YU - MEDICINE
PASSION ACADEMIC TEAM

Central Nervous System

Sheet# 4 - Physiology

Lec. Title : Somatic Sensation - Sensory Systems (Part 1)

Written By : Amira Otoum

If you come by any mistake , please kindly report it to shaghafbatch@gmail.com

Somatic sensation - Sensory systems (Part I)

Done by : Ameera otoum

Dr.Ejlal Abu-El-Rub, Pharm.D, PhD
Physiology and Pathophysiology, Department of Basic Medical Sciences, Faculty of Medicine, Yarmouk University

General features of sensory and motor systems

Definition

- The somatosensory system provides information to the central nervous system (CNS mainly brain) about the state of the body and its contact with the world.
- *كل المعلومات تبعون البيئة المحيطة يتم نقلها عن طريق ال somatosensory system الى الدماغ حتى يصيرلها processing
- It does so by using a variety of sensory receptors that transduce mechanical (pressure, stretch, and vibrations) and thermal energies into electrical signals. (or to the form of information that has been transmitted to the CNS mainly brain for processing)
- These electrical signals, called generator potentials, occur in the distal ends of axons of first-order somatosensory neurons and trigger action potential trains that reflect information about the characteristics of the stimulus.

Synaptic relays

- The simplest synapses are one-to-one connections consisting of a presynaptic element and a postsynaptic element.
- However, many synapses are more complicated and use synapses in **relay nuclei** to integrate converging information.

Note 1 :relay nuclei contain : 1)many synapses from afferent neurons that combine in one area to converge these information 2)contain interneurons and projection neurons

Note 2 : these relay nuclei present in all parts of CNS but the most important one is thalamic relay nuclei

- Relay nuclei are found throughout the CNS, but they are especially prominent in the *thalamus*.

Synaptic relays

- Relay nuclei contain several different types of neurons including local **interneurons and projection neurons.**
  - The projection neurons extend long axons out of the nuclei to synapse in other relay nuclei or in the cerebral cortex to reach the area of processing.
- Almost all information going to and coming from the cerebral cortex is processed and filtered in thalamic relay nuclei.
- Note : thalamus is responsible for filtering the sensory input information and discard high percentage up to 99% of these sensory input and transmit to cerebral cortex and from cerebral cortex also the output will be filtered to go to the efferent divisions .

Topographic Organization

- Information of sensory and motor systems is encoded in **neural maps.(the information will reflect specific area in cerebral cortex)**

Topographic Organization

- The topographic coding is preserved at each level of the nervous system, even as high as the cerebral cortex.

  ➢ Thus in the somatosensory system, the topographic information is represented as a **sensory homunculus** in the cerebral cortex.

  ➢ يعني كل ال sensory areas الهم منطقة خاصة فيهم حتى يصيرلهم فيها processing هاي اسمها topographic area

