بسم الله الرحمن الرحيم

Somatic Sensations (Pt .2)

MID | Lecture 2

﴿إِنِّي تَوَكَّلْتُ عَلَى ٱللَّهِ رَبِّي وَرَبِّكُم مَّا مِن دَآبَّةٍ إِلَّا هُوَ ءَاخِذُۢ بِنَاصِيَتِهَآ إِنَّ رَبِّي عَلَىٰ صِرَٰطٍ مُّسْتَقِيمٍ﴾

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PHYSIOLOGY

رحلة اليقين مع سورة يس

بِسۡمِ ٱللَّهِ ٱلرَّحۡمَٰنِ ٱلرَّحِيمِ

وَسَوَآءٌ عَلَيۡهِمۡ ءَأَنذَرۡتَهُمۡ أَمۡ لَمۡ تُنذِرۡهُمۡ لَا يُؤۡمِنُونَ (١٠) إِنَّمَا تُنذِرُ مَنِ ٱتَّبَعَ ٱلذِّكۡرَ وَخَشِيَ ٱلرَّحۡمَٰنَ بِٱلۡغَيۡبِۖ فَبَشِّرۡهُ بِمَغۡفِرَةٖ وَأَجۡرٖ كَرِيمٍ (١١)

{ وَسَوَاءٌ عَلَيْهِمْ أَأَنْذَرْتَهُمْ أَمْ لَمْ تُنْذِرْهُمْ لَا يُؤْمِنُونَ } وكيف يؤمن من طبع على قلبه، ورأى الحق باطلا والباطل حقا؟!

والقسم الثاني: الذين قبلوا النذارة، وقد ذكرهم بقوله: { إِنَّمَا تُنْذِرُ } أي: إنما تنفع نذارتك، ويتعظ بنصحك { مَنِ اتَّبَعَ الذِّكْرَ } أي: من قصده اتباع الحق وما ذكر به، { وَخَشِيَ الرَّحْمَنَ بِالْغَيْبِ } أي: من اتصف بهذين الأمرين، القصد الحسن في طلب الحق، وخشية الله تعالى، فهم الذين ينتفعون برسالتك، ويزكون بتعليمك، وهذا الذي وفق لهذين الأمرين { فَبَشِّرْهُ بِمَغْفِرَةٍ } لذنوبه، { وَأَجْرٍ كَرِيمٍ } لأعماله الصالحة، ونيته الحسنة.

Neurophysiology

Sensation 2

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Quick review [1]

Functions of the nervous system:

1.Sensory function → **Sensation:** conscious or subconscious awareness of changes in the external or internal environment.

2.Perception: the conscious interpretation of sensory input, which occurs in the cerebral cortex.

Sensory modalities:

A. **Special senses:**

•Vision

•Hearing

•Taste

•Equilibrium (balance)

B. **General senses:**

These are divided into:

1.Somatic senses:

1. Mechanical sensations: tactile (touch, pressure, vibration, tickle, itch)
2. Thermal sensations
3. Pain
4. Proprioception (static and dynamic)

Quick review (2)

1. Muscle length and rate of stretch are detected by the muscle spindle (primary endings detect dynamic stretch; secondary endings detect static length).

2. Visceral (internal) sensations:

1. Sensations arising from internal organs (e.g., stretch, chemical changes, visceral pain).

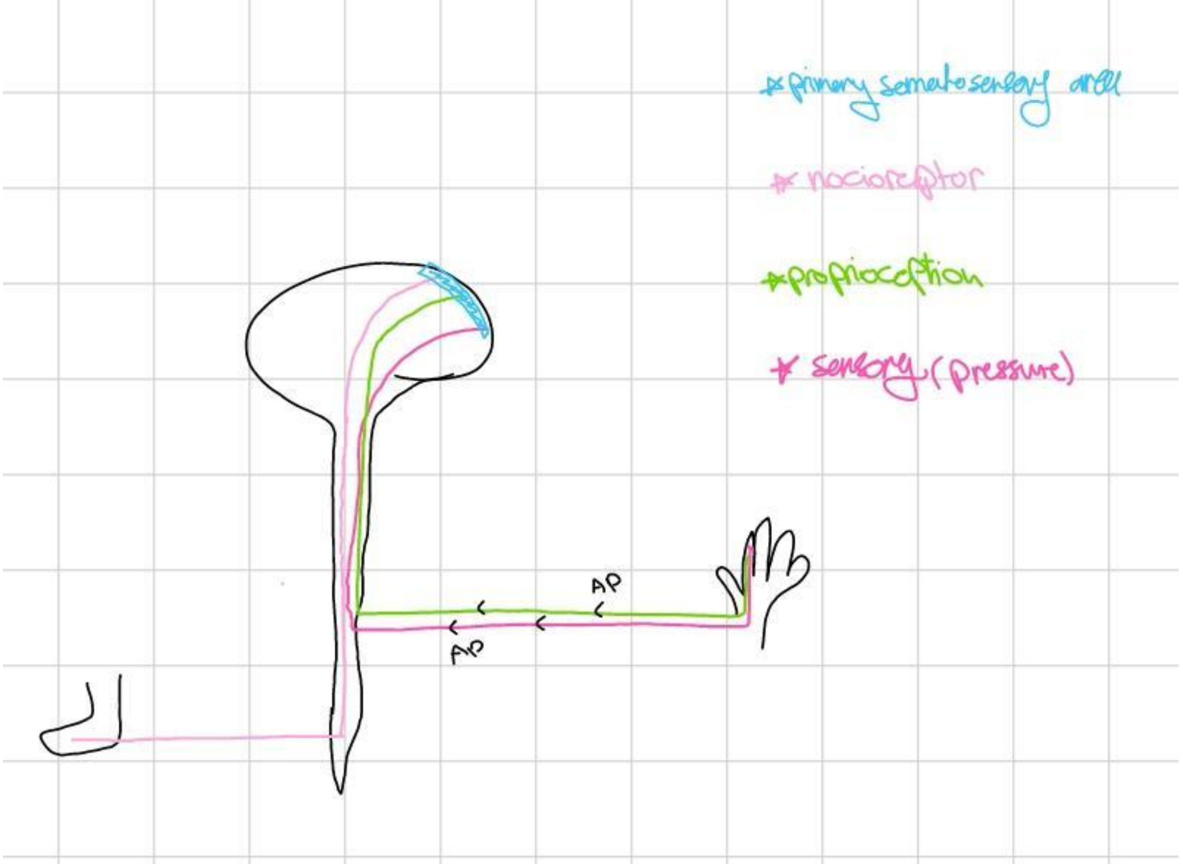
3.Integration: processing and interpretation of sensory information.

Integration begins at the spinal cord and brainstem levels, while initial cortical processing and localization of somatic sensation occur in the primary somatosensory cortex. Further interpretation involves association areas.

4.Motor function: response to integration, which may be

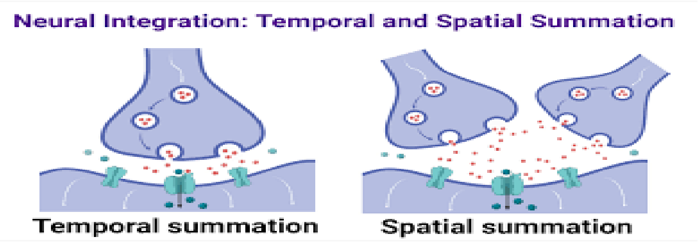
1. **Voluntary (somatic motor system)**
2. **Involuntary (autonomic nervous system)**

Labeled line principle



- How do we know the intensity of the stimulus?

Frequency → rate of firing (spatial and temporal summations)



- How does the primary somatosensory cortex differentiate between the types of signals it receives if all of them are propagated as action potentials?

This is explained by the Labeled Line Principle.

- Each sensory receptor is specialized to detect a specific modality (e.g., pressure, proprioception, or pain). The signal generated by that receptor travels through a specific neural pathway, and this pathway projects to a specific region in the primary somatosensory cortex in a somatotopic manner.

=> CNS <u>decodes the location and type of stimulus</u>

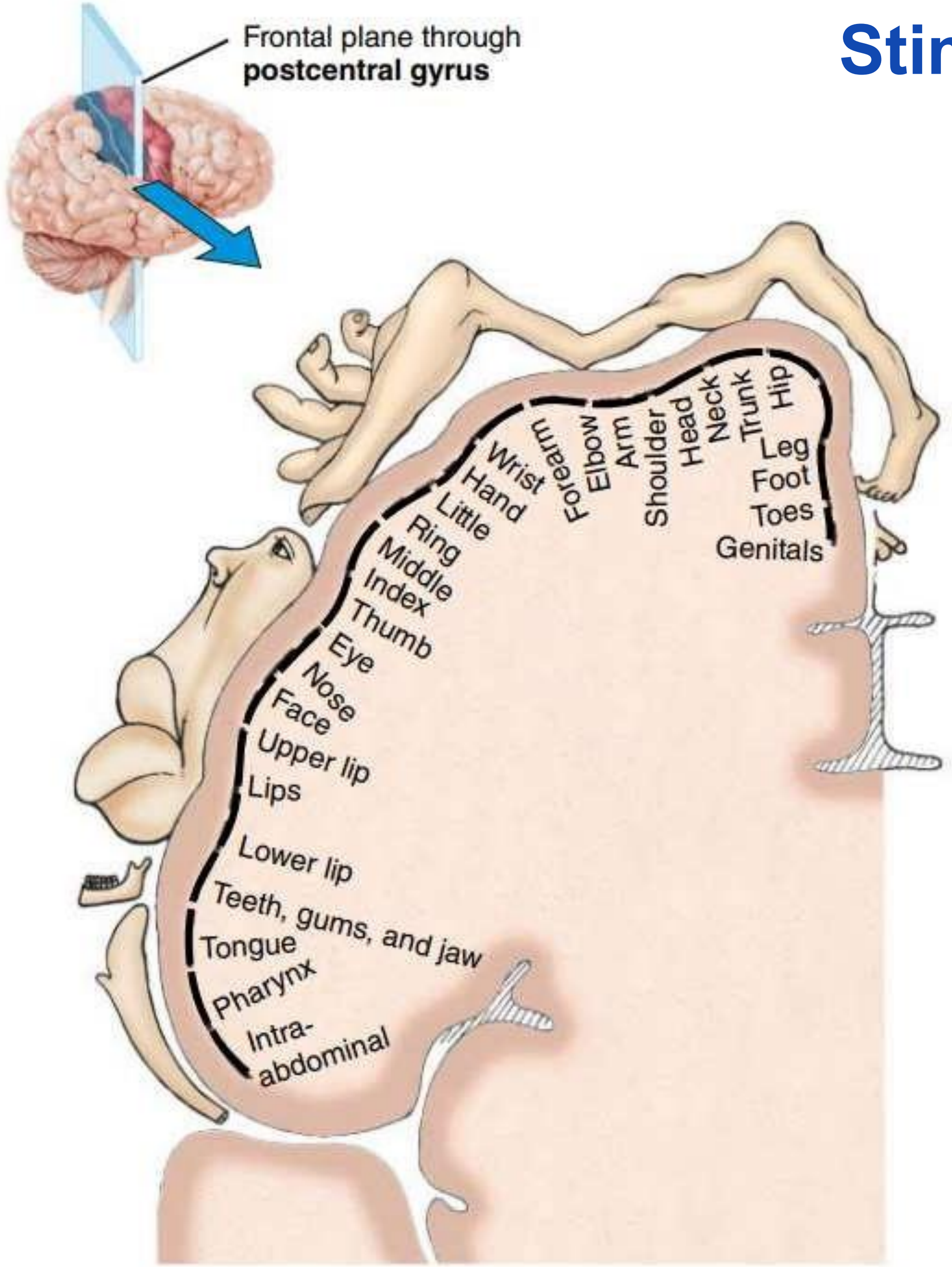
Labeled Line Principle

- Even though all information is propagated to the CNS via the same type of signal (action potentials), the brain can **decode** the type and location of the stimulus.

