Sensory Receptors; Neuronal Circuits For Processing Information

Faisal I. Mohammed, MD, PhD
Objectives

➢ Define receptors (Transducers) and classify them
➢ Describe the generator (receptor) potential and its importance in sensory coding
➢ List the types of somatic receptors in the skin
➢ Explain the mechanism of sensory coding
➢ 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
Types of Sensory Receptors: Classification by Modality (Stimulus they transduce)

- **Mechanoreceptors**
  - detect deformation, Touch and Pressure

- **Thermoreceptors**
  - detect change in temperature

- **Nociceptors**
  - detect tissue damage (pain receptors)

- **Electromagnetic (Photoreceptors)**
  - detect light (Rods and Cones)

- **Chemoreceptors**
  - taste, smell, CO$_2$, O$_2$, etc.
Classification by Location

➢ Exteroceptors – sensitive to stimuli arising from outside the body
  ➢ Located at or near body surfaces
  ➢ Include receptors for touch, pressure, pain, and temperature

➢ Interoceptors – (visceroceptors) receive stimuli from internal viscera
  ➢ Monitor a variety of stimuli (distension of viscera, pain)

➢ Proprioceptors – sense of position- monitor degree of stretch
  ➢ Located in musculoskeletal organs (muscle, tendons and skin around joints)
Types of Sensory Receptors

- Free nerve endings
- Expanded tip receptor
- Tactile hair
- Pacinian corpuscle
- Meissner’s corpuscle
- Krause’s corpuscle
- Ruffini’s end-organ
- Golgi tendon apparatus
- Muscle spindle
Merckel’s disc for mechanical sensation (Touch in hairy skin)

Iggo dome receptors

Figure 47-1

Iggo dome receptor. Note the multiple numbers of Merkel’s discs connecting to a single large myelinated fiber and abutting tightly the undersurface of the epithelium. (From Iggo A, Muir AR: The structure and function of a slowly adapting touch corpuscle in hairy skin. J Physiol 200: 763, 1969.)
Tactile Receptors

- Free nerve endings (Aδ and C fibers)
  - detect touch and pressure
  - found everywhere in the skin and other tissues
- Meissner’s corpuscles (Aβ)
  - rapidly adapting (within a fraction of a second) and detect movement of light objects over skin
  - found on nonhairy skin (glabrous skin), fingertips and lips
- Merkel’s discs (Aβ)
  - respond rapidly at first and then slowly adapt, detect the “steady state”
  - found on hairy as well a glabrous (non hairy) skin
Tactile Receptors

- Hair end organ
  - adapts rapidly and detects movement over the body
- Ruffini’s end organ
  - slowly adapting and respond to continual deformation of the skin and joint rotation
- Pacinian corpuscle
  - very rapidly adapting and is stimulated only by rapid movement
  - detects vibration and other rapid changes in the skin
Tactile Sense Transmission

- Meissner’s corpuscles, hair receptors, Pacinian corpuscles and Ruffini’s end organs transmit signals in type Aβ nerve fibers at 30-70 m/sec.
- Free nerve endings transmit signals in type Aδ nerve fibers at 5-30 m/sec, some by type C unmyelinated fibers at 0.5-2 m/sec.
- The more critical the information the faster the rate of transmission.
Sensory Receptors: General structure

Receptor area is None-excitable region so as it can discriminate different intensities, otherwise it will not be able to differentiate strengths of stimuli.
Conversion of Receptor and Generator Potentials into Action Potentials

Receptor Potential

Generator Potential

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Law of Specific Nerve Energies

- Sensation characteristic of each sensory neuron is that produced by its normal or adequate stimulus.
- Adequate stimulus:
  - Requires least amount of energy to activate a receptor.
- Regardless of how a sensory neuron is stimulated, only one sensory modality will be perceived (specificity of receptors)
  - Allows brain to perceive the stimulus accurately under normal conditions.
Sensation

➢ Each of the principle types sensation; touch, pain, sight, sound, is called a *modality of sensation*.

➢ Each receptor is responsive to one type of stimulus energy. Specificity is a key property of a receptor, it underlines the most important coding mechanism, *the labeled line principle*

➢ How the sensation is perceived is determined by the characteristics of the receptor and the central connections of the axon connected to the receptor.
Receptor Excitation

➢ mechanical deformation which stretches the membrane and opens ion channels
➢ application of chemicals which also opens ion channels
➢ change in temperature which alters the permeability of the membrane through changing the metabolic rate
➢ electromagnetic radiation that changes the membrane characteristics
General Structure of Receptors

Receptor Region

Conducting Region

Spike Generating Region
Receptor Excitation
Receptor Potential

➢ The membrane potential of the receptor
➢ Excitation of the receptor results from a change in this potential.
➢ When the receptor potential rises above the threshold, action potentials appear and the receptor is active.
➢ The greater the intensity of the stimulus, the greater the receptor potential, and the greater the rate of action potential generation.
Generator Potentials

- In response to stimulus, sensory nerve endings produce a local graded change in membrane potential.
- Potential changes are called receptor or generator potential.
  - Analogous to EPSPs.
Relationship between Receptor Potential and Action Potentials
The effect of stimulus strength on RP amplitude

Greater sensitivity region

Lesser sensitivity region

Slop of the curve
The effect of the amplitude of RP on the frequency of impulses generated

![Graph showing the relationship between spike frequency and amplitude of generator potential. The frequency increases linearly with the amplitude.]
Adaptation of Receptors

When a continuous stimulus is applied, receptors respond rapidly at first, but response declines until all receptors stop firing.
Adaptation

