Lecture 29. Introduction to Sensory Systems & Somatosensory System

Professor Nilay Yapici

Pre-lecture preparation

Posted on the course website before the lecture

Reading – Chapter 12- Pages 415-437, 449-451

Optional Readings- Posted on the course website site before the lecture

Lecture Objectives

- To understand the basic structure and function of sensory systems; what is a sensory neuron what is a sensory receptor.
- Be able to understand receptive fields of sensory neurons and cortical maps.
- To understand the structure and function of the somatosensory system.
- To be able to discriminate the types of different somatosensory modalities.
- To learn the molecular pathways of pain and temperature sensation
- To understand how body is represented in the somatosensory cortex and how this representation is plastic.

Lecture outline

This lecture will make an introduction to sensory systems; how they function and what are the common mechanisms they use to transform the external world to internal representations in the brain. We will also discuss the anatomical and functional structures of the somatosensory system and how the skin detects various stimuli such as mechanical touch, temperature and pain.

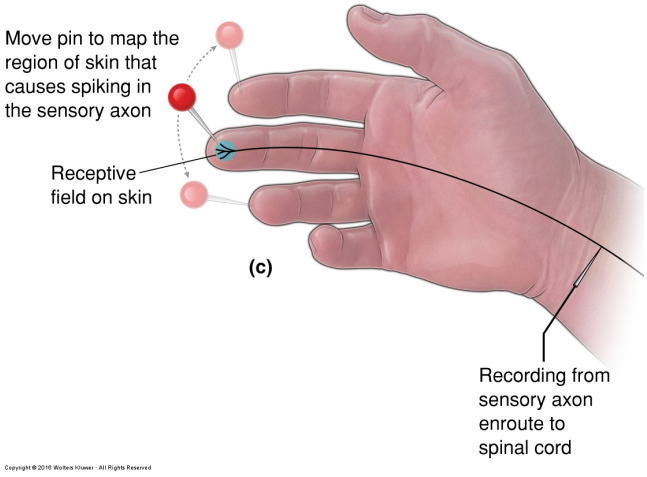
1) Each of our senses functions through interactions with the physical world. For each sense, a specific type of signal has to be converted into a signal the brain understands: light waves/particles, sound pressure waves, chemical signals, touch pressure and temperature. Each of these has specific features and axes along which they vary. For example, light varies in wave length, amplitude and location, sound varies in combination of frequencies, chemical stimuli in concentration, types and size of molecules. Each of these senses have distinct mechanisms to convey the sensory information to the central nervous system.
2) Physical stimuli have to be converted to electrical signals in order to be processed by neurons and neural networks. Each sensory system has evolved specific types of receptors which convert signals from the outside world into “brain” signals, using diverse mechanisms.
3) Sensory receptive fields directly arise from the transduction of physical stimuli and are the basis for perception and further processing. Receptive fields usually refer to the ensemble of stimuli a given receptor (or CNS neuron) responds to. For example, each olfactory receptor can bind to a large number of chemicals defining its chemical receptive field.
4) Unlike other senses, somatosensory system is located throughout the body rather than in a localized,

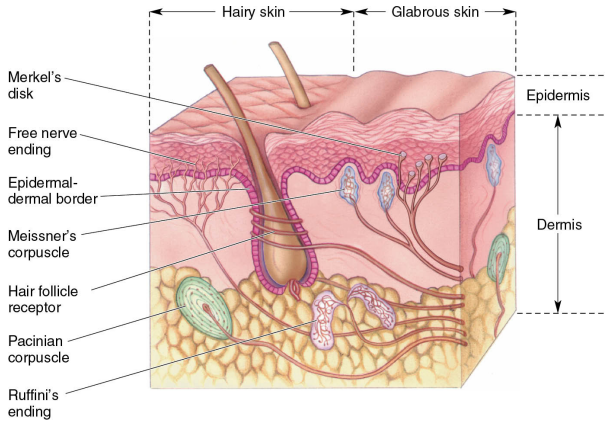
specific organ. One type of somatosensation is called cutaneous senses, which include the skin senses of touch, temperature, and pain. Another type called proprioception, or kinesthetic perception, tells the brain where the parts of the body are.

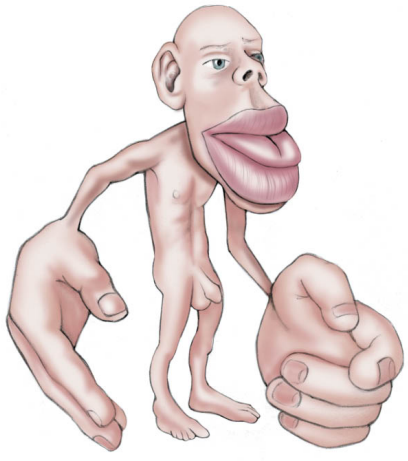
5) Mechanoreceptors have unmyelinated axon terminals. Mechanosensitive ion channels convert mechanical force into change of ionic current. Mechanical stimuli may trigger release of second messengers. Specific types of channels in most somatic sensory receptors are still unidentified.
6) Somatic sensory information is segregated within the spinal cord and cerebral cortex. Perception of handled object involves seamless coordination of all facets of somatic sensory information. The mapping of the body surfaces in the brain is called somatotopy. In the cortex, it is also referred to as the **cortical homunculus**. This brain-surface ("cortical") map is not immutable, however. Dramatic shifts can occur in response to stroke or injury.

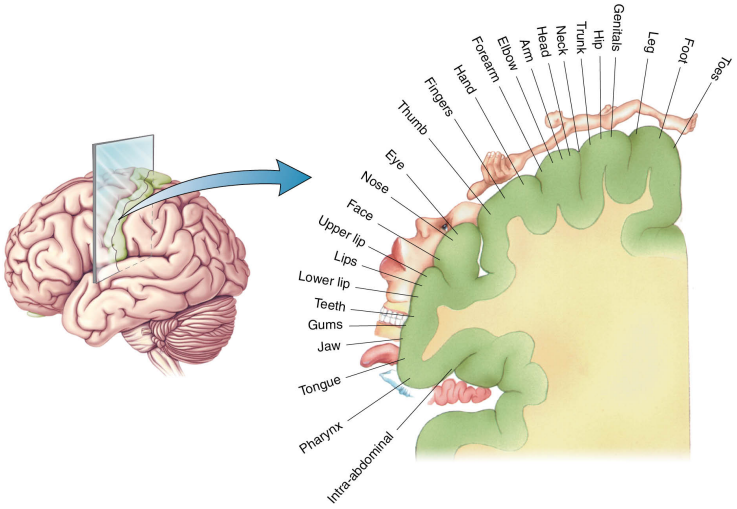
Study questions:

1) How do sensations become perceptions?
2) What is a receptive field of a sensory neuron?
3) How does the somatosensory cortex integrate information coming different body locations?
4) How do we discriminate temperature sensation from noxious heat or cold?








Genitals
Leg
Foot
Toes
Hip
Trunk
Neck
Head
Arm
Elbow
Forearm
Hand
Fingers
Thumb
Eye
Nose
Face
Upper lip
Lips
Lower lip
Teeth
Gums
Jaw
Tongue
Pharynx
Intra-abdominal

Lecture 29: Intro to Sensory Systems and the Somatosensory System

Nilay Yapici (ny96@cornell.edu)

Office Hours: Wednesdays 2PM-5PM

Sensory Systems

Timeline

Lecture 29: Introduction to sensory systems Somatosensory system	4/8/19
Lecture 30: Chemical Senses	4/10/19
Lecture 31: Auditory System	4/12/19
Lecture 32: Visual System: Retina	4/15/19
Lecture 33: Higher Order Visual Processing	4/17/19
Lecture 34: Visceral Senses & the Autonomic Nervous System	4/19/19

Class Engagement

1. This is a safe environment.
   - PLEASE Ask questions. Even you think they might be simple or silly.

2. Come to office hours if you have any problems/ questions.

3. Speak to your TAs about any problem you have regarding the material.

Reading assignments and exam questions

1. Please try to read chapters regarding each sensory system in the book once. Do not try to remember everything in the book.
   - Lecture 34 has a required reading which is posted on the course web page. Human Anatomy by Elaine N. Marieb, Patricia Brady Wilhelm, Chapter 1

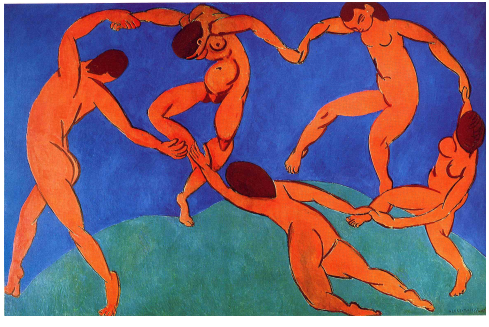
2. Exam questions will focus on the topics we go through during the lecture.

Learning objectives

1. To understand the basic structure and function of sensory systems; what is a sensory neuron what is a sensory receptor.
2. Be able to understand receptive fields of sensory neurons and cortical maps.
3. To understand the structure and function of the somatosensory system.
4. To be able to discriminate the types of different somatosensory modalities.
5. To learn the molecular pathways of pain and temperature sensation
6. To understand how body is represented in the somatosensory cortex and how this representation is plastic.

Everything we know about the world is derived from our senses

Our senses bring us pleasure

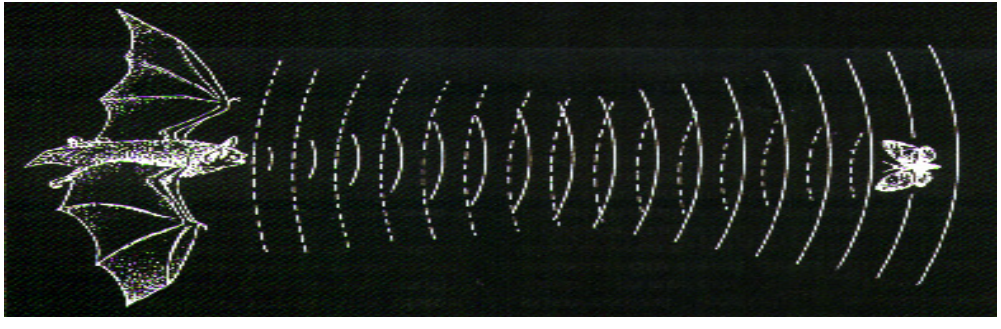


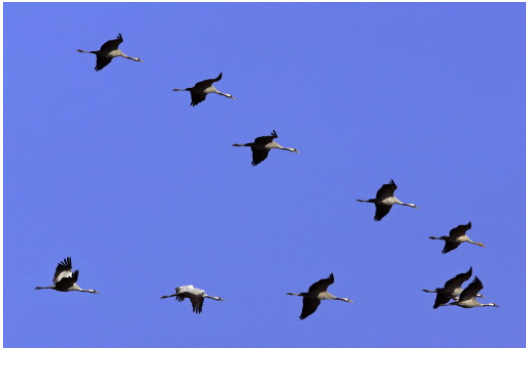
Everything we know about the world is derived from our senses

They protect us from danger

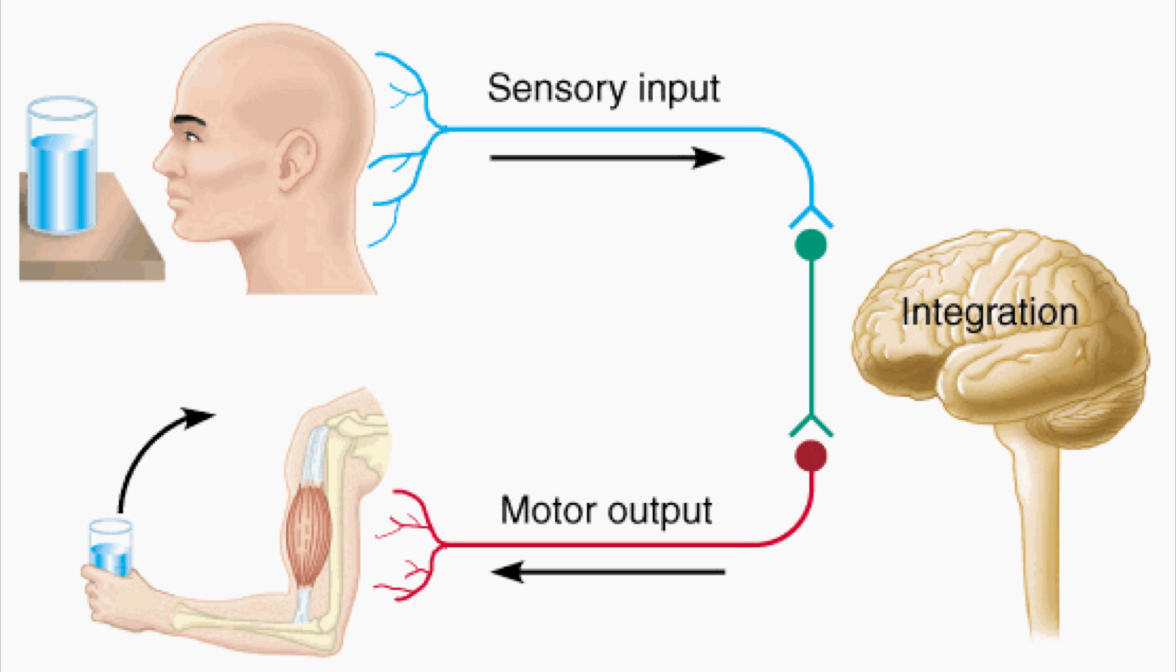
Everything we know about the world is derived from our senses

Allow us to navigate





Brain integrates sensory information and execute motor actions



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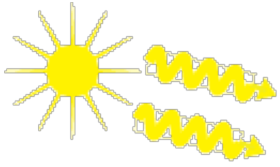
How do we sense the external world?



