Behavioral Neuroscience A
10: Touch/Pain

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https://youtu.be/C0UMzQ1TCE0

Lecture Video at above link.

Touch and Pain

Mechanoreceptors in skin: convert mechanical sensors into nerve excitation, perceived as touch (sometimes pain)

Nociceptors: convert chemical signals or physical signals into nerve excitation, perceived as pain.

How are these signals transmitted and processed by the brain?

Today's Topics

Touch and pain

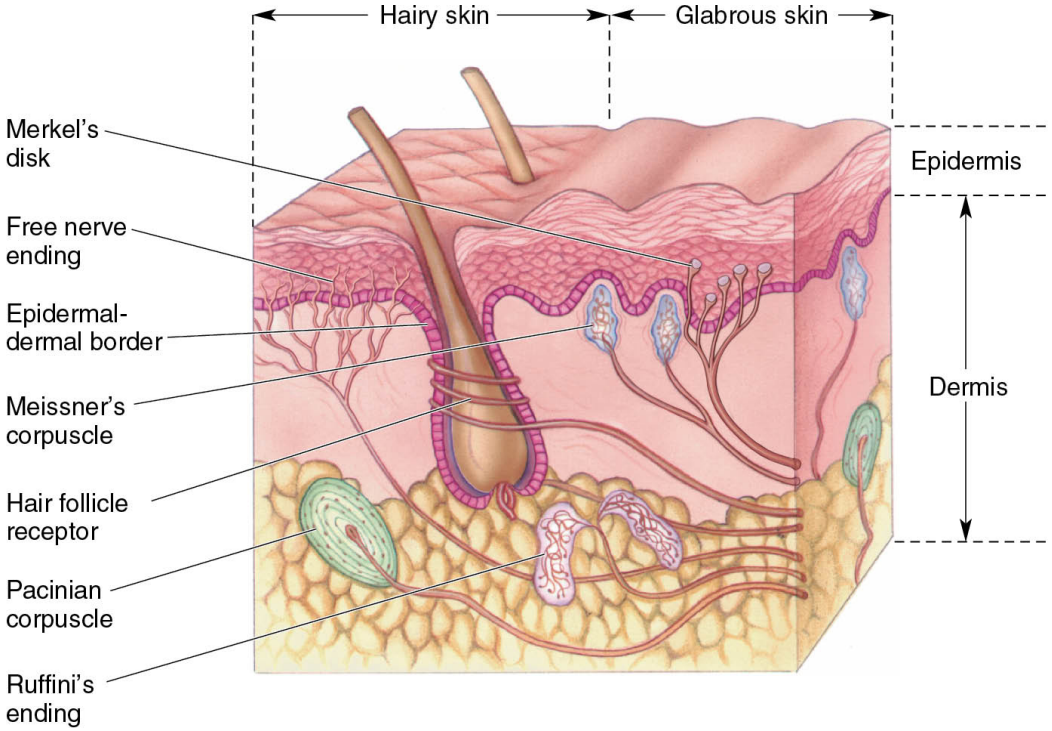
1) Mechanoreceptors and pain receptors in the skin

2) Dorsal column-medial lemniscal pathway (touch)

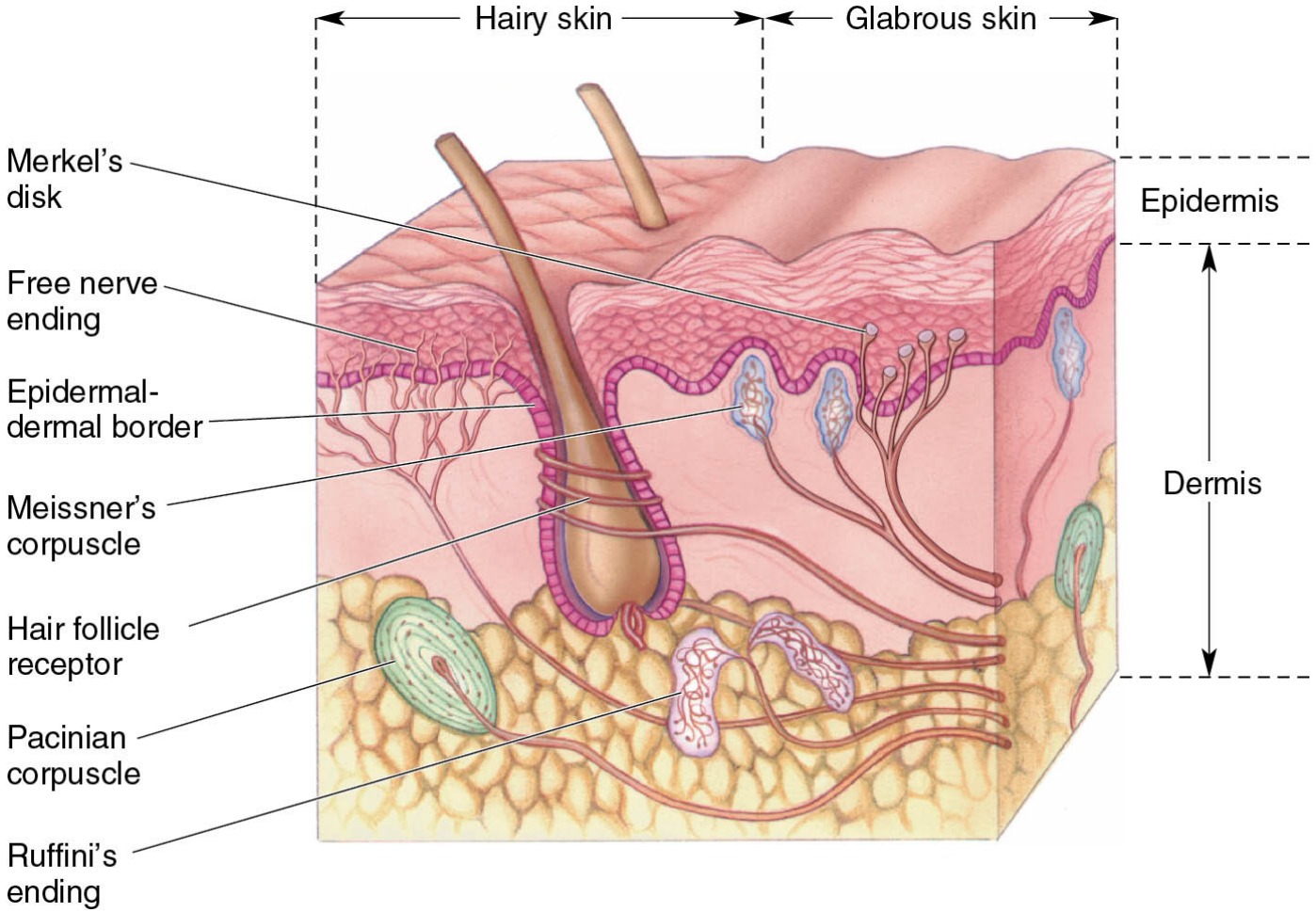
3) Somatosensory cortex

4) Nociceptive (pain-sensitive) pathway

5) Rubber hand illusion

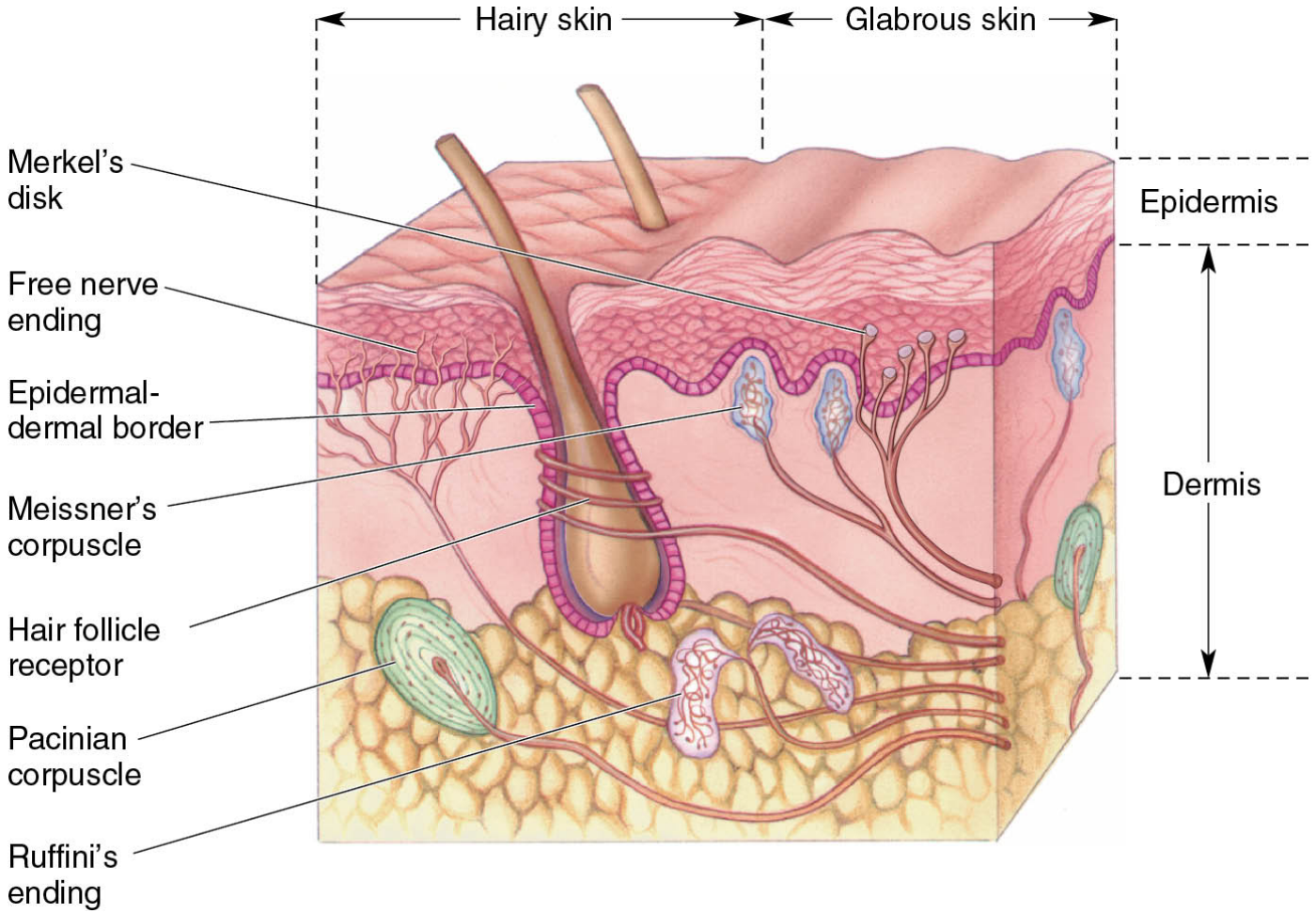


Mechanoreception



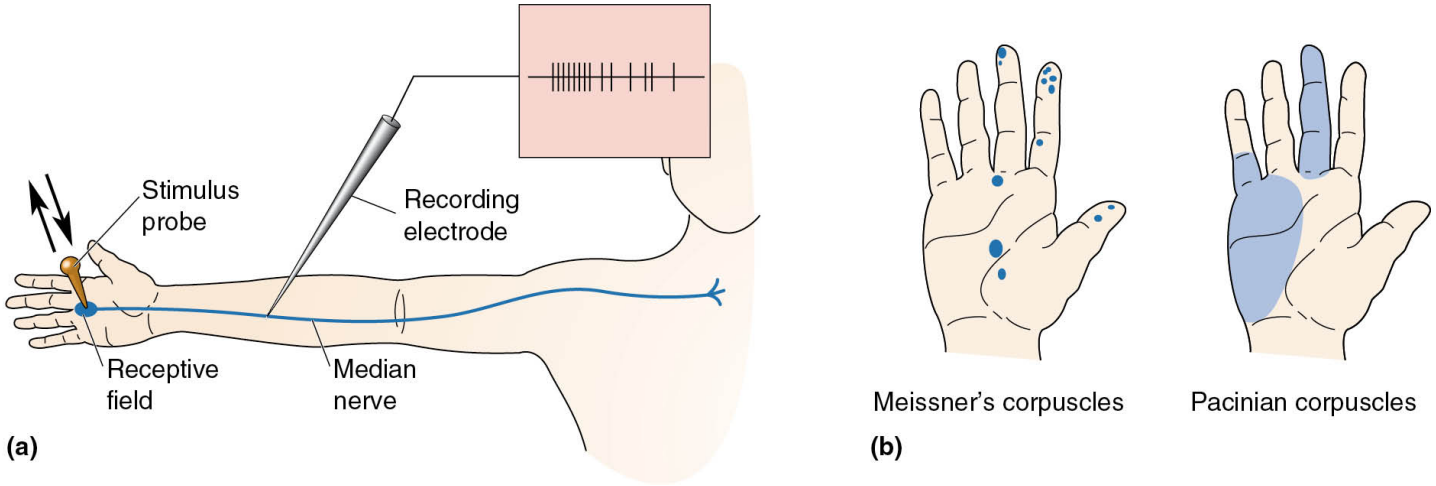
Various mechanoreceptors are responsible for the perception of touch, in particular Merkel's disks, Meissner's corpuscles, Pacinian corpuscles, and Ruffini's endings.

Nociception



Free nerve endings in skin and internal organs respond to tissue damage, chemicals, and cold or hot temperatures, resulting in pain.

