General physiology
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L18
Sensory receptors, sensory transduction and coding of sensory information

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Lectures objectives

- Describe the location, type, and function of sensory receptors Describe the steps involved in sensory transduction and action potential
- Explain why sensory receptors have specificity to sense one type of environmental energy over another.
- Describe the steps involved in sensory transduction and action potential and describe the generator (receptor) potential and its importance in sensory coding
- Explain the basic elements of sensory coding including modality, location, intensity, and duration of sensations
- Interpret the mechanism of receptor adaptation and classify the types of receptors accordingly (Phasic and Tonic receptors)
- Describe sensory neuronal processing and its functional importance
- Identify the various types of neuronal circuits and their function and importance of processing of neuronal signals

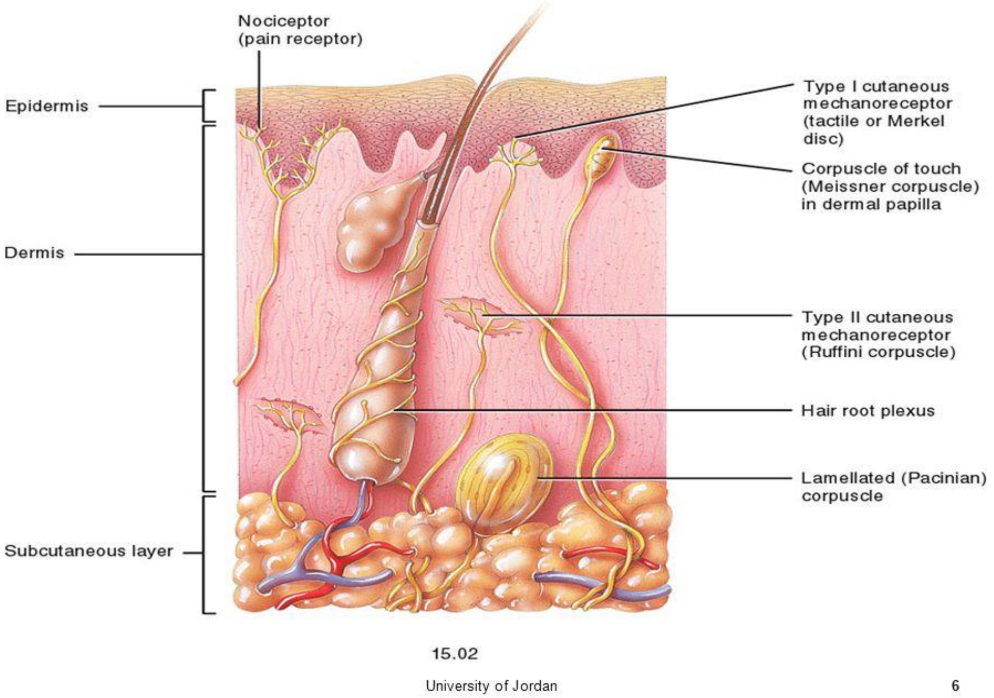
What is the significance of sensation to our body?

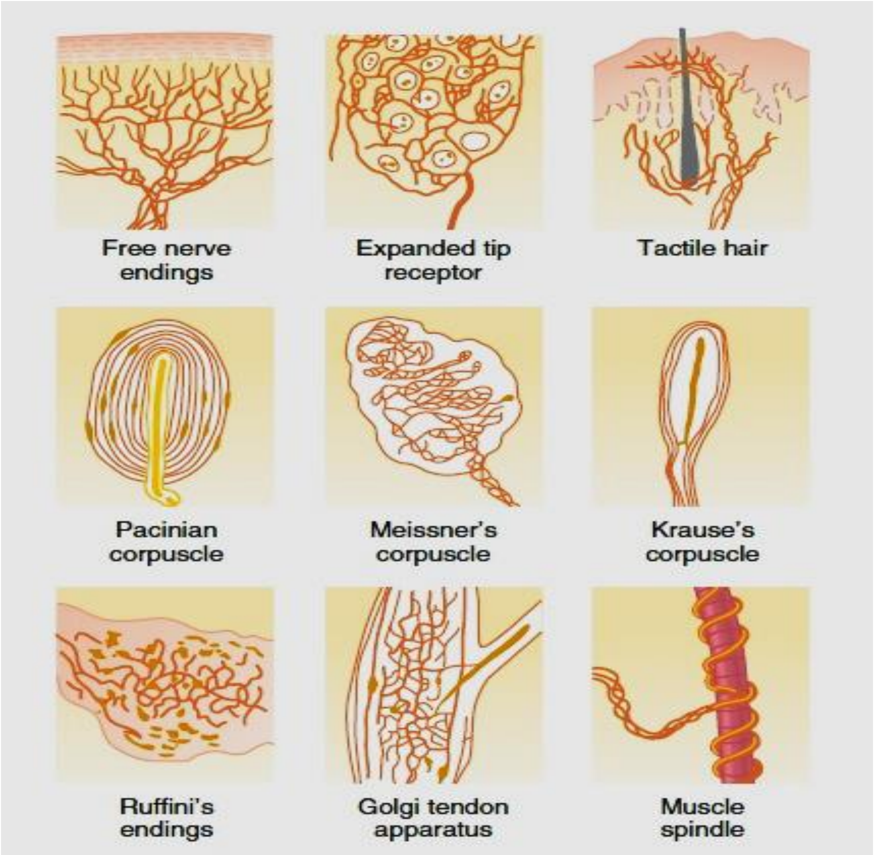
- The survival of any organism depends on having adequate information about the external environment as well as information about the state of internal bodily processes and functions.
- Essential for the control of efferent output.
- Critical for cortical arousal and consciousness.
- Central processing of sensory information gives rise to our perceptions of the world around us.
- Selected information delivered to the CNS may be stored for future reference as memories.
- Sensory stimuli can have a profound impact on our emotions.

