Sensory Receptors
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OBJECTIVES

After studying the material of this lecture the student should be familiar with:

1. Define the terms stimulus modality, adequate stimulus, and threshold.
2. Describe the relationship between receptor potential and action potential firing rate.
3. Explain the differences between tonic and phasic mechanoreceptors.
4. Describe the relationship between nerve fiber diameter and conduction velocity.
5. Describe a method used to classify nerve fibers.

I. SENSE ORGANS AND RECEPTORS

Sense organs play an important role in providing the nervous system with information about our external and internal environments. Specialized receptors provide continuous monitoring of both internal (P_{CO2}, blood pressure, muscle spindles...) and external (visual, auditory, chemical...) stimuli. Sensory receptors function to detect and transduce stimulus information into electrical signals that can be transmitted by way of sensory nerve fibers to specialized regions of the central nervous system.

A. Structure and Function

1. Accessory structure

Stimulus energy reaches sensory receptors directly or by way of accessory structures that attenuate, direct, or modify the stimulus.

2. Transduction

The stimulus interacts with the receptor cell membrane to produce a graded change in membrane potential. This change in membrane potential is known as the receptor potential.

3. Receptor potential

Changes in membrane potential cause ion channels to open and local current flow within the sensory receptor cell. If the receptor cell has an axon (i.e., is a sensory neuron) then this current could act to depolarize the axon and initiate an action potential. These graded depolarizations when observed in sensory neurons are called generator potentials.
4. **Threshold**

When generator potentials reach a threshold level, action potentials are initiated and impulses are transmitted down the sensory nerve fiber towards the CNS.

**B. Terms and Concepts**

1. **Stimulus Modality**

The sensation or sensory impression mediated by a particular sense organ is referred to as a **modality**. The five basic senses of touch, sight, sound, smell and taste are examples of sensory modalities. Other modalities include vibration, warmth, coolness, and pain.

2. **Adequate Stimulus**

The stimulus modality to which a sense organ responds optimally is referred to as the **adequate stimulus**. Although it is possible for some receptors to respond to strong stimuli of a different modality (i.e., intense pressure or a blow to the eyes gives the sensation of seeing "stars"), in general receptors are most sensitive (have lowest threshold) to a single stimulus modality.

3. **Labelled Line Principle**

Fiber tracts that mediate sensations of a particular sensory modality are referred to as labeled lines. These fibers project to specific regions or centers in the nervous system and when stimulated produce a sensation similar to that produced by stimulation of their receptors. Thus the fibers of the optic nerve represent a labeled line for vision, the olfactory nerves a labeled line for smell, and the auditory nerves a labeled line for hearing.

4. **Stimulus Quality**

Within a given sensory modality there are usually differences in the quality or the level of the sensory impression. For example, light can appear to be red, green, blue, etc. (color spectrum). Pitch or frequency is a quality of sound, and sweet, sour, bitter, and salty are qualities of taste. Quality is determined by the specific sensory stimuli and its interaction with receptor cells within a sense organ.

5. **Stimulus Quantity (Intensity)**

The **quantity** of a sensory impression refers to the **intensity or strength**
of the stimulus. The lowest stimulus intensity capable of eliciting a response is called the **stimulus threshold**.

II. **Classification of Sensory Receptors**

Sensory receptors are classified into groups according to the type of stimulus energy to which they respond. These groups include: mechanoreceptors, thermoreceptors, electromagnetic receptors (photic receptors), chemoreceptors, and nociceptors.

III. **Table 1 Types and Examples of Sensory Receptors (From Costanzo 2006, 3-2)**

<table>
<thead>
<tr>
<th>Type of Receptor</th>
<th>Modality</th>
<th>Receptor</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanoreceptors</td>
<td>Touch, Audition,</td>
<td>Pacinian corpuscle</td>
<td>Skin</td>
</tr>
<tr>
<td></td>
<td>Vestibular</td>
<td>Hair cell</td>
<td>Organ of Corti</td>
</tr>
<tr>
<td>Photoreceptors</td>
<td>Vision</td>
<td>Rods and cones</td>
<td>Cupula, semicircular canal</td>
</tr>
<tr>
<td>Chemoreceptors</td>
<td>Olfaction, Taste,</td>
<td>Olfactory receptor</td>
<td>Retina</td>
</tr>
<tr>
<td></td>
<td>Arterial $P_O_2$, pH of CSF</td>
<td>Taste buds</td>
<td></td>
</tr>
<tr>
<td>Thermoreceptors</td>
<td>Temperature</td>
<td>Cold receptors</td>
<td>Tongue</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Warm receptors</td>
<td>Carotid and aortic bodies</td>
</tr>
<tr>
<td>Nociceptors</td>
<td>Extremes of pain and temperature</td>
<td>Thermal nociceptors</td>
<td>Ventrolateral medulla</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Polymodal nociceptors</td>
<td></td>
</tr>
</tbody>
</table>

CSF: Cerebrospinal fluid. $P_O_2$: partial pressure of oxygen.

A. **Receptor Potential** (Generator Potential)

Different types of stimuli (mechanical, chemical, thermal, electromagnetic radiation, etc.) all act to alter membrane permeability of the receptor and generate receptor potentials. **Receptor potentials** are graded electrical responses of a sensory receptor cell to an external stimulus. If the receptor cell is a sensory neuron then the receptor potential is also called a **generator potential**. In some cases, sensory receptors are not neurons (taste receptors, auditory hair cells...) and the receptor potential must be transferred in some way to the sensory neuron. A graded membrane potential (generator potential) must be set up in a sensory neuron in order to generate action potentials.
In the case of the pacinian corpuscle mechanical deformation of the nonmyelinated tip of the receptor leads to a local depolarization of the membrane. This depolarization is both a receptor and generator potential since in this particular case the receptor cell is also the primary sensory neuron.