Receptive Field Sizes

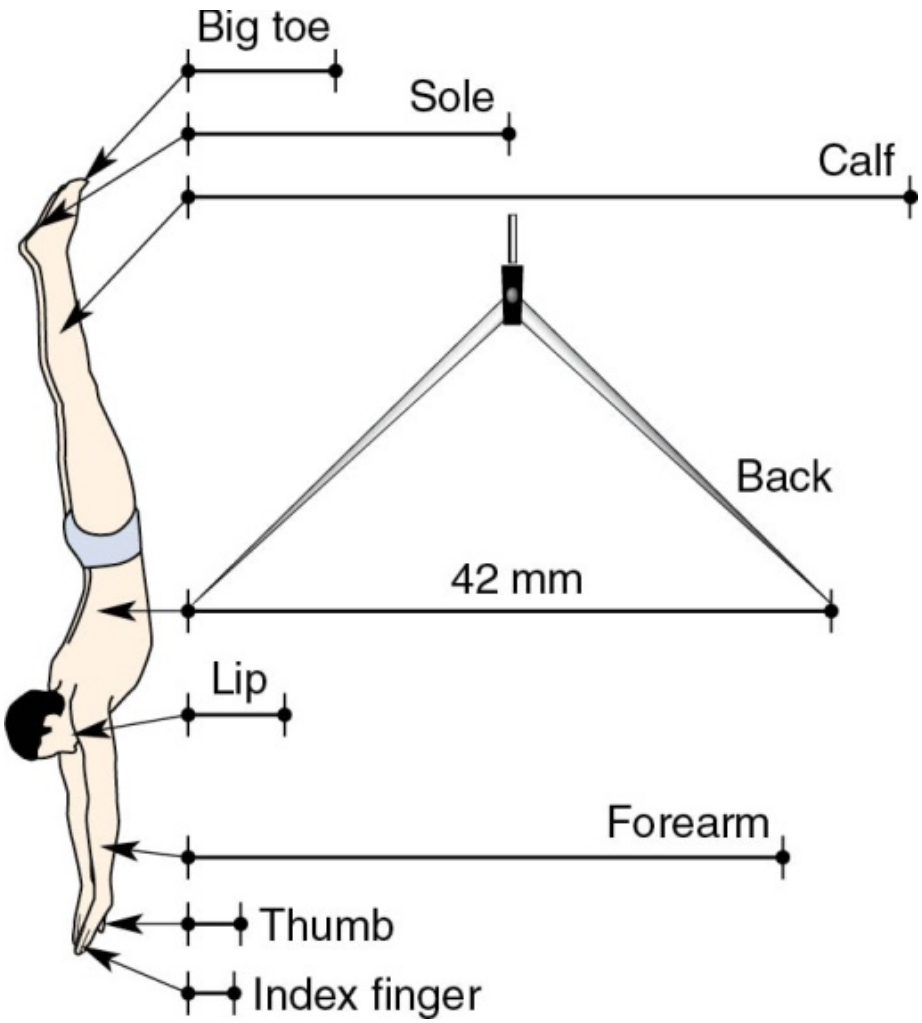


The size of receptive fields of sensory receptors depends on the type: Meissner's corpuscles have very small receptive fields, Pacinian corpuscles large receptive fields (b).

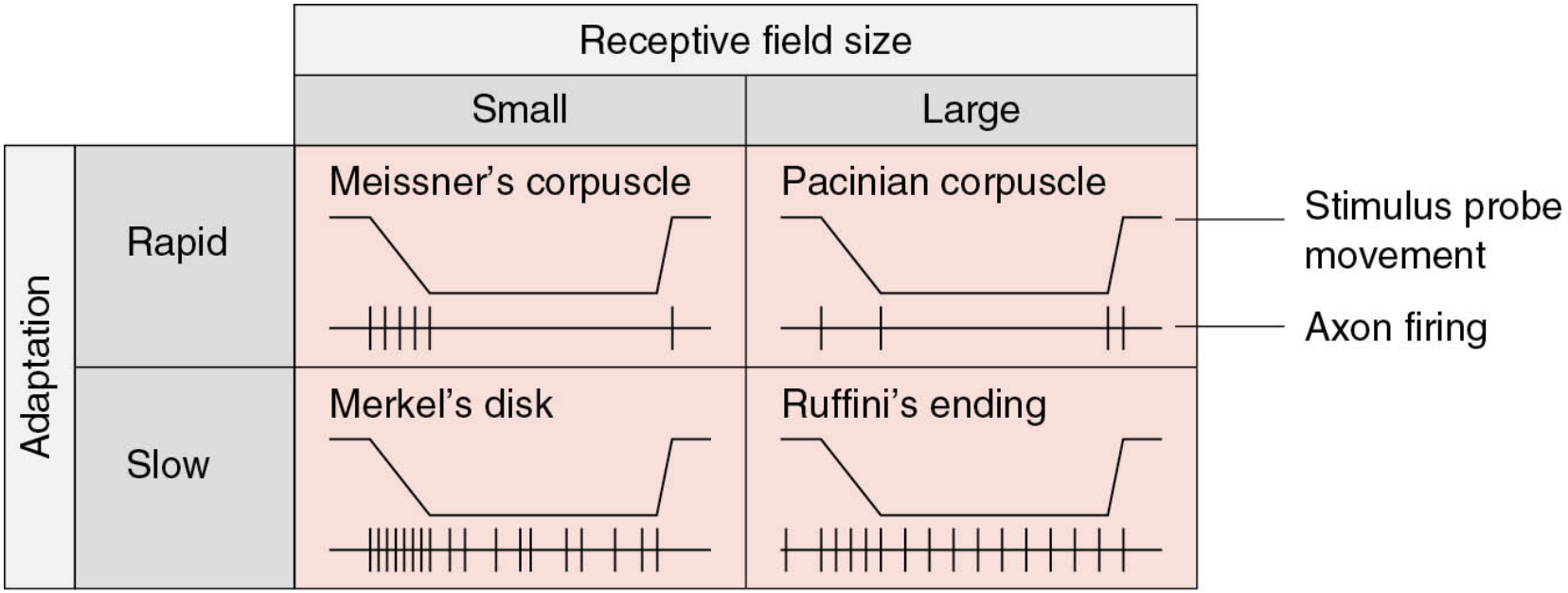
Two-point discrimination

The size of receptive fields of sensory receptors also depends on the innervated area: while our fingers have very small receptive fields, back and calf have large receptive fields.

This indicates the importance of some areas with small receptive fields (e.g., hand) for touch. The size of receptive fields can be tested with two-point discrimination test (the picture shows the minimum distance to discriminate two points).



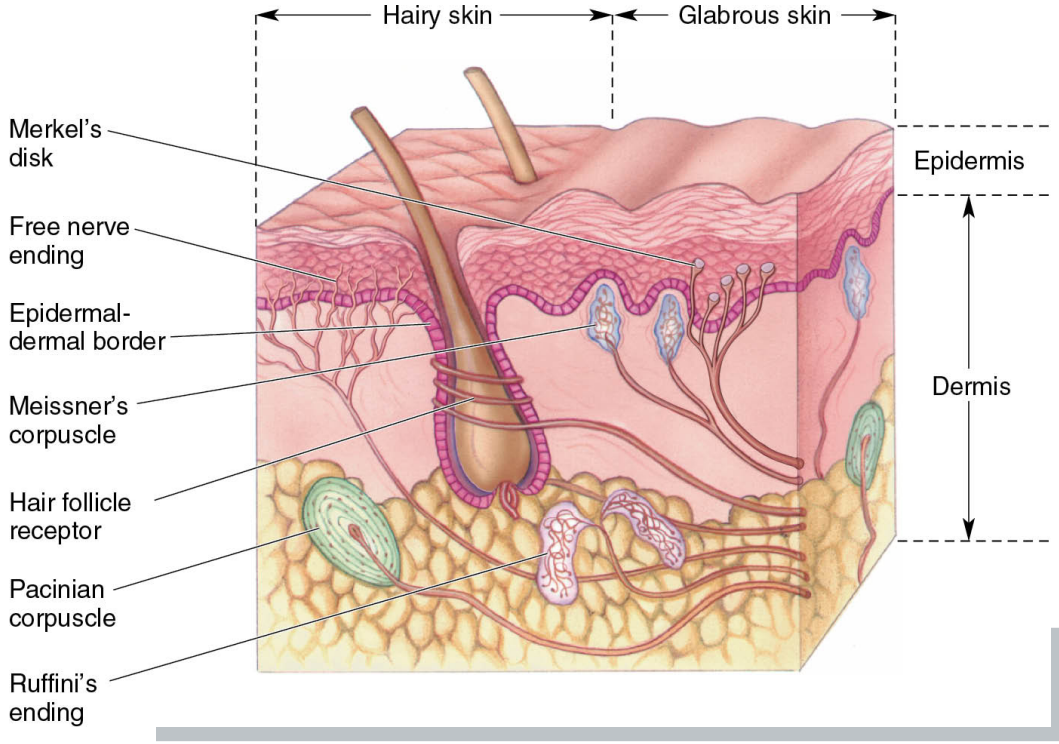
Response types of mechanoreceptors

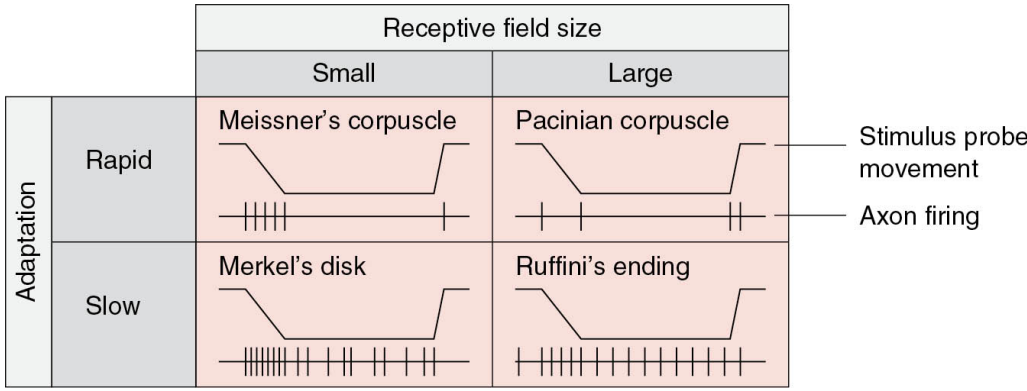


The mechanoreceptors can also be classified by their adaptation properties: Meissner's and Pacinian corpuscles quickly reduce their response to a constant stimulus, while Merkel's disks and Ruffini's endings keep a sustained response.

Mechanoreceptor Types

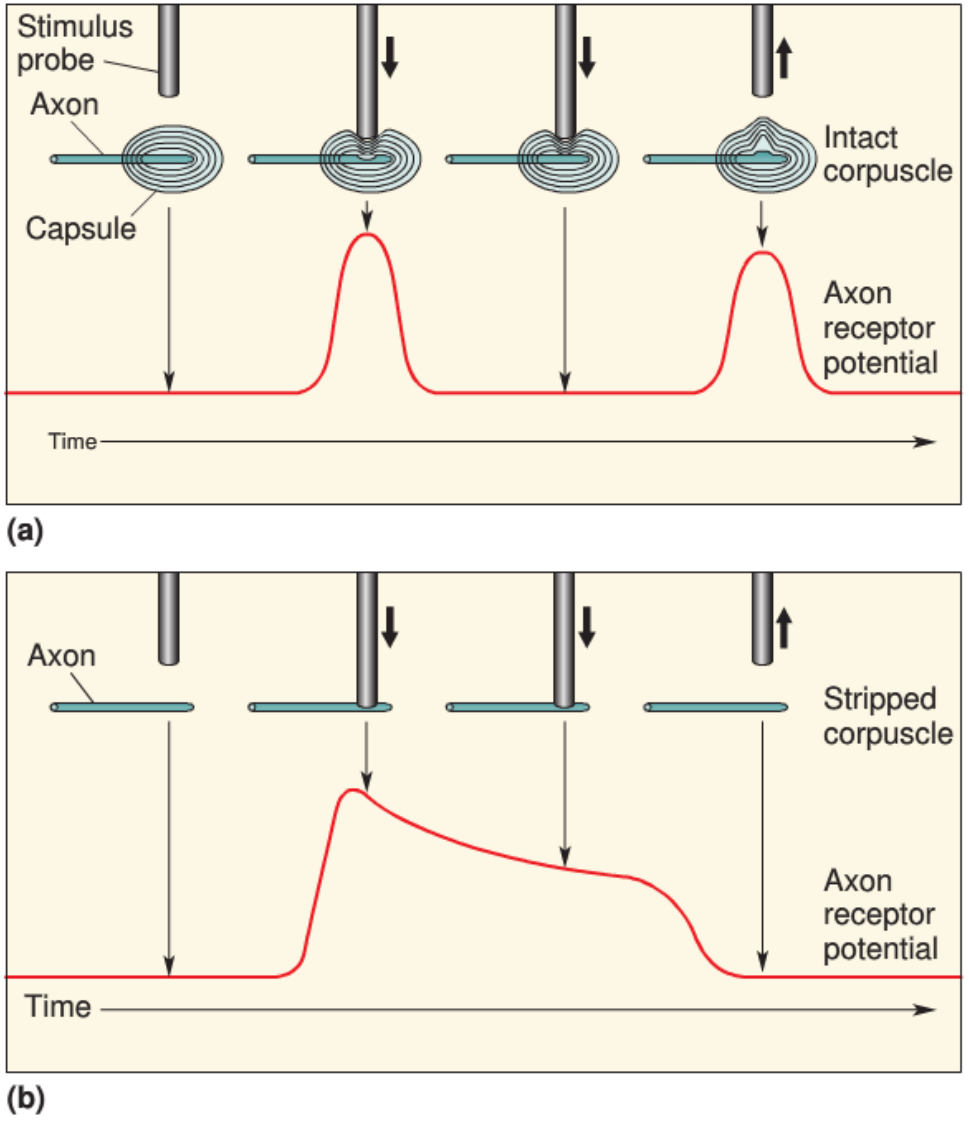
Sensors innervated by slowly adapting fibers are sensitive to constant pressure on skin. Merkel's disks are sensitive to object form and edges and are important for Braille reading. Ruffini endings are sensitive to skin stretch and are active when large objects are grasped and they signal position/movement of hand and fingers.
Sensors innervated by rapidly adapting fibers are sensitive to motion and vibration. Meissner's corpuscles are active when we first touch an object or when we move our hand over a surface and feel the texture. Pacinian corpuscles are very sensitive to vibration.





