German University in Cairo

Spring 2020

CSEN 1099 – Introduction to Biomedical Engineering

Anatomy and Physiology Background (2)

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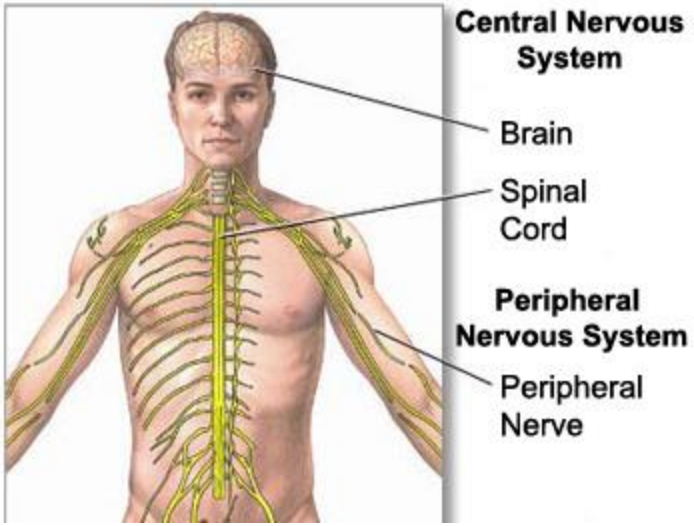
Nervous System

- The nervous system is responsible for the integration and control of all the body's functions



- It has two major divisions:
  - Central Nervous System (CNS):

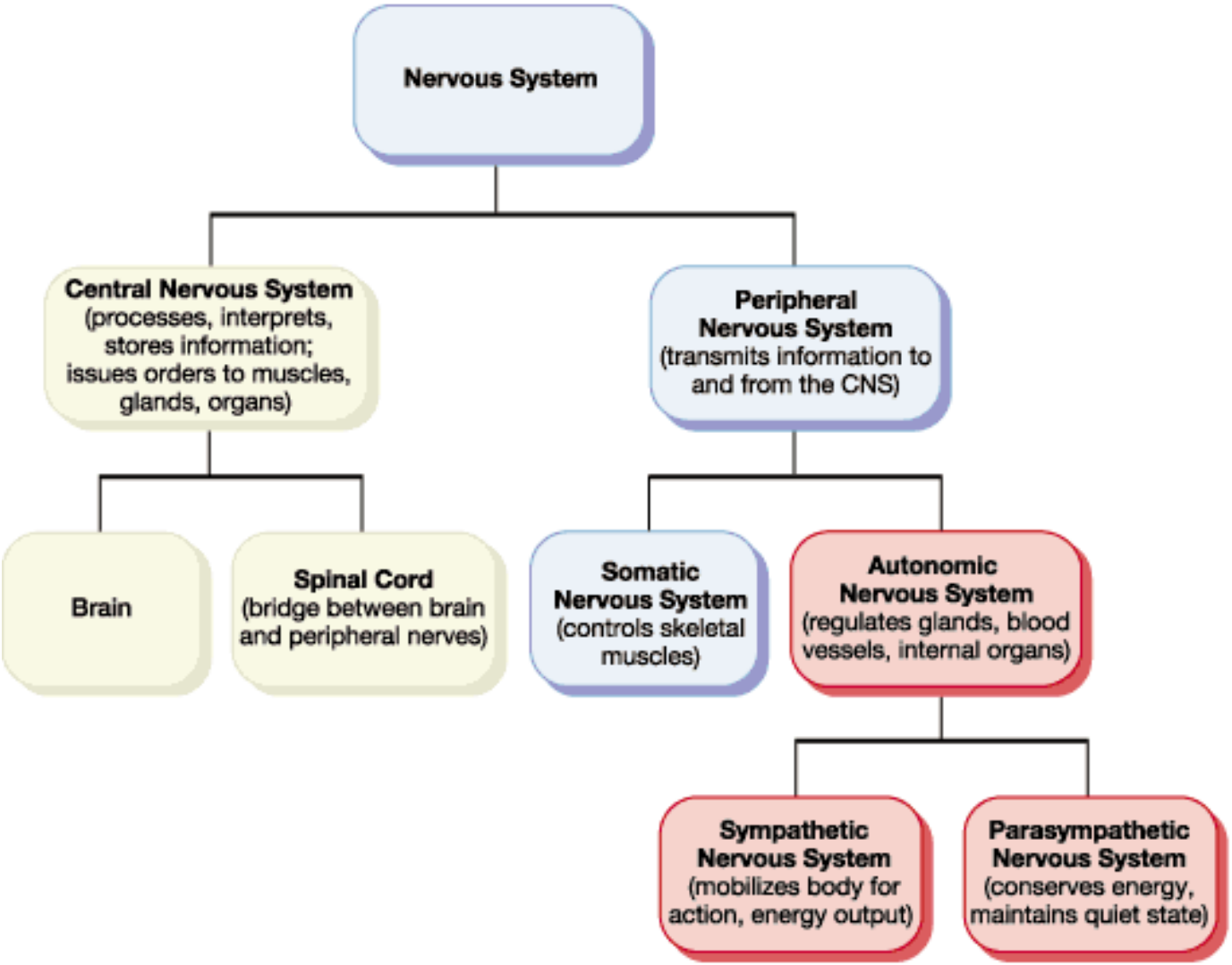
    The brain and the spinal cord

  - Peripheral Nervous System (PNS):

    Enables the body to detect and respond to both internal and external stimuli

Nervous System

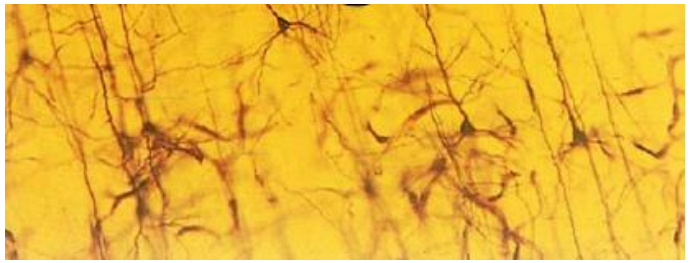
- The nervous system can also be further divided as shown below



The Neuron

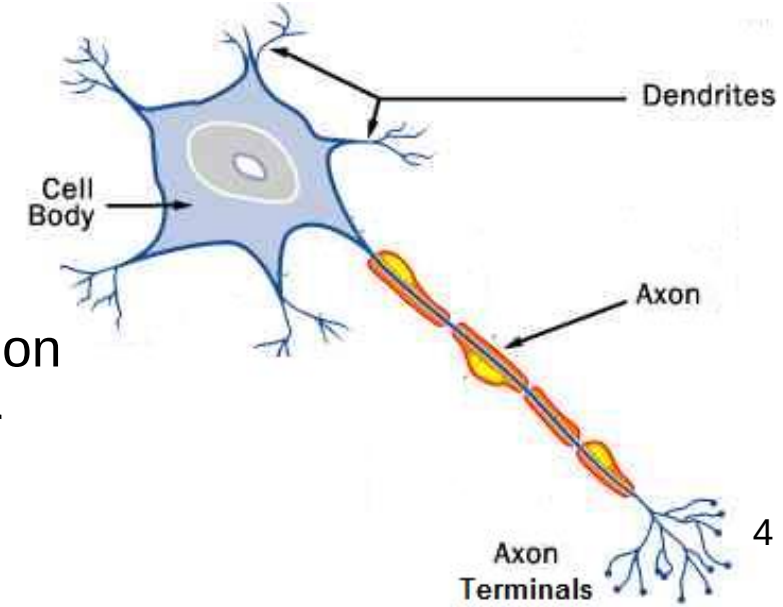
- Adult human brain contains about 100 billion neurons, each neuron receives an average of 7000 connections

- The brain consists of highly connected network



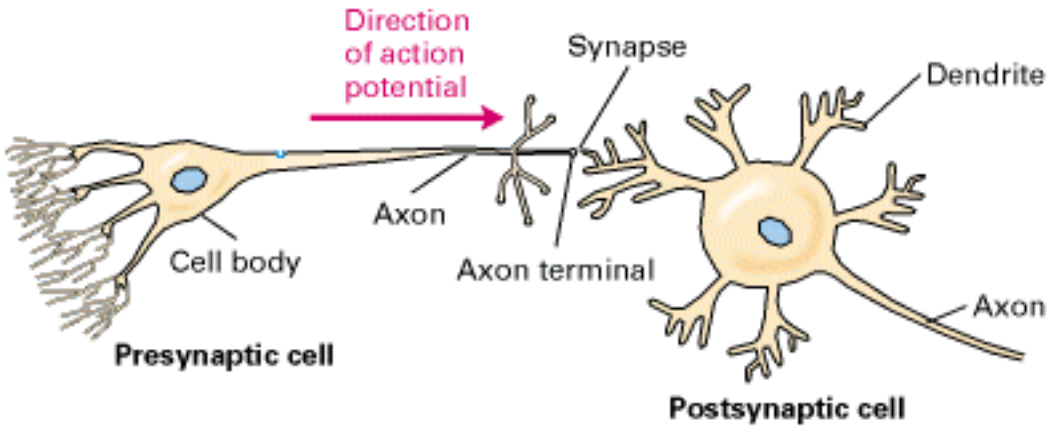
Neurons Under the Microscope

- Neuron Structure:
  - Dendrites: Receives inputs
  - Cell Body: Does the processing
  - Axon: Carries electrical pulses (action potentials) to axon terminals to other neurons