- A particular sensory modality detected by a specialized receptor type is sent over a **specific afferent** and ascending pathway to excite a defined area in the somatosensory cortex.

- Thus, different types of incoming information are kept separated within specific labeled lines between the periphery and the cortex.

Stimulus intensity



- The image displays a **distorted** and **disproportionate** cortical map of the body (sensory homunculus), where certain body parts, such as the **hands**, **lips**, and **tongue**, **occupy a disproportionately large area** of the primary somatosensory cortex, while larger body regions, like the **trunk** and **back**, **occupy a much smaller cortical area.**

- What is the reason behind this disproportionality?

Receptor density => sensory receptors are distributed unevenly. **(The cortical representation of a body part is proportional to its receptor density and functional importance, not its physical size.)**

- Why specifically the hands, lips, and tongue?

These regions are heavily involved in interaction with the **external environment**, such as **fine touch**, **manipulation**, **speech**, and **taste**.
They require fine sensory discrimination (the ability to precisely detect and distinguish stimuli in the environment).

Stimulus intensity

- The intensity of the stimulus is reflected by the magnitude of the **receptor potential**.

- The larger the receptor potential, the greater the frequency of action potentials generated in the afferent neuron.

- Stimulus strength is also reflected by the size of the area stimulated: Stronger stimuli usually affect larger areas, so correspondingly more receptors respond.
- Temporal and spatial summation

Somatic sensory receptors distribution

- Receptors are **distributed unevenly**.

- The areas with the highest density of somatic sensory receptors are the **tip of the tongue, the lips, and the fingertips.**

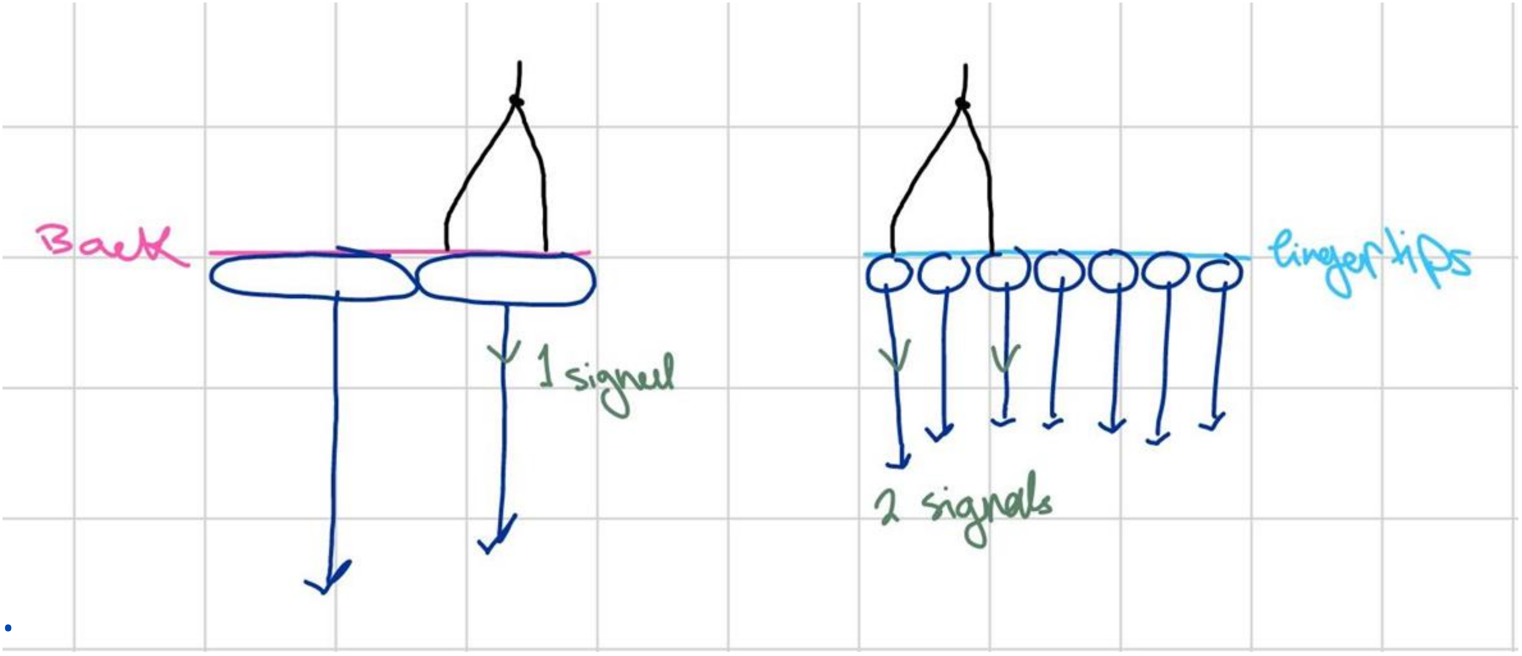
Receptive Field

- **Receptor density is inversely related to receptive field size**

Receptive field: the area of the body surface where stimulation activates a single sensory neuron.

High receptor density → small receptive fields → high spatial resolution → fine discrimination.
Low receptor density → large receptive fields → poor spatial resolution.

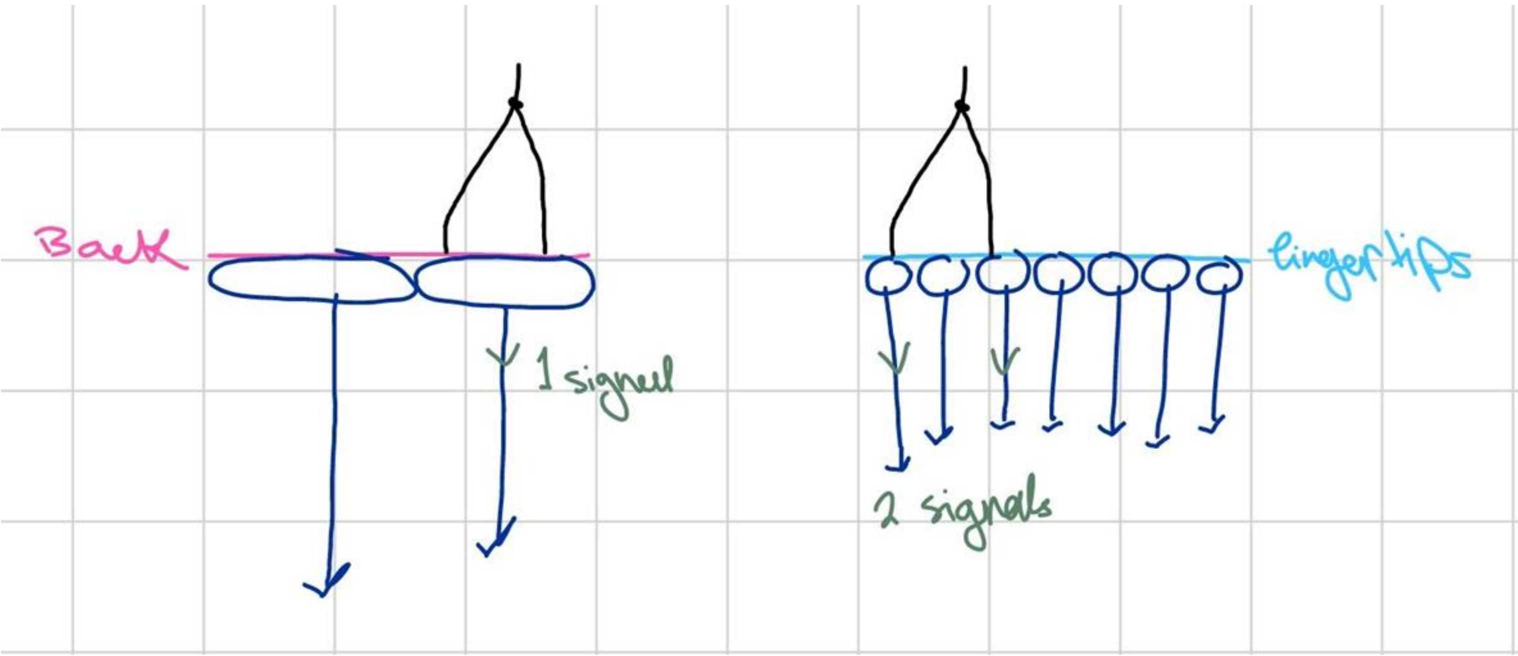
Therefore, the ability to discriminate between two stimuli varies depending on the body region.

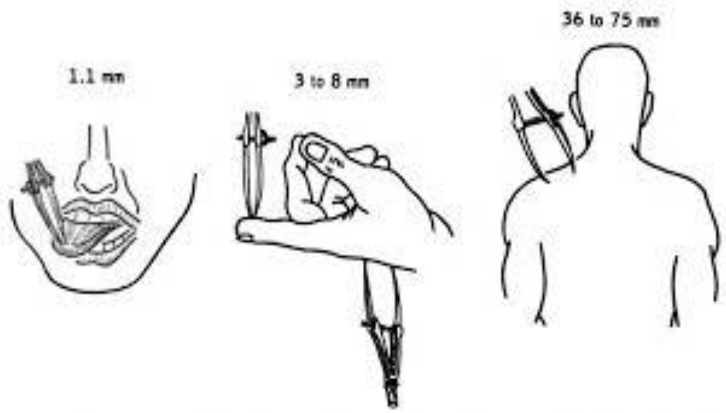


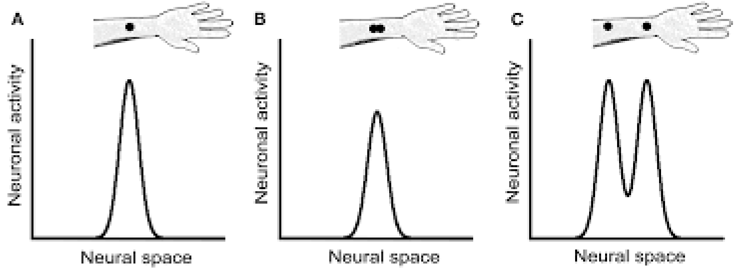
The length is the same for both drawings

Receptive Field

Clinically, **two-point discrimination** is tested by touching an area of the body using a **caliper (or two-point discriminator)**, applying either **one point or two points simultaneously.**
The patient is asked to report **whether they feel one point or two separate points**, while their **eyes are closed.**
This test measures the **minimum distance at which two points can be perceived as distinct.**
It evaluates the integrity of the **dorsal column-medial lemniscus pathway and the primary somatosensory cortex.**