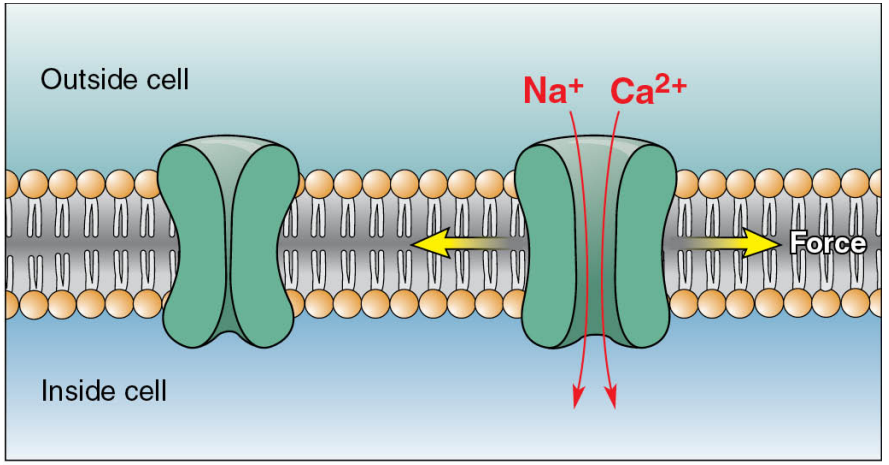
How do they work?

The adaptive properties of mechanoreceptors depend on their structure: in this case, a Pacinian corpuscle shows adaptation to indenture (a) because of the presence of the onion-like encapsulation. Removing the encapsulation (b) results in unadapted neural responses.



How do they work?

The conversion of mechanical energy happens through ion channels that are sensitive to stretching or bending and that allow for flow of Na^+ or Ca^{2+} into the cell, depolarization, initiation of an action potential, and neurotransmitter release.



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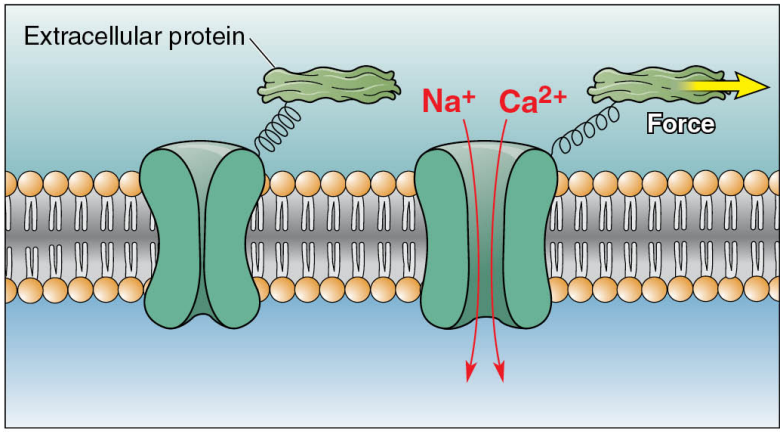
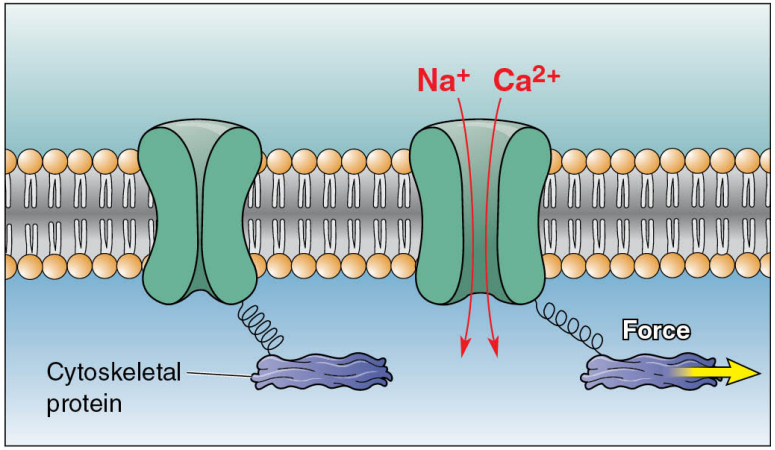




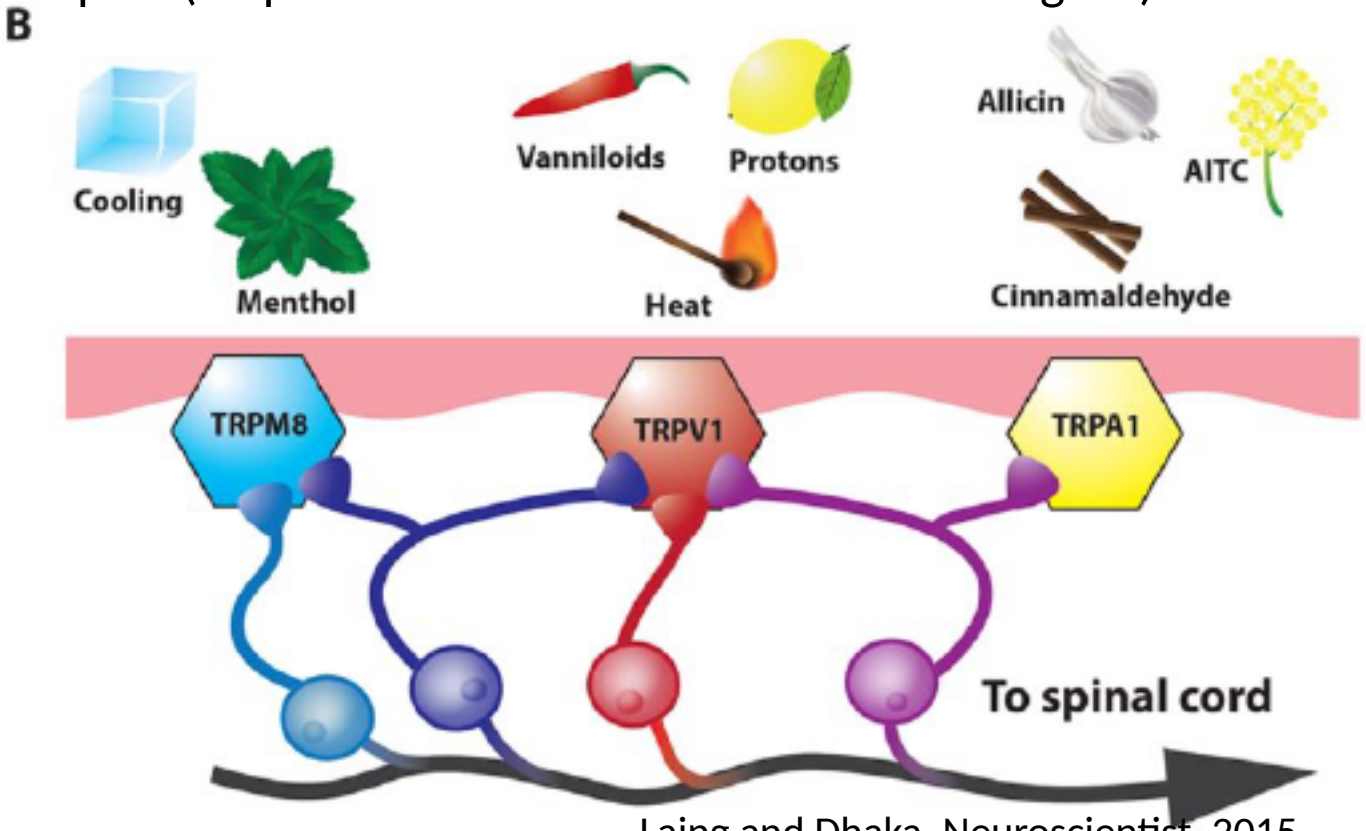
Some channels are sensitive to force applied to the membrane (top), or to a protein outside (bottom, left) or inside a cell (bottom, right).

Nociceptors

Nociceptors located in skin, visceral organs, tendons, etc. can be grouped into four classes:

- Thermal (responds to temperatures >45˚C or <5˚C)
- Mechanical (responds to intense mechanical stimulation)
- Polymodal (responds to thermal, mechanical or chemical stimulation)
- Silent nociceptor (responds to inflammation in visceral organs)

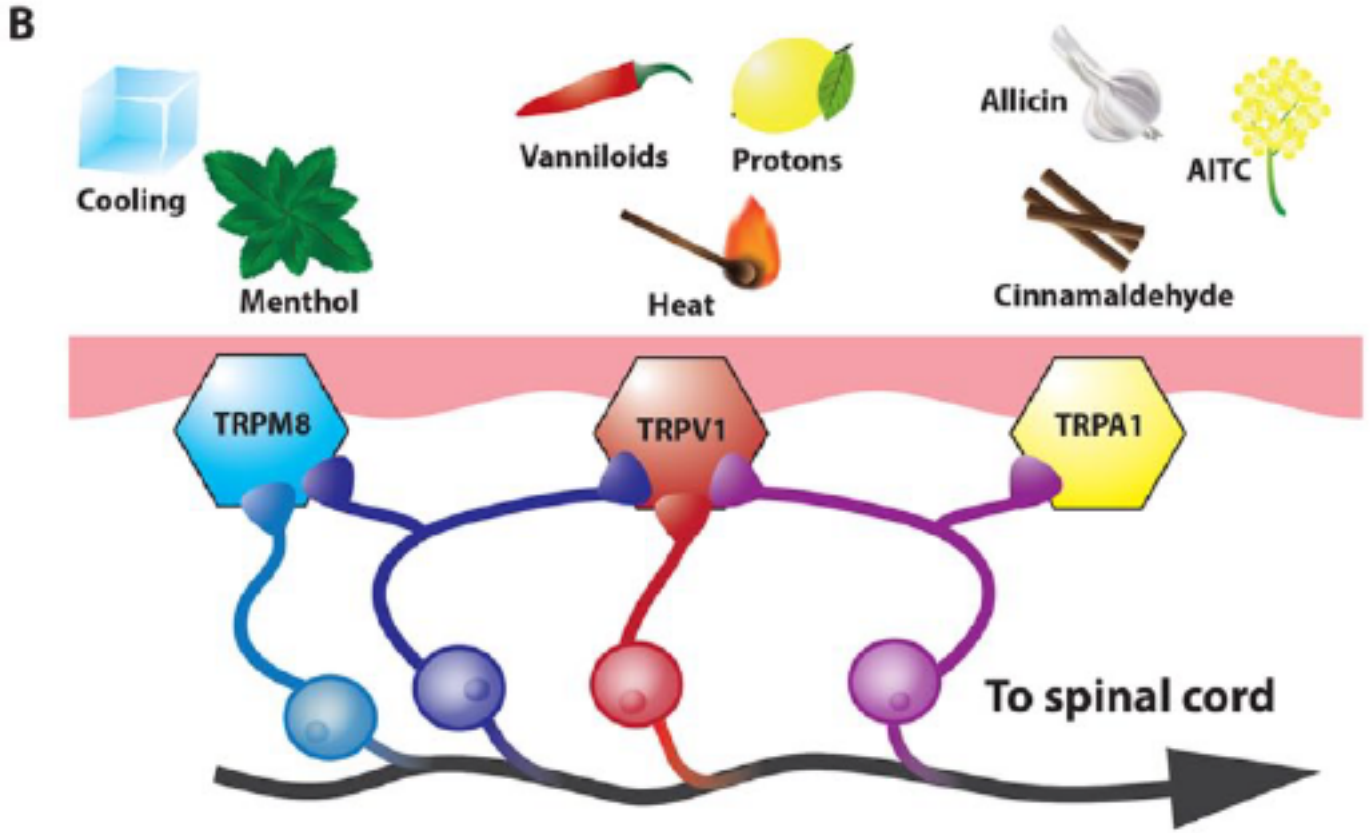
Activation of these channels leads to inflow of Na^{+} or Ca^{2+} ions, depolarization, and neurotransmitter release.



Laing and Dhaka, Neuroscientist, 2015

Nociceptors

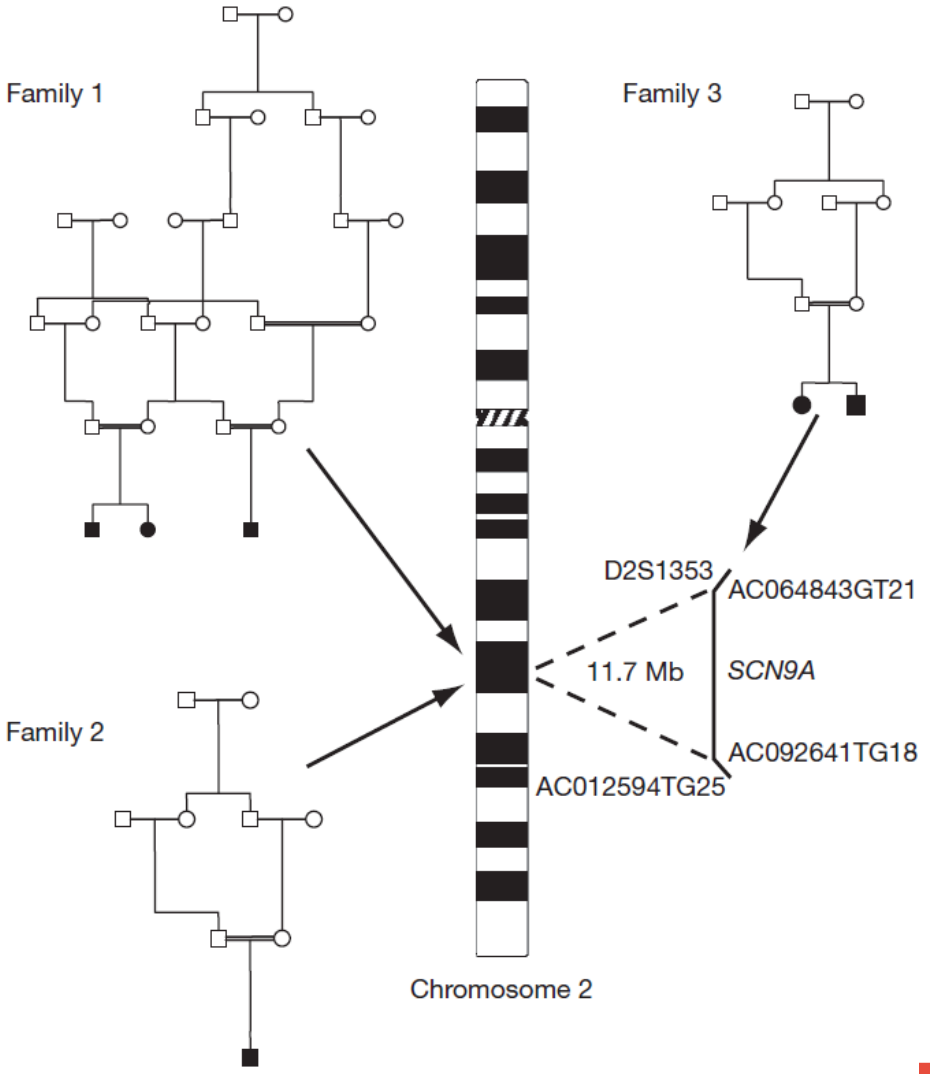
Pain-sensitive membrane channels are situated in free nerve endings in the skin or internal organs. Several different membrane proteins are responsive to different types of stimulation. E.g., TRPM8 (transient receptor potential cation channel M8) responds to cool temperature (<26˚C) and menthol; the TRPV1 channel responds to heat (>43˚C), acid (protons), and capsaicin (a vanilloid found in chili plants). TRPA1 is activated amongst other substances by AITC (mustard/wasabi).