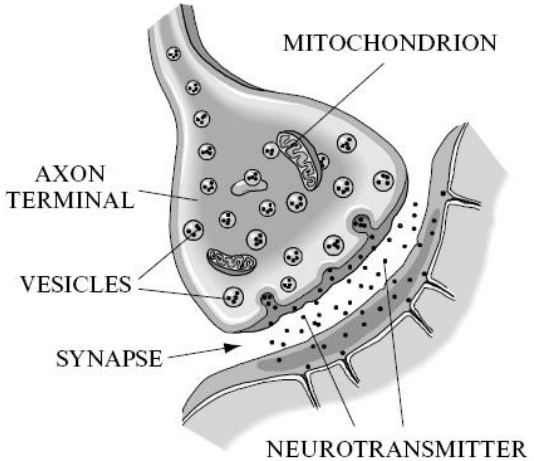


The Neuron

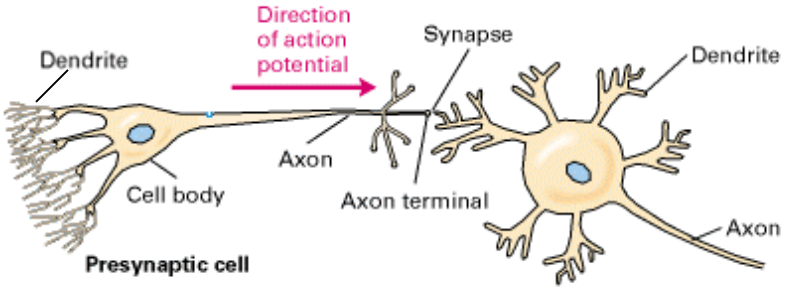
- Syanpse: The site of communication between two neurons

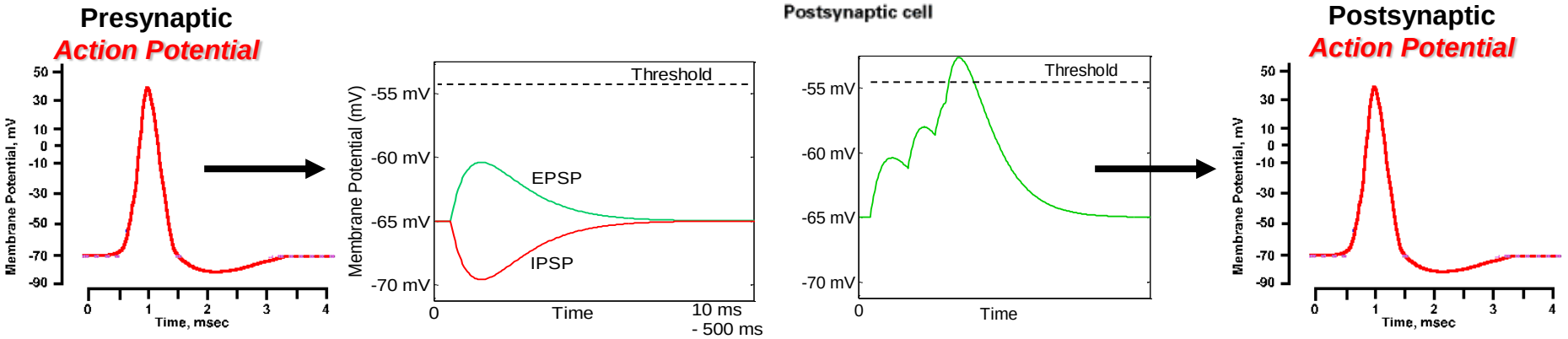


- Following stimulation, vesicles in the axon terminal release neurotransmitters into the space between the axon and the next cell. The neurotransmitters diffuse across the synapse and elicit a response from the adjacent cell



The Neuron

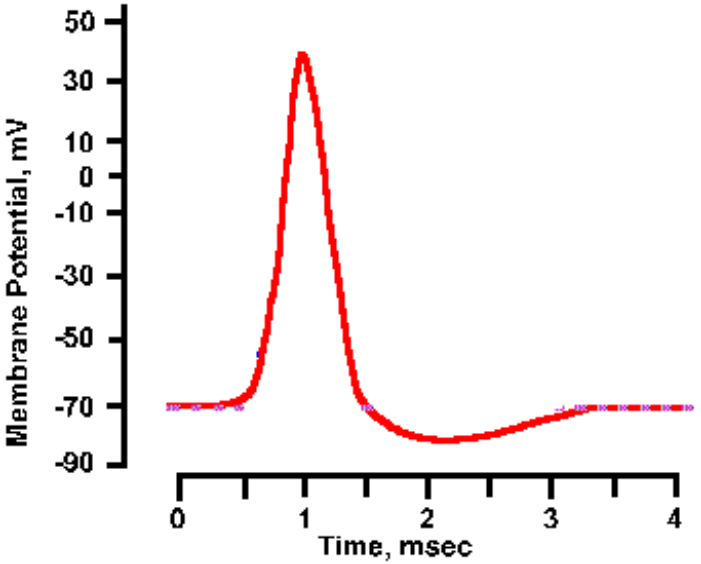




- A presynaptic action potential causes a change in the membrane potential of the postsynaptic neuron
- Changes are either Excitatory or Inhibitory Postsynaptic Potentials (EPSP or IPSP) depending on the type of the connection
- When the postsyanptic neuron potential exceeds a certain threshold, a postsynaptic action potential is elicited

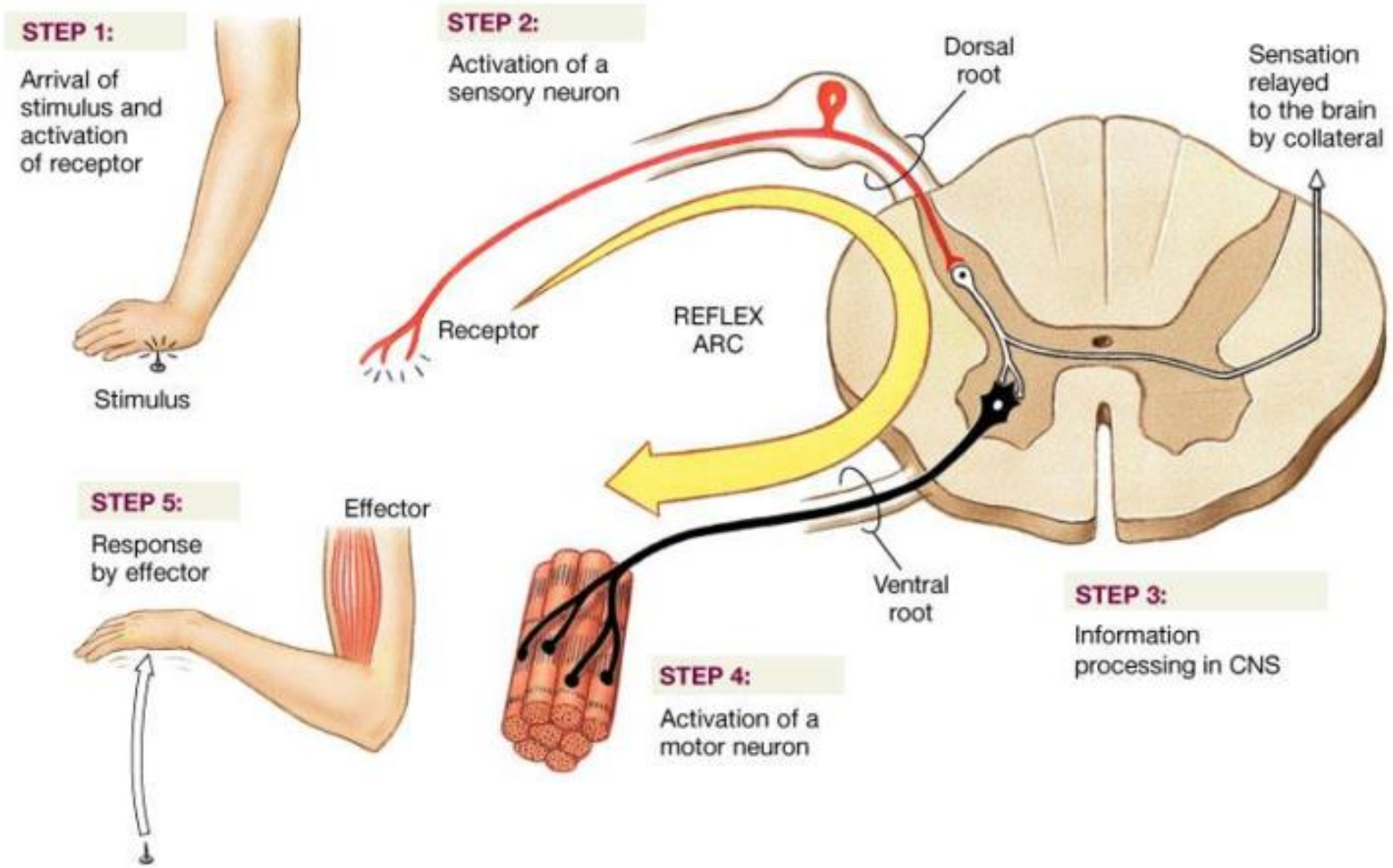
The Neuron

- The output of neurons is binary: Either they produce an action potential or they don't
- All neurons generate the same shape of an action potential
- The duration of an action potential is about 3 msec



