CNS
PHYSIOLOGY

1+2

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This lecture we will:

-State the parts of the central nervous system (brain stem & spinal cord).

-Describe the level of organization of the CNS (**1-** Lower level of spinal cord. **2-** Middle: brain stem. **3-**Higher: cerebral cortex)

-List the major functions of the CNS

-Compare the Endocrine system and nervous system

-Describe the anatomy of the functional unit of the nervous system

-Determine the area of communication in the CNS (synapse).

Comparison between Nervous and Endocrine Control System

- ✓ **Nervous system** is fast compared to **endocrine** which is slow because the nervous system uses action potentials which travel through the axons at speed that might reach 120m/s and even in nonmyelinated neurons might reach 2 or 5m/s. On the other hand, the **endocrine system** is slow because it uses hormones that are going to be secreted from gland and travel in blood and then they go to the target cell to bind with the receptors that will end in receptor-hormone interactions and this process is really slow process.

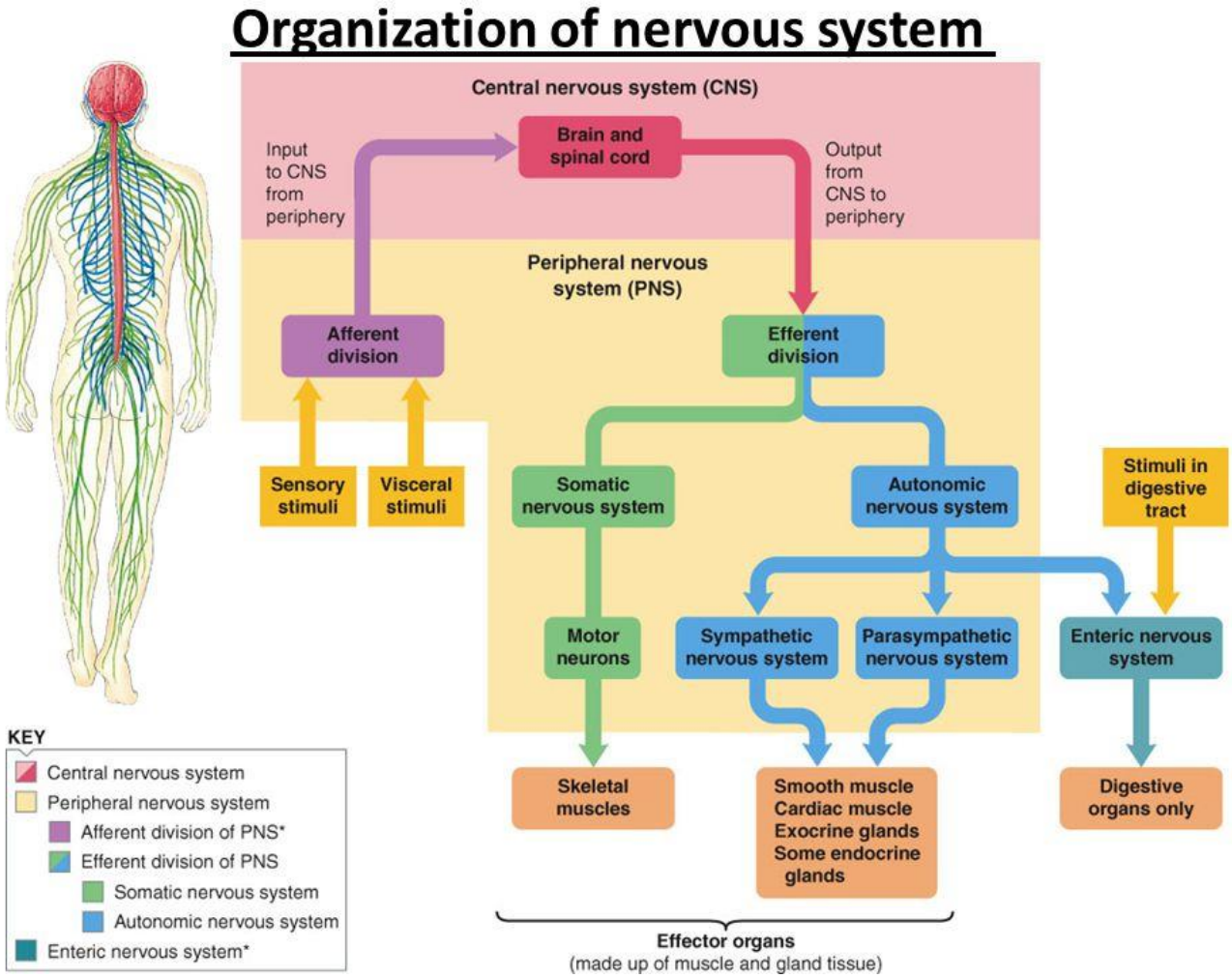
- ✓ **Nervous system** has low gain compared to very high gain for the **Endocrine system**

GAIN = CORRECTION / ERROR

E.g. The normal MAP=100mmHg, if it rises to be 120mmHg:
-The baroreceptors which are referred to **nervous system** might bring the bp to 105 for example, so the gain is equal -3 (negative feedback).
-In the **endocrine system**, the hormones try to bring blood pressure back to almost 100 with zero error; the gain will be infinite.

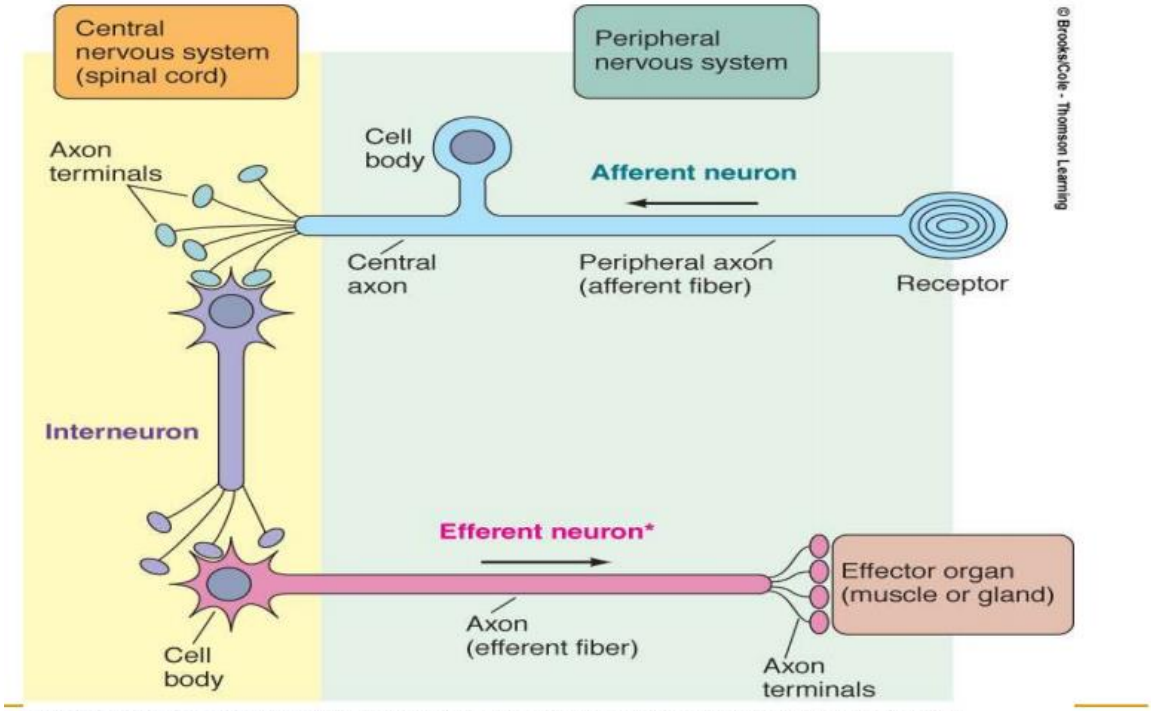
- ✓ **Nervous system** affects skeletal muscles and glands, but the **endocrine** affects growth, metabolism and reproduction.

Organization of Nervous System



- **Notes:**

1- In the CNS, ***afferent*** is sensory, ***efferent*** is motor.
2- The ***sensory*** receives its information form the sensory stimuli whether it's somatic or visceral.
3- The ***motor*** part goes to somatic nervous system that supplies the skeletal muscles or autonomic nervous system the supplies smooth muscles.
4- **Divisions**:
   - Sensory Division: ***general sensations***: tactile and others. ***Special sensations***: visual, auditory, olfactory.
   - Integrative Division: process information, creation of memory.
   - Motor Division: respond to and move about in our environment.