Types of Sensory Receptors: Classification by Modality

- Mechanoreceptors t which detect mechanical compression or stretching of the receptor or of tissues adjacent to the receptor. Example Touch pressure, vibration Mechanoreceptors in cochlea which detects sound waves
- Thermoreceptors detect change in temperature **(Cold and warm rectors in skin) , central thermoreceptors in hypothalamus**
- Nociceptors detect tissue damage (pain receptors)
- Electromagnetic (Photoreceptors) detect light (Rods and Cones)
- Chemoreceptors taste, smell, CO2, O2 level in the arterial blood, osmolality of the body fluids, carbon dioxide concentration, the chemical content of the digestive tract, blood glucose etc.
- Some sensations are compound sensations, in that their perception arises from the central integration of several simultaneously activated primary sensory inputs. Example; the perception of **wetness** (touch, pressure, and thermal).

Several types of somatic sensory nerve





Several types of somatic sensory nerve endings.

Other Classifications of Receptors

- *Exteroreceptive sensations* are those from the surface of the body.
- *Proprioceptive sensations* are those relating to the physical state of the body, including position sensations, tendon and muscle sensations (Muscle spindles
- Golgi tendon receptors) , pressure sensations from the bottom of the feet,
- *Visceral sensations* are those from the viscera of the body. When using this term, one usually refers specifically to sensations from the internal organs.
- *Deep sensations* are those that come from deep tissues, such as from fasciae, muscles, and bone. They include mainly "deep" pressure, pain, and vibration

Differential Sensitivity of Receptors

- Each type of receptor is highly sensitive and highly specialized to respond to one **type of stimulus** . The stimulus which a receptor is most sensitive to is called **adequate stimulus**
- For example, photoreceptors are sensitive light, Osmoreceptors are sensitive to change in plasma osmolarity
- The minimum stimulus required to activate the receptor is known as the **threshold**.