Example: Reflex Arc Circuit

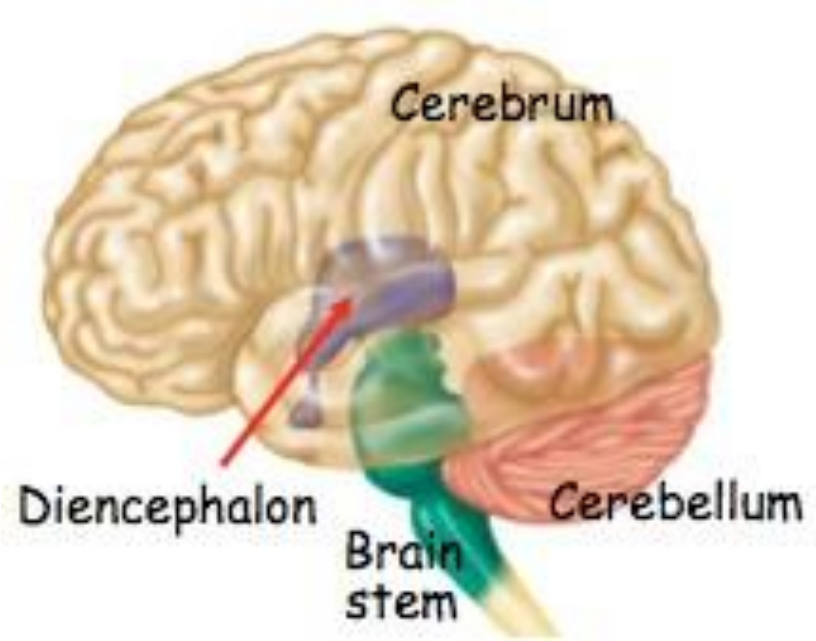
- The reflex arc is a special type of neural circuits that begins with a sensory neuron at a receptor (e.g., a pain receptor in the fingertip) and ends with a motor neuron at an effector (e.g., a skeletal muscle)



Brain Structure

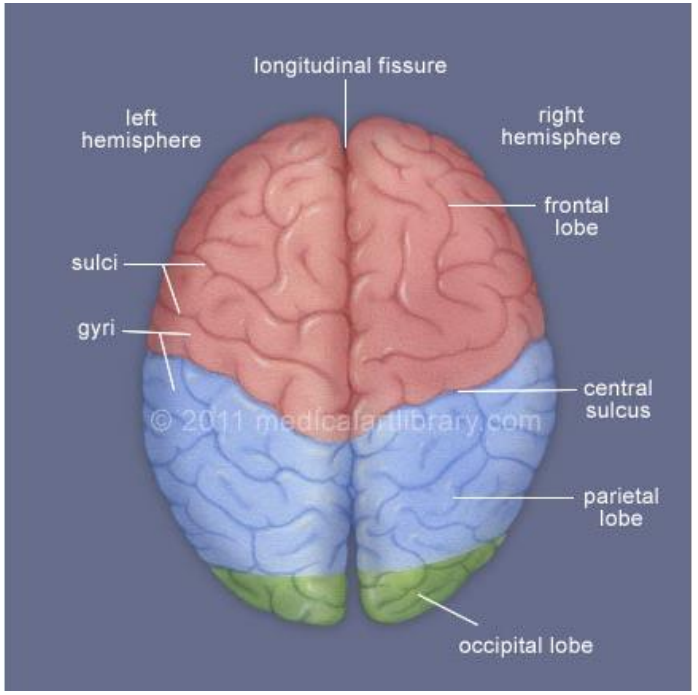
- The brain is a large soft mass of nervous tissue and has three major parts:

  (1) Cerebrum
  (2) Diencephalon
  (3) Brain stem and Cerebellum



Brain Structure: Cerebrum

- The Cerebrum is divided into 2 hemispheres
- The left hemisphere is responsible for the right side of the body and vice versa
- **The frontal lobe** is responsible for initiating voluntary movement, analyzing sensory experiences, providing responses relating to personality, and mediating responses related to memory, emotions, reasoning, judgment, planning, and speaking

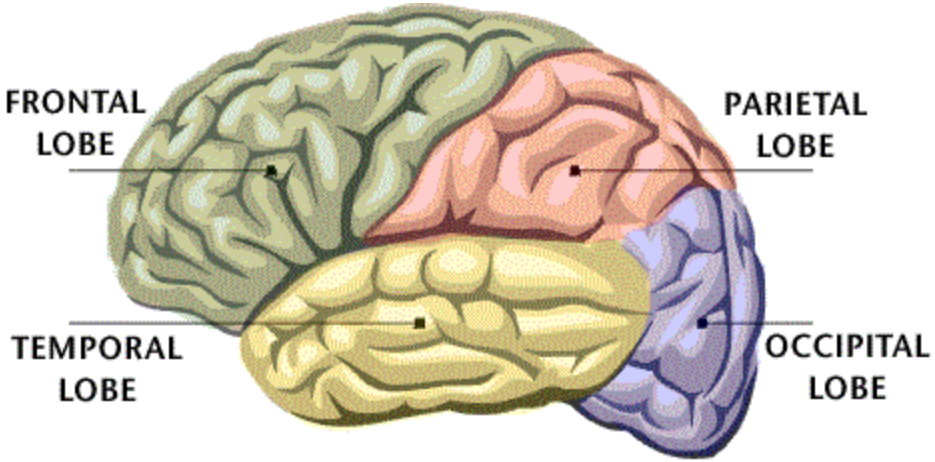


Brain Structure: Cerebrum

- **The parietal lobes** respond to stimuli from cutaneous (skin) and muscle receptors throughout the body

- **The temporal lobes** interpret some sensory experiences, store memories of auditory and visual experiences, and contain auditory centers that receive sensory neurons from the cochlea of the ear

- **The occipital lobes** integrate eye movements by directing and focusing the eye and are responsible for correlating visual images with previous visual experiences and other sensory stimuli



Brain Structure: Cerebrum

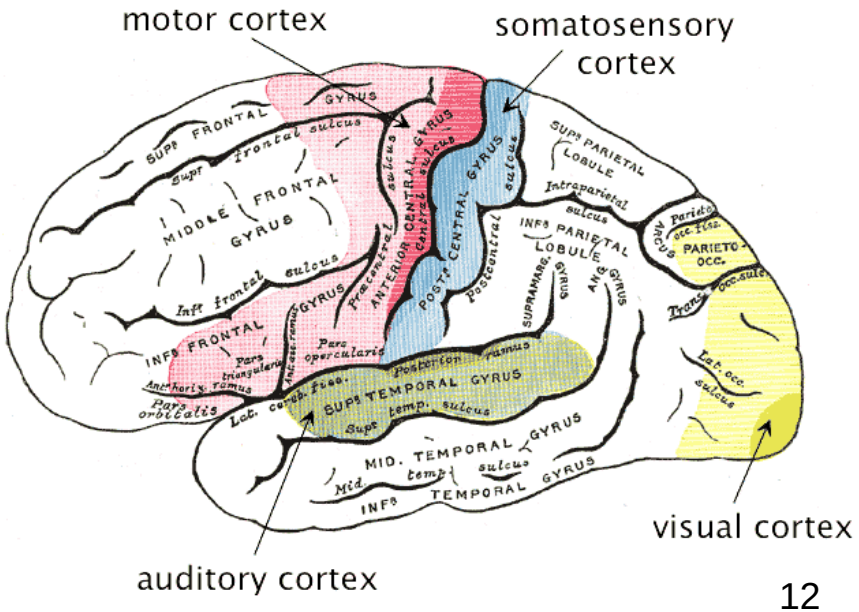
- The outer layer of the cerebrum is called the cerebral cortex

- The cerebral cortex has 4 major areas:
  - Motor Cortex: Plans and executes voluntary movements