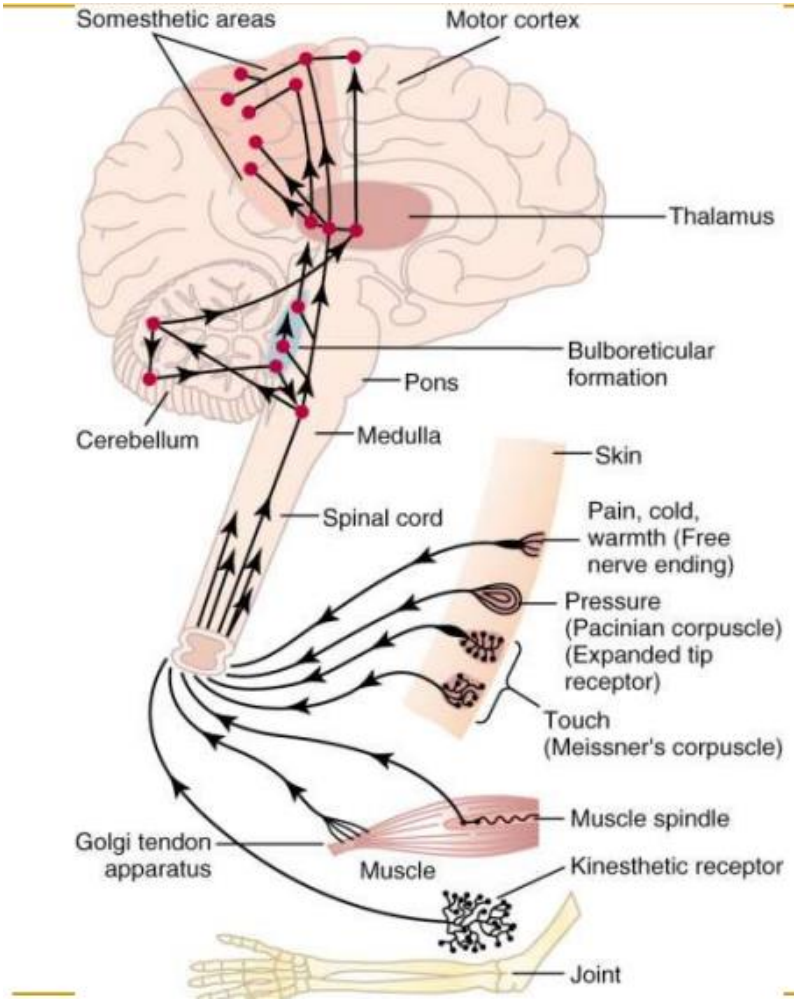
* Efferent autonomic nerve pathways consist of a two-neuron chain between the CNS and the effector organ.

- ✓ The receptors sense any changes in the environment; tactile sensations are mechanical, visual are electromagnetic energy and so on.
- ✓ The **receptors** are transducers; they covert any type of energy into electrical energy (action potential)
- ✓ The cell bodies of afferent neurons are found in the dorsal root ganglia, then it enters the spinal cord to synapse with interneurons.
- ✓ The interneurons connect the sensory to the motor.
- ✓ The efferent neurons go out from spinal cord to the effector organ.

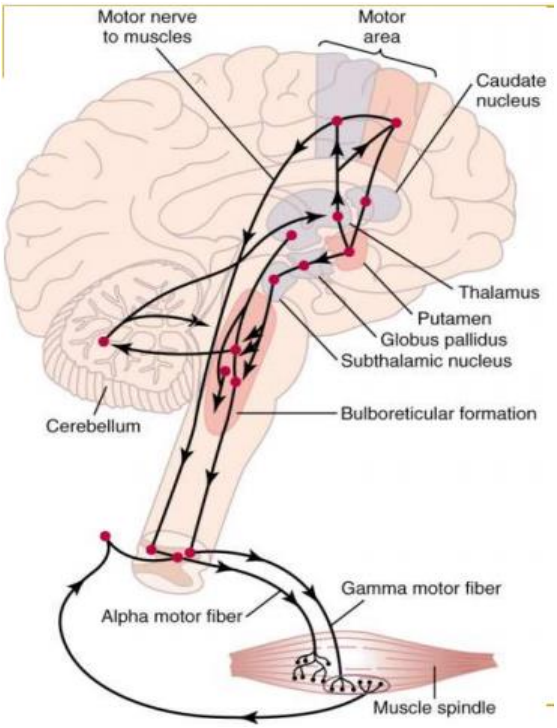
Functional Classes of Neurons

- ✓ Afferent neurons
  Inform CNS about conditions in both the external and internal environment.
- ✓ Efferent neurons
  Carry instructions from CNS to effector organs – muscles and glands.
- ✓ Interneurons
  -Found entirely within CNS; most of neurons are interneurons.
  -Responsible for:
  - Integrating afferent information and formulating an efferent response
  - Higher mental functions associated with the "mind"

Somatosensory Axis of the Nervous System



- It starts with sensory receptors for pain and temperature (usually free nerve ending), receptors for pressure in the dermis (Pacinian corpuscle), for touch in the epidermis (Meissner's corpuscle), receptors that are found in the muscle (muscle spindles) and the receptors that are found around the joints(kinesthetic receptors; proprioceptors).
- Afferent neurons carry these signals to the spinal cord and these signals will go to cerebral cortex (highest order area)>>**primary somatosensory area** in the postcentral gyrus.
- These sensations usually stop at the **thalamus**, so the thalamus is the relay station for almost all sensations except olfaction.
- From the thalamus they go to their destinations in the cerebral cortex in the **postcentral gyrus.**



- The **motor tract** (descending tract) starts from motor area in the cortex and descends as <u>upper motor neuron</u> and ends in the spinal cord to synapse with the <u>lower motor neuron</u> that will go to skeletal muscles to initiate the contraction.

Nerve: is a collection of axons in the peripheral nervous system

Tract: is a collection of axons in the central nervous system

Gyrus: is the area between two sulci

Levels of CNS Function

1- The spinal cord level

It's more than just a conduit for signals from periphery of body to brain and vice versa; it contains:

- ✓ walking circuits
- ✓ withdrawal circuits
- ✓ support against gravity circuits for antigravity muscles that are important for position(posture), equilibrium and balance.
- ✓ circuits for reflex control of organ function

2- The Lower Brain Level

- ✓ Contains: brainstem(medulla, pons, mesencephalon), hypothalamus, thalamus, cerebellum and basal ganglia
- ✓ Controls subconscious body activities: arterial pressure, respiration, equilibrium, feeding reflexes, emotional patterns

>> subconscious is in between consciousness and unconsciousness.

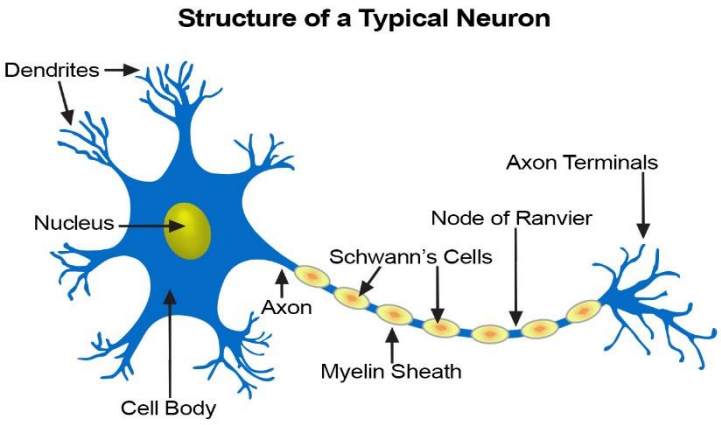
3- The Higher Brain or Cortical Level

- ✓ Cortex never functions alone, always in association with lower centers
- ✓ Large memory storehouse
- ✓ Essential for thought processes
- ✓ Each portion of the nervous system performs specific functions, but it is the cortex that opens the world up for one's mind.

