physiology

premed 2018 - JU

◉ Sheet ○ Slides

Number

14

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➢ **Topics that will be discussed throughout this sheet:**

1. Sensory receptors and stimulus energy.
2. Classifications of Sensory receptors.
3. Types of Sensory receptors.
4. Tactile receptors (touch and pressure receptors).
5. General structure of Sensory receptors (Receptor and Generated potentials).
6. Relation between Rate of action potential and intensity of the stimulus.
7. Adaptation (mentioned very briefly throughout this sheet. It will hopefully be thoroughly discussed in the following sheets.

➢ Sensory receptors and stimulus energy:

i. **Sensory receptors** are structures that **transduce stimulus energy** to **electrical energy (action potential)**, to be able to sense pain, pressure, touch, smell, etc…

ii. **Stimulus energy** is the energy that the sensory receptors detect and transduce to action potentials, it can be chemical energy (smell and pain), it can be mechanical energy (touch and pressure), it can be photoelectric energy (light) etc…

- Sensory receptors transduce **stimulus energy** to **electrical energy** (action potential), so no matter what the stimulus is (heat, pain, touch etc…) , it will get transduced to electrical energy, and the stimulus that will reach your brain is always electrical (action potential), so how does the brain (cerebral cortex) determine:

A. the **type** of the stimulus (pain, touch, etc…).
B. the **strength** (intensity) of the stimulus.
C. the exact **location** of the stimulus (hand, leg, shoulder etc…).

A. How does the brain determine the type of stimulus?

- **Through the specificity of the receptors:**
  When a stimulus is applied, not all sensory receptors respond, only those sensitive to the specific type of stimulus applied, which consequently have a specific pathway and destination in the brain.

- **Through the specific pathway (tract)** starting from the sensory receptor and terminating in the brain. Each receptor has its own unique pathway. Once the electric current reaches the brain through a certain pathway, the brain can interpret that current as a sensation according to which pathway it arrived from and where in the brain it terminated.
- No matter where the stimulus takes place along a specific pathway, if it travels through the same tract and ends at the same point in the brain, the action potential will always be interpreted as the same sensation.

- **Example:** there is a certain pathway for pain receptors, so if these receptors are stimulated, the stimulus (pain) gets transduced through receptors to electrical energy, and through that pathway it will reach the brain, then the brain interprets the electrical current as a sensation of pain because the current came through the pathway of pain.

B. How does the brain determine the strength of the stimulus?

- All signals that reach the brain are represented electrically in the form of action potentials. But action potentials have constant magnitude. The brain distinguishes a strong stimulus from a weak one not through the magnitude of the action potential (which is constant), but instead through the **<u>frequency (rate) of action potentials that reach it</u>**.

- **Example:** you feel pain in both your hand and shoulder, the one in your hand is sending to the brain 200 action potentials/sec, and the one in your shoulder is sending 300 action potentials/sec, this means you feel more pain in your shoulder than your hand (stronger stimulus).

C. How does the brain determine location of the stimulus?

- Similar to point A mentioned previously, the tract and pathway through which the signal passes and where it terminates in the brain causes the brain to identify the original location of the stimulus (hand, leg …etc).

- **Receptors** are **Transducers**
  Transducer: (in general) is something that converts any type of energy to electrical energy.

➢ Classifications of sensory receptors:

❖ **Sensory receptors can be classified according to:**

1) **Modality** (the kind of sensation (stimulus) this receptor can transduce)

a) **Mechanoreceptors**: detect deformation, touch, pressure.

b) **Thermoreceptors**: detect change in temperature (hot/cold)

c) **Nociceptors**: detect tissue damage (pain receptors)*.

d) **Photoceptors**: detects light, examples are rods and cones (العصيات و المخاريط)

e) **Chemoreceptors**: taste, smell, CO_2, O_2 etc…

* Nociceptors: detect pain, and pain is due to tissue damage, and such receptors are sensitive to chemicals that are associated with and cause tissue damage.