  - Somatosensory Cortex: Receives and processes information related to touch

  - Auditory Cortex: Receives and processes information coming from the ear

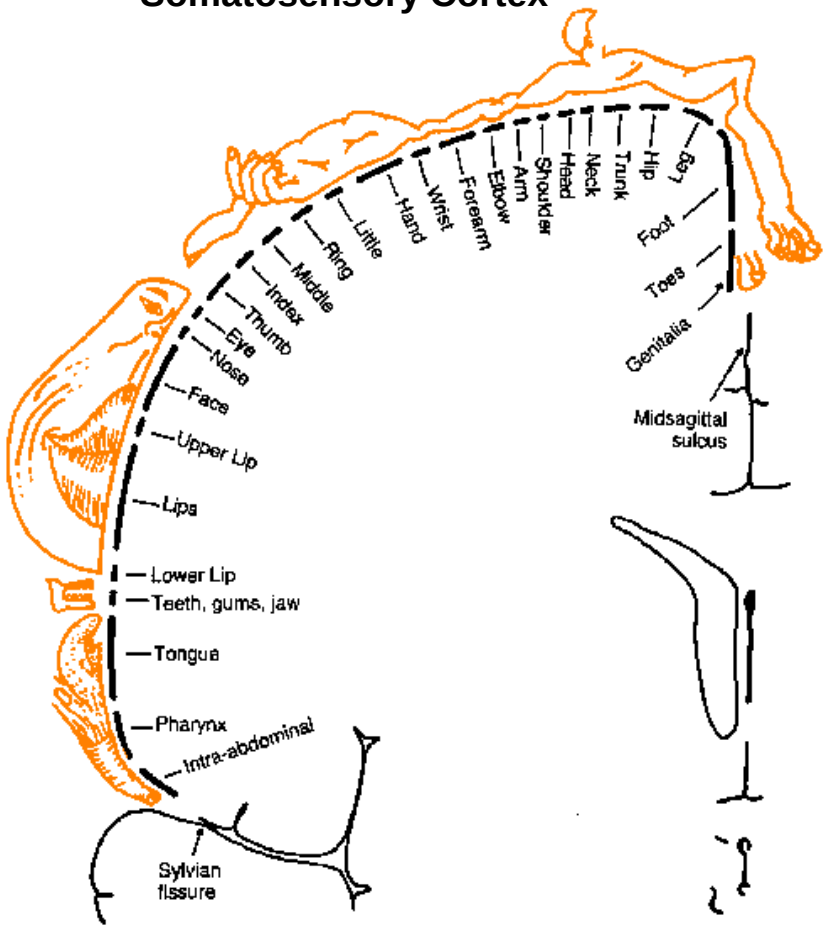
  - Visual Cortex: Receives and processes information coming from the eyes



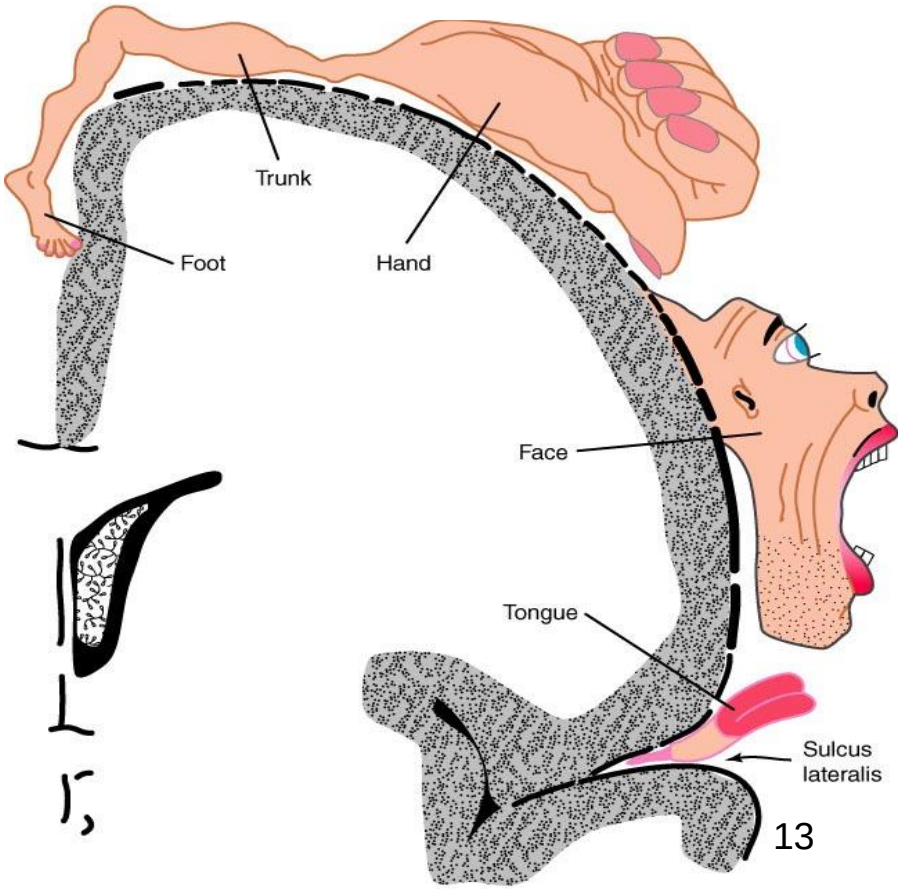
Brain Structure: Cerebrum

- The motor cortex and the somatosensory cortex are somatotopically organized: Each part of them corresponds to a certain part of the body (The Homunculus)

Somatosensory Cortex

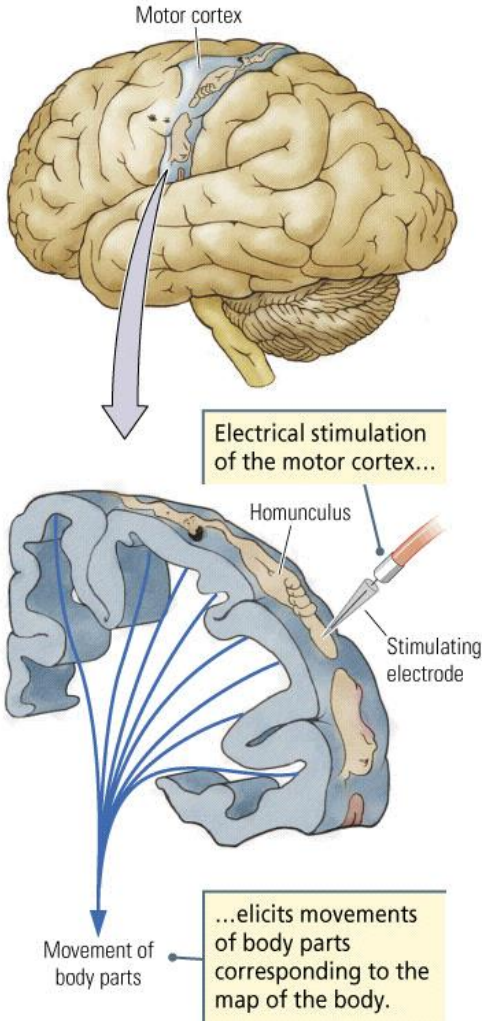


Motor Cortex



Brain Structure: Cerebrum

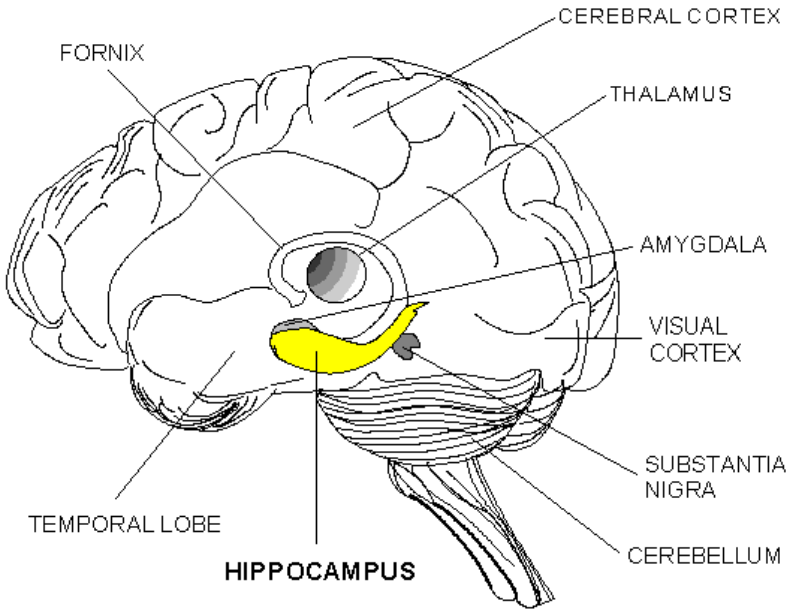
- Electrical stimulation of a certain area in the motor cortex causes movements of the corresponding body part



Brain Structure: Cerebrum

- One important region of the cerebrum is the hippocampus

- It plays important roles in the consolidation of information from short-term memory to long-term memory and spatial navigation

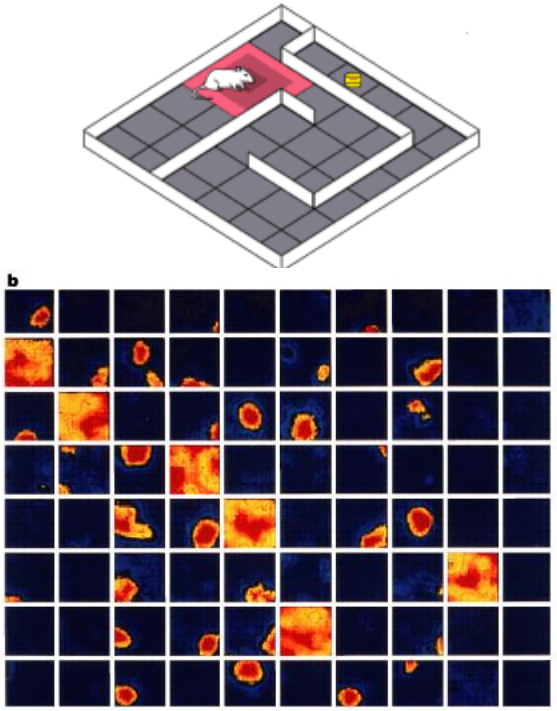


Brain Structure: Cerebrum

- Place cells have been discovered in the hippocampus

- Place cells are neurons that exhibit a high activity whenever the subject is in a specific location in an environment corresponding to the neuron's “place field”

