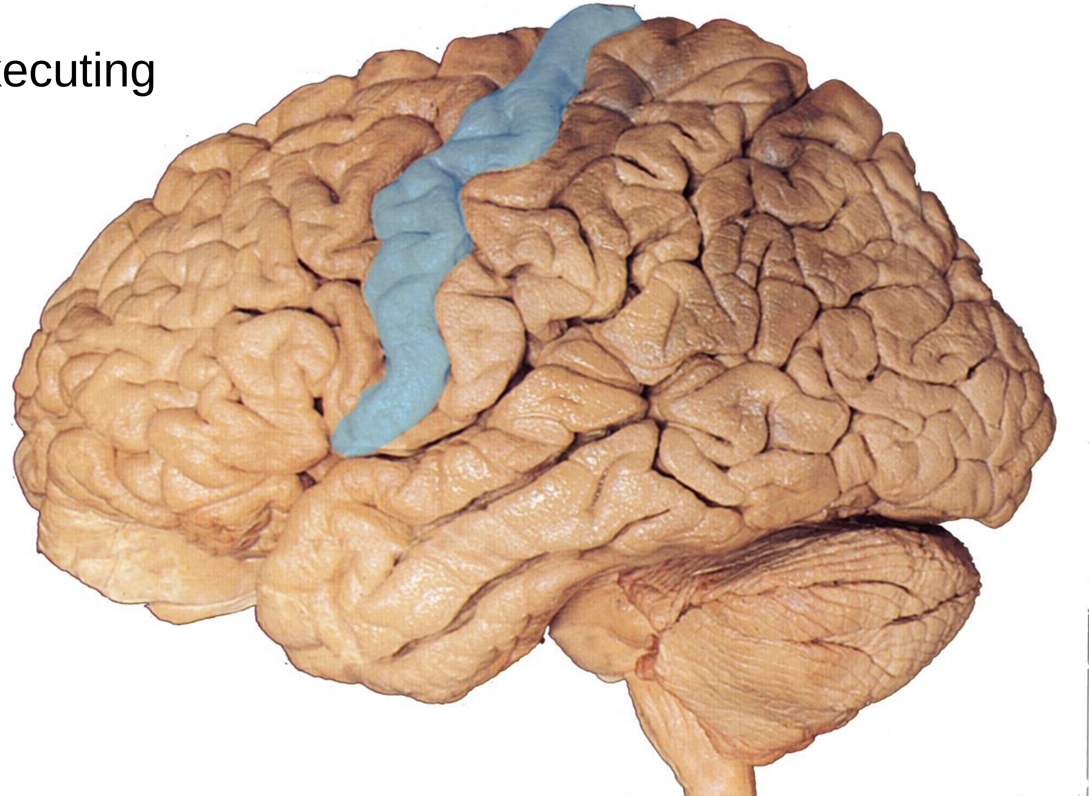
- These range from local monosynaptic circuits such as the stretch reflex to circuits that involve multiple levels and both sides of the spinal cord and brainstem.

- Some reflexes respond to sensory input pertaining to the environment, while others fine tune movements.



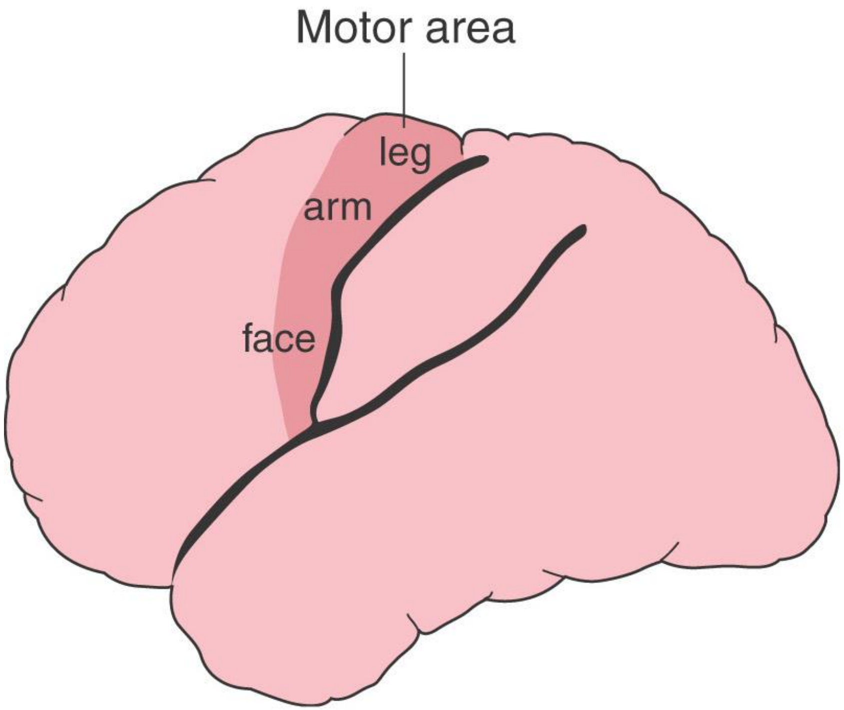
Motor Cortex

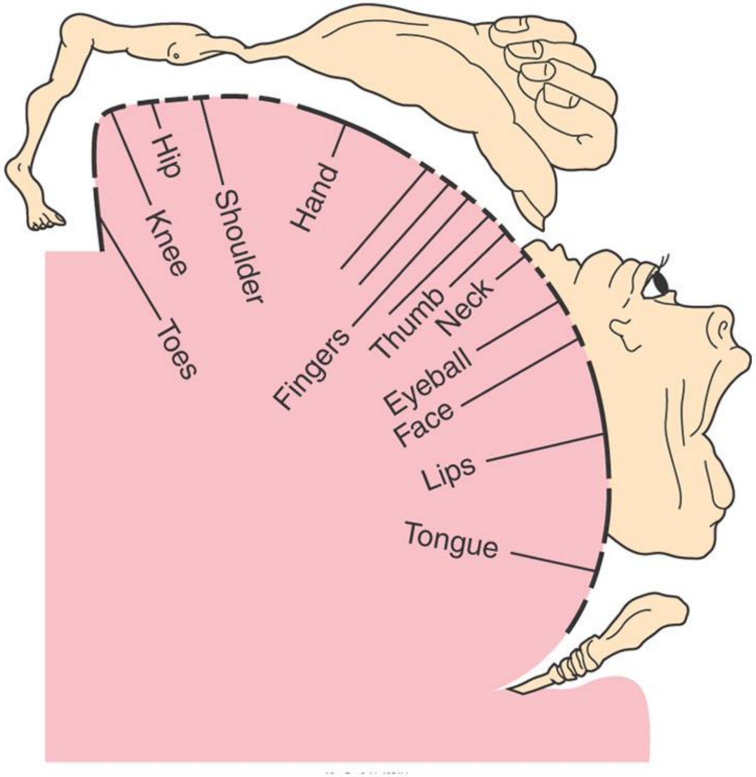
- The largest descending input to motor neurons is from primary motor cortex in the precentral gyrus of the frontal lobe.
- Axons descending from motor cortex are from upper motor neurons in cortical layer V.
- Motor cortex is essential for executing voluntary movements.



Motor Cortex

- Motor cortex is somatotopically organized (homunculus).
- A stoke in a part of motor cortex results in paralysis of the part of the body served by that area of cortex.