Laing and Dhaka, Neuroscientist, 2015

Congenital Insensitivity to Pain

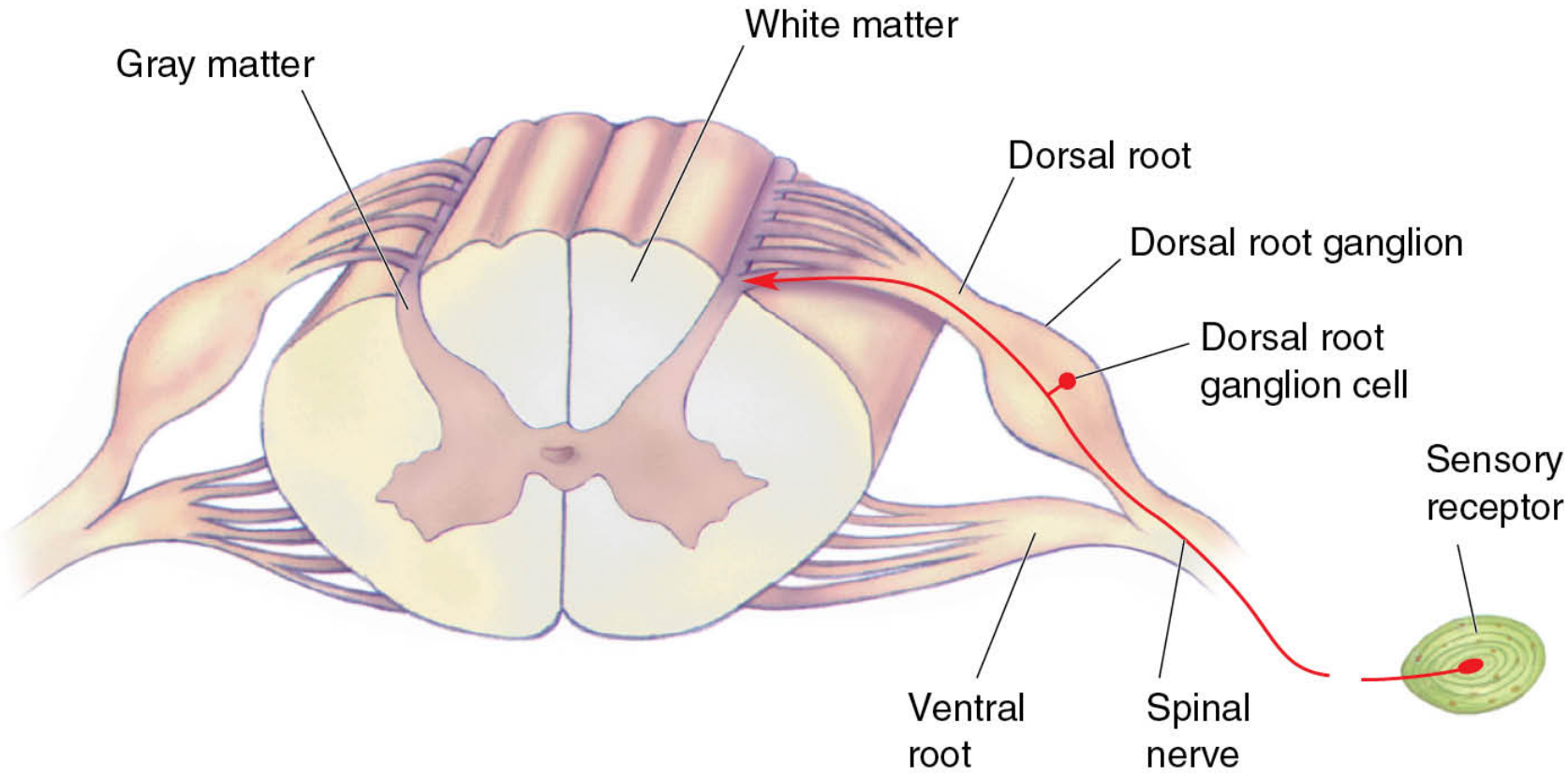
Some mutations can lead to an inability to perceive pain. For example, the gene SCN9A codes for a specific type of sodium channel expressed in nociceptive neurons. A gene mutation in some families in Pakistan led to a nonfunctional sodium channel in these nociceptive neurons.
The affected family members were insensitive to pain and experienced many cuts, bitten lips and tongues, bruises, etc.



Cox et al., Nature, 2006

Touch/Pain via the Spinal Cord

Somatosensory and nociceptive neurons have their cell bodies in the dorsal root ganglia (see cross section of spinal cord below). They enter the spinal cord through the dorsal root.



Primary Afferent Axons

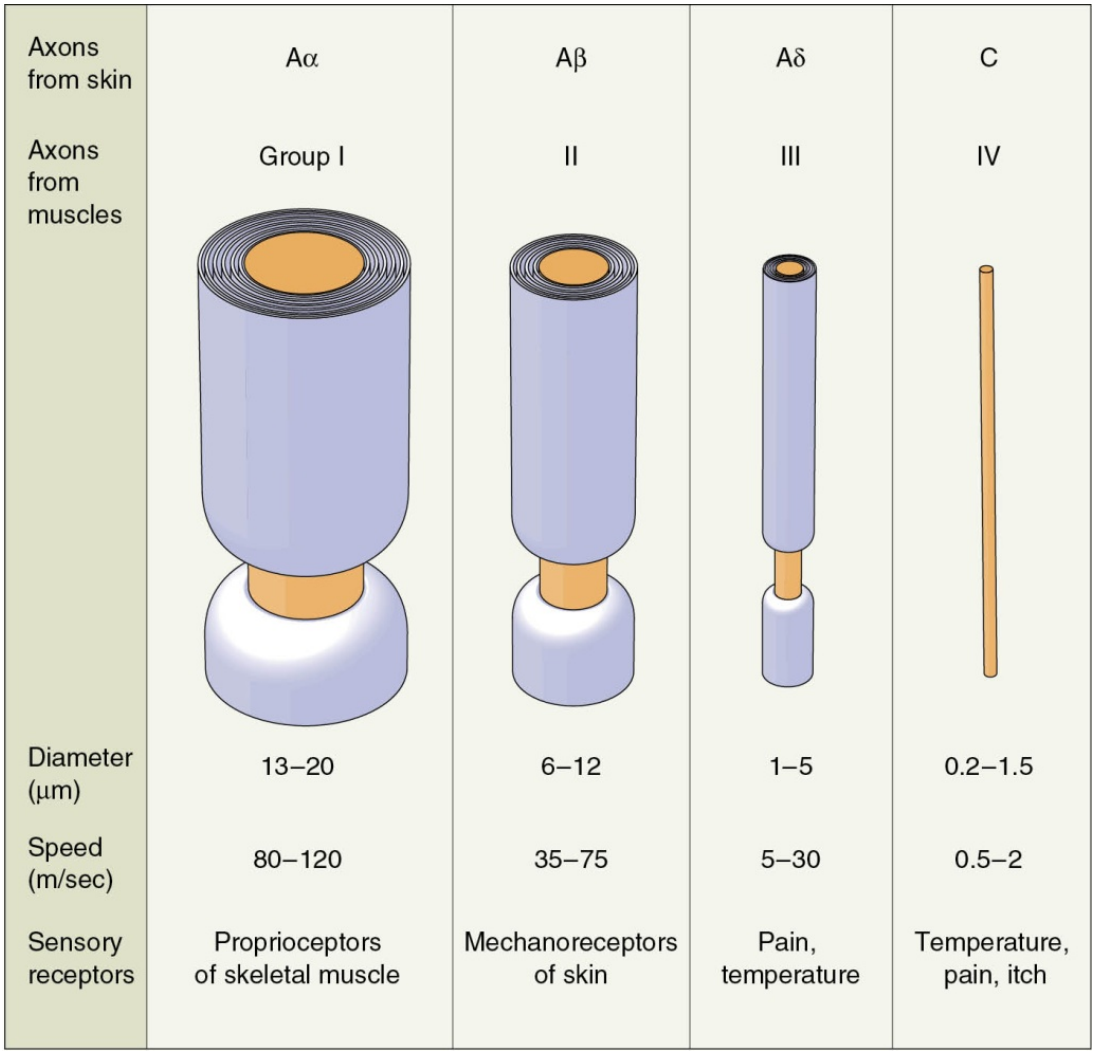
Speed of impulse conduction depends on the diameter of the nerve fiber and its coating with myelin (electrical insulation).

Input from proprioceptors (sensors that report position of limbs/body) is transmitted by the thickest and fastest axons (Aα).

Input from skin mechano-receptors is transmitted by Aβ axons.

The pain pathway uses two types of nerve fibers:

- fast Aδ fibers
- slower C fibers



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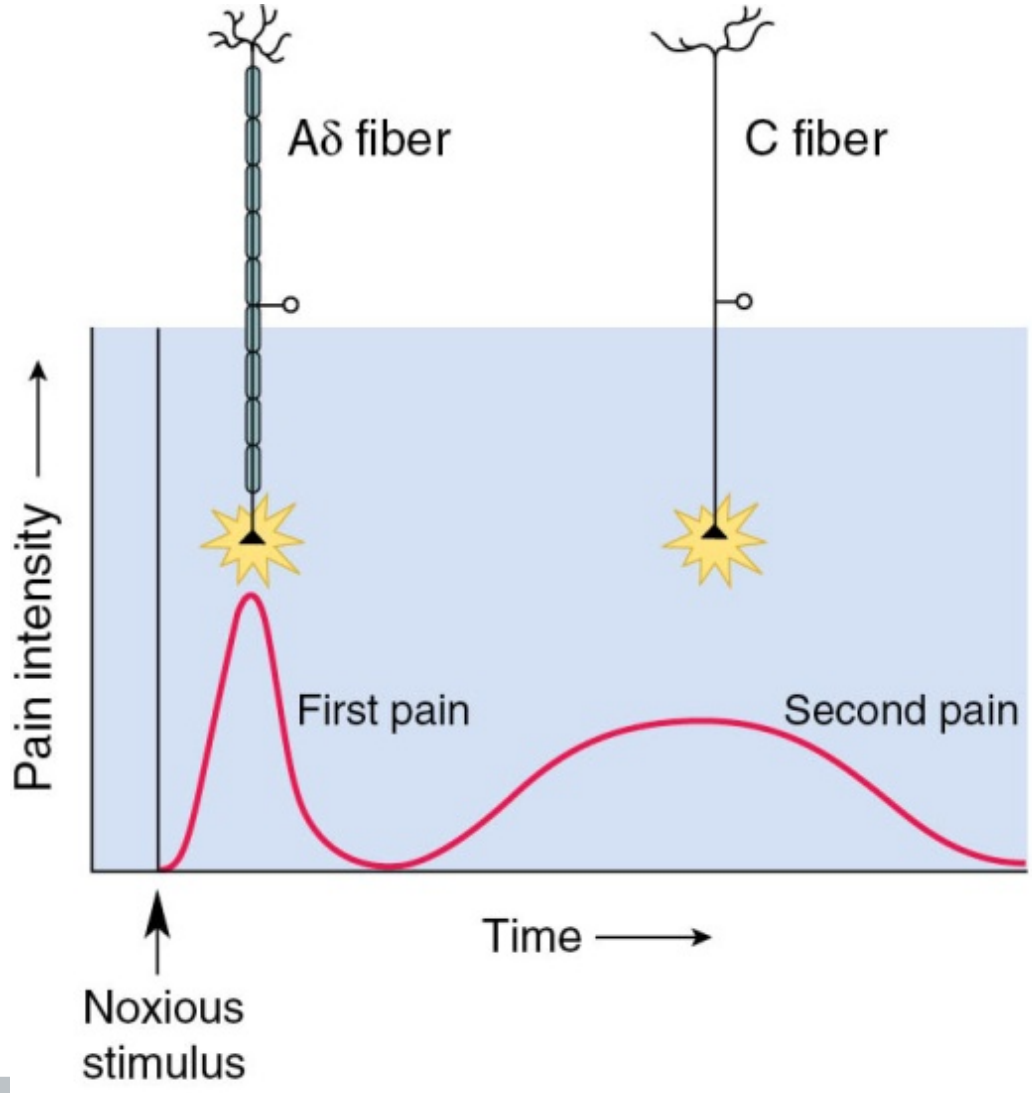
Nociceptive Axons

Differences in transmission speed of nociceptive axons lead to two pain stages:

1) A fast “first pain” phase mediated by Aδ fibers.

2) A slower, longer lasting “second pain” phase mediated by C fibers.



