SENSORY NERVOUS SYSTEM
&
SENSORY RECEPTORS

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Learning Objectives

By the end of the lecture, you should be able to:
1. Define sensory receptors.
2. Classify sensory receptors.
3. Explain the process of sensory transduction.
4. Describe the structure, function and adaptation of the various mechanoreceptors.
5. Enlist the properties of the sensory receptors.
6. Comprehend the transmission and processing of signals in neuronal pools.
7. Classify the nerve fibers.
Sensory Deprivation Tank
Is the world really as we perceive it?
Is the world really as we perceive it?

NO. The world is different from how we perceive it.
WHAT IS NOT DETECTED BY THE RECEPTORS, THE BRAIN WILL NEVER KNOW.
Most sensory signals can reach conscious awareness, but others are processed completely at the subconscious level.
What is the Sensory or Somatosensory System?

The somatosensory system (or somato-visceral sensory system) transmits information from sensory receptor organs in the skin, muscles, joints and viscera to the cerebral cortex.
SENSORY SYSTEM

**CONSCIOUS**

Special senses
- Vision
- Hearing
- Taste
- Smell
- Equilibrium

Somatic senses
- Touch/pressure
- Temperature
- Pain
- Proprioception

**SUBCONSCIOUS**

Somatic stimuli
- Muscle length and tension

Visceral & Chemical stimuli
- Blood pressure
- pH/oxygen content in blood
- Osmolarity of body fluids
So many senses that need to be monitored, so much information that needs to be send to the CNS, but first, there must be a language in which all this information is conveyed.

What language would that be?
REMEMBER!
The only language that the Brain understands is ACTION POTENTIAL.

Thus, all forms of physical/ chemical/ thermal stimuli must be converted into Action Potential.
Sensory systems are designed to respond to the environment!
STIMULUS & MODALITIES

• A **stimulus** is a change in the environment that excites sensory receptors. The Sensory receptors then provide information about this stimulus to the CNS.

• Stimuli exist in a variety of energy forms, or **modalities**, such as heat, light, sound, touch, pressure, and chemical changes.

• All the information regarding all these senses is send to the CNS via **afferent/sensory neurons**.

• The **Response** to the stimulus is the effect that the stimulus has on the organism. Responses can be recognized at several levels:
  1. Receptor potential in sensory receptors
  2. Conversion of Receptor potential into Action Potential
  3. transmission of Action Potential along axons in the sensory neurons.
  4. Synaptic events in sensory neural networks
  5. Motor activity triggered by sensory stimulation, and ultimately
  6. **Behavioral** events.
How do receptors convert diverse physical stimuli, such as touch, heat or light or sound into electrical signals?
The first step is **TRANSDUCTION**
**TRANSDUCTION**

- **Transduction** is the conversion of stimulus energy (depending on the stimulus) into a graded potential and later into an action potential, so that the nervous system can understand it.

  **Stimulus**
  
  *Sensory* ↓ **Transduction**
  
  **RECEPTOR**
  
  ↓
  
  Receptor Potential
  (Graded Potential)
  
  ↓
  
  Action Potential
  (Afferent Neuron)
  
  ↓
  
  CNS

*FIGURE 6-6*  *Signal transduction*. An everyday example of signal transduction is a radio, which contains a transducer that converts radio waves into sound waves.
PLEASE NOTE

The change in potential produced in the sensory receptor is actually a graded potential and NOT an Action Potential. It is called the Receptor Potential.
Usually called Receptors are specialized sensory cells which act as biological transducers and convert various forms of energy into action potentials. They are either present as part of a neuron (afferent nerve ending) or separately as encapsulated or non-capsulated structures.

**SENSORY RECEPOTORS**
2 Types of Receptors

- Primary (1°)
  - Receptor membrane is part of the afferent neuron (e.g. pain receptors, Pacinian corpuscles)

- Secondary (2°)
  - Receptor membrane is a specialized sensory cell
  - Synapses with afferent neuron
(a) Receptor potential in specialized afferent ending

1. Stimulus-sensitive nonspecific cation channel
2. Sensory receptor (modified ending of afferent neuron)
3. Action potential

(b) Receptor potential in separate receptor cell

1. Stimulus-sensitive nonspecific cation channel
2. Voltage-gated Ca^{2+} channel
3. Separate receptor cell
4. Neurotransmitter
5. Chemically gated receptor-channel
6. Action potential
How is a physical or a chemical stimulus converted into a change in membrane potential?