Anatomy of a Neuron

-3 major components:

1. Soma: main body of the neuron
2. Axon: extends from soma to the terminal the effector part of the neuron
3. Dendrite: projections from the soma the sensory portion of the neuron



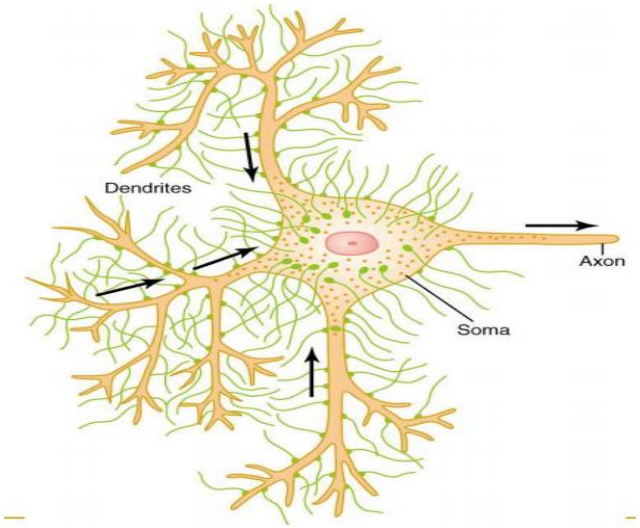
Notes:

- ✓ **Dendrites** have a very high resistance, they're unable to produce action potential because they have very low density of sodium voltage gated channel.
- ✓ Sometimes action potential is produced at the soma but the best area to produce action potential is the axon hillock.

- ✓ Axon hillock is the first unmyelinated area of the axon; it has the highest density of sodium voltage gated channels, so it has the lowestl threshold for action potential.
- ✓ The soma contains all organelles as in other cells except the centrioles; neurons are unable to divide and regenerate (problem in CNS).
- ✓ The CNS is enclosed by bony structures for protection; the brain is enclosed by the skull and the spinal cord by vertebral column.
- ✓ CNS is also protected by meninges,3 layers of protection from outside to inside; dura mater, arachnoid mater and pia mater.
- ✓ Some neurons are myelinated by myelin sheath that is formed from Schwann cells in PNS and from oligodendrocytes in the CNS.
- ✓ Myelin is interrupted by unmyelinated area called node of Ranvier.
- ✓ At the end we have axon terminals(buttons,knobs) that contain chemical substances (neurotransmitters) that are released upon stimulation of neurons by action potential, we have 50 types of neurotransmitters in CNS.

anterior motor neuron

it's a kind of neurons, contains many synapses; axosomatic with soma, axodendritic with dendrites and axoaxonic with axons.



Communication Between Neurons

- ✓ Through release of chemical transmitters more than 50 compounds have been identified as transmitter substances.

- ✓ General characteristics of neuronal communication: **one-way conduction** from presynaptic to postsynaptic neuron, always transmits signals in one direction this allows signals to be directed toward specific goals (chemical synapse).
  - ➢ Note: signals might go both ways in the electrical synapse which isn't common in CNS.

And that wraps up the intoduction.

This lecture we will:

-List the types of mechanoreceptive sensations and its receptors.

-Describe the two pathways for its transmission (dorsal column medial lemniscal tracts and anterolateral spinothalamic tracts).

-Follow these pathways to the cortex.

-Differentiate the two pathways.

Classification of Somatic Sensations

- According to the type:

1- **Mechanoreceptive**: they are stimulated by mechanical displacement.
   - tactile: touch, pressure, vibration, tickle and itch.
   - position or proprioception: static position and rate of change(dynamic).
2- **Thermoreceptive**: detect heat and cold (they detect the changes in the stimulus).
3- **Nociceptive (pain receptors)**: detect pain and they are activated by any factor that damages tissue.

Tactile Receptors

✓ Free nerve endings
- They are connected to Aδ and C fibers.

❖ Note: A is myelinated fiber, C is unmyelinated fiber.
- detect touch and pressure.
- they're found everywhere in the skin and other tissues.

✓ Meissner's corpuscles
- They are connected to Aβ (large myelinated fiber).
- rapidly adapting (within a fraction of a second) because they're encapsulated receptors.
- detect movement of light objects over skin.
- They are found on nonhairy skin (glabrous skin), fingertips and lips down in the epidermis.

✓ Merkel's discs
- They are connected to Aβ.
- respond rapidly at first and then slowly adapt, detect the "steady state".
- found on hairy as well as glabrous (non hairy) skin.
- They detect touch.

✓ Hair end organ
- found around hair shaft to detect the movement of hair.
- adapts rapidly and detects movement over the body.

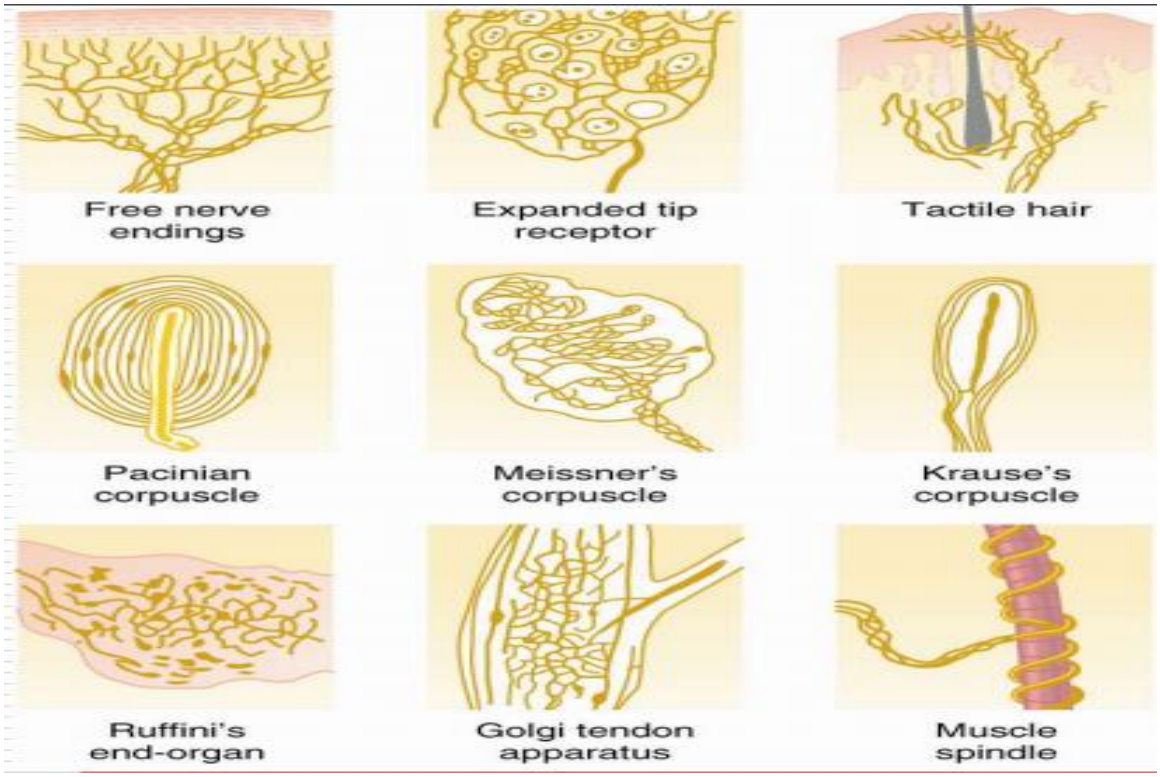
✓ Ruffini's end organ

- They are found deep in the dermis and detect the changes in pressure and joints formation.
- slowly adapting and respond to continual deformation of the skin and joint rotation.

✓ Pacinian corpuscle

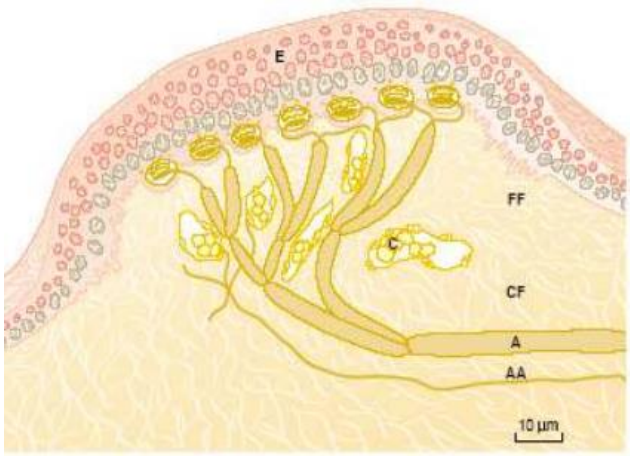
- They are found down in the dermis and connected to Aβ fibers.
- very rapidly adapting because they're corpuscular and stimulated only by rapid movement.
- detects vibration, pressure and other rapid changes in the skin.
- they are like onion rings.