How many points will be felt?
1; only one nerve is stimulated

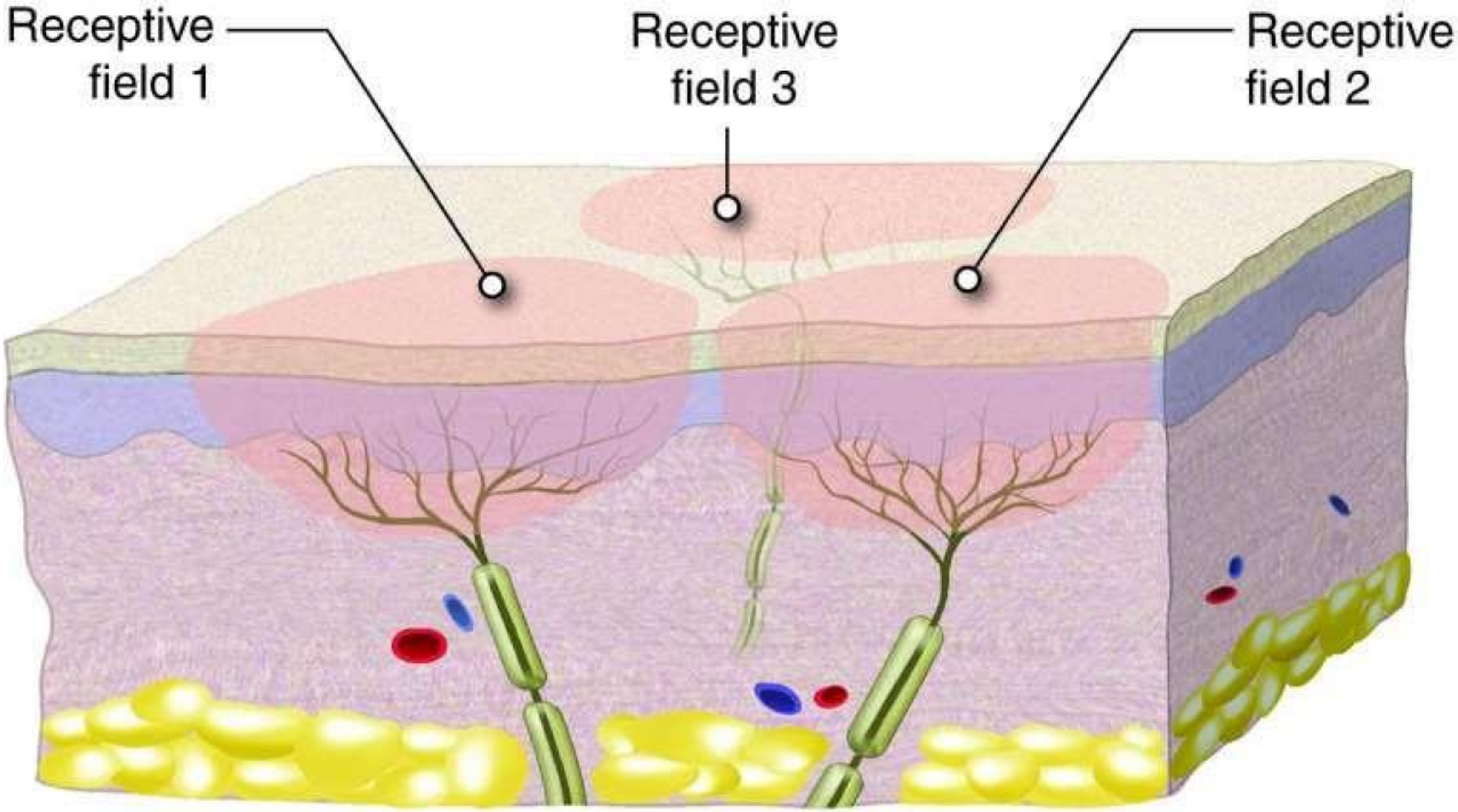
How many points will be felt?
2; 2 nerves are stimulated.

Receptive Field

- Each sensory neuron responds to a stimulus only within a specific region surrounding it, this region is called its **receptive field**.

- The size of a receptive field varies inversely with the density of receptors in the region.

- The smaller the receptive field is in a region, the greater its acuity or discriminative ability: **2 point discrimination**



https://psychology.stackexchange.com/questions/13172/what-is-the-definition-of-a-receptive-field

Lateral Inhibition

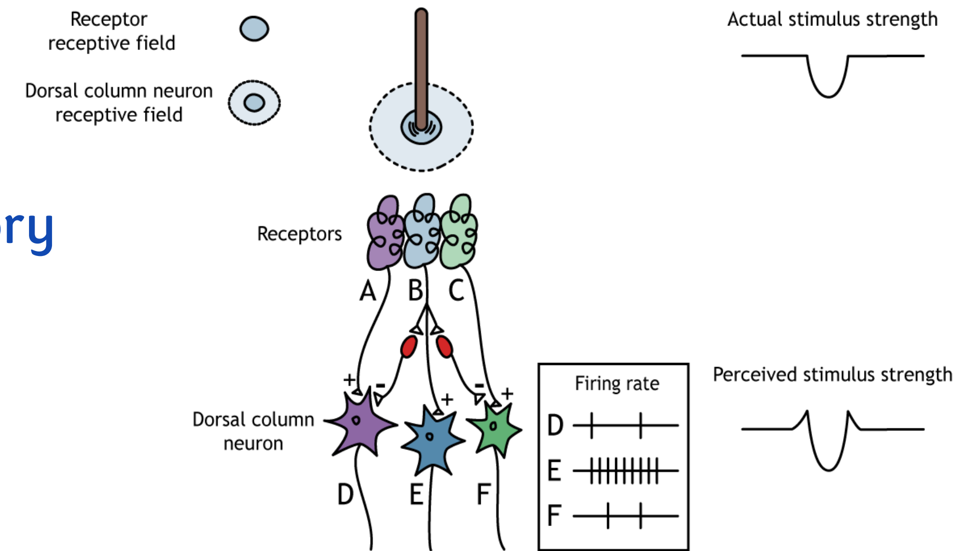
- A **pressure stimulus produces deformation of the skin**, activating multiple nearby sensory receptors.

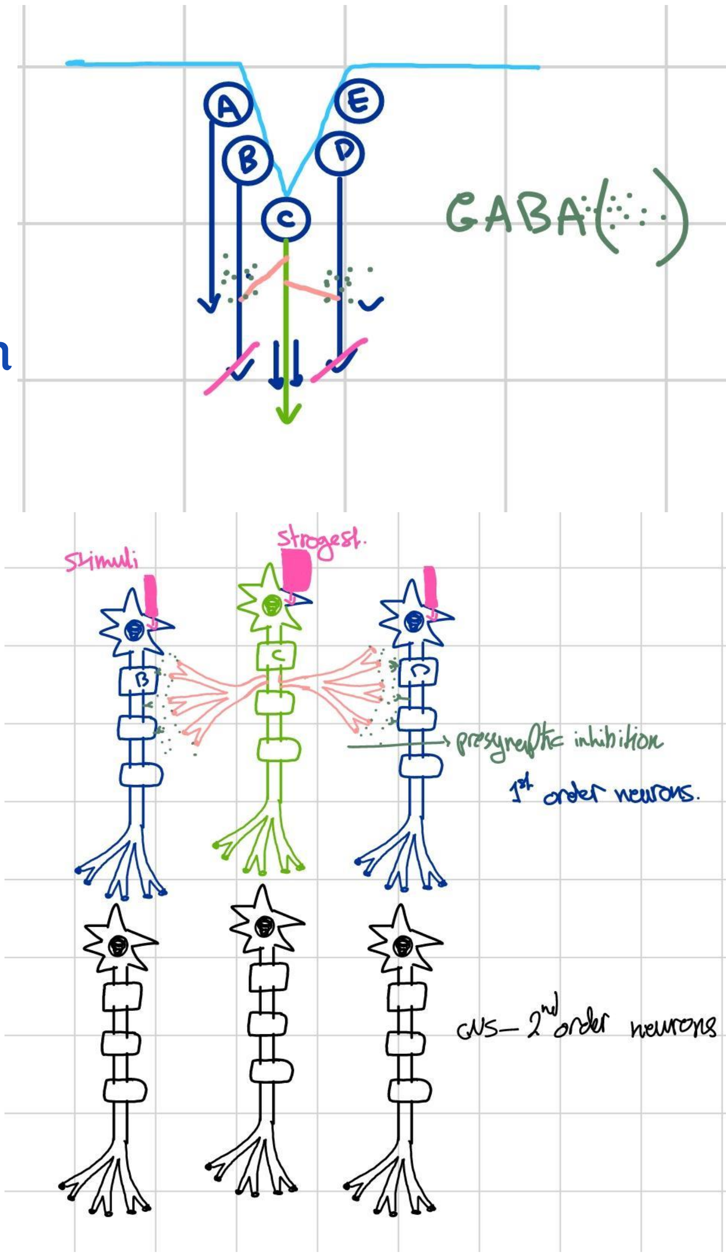
Among these points, **point C** (in the right image) generates the **strongest stimulus**, producing the highest frequency of action potentials.

- In sensory modalities such as **vision and fine touch**, the nervous system enhances contrast and identifies the strongest stimulus through a mechanism called **lateral inhibition.**

In lateral inhibition, the **most strongly activated primary afferent excites its corresponding second-order neuron**, which then activates **inhibitory interneurons.** These interneurons suppress the activity of adjacent second-order neurons, thereby enhancing contrast and improving spatial resolution.

- Inhibition is mediated by inhibitory neurotransmitters, **such as GABA (and glycine in the spinal cord).**





Lateral Inhibition

- Blockage of further transmission in the weaker inputs **increases the contrast** between wanted and unwanted information so that the stimulus is precisely localized.

- With lateral inhibition, each activated signal pathway inhibits the pathways next to it by stimulating inhibitory interneurons that pass laterally between ascending fibers serving neighboring receptive fields.

- The extent of lateral inhibitory connections within sensory pathways varies for different modalities. Those with the most lateral inhibition: **touch and vision**

True or false

- Stimuli of the same intensity always result in receptor potentials of the same magnitude in the same receptor.

False; **adaptation**!

Adaptation is at:

- the receptor level.
- CNS level.

At the receptor level, a stimulus generates a receptor potential of a certain amplitude .If the signal is constant, then the R potential is reduced to a sub-threshold level **despite** the constant stimulus.

- The perception of the stimulus will fade or disappear, similar to wearing a watch, jacket, perfume ect..

You can feel them right when you put them and after time passes, you "get used" to them = not feeling them => **reduces sensory overload!**

Integrative CNS functions

- The integrative function of the CNS (Decision making) are 1 of 3 options:

1) Motor function (Active response to stimuli)
2) Data Archiving (Storage of the information for later use)
3) Removal/discarding of data

90% of sensory information gets discarded, due to the **concept of prioritization.**
(We need our brains to focus on the most important stimuli)

- Sensory receptors also exhibit adaptation, which is distinct from the adaptation that occurs in the CNS.

This will be discussed in the following slides ..

Adaptation in sensory receptors

- A characteristic of most sensory receptors is **adaptation**, in which the receptor potential decreases in amplitude during a maintained, constant stimulus.

- Because of adaptation, the perception of a sensation may fade or disappear even though the stimulus persists.

  Almost all sensory receptors are adaptive but they differ in the **mechanism** and **rate** of adaptation.

- Receptors vary in **how they adapt and how quickly they adapt** (tonic vs phasic).

Position sensory receptors

- The Pacinian corpuscles (detect changes in pressure/ vibration)and muscle spindles are especially adapted for detecting rapid rates of change.
- These are likely the receptors most responsible for detecting the rate of movement (dynamic changes).

- Rapid adaptation is essential for this function. The receptor must quickly detect a change in movement and then rapidly reduce its firing, allowing it to respond effectively to subsequent changes in movement.

- Pacinian corpuscles exhibit mechanical adaptation. This occurs because of their encapsulated, multilayered structure containing gelatinous material between the layers. When a constant stimulus is applied, the capsule redistributes the pressure, so the central nerve ending is no longer deformed, even though the stimulus persists.
- Mechanical adaptation therefore refers to the reduction in receptor firing due to redistribution of mechanical forces, not because the external stimulus has disappeared.

Adaptation in other sensory receptors

- Olfactory receptors chemically adapt.

- In general, tactile sensations are rapidly adapting, the slowest adapting modality is pain. Nociceptors show minimal or no adaptation, and may even become sensitized with continued stimulation. Since pain signals tissue injury, persistent perception is protective and essential for initiating corrective actions, to reduce the stimulus, (suturing of cuts, painkillers, etc..)

- Other sensory receptors exhibit varying rates of adaptation that lie along a spectrum between rapidly adapting receptors (like Pacinian corpuscles) and non-adapting pain receptors.

Transmission of sensory signals via nerve fibers

- There is another factor, besides adaptation, that plays a major role in the transmission of sensory signals: the type of nerve fiber carrying the signal.