Stimulus
(chemical/ mechanical/ thermal)
↓
Receptor which is either:
1. A specialized ending of the afferent neuron, OR
2. A separate receptor cell associated with a peripheral nerve ending.
↓
A graded potential is generated called RECEPTOR POTENTIAL.
↓
If the Receptor Potential is large enough
↓
An Action Potential is generated
Classification of Receptors (according to the SOURCE of the stimulus they respond to)

RECEPTORS

INTEROCEPTORS
Receptors which give response to stimuli arising from WITHIN the body.

EXTEROCEPTORS
Receptors which give response to stimuli arising from OUTSIDE the body.
INTEROCEPTORS

VISCEROCEPTORS
- Stretch Receptors (Heart)
- Baroreceptors (pressure changes in b.v)
- Chemoreceptors (chemical changes in blood)
- Osmoreceptors (Osmotic Pressure changes Urinary Tract & Brain)

PROPRIOCEPTORS
- Muscle Spindle
- Golgi Tendon Organs
EXTEROCEPTORS

CUTANEOUS RECEPTORS/MECHANO-RECEPTORS

ENCAPSULATED
- MEISSNER’S CORPUSCLE
- PACINIAN CORPUSCLE
- KRAUSE’S END BULB
- Merkel’s Disc
- Ruffini Endings

Expanded Tip on Free nerve Endings

Free or Naked Nerve endings

SPECIAL SENSES

CHEMORECEPTORS
- (Taste)

TELERECEPTORS
- (Vision, Smell & Hearing)

Pain
CLASSIFICATION

(According to the energy form they respond to)

- Chemoreceptors: $pH$, $O_2$, organic molecules
- Mechanoreceptors: vibration, acceleration, sound
- Photoreceptors: light
- Thermo receptors: temperature
- Nociceptors: tissue damage (pain)
TYPES OF MECHANO RECEPTORS
Skin Anatomy

**Epidermis**
- Two layers: dead outermost layer & inner living layer
- Keratin
- Melanin
- No blood vessels

**Dermis**
- Next inner layer
- Collagen
- Many blood vessels
- Nerve endings
- Sensory receptors
- Glands: sweat & sebaceous
- Smooth muscles
- Hair follicles

**Hypodermis**
- Mainly fat storage
- Contains larger blood vessels & larger nerve fibers
**PACINIAN CORPUSCLE**

- Multilayered capsules of CT in which axons end after they lose their myelin sheath. Under a microscope, it resembles an onion as it consists of concentric layers of CT around it.

- **SENSATION DETECTED:**
  Deep pressure & vibration.

- **LOCATION:**
  Dermis and partly in hypodermis of the extremities and also in pleura, peritoneum, mesenteries, external genitalia, walls of many viscera, periosteum, ligaments and joint capsules.

- **ADAPTATION:** Rapidly Adapting.
**MEISSNER’S CORPUSCLE**

- Multilayered capsules of CT surrounding a core of cells in which axons end after they lose their myelin sheath.
- Neuron is A-beta myelinated.

**SENSATION DETECTED:** Touch and pressure and to movement of objects across the skin and light vibration. Recognizes texture of objects.

**LOCATION:** Dermis and in papillae of the non-hairy or glabrous skin just below the epidermis. They are seen in palmer surface of fingers, lips, margins of the eyelids, nipples and external genital organs.

**ADAPTATION:** Very Rapidly Adapting (a reason why brain ignores clothes you are wearing after a while).
KRAUSE’S END BULBS

• SENSATION DETECTED: Cold sensation.