✓ Golgi tendon apparatus and muscle spindles, they are found in the skeletal muscles.



✓ Iggo dome receptors

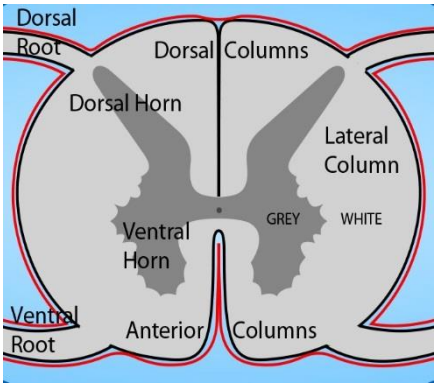
- Note the multiple numbers of Merkel's discs, they're connected to a single large myelinated fiber under epithelium.
- Detect touch.
- They are found under the hairy skin.



- Meissner's corpuscles, hair receptors, Pacinian corpuscles and Ruffini's end organs transmit signals in type Aβ nerve fibers at 30- 70 m/sec (very fast).
- Free nerve endings transmit signals in type Aδ nerve fibers at 5-30 m/sec, some by type C unmyelinated fibers at 0.5-2 m/sec.
- The faster the rate of transmission the more critical the information so fine touch is transmitted very fast through Aβ or Aα.

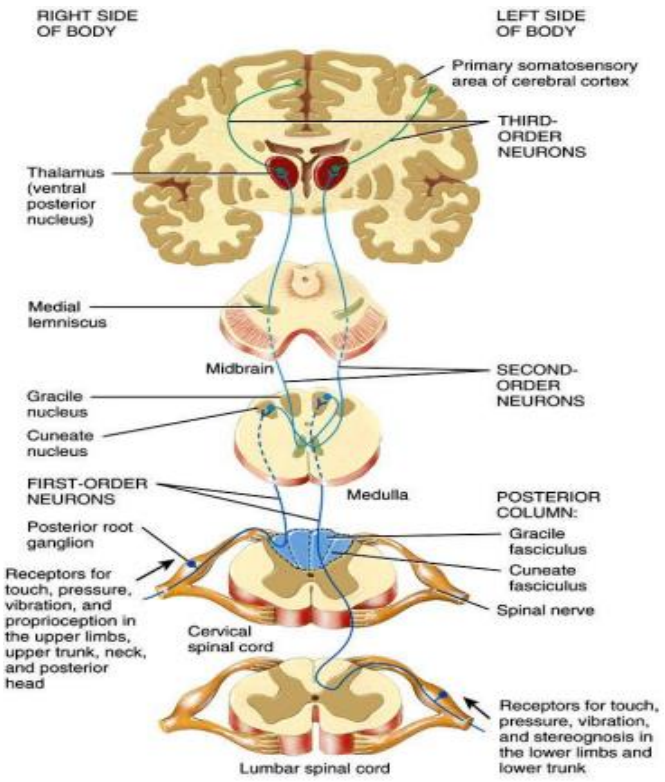
❖ Pathways for the Transmission of Sensory Information

- Almost all sensory information enter the spinal cord through the dorsal roots of the spinal nerves.



❖ Dorsal column-medial lemniscal system

- ✓ This tract ascends in the dorsal column of spinal cord and forms medial lemniscus.
- ✓ Contains large myelinated nerve fibers for fast transmission (30-110 m/sec), usually Aβ fibers .
- ✓ High degree of spatial orientation that is maintained throughout the tract; the fibers come from each part in the body and arranged in highly organized way(spatial fidelity) .
- ✓ Transmits information rapidly with a high degree of spatial and temporal fidelity (faithfulness) (i.e., discrete types of mechanoreceptor information).
- ✓ **Spatial**>>position/space
- ✓ **Temporal**>>time
- ✓ Modalities: Fine touch, vibration, position, fine pressure and stereognosis.



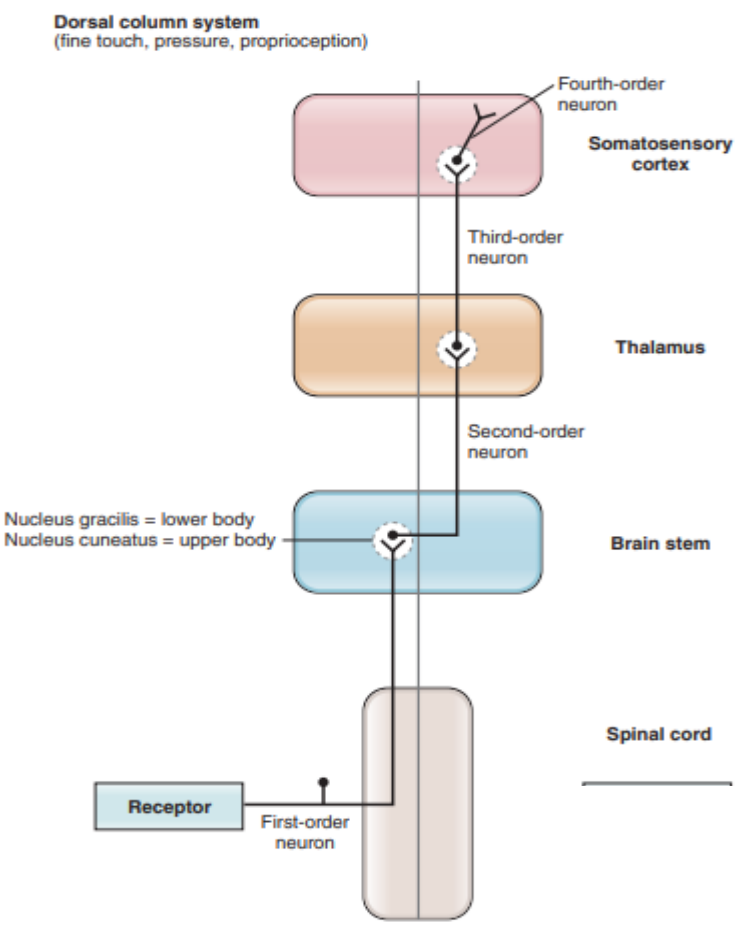
- Pathway of the dorsal tract:

-The afferent neurons (1st order neurons) enter the spinal cord to the posterior horn, their cell bodies are found in dorsal root ganglia and they ascend until they reach their respective nuclei.

- **This tract consists of two parts:**
  ii. Fasciculus gracilis (medial): transmits information from the lower part of the body.
  iii. Fasciculus cuneatus (lateral): transmits information from the upper part of the body.

> ➢ Remember these two tracts are found in both sides in spinal cord and the crossing occurs in both sides.
>
> ➢ The information that comes from right side of the body are going to the left side of the cortex and vice versa (decussation).
>
> ➢ The left and right brain cannot work by themselves; they have to work together.