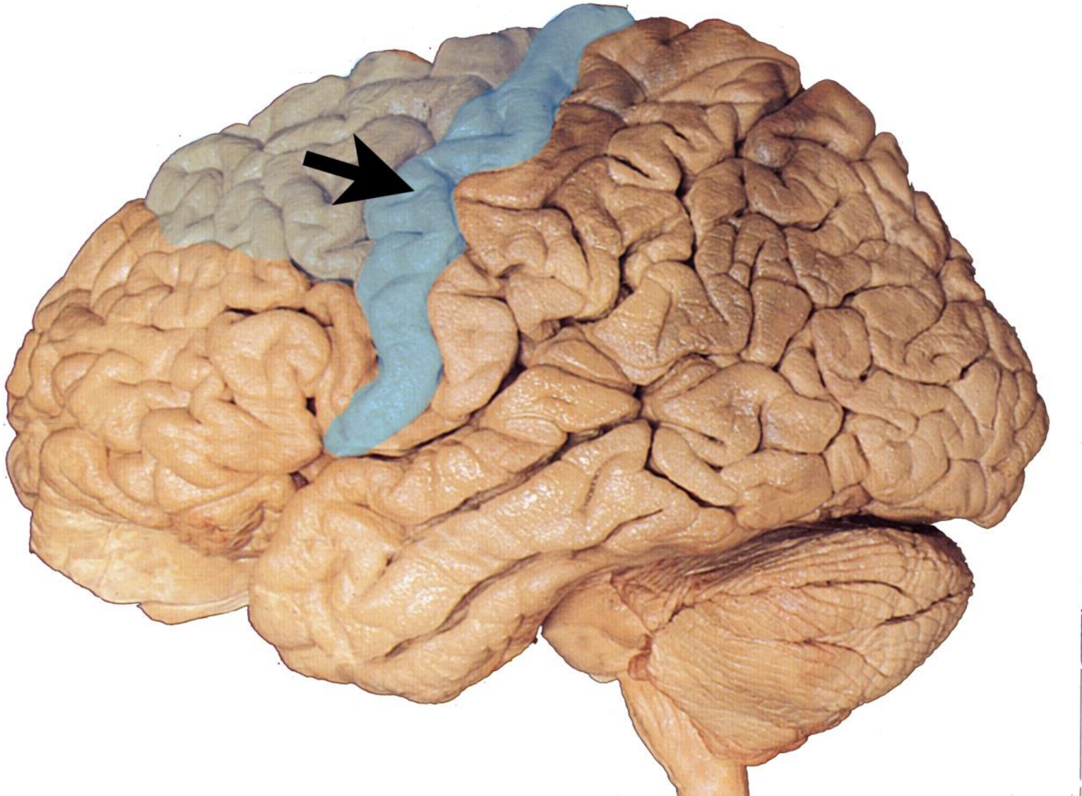




Motor Cortex

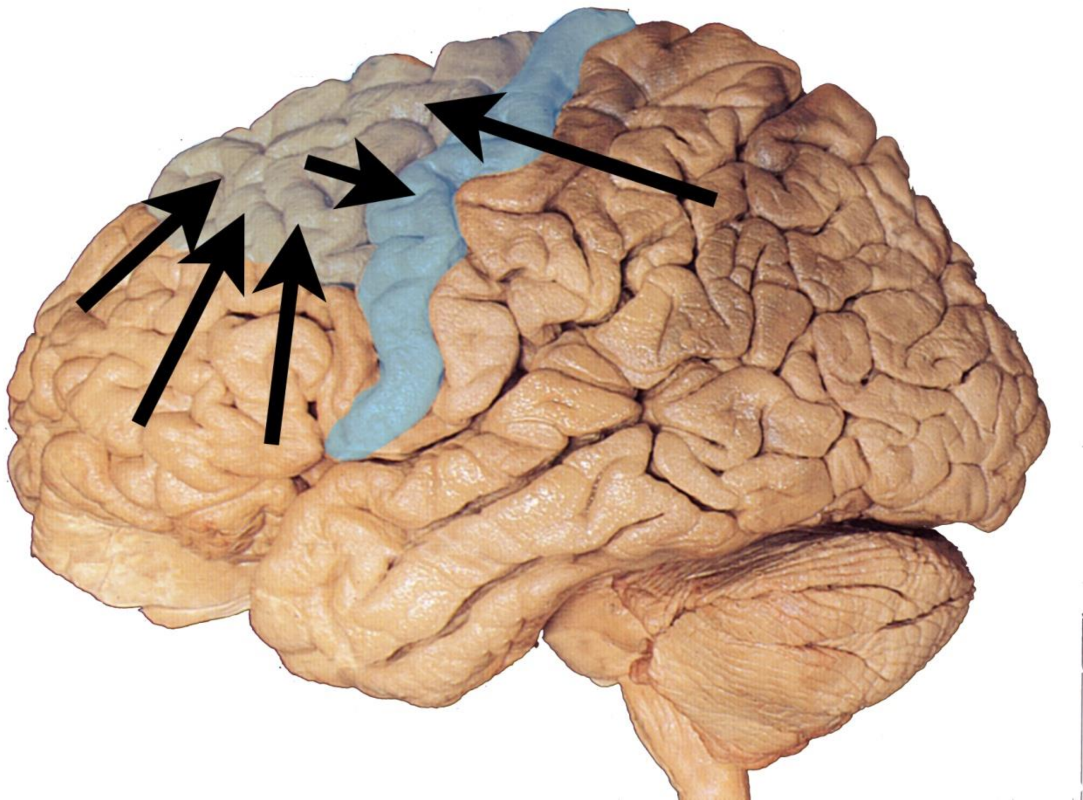
- Major inputs to motor cortex include somatosensory cortex and premotor cortex.

- Premotor cortex is essential for planning movements and for learned movements.



Motor Cortex

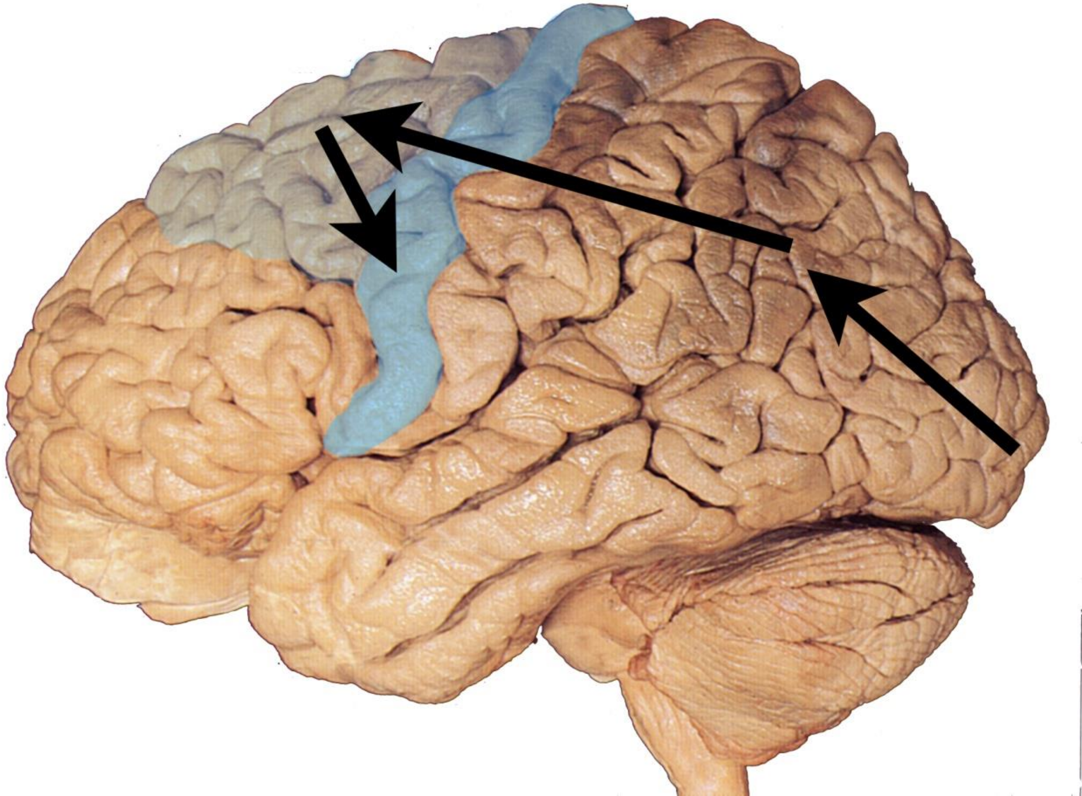
- More than a dozen accessory motor areas and association areas project to premotor cortex.