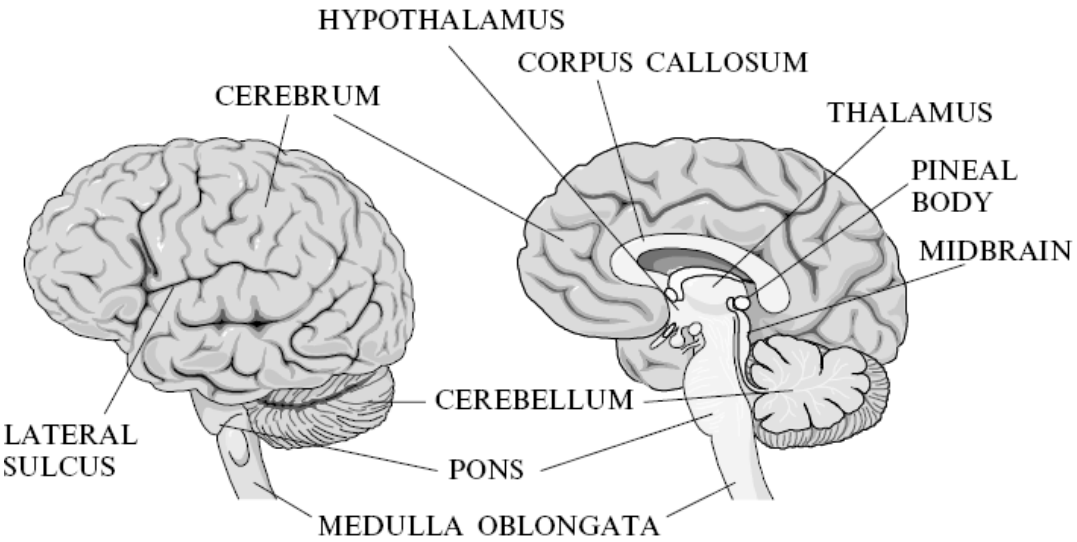
Rat moving in a straight line and the activity of the recorded neurons for each location



Rat exploring a square area and activity of 80 cells that correspond to each location of the square area

Brain Structure: Diencephalon

- The diencephalon is the deep part of the brain that connects the midbrain of the brain stem with the cerebral hemispheres



- The main region of the diencephalon is the Thalamus

- The thalamus is involved with sensory and motor systems, general neural background activity, and the expression of emotion and uniquely human behaviors

Brain Structure: Brain Stem and Cerebellum

- The brain stem connects the brain with the spinal cord and automatically controls vital functions such as breathing

- The cerebellum is located behind the pons and is the second largest part of the brain

- It processes sensory information that is used by the motor systems and is involved with coordinating skeletal muscle contractions and impulses for voluntary muscular movement that originate in the cerebral cortex

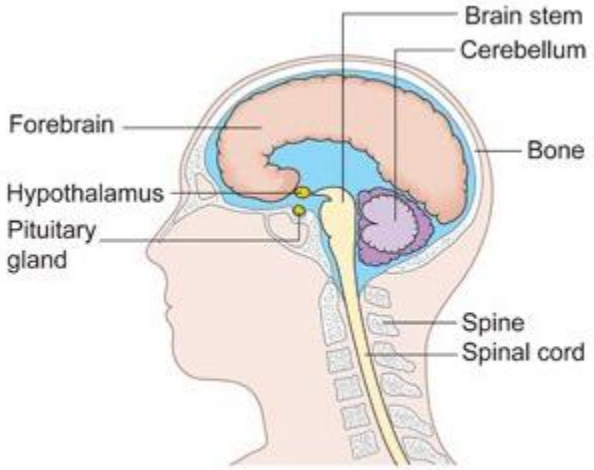
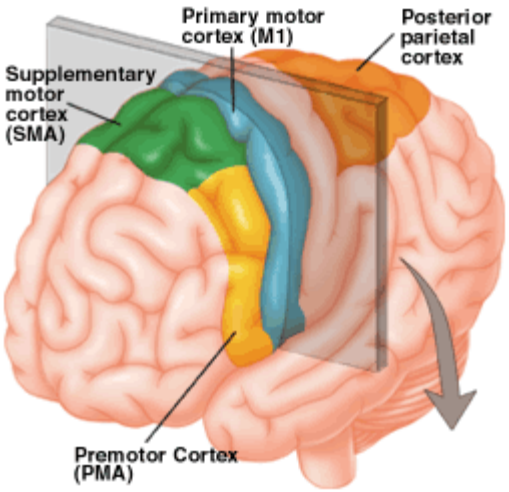


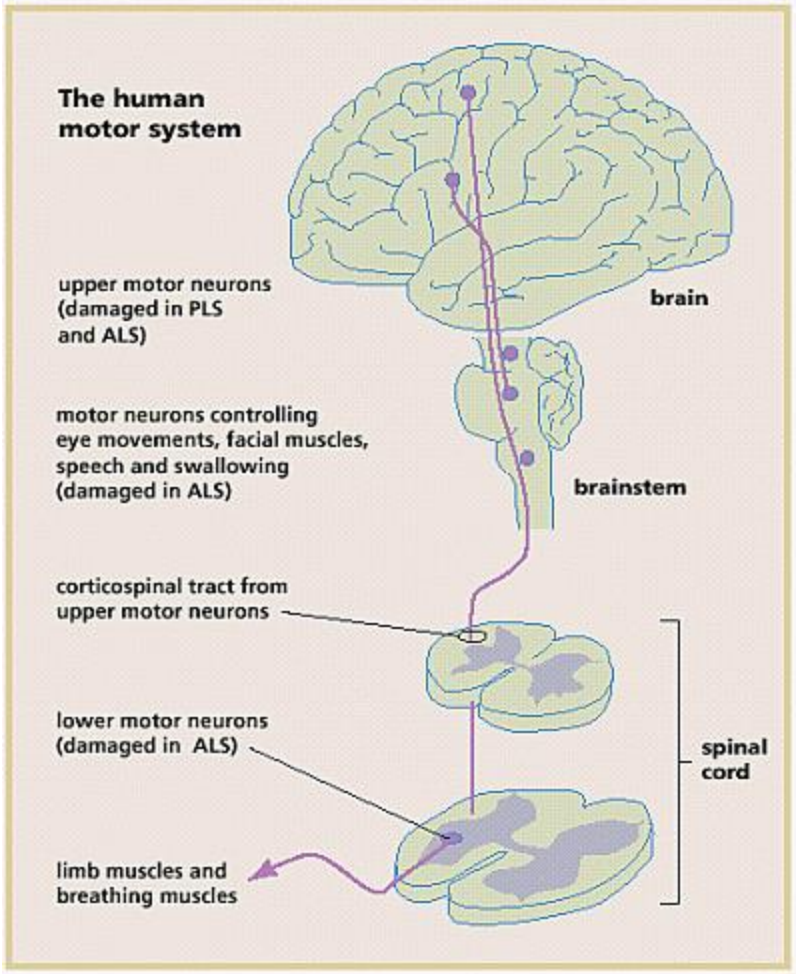
Diagram showing the parts of the brain

Motor System

- The motor system is the part of the central nervous system that is involved with movement

- In the cortex, there are 3 areas related to movement:
  - Primary Motor Cortex (M1)
  - Premotor Cortex (PMA)
  - Supplementary Motor Cortex (SMA)



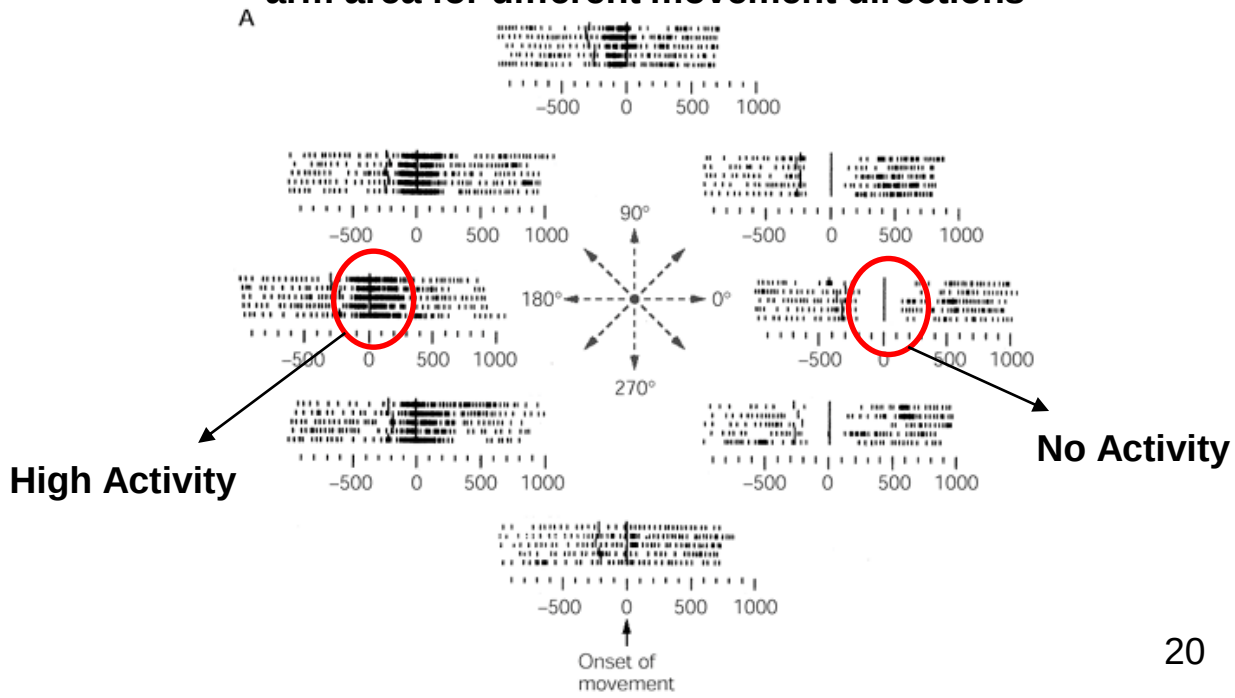


Motor System

- The Primary Motor Cortex (M1) is responsible for executing movements, other areas for movement planning