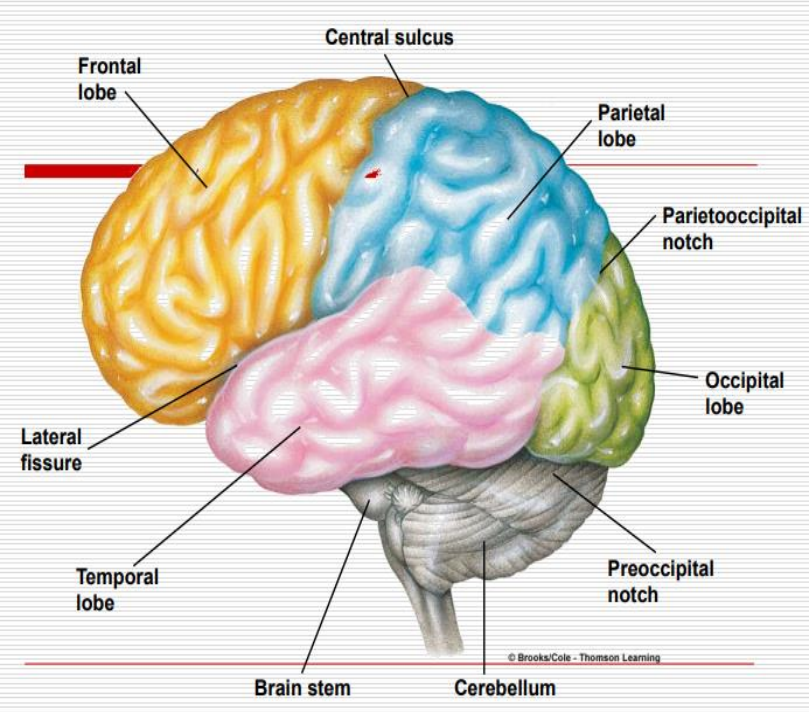
i. They ascend until they reach their respective nuclei in the medulla, it contains cuneatus nucleus and gracilis nucleus, each of these tracts synapse in its nucleus with the 2nd order neuron.
ii. The 2nd order neuron crosses the midline (decussates) in the medulla oblongata and ascends as medial lemniscus to the thalamus.
iii. In the thalamus it goes to ventrobasal complex to synapse in VPL with the 3rd order neuron, the 3rd order neuron ascends to **primary somatosensory cortex**.
iv. Ventrobasal complex consists of two parts; ventral posterolateral (VPL) and ventral posteromedial (VPM).



✓ Dorsal column-medial lemniscal system conveys nerve impulses for:
- Fine touch (well localized) and fine pressure because it transmits its information through rapidly transmitting neurons.
- Vibration and weight discrimination (to discriminate which object is heavier or lighter than the other one).
- Two points discrimination to see if the stimulus at one or two points.

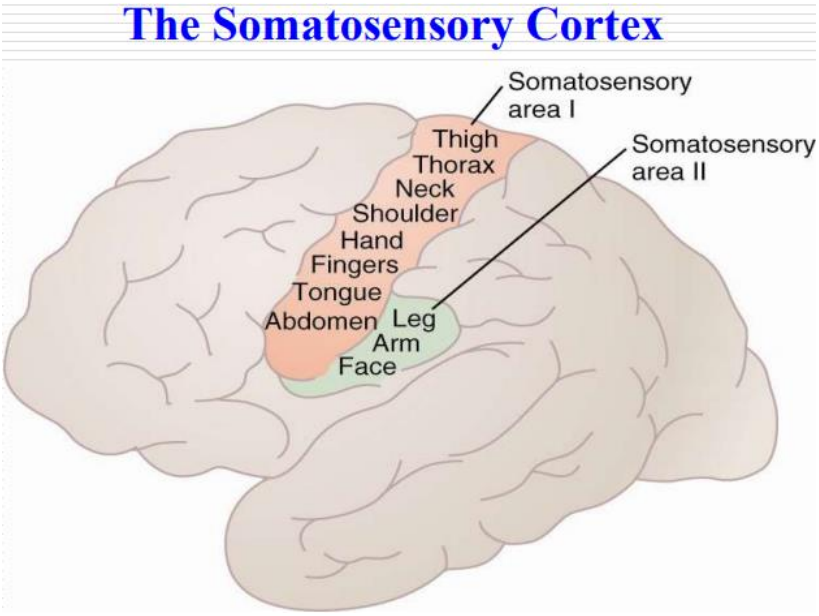
- Stereognosis; by moving your hand over the object you can determine the form, shape and smoothness of the object. (Braille language in case of blindness by moving the fingers over dots so you can determine the letters by highly developed sensation because it is used very much).
- Conscious proprioception (sensation of position) from the limbs, trunk, neck, and posterior head to the postcentral gyrus of the cerebral cortex.

❖ Lateral view of the cerebral cortex.



✓ The cerebral cortex is divided into lobes by sulci; frontal lobe anterior to the central sulcus, parietal lobe posterior to the central sulcus, temporal lobe inferior to lateral fissure and finally the parietooccipital notch separates the parietal lobe from the occipital lobe.

✓ Posterior to the central sulcus in the parietal lobe we have postcentral gyrus.



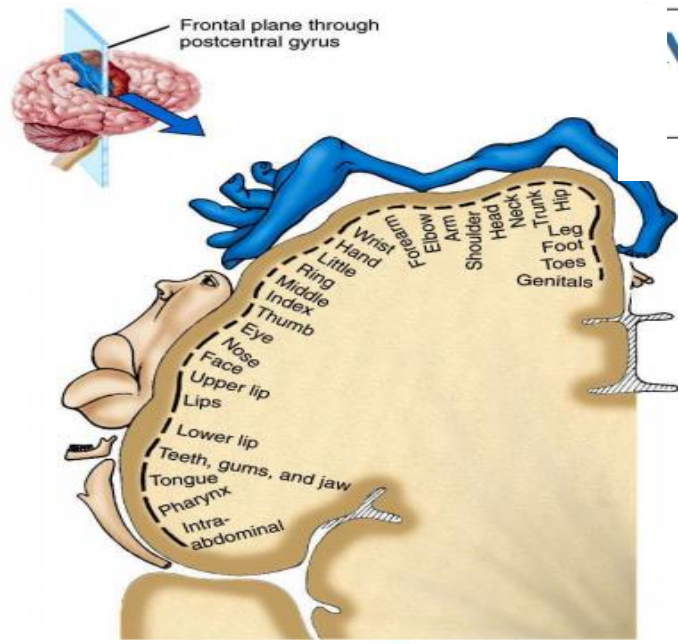
✓ Postcentral gyrus is the primary somatosensory area which has a very high level of organization.

✓ Gyrus is the area between two sulci.

✓ There is another area posterior to area 1 which has a gross representation of our body.

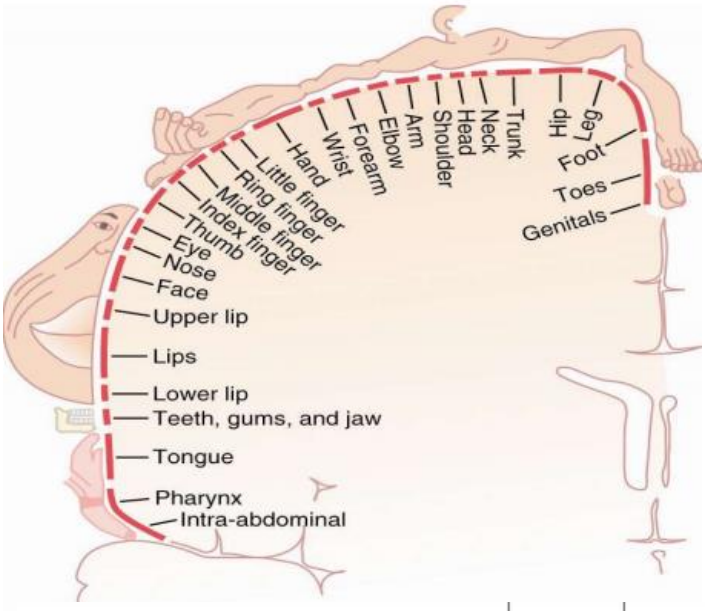
Mapping of the Primary Somatosensory Area(postcentral gyrus)

- This is a frontal section of primary somatosensory area (lateral aspect).



- The representation is upside-down and contralateral; the right side of the cortex represents the left side of the body and vice versa.

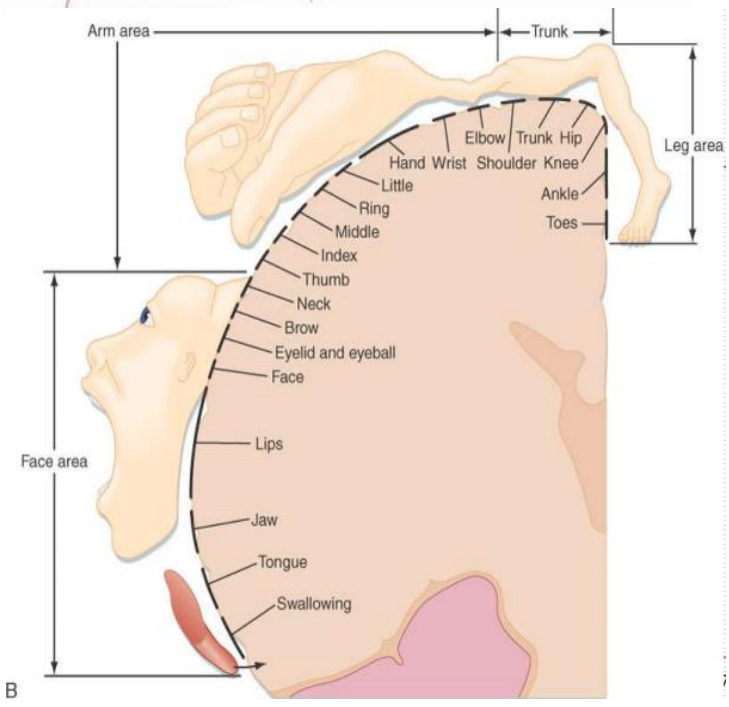
- The area of cerebral cortex that represents any part of our body isn't proportional to the size of that area in our body but it's proportional to the number of the receptors in that area.