  او sensory homonuculus

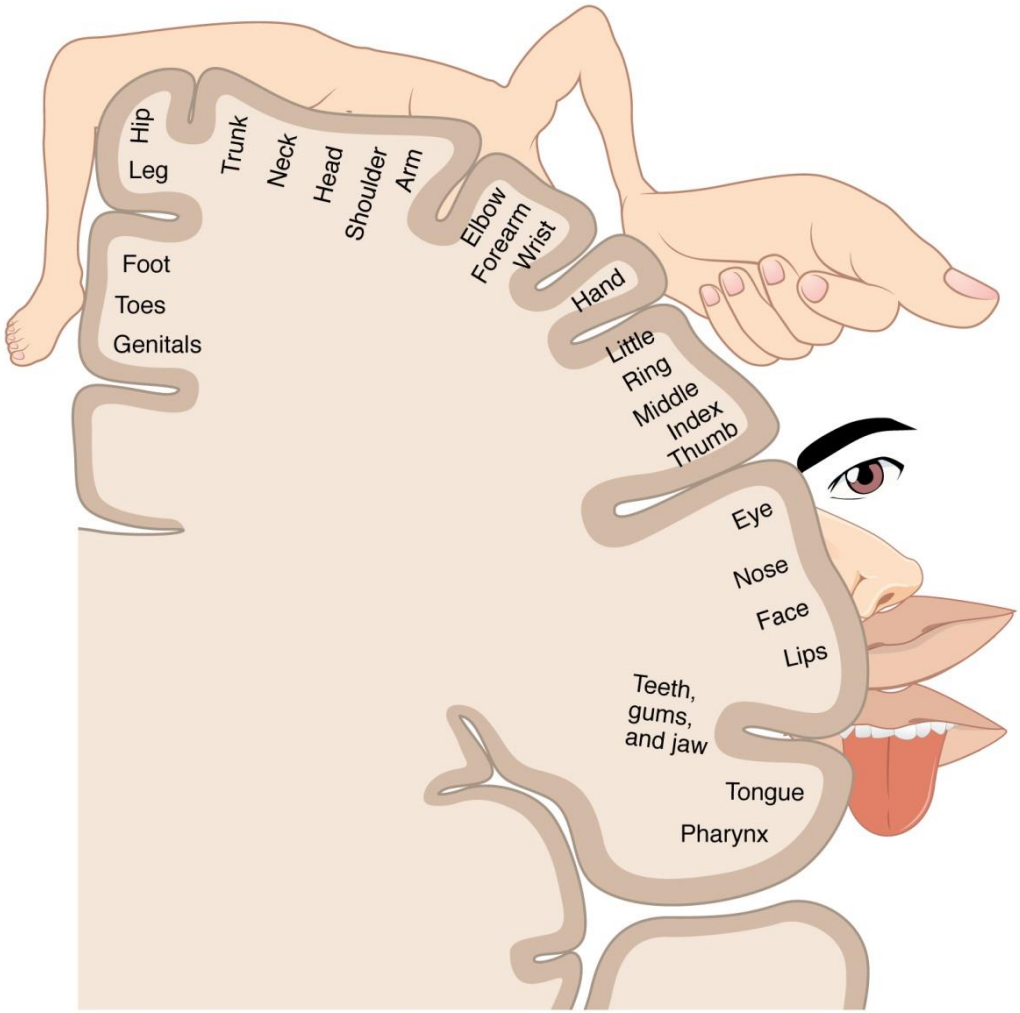
- In the visual system, the topographic representation is called **retinotopic(related to visual stimulus)**
- **In the auditory system** it is called **tonotopic(related to hearing stimulus)**
- ***note : so each environmental stimulus has specific area in cerebral cortex for processing as a map (so if this area intact the processing for that stimulus will be more efficient compared to if there is lesion or disturbance)**

Types of somatosensory homunculus:

A motor homunculus represents a map of brain areas dedicated to motor processing. The primary motor cortex is located in the precentral gyrus (anterior to central sulcus), and handles signals coming from the premotor area of the frontal lobes

A sensory homunculus represents a map of brain areas dedicated to sensory processing. The primary sensory cortex is located in the postcentral gyrus (posterior to central sulcus) , and handles signals coming from the thalamus.

*homunculus called little map or cortex sittle map



* لازم من الرسمة نعرف كل منطقة الها علاقة باي جزء

Sensory homunculus

- معلومة عن السلايد السابق حكتها الدكتورة : ال neurosurgeons لو جاب electrode وحط ال electrode على اي منطقة من مناطق ال somatosensory homunculus الشخص رح يحس انو لمس ال organ او الجزء يلي مثله هذا الجزء من ال homunculus
- مثلا لو حطه على منطقة ال lips رح يشعر انو لمس ال lips تبعونه

Decussations

- Almost all sensory and motor pathways are bilaterally symmetric, and information crosses from one side (ipsilateral) to the other (contralateral) side of the brain or spinal cord.(in certain midline(could be in spinal cord or mid brain) they cross and change their direction so that the right site control the oppsite side)
- All pathways do not cross at the same level of the CNS. Some pathways cross in the spinal cord (e.g., pain), and many cross in the brain stem.
- These crossings are called **decussations.**

Decussations

- Areas of the brain that contain decussating axons are called **commissures** (ex.: corpus callosum (connect the right hemisphere to the left one so the cerebral hemisphere works whole system).

- Some systems are mixed, having both crossed and uncrossed pathways.
  - For example, in the visual system, half of the axons from each retina cross to the contralateral side and half remain ipsilateral. Visual fibers that cross do so in the **optic chiasm.**

Types of nerve fibers

- Nerve fibers are classified according to their *conduction velocity*, which depends on:
  - the size of the fibers, and

(More size so less resistance)…. يعني بتقل المقاومة تبعت النقل

  - the presence or absence of myelination.(because myeline sheaths do insulation and decrease the capacitance).
  - Capacitance : means good separation between the charged ions so more capacitance so less separation so less velocity in conduction of electrical impulses and vice versa

- The larger the fiber, the higher the conduction velocity.
- Conduction velocity also is increased by the presence of a myelin sheath around the nerve fiber.