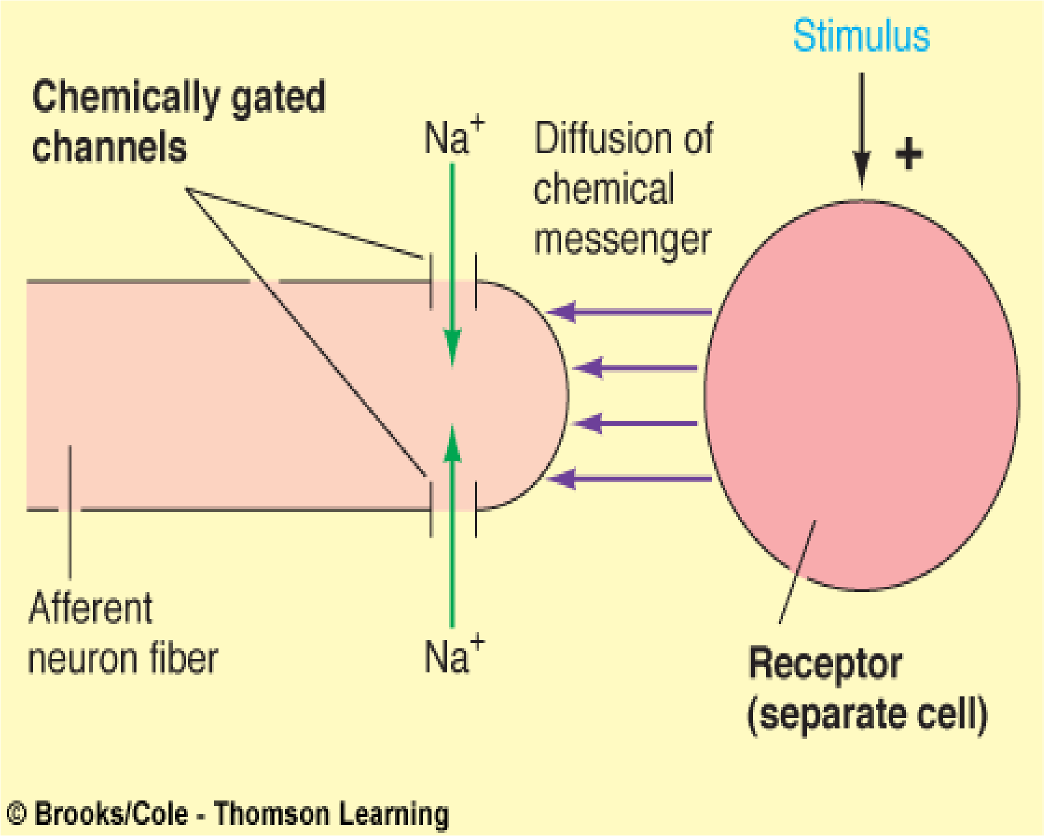
Modality of Sensation
The "Labeled Line" Principle

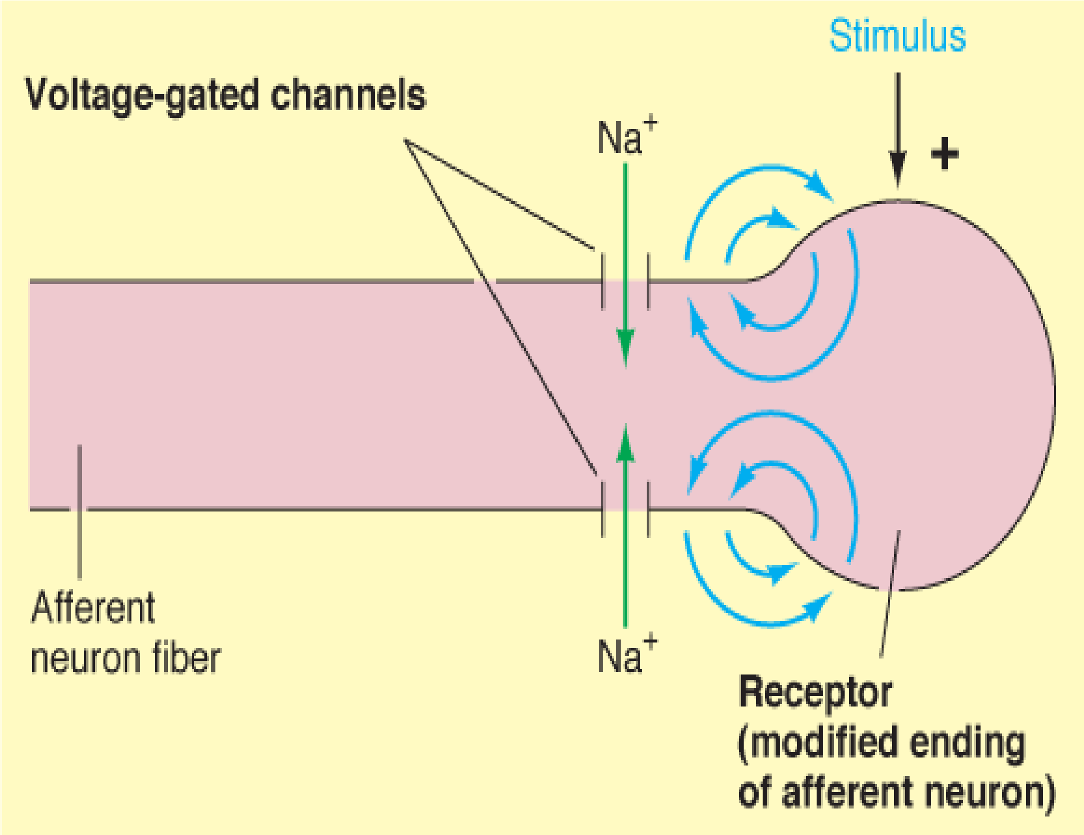
- Modality of sensations Each of the principal types of sensation that we can experience—pain, touch, sight, sound, and so forth—is called a *modality* of sensation
- However sensory fibers transmits sensation in the form of nerve impulses Therefore, how do different nerve fibers transmit different modalities of sensation?
- The answer is The type of sensation felt is determined by the **point in the central nervous system** at which the nerve fiber tract carrying sensations terminates
- This specificity of nerve fibers for transmitting only one modality of sensation is called the **labeled line principle**.