For example, if fine touch and tickle stimuli of the same intensity are applied at the same time, the fine touch signal will reach the CNS faster than the tickle sensation. This difference occurs because different sensory modalities are transmitted by different types of nerve fibers, which vary in diameter and degree of myelination, and therefore in conduction velocity.

- **Aα** are the **largest**, most heavily myelinated nerve fibers, and therefore exhibiting the highest nerve conduction velocity. The primary endings of the **muscle spindle** (classified as Aα)transmit proprioceptive signals rapidly. This fast conduction is essential for the **stretch reflex** in the spinal cord, allowing rapid postural adjustments.

- **Aβ** fibers are **moderately large**, myelinated fibers that transmit signals related to **fine touch**, **pressure**, and **vibration**. These modalities are primarily detected by mechanoreceptors in the skin.

- **Type C** is the **smallest** in size, unmyelinated nerve fibers with slow conduction velocity. that carry signals for **tickle**, **itch**, **warmth thermoreceptors** and **chronic (dull) pain.**

○ Thermoreception involves multiple receptor types, including **cold** receptors (mainly Aδ fibers), **warmth** receptors (mainly C fibers), and **thermal pain** receptors.

<u>Pain is transmitted by two main fiber types:</u>

· Acute (sharp, well-localized) pain, transmitted by Aδ fibers.

· Chronic (dull, poorly localized) pain, transmitted by C fibers.

Transmission of tactile signals in peripheral nerve fibers

- Almost all specialized sensory receptors, such as Meissner's corpuscles, transmit their signals in type **Aβ** nerve fibers.

- Free nerve ending tactile receptors transmit signals mainly via the small type **Aδ** myelinated fibers.

- Some tactile free nerve endings transmit via type **C** unmyelinated fibers such as in itch and tickle senses.

Thermoreceptors

- Cold receptors transmitted by Aδ
- Warmth receptors transmitted by type c
- Pain receptors (stimulated only by extreme degrees of heat or cold).

- They are located immediately under the skin at discrete separated spots.
- Most areas of the body have more cold receptors than warmth.
- The number of receptors in different areas of the body varies.

Thermoreceptors

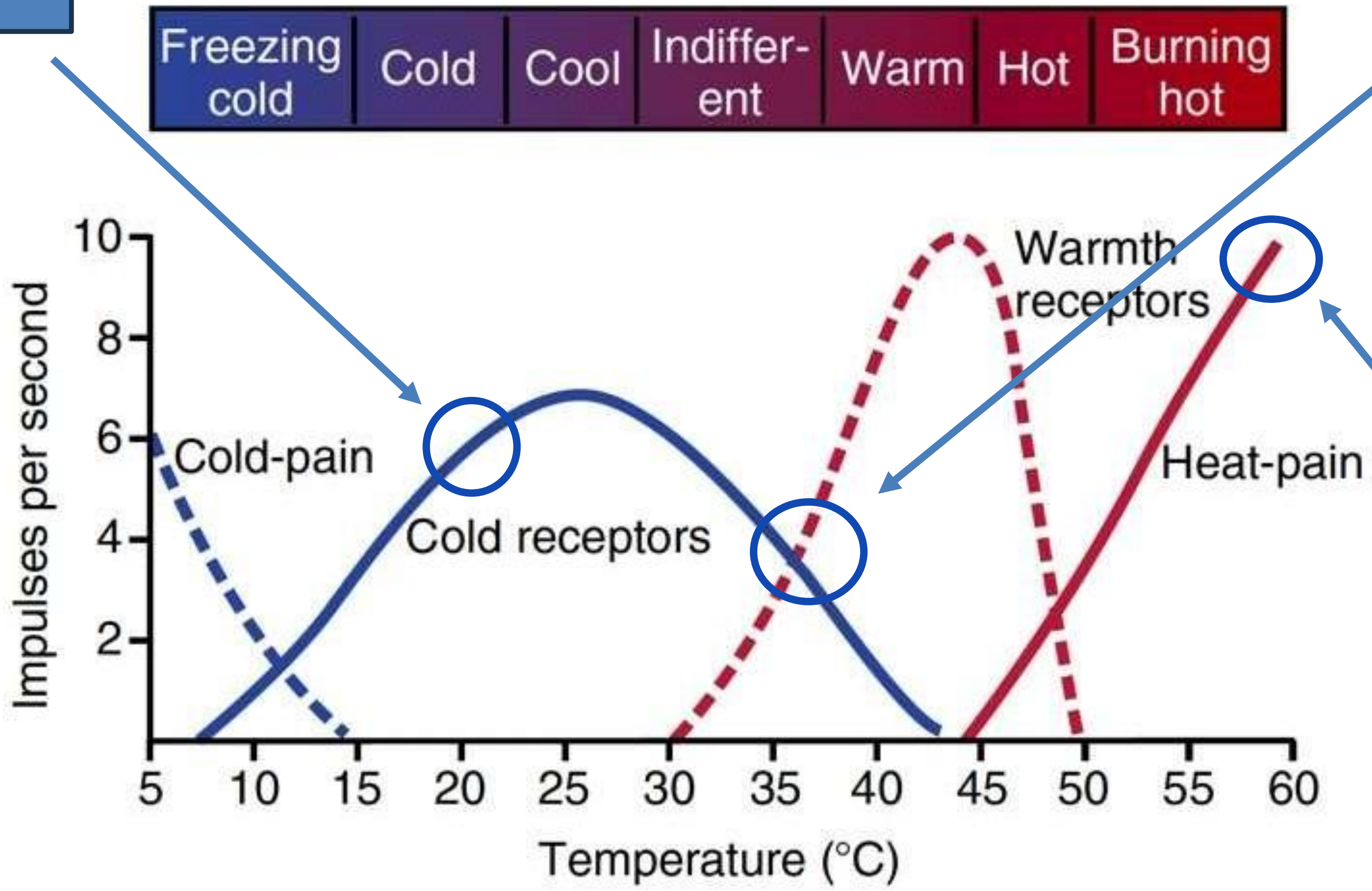
- Free nerve endings.
- Warmth signals are transmitted mainly over type C nerve fibers.
- Cold signals are transmitted mainly via type Aδ nerve fibers.
- In general, thermal signals are transmitted in pathways parallel to those for pain signals.

Thermal sensations

4 types of thermo-receptor as showcased in the graph:

At 20°C cold receptors are stimulated at 6 impulses per second, which the body interprets as cold

At 36°C we have equal stimulation of warm and cold receptors. Thus the temperature is neutral



At 55°C heat pain receptors are stimulated at 8 impulses per second which is a burning hot temperature inducing withdrawal reflex since it's painful

Thermal sensations

- The different gradations of thermal sensations can be determined by the relative degrees of stimulation of the different types of thermoreceptors and nociceptors.

- Because the number of cold or warmth endings in any one surface area of the body is slight, It is difficult to judge gradations of temperature when small skin areas are stimulated.

- However, when a large skin area is stimulated all at once, the thermal signals from the entire area are cumulative.

Adaptation in thermal receptors

- Thermal senses respond markedly (are more sensitive) to changes in temperature than to steady states of temperature (absloute temperature).

- This means that when the temperature of the skin is actively falling, a person feels much colder than when the temperature remains cold at the same level.

- For example, if someone entered cold water (such as in a pool), after a bit of time they'll feel warmer even though the temperature of the water didn't change.

Thermal receptors

- Transduction of warm temperatures involves transient receptor potential (TRP) channels in the family of vanilloid receptors (TRPV).

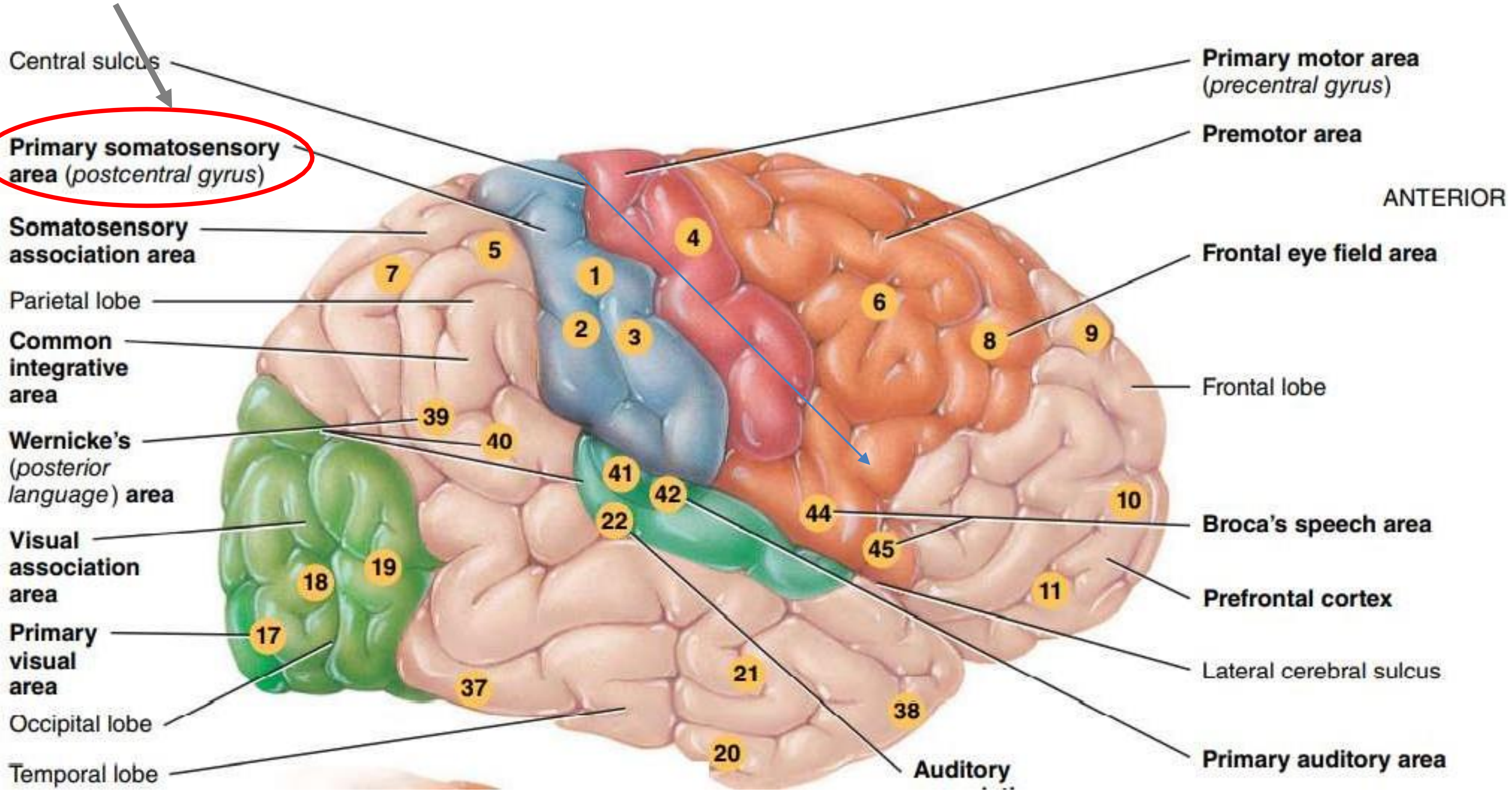
- These channels are activated by compounds in the vanilloid class, which includes capsaicin, an ingredient in spicy foods. (This phenomenon explains why people describe the taste of chili peppers as “hot.”)

Thermal receptors

- Transduction of cold temperatures involves a different TRP channel, TRPM8, which is also opened by compounds like menthol (which gives a cold /cool sensation).

Cerebral cortex

The main processing center for bodily sensations.



Somatic sensory pathways

- A somatic sensory pathway to the cerebral cortex consist of thousands of **sets of three neurons**:

- a first-order neuron, a second-order neuron, and a third-order neuron.

- Integration (processing) of information occurs at each synapse along the pathway.