- There are two classification systems for nerve fibers according to their conduction velocities.
  1. A, B and C nomenclature → applies to both sensory (afferent) and motor (efferent) nerve fibers.
  2. I, II, III, IV nomenclature (latin numbers)→ applies only to sensory nerve fibers.

Fiber types and conduction velocity

Classification of Nerve Fibers

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

- مطلوب شرحت منه :
- Sensory and motor B has small diameter but its velocity medium because it is myelinated
- While C small diameter and non myelinated so very small velocity

Sensory systems

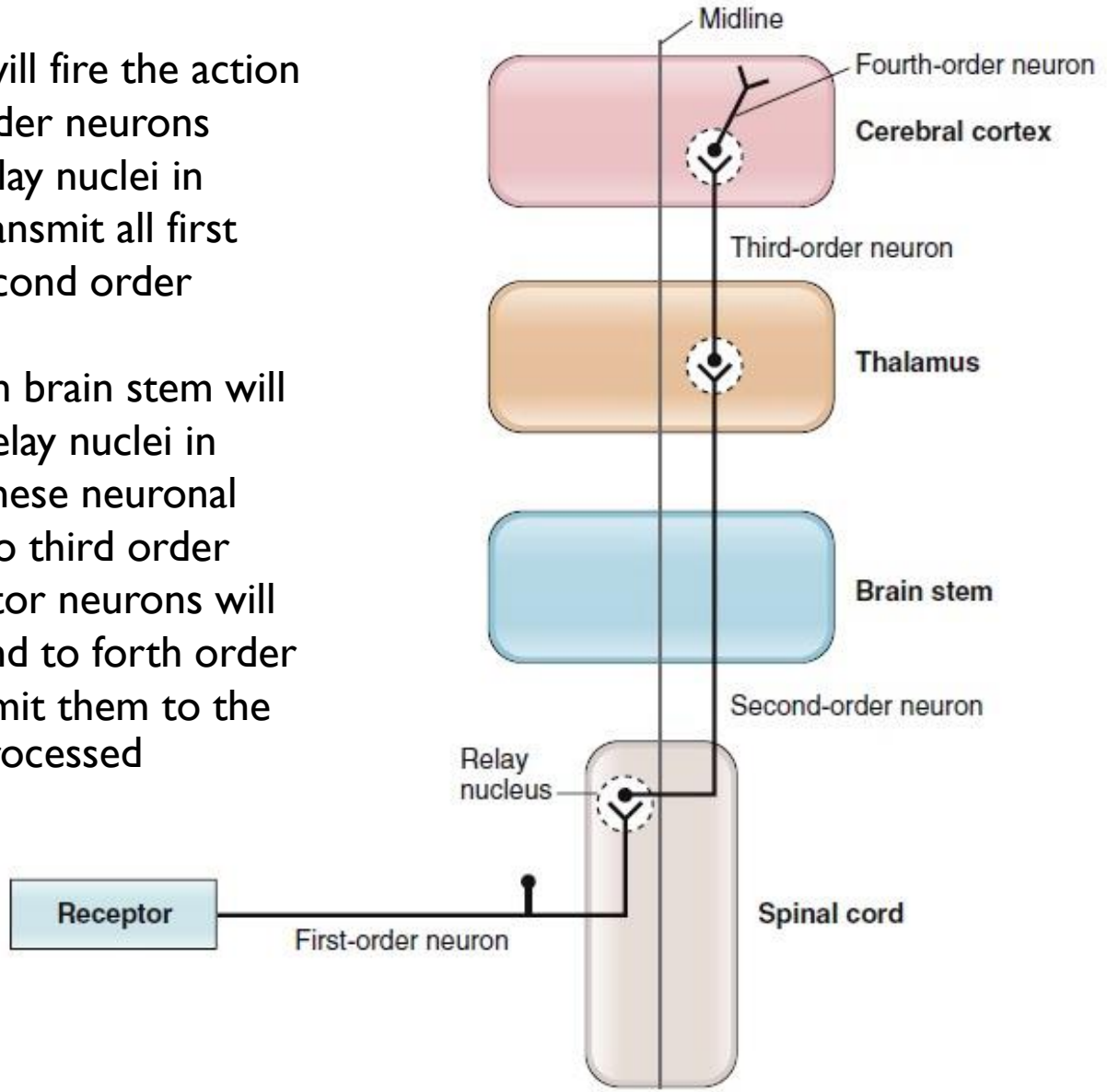
Sensory pathways from the sensory receptor to the cerebral cortex