General Structure and Properties of Sensory Receptors

- All afferent neurons have receptors at their peripheral endings that respond to a stimulus in both the **external** and **internal** environments.
- A receptor may be either:
  - A specialized ending of the afferent neuron or free nerve endings
  - A separate receptor cell closely associated with the peripheral ending of the neuron.
  - Axons of receptors can be **myelinated** or **unmyelinated**.
- Somatosensory receptors such as free nerve endings consist of a neuron with an exposed receptor, whereas the special senses receptor in the ear for which detects a mechanical stimulation (non-neural) into a neural signal by synapsing onto a sensory neuron.
- All stimuli are <u>converted to action potentials</u> in sensory neurons.
- The sensory system codes the following properties of sensation : **modality of sensation** , **intensity**, **location**, and **duration of stimulus evoking sensations.**
- The CNS is able to accurately differentiate the incoming sensory stimuli from the PNS, by using four basic properties of the stimuli. These properties include **modality**, **intensity**, **location**, and **duration**.

General structure of receptors



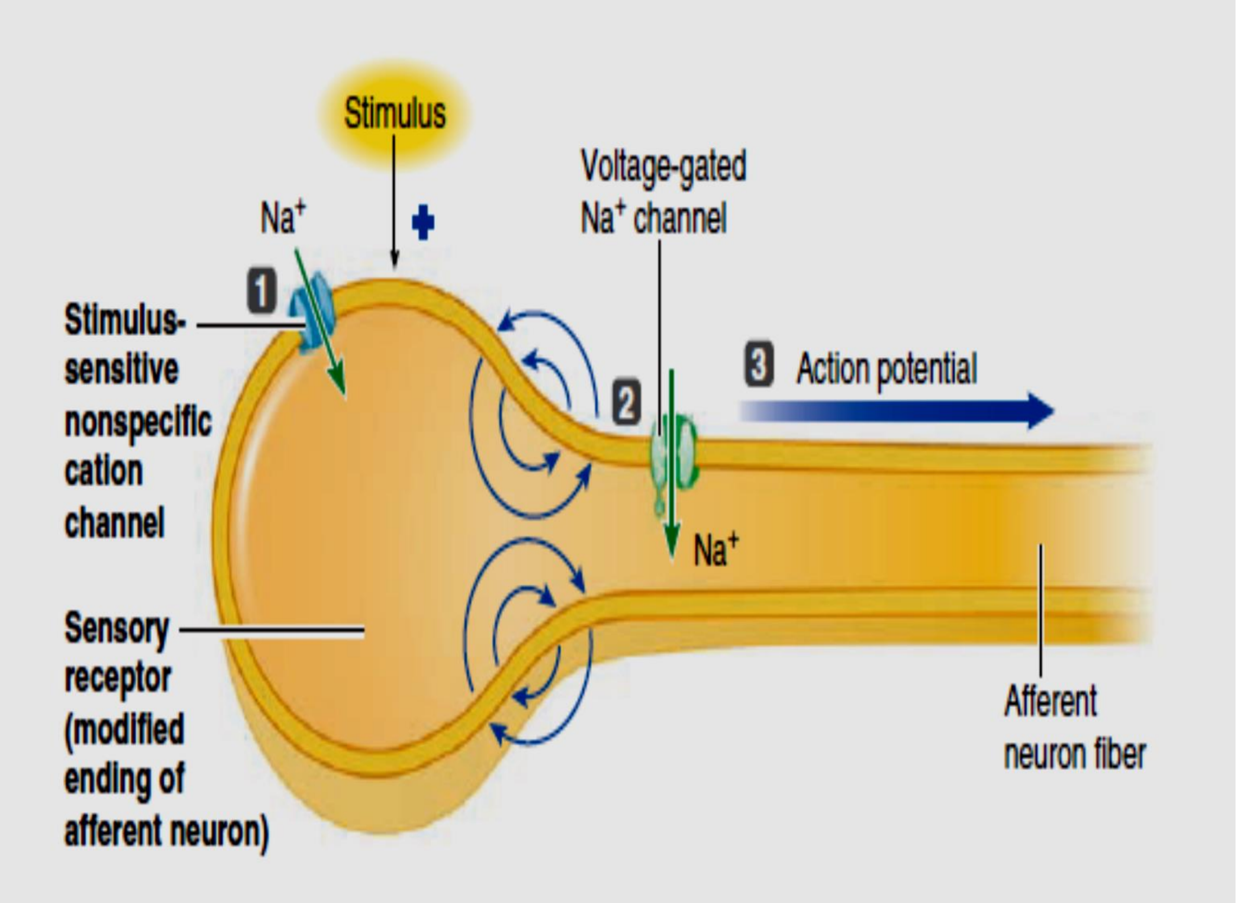


Transduction of Sensory Stimuli by Sensory Receptors