2) **Location** (where the receptor is located):

a) **Exteroceptors:**

- ✓ sensitive to stimuli arising from outside the body e.g. temperature, pressure, touch, pain etc …
- ✓ Located at or **near body surfaces**
- ✓ Include receptors for touch, pressure, pain and temperature

b) **Interoreceptor (viscerocepters):**

- ✓ located on **internal organs** and receive stimuli from internal viscera (internal organs in cavities). e.g. internal pain, hunger etc…
- ✓ Monitor a variety of stimuli (distension of viscera, pain)

c) **Proprioceptors:**

- ✓ Sense of position
- ✓ Monitor degree of stretch
- ✓ Located in **musculoskeletal organs** (muscles, tendons and skin around joints). It detects change in position through monitoring the contraction of muscles, motion of tendons and joints.

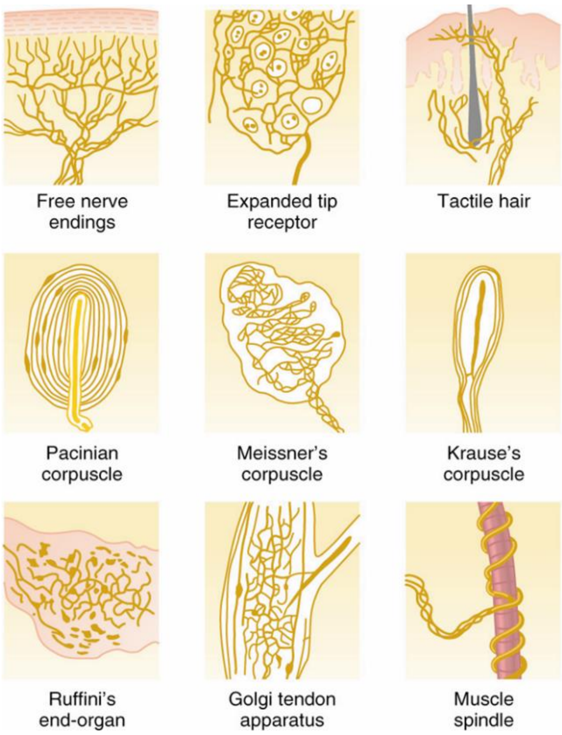
➢ **Types of Sensory receptors (sensory nerve endings):**

1) Free nerve endings:
- ✓ found under the epidermis
- ✓ sensitive to pain, touch and pressure

2) Expanded tip receptors:
- ✓ Under the epidermis

3) Tactile hair:
- ✓ Around hair shaft
- ✓ Affected by hair movement

4) Pacinian corpuscle:
- ✓ Like onion rings
- ✓ Fast-adapting (corpuscles are generally fast-adapting)
- ✓ Deep in the dermis, and thus **sensitive to pressure.**



5) Meissner's corpuscle:

- ✓ under epidermis

6) Krause's corpuscle:

- ✓ in epidermis
- ✓ sensitive to touch

7) Ruffini's end-organ:

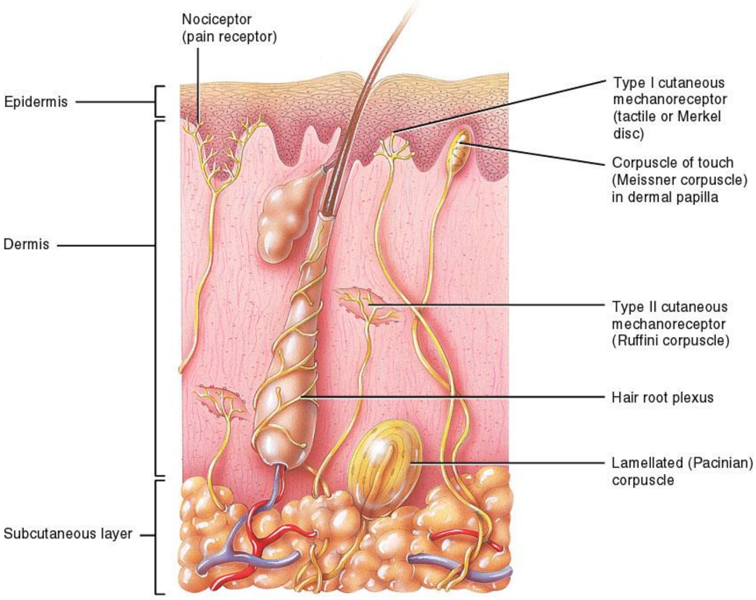
- ✓ In dermis

8) Golgi tendon organ (apparatus):

- ✓ Found in tendons
- ✓ Sensitive to position (proprioception)

9) Muscle spindle:

- ✓ Skeletal muscle
- ✓ Sensitive to position (change in position)



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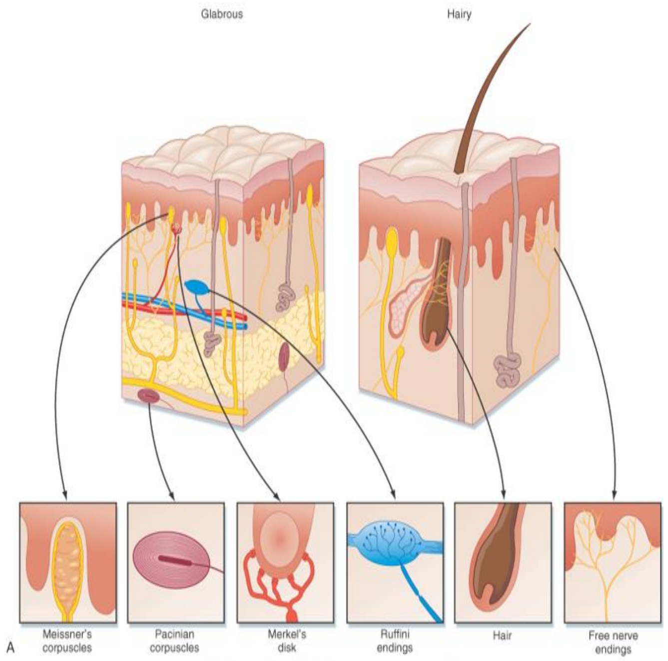
➢ **<u>Notes on adjacent image:</u>**

- ✓ Meissner's corpuscle under epidermis (touch)
- ✓ Pacinian corpuscle: down in the dermis (pressure)
- ✓ Merkel's disk: in epidermis (touch)
- ✓ Ruffini's end organ down in the dermis (pressure)
- ✓ Hair end organ: movement of hair
- ✓ Free nerve endings: pain or temperature or touch



➢ **<u>Merkel's disc for mechanical sensation (touch in hairy skin):</u>**

- ✓ A nerve fiber may give rise to or end in multiple merkel's discs which form a dome under the epidermis (slight elevation in epidermis). This dome is called **<u>Iggo dome.</u>** It is sensitive to **touch**. Look at the following image:

Iggo dome receptors

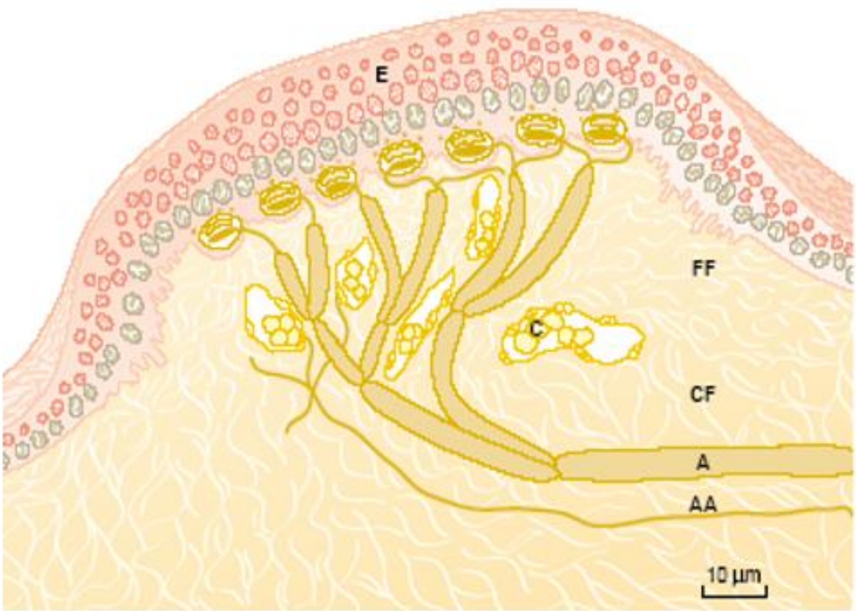


Figure 47–1

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:

- We discussed the types of sensory nerve endings previously, so now we can go into a bit more detail about a specific type of receptors, which is **tactile receptors** (related to touch). These receptors include many of the nerve endings mentioned before (free nerve endings, meissner's corpuscles..etc), and each type has different properties and serves a specific yet similar function in tactile receptors.

➢ Free nerve endings:

- ✓ connected to **Aδ (smallest myelinated)** fibers and **C (unmyelinated and slow)** fibers
- ✓ detect **touch and pressure**
- ✓ found everywhere in the skin and other tissues

➢ Meissner's corpuscles:

- ✓ Connected to **Aβ** fibers (fast)
- ✓ Found in **non-hairy** skin **(glabrous skin),** fingertips and lips. (**NOT** in armpits because they are hairy)
- ✓ Rapidly adapting (within a fraction of a second)
- ✓ Detect movement of light objects over skin

- **Merkel's discs:**
  - ✓ Connected to **Aβ** fibers
  - ✓ Respond rapidly at first and then slowly adapt
  - ✓ Detect the "steady state"
  - ✓ Sensitive to touch
  - ✓ Found on hairy as well glabrous (non-hairy) skin

- **Hair end organs:**
  - ✓ Found in hair shaft
  - ✓ Adapts rapidly and detects movement over the body

- **Ruffini's end organ:**
  - ✓ Connected to **Aβ fibers**
  - ✓ Slowly adapting and respond to continual deformation of the skin and joint rotation and pressure

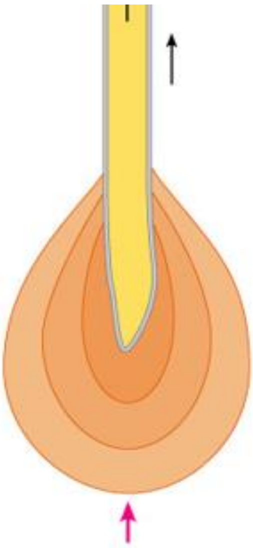
- **Pacinian corpuscle:**
  - ✓ Connected to **Aβ fibers**
  - ✓ Located down in dermis
  - ✓ Very rapidly adapting and is stimulated by rapid movement
  - ✓ Detects vibrations and other rapid changes in the skin

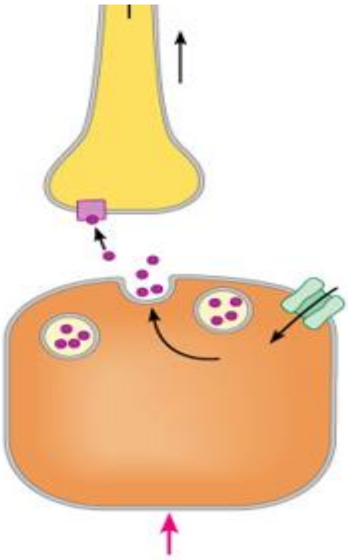
Receptors	
Meissner's corpuscle **Hair receptors** **Pacinian corpuscles** **Ruffini's end organs**	**transmit signals in type Aβ nerve fibers at 30-70 m/s**
Free nerve endings	**transmit signals in type Aδ nerve fibers at 5-30 m/s, some by C unmyelinated fibers at 0.5-2 m/s**