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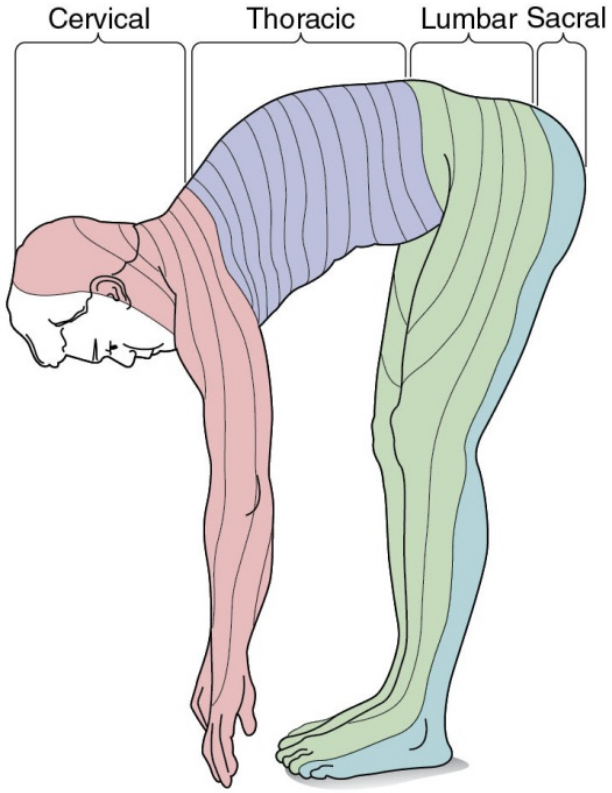
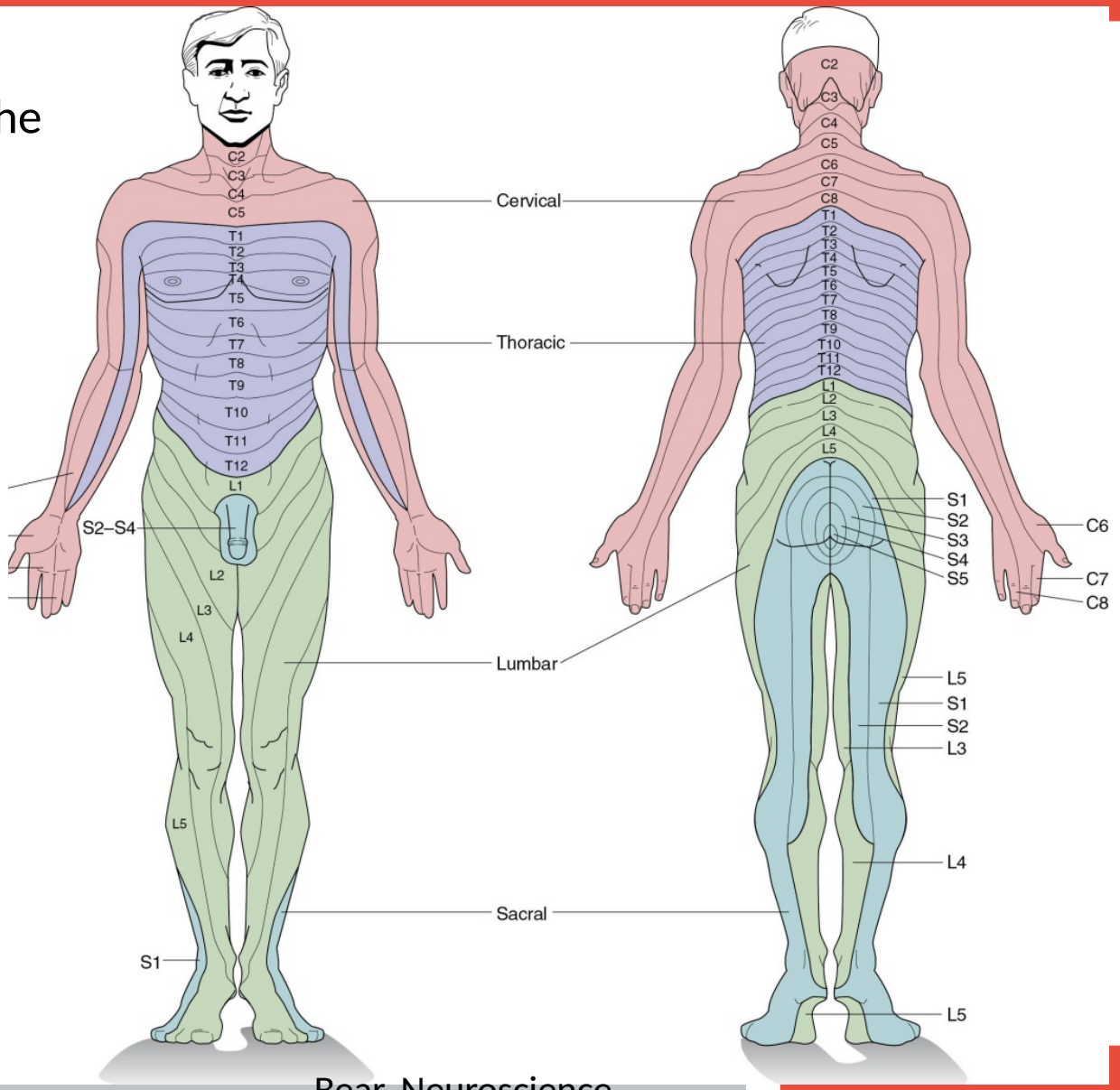
Dermatomes

Nerves sensitive to touch, temperature, and pain enter the spinal cord grouped along so-called dermatomes.





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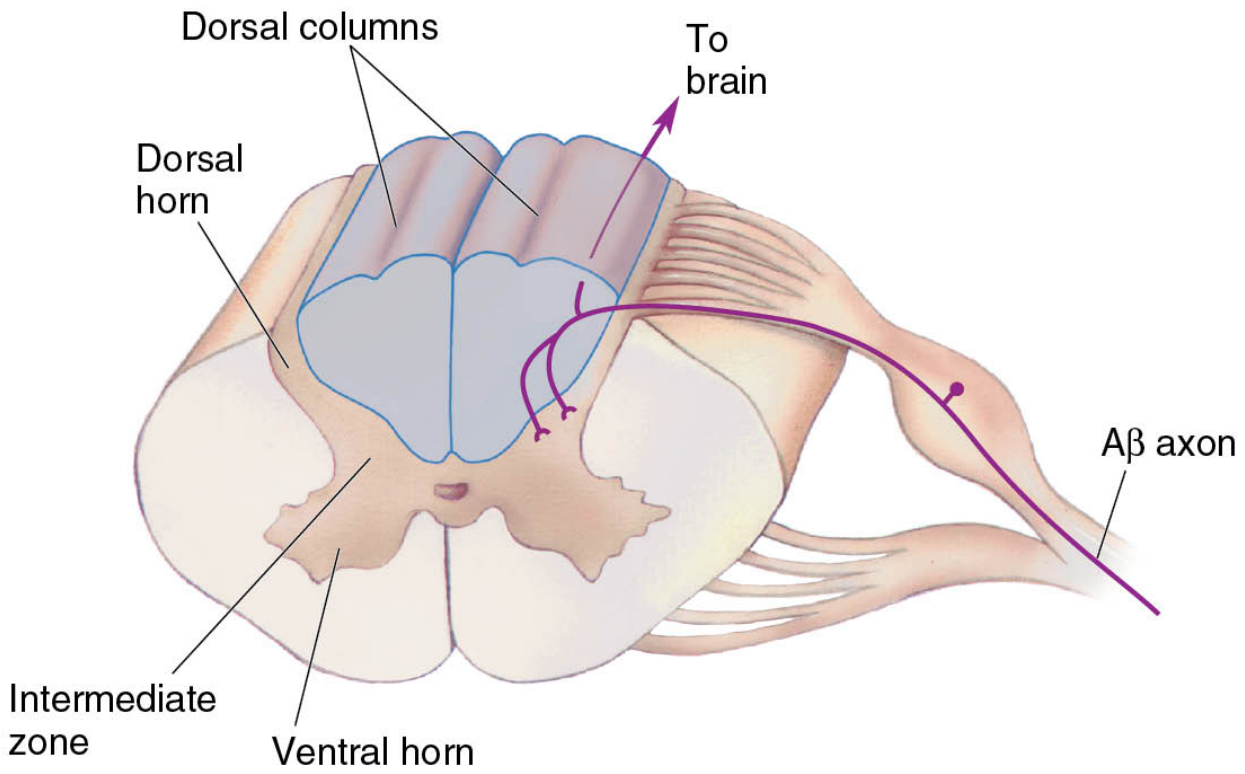
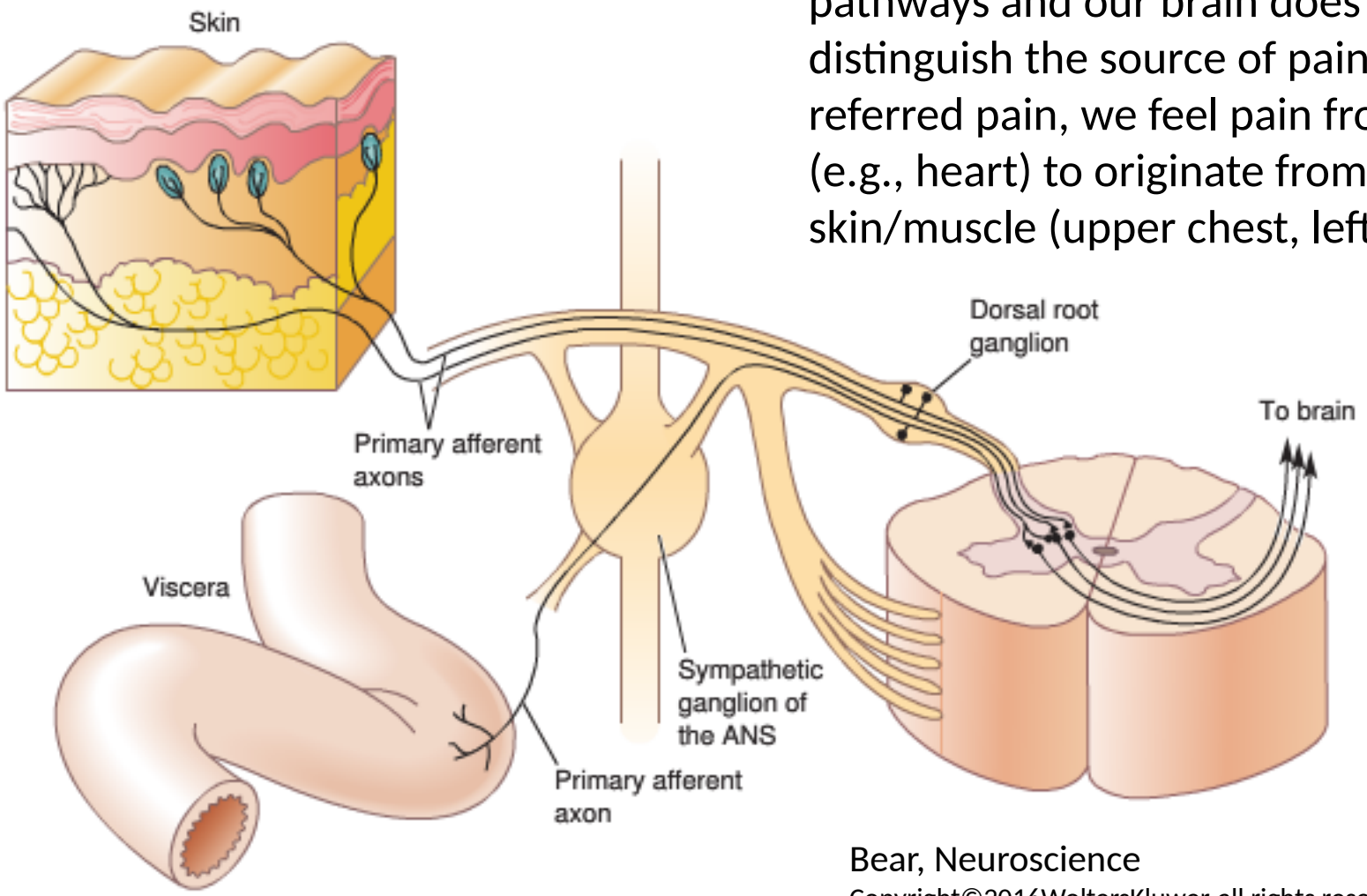
Somatic sensory pathway



Touch-sensitive neurons (with Aβ axons) have their cell bodies in the dorsal root ganglia. The ascending branch of these axons enter the spinal cord through the dorsal root and conduct information to the brain via the dorsal columns. The axons also branch to connect to spinal cord neurons (second-order sensory neurons).

Referred Pain

Nociceptive nerves from skin and viscera project to the spinal cord along common pathways and our brain does not distinguish the source of pain. During referred pain, we feel pain from viscera (e.g., heart) to originate from the skin/muscle (upper chest, left arm).