- Neurons in M1 are tuned to movement directions where the activity of each neuron is maximum with a preferred direction and minimum in the opposite direction

Multiple trial activity of an M1 neuron in the arm area for different movement directions



Motor System

- When you sign your name on a paper, the following brain areas are involved:

  - Prefrontal Cortex: I'll sign my name

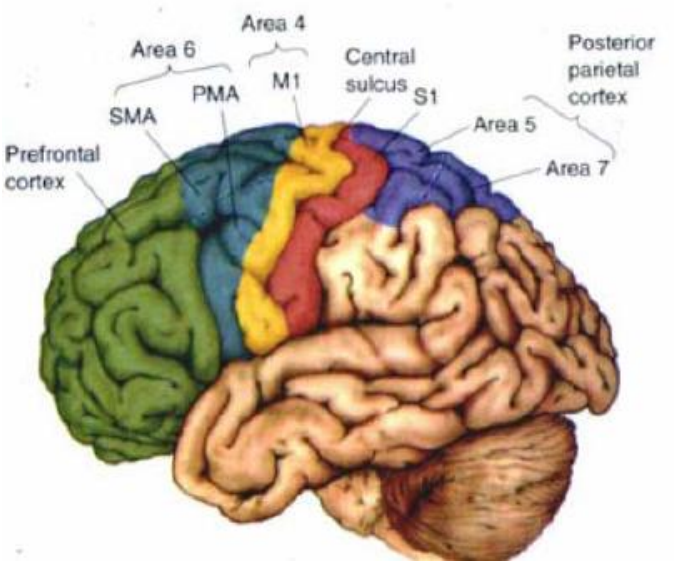
  - Posterior Parietal: combine visual and somatosensory information to localize pen with respect to body

  - Premotor Cortex: plan motion of hand with respect to target path

  - Cerebellum: formulate details of movement in terms of dynamics

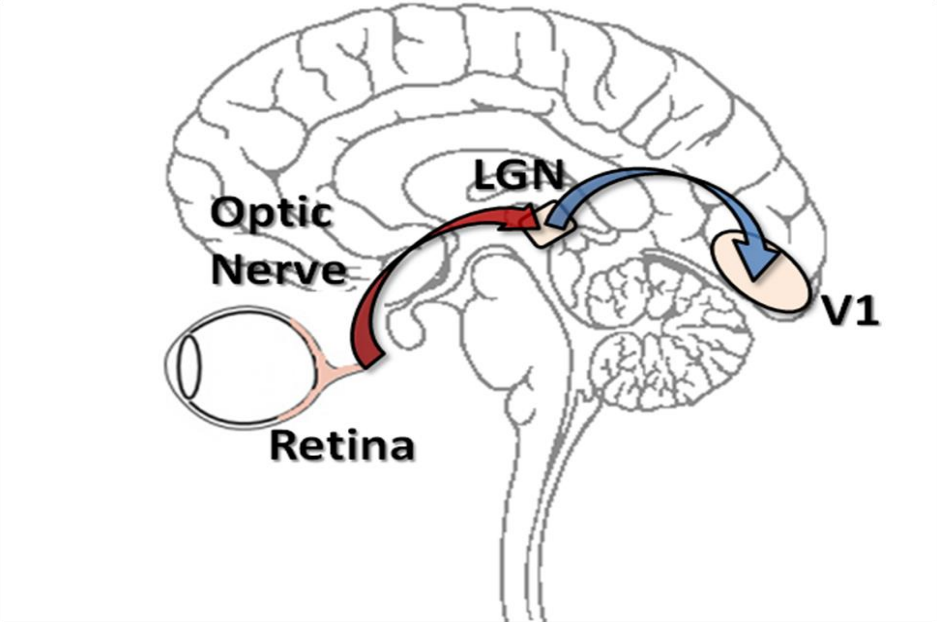
  - Primary Motor Cortex: sends motor commands down spinal cord

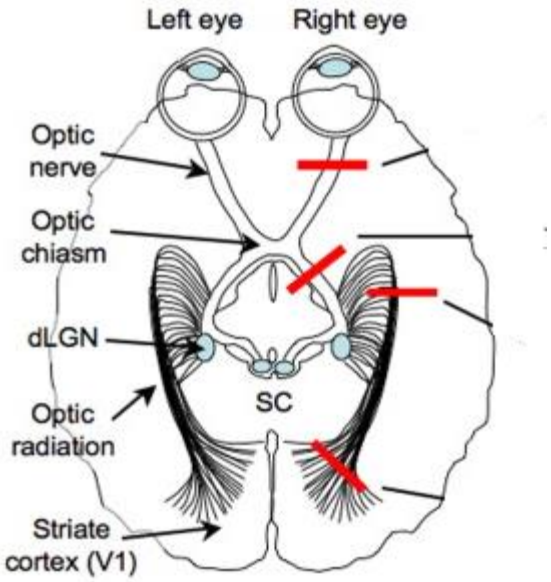
  - Brain Stem: maintains stable posture during writing



Visual System

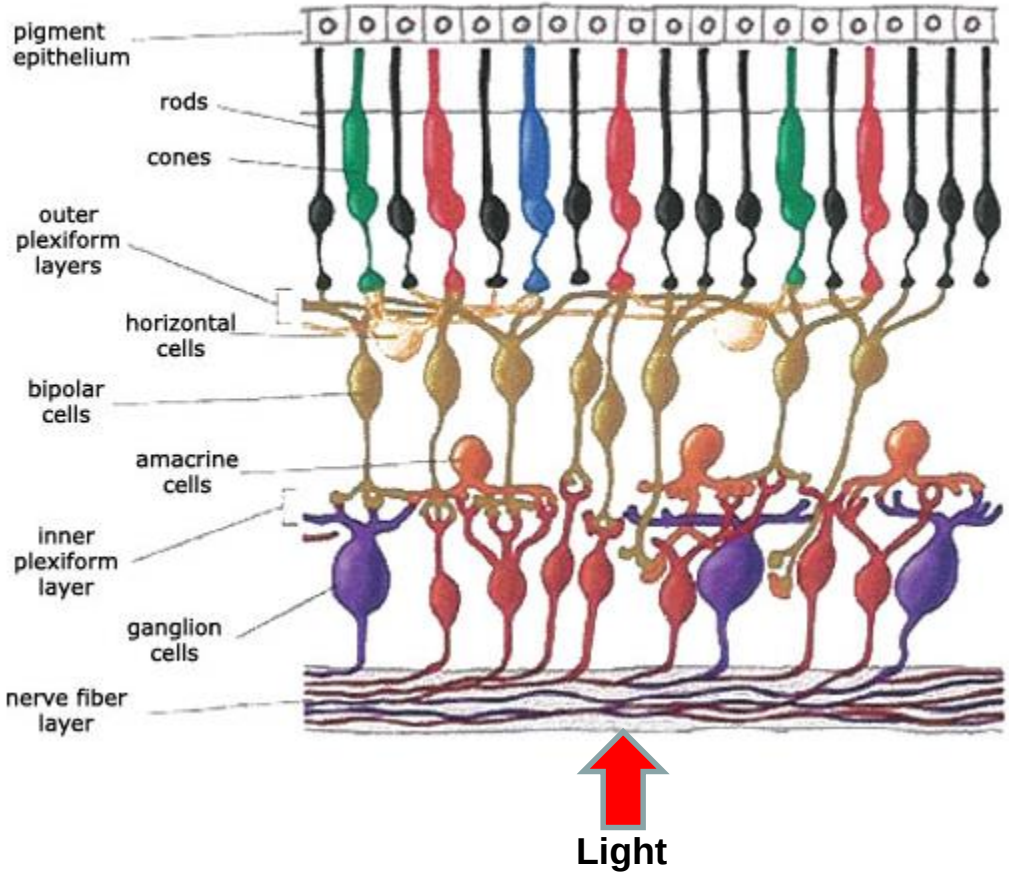
- The visual system consists of 5 major parts:
  - Eye: The lens
  - Retina: Converts light to electrical pulses
  - Optic Nerve: Carries electrical pulses to the brain
  - Lateral Geniculate Nucleus (LGN): Relay point of electrical pulses
  - Primary Visual Cortex (V1): Perception