• LOCATION: Present in Conjunctiva, in papilla of lips and tongue, in skin of external genitalia.
MERKEL’S DISCS

- Expanded disc-like terminations termed as Merkel’s cell.
- Several Merkel’s cells may group together to form a single receptor organ, the IGGODOME receptor.
- **SENSATION DETECTED:** Sustained light touch, vibration and texture. Do NOT have a capsule, thus, they continuously produce action potentials.
- Innervated by a large myelinated A-beta nerve fiber.
- **LOCATION:** Epidermis and its junction with dermis of hairless and glabrous skin as well as skin containing hair.
- **ADAPTATION:** Initially strong and partially adapting and then slowly adapting. Thus, they give steady-state signals allowing one to appreciate continuous touch against the skin.
RUFFINI END ORGANS

• Ruffini Endings are enlarged dendritic endings with elongated capsules.

• **SENSATION DETECTED:** Sustained deep touch (as during a massage) and pressure. They also respond to stretch.

• **LOCATION:** Present in deeper dermis e.g. periosteum, ligaments and joint capsules (inform about joint rotation).

• **ADAPTATION:** Very Slowly adapting, thus, helpful in signaling continuous states of deformation.
A free nerve ending (FNE) is an unspecialized, afferent nerve ending. They detect pain. Where they detect pain, they are called NOCICEPTORS.

- They are the most widely distributed receptors in the body and can be excited by touch, cold, warmth and pain.
- Nerve fibers arising from them are myelinated A-delta and unmyelinated C fibers.
- If present around the hair base, they are called HAIR END-ORGAN.

LOCATION: All over the body: Skin, hair follicles, mucous membranes, serous membranes, deep tissues, muscle, tendons.

ADAPTATION: fast to slow adapting.
GENERAL PROPERTIES OF SENSORY RECEPTORS
The following are the properties of the Sensory Receptors:

1. Receptor Potential.
2. Adequate stimulus
3. Specificity of stimulus
4. Receptor field & Sensory Unit
5. Adaptation
6. Threshold.
1. RECEPTOR POTENTIAL

Receptor potential also called generator potential does not follow the all or none law, is a localized non-propagating change, is proportional to the strength of the stimulus and shows summation.
Figure 46-3 Excitation of a sensory nerve fiber by a receptor potential produced in a pacinian corpuscle. (Modified from Loëwenstein WR: Excitation and inactivation in a receptor membrane. Ann N Y Acad Sci 94:510, 1961.)
2. ADEQUATE STIMULUS

Receptors are specific to their stimulus and for each receptor, there is an adequate stimulus. Thus, adequate stimulus is the particular form of energy to which a receptor is most responsive.
**Adequate Stimulus**

- Even when activated by a stimulus other than its adequate stimulus, a receptor will give rise to the sensation detected by that receptor type.

- Photoreceptors of the eye respond most readily to light, for instance, but a blow to the eye may cause us to “see stars” - an example of mechanical energy providing sufficient force to stimulate the photoreceptors.

- We cannot “see” with our ears or “hear” with our eyes!
3. RECEPTIVE FIELD and SENSORY UNIT.

The location of a stimulus is coded according to the receptive fields that are activated.

RECEPTIVE FIELD: The sensory region supplied by a single sensory neuron and all its branches is called a receptive field.
- The more the number of receptive fields supplying an area the better the Two point discrimination.
- (It is similar to a motor unit and can be simplified for understanding as a sensory unit)

SENSORY UNIT: A sensory unit is a single primary afferent nerve including all its peripheral branches and the area they supply.
Only one receptive field stimulated by the two points of stimulation the same distance apart as in (a):

One point felt

Two receptive fields stimulated by the two points of stimulation:

Two points felt
Sensory Units and Receptive Fields

Figure 10.5

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4. SPECIFICITY OF STIMULUS
SPECIFICITY OF THE STIMULUS

CNS must distinguish four properties of a stimulus to be able to specify a stimulus:

- NATURE OR MODALITY
- LOCATION
- DURATION
- INTENSITY
Modality/ Nature of the stimulus

A sensation that we can experience is called a modality of sensation/stimulus.