- The **more critical** the information, **the faster the rate** of transmission.
- Notice that type B nerve fibers (partially myelinated) were not mentioned here, because this type is present in the autonomic nervous system.

❖ Sensory Receptors: General Structure:

A) Receptor is the terminal part of the neuron	B) Receptor is a separate part from the neuron





A) Receptor is the terminal part of the neuron:

- ✓ If you affect this area, you will open stimulus-gated channels (for instance sodium channels), causing depolarization (local potential). If threshold is reached in the neuron, an action potential is achieved.
- ✓ The local potential produced in this type of receptor is called **Generator Potential.**

B) Receptor is separate from the neuron:

- ✓ When you apply a stimulus, it will change the permeability of the stimulus gated channels -it's like ligand channels- because it causes local potentials and not an action potential, and then it **releases neurotransmitters** that affect the neuron and cause an action potential in the neuron.
- ✓ The local potential produced in this type of receptor is called **Receptor Potential.**

Note: Receptor area is a non-excitable region so it can discriminate different intensities, otherwise it will not be able to differentiate strengths of stimuli

- **Why is the receptor area non-excitable?**
- Let's make a few assumptions:
    - ✓ If the receptor area was **excitable** (which is not the case in our bodies), an action potential would be immediately created as soon as we reach the threshold. Applying another stronger stimulus would also cause an action potential instantly, so NO discrimination between intensities of stimuli is present.

    - ✓ If the receptor area is **non-excitable** (which is the case in our bodies):
        - If the stimulus is weak, threshold will not be reached, so no action potential is created
        - If stimulus is stronger (receptor potentials add up to reach threshold), an action potential is created
        - If stimulus is even stronger, it will cause an even greater receptor potential (remember that receptor potentials are graded), and it will also cause an action potential, but at an even faster rate. How?
- **Example**: Let's say that if the stimulus just reaches the threshold, the rate of action potentials would be one action potential per 10 milliseconds: (these are arbitrary numbers just for the sake of understanding)

Rate= number of action potentials/time = 1/0.01= 100 AP/second.

If a stronger (or suprathreshold) stimulus is applied and exceeds the threshold, consequent action potentials can be elicited earlier in the relative refractory period. So, for instance, we get one action potential every 8 milliseconds. **Rate=1/.008=125 AP/second**. (notice that the magnitude of the AP is constant, the changing variable here is the frequency).

Also notice that as the **stimulus increases in strength**, we induce action potentials **earlier and earlier in the relative refractory period** and the **frequency increases**, until we reach the **absolute refractory period** where any stronger stimuli will no longer affect the frequency. So the **absolute refractory period LIMITS and DETERMINES the MAXIMUM frequency (rate) of action potentials**.

- The cerebral cortex in the brain interprets the **higher frequency** of action potentials as a **stronger stimulus**. This is how the brain distinguishes between intensities of different stimuli. Rate of APs depends on stimulus strength.