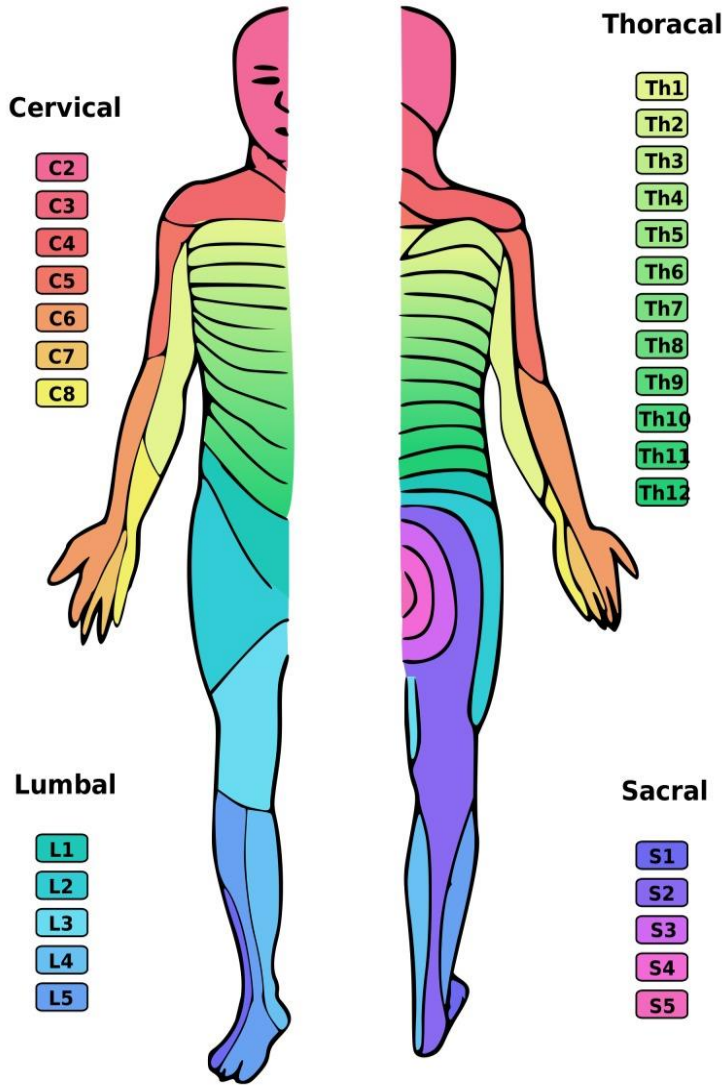
- Look to the hand here, the area that represents the hand of the cerebral cortex is much larger than the area that represents the lower limbs because the number of receptors of the hand is much more than the number of receptors in the legs.

- Size of the cortical region representing a body part depends on the density of the receptors in that part and sensory impulses received from that part.

- In this picture, note how big is the area of the face and how small is the area of trunk and lower limb.



Dermatomes



- ✓ A dermatome is an area of the skin of the human anatomy that is mainly supplied by branches of a single spinal sensory nerve root.

- ✓ As we all know the embryo started as a tube and this tube consists of segments, these segments consist of 3 layers; endoderm, mesoderm and ectoderm, from these layers the spinal cord segments develop; 8 cervical, 12 thoracic, 5 lumbar, 5 sacral and 1 coccygeal.

- ✓ The nerves of nervous system develop from ectoderm, the soft tissue from mesoderm and the epithelium from endoderm.

- ✓ C8, T1, T2 supply the medial aspect of the hand and the heart comes from the same segments C8, T1, T2.

- ✓ This is important when we talk about pain; afferent sensory fibers from the appendix are carried on the sympathetic nerve fibers to enter the spinal cord at T10 which corresponds to umbilical dermatome.

❖ Anterolateral system (SPINOTHALAMIC PATHWAY SYSTEM)

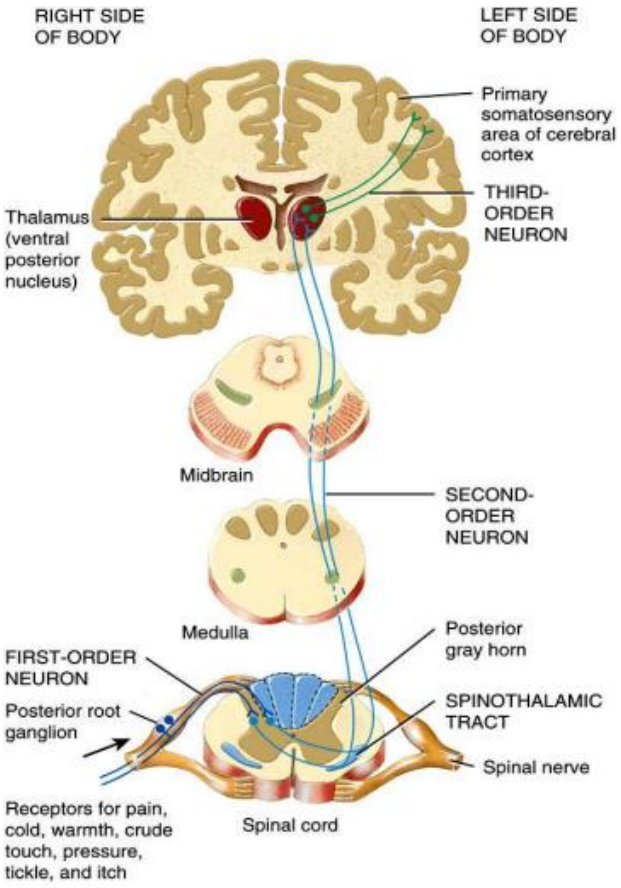
- ✓ This tract ascends in the anterior and lateral columns of spinal cord.
- ✓ Smaller myelinated and unmyelinated fibers for slow transmission (0.5-40 m/sec) (Aδ and C fibers).

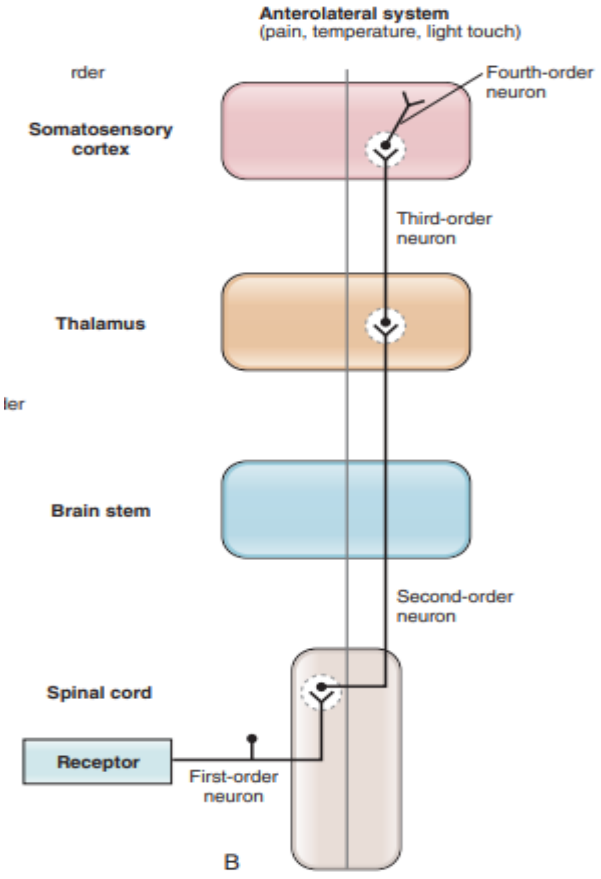
- ✓ Low degree of spatial and temporal orientation because of the slow conducting fibers and there is a lot of divergence.