- **Transduction** is the conversion of the mechanical or chemical stimulation etc by a sensory receptor into an electrical signal (receptor potential and action action potential). This conversion is mediated through changes in ion permeability at controlled ion channels.
- Whatever the type of stimulus that excites the receptor, its immediate effect is an alteration in its membrane permeability and the generation of depolarization potential know as **receptor potential** due to nonselective opening of all small ion channels. Except for photoreceptors that hyperpolarize upon stimulation.
- The receptor potential is a **graded potential localized potntial** whose amplitude and duration can vary, depending on the strength and the rate of application or removal of the stimulus.

Sensory transduction in different receptors
Conversion of a stimulus to receptor potential and action potential

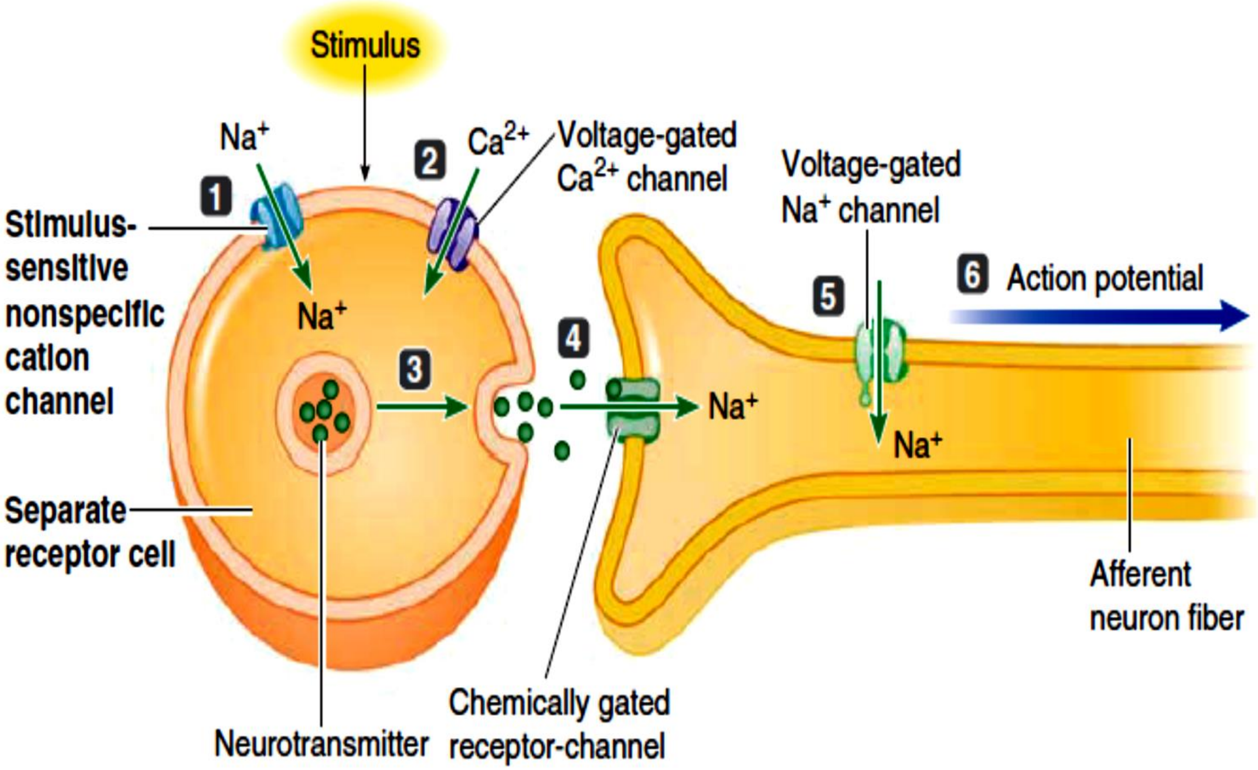
- In sensory receptors that are specialized afferent neuron endings, stimulus opens stimulus-sensitive channels, permitting net Na+ entry that produces receptor potential.
- Local current flow between depolarized receptor ending and adjacent region opens voltage-gated Na+ channels.
- Na+ entry initiates action potential in afferent fiber that self-propagates to CNS.