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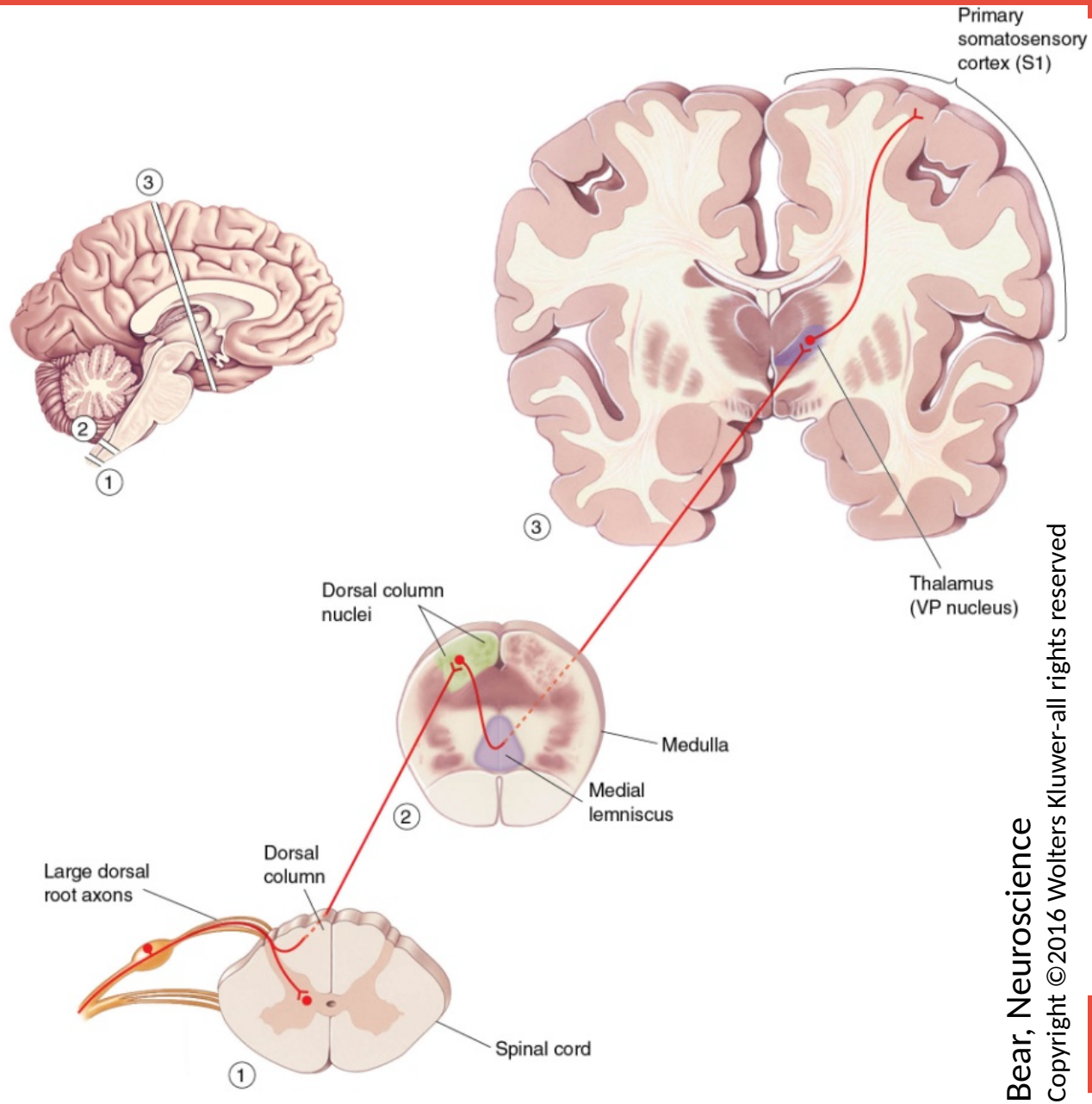
Dorsal Column: Medial Lemniscal Pathway

Pathway for touch, vibration, proprioception.

The axons of the dorsal column end in the dorsal column nuclei (junction of spinal cord and medulla).

They then decussate (cross sides from ipsilateral to contralateral) and ascend via the medial lemniscus to the thalamus (Ventral posterior = VP nucleus) and somatosensory cortex (SI).



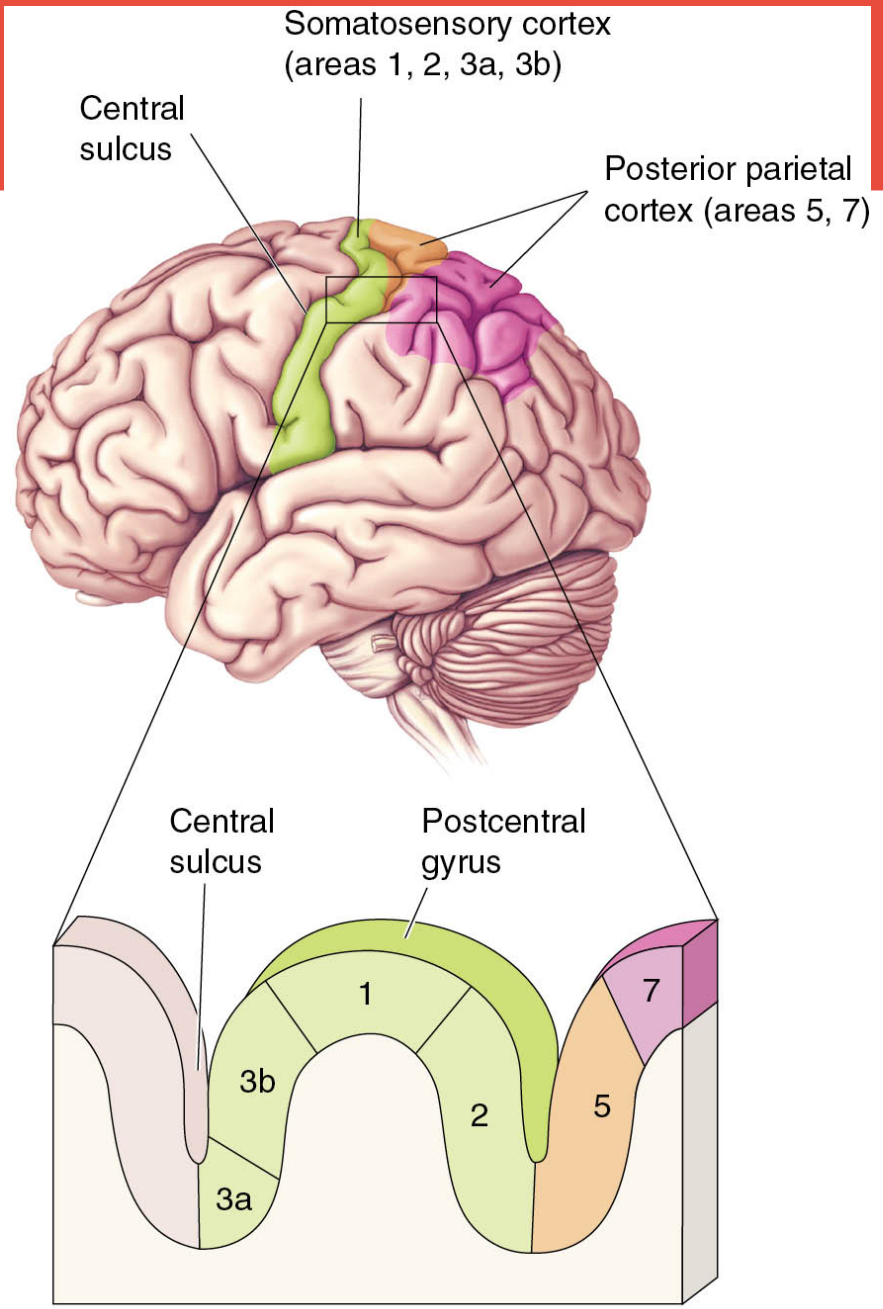
Somatosensory Cortex

Area 3b is primary somatosensory cortex, receiving dense input from thalamus.

Area 3a also receives dense input from thalamus, but is more involved proprioception rather than touch.

Areas 1 and 2 are higher-order somatosensory areas, with area 1 more involved in texture processing, 2 more in size, shape, and proprioception.

(sometimes areas 3b, 3a, 1, and 2 together are called S1 or SI: primary somatosensory cortex)



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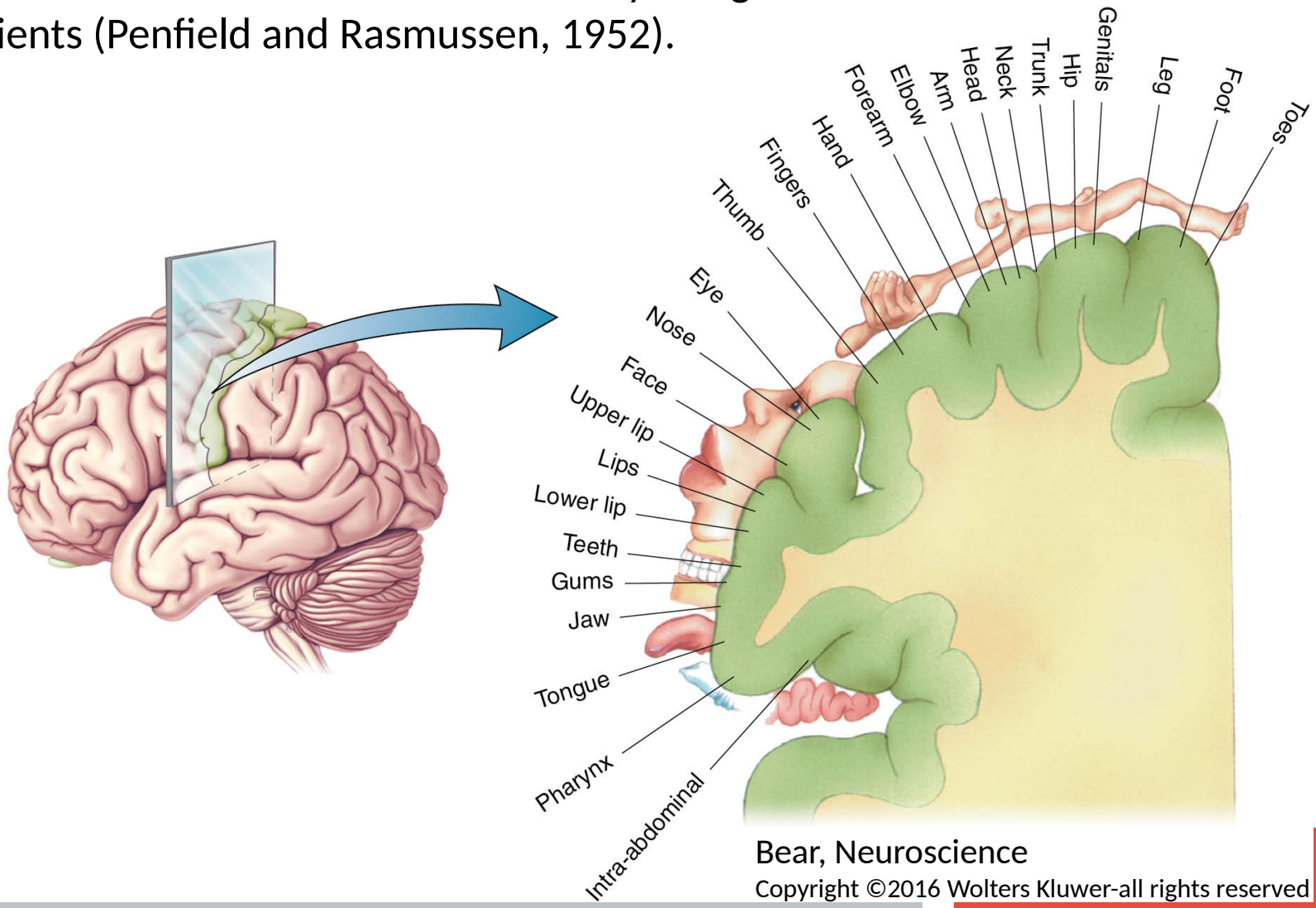
The homunculus (somatotopy in S1)

Somatosensory cortex has a topographical representation of the body – somatotopy. This so-called homunculus has been first described by using electrical stimulation on neurosurgical patients (Penfield and Rasmussen, 1952).



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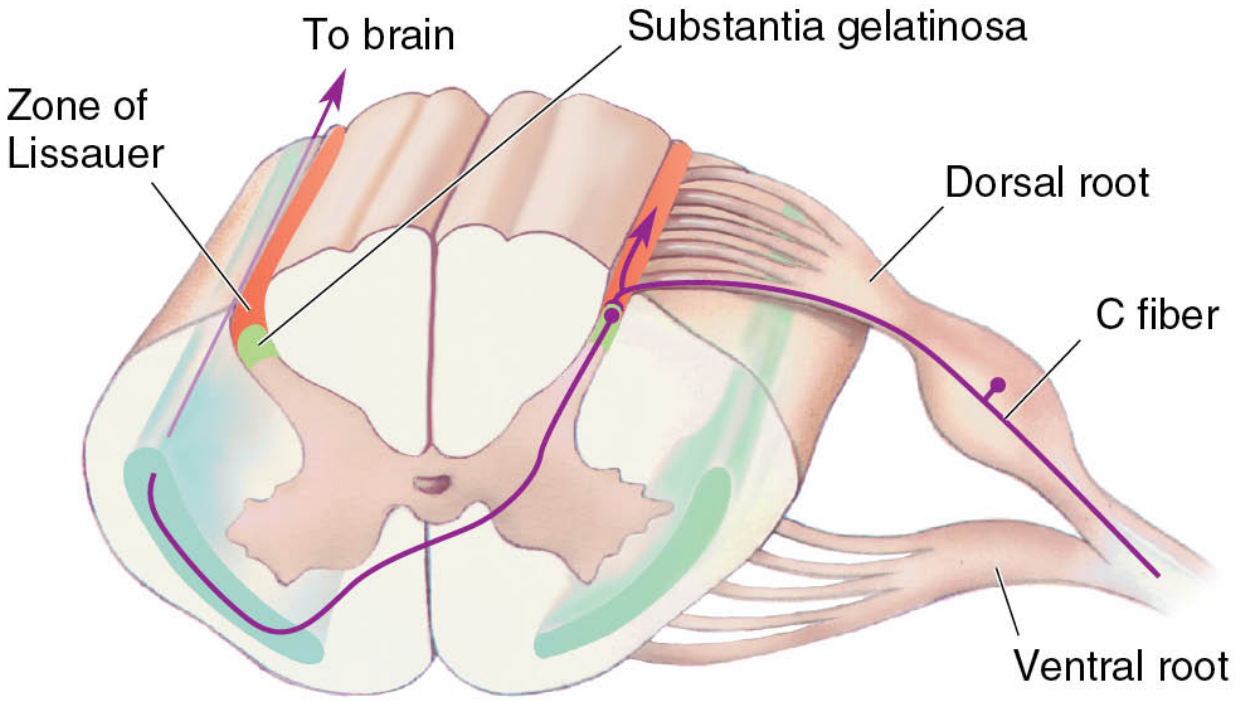
Nociceptive Pathway

Nociceptors also have their cell bodies in the dorsal root ganglia. They enter the spinal cord through the dorsal root and connect to neurons within the substantia gelatinosa of the dorsal horn. Axons from there cross to the contralateral side and ascend along the spinothalamic pathway.