Somatic sensory pathways

- First-order neurons begin at the sensory receptors, then enter the CNS through the spinal cord or the brainstem (in case of cranial nerves). In the CNS they synapse with the 2nd order neurons, which immediately undergo decussation (crossing to the other side). 2nd order neurons continue ascending (sensory pathways are ascending pathways), till they reach the thalamus, specifically the VPL nucleus (where somatic sensation terminates) and synapse with 3rd order neurons. 3rd order neurons terminate in the primary somatosensory area.

- The different ascending sensory pathways differ in several key aspects:

1. The location where the first-order neuron synapses with the second-order neuron. In many pathways, decussation (crossing to the opposite side) occurs near the site of this synapse, but it is not always exactly the same anatomical location.
2. The specific sensory modalities transmitted.
3. The regions of the body from which sensory information is collected.

First-order (primary) neurons

- Sensory neurons that conduct impulses from somatic sensory receptors into the brainstem or spinal cord.

- Somatic sensory impulses propagate along spinal or cranial nerves.

- All other neurons in a somatic sensory pathway are located completely within the CNS.

Second-order (secondary) neurons

- Conduct impulses from the brainstem or spinal cord to the **thalamus**.

- Axons of second-order neurons **decussate** (cross over to the opposite side) as they course through the brainstem or spinal cord before ascending to the thalamus.

Third-order (tertiary) neurons

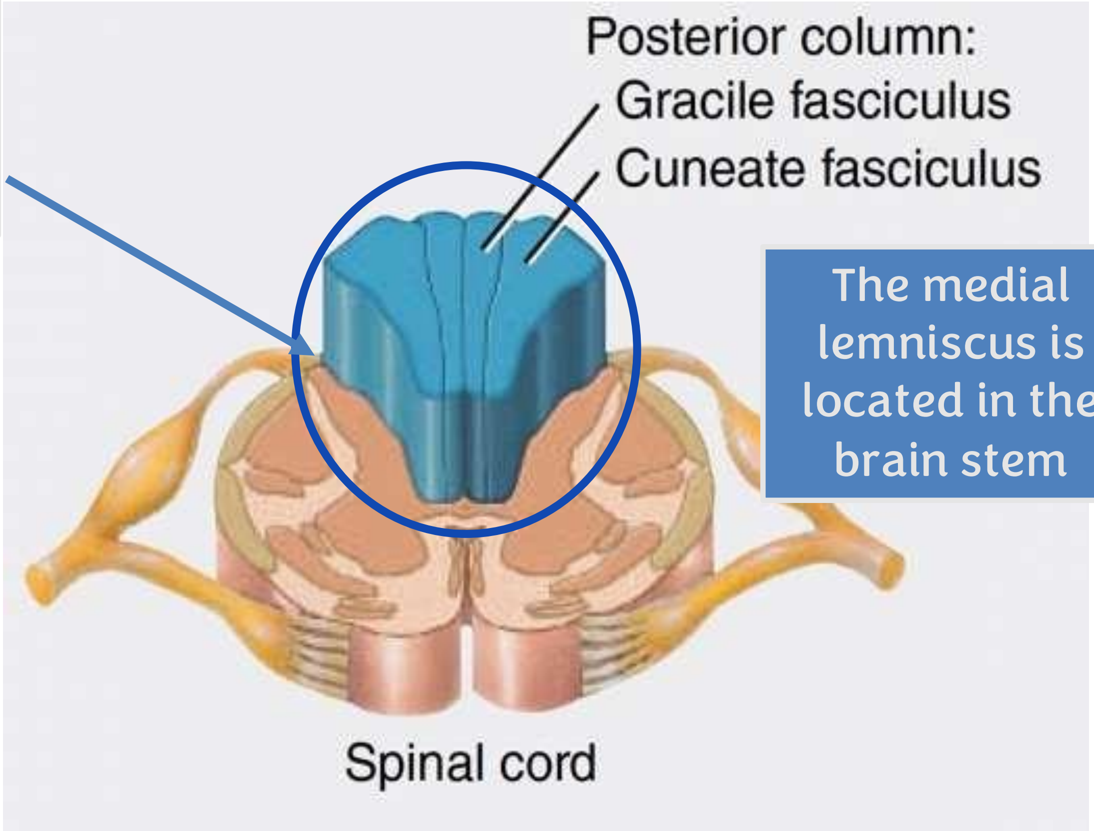
- Conduct impulses from the thalamus to the primary somatosensory area on the same side.
- Somatic sensory information on one side of the body is perceived by the primary somatosensory area on the opposite side of the brain.

Posterior (Dorsal) Column- Medial Lemniscus Pathway

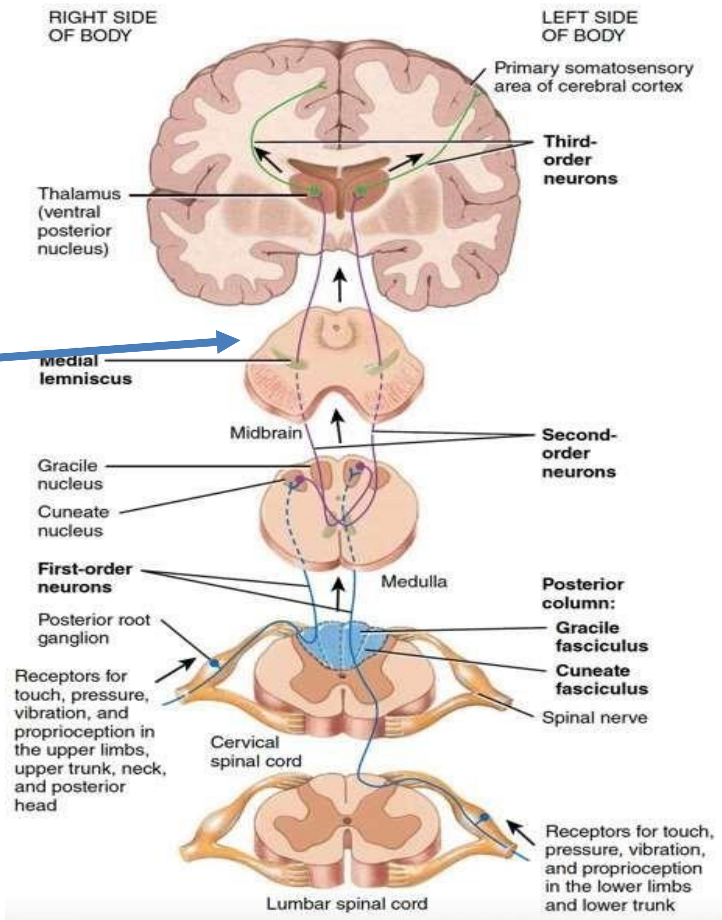
- Pathways are named according to the major anatomical structures they pass through in sequence. For example, the posterior column–medial lemniscus pathway travels first in the posterior column and then in the medial lemniscus.
- However, this does **not** mean that the pathway begins in the posterior column or terminates in the medial lemniscus. The name reflects the key tracts it traverses, not its exact origin or final cortical destination.

This whole blue region is considered the posterior column

As shown the posterior column is large, thus it would make sense for it to transport large nerve fibers: touch, vibration, pressure, proprioception.. (modalities carried by Aβ nerve fibers)



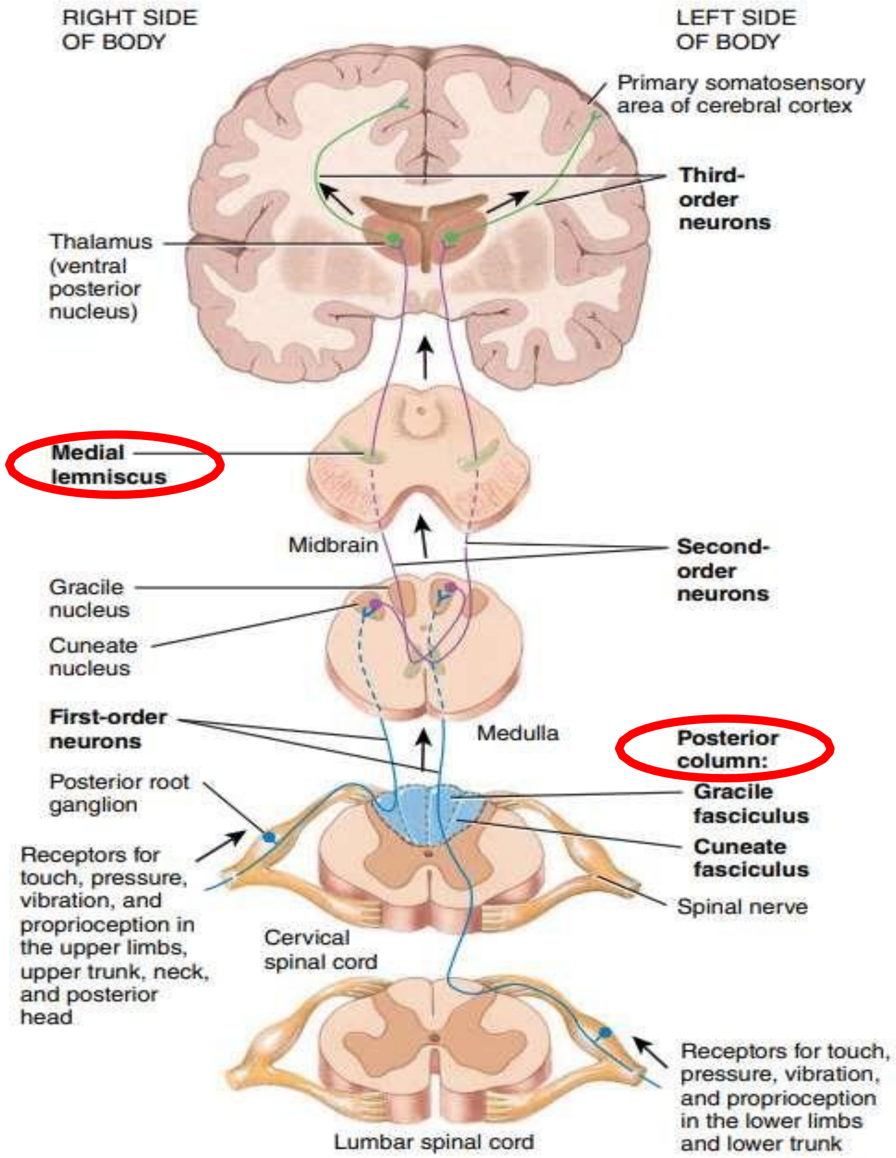
The medial lemniscus is located in the brain stem



Posterior column - medial lemniscus pathway

Three important questions you should know for every pathway:
1) Which part of the body does it carry information from?
2) Which modalities does it carry?
3) Where does the 1st order neuron synapse the 2nd? (Decussation occurs)