- Transmits a broad spectrum of modalities; remember the dorsal column system transmits one kind of modalities which is mechanoreceptive sensations that depend on mechanical receptors, in the anterolateral system transmits different sensations and modalities.

- ✓ Modalities: Pain, thermal sensations, crude touch and pressure (poorly localized), tickle and itch, sexual sensations.

- ➢ Pain is very important sensation because it's protective in nature. If you feel pain it means that you can end the damage by stopping the damaging stimuli.





Pathway of anterolateral tract:

i. The afferent neurons (1st order neurons) enter the spinal cord to the posterior horn and their cell bodies located in the dorsal root ganglia.

ii. In the posterior horn the 1st order neuron synapses with 2nd order neuron, usually the 2nd order neuron goes one or two segments up or down then crosses (decussates) to the other side of spinal cord, the crossing occurs anterior to the central canal.

iii. The 2nd order neuron ascends either in anterior or lateral column of spinal cord to reach the ventrobasal part (VPL, VPM) of the thalamus. (for pain it goes to intralaminar nuclei).

iv. In the thalamus, the 2nd order neuron synapses with the 3rd order neuron, then the 3rd order neuron goes to postcentral gyrus (primary somatosensory area).

- So, this system conveys nerve impulses for crude touch (poorly localized), crude pressure, pain, cold, warmth, itch, and tickle (important for sexual sensations) from the limbs, trunk, neck, and posterior head to the postcentral gyrus of the cerebral cortex.

- **Note**: modality is the type of sensation.

Comparison between the two systems

1- Dorsal column is well localized, compared to anterolatetral.
2- Dorsal column has better temporal and spatial faithfulness (i.e speed of transmission 30-120 m/sec compared to 8-40 m/sec for the anterolatetral). Remember, the higher the speed of transmission the higher degree of spatial orientation.
3- Dorsal column has better intensity gradation (more than 100 compared to less than 20 for anterolateral)>> less differences between stimuli because it transmits the signal faster.
4- Repetitive stimuli only confine to dorsal column tracts because it transmits signals at a higher speed.
5- Modalities, anterolateral system transmits a broad spectrum modalities of sensation.
6- The crossing level; the 2nd order neuron in dorsal column system decussates at the level of brain stem (medulla oblongata) while in the anterolateral system decussates at the level of spinal cord.

Trigeminothalamic Pathway

- ✓ It transmits all sensations from **both systems**; dorsal column and anterolateral systems.
- ✓ Conveys nerve impulses for most somatic sensations from the face, nasal cavity, oral cavity and teeth to the cerebral cortex.
- ✓ The afferent neuron goes to the nuclei of trigeminal nerve to synapse and then crosses to the other side and goes to the VPL in the thalamus and finally to the somatosensory cortex (post central gyrus).

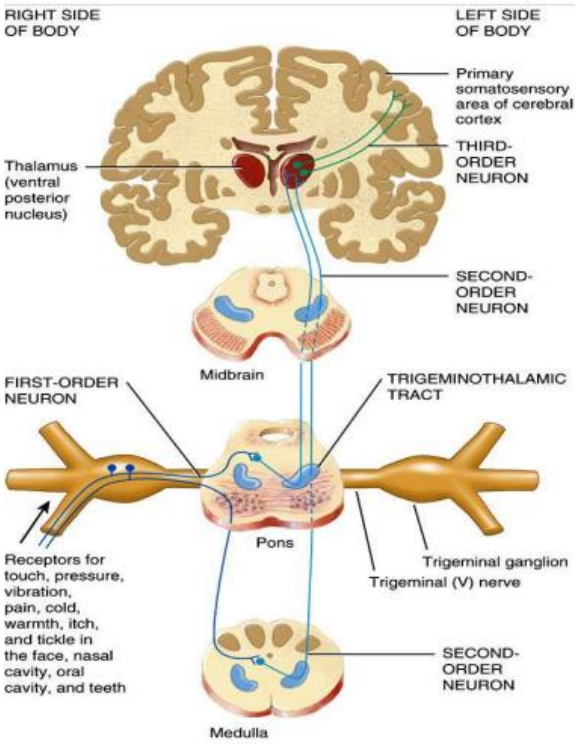


Figure 16.07 Tortora - PAP 12/e

➢ Why is it important to know the level of crossing?

- ✓ In dorsal column tract, If the damage/transection is below the level of medulla, the loss of sensation is ipsilateral (at the same side of damage).
- ✓ In anterolateral tract, If the damage is below the level of medulla, the loss of sensation is contralateral (at the opposite side of damage).
- ✓ If the damage is above the level of medulla, the loss of sensation is contralateral (at the opposite side of damage) in both systems.

Somatic Sensory Cortex

- Located in the postcentral gyrus.
- Highly organized distinct spatial orientation.
- Each side of the cortex receives information from the opposite side of the body .
- Unequal representation of the body.

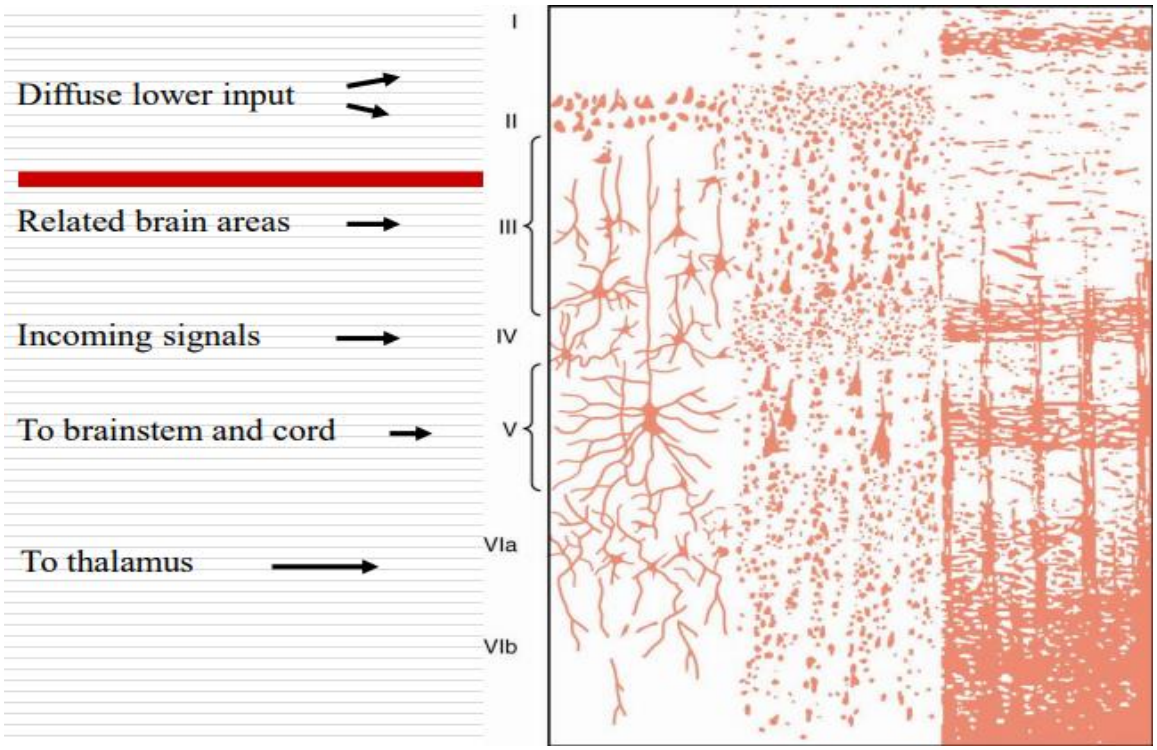
- lips have the greatest area of representation followed by the face and the thumb (large number of receptors).
- trunk and lower body have the least area (less number of receptors).

Cellular Organization of the Cortex

- Six separate layers of neurons with layer I near the surface of the cortex and layer VI deep within the cortex.
- Incoming signals enter layer IV and spread both up and down.
- Layers I and II receive diffuse input from lower brain centers.
- Layer II and III neurons send axons to closely related portion of the cortex presumably for communicating between similar areas.
- Layer V and VI send axons to more distant parts of the nervous system, layer V to the brainstem and spinal cord, layer VI to the thalamus.
- Within the layers, the neurons are also arranged in columns.
- Each column serves a specific sensory modality (i.e., stretch, pressure, touch).
- Different columns interspersed among each other.