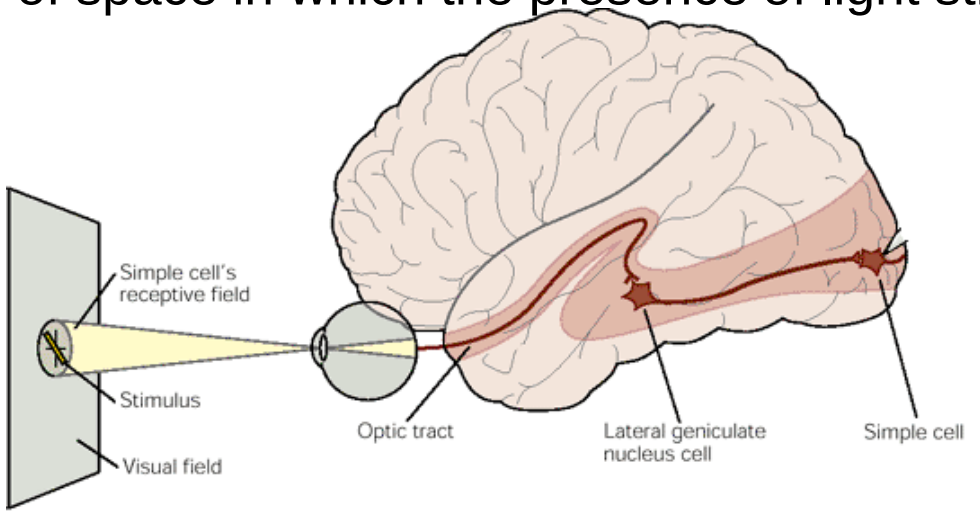
Visual System

- Photoreceptors in the retina convert light to electrical pulses
- Two types of photoreceptors:
  - Rods (For low-light vision not sensitive to colors)
  - Cones (For bright-light vision sensitive to colors)

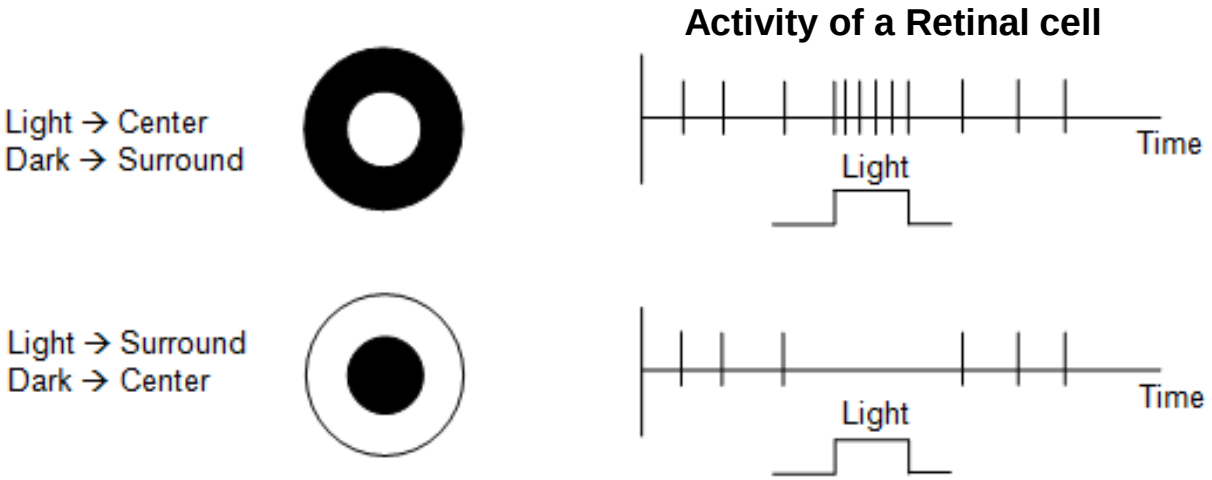


Visual System

- Each neuron in the retina and the LGN has a "Receptive Field" which is a region of space in which the presence of light stimulates the neuron

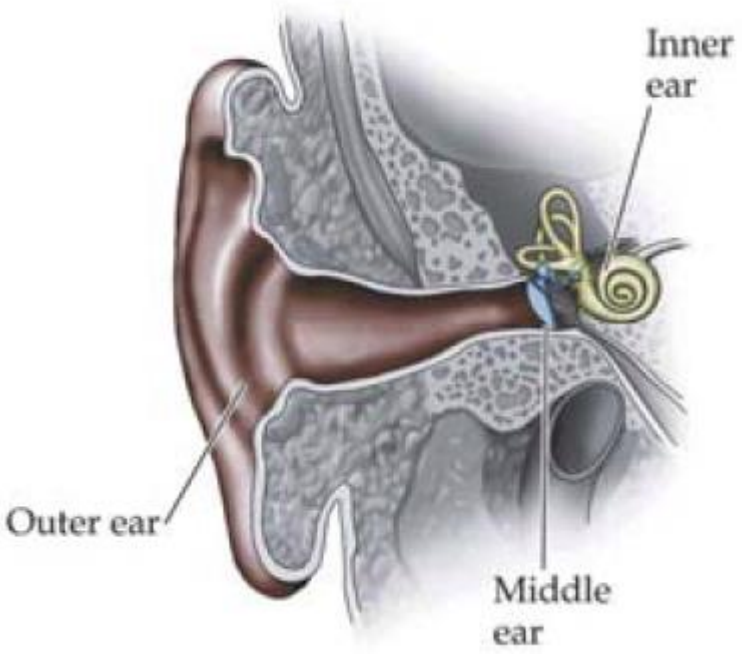


- Receptive fields have ON and OFF regions



Auditory System

- The auditory system consists of:
  - The Outer Ear
  - The Middle Ear
  - The Inner Ear
  - The Primary Auditory Cortex (A1)



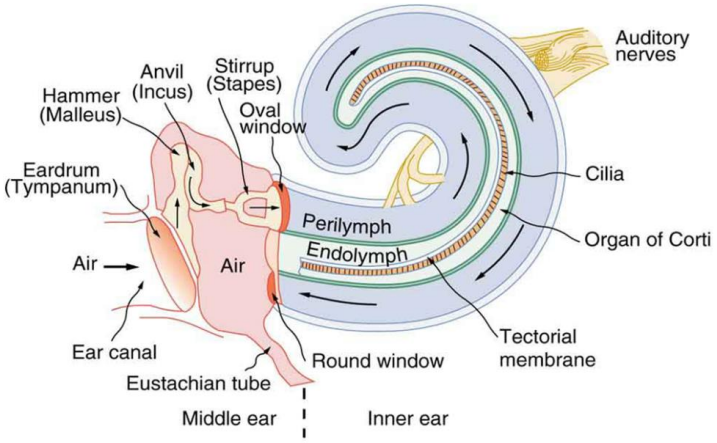
- The outer ear reflects and attenuates sound and passes it to the middle ear

- The middle ear transforms acoustic variations in air pressure into vibrational displacements in the membrane of the inner ear

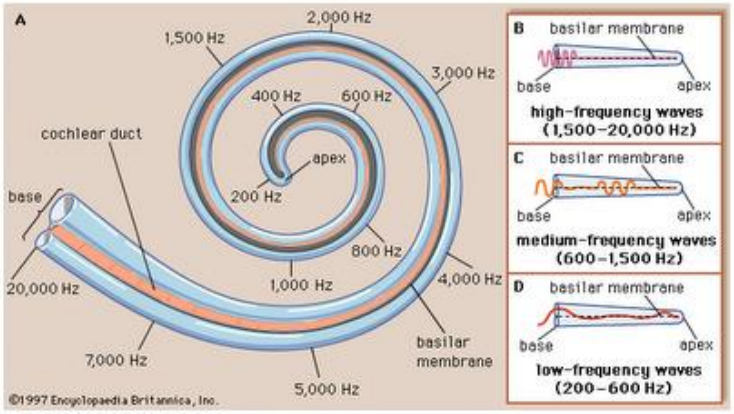
- Motion of the membrane moves fluid in the cochlea which contains the apparatus for transforming the physical motion of the membrane to a neuronal response

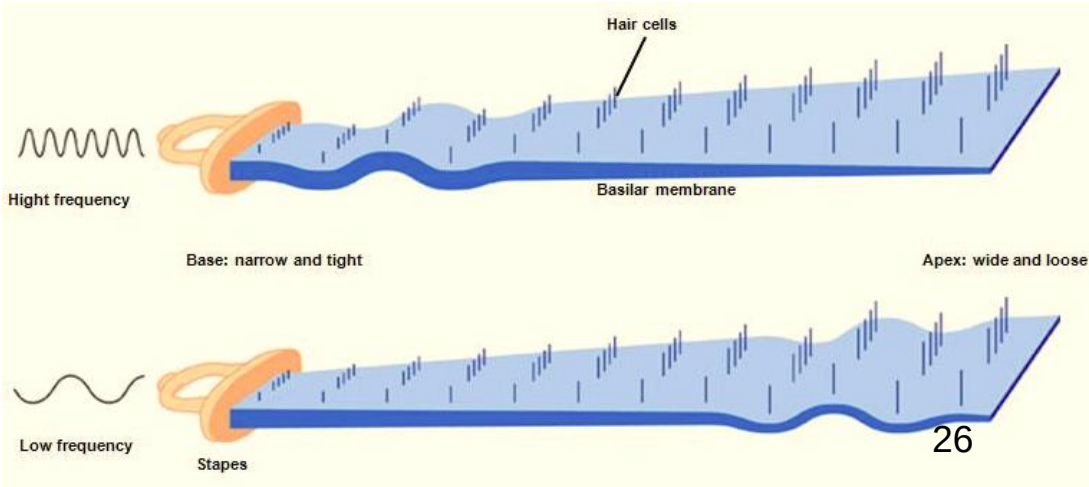
Auditory System

- The Organ of Corti lies inside the cochlea and it contains the Auditory receptor cells (hair cells) which convert mechanical energy to electrical pulses