(a) Receptor potential in specialized afferent ending

Receptor potential in separate receptor cell afferent fiber that self-propagates to CNS.

- In sensory receptors that are separate cells, stimulus opens stimulus-sensitive channels, permitting net Na+ entry that produces receptor potential.
- This local depolarization opens voltage-gated Ca2+ channels. Ca2+ entry triggers exocytosis of neurotransmitter.
- Neurotransmitter binding opens chemically gated receptor-channels at afferent ending, permitting net Na+ entry.
- Resultant depolarization opens voltage gated Na+ channels in adjacent region.
- Na+ entry initiates action potential in afferent fiber that self-propagates to CNS.

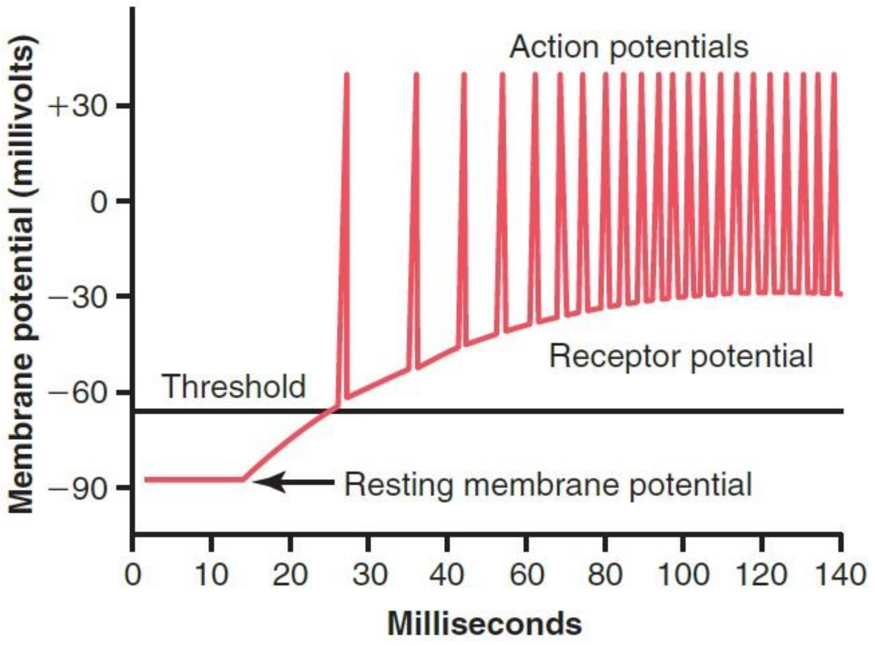


Transduction of Sensory Stimuli (cont.):

- Receptor stimulation and generation of receptor potentials are caused by one of the following :
  1. Mechanical deformation of the receptor, which stretches the receptor membrane and opens ion channels.
  2. Application of a chemical to the membrane, which also opens ion channels.
  3. Change of the temperature of the membrane, which alters the permeability of the membrane.
  4. The effects of electromagnetic radiation, such as light on a retinal visual receptor, which either directly or indirectly changes the receptor membrane characteristics and allows ions to flow through membrane channels.

Transduction of Sensory Stimuli (cont.):

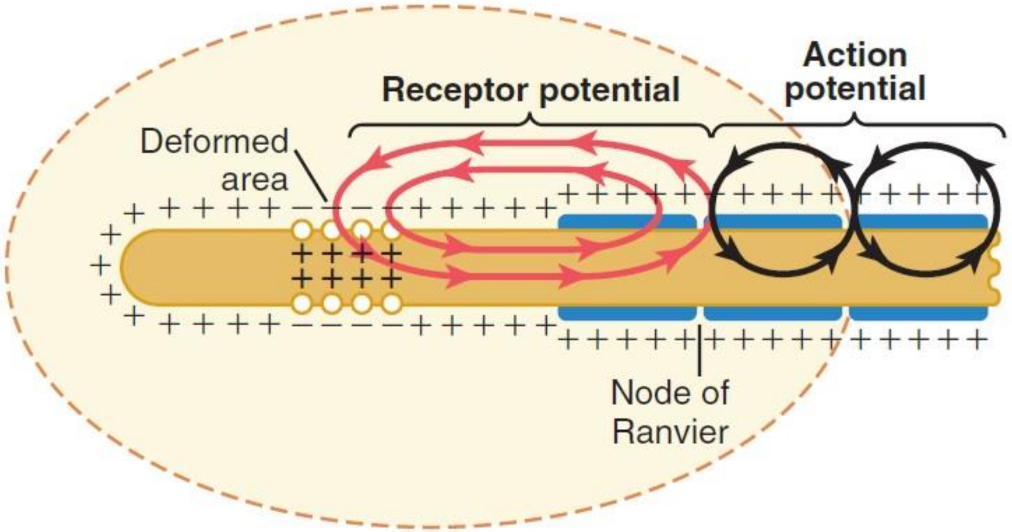
- The maximum amplitude of most sensory receptor potentials is about 100 millivolts. This is almost the same voltage recorded in action potentials and is also similar to the change in voltage when the membrane becomes maximally permeable to sodium ions.
- When the receptor potential rises above the threshold for eliciting action potentials in the nerve fiber attached to the receptor, then action potentials occur.
- The more the receptor potential rises above the threshold level, the greater becomes the action potential frequency.