As the magnitude of the membrane depolarization increases so does the amount of positively charged ions that enter the nerve ending. The flow of positively charged ions travels down the core of the nerve fiber and causes a membrane depolarization at the first node of Ranvier. If the depolarization at the node of Ranvier exceeds a threshold level an action potential is generated.

The passive flow "electrotonic spread" of ions is limited to short distances and is determined by the length constant of the membrane. In contrast the action potential is an active process and can be propagated over relatively long distances.

B. **Stimulus Strength vs. Receptor Potential**
As the stimulus strength increases the amplitude of the receptor potential increases. The amplitude of the receptor potential decreases with distance along the length of the receptor membrane. Stimulation at different points along the receptor can have an additive effect on receptor potential (spatial summation).

C. **Generator Potential vs. Firing Rate**

![Figure 3: From Guyton & Hall, 1996](image)

When the generator potential (or receptor potential) reaches threshold, an action potential is initiated. Further increases in membrane potential leads to an increase in the number of action potentials produced. The number of action potentials (firing rate) is almost directly proportional to the amplitude of the generator potential.

D. **Adaptation**

Adaptation is a property of all sensory receptors. The rate at which receptors adapt plays an important role in receptor function.

![Figure 4. Rapidly and Slowly Adapting Receptors](image)
1. **Tonic receptors**

Tonic receptors are **slowly adapting** and as such are good indicators of stimulus strength. Their response is proportional to the stimulus intensity and they maintain their response for the duration of the stimulus. They help to keep the brain constantly appraised of the status of the body and its external as well as internal environment. Mechanoreceptor located on the glabrous skin and joint receptors are good examples of tonic receptors.

2. **Phasic receptors**

Phasic receptors are **rapidly adapting** and signal temporal changes in the stimulus. Phasic receptors are usually not very good at signaling stimulus intensity. They are good at detecting rapid changes such as stimulus onset, movement, and termination of a stimulus event. These receptors are especially good at signaling the rate at which a change is taking place. This is an important function in predicting future events so that the nervous system can make predictions ahead of time and make necessary adjustments to such changes. The pacinian corpuscle is a classic example of a phasic or rapidly adapting mechanoreceptor.

### III. CLASSIFICATION OF NERVE FIBERS

#### A. Fiber Diameter and Conduction Velocity

![Figure 5. Conduction velocity of nerve fibers](image)

Nerve fibers are classified according to their size and conduction velocity. The larger myelinated axons have the fastest conduction velocities reaching speeds of up to 120 meters/sec. These rapidly conducting fibers are critical for such functions as body and limb movement where split second changes and corrections are necessary for coordinated movement. As fiber diameter decreases and the thickness of myelin decreases, conduction velocity becomes slower. The smallest
fibers (C fibers) are unmyelinated and have conduction velocities ranging from only .5 to 2 meters/second.

B. **Two Classification Systems**

1. **Gasser & Erlanger System** (General)

   A general classification system that includes all sensory, motor, and autonomic nerve fibers. This system is based on electrophysiological measurements of conduction velocity determined from compound action potentials of mixed nerve.

2. **Lloyd & Hunt System** (Sensory only)

   This is a system developed for sensory fibers and is based primarily on size and fiber origin. The major components are: Group Ia (primary muscle spindle afferents), Group Ib (golgi tendon organ), Group II (secondary muscle spindle afferents, cutaneous touch and pressure), Group III (deep pressure and touch), and Group IV (pain and temperature).

**Table 2** Classification of Nerve Fibers  (From Costanzo, 2006, 3-1)

<table>
<thead>
<tr>
<th>Classification</th>
<th>Type of Nerve Fiber</th>
<th>Example</th>
<th>Relative Diameter</th>
<th>Relative Conduction Velocity</th>
<th>Myelination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensory and Motor</td>
<td>A alpha (Aα)</td>
<td>α Motoneurons</td>
<td>Largest</td>
<td>Fastest</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>A beta (Aβ)</td>
<td>Touch, pressure</td>
<td>Medium</td>
<td>Medium</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>A gamma (Aγ)</td>
<td>γ Motoneurons to muscle spindles (intrafusal fibers)</td>
<td>Medium</td>
<td>Medium</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>A delta (Aδ)</td>
<td>Touch, pressure, temperature, pain</td>
<td>Small</td>
<td>Medium</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>Preganglionic autonomic nerves</td>
<td>Small</td>
<td>Medium</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>Slow pain; postganglionic autonomic nerves; olfaction</td>
<td>Smallest</td>
<td>Slowest</td>
<td>No</td>
</tr>
<tr>
<td>Sensory Only</td>
<td>Ia</td>
<td>Muscle spindle afferents</td>
<td>Largest</td>
<td>Fastest</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Ib</td>
<td>Golgi tendon organ afferents</td>
<td>Largest</td>
<td>Fastest</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>Secondary afferents of muscle spindles; touch, pressure</td>
<td>Medium</td>
<td>Medium</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>Touch, pressure, last pain, temperature</td>
<td>Small</td>
<td>Medium</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>IV</td>
<td>Pain, temperature; olfaction</td>
<td>Smallest</td>
<td>Slowest</td>
<td>No</td>
</tr>
</tbody>
</table>

**ADDITIONAL REFERENCES**