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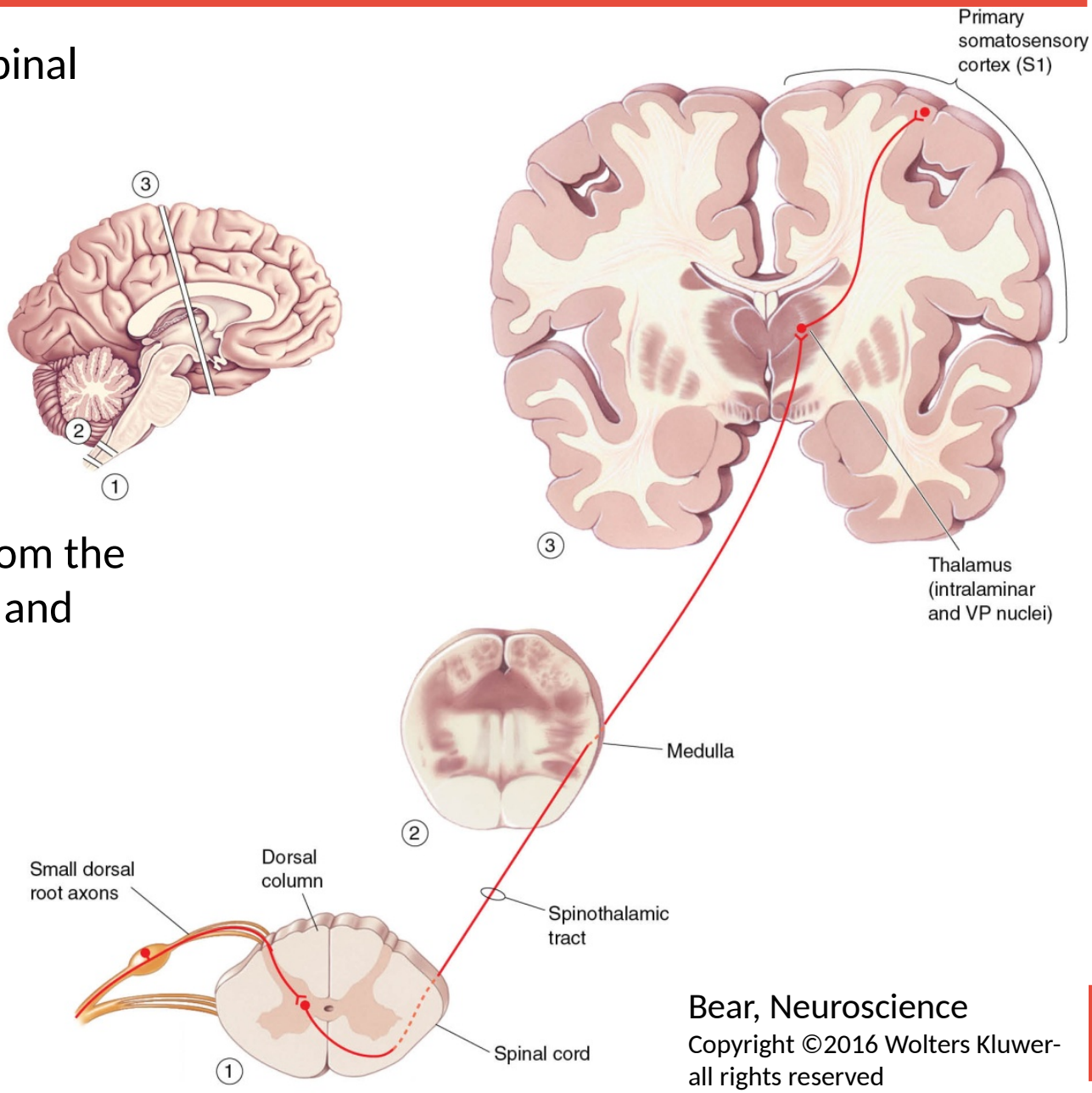
Spinothalamic pathway

Nociceptors synapse with spinal cord neurons (1).

The nerve fibers cross the body midline at the level of the spinal cord segment.

The spinothalamic tract consists of fibers (2) from the spinal cord to thalamus (VP and intralaminar nuclei).

Neurons from thalamus project to somatosensory cortex (3), insular and cingulate cortex.



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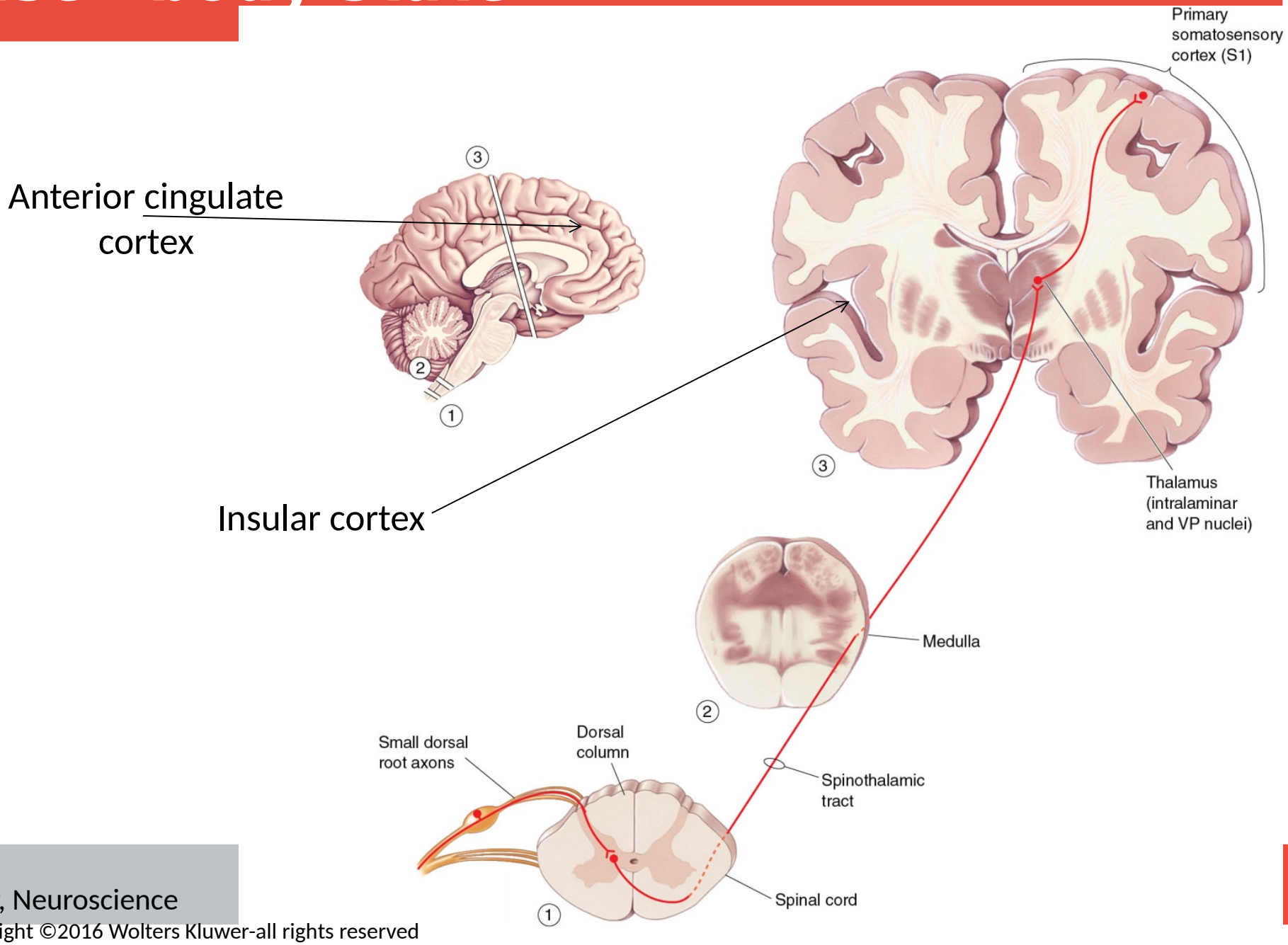
Insular and cingulate cortex: sense “body state”



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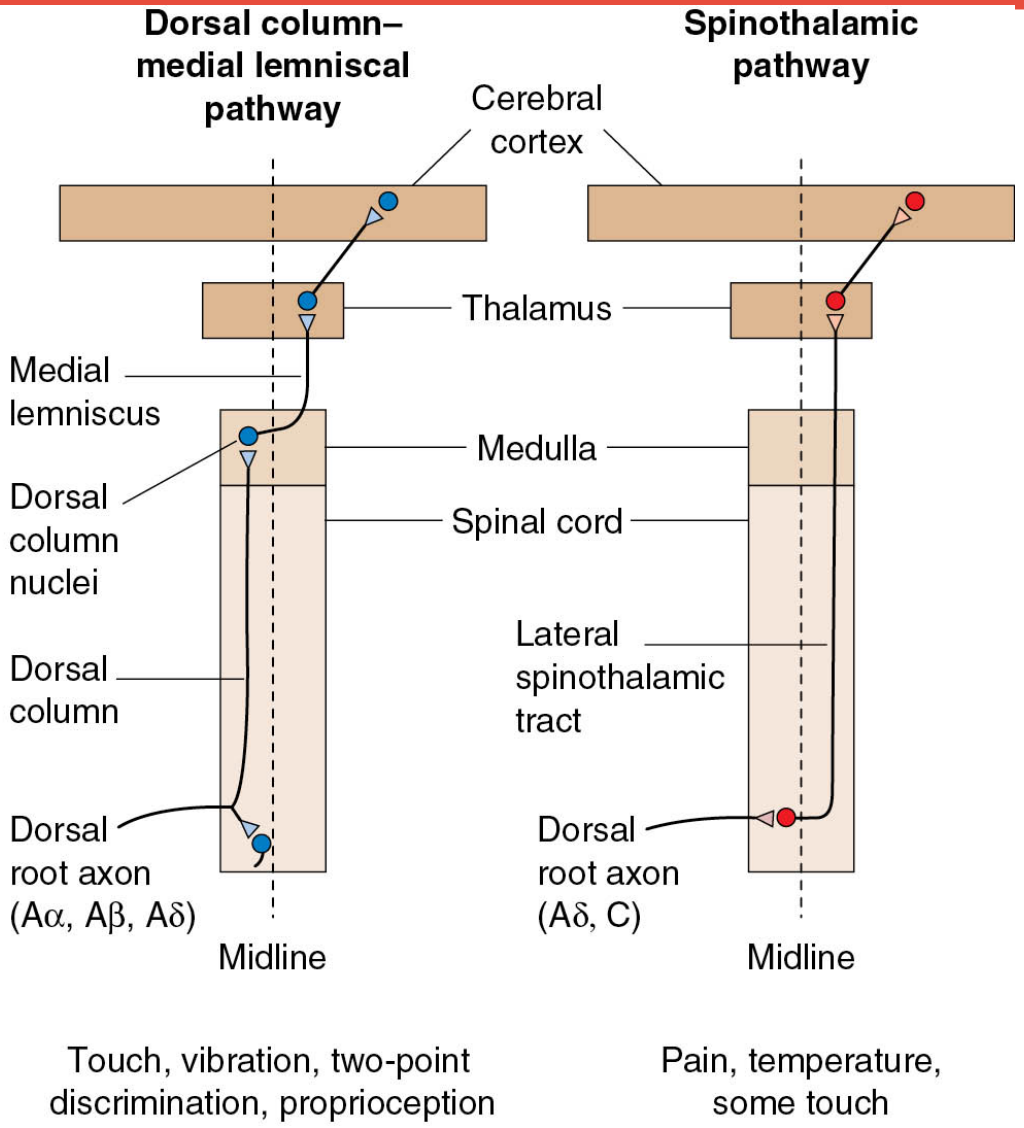
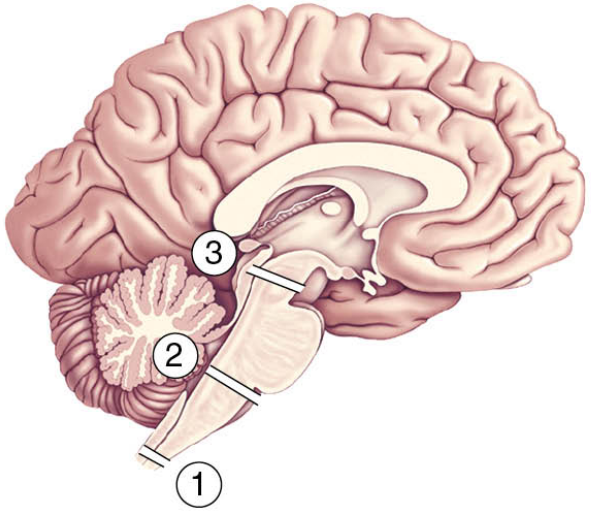
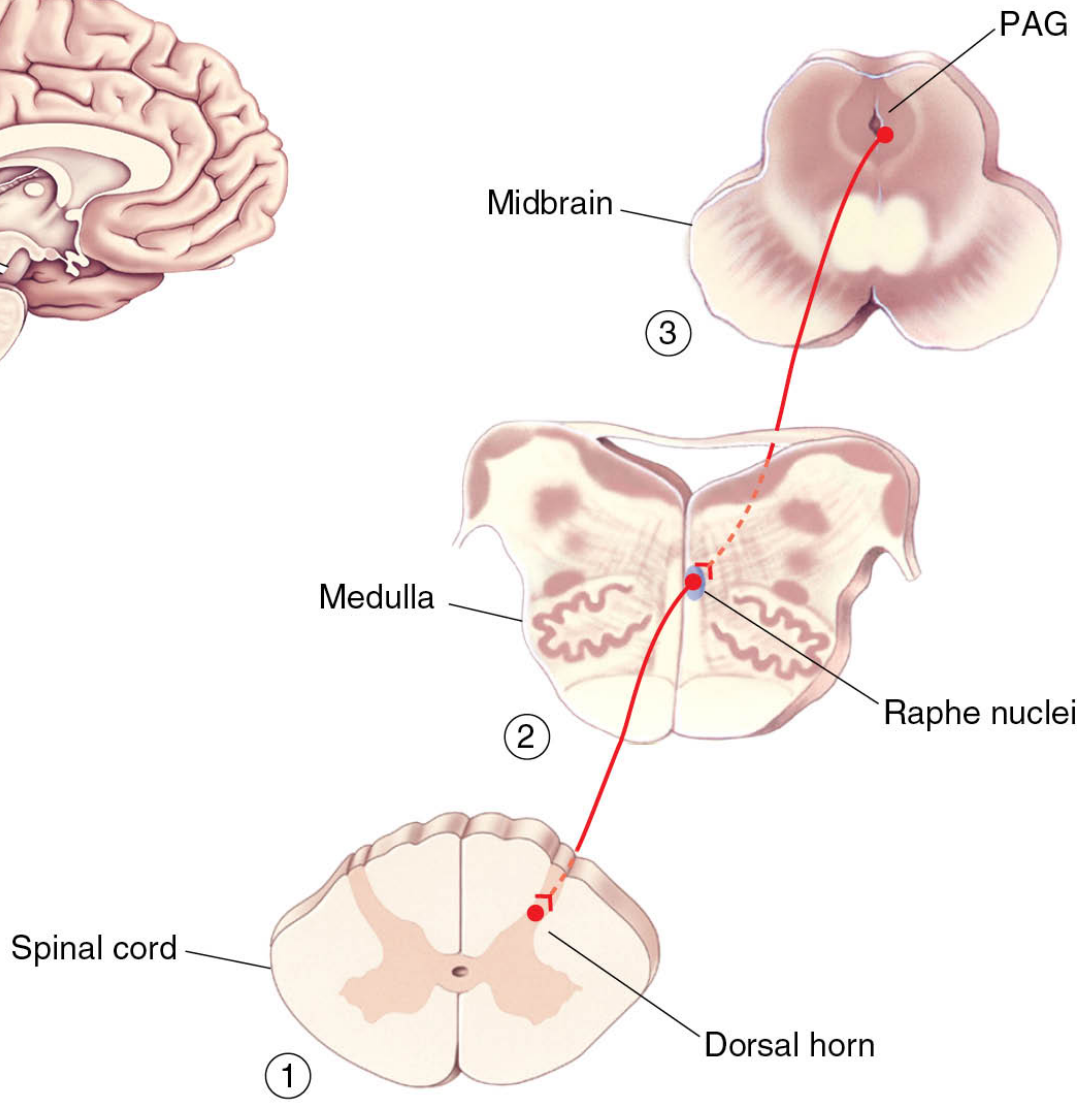
The two pathways for touch/pain

The touch-sensitive pathway (dorsal column-medial lemniscal pathway) crosses the midline at the level of the medulla, the spinothalamic pathway at the level of the spinal cord segment.



Pain suppression: Top-down control of pain





In highly emotional or stressful situations (fight, sports tournament, etc.), pain perception can be reduced (analgesia).

This requires control of the pain pathway by cortical centers.

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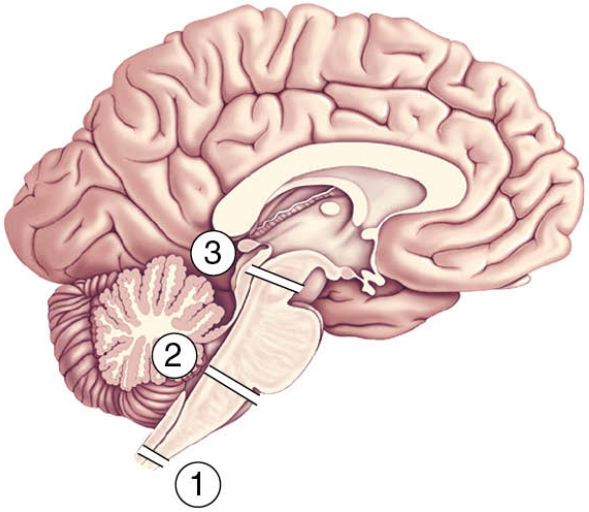
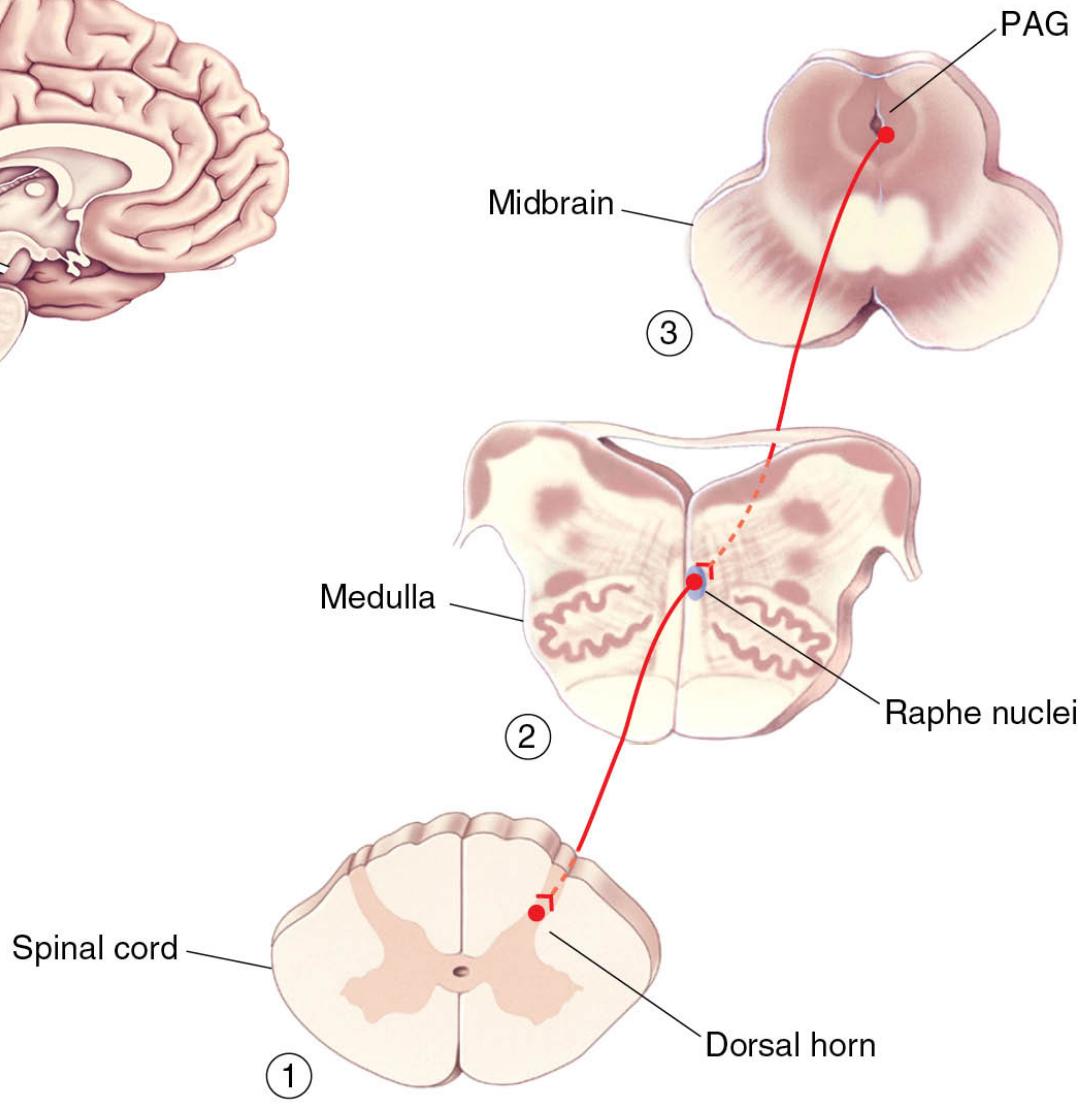
Pain suppression: Top-down control of pain





The PAG (periaquaeductal gray) in midbrain and the Raphe nuclei are relay stations of cortical control of pain and can modulate pain-related neural activity in the spinal cord.

Electrical stimulation of these structures can reduce pain perception.

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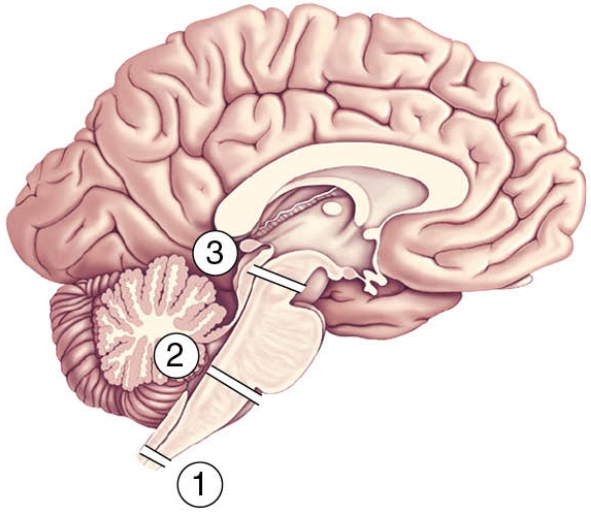
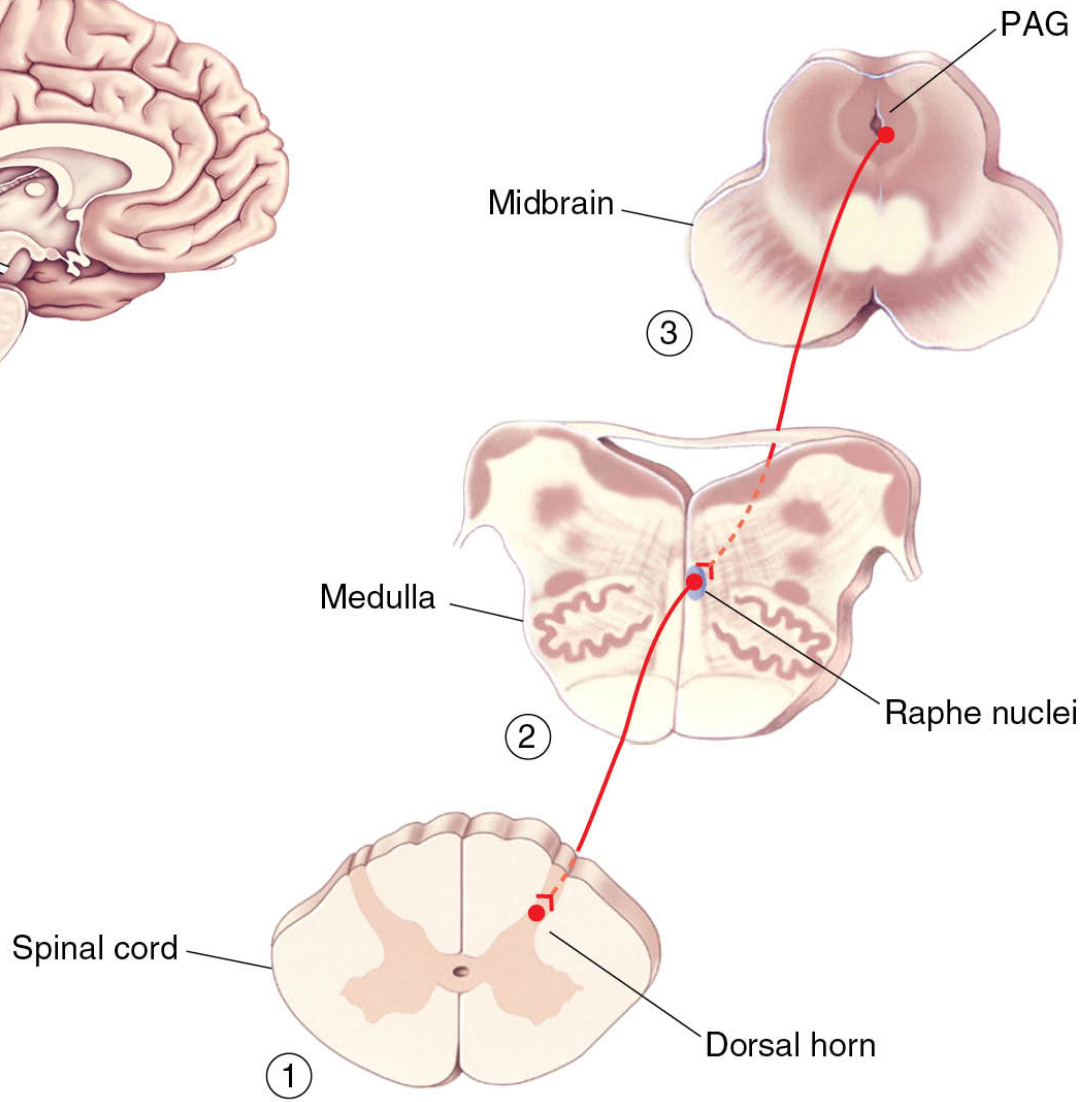
Pain suppression: Top-down control of pain





Opioids (from poppy plants) can reduce pain. Receptors for opioids can be found in the brain, but also in PAG, the Raphe nuclei and the dorsal horn of the spinal cord.

The nervous system produces endogenous opioids: endorphins.

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Some feeling is “cognitive”: Top-down control of somatosensation

The **rubber hand illusion** occurs when a person can be convinced that a rubber hand is their own hand. This is achieved by hiding their real hand and stroking both the real and the rubber hand (which they can see) at the same time. The person sees how the rubber hand is touched the same time as they feel the touch on their real hand.
Integration of visual, proprioceptive, and haptic information leads to this illusion (Botvinick and Cohen, Nature, 1998).

Summary
Touch and Pain

- Mechanoreceptors and pain receptors (nociceptors) in the skin, the muscles, joints, tendons, and the enteric organs provide somatic sensory information.

- Different types of sensory information (touch, pain) follow segregated pathways: the dorsal column – medial lemniscal pathway for touch, vibration, and proprioception and the spinothalamic pathway for pain and temperature.

- Somatosensory cortex has multiple somatotopic representations of the body.