Typical relation between receptor potential and action potentials when the receptor potential rises above threshold level.

Transduction of Sensory Stimuli (cont.):

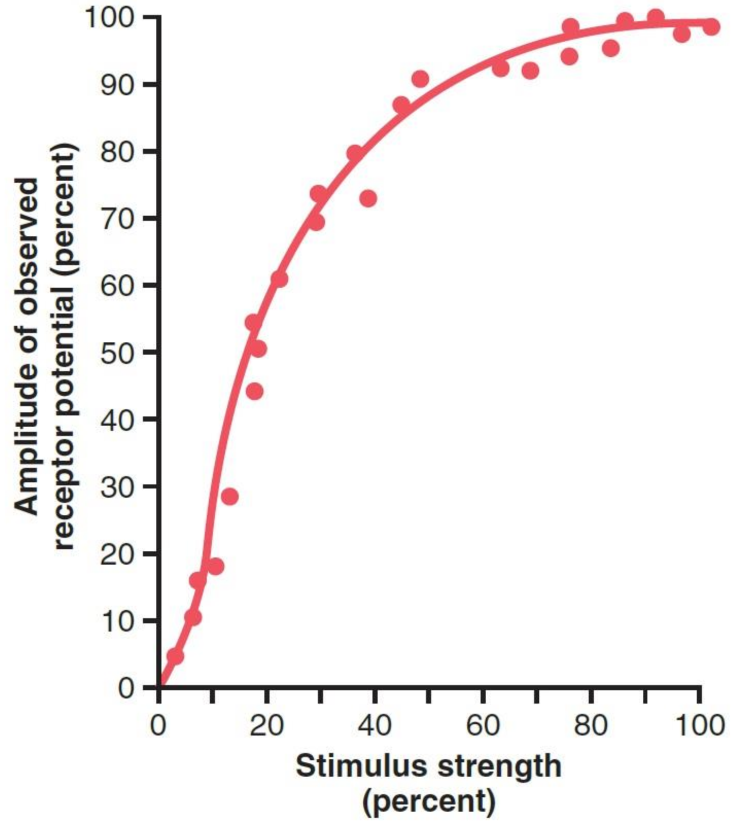
- The receptor potential is equal to the **increased positivity** inside the sensory nerve fiber.
- The receptor potential induces a local circuit of current flow that spreads along the nerve fiber.
- This local circuit can sets off typical action potentials that are transmitted along the sensory nerve fiber toward the central nervous system.



Excitation of a sensory nerve fiber by a receptor potential produced in a Pacinian corpuscle.

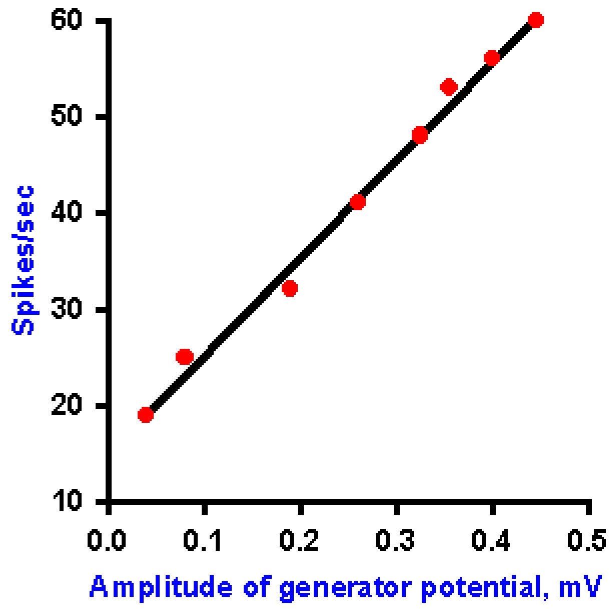
Transduction of Sensory Stimuli (cont.):

- The stronger the stimulus, the greater is the change in ion permeability, and the larger the amplitude of the receptor potential.
- This in turn increases frequency of repetitive action potentials transmitted from sensory receptors, approximately in proportion to the increase in receptor potential.