Motor Cortex

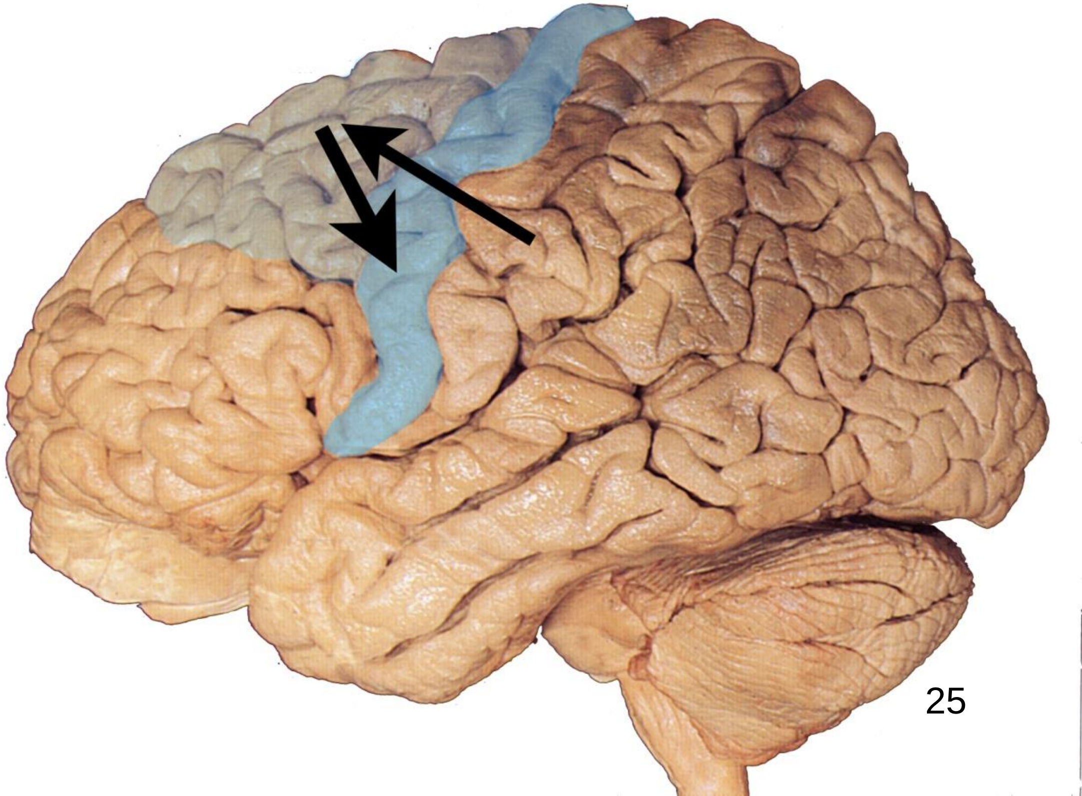
- The magnocellular visual pathway (dorsal stream) carrying information about movement and position goes from visual cortex to parietal cortex to premotor cortex.

- This pathway is important for visually guided motor tasks.



Motor Cortex

- Vestibular information also is sent from parietal cortex to premotor cortex.
- Vestibular input is used to plan and modify movements.

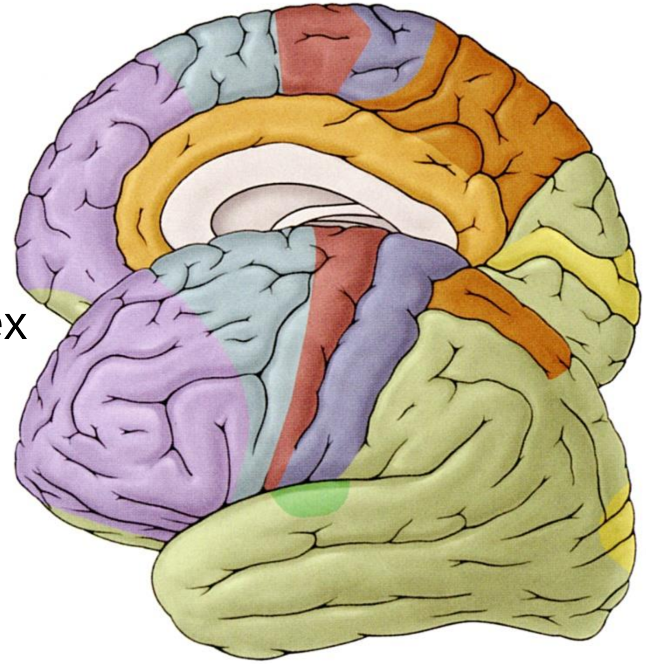


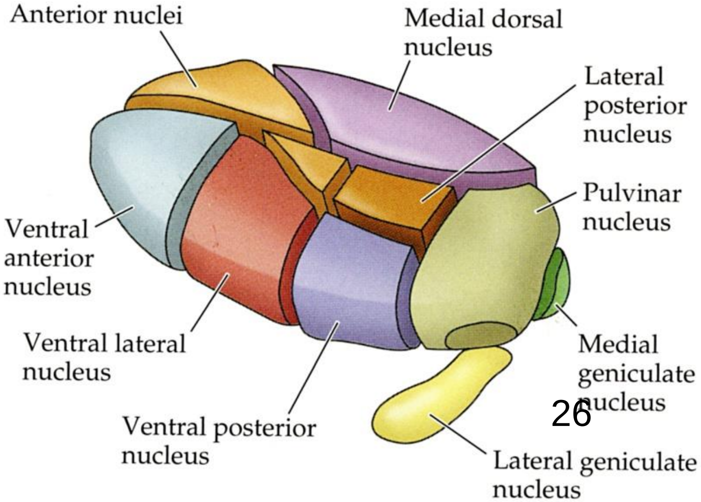
Motor Cortex

- Thalamus projects to premotor and motor cortex:

basal ganglia ⟶ ventral anterior nucleus ⟶ cortex

cerebellum ⟶ ventral lateral nucleus ⟶ cortex





Motor Cortex

Descending projections of motor and premotor cortex:

- Lateral corticospinal tract – to entire contralateral spinal cord
- Ventral corticospinal tract – to bilateral cervical & upper thoracic cord
- Corticobulbar tract – to bilateral brainstem cranial nerve motor nuclei

cranial nerve		***function***			
		general motor	***parasympathetic***	***general sensory***	***special sensory***
I	Olfactory				X (olfaction)
II	Optic				X (vision)
III	Oculomotor	X[a]	X		
IV	Trochlear	X[a]			
V	Trigeminal	X[b]		X[c]	
VI	Abducens	X[a]			
VII	Facial	X[b]	X	X	X (taste)
VIII	Vestibulocochlear				X (auditory & vestibular)
IX	Glossopharyngeal	X[b]	X	X[c]	X (taste)
X	Vagus	X[b]	X	X[c]	X (taste)
XI	Accessory *	X[a]			
XII	Hypoglossal	X[a]			

* cervical component; cranial component included with vagus

[a] somatic motor – innervates muscles that develop from somites

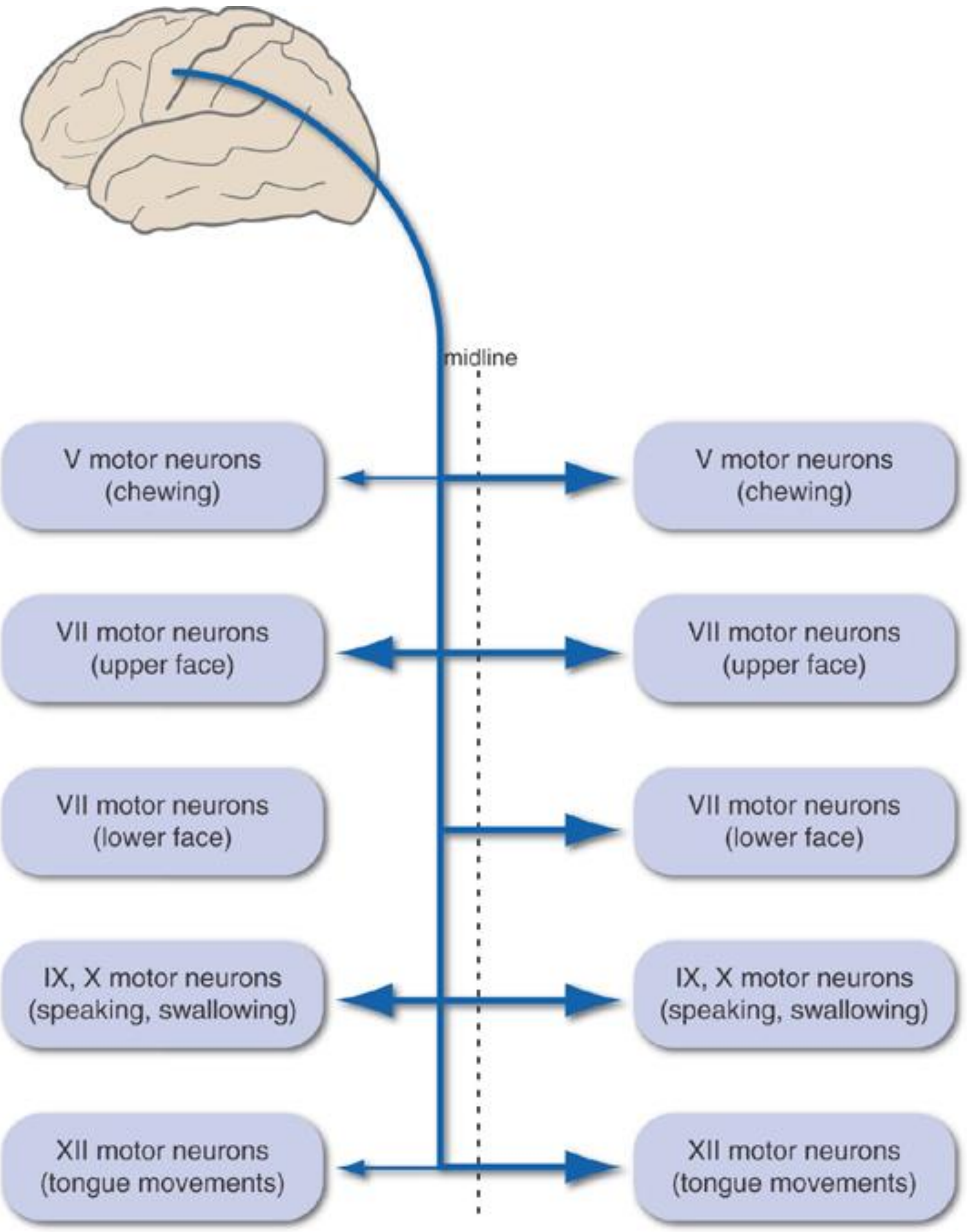
[b] branchial motor – innervates muscles that develop from pharyngeal arches