1. Sensory receptors
2. First-order neurons
3. Second-order neurons
4. Third-order neurons
5. Fourth-order neurons

integration and *بالنهاية بتوصل للمنطقة يلي بده يصير فيها processing

Sensory pathways from the sensory receptor to the cerebral cortex

We start by receptor will fire the action potential In the first order neurons
This will integrate in relay nuclei in spinal cord then will transmit all first order output to the second order neurons .
Second order neuron in brain stem will go to the thalamus in relay nuclei in thalamus will filter all these neuronal input then send them to third order neurons then third motor neurons will send them to cortex and to forth order neurons that will transmit them to the area where it will be processed



Sensory pathways from the sensory receptor to the cerebral cortex

1. Sensory receptors

- are activated by environmental stimuli.
- may be specialized epithelial cells (e.g., photoreceptors, taste receptors, auditory hair cells).
- may be primary afferent neurons (e.g., olfactory chemoreceptors).
- **transduce** the stimulus into **electrochemical energy** (i.e., receptor potential or action potential).

Sensory pathways from the sensory receptor to the cerebral cortex

2. **First-order neurons**

- are the **primary sensory afferent neurons** that receive the transduced signal and send the information to the CNS.
- Cell bodies of the primary afferent neurons are usually in a **dorsal root or spinal cord ganglion.** (Exceptions are the auditory, olfactory, and visual system)

Sensory pathways from the sensory receptor to the cerebral cortex

3. Second-order neurons

- are located in the spinal cord or brain stem.
- receive information from one or more primary afferent neurons in **relay nuclei and** transmit it to the **thalamus.**
- Axons of second-order neurons may **cross the midline in a relay nucleus in the spinal** cord before they ascend to the thalamus.

➢ Therefore, sensory **information originating on one side of the body ascends to the contralateral thalamus.**

Sensory pathways from the sensory receptor to the cerebral cortex

4. **Third-order neurons**

- are located in the relay nuclei of the **thalamus**. From there, encoded sensory information ascends to the cerebral cortex.

Sensory pathways from the sensory receptor to the cerebral cortex

5. **Fourth-order neurons**

- are located in the appropriate sensory area of the cerebral cortex. The information received results in a **conscious perception** of the stimulus.(ببلش احس بخصائص المحفز يلي اثر علي)

Sensory receptors

- are specialized epithelial cells or neurons that **transduce environmental signals** into neural signals.

- The environmental signals that can be detected include
  - **mechanical force(strech)**
  - **light**
  - **sound**
  - **chemicals**
  - **Temperature**
  - **Certain damage**

Types of sensory transducers

1. **Mechanoreceptors**

- Pacinian corpuscles (in Glabrous skin(hairless cells))
- Joint receptors
- Stretch receptors in muscle
- Hair cells in auditory and vestibular systems
- Baroreceptors in carotid sinus(control blood pressure)

2. **Photoreceptors**

- Rods (low light levels) and cones (high light levels) of the retina.
- Rods work in dark so they are not responsible for coloring of the image, while cones recieve high light levels so will do coloring of the image and also details for this image

Types of sensory transducers

3. **Chemoreceptors(respond to chemicals)**
   - Olfactory receptors
   - Taste receptors (مثلا اكلت سكر او ملح يتم نقله عن طريق هذه المسقبلات)
   - Osmoreceptors
   - Carotid body O_2 receptors
4. **Extremes of temperature(very high or very low) and pain associated with this extreme level of temeprature**
   - Nociceptors()