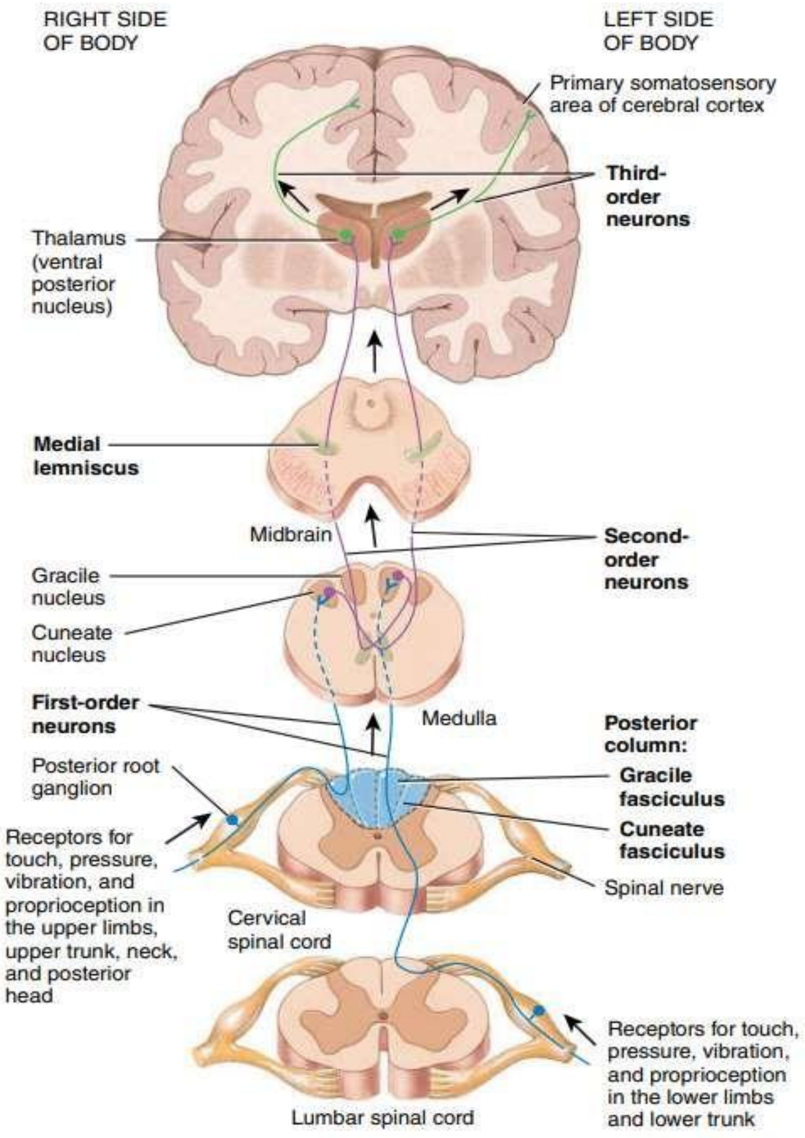
1) Which part of the body does it carry information from?
Every part of the body:- (limbs, trunk, posterior part of head...) **except the anterior part of head.**



Posterior column - medial lemniscus pathway

2) Which modalities does it carry?

Touch (fine)
Vibration
Pressure
Proprioception



Posterior column - medial lemniscus pathway

3) Where does the 1st order neuron synapse the 2nd ?

Decussation in the medulla

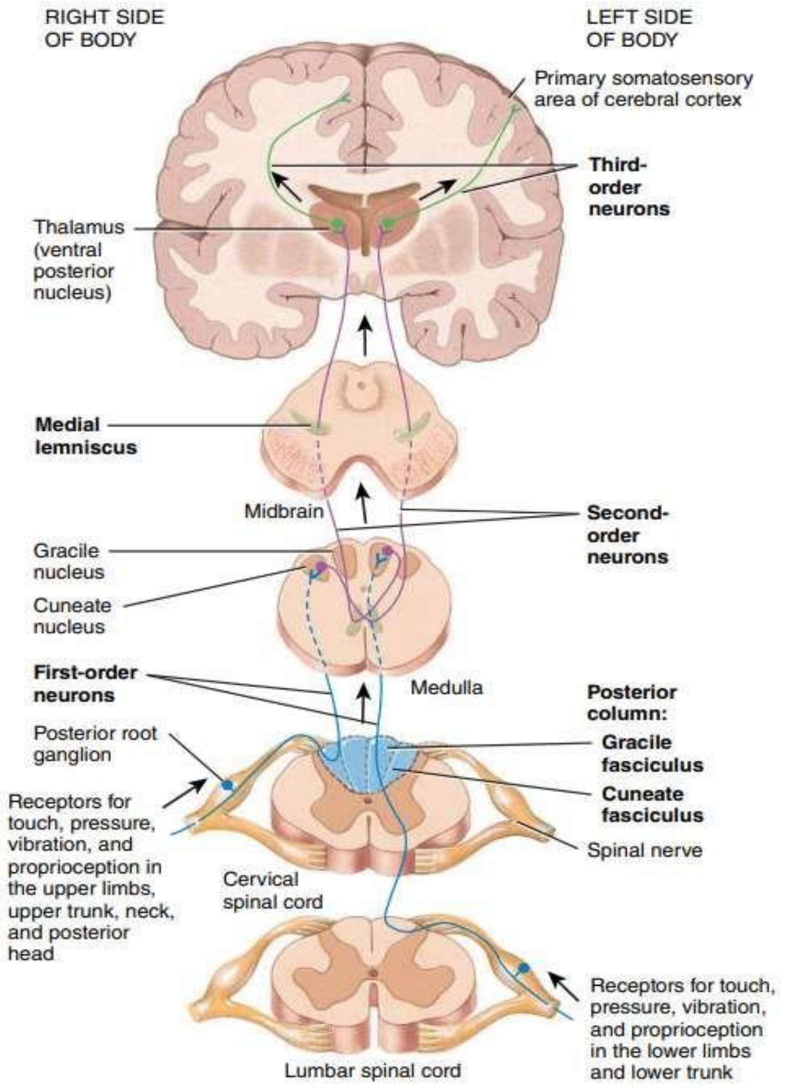
· The 1st-order neuron starts from the sensory receptor, and its cell body is located in the dorsal root ganglion. It enters the CNS through the dorsal root and ascends in the posterior column.

The posterior column is somatotopically organized: fibers from the lower body are medial, while fibers from the upper body are more lateral. Therefore, the effects of a lesion depend on its exact location within the posterior column.

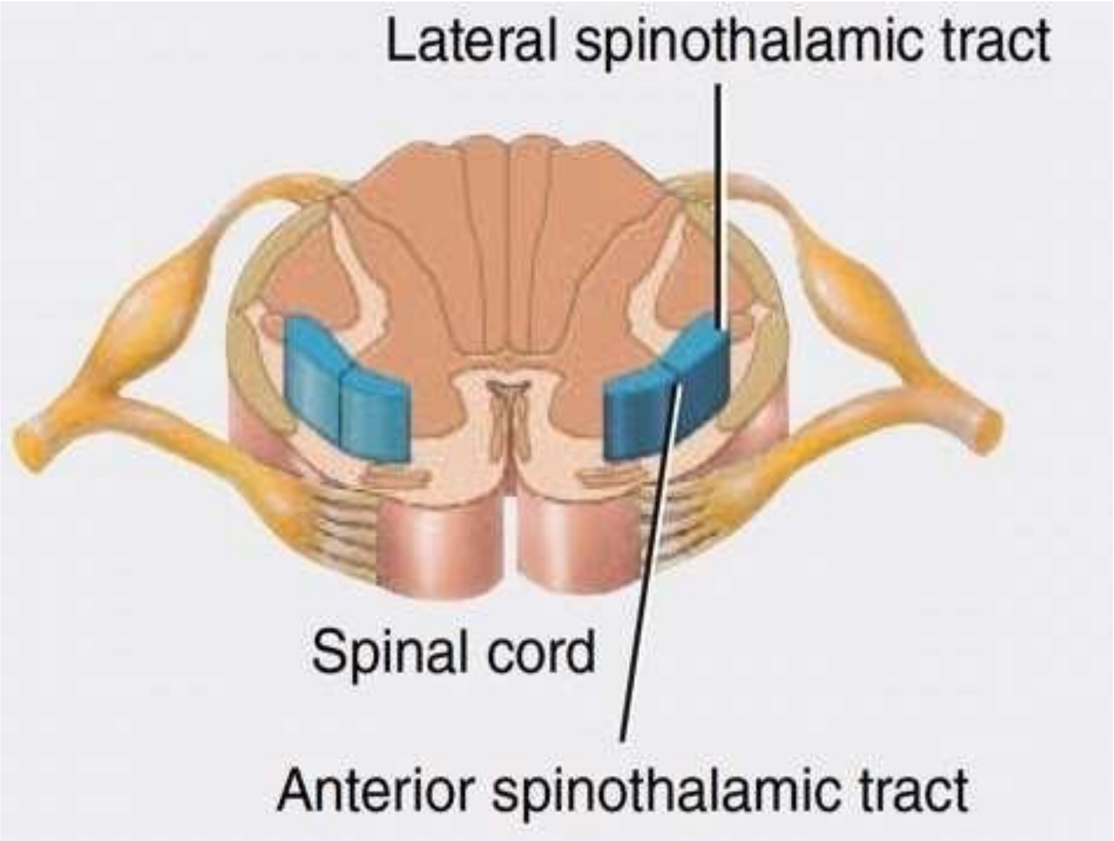
· The 1st-order neuron ascends ipsilaterally to the medulla, where it synapses with the 2nd-order neuron.

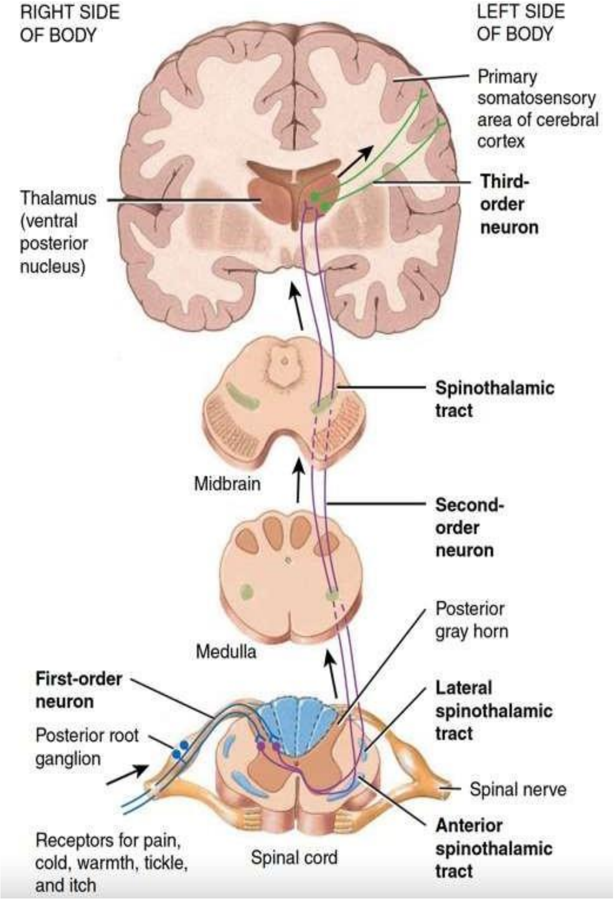
· The 2nd-order neuron decussates in the medulla, then ascends to the thalamus, where it synapses with the 3rd-order neuron.

· Finally, the 3rd-order neuron projects to the primary somatosensory cortex.



Antero-Lateral Spinothalamic Pathways





· It is called the anterolateral pathway because it passes through the anterior and lateral regions of the spinal cord.

· Compared to the posterior column, it appears smaller; however, this does not determine the size of the nerve fibers it carries. The anterolateral system primarily transmits sensations such as pain, temperature, itch, and tickle.

The main ascending component of this system is the spinothalamic tract.

Anterolateral spinothalamic pathway

1) Which part of the body does it carry information from?