The nature or modality of the stimulus is determined by the type of receptor activated and the pathway over which this information is send to a particular area in the cerebral cortex (Labeled Line Coding).
Labeled Line Coding

When a specific sensory modality detected by a specific receptor is sent over a specific afferent pathway and it excites a specific area in the somatosensory cortex, this is called **Labeled Line Coding**.

It is the specificity of the nerve fiber for transmitting only one modality of sensation.

**Example:** Stimulation of a cold receptor is always perceived as cold, whether the actual stimulus was cold or an artificial depolarization of the receptor or the nerve fiber was stimulated at any point throughout its path.
Location of the stimulus

Location of a stimulus is determined by its RECEPTOR FIELD.

Each area supplied by a receptor has a specific area represented in the Cerebral Cortex.

**Lateral inhibition** of the less activated regions leads to release of inhibitory NT that inhibits the region around the stimulated area.

The contrast leads to a better localization of the stimulated area known as Tactile localization.
### INTENSITY OF STIMULUS

<table>
<thead>
<tr>
<th>Increased Stimulus intensity</th>
<th>↓</th>
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<tbody>
<tr>
<td>Increased Receptor Potential strength</td>
<td>↓</td>
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<tr>
<td>Increased <strong>frequency</strong> of action potentials in the primary sensory neuron increases,</td>
<td>↓</td>
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<tr>
<td>Up to a maximum rate.</td>
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### DURATION OF STIMULUS

- The duration of a stimulus is determined by the duration of action potentials in the sensory neuron.
- A longer stimulus generates a longer series of action potentials.
COLDING FOR STIMULUS INTENSITY AND DURATION

Longer or stronger stimuli release more neurotransmitter.

1. Receptor potential strength and duration vary with the stimulus.
2. Receptor potential is integrated at the trigger zone.
3. Frequency of action potentials is proportional to stimulus intensity. Duration of a series of action potentials is proportional to stimulus duration.
4. Neurotransmitter release varies with the pattern of action potentials arriving at the axon terminal.
5. ADAPTATION (also called Desensitization.)

It is the decrease in response of receptors on being continuously stimulated. There are two types of receptors based on their adaptation:

1. Tonic receptors
2. Phasic receptors
THE PROCESS OF ADAPTATION TAKES PLACE THROUGH ONE OF THE TWO MECHANISMS:

**Redistribution of Viscous component of the receptor**

- When a distorting force is suddenly applied to one side of the corpuscle, this force is instantly transmitted by the viscous component eliciting a receptor potential.
- However, within a few hundredths of a second, the fluid within the corpuscle redistributes and the receptor potential is no longer elicited.
- Thus, the receptor potential appears at the onset of compression but disappears within a small fraction of a second even though the compression continues.

**Accommodation**

- Progressive “inactivation” of the sodium channels in the nerve fiber membrane, causing them to close gradually.
Part of the adaptation results from readjustments in the structure of the receptor itself, and part from an electrical type of accommodation in the terminal nerve fibril.

There are 02 (two) types of receptors based on whether the sensory receptors show adaptation or not.

1. Tonic Receptors
2. Phasic Receptors
Tonic Receptors are slowly adapting receptors that respond rapidly when first activated, then slow down and maintain their response (over many hours or even days).

E.g.: Baroreceptors, pain receptors, chemoreceptors and proprioceptors (golgi tendon organs and muscle spindle).

In general, the stimuli that activate tonic receptors are parameters that **must** be monitored continuously by the body.

It is important that these receptors do not adapt to a stimulus and continue to generate action potentials to relay this information to the CNS.
PHASIC RECEPTORS

Phasic receptors are rapidly adapting. They respond when they first receive a stimulus but stop responding if the strength of the stimulus remains constant.

E.g. many tactile receptors in the skin.

Some phasic receptors, most notably the Pacinian corpuscle, respond with a slight depolarization called the off response when the stimulus is removed. They are important in situations where it is important to signal a change in stimulus intensity.

When you put something on, you soon become accustomed to it.