- Each section of the Organ of Corti corresponds to a certain frequency

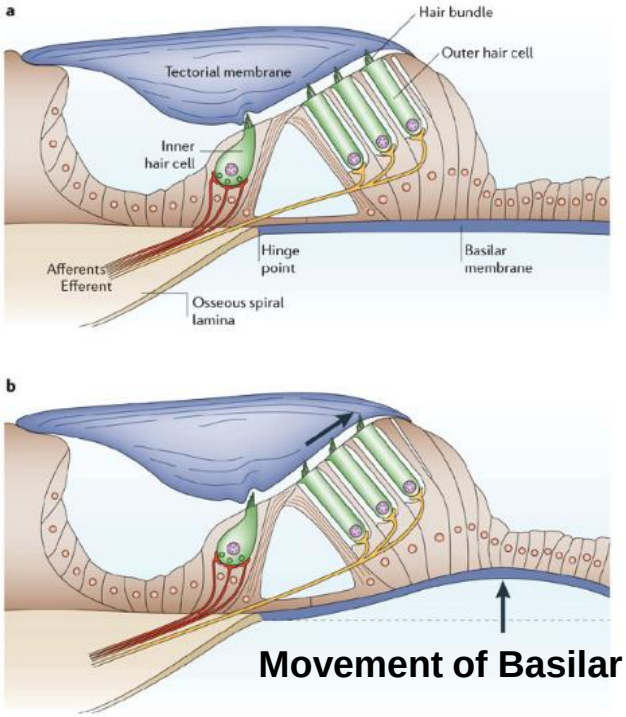




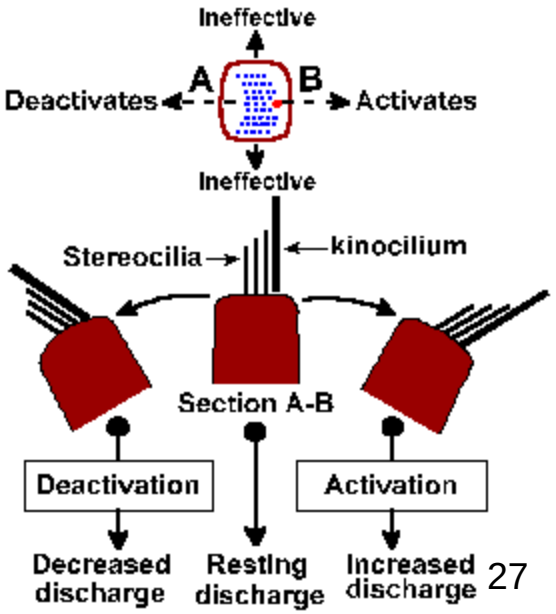
Auditory System

- High frequency sounds give rise to high frequency vibrations of the basilar membrane that travel along its length only a short distance before peaking and dying out. Low frequency sounds travel further

- Inner ear membranes move hair cells resulting in an inward K^+ current which depolarizes the membrane. When they move in the opposite direction, they close the channels and thus hyperpolarize the membrane



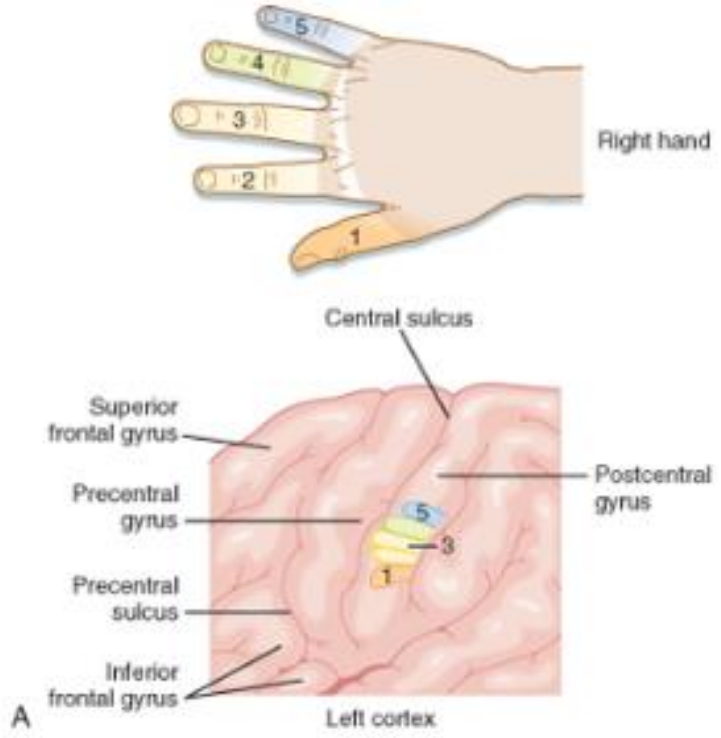
Movement of Basilar Membrane

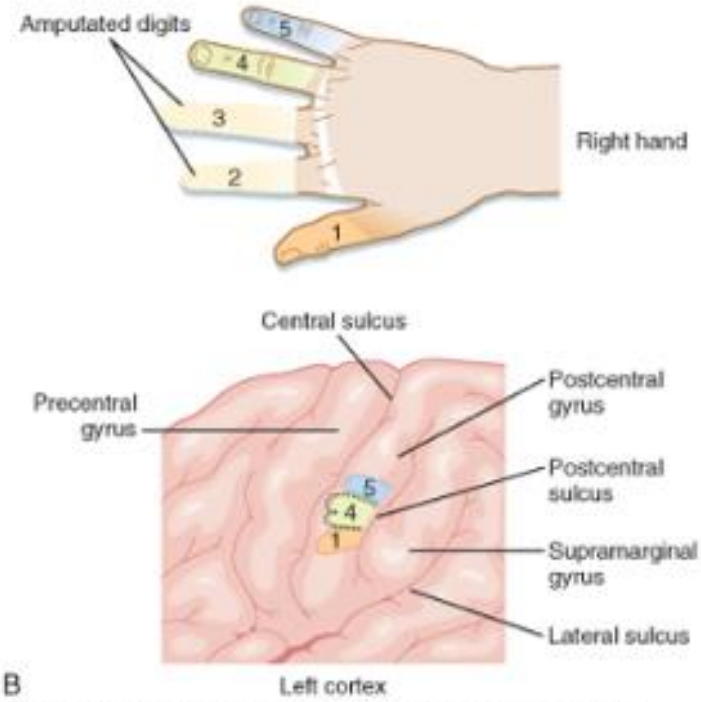


Brain Plasticity

- It refers to changes in the brain which are due to changes in behavior, environment and neural processes, as well as changes resulting from bodily injury

- Example: When a finger is cut, the area of the brain that corresponds to this finger gets used for other fingers





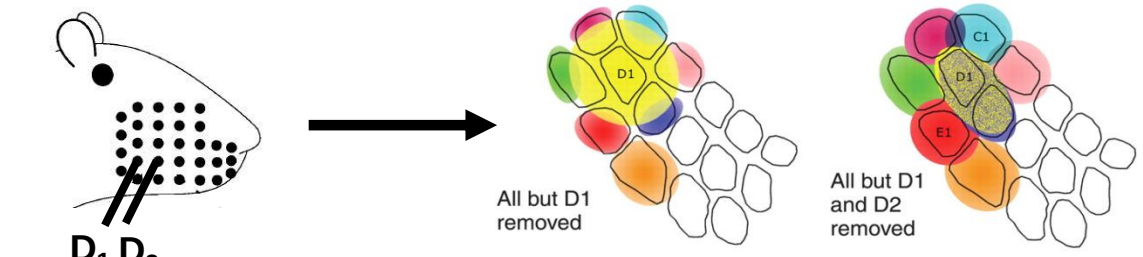
Brain Plasticity

- A study showed that London taxi drivers have a larger hippocampus than London bus drivers. This happens because this region of the hippocampus is specialized in navigation. Taxi drivers have to navigate around London whereas bus drivers follow a limited set of routes

- Experience-dependent Plasticity in Rats

  Donald Hebb in 1949 postulated that “Neurons that fire together wire together”

  When two whiskers are moved simultaneously and repetitively, their corresponding areas in the brain merge



(Feldman and Brecht, 2005)

Society for Neuroscience (SfN) Conference

- SfN is the largest neuroscience conference in which about 30,000 researchers meet every year trying to discover how the brain works

- What is known about the brain is a lot less than what is unknown