➢ Rate of adaptation varies with type of receptor.
➢ Therefore, receptors respond when a change is taking place (i.e., think of the feel of clothing on your skin.)
Adaptation of Sensory Receptors

- Receptors responding to pressure, touch, and smell adapt quickly
- Receptors responding slowly include Merkel’s discs, Ruffini’s corpuscles, and interoceptors that respond to chemical levels in the blood
- Pain receptors and proprioceptors do not exhibit adaptation
Slowly Adapting (Tonic) Receptors

- continue to transmit impulses to the brain for long periods of time while the stimulus is present
- keep brain apprised of the status of the body with respect to its surroundings
- will adapt to extinction as long as the stimulus is present, however, this may take hours or days
- these receptors include: muscle spindle, golgi tendon apparatus, Ruffini’s endings, Merkels discs, Macula, chemo- and baroreceptors
Sensory Adaptation

- **Tonic receptors:**
  - Produce constant rate of firing as long as stimulus is applied.
  - Pain.

- **Phasic receptors:**
  - Burst of activity but quickly reduce firing rate (adapt) if stimulus maintained.
  - Sensory adaptation:
    - Cease to pay attention to constant stimuli.
Rapidly Adapting (Phasic) Receptors

- respond only when change is taking place
- **Rate and Strength** of the response is related to the **Rate and Intensity** of the stimulus
- important for predicting the future position or condition of the body
- very important for balance and movement
- types of rapidly adapting receptors: *pacinian corpuscle, semicircular canals* in the inner ear
Importance of Signal Intensity

- Signal intensity is critical for interpretation of the signal by the brain (i.e., pain).
- Gradations in signal intensity can be achieved by:
  1) increasing the number of fibers stimulated, **spatial summation**
  2) increasing the rate of firing in a limited number of fibers, **temporal summation**.
An example of spatial summation
Coding in the sensory system

- Intensity is coded for by:
  - Frequency of action potential
  - The No. of neurons stimulated

- Location is coded for by the labeled line principles

- Type of stimulus is coded for by the kind of receptor stimulated (Adequate stimulus) and specificity of the receptors.
<table>
<thead>
<tr>
<th>STIMULUS PROPERTY</th>
<th>MECHANISM OF CODING</th>
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<tbody>
<tr>
<td>Type of Stimulus (stimulus modality)</td>
<td>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</td>
</tr>
<tr>
<td>Location of Stimulus</td>
<td>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</td>
</tr>
<tr>
<td>Intensity of Stimulus (stimulus strength)</td>
<td>Distinguished by the frequency of action potentials initiated in an activated afferent neuron and the number of receptors (and afferent neurons) activated</td>
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</table>
Mapping of the Primary Somatosensory Area

- Mapping of the postcentral gyrus.
- Size of the cortical region representing a body part depends on density of receptors on that part and the sensory impulses received from that part.
Receptive Fields

- Area of skin whose stimulation results in changes in the firing rate of the neuron.
  - Area of each receptor field varies inversely with the density of receptors in the region.
- Back and legs have few sensory endings.
  - Receptive field is large.
- Fingertips have large # of cutaneous receptors.
  - Receptive field is small.
An example of spatial summation
Two-Point Touch Threshold

- Minimum distance at which 2 points of touch can be perceived as separate.
  - Measures of distance between receptive fields.
- Indication of tactile acuity.
  - If distance between 2 points is less than minimum distance, only 1 point will be felt.
Neuronal Processing
Relaying Signals through Neuronal Pools
Neuronal Pools

- groups of neurons with special characteristics of organization
- comprise many different types of neuronal circuits
  - converging
  - diverging
  - reverberating
Neuronal Pools: Localization of sensory Information modification

A

Divergence in same tract

A

Convergence from single source

B

Convergence from multiple sources
Convergence and Divergence

Convergence of input
(one cell is influenced by many others)

Divergence of output
(one cell influences many others)

Arrows indicate direction in which information is being conveyed.
Neuronal Pools: Modification of Localization: Sharpening of signals

Lateral inhibition
Lateral Inhibition

- Sharpening of sensation.
  - When a blunt object touches the skin, sensory neurons in the center areas are stimulated more than neighboring fields.
  - Stimulation will gradually diminish from the point of greatest contact, without a clear, sharp boundary.
  - Will be perceived as a single touch with well defined borders.
- Occurs within CNS.
Lateral Inhibition in the sensory System as a way of sharpening of the stimulus
Reverberating Circuits: prolongation of Time of the signals
The Organization of Neuronal Pools

(a) Divergence

(d) Parallel processing

(b) Convergence

(c) Serial processing

(e) Reverberation
Types of Circuits in Neuronal Pools

(a) Divergence in same pathway
(b) Divergence to multiple pathways
(c) Convergence, multiple sources
(d) Convergence, single source
(e) Reverberating circuit
(f) Parallel after-discharge circuit
Neural Circuits

(a) Diverging circuit
(b) Converging circuit
(c) Reverberating circuit
(d) Parallel after-discharge circuit

Figure 12.28  Tortora - PAP 12/e
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Other mechanisms for prolongation of time

- Synaptic afterdischarge: since the time of EPSP (15-20 msec) is longer than the time of AP (0.1 – 10 msec) then more No. of AP per one EPSP
- Parallel circuits
Stabilization of neuronal discharge

- Synaptic fatigue: short term and acute adjustment of sensitivity

- Neuronal inhibitory circuits:
  - Gross inhibition –Basal ganglia inhibits muscle tone
  - Feed back inhibition-Cortico-fugal fibers from cerebral cortex descending fibers to control the intensity and sharpness

- Downregulation and upregulation- Long term stabilization through modification of the receptor availability (internalization or externalization)