[c] includes visceral sensory as well as somatosensory

Motor Cortex

Corticobulbar tract:

- mostly bilateral to brainstem cranial nerve motor nuclei except for facial nerve motor nucleus for muscles of facial expression, which is only contralateral.



Motor Cortex

Route of descending projections from motor and premotor cortex to spinal cord:

- Internal capsule
- Cerebral peduncle (midbrain)
- Corticospinal & corticobulbar tracts (pons)
- Pyramids (upper medulla)

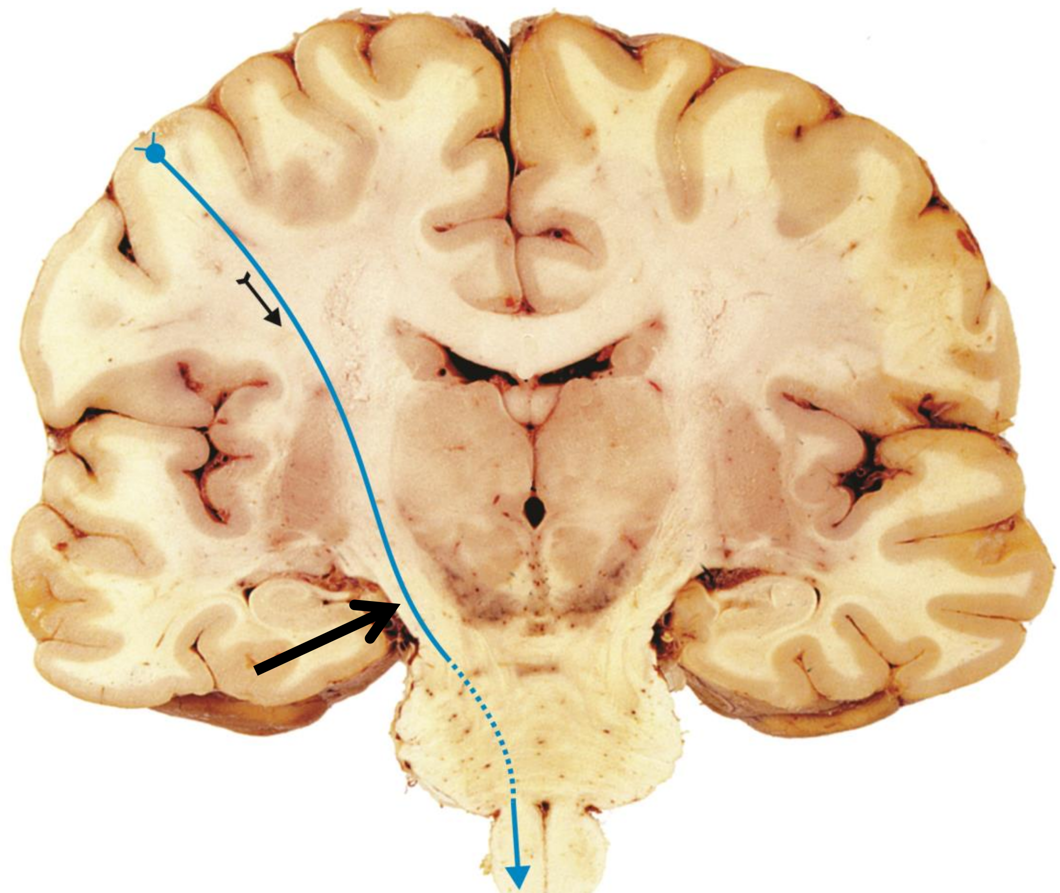
crossed axons in:

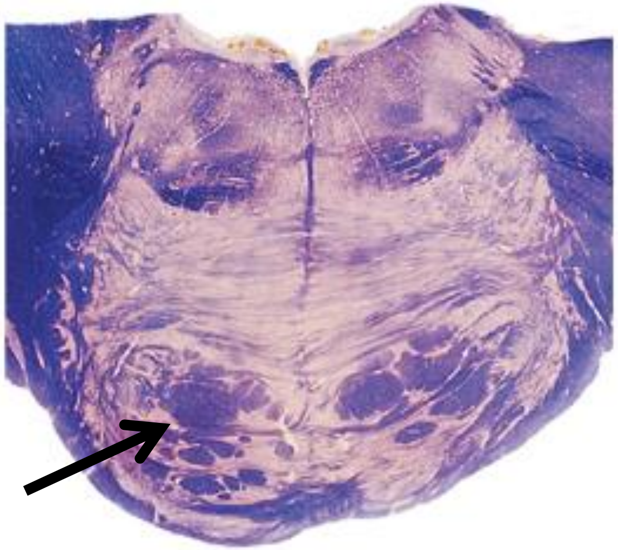
- Pyramidal decussation (lower medulla)
- Lateral corticospinal tract (spinal cord)

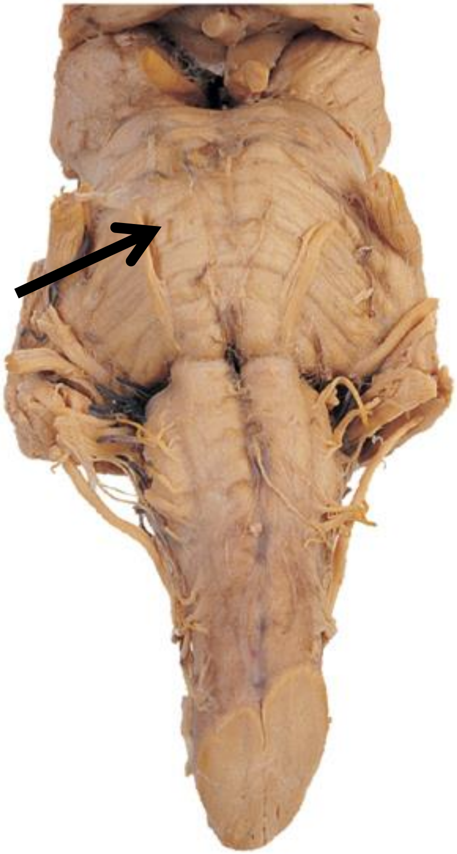
uncrossed axons in:

- Ventral corticospinal tract (spinal cord)