Relation of amplitude of receptor potential to strength of a mechanical stimulus applied to a Pacinian corpuscle.

Relation of generator potential amplitude and action potential frequency in afferent sensory neurons



Transduction of Sensory Stimuli (cont.):

- **Intensity** of a stimulus is a measure of the energy content available to interact with a sensory receptor.
- The intensity of the stimulus is reflected by the greater the frequency of action potentials generated in the afferent neuron. Stimulus intensity is also reflected by the size of the area stimulated, so correspondingly more receptors respond.
- Stimulus intensity is therefore distinguished both by the frequency of action potentials generated in the afferent neuron and by the number of receptors activated within the area.

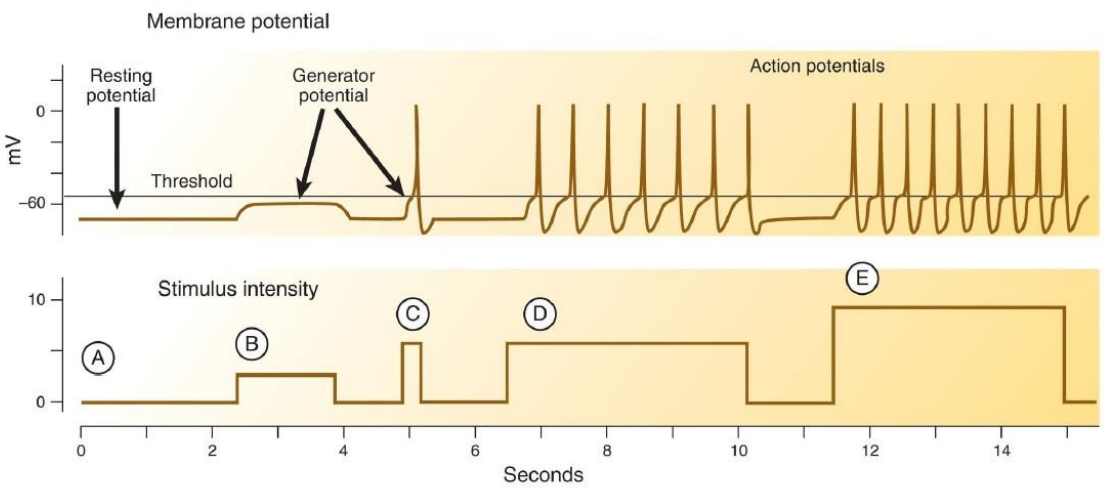


Figure Sensory nerve activity with different stimulus intensities and durations. **(A)** With no stimulus, the membrane is at rest. **(B)** A subthreshold stimulus produces a generator potential too small to cause membrane excitation. **(C)** A brief, but intense, stimulus can cause a single action potential. **(D)** Maintaining this stimulus leads to a train of action potentials. **(E)** Increasing the stimulus intensity leads to an increase in the action potential firing rate.

- As is true of all graded potentials, receptor potentials have **no refractory period**, so summation in response to rapidly successive stimuli is possible.

Coding of Sensory Information

Property of stimulus	Mechanism of coding
Type of Stimulus (stimulus modality)	Distinguished by the type of receptor activated and the specific pathway over which this information is transmitted to a particular area of the cerebral cortex Labeled line principle
Location of Stimulus	Distinguished by the location of the activated receptive field and the pathway that is subsequently activated to transmit this information to the area of the somatosensory cortex representing that particular location
Intensity of Stimulus (stimulus strength)	Distinguished by the frequency of action potentials initiated in an activated afferent neuron and the number of receptors (and afferent neurons) activated
Duration of Stimulus	Type of adaptation in receptors

Clinical note :

Diabetic patients can suffer from peripheral neuropathy of the longer afferent nerves first. That is why they may experience numbness or reduced ability to feel pain or temperature changes in the extremities.

Patients with diabetic neuropathy are unable to initiate or propagate adequate action potentials in response to mechanoreceptors, thermoreceptors, or even pain receptor stimulation.

Test Question:

Q. Which of the following represents the basis for transduction of a sensory stimulus into nerve impulses?

A. Change in the ion permeability of the receptor membrane
B. Generation of an action potential
C. Inactivation of a G-protein-mediated response
D. Protein synthesis
E. Intensity of stimulus at the free nerve ending