Same thing as the previous pathway, all parts of the body except the anterior part of the head

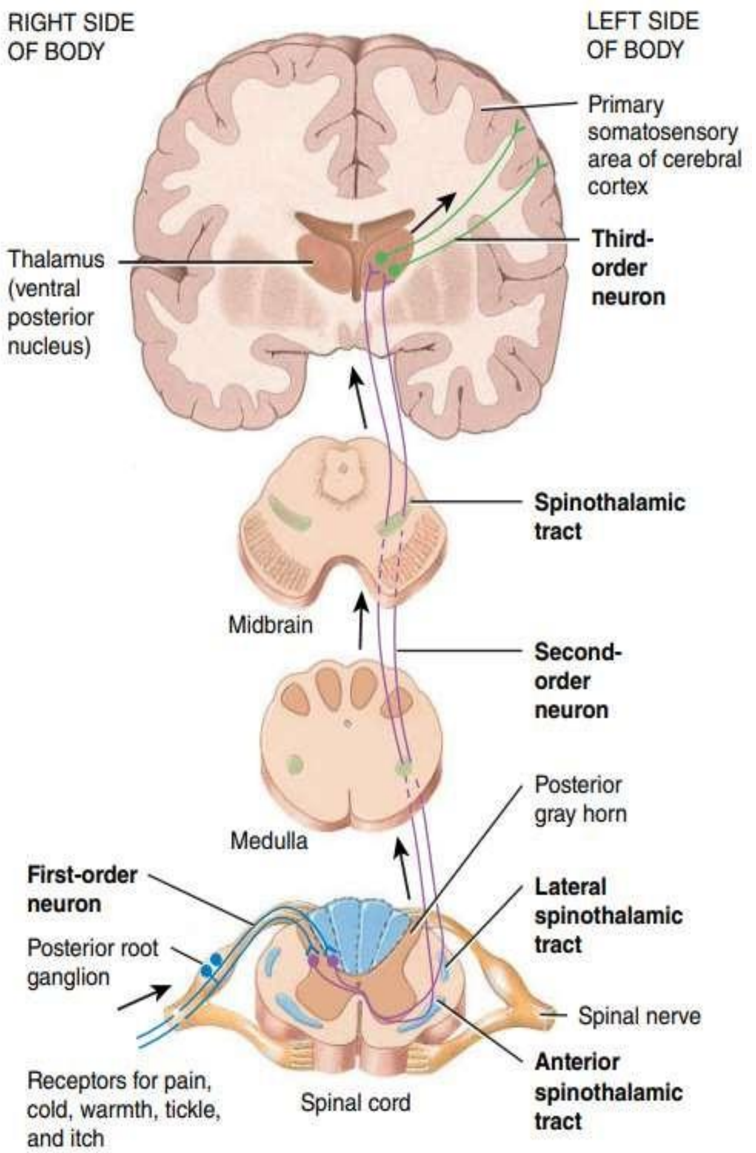
2) Which modalities does it carry?

Pain

Temperature

Itch

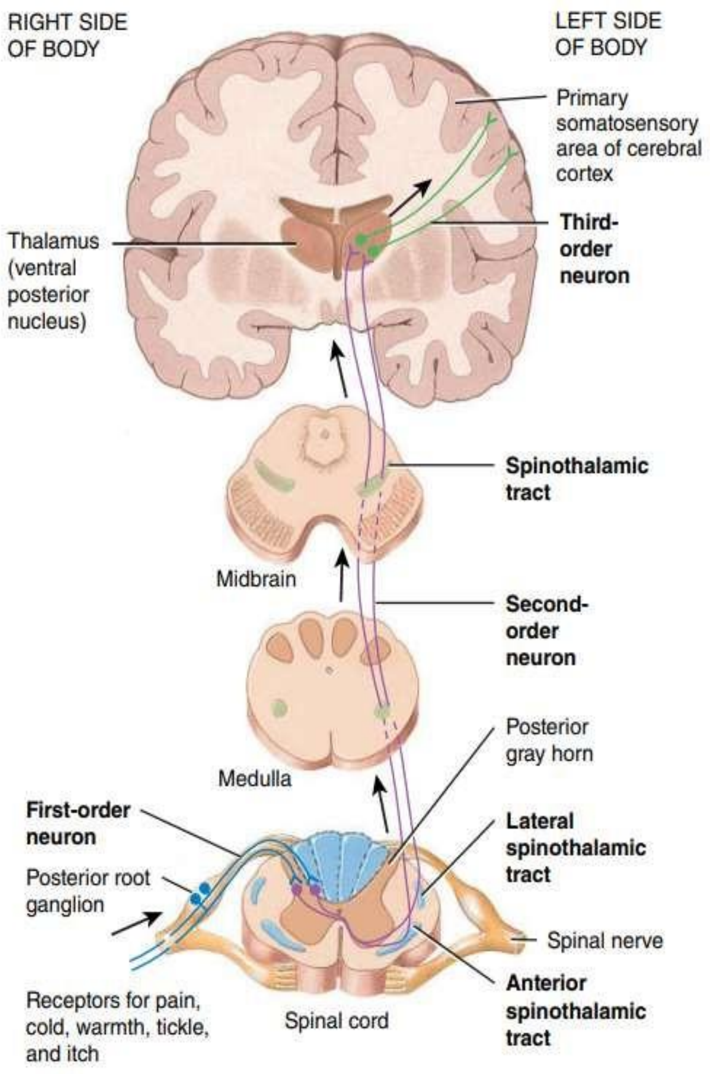
Tickle



Anterolateral spinothalamic pathway

3) Where does the 1st order neuron synapse the 2nd ?
(Decussation occurs)

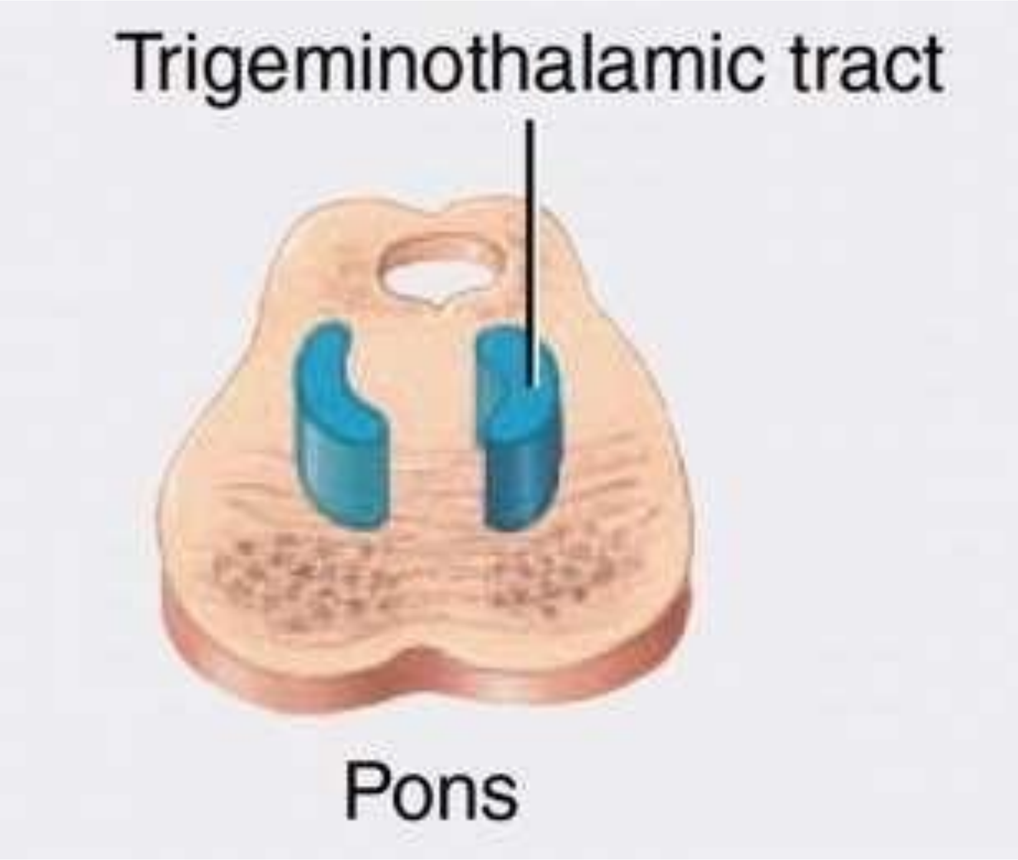
Decussation in spinal cord



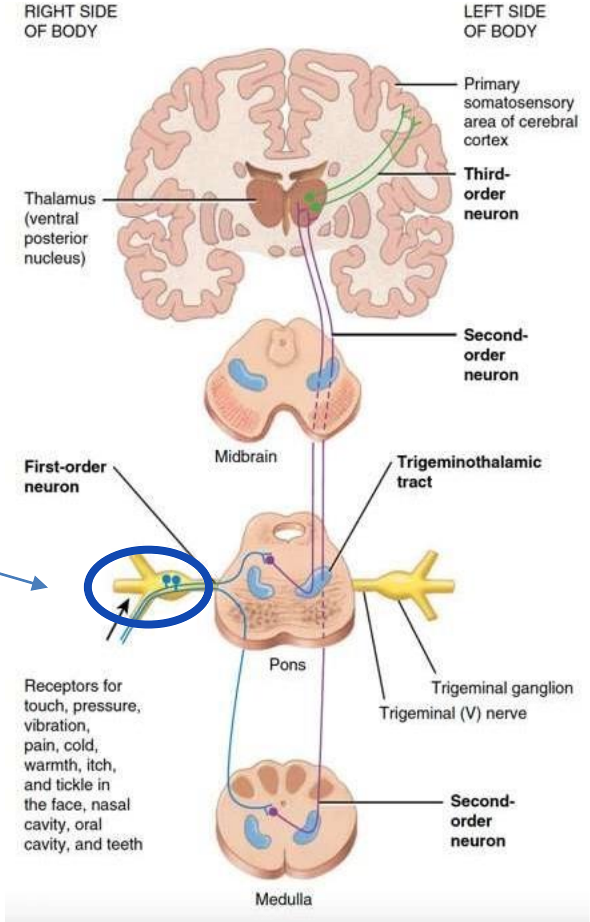
Question: If a stroke affected the right primary somatosensory cortex, which modalities and which part of the body would be affected?

Answer: The left (contralateral) side of the body would be affected, and all major somatic sensory modalities (fine touch, proprioception, pain, and temperature) would be impaired. The question would be more complex if the lesion occurred below the medulla, because the posterior column pathway decussates in the medulla, whereas the anterolateral (spinothalamic) tract decussates in the spinal cord. Therefore, spinal cord lesions may produce different patterns of sensory loss depending on the pathway involved.

Trigeminothalamic Pathway



The trigeminal ganglion is at the level of the pons.



- The remaining sensory region is the anterior part of the head, including sensations such as toothache and touch/pressure in the face.
- The 1st-order neuron synapses with the 2nd-order neuron in the trigeminal sensory nuclei in the brainstem (pons for touch, spinal trigeminal nucleus for pain). The 2nd-order neuron then decussates, ascends to the thalamus, where it synapses with the 3rd-order neuron, and finally projects to the primary somatosensory cortex.