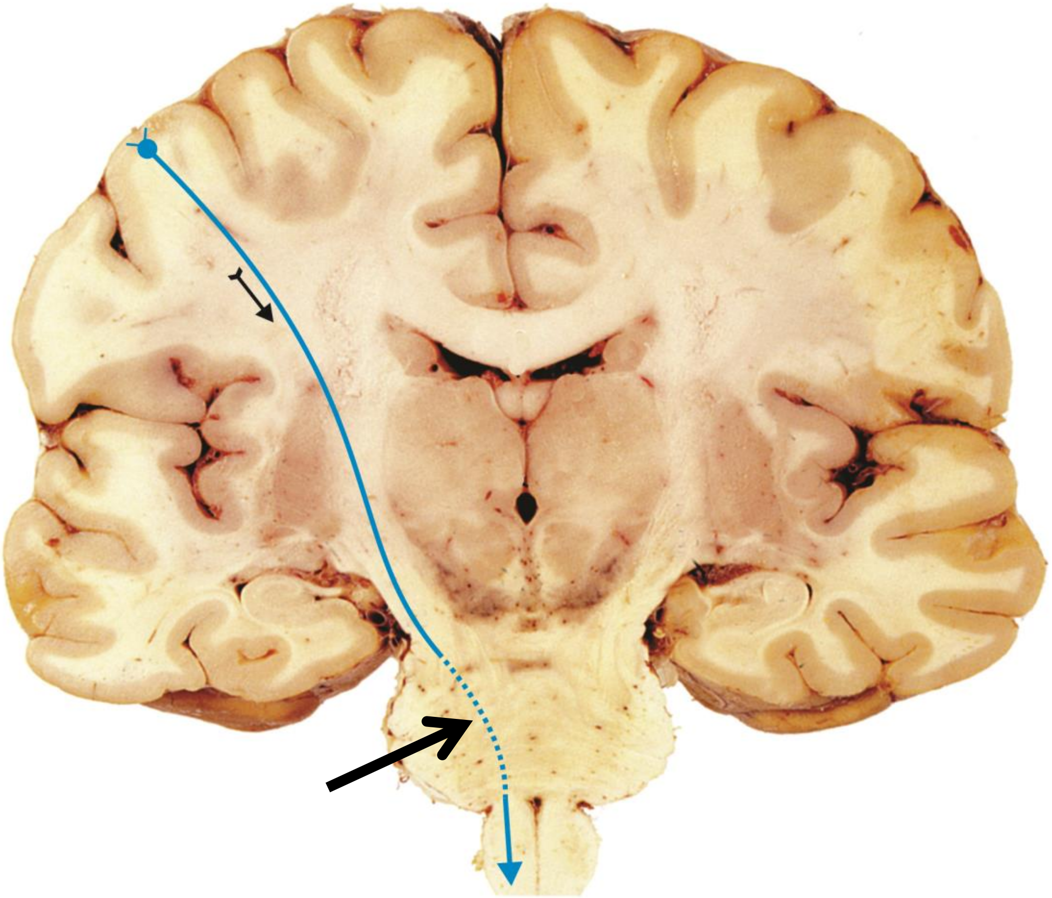
- internal capsule (telencephalon)
- cerebral peduncle (midbrain)

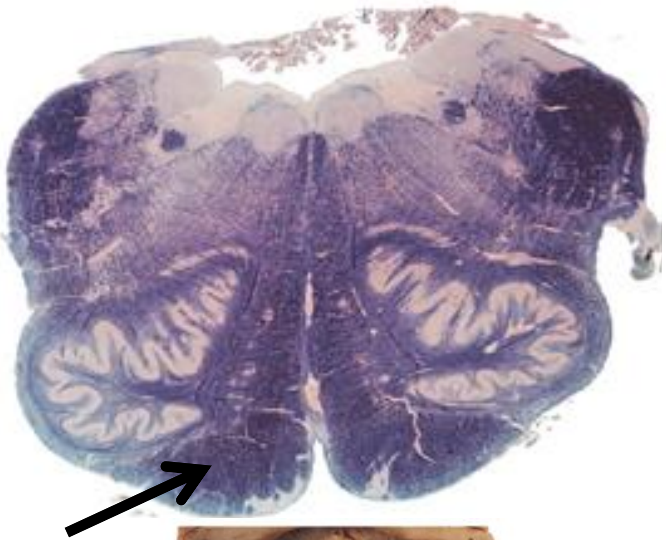


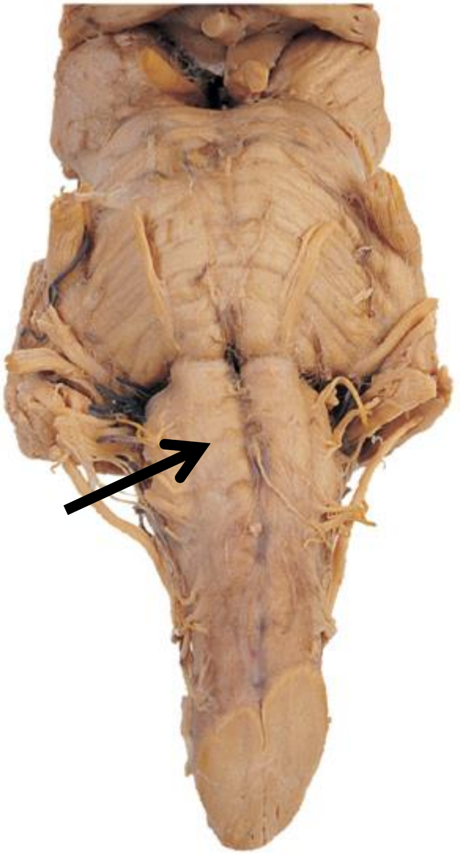




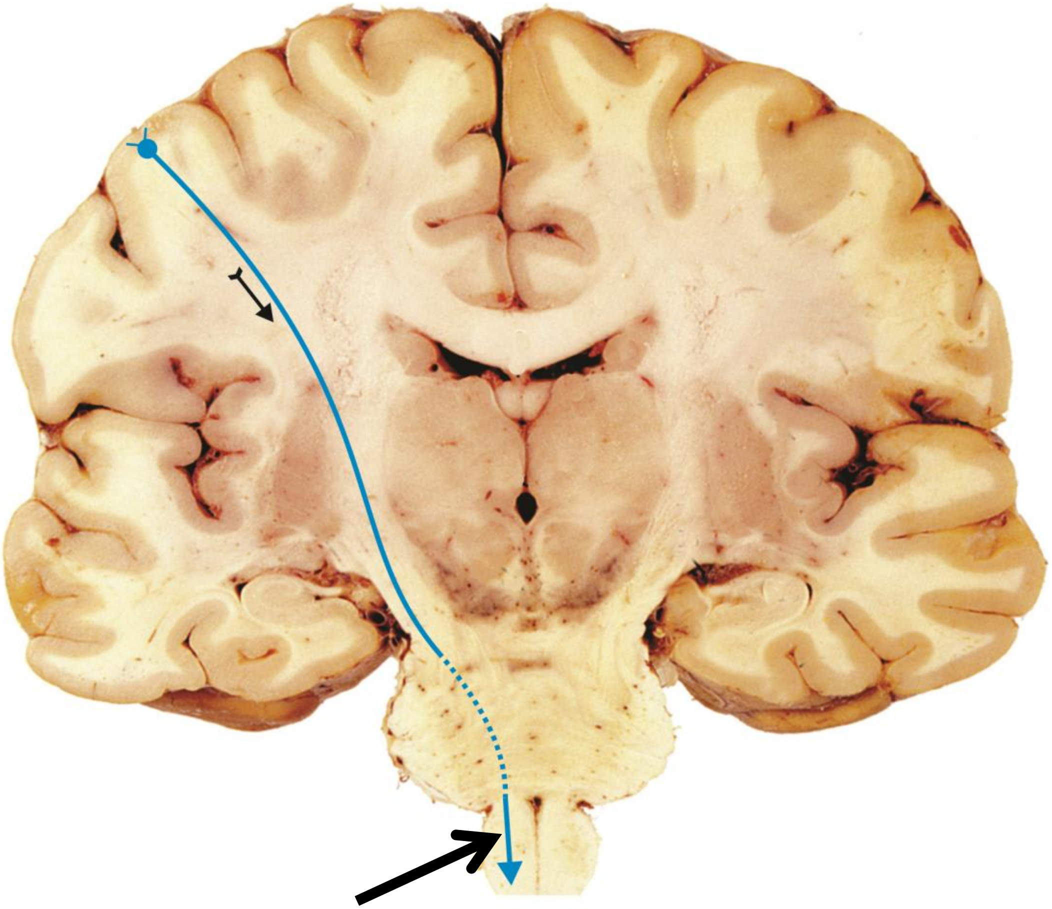
- corticospinal & corticobulbar tracts (pons)