When you take the item off, you are aware of its removal because of the “off” response.
6. THRESHOLD

All receptors need a minimum strength of stimulus to start showing activity; this strength is called the threshold.
IMPORTANT TERMS/CONCEPTS IN TRANSMISSION AND PROCESSING OF SIGNALS IN NEURONAL POOLS
Neuronal Pools

• A neuronal pool is a collection of neurons with their own special organization. They process signals in their own unique way. Some of these pools have few neurons while others have vast numbers.

E.g.

• Cerebral cortex pool of neurons
• Thalamus pool of neurons
• Cerebellum pool of neurons
Stimulatory field of a neuron

The neuronal area stimulated by each incoming nerve fibre is called its Stimulatory field.

The further away the neuron from an incoming neuron, the fewer the number of terminals stimulating it.

Presynaptic neuron 1 is excitatory for neuron a, and causes it to discharge, by giving suprathreshold stimulation. However, the same neuron 1 provides subthreshold stimulation to neuron b and c, making them facilitated.

Figure 46-9  Basic organization of a neuronal pool.
DIVERGENCE

- When weak signals entering a neuronal pool excite a larger number of nerve fibers, it is called Divergence.
- It can be of 2 types:
  1. AMPLIFYING DIVERGENCE (within the same tract) (Fig. A)
  2. DIVERGENCE INTO MULTIPLE TRACTS (Fig. B)

CONVERGENCE

- Convergence means signals from multiple inputs uniting onto a single neuron.
- It can be of 2 types:
  1. Convergence from a single source.
  2. Convergence from multiple sources
Neuronal circuits with both Excitatory & Inhibitory Output Signals

The input signal stimulates one neuron and inhibits another neuron...important in reciprocal inhibition in antagonistic muscles and also to prevent over activity in many parts of the brain.
Discharge zone

• Also called the excited zone or liminal zone.

• All the neurons synapsing with the terminals of the input fibres are stimulated in the central portion designated by the circle.

• To each side, the neurons are facilitated but not excited, and these areas are called the facilitated zone (also called the subthreshold zone or subliminal zone).
Prolongation of a signal by a neuronal pool: 

**Afterdischarge**

When a signal coming from a neuronal pool causes a prolonged output discharge, lasting a few milliseconds to as long as many minutes after the incoming signal is over, it is called an **Afterdischarge**.

It can be due to:

1. Synaptic discharge (due to neuromodulators)
2. Reverberatory circuits
Reverberatory Circuits

These are the most important circuits in the entire nervous system that are caused by positive feedback within the neuronal circuit that feeds back to re-excite the input of the same circuit. Thus, the circuit may discharge repetitively for a long time.
Classification of Nerve fibers
There are 2 types of classifications:
1. General Classification
2. Sensory Classification
And they are classified according to the following 5 parameters:
1. Myelination of the nerve fiber
2. Diameter of the nerve fiber
3. Conduction velocity of the nerve fiber
4. Sensory functions
5. Motor functions
**SENSORY CLASSIFICATION OF THE NERVE FIBERS**

- **Type A fibers** are the typical large and medium-sized *myelinated* fibers of spinal nerves.
- **Type C fibers** are the small *unmyelinated* nerve fibers that conduct impulses at low velocities. The C fibers constitute more than one half of the sensory fibers in most peripheral nerves, as well as all the postganglionic autonomic fibers.
- Note that a few large myelinated fibers can transmit impulses at velocities as great as 120 m/sec, a distance in 1 second that is longer than a football field.
- Conversely, the smallest fibers transmit impulses as slowly as 0.5 m/sec, requiring about 2 seconds to go from the big toe to the spinal cord.
SENSORY FIBER CLASSIFICATION
Diagram showing comparative fiber sizes and thickness of myelin sheaths

A-alpha
- Group I
- Muscle Spindle I
- Muscle Tendon (Golgi)
- Vibrations
- Hair Receptors
- 120 to 60 m/sec.

A-beta
- II
- Muscle Spindles II
- Light Touch
- Hair Receptors
- 60 to 30 m/sec.

A-Delta
- III
- Deep Pressure
- Pricking Pain
- Cold
- 30 to 6 m/sec.

C
- IV
- Aching Pain
- Crude Touch
- Pressure
- Warm
- 2.0 to 0.5 m/sec.

Fig. 2