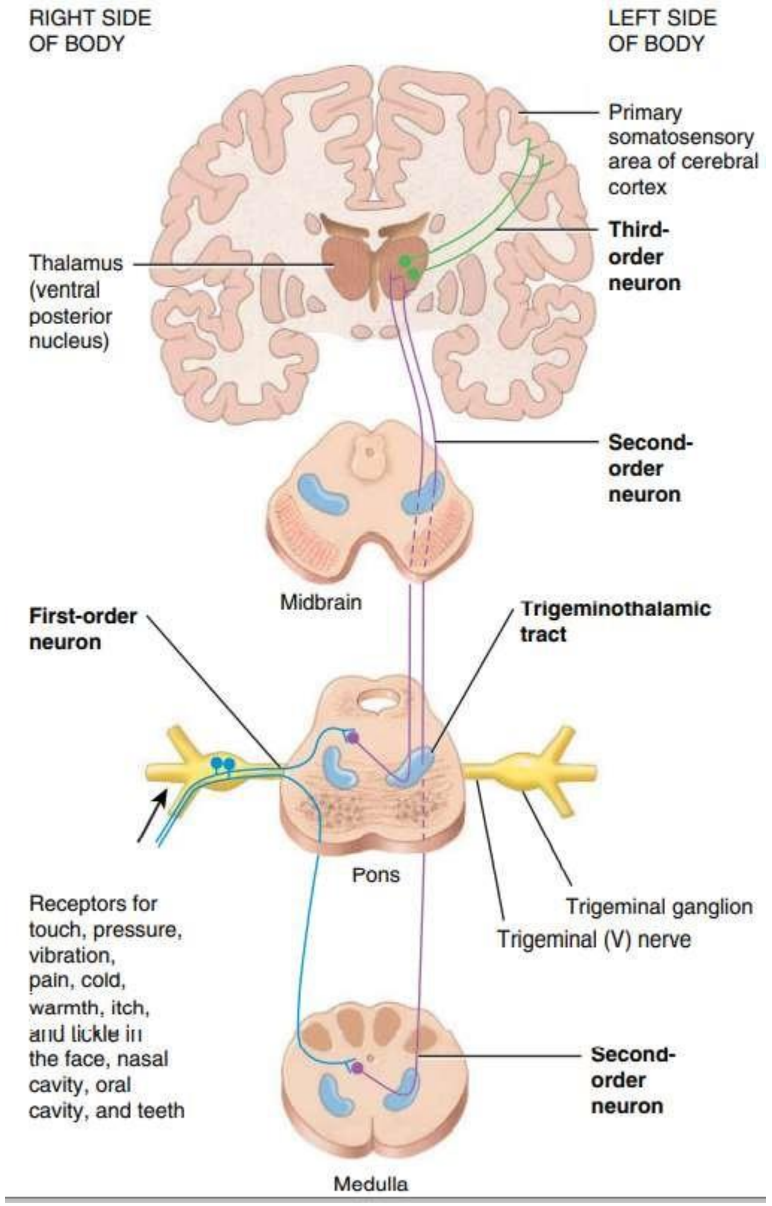
Trigeminothalamic pathway

1) Which part of the body does it carry information from? Anterior part of the head

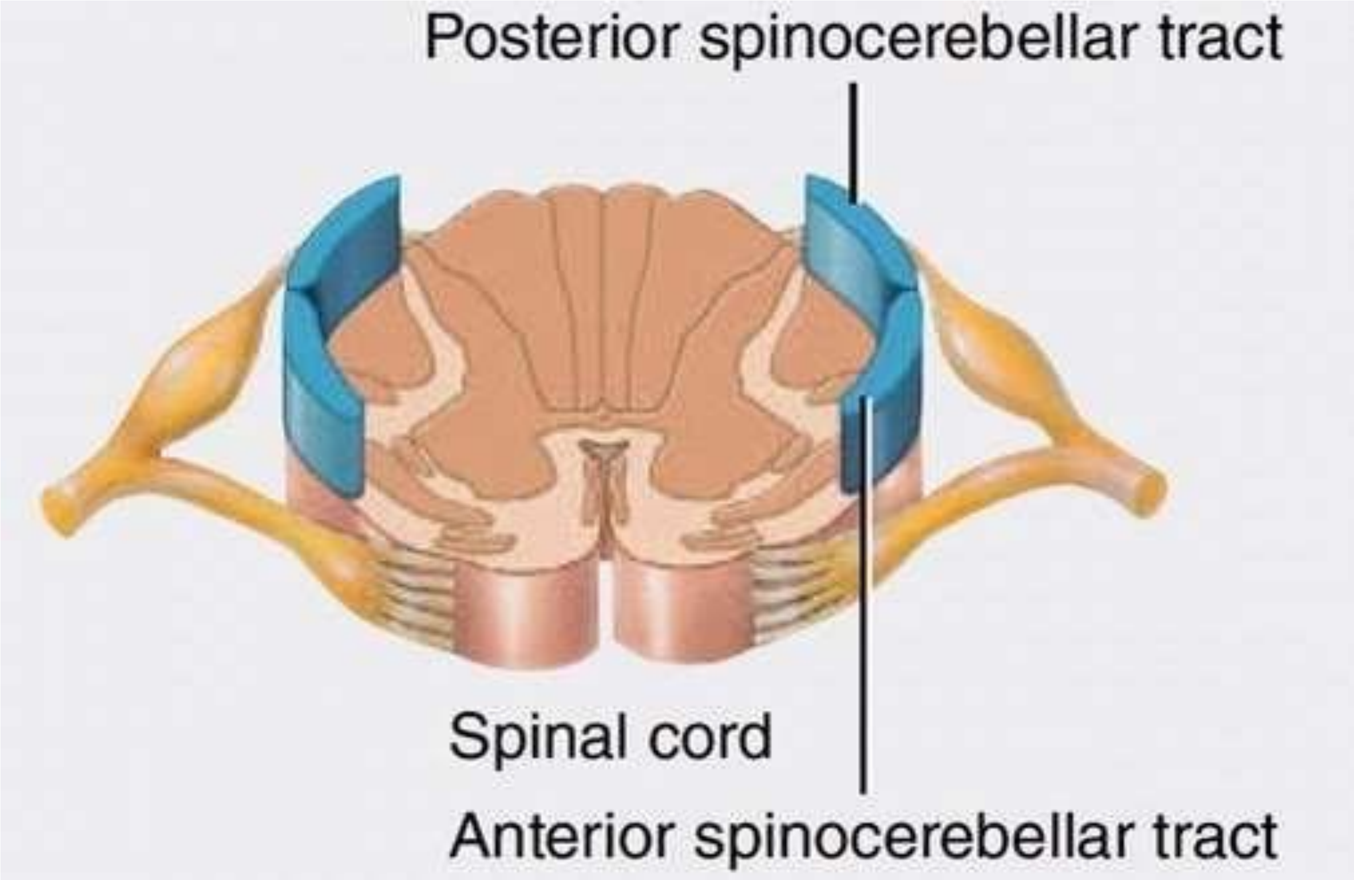
2) Which modalities does it carry? All (divided into the ventral and dorsal pathways)

3) Where does the 1st order neuron synapse the 2nd ? (Decussation occurs) - depending on the modality-
a) Pain and temperature- synapse in the trigeminal nucleus- decussation at the medulla

b) Fine touch- synapse at the principle nucleus- decussation at the pons

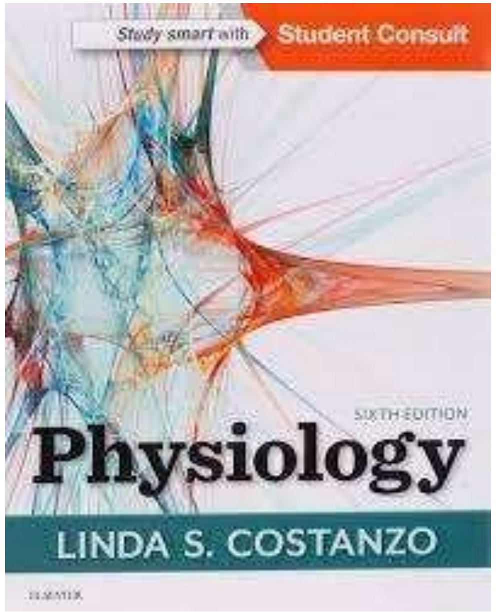


Anterior and Posterior Spinocerebellar Pathways



- Minor but important pathways. Sensory information carried by those pathways **do not** reach the cerebral cortex, rather the cerebellum. This is essential because the cerebellum is responsible for coordination of movement, posture, and balance. It uses this information to fine-tune motor activity. These pathways primarily carry unconscious proprioceptive information.

References



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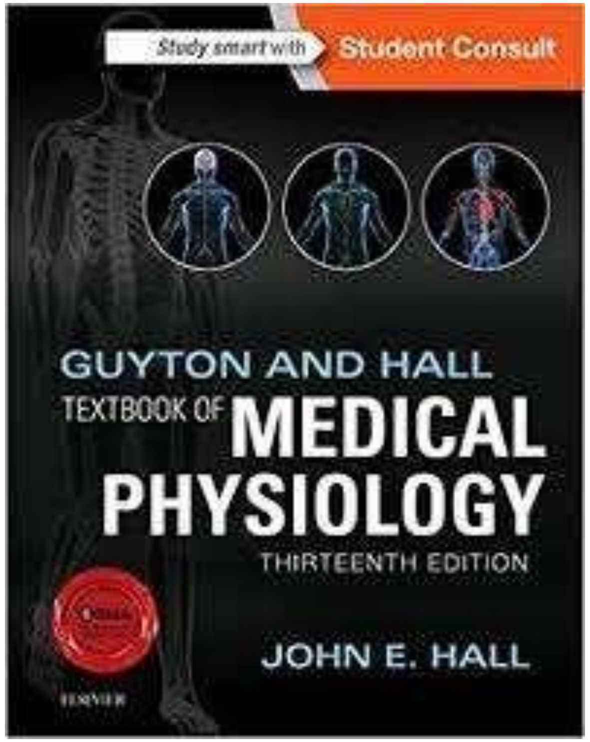

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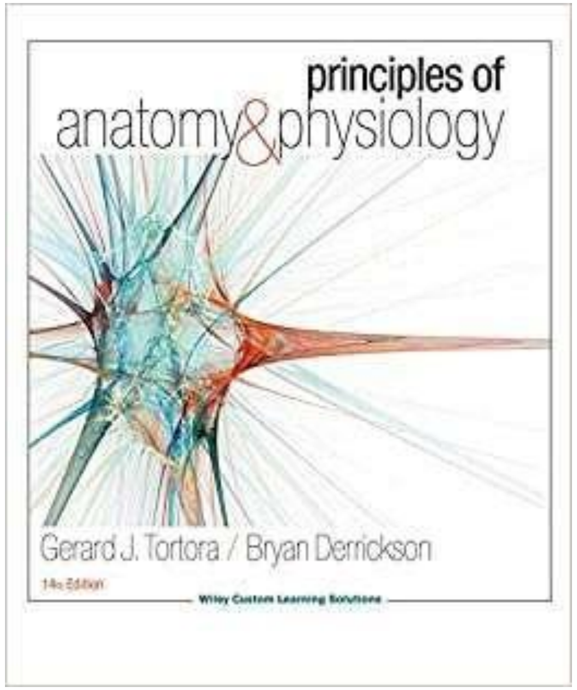

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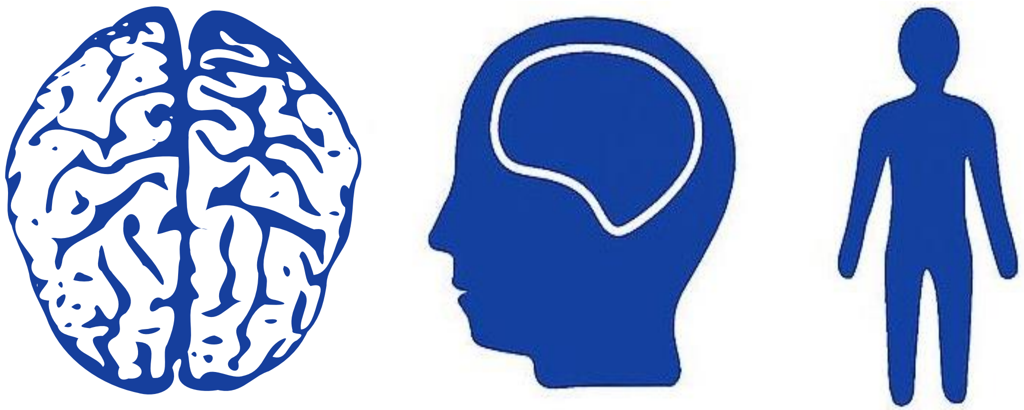

PHYSIOLOGY QUIZ
LECTURE 2

External Resources

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أنت أهل الوفاء والحق، فاغفر له وارحمه إنك أنت الغفور الرحيم.

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Corrections from previous versions:

Versions	Slide # and Place of Error	Before Correction	After Correction
V0 → V1	22 45	“ A**δ** nerve fibers are the largest,…., **“**Type c is the smallest in size, …. That carry signals for **cold** thermoreceptors**”** Added more details regarding the trigeminothalamic pathway	Corrected to A**α** nerve fibers Corrected to **warmth** thermoreceptors
V1 → V2			