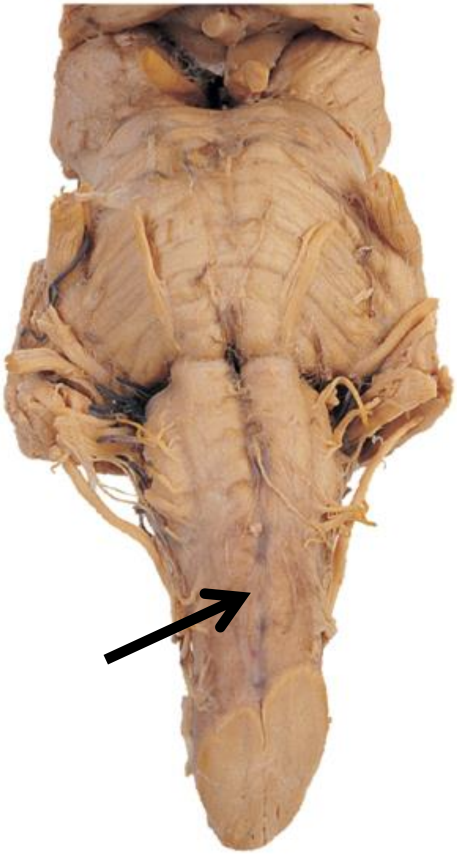


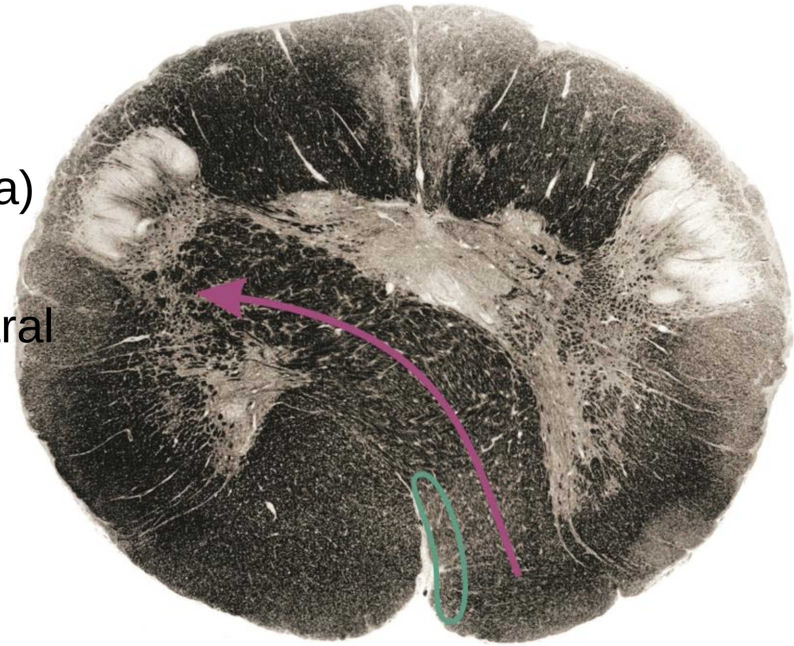
- pyramids (upper medulla)

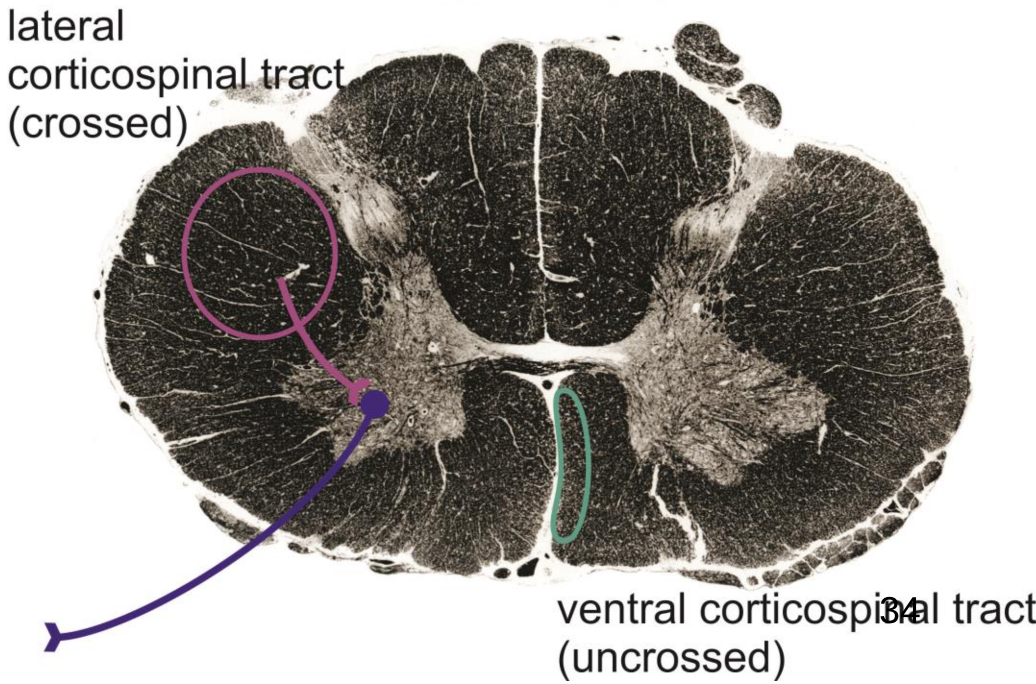


Lateral Corticospinal Tract

- Decussation of the pyramids (lower medulla)
- to lateral corticospinal tract (spinal cord)
- to synapse with lower motor neuron in ventral horn of spinal cord