- interaction of the columns occurs at different cortical levels which allows the beginning of the analysis of the meaning of the sensory signals.

Cellular Organization of the Cortex



Function of the Somatic Sensory Cortex

- Destruction of somatic area I results in:
  - ✓ Loss of discrete localization ability.
  - ✓ Inability to judge the degree of pressure.
  - ✓ Inability to determine the weight of an object.
  - ✓ Inability to determine the shape or form of objects, called Astereognosis.
  - ✓ Inability to judge texture.

Somatic Association Areas

- ✓ Located behind the somatic sensory cortex in the parietal area of the cortex.
- ✓ Association area receive input from somatic sensory cortex, ventrobasal nuclei of the thalamus (ventroposteriolateral-VPL-and ventroposteromedial-VPM-), visual and auditory cortex.
- ✓ Function is to decipher sensory meaning; it has a high level of interpretation by knowing where is this area compared to the other areas and forming 3D position of the sensation.
- ✓ Loss of these areas results in the inability to recognize complex objects and loss of self (Amorphosynthesis), the patient is unable to form the shape of the objects.

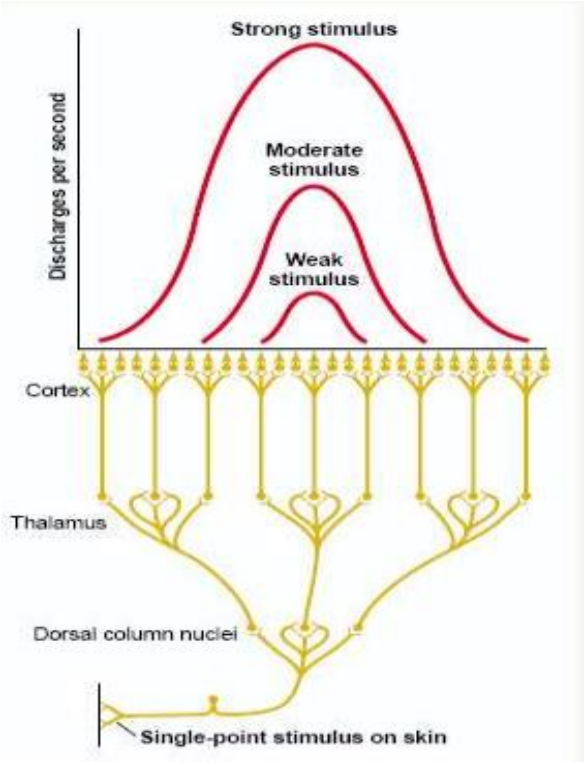
Special Aspects of Sensory Function

- ✓ Thalamus has some ability to discriminate tactile sensation because some of a neurons end in the thalamus.
- ✓ Thalamus has an important role in the perception of pain and temperature, so if there is a damage of postcentral gyrus still person can feel pain and temperature but very little regarding tactile sensations.
- ✓ Corticofugal fibers
  - Descending fibers from the cortex back to the sensory relay areas of thalamus, medulla and spinal cord.
  - These fibers are inhibitory, they can suppress the sensory input (negative feedback).
  - Function to decrease the spread of a signal and sharpen the degree of contrast and adjust the sensitivity of the system.

Coding for the intensity of the stimulus as percieved at the cerebral cortex.

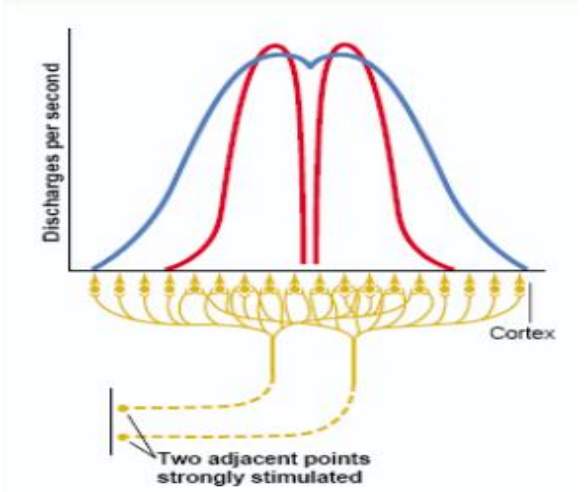
- If the stimulus is weak it's able to stimulate the central part of the cerebral cortex cells>> weak stimulus.
- If the stimulus is strong it's able to diverge to stimulate larger number of cortical cells>> moderate stimulus.
- If the stimulus is very strong it's able to stimulate a very high number of cortical cells>> strong stimulus.

❖ So, coding for intensity of the stimulus is percieved as number neurons that are stimulated and the number of impulses.



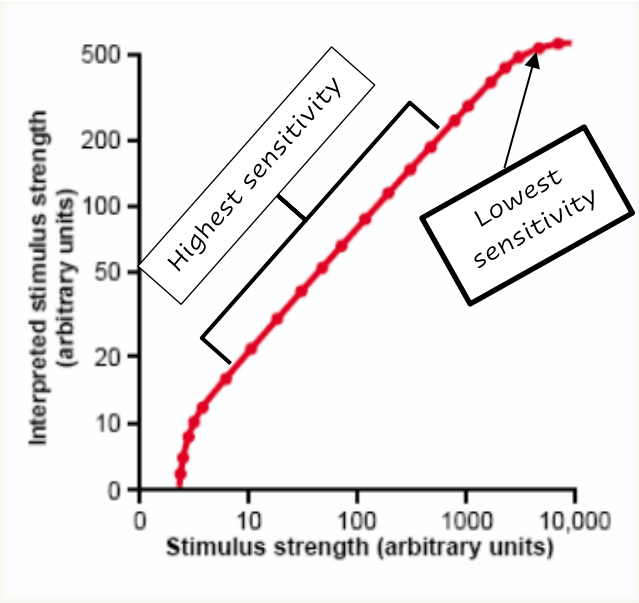
Processing of two-points discrimination at the cerebral cortex: the use of lateral inhibition.

- We have two stimuli and an inhibition between them so you feel the two stimuli as two peaks.



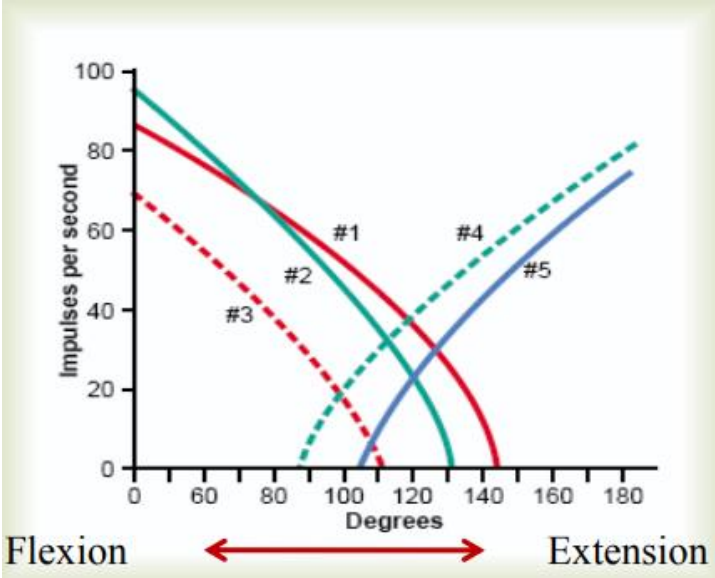
Graphical demonstration of the relation between actual stimulus strength and the interpreted stimulus strength (power law).

- a stronger stimulus is perceived as stronger, due to the higher number of impulses.
- The red curve represents the number of impulses.
- Note that the power law does not hold at either very weak or very strong stimulus strength.
- Note that the highest sensitivity area is in the middle.



Processing of position sense

- When you're extending the limb (moving to higher degree of extension) the impulses of some neurons in the thalamus (1,2,3) decreases, on the other hand the impulses of neuron 4 and 5 increases >> the system knows this is an **extension**
- The opposite happens regarding to **flexion**.



- When you change the angle of the joint, some neurons transmit more impulses while other neurons transmit less impulses; this combination of the number of impulses in these neurons(maybe 100 neurons), your system will interpret it as **flexion** or **extension**.

Good luck