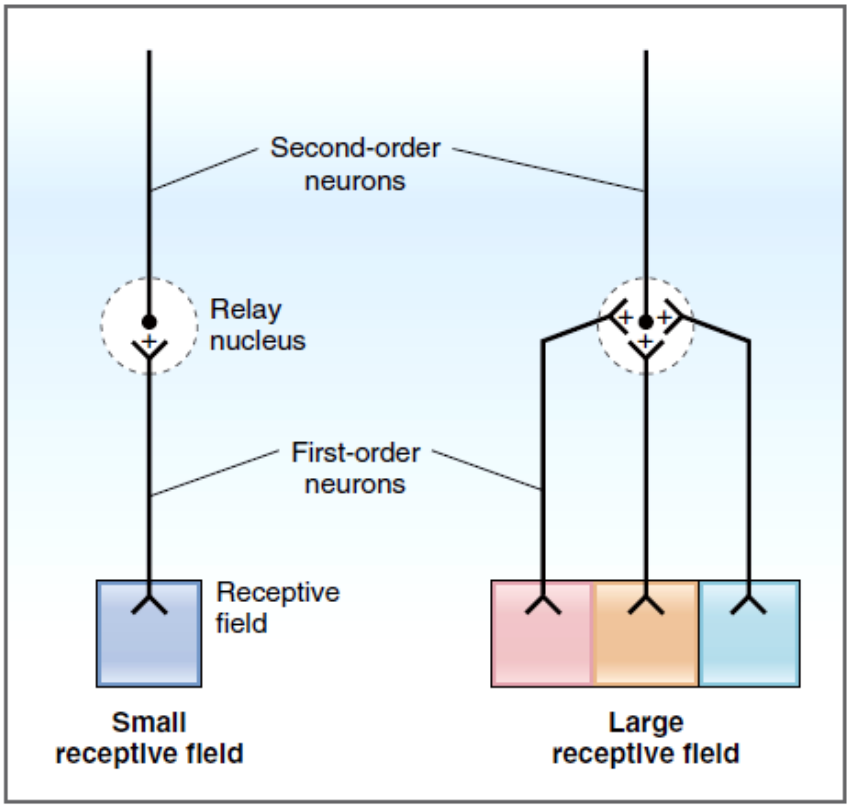
Receptive field

- Is an area of the body that, when stimulated, changes the firing rate of a sensory neuron depending on the type of stimulus .

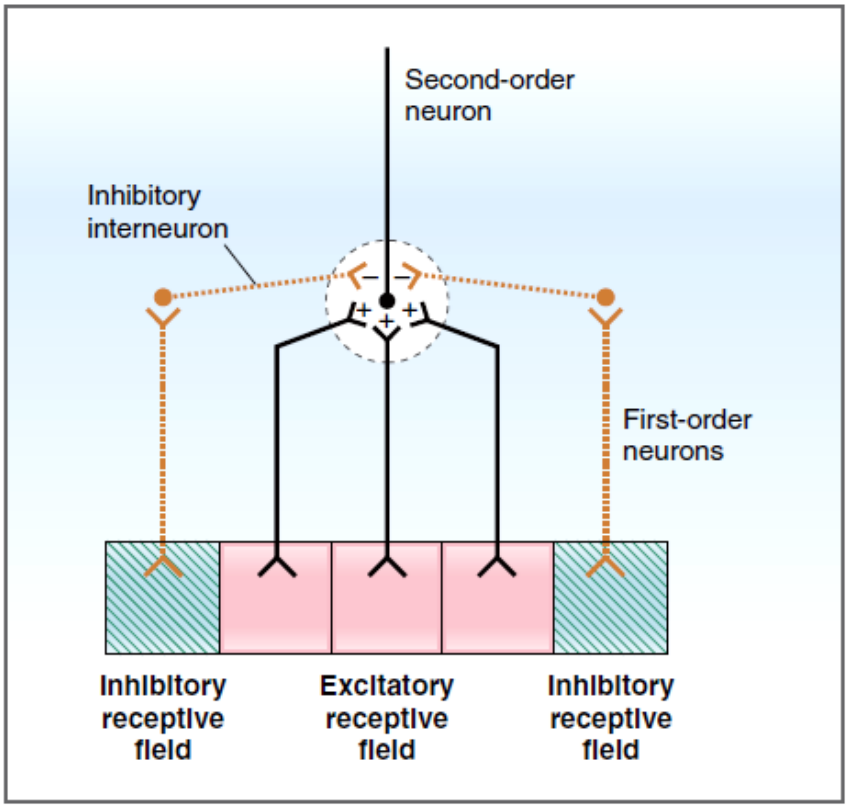
- If the firing rate of the sensory neuron is increased, the receptive field is **excitatory.**

- If the firing rate of the sensory neuron is decreased, the receptive field is **inhibitory.**

Receptive field



Size of receptive fields of sensory neurons.



Excitatory and inhibitory receptive fields of sensory neurons.

*the initiation of action potential in receptive field depends on : 1)diameter (size) of the receptive field(more size so more action potential) 2) type of the stimulation that reach the receptive field (their will be summation of the receptive field stimulation , if there is inhibition with excitation , the sum of the signals will determine if there is excitation or inhibition (could be weak signal or strong signal) and this summation will transmitted to the second order neurons)

Steps in sensory transduction

1. **Stimulus arrives at the sensory receptor.**
   - The stimulus may be a photon of light on the retina, a molecule of NaCl on the tongue, a depression of the skin, and so forth.

2. **Ion channels are opened in the sensory receptor,** allowing current to flow.
   - Usually, the current is inward, which produces **depolarization** of the receptor due to inry of sodium and firing of the action potential.
   - The exception is in