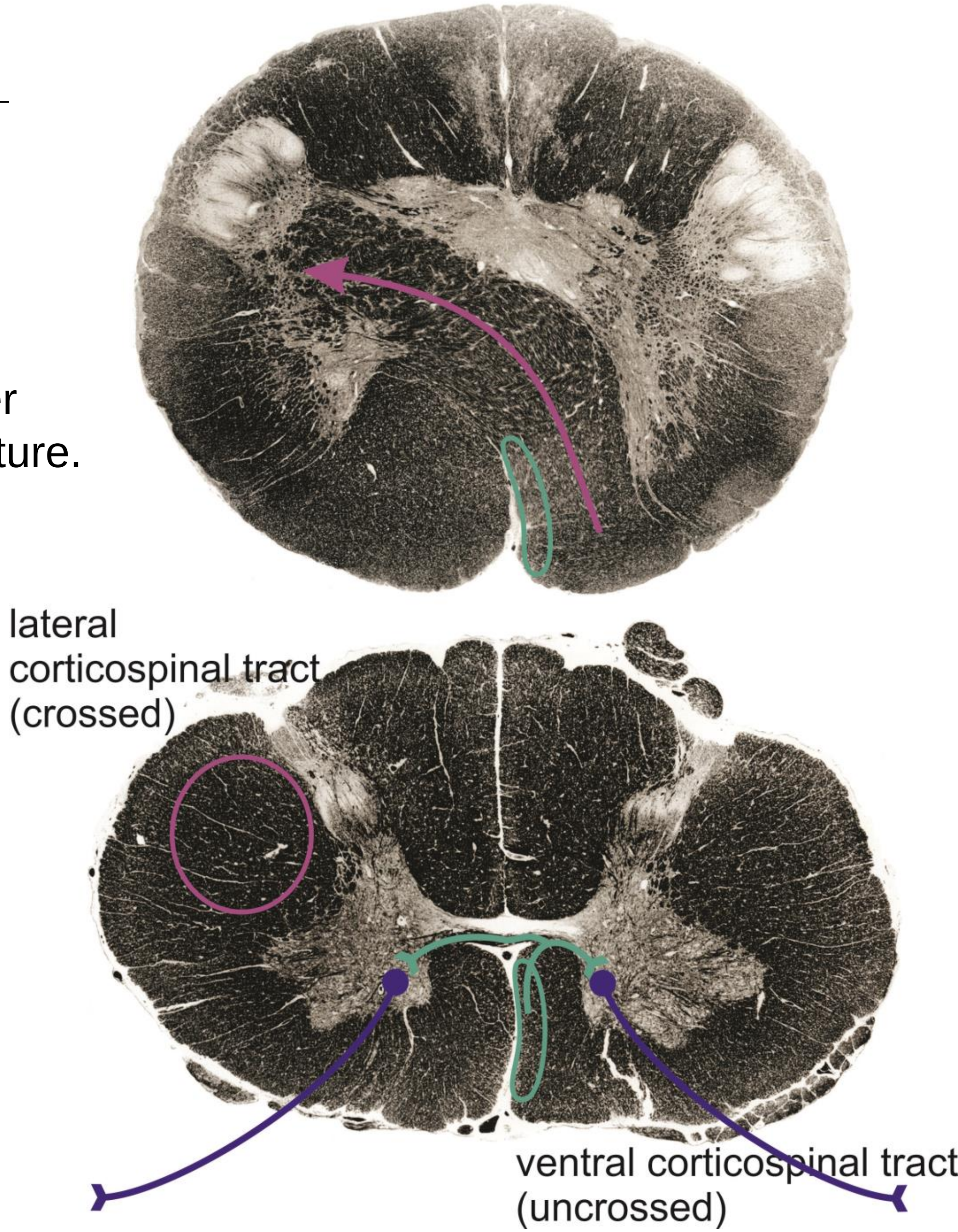






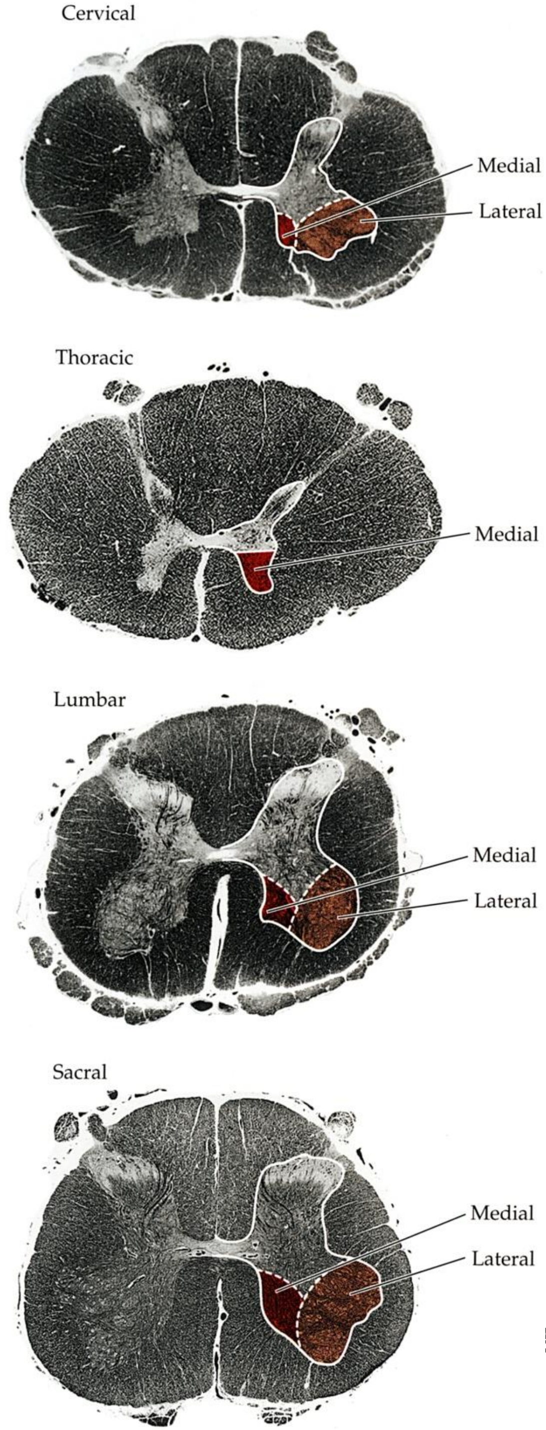
Ventral Corticospinal Tract

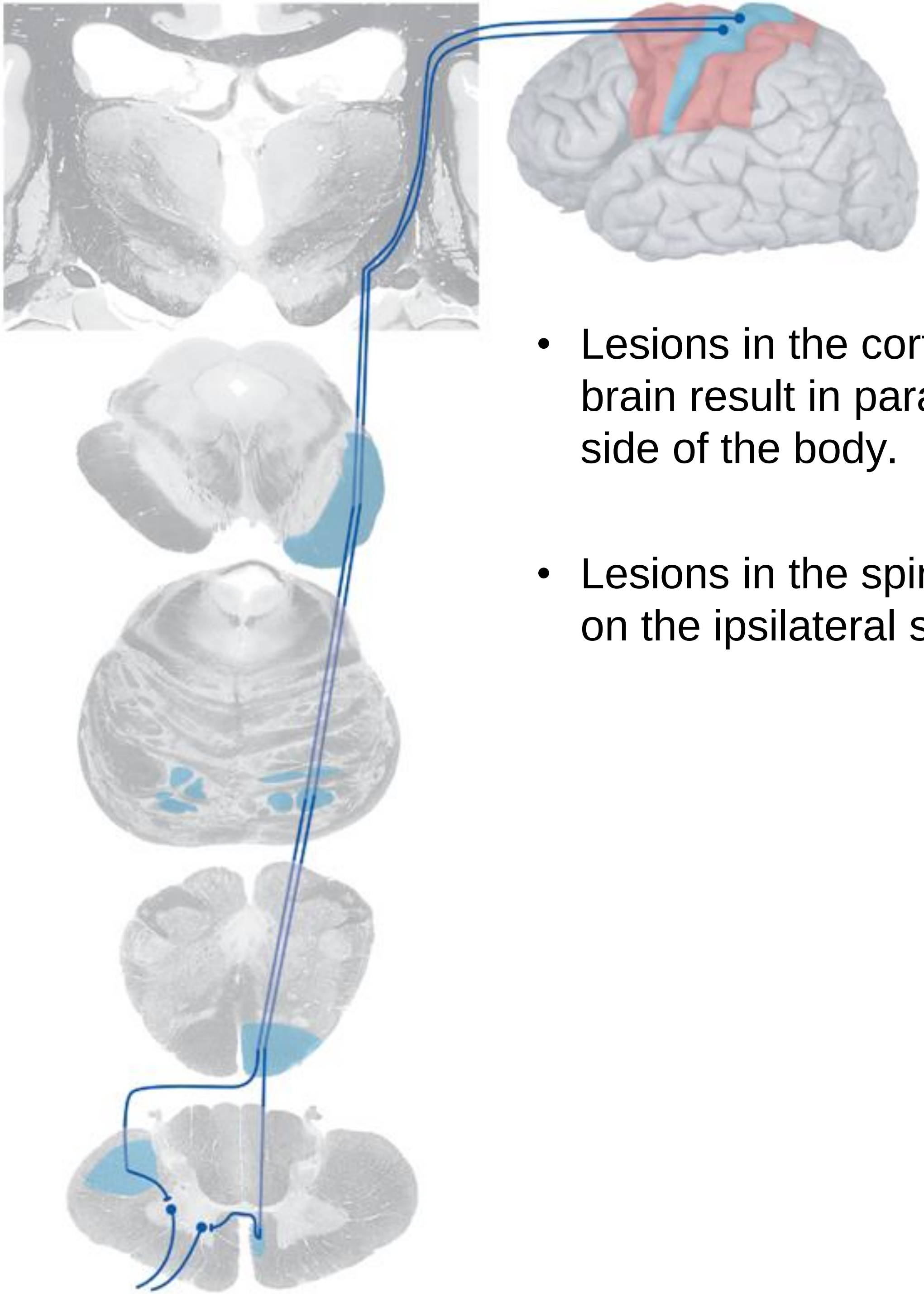
- descends in the spinal cord uncrossed.
- projects bilaterally mainly to lower motor neurons for trunk musculature.



Corticospinal Tracts

- Motor neurons for limb muscles are in lateral ventral horn.
- Motor neurons for trunk muscles are in medial ventral horn.