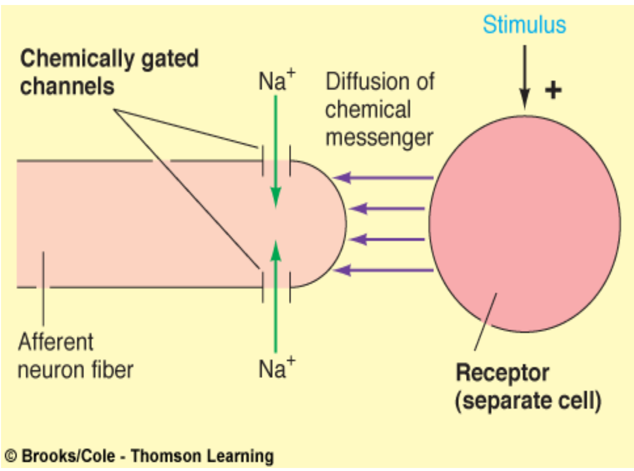
❖ Conversion of receptor and generator potentials into action potentials:

❖ **Receptor potential**: a stimulus attaches to a receptor separate from the nerve fiber end which causes chemical messengers to get released from the receptor to the nerve fiber where action potential happens. (has chemical-gated channels)

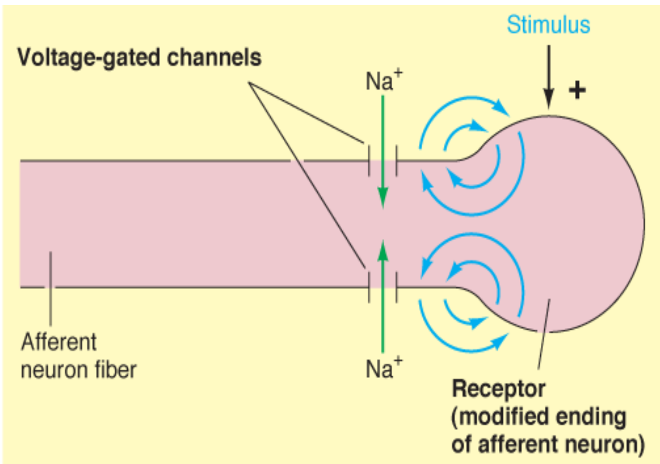
❖ **Generator potential**: a stimulus attaches to a receptor connected to the nerve fiber end which causes depolarization (not action potential) which will cause action potential in the nerve fiber end.

> **Note**: generator and receptor potentials are the exact same. The only difference is in the attachment of the receptor to the nerve fiber end. Also, generator and receptor potentials are graded (can be summated), and they are exactly like EPSPs. These potentials have long time periods (20 milliseconds), meaning they last longer than action potentials (AP : 1 millisecond)

Receptor potential



Generator potential



Note: **NO** action potential can happen on the receptors (no voltage gated channels), action potentials only happen on the nerve fiber.

❖ Law of Specific Nerve Energies:

- Sensation characteristic of each sensory neuron is that produced by its normal or **adequate stimulus**.

- **Adequate Stimulus:** is the stimulus that requires the least amount of energy to activate the receptor. In other words, it is the stimulus to which the receptor is most sensitive.
  - ✓ the **adequate stimulus** for pain receptors is: **pain**
  - ✓ the **adequate stimulus** for touch receptors is: **touch**

  Note: "adequate stimulus" is a qualitative description, not quantitative. By that we mean that the stimulus is suitable, not in terms of intensity or quantity, but rather in terms of quality.

- However, pain receptors, for instance, can also be stimulated by stimuli other than pain, like heat. **BUT**, it would require very great heat to stimulate these receptors or very extreme cold, because temperature is not the adequate stimulus for pain receptors and so we need high energy or extreme values of this stimulus (which is not adequate) to activate a receptor. Regardless of how a sensory neuron is stimulated, only one sensory modality will be perceived. (specificity of receptors). Whether the pain receptor is stimulated by pain or temperature, it will always be perceived as pain because this receptor has a fixed pathway to the brain (Remember: the same pathway always leads to the same sensation).
- The **threshold** of pain receptors for "pain" stimuli is **low**
- The **threshold** of pain receptors for "temperature" stimuli is **very high**.
- All what was mentioned previously is referred to as the **Law of Specific Nerve Energies.** It allows the brain to perceive the stimulus accurately under normal conditions.

❖ Sensation:

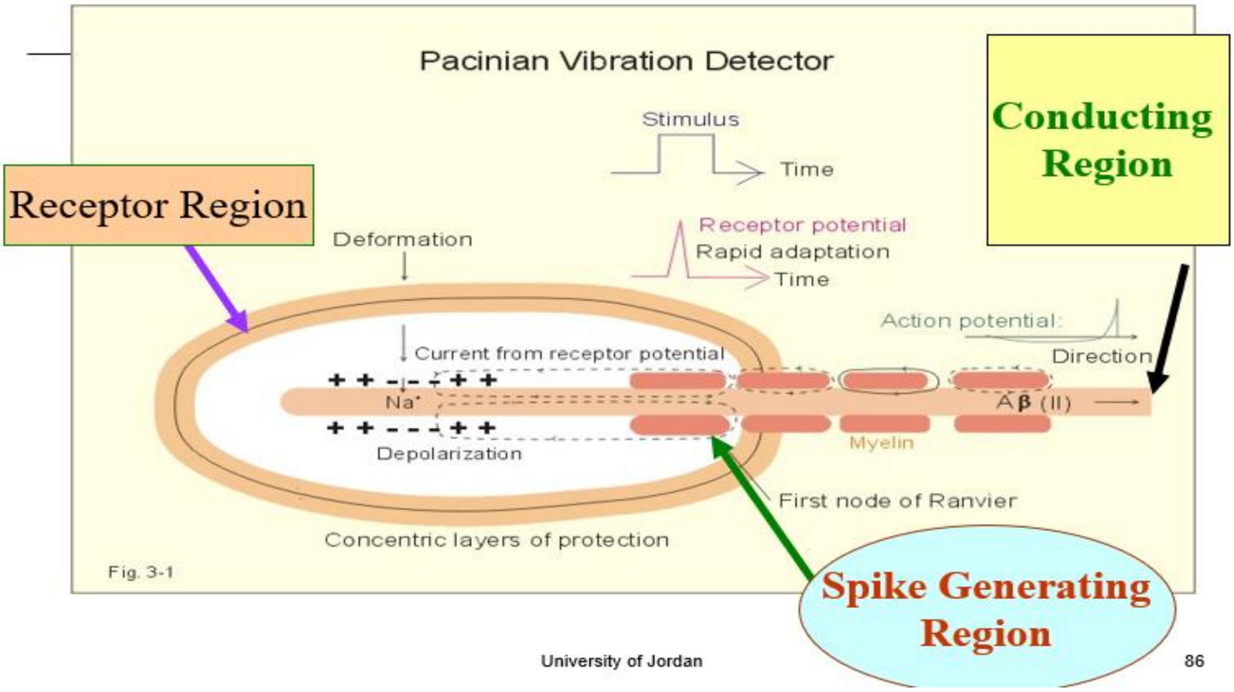
- ❖ **Each of the principle types of sensation; touch, pain, sight, sound, is called a *modality of sensation*.**
- ❖ **Each receptor is responsive to one type of stimulus energy. Specificity is a key property of a receptor, it underlines the most important coding mechanism, *the labeled line principle* (whether the neuron is stimulated from the surface or from inside, if it is the same pathway, it will induce the same sensation- each receptor has a specific pathway)**
- ❖ **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

(whether the stimulus is temperature, pain, touch ..etc, it will change the permeability of stimulus-gated channels)

General structure of receptors



- Notice the receptor area which is not excitable
- We affect it opening stimulus-gated channels, which causes receptor/generator potentials, if the receptor potential reaches threshold, an action potential is created.
- Concerning sensory receptors, the action potential starts at **the first node of Ranvier**.

➢ **Receptor structure is divided into 3 areas:**

1) **Receptor region: non-excitable area where receptor potential is generated.**
2) **Spike generating region: where the first action potential takes place.**
3) **Conducting region: the area where action potential travels and is conducted.**