Signal → Collection → Transduction → Processing → Action

Sensory receptors

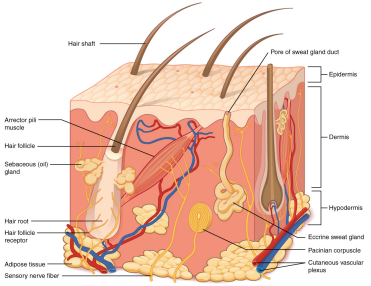
Sensory neurons

Central Brain

Motor System

Sensory Systems can be divided to 4 main classes

Somatosensory System



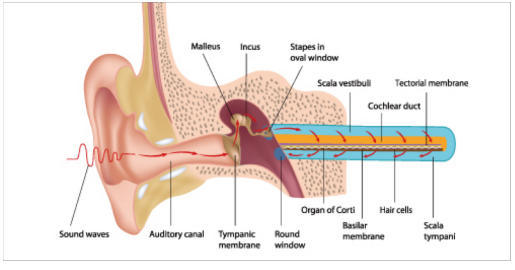
Chemical Senses

Smell

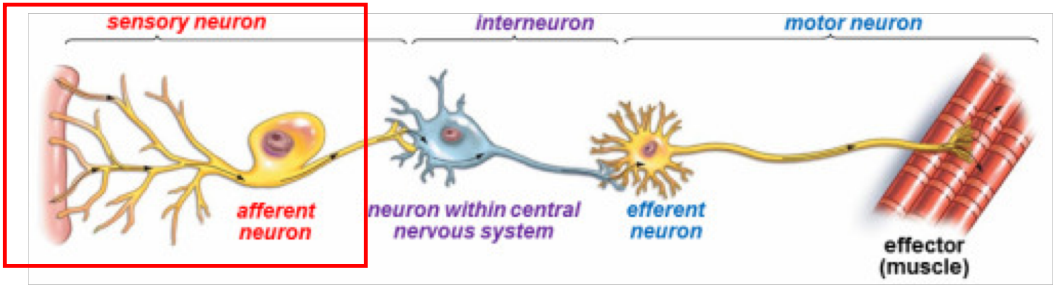
Taste

Visual System

Auditory System



What is a sensory neuron?



- Sensory neurons are nerve cells that are located in the sensory organs; eye, skin, nose, tongue, ear
- Sensory neurons are responsible for converting external stimuli from the organism's environment into internal electrical impulses.
- Each sensory neuron carries a particular sensory receptor.

What is a sensory receptor?

Sensory receptors are membrane proteins that convert external sensory information to an action potential in the sensory neuron.

Types of sensory receptors

- Touch
- Temperature
- Pressure

Somatosensory

- Taste
- Smell

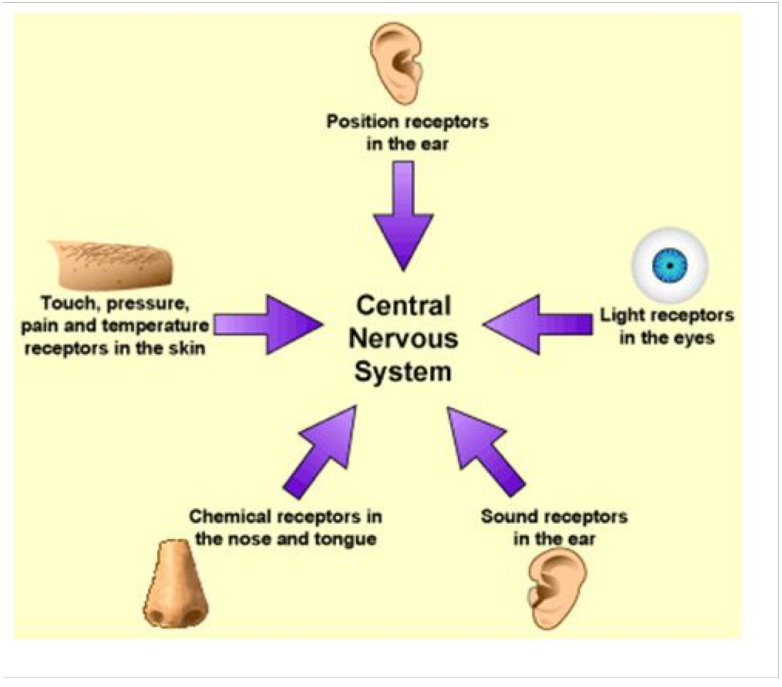
Chemosensory

- Sound

Auditory

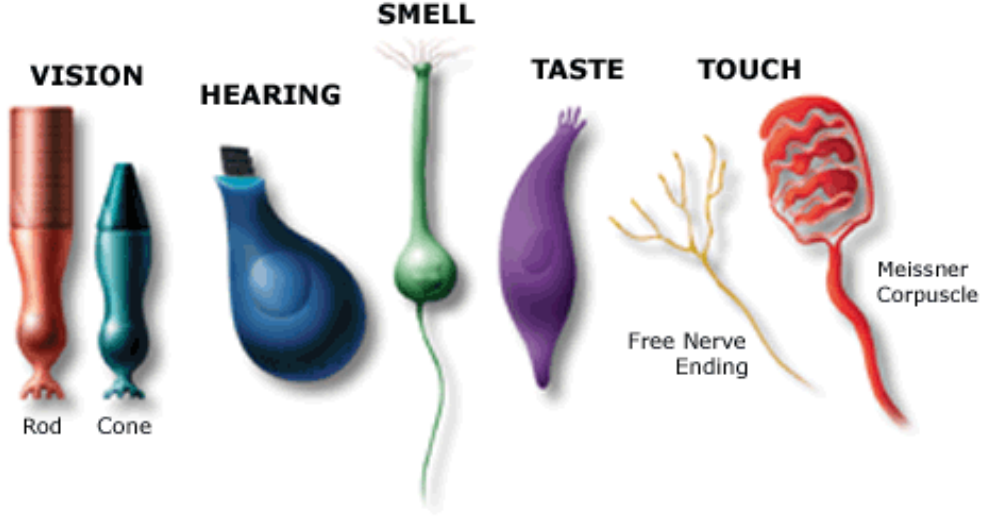
- Vision

Visual



What is a receptive field of a sensory neuron?

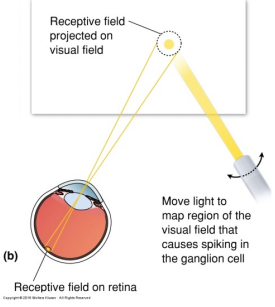
The receptive field of an individual neuron is the particular region of the sensory space (e.g., the body surface, the visual field, the tone frequency or location, the odor or taste identity) in which a stimulus will trigger a change in the activity of that neuron.



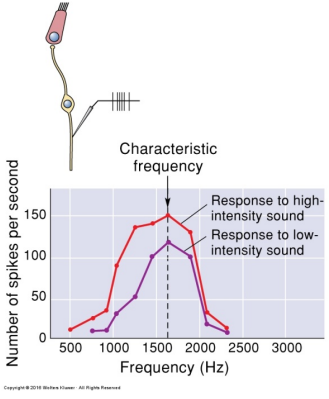
What is a receptive field of a sensory neuron?

Some sensory neurons might have large receptive fields and some might be finely tuned to a particular stimulus.

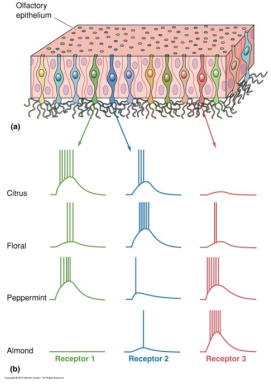
VISION



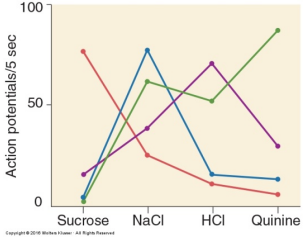
HEARING



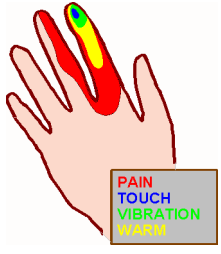
SMELL



TASTE

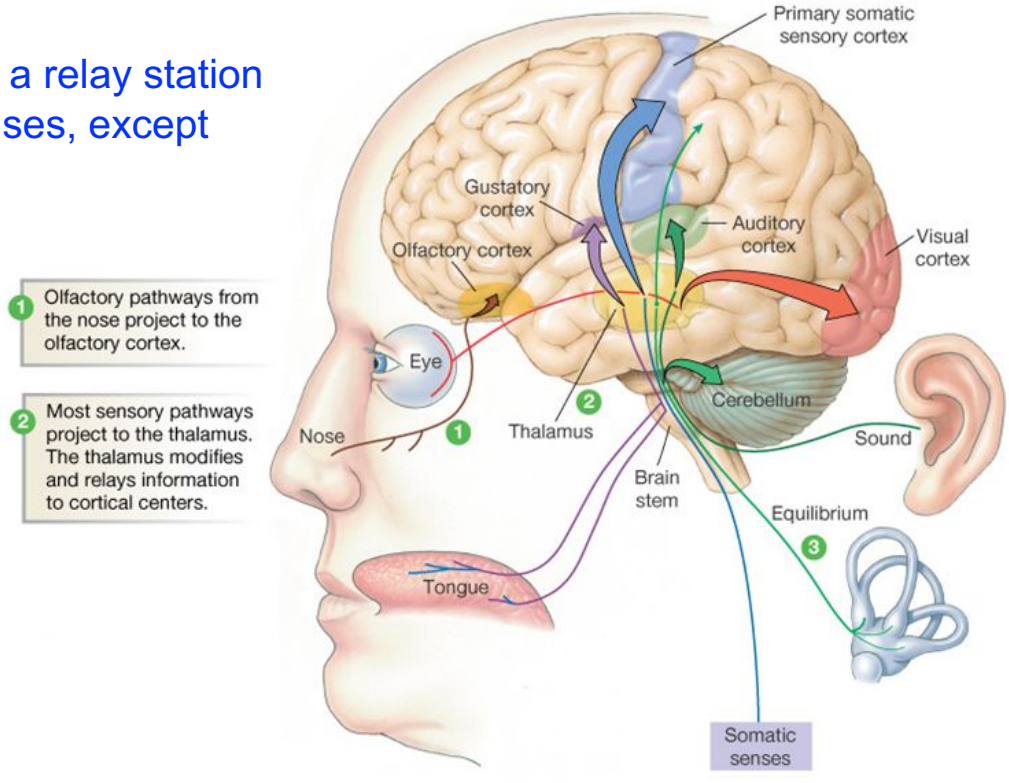


TOUCH



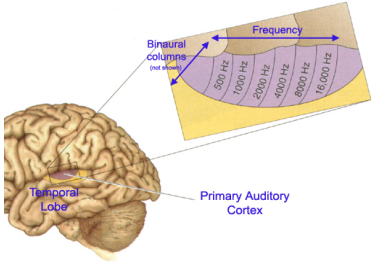
General Properties of Sensory Systems

- Thalamus is a relay station for most senses, except olfaction.

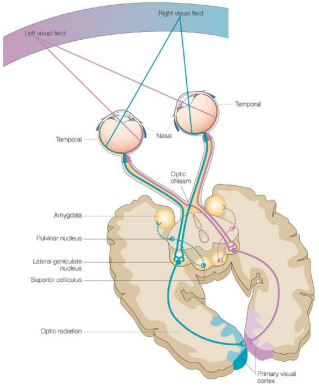


What are cortical sensory maps?

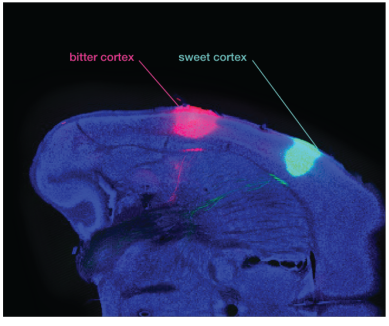
HEARING



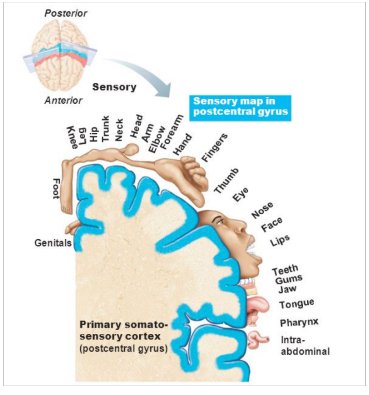
VISION



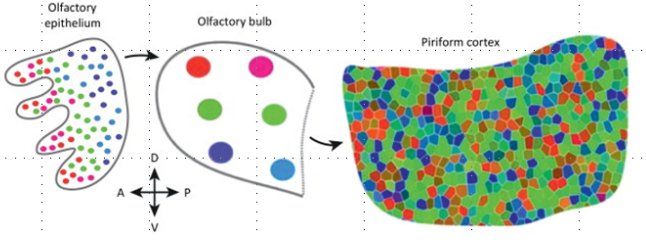
TASTE



TOUCH



SMELL: NO MAP HAS BEEN IDENTIFIED!



Clicker Question 1:

The **receptive field** of an individual neuron is the particular region of the sensory space in which a stimulus will trigger a change in the activity of that neuron. Which of the sensory system have cells that have receptive fields distributed throughout the body?

A. Vision
B. Hearing
C. Taste
D. Touch
E. Olfaction

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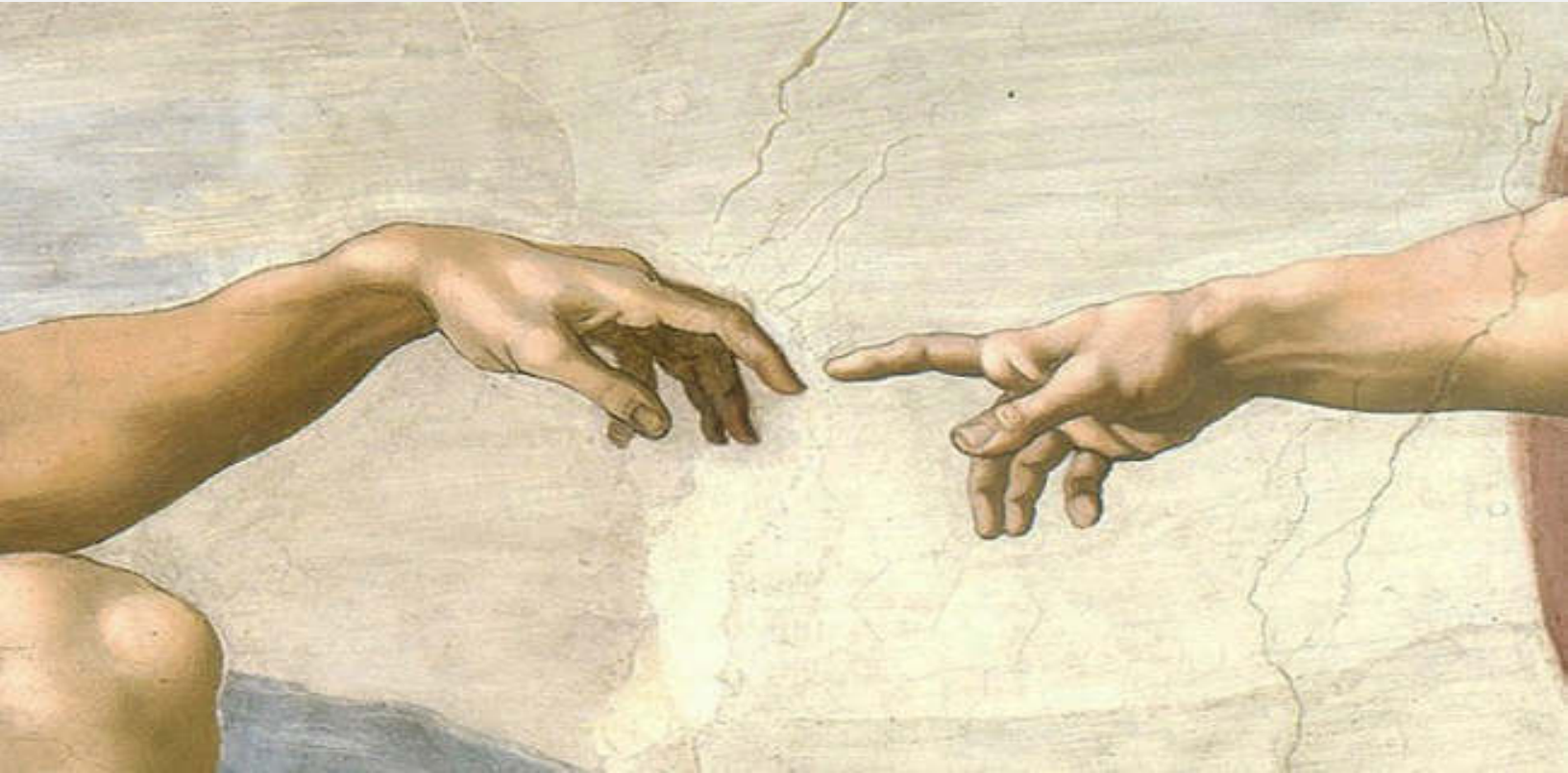
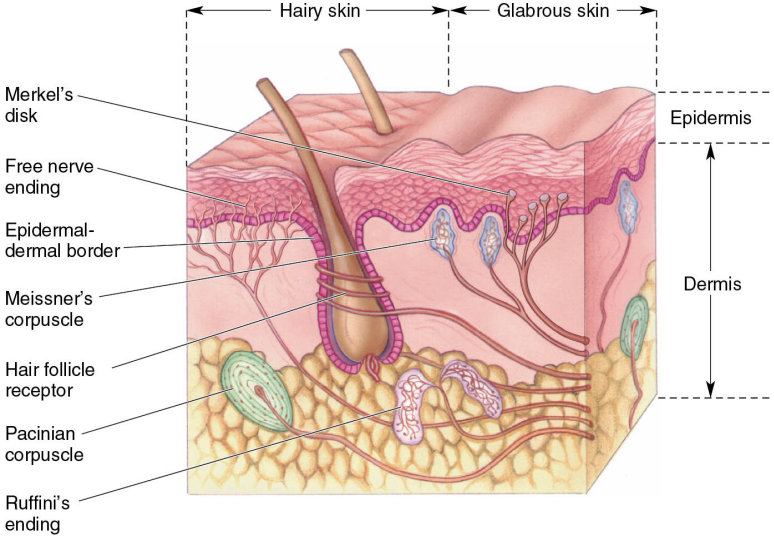
Somatosensory System



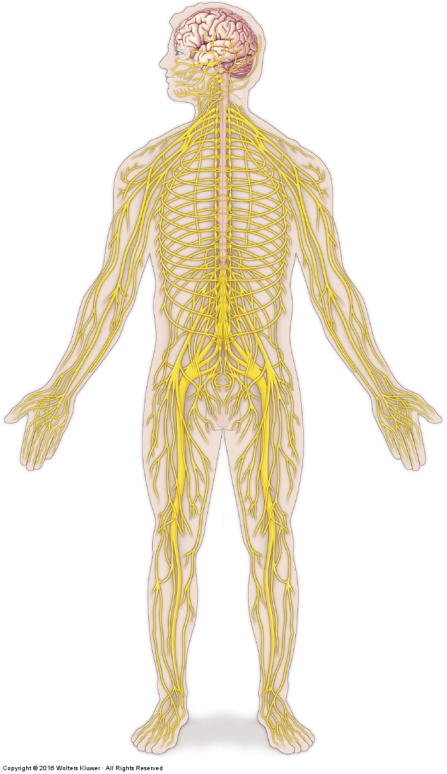
Somatosensory System



Somatic sensation enables body to

1. Feel touch and pressure,
2. Sense temperature,
3. Feel pain

Somatosensory System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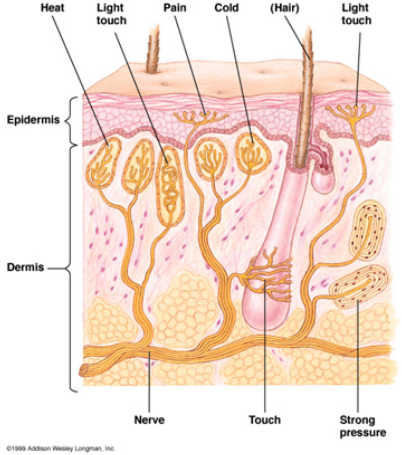
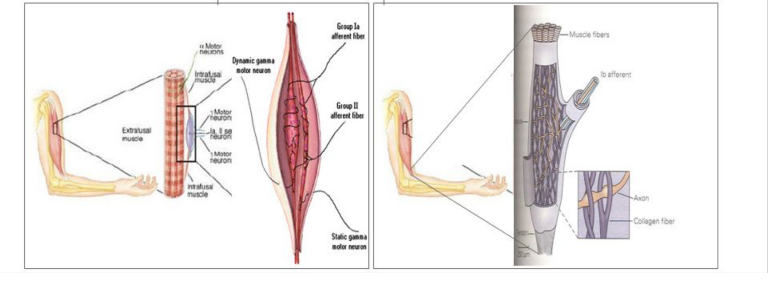
Somatic sensation is different from other sensory systems.

Somatic receptors and nerves are broadly distributed in the body

Somatosensory System

Somatosensory receptors are located in the skin, epithelial tissues, muscles, bones and joints, internal organs





There are two types of somatosensation

1.Proprioception

Mechano receptors

2. Cutaneous senses

Touch

Mechano receptors

Temperature

Warm Cold

Thermo receptors

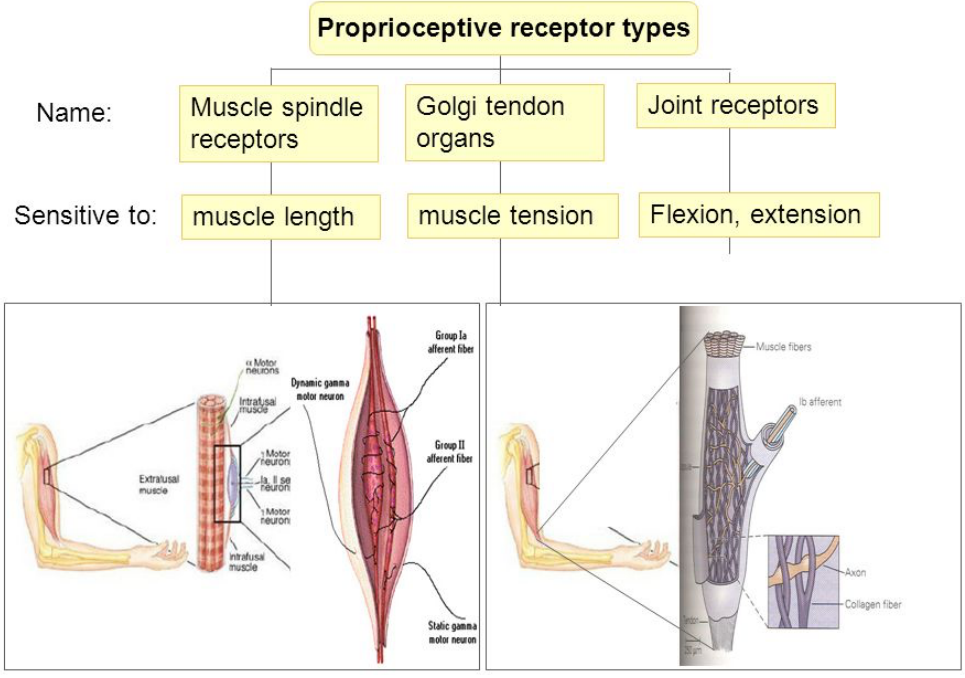
Nociception

Pain Noxious cold or hot

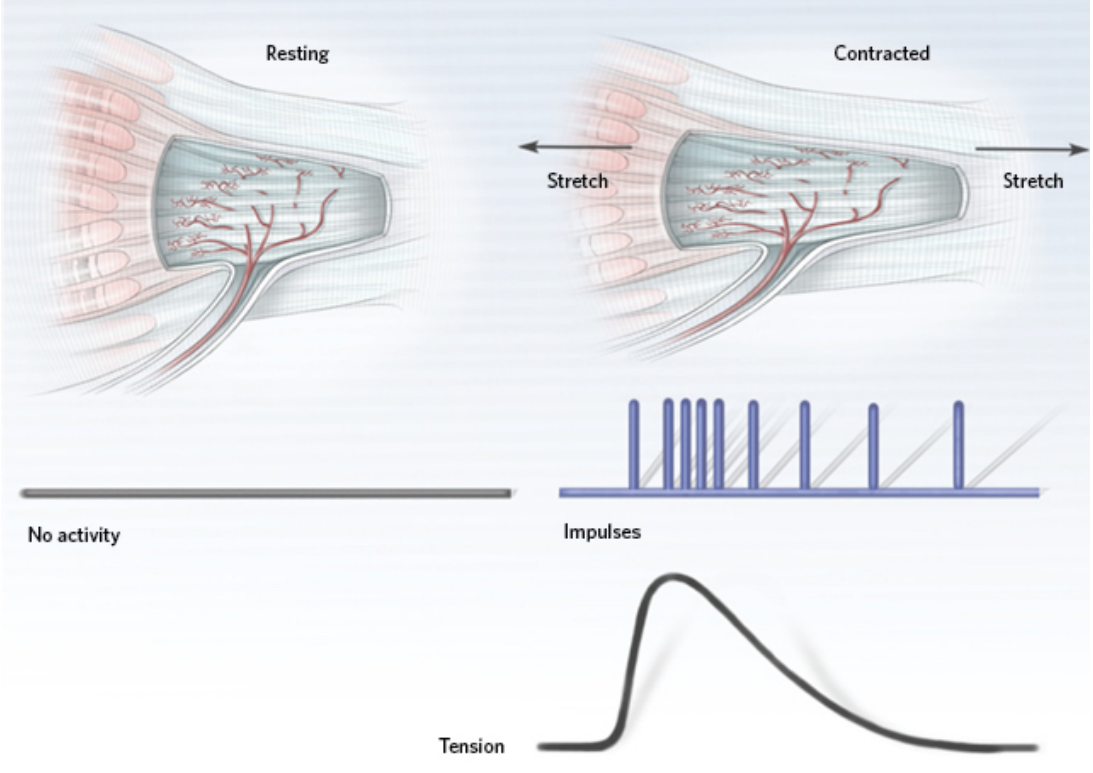
Nociceptors

Proprioception means ”sense of self”

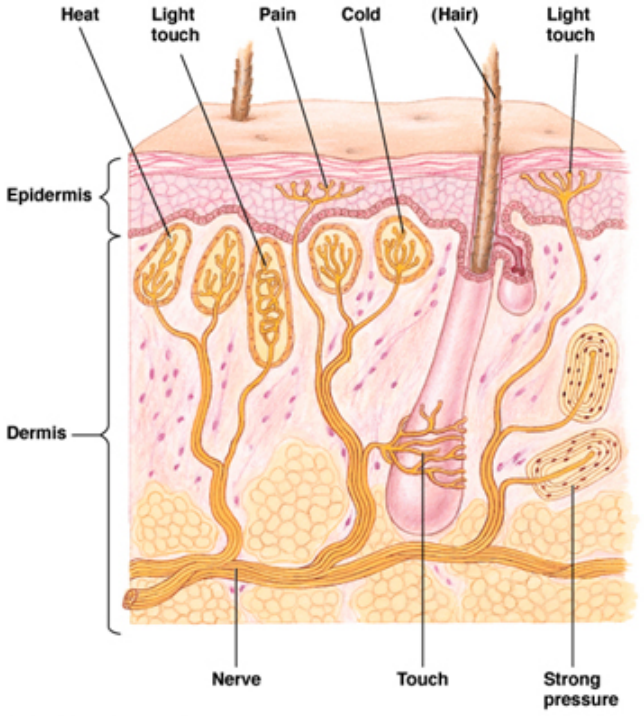
The proprioceptors are sensors that provide information about joint angle, muscle length, and muscle tension, which is integrated to give information about the position of the body in space.



Proprioceptors generate action potentials in response to stretch



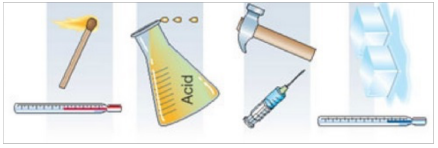
Cutaneous senses-The skin



Touch

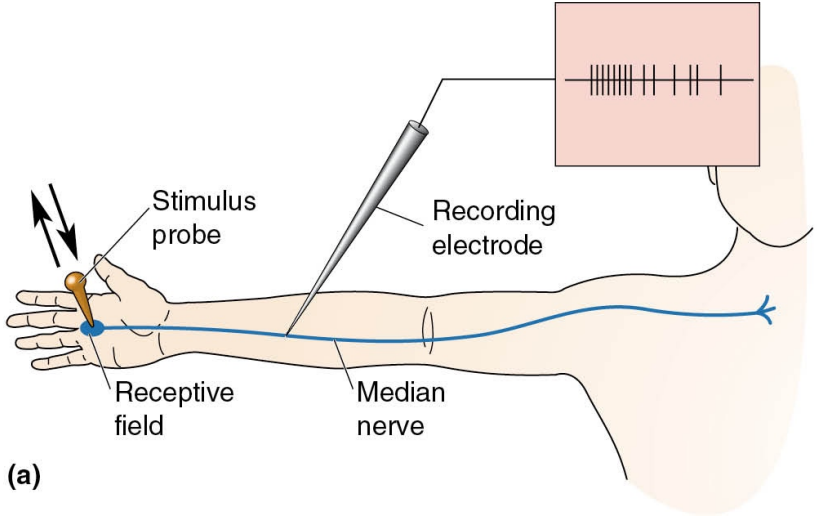
Temperature

Nociception

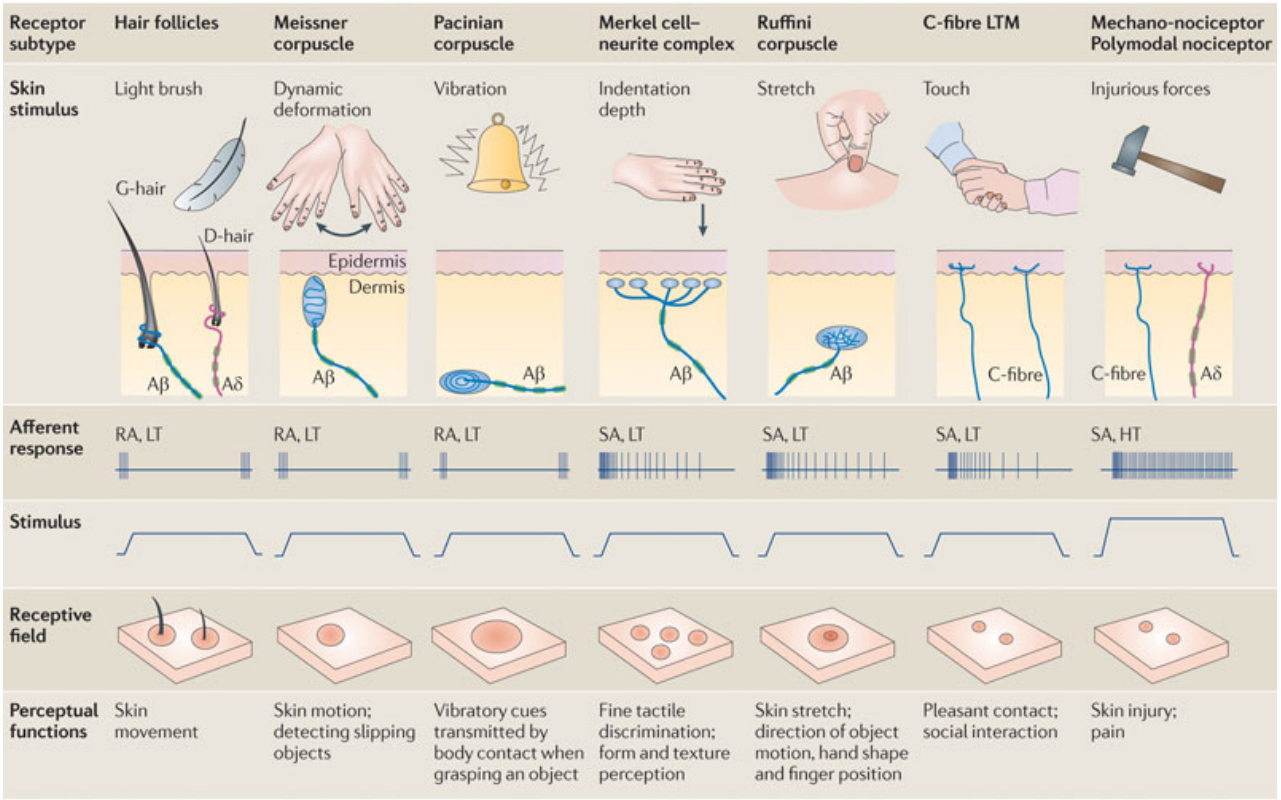


Mechanoreceptors of the skin

Mechanoreceptors of the skin converts mechanical forces into change of ionic currents in the sensory neuron that are innervating the skin.



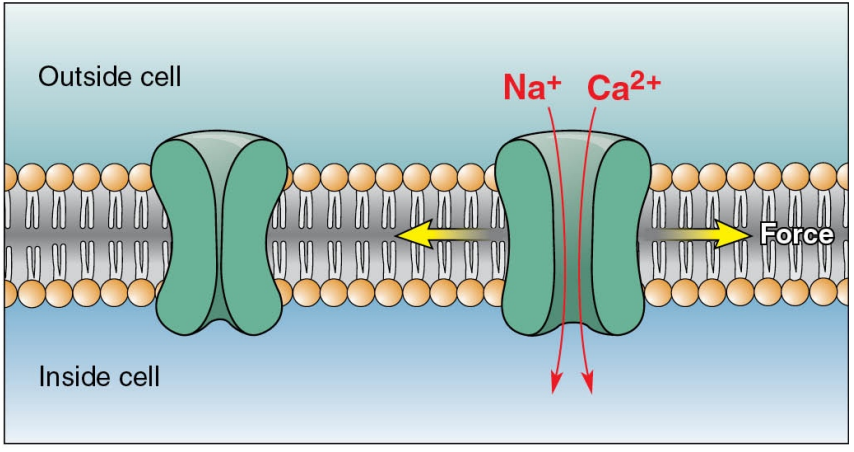
Different skin mechanoreceptors have different functions



Mechanoreceptors respond to mechanical force

Mechanical Force can be;

<u>Direct stretching of the lipid membrane</u>

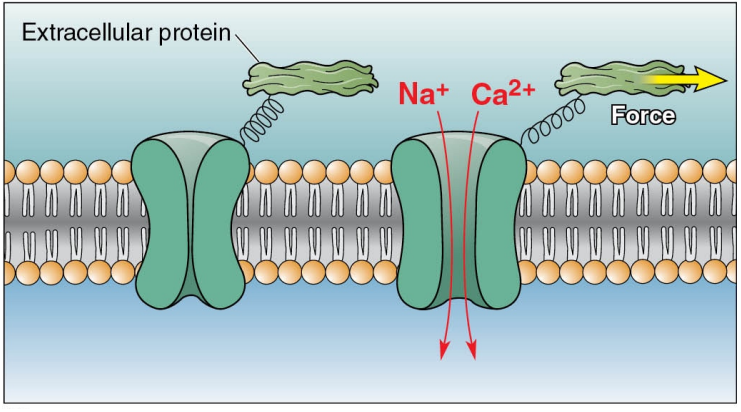


Mechanoreceptors respond to mechanical force

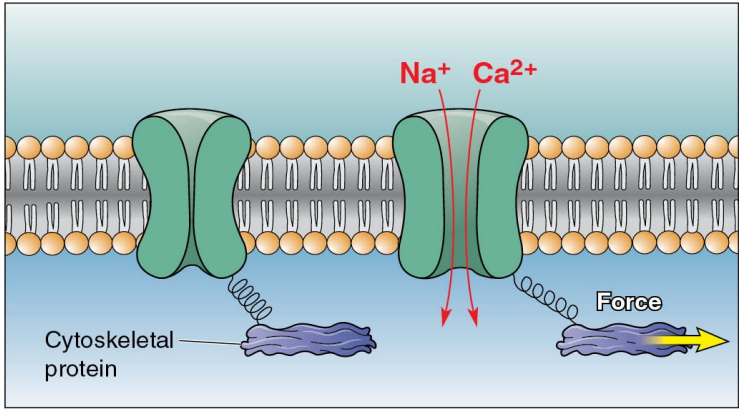
Or

Force applied to extracellular or intracellular structures

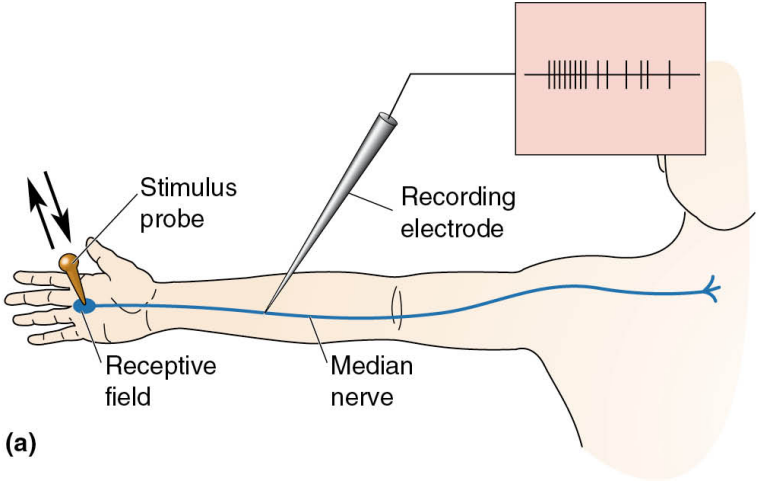
Extracellular

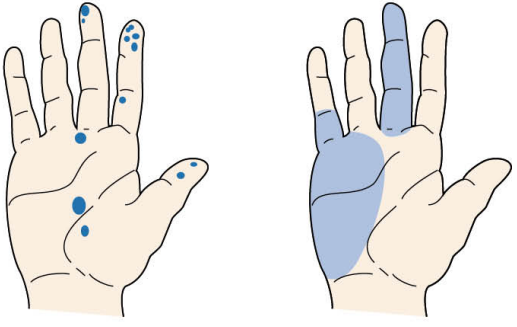


Intracellular



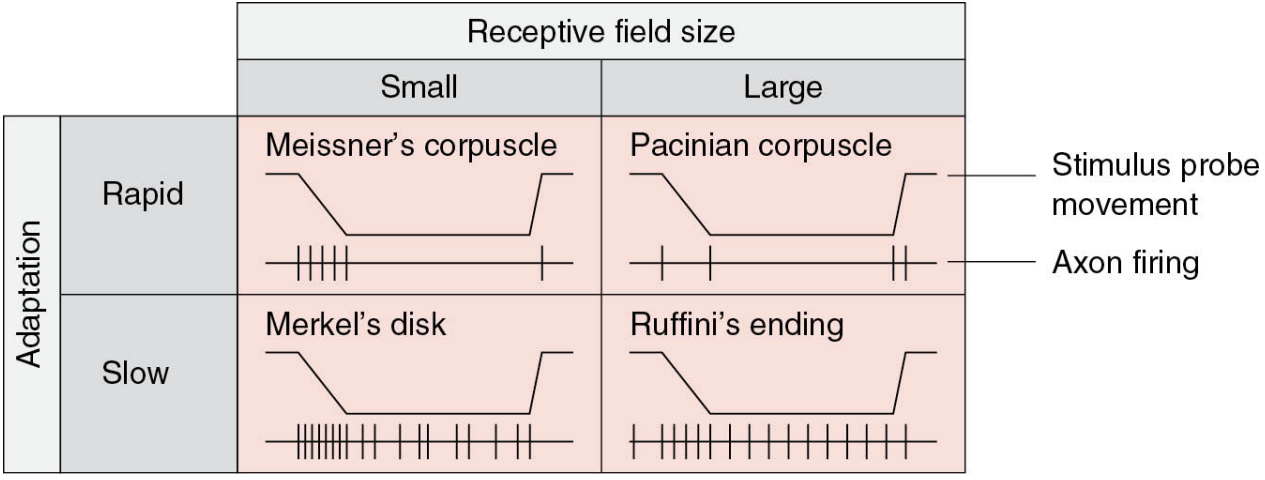
Mechanoreceptors have different “receptive fields”



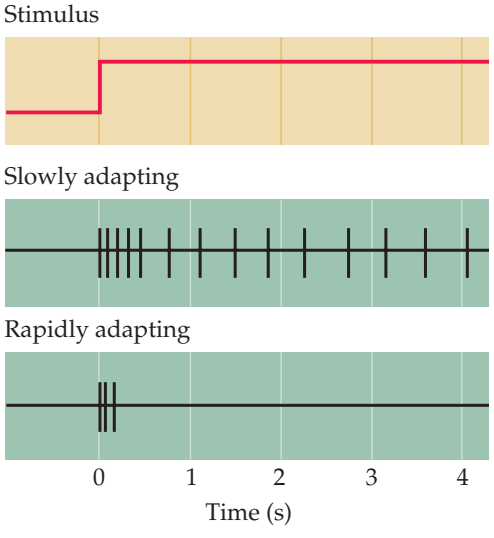


Mechanoreceptors have different “adaptation times”

Adaptation time determines how long the sensory neuron will respond to stimulus



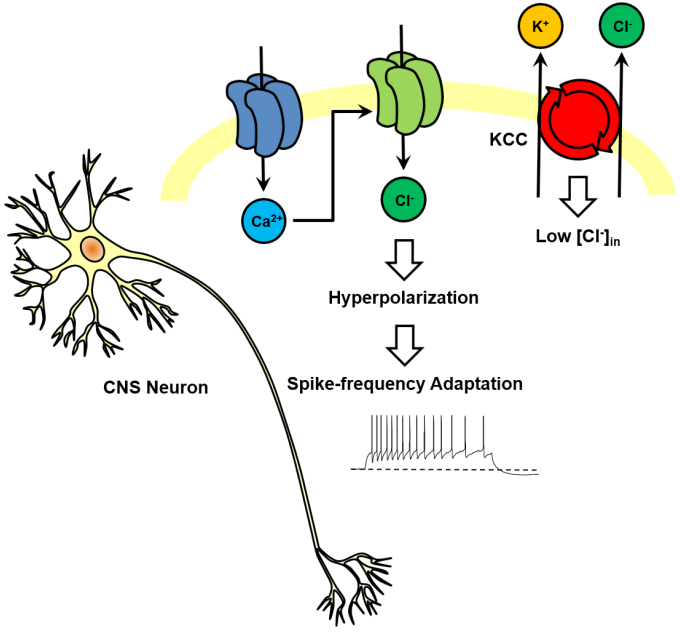
Mechanoreceptors have different “adaptation times”



- Spike frequency adaptation is **one way** of sensory neurons to adapt to a stimulus.
- It refers to the progressive slowing of the frequency of discharge of action potentials following initial spikes during an extended period of excitation. Learn this well.

Mechanoreceptors have different “adaptation times”

- Slow-activating currents that gradually hyperpolarize the membrane are a mechanism for spike frequency adaptation. For example Calcium activated Cl- currents.

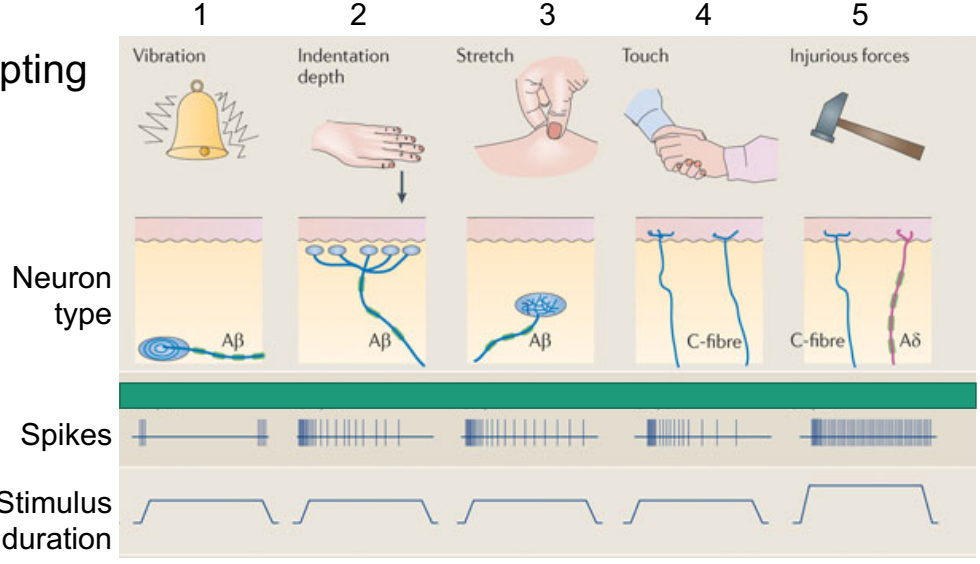


For more detailed explanation, watch the optional video on blackboard.

Clicker Question 2:

Which neuron is the fastest adapting mechanosensory neuron?

A. 1
B. 2
C. 3
D. 4
E. 5



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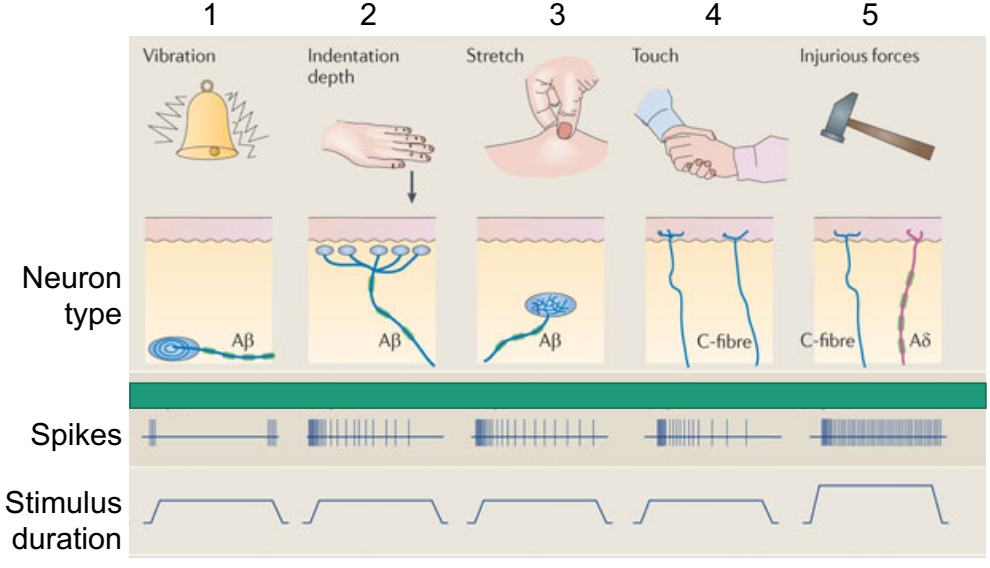
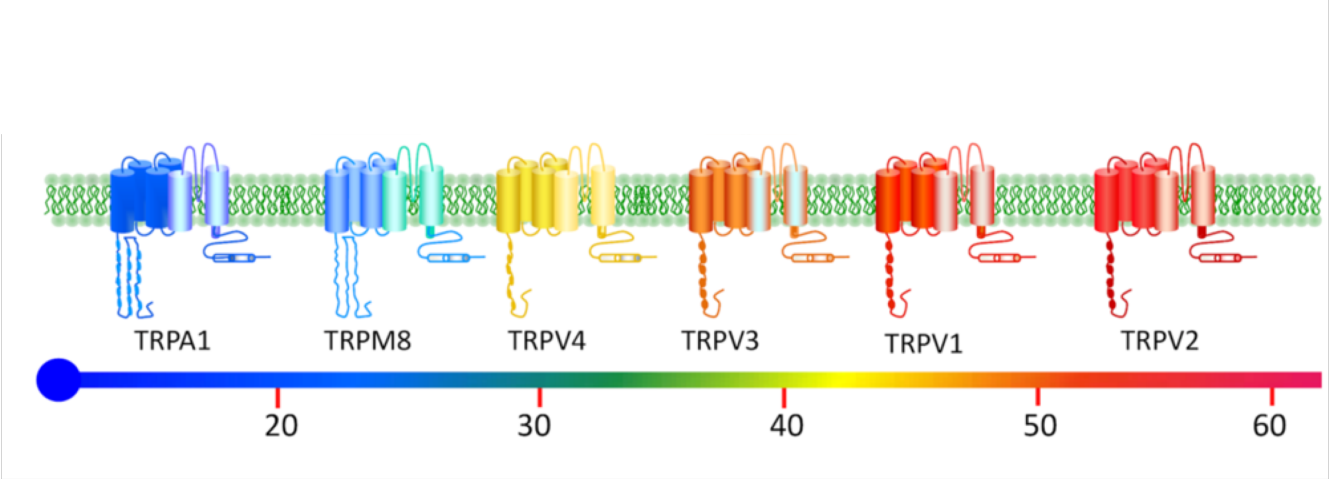


2. Temperature sensation

Thermoreceptors convert temperature changes to change of ionic currents in the sensory neurons.

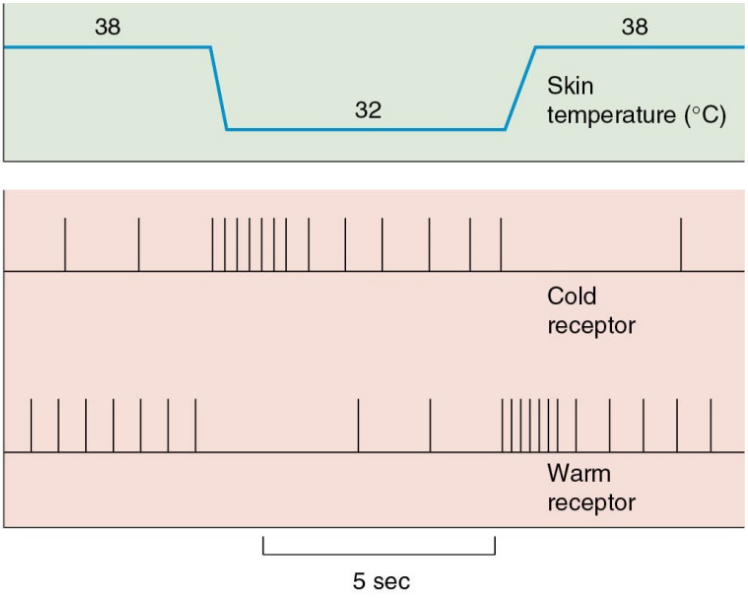
Known thermoreceptors are TRP channels

Transient receptor potential **(TRP)** channels have varying sensitivities!



Known thermoreceptors are TRP channels

Thermoreceptors can be fast or slow adapting:
Eventually they stop responding to temperature change



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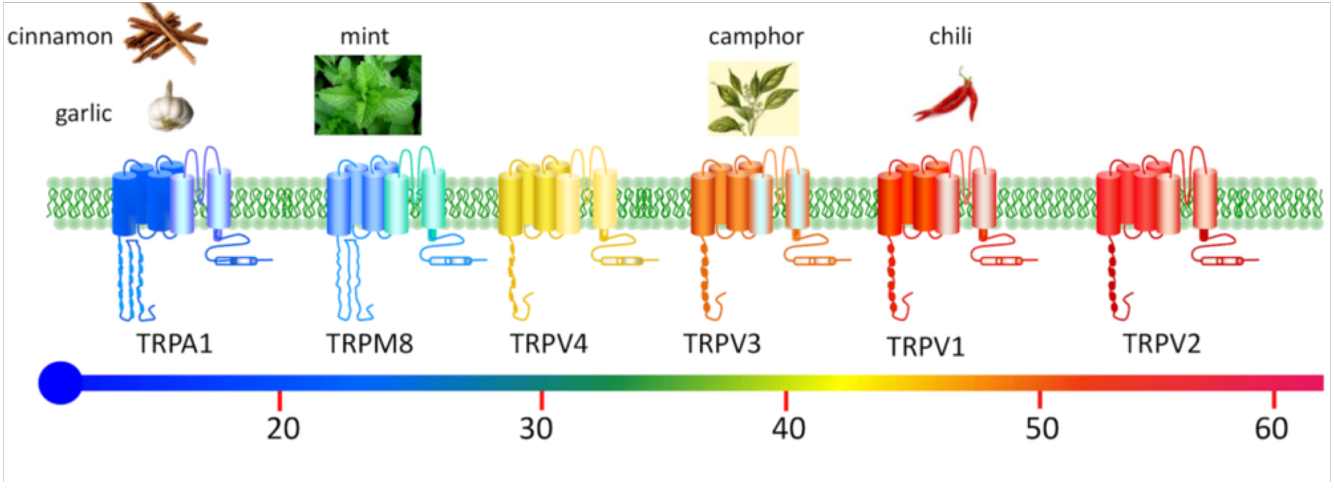
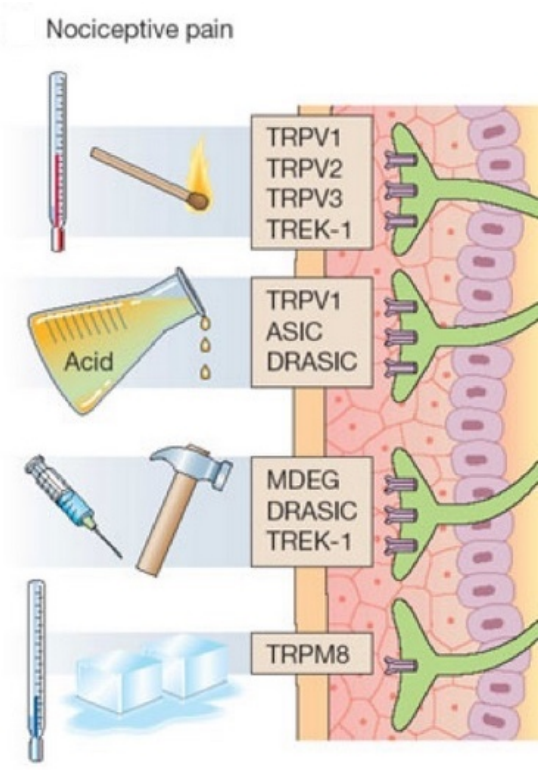


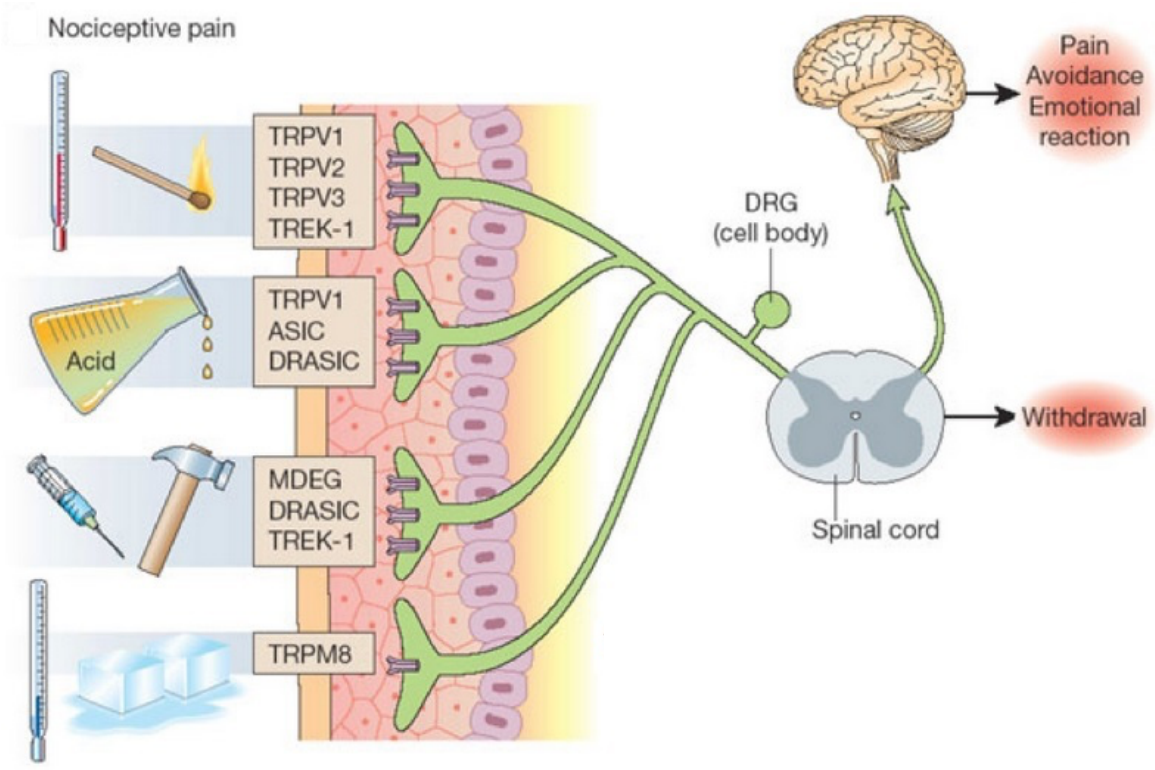
3. Pain sensation



Nociceptors sense painful stimuli such as

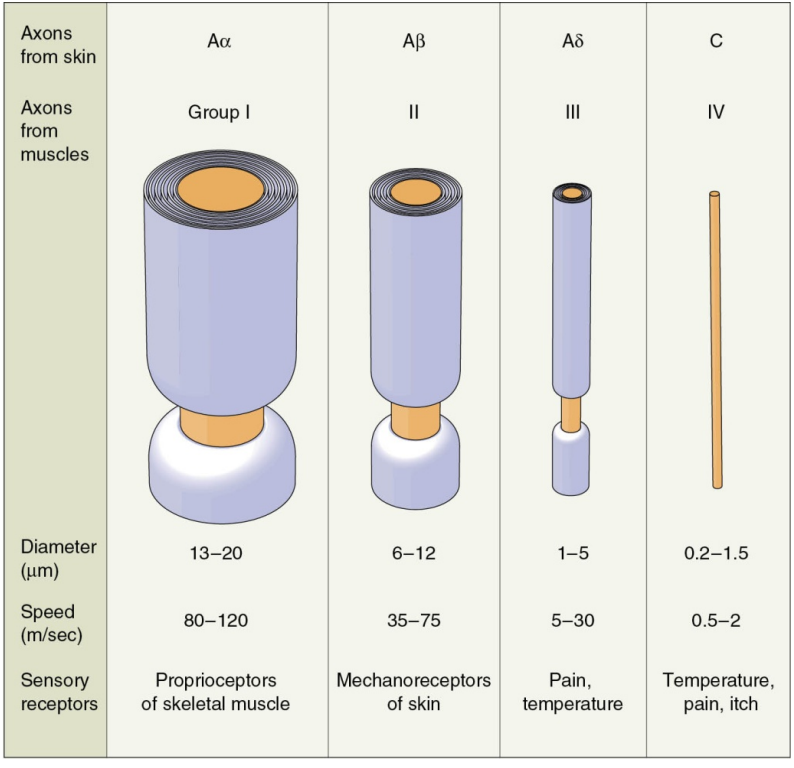
- Temperature extremes
- Strong mechanical stimulation,
- Toxic chemicals

3. Central pathways of pain sensation



Somatosensation is carried to the brain by specific pathways

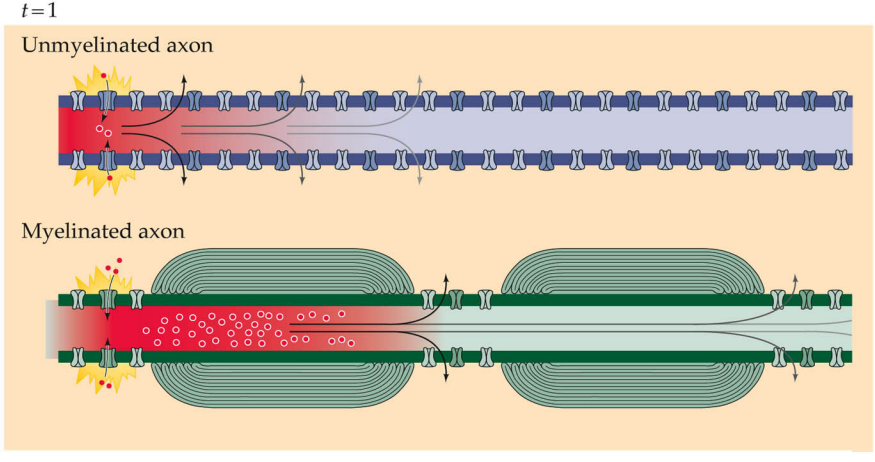
- Most of the axons of somatosensory receptor neurons are myelinated for fast transmission of sensory stimulus.
- Exception is C fibers.



Myelination speeds action potential propagation

Remember Lecture 06 and Professor Fetcho

Unmyelinated versus myelinated axons

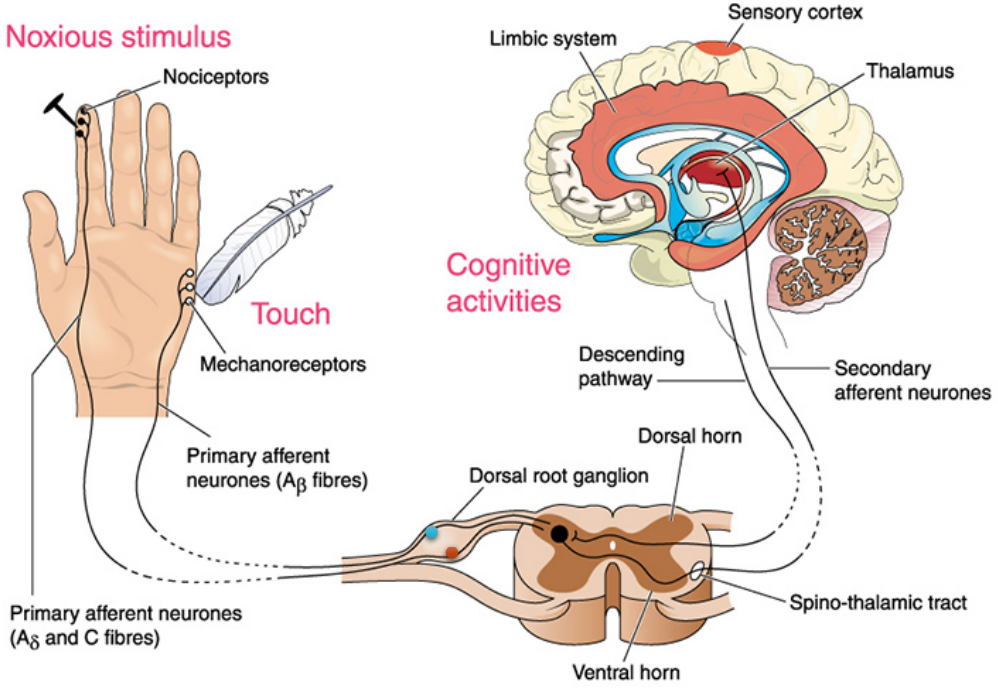


AP regenerates all along the membrane

AP regenerates only at breaks in Myelin - Nodes of Ranvier

Somatosensation is carried to the brain by specific pathways

- Aβ and Aα fibers carry touch sensations and proprioception
- Aδ and C fibers carry pain, temperature, and itch.



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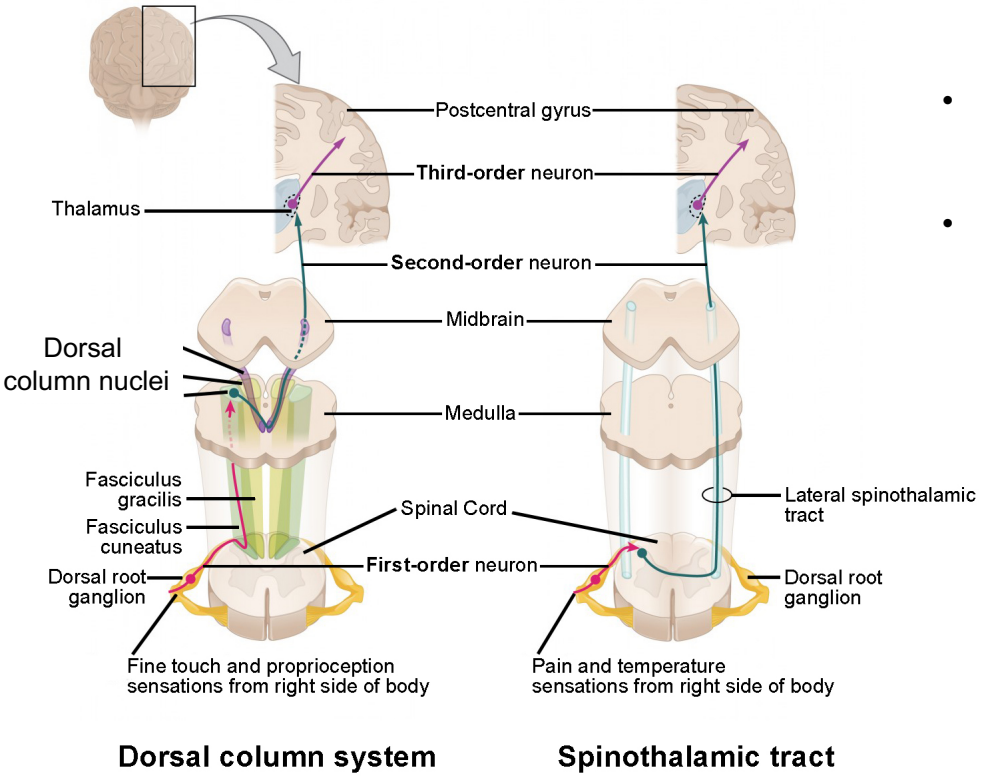
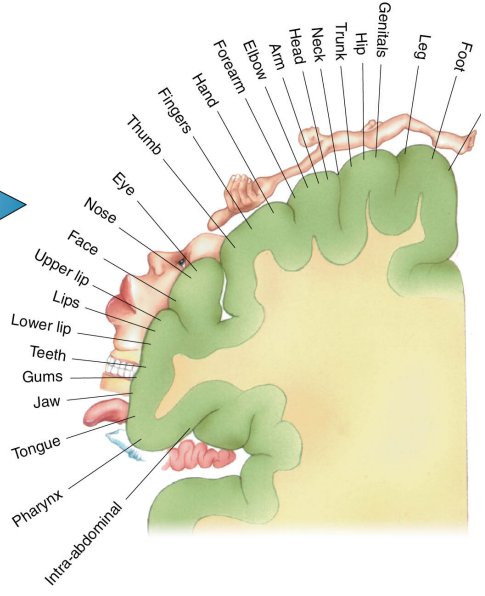
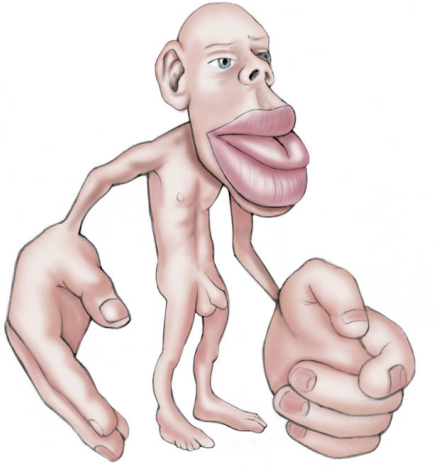


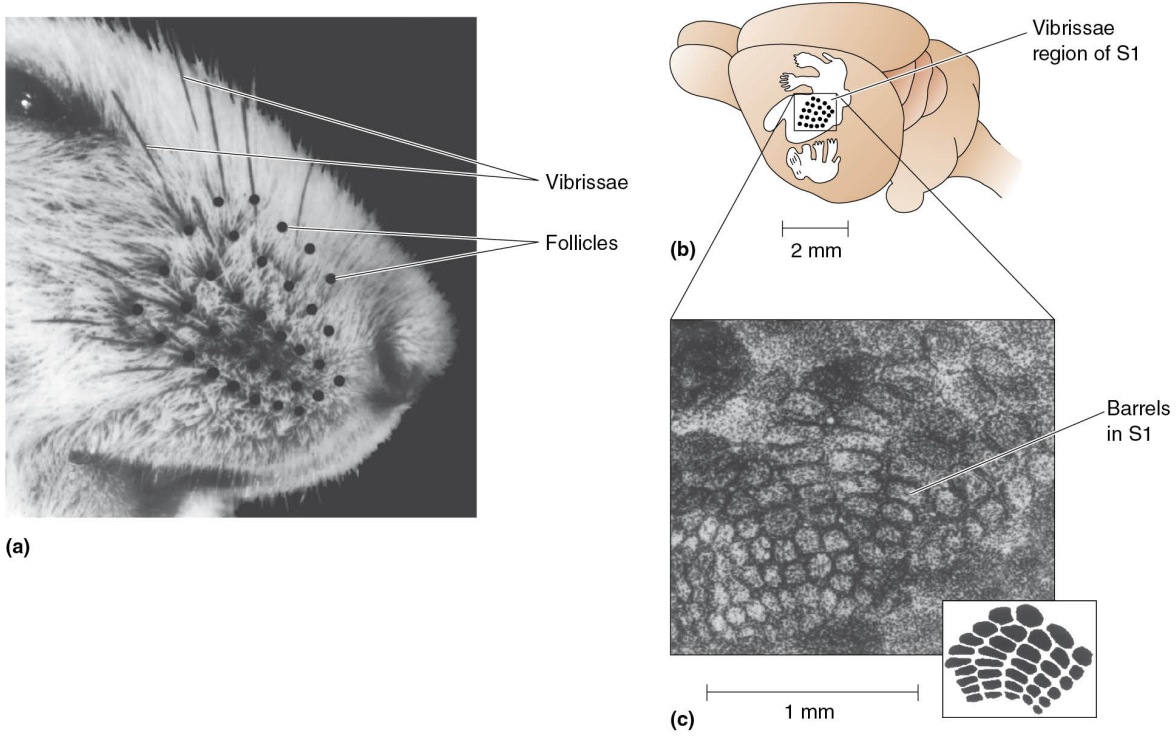
- **You do not need to memorize these pathways in detail,**
- But remember fine touch and proprioception goes through the dorsal column system and pain and temperature goes through the spinothalamic tract.

Somatosensory information is encoded in cortical maps





Somatotopic Map of Facial Vibrissae on Mouse Cerebral Cortex



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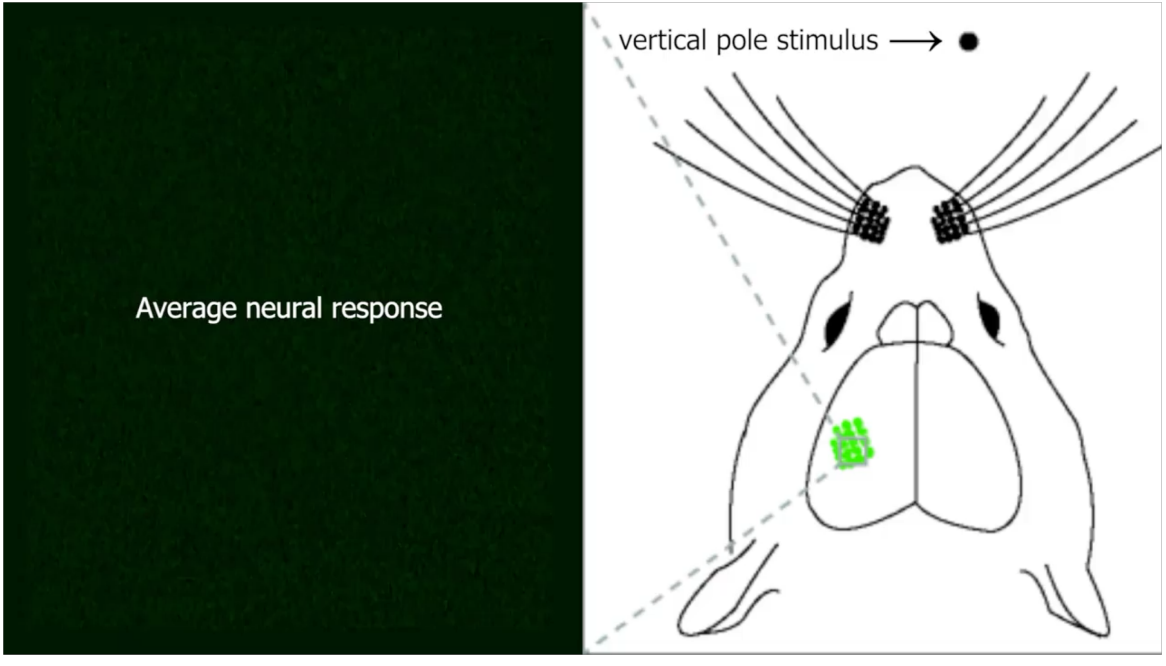
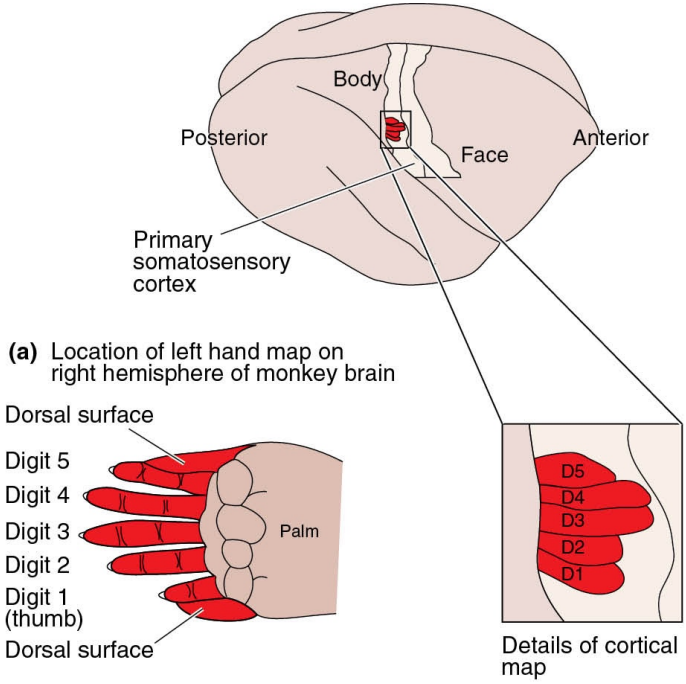
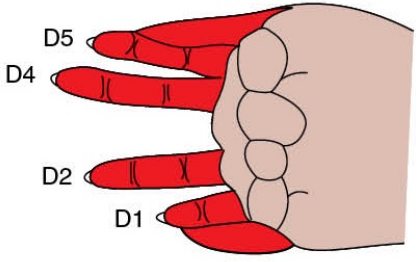


Video by Evan Lyall and Hillel Adesnik, UC Berkeley

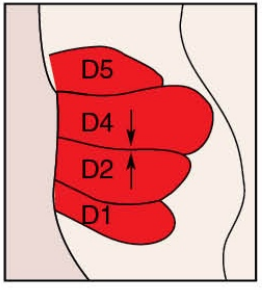
Somatotopic maps are plastic



Somatotopic maps are reorganized after injury



(c) Reorganization of cortical map after surgical removal of third finger (D3)

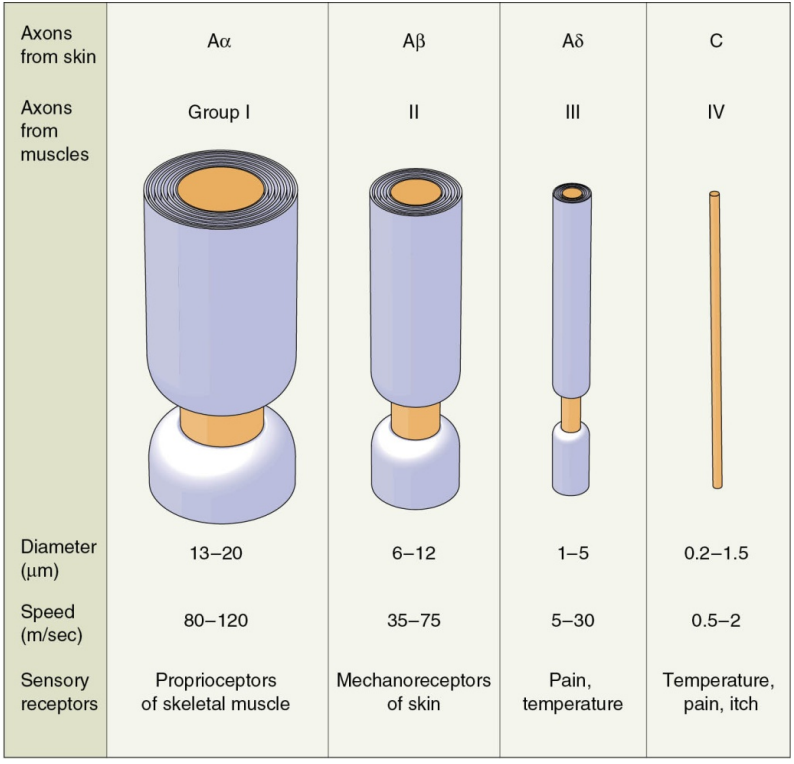


After reorganization of somatosensory cortex

Clicker Question 3:

Which of the following sensation will have a slower sensory percept?

A. Stretching your legs
B. Touch on your toes
C. Burning your finger tips
D. Itching your arm
E. Turning your neck



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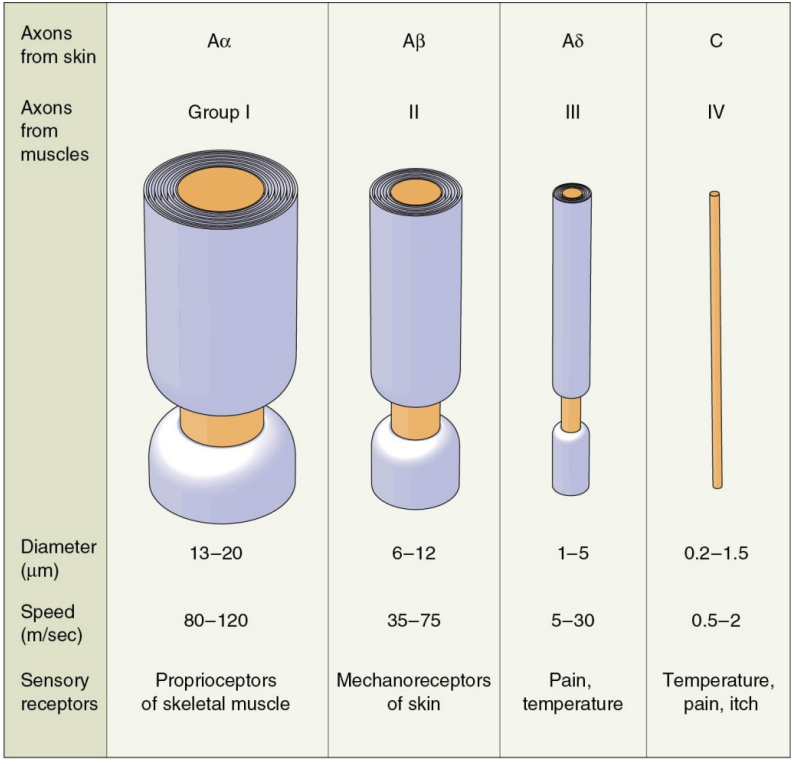


Take home messages: Sensory Systems

1. Sensory neurons convert physical/chemical stimuli to electrical signals through activation of sensory receptors through mechanisms we call sensory transduction.

2. Each sensory neuron has a receptive field. The magnitude of the receptive fields depend on the location of the sensory neuron as well as the neurophysiological properties of the receptor and the number of sensory receptors a given sensory neuron carry.

3. The sensory receptive fields are integrated in the brain to form cortical sensory maps. Exception is olfaction.

Take home messages: Somatosensation

1. Somatosensation is divided to two major classes. Proprioception, the sense of self motion that is mediated by stretch activated receptors in muscles and connecting tissues. Cutaneous senses that rely information to the brain about touch, temperature and pain.

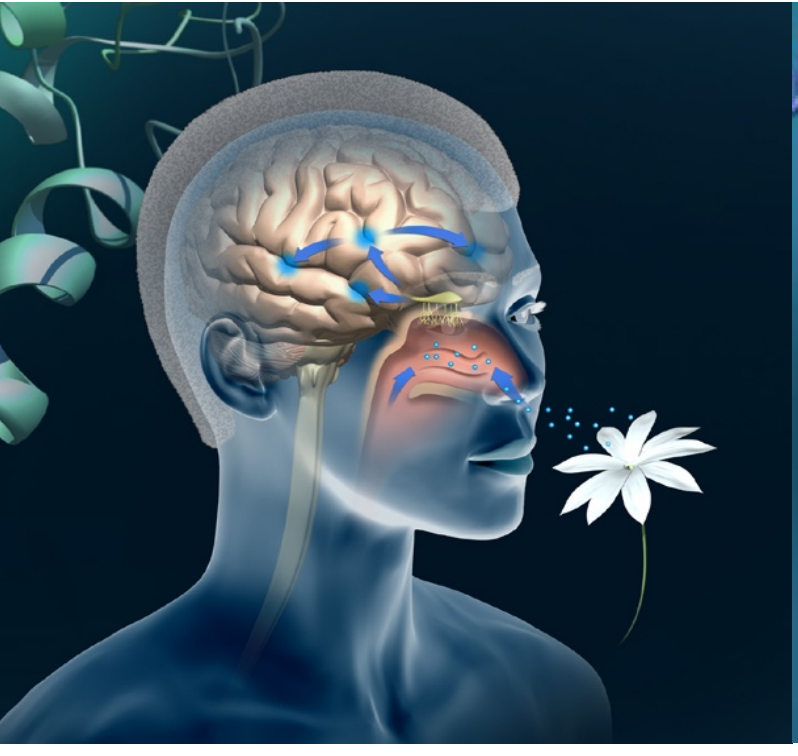
2. The sensory adaptation and speed of information transfer in cutaneous senses vary based on the structural and neurophysiological properties of the sensory neurons and the neural circuits that carry the information from them to the central brain .

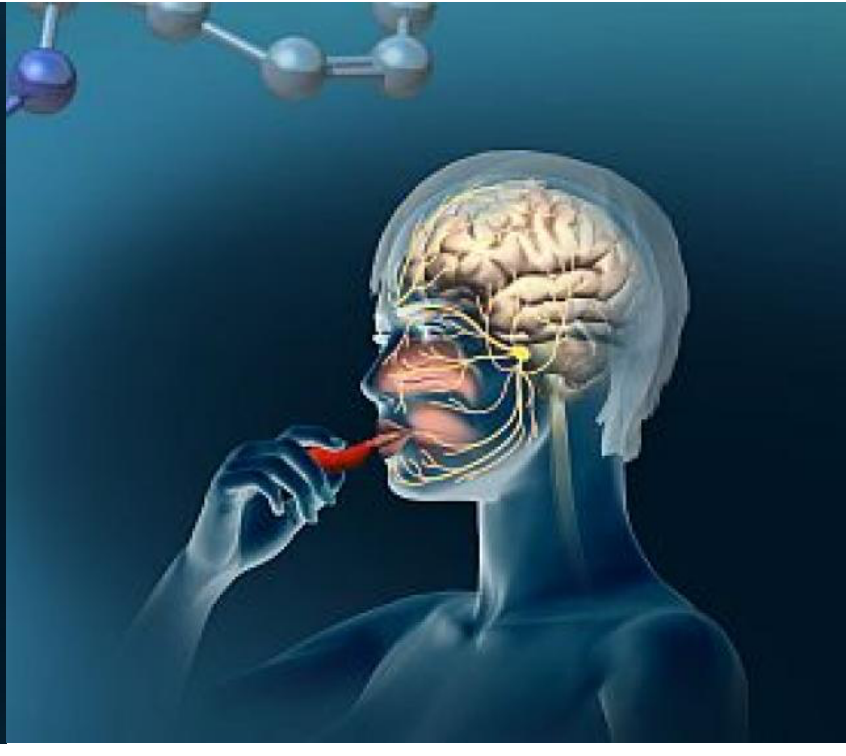
3. Somatic maps in the cortex are plastic, change in the anatomy of the peripheral sensory neurons will change the representation of the sensory stimuli in the cortex.

There is no truth. There is only perception.

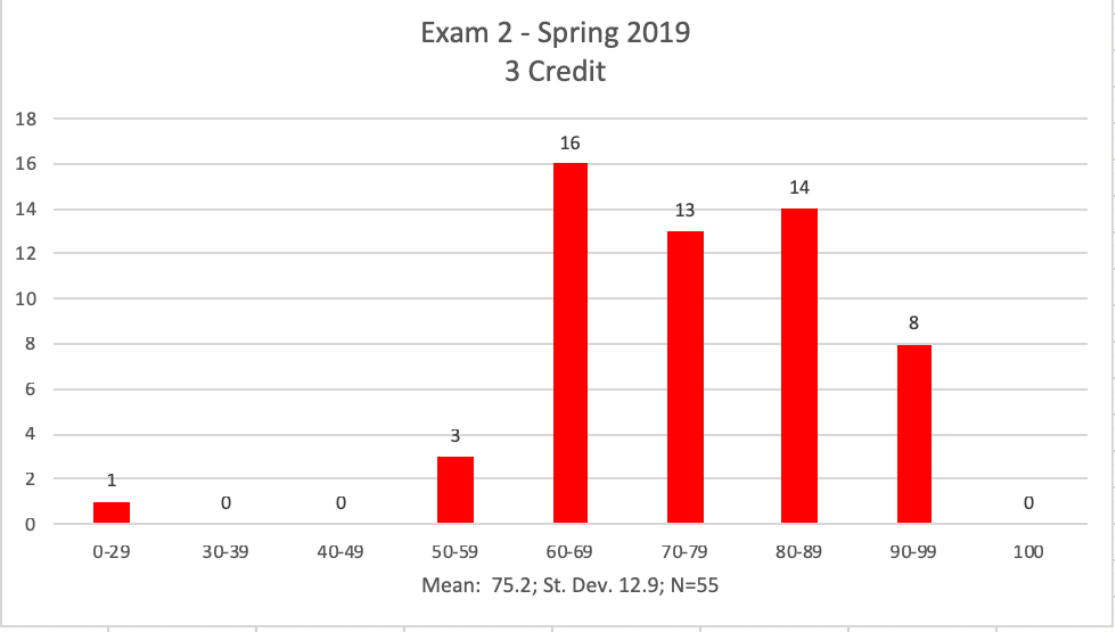
(Gustave Flaubert)

Next lecture: Chemical Senses





Exam Results



Exam Results