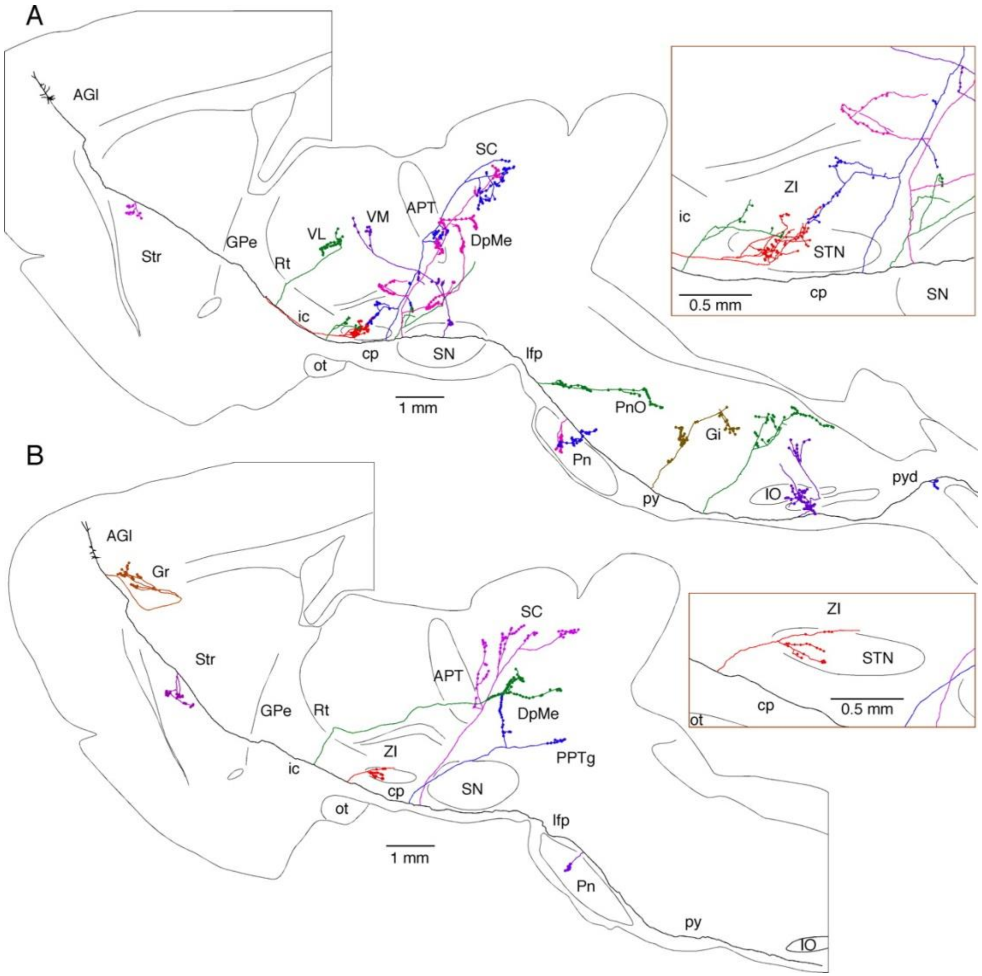


Corticospinal Tracts

- Lesions in the cortex and corticospinal tract in the brain result in paralysis mostly on the contralateral side of the body.
- Lesions in the spinal cord result in paralysis mostly on the ipsilateral side of the body.

Motor Cortex

- Motor cortex has complex connections with many parts of the brain.



Kita T , and Kita H J. Neurosci. 2012;32:5990-5999

Motor Control

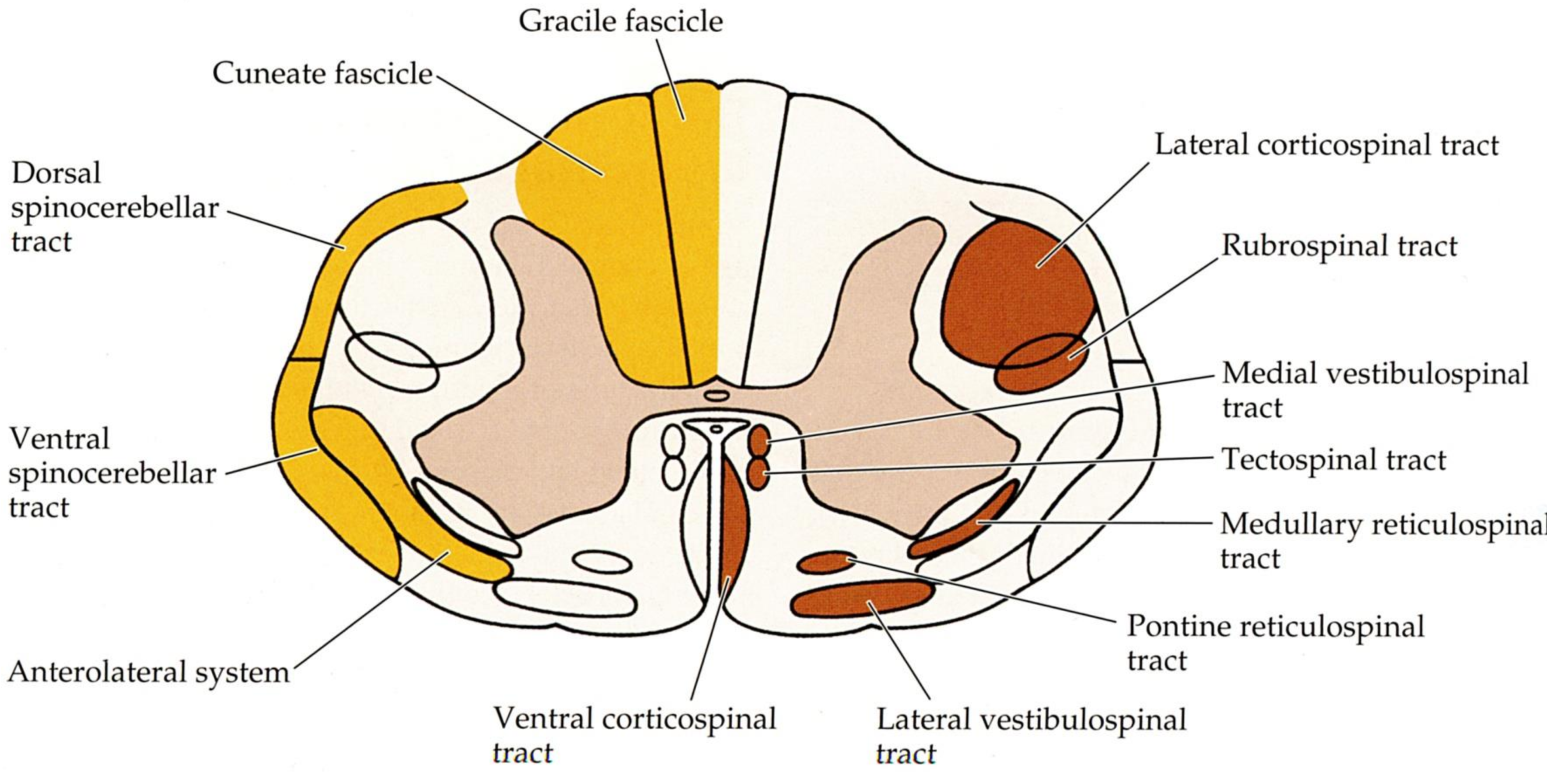
Other pathways to motor neurons:

- Rubrospinal tract – from red nucleus in midbrain, runs close to lateral corticospinal tract to all levels of the spinal cord for fine tuning limb movements

- Vestibulospinal tract – from vestibular nuclei to all levels of the spinal cord for balance and adjusting head position

- Reticulospinal tract – from reticular formation in pons and medulla to all levels of the spinal cord for automatic control of trunk muscles for posture and limb muscles for learned movements

- Tectospinal tract – from superior colliculus to cervical spinal cord for coordination of head & eye movements



Gracile fascicle
Cuneate fascicle
Dorsal spinocerebellar tract
Ventral spinocerebellar tract
Anterolateral system
Ventral corticospinal tract
Lateral vestibulospinal tract
Pontine reticulospinal tract
Medullary reticulospinal tract
Tectospinal tract
Medial vestibulospinal tract
Rubrospinal tract
Lateral corticospinal tract

Motor Control

- Cortical motor control is most important for initiating movements and for consciously controlled, unique movements.
- Brainstem motor control is most important for subconscious balance and midcourse corrections (coordination).
- Local circuits maintain repetitive movements and coordinate flexor and extensor muscle groups and left-right sequences (such as walking).

Motor Neuron Disease

- Amyotrophic lateral sclerosis (ALS) or Lou Gehrig’s disease
  - ALS is the loss of motor control due to the rapidly progressing degeneration of upper and/or lower motor neurons.
  - Death is usually from respiratory failure.
  - ~10% of the cases are due to a mutation in one of several genes involved in various metabolic processes; most cases are idiopathic.

Botox

- Botulinum toxin (botox) is produced by a bacteria.
- The toxin is taken up by motor neuron axon terminals and blocks fusion of synaptic vesicles to the presynaptic membrane.
- Thus, the toxin blocks release of acetylcholine and results in muscle paralysis.
- The bacteria and its toxin is the cause of a disease called botulism. It is the most lethal toxin known.

Botox

- Botox is used 'clinically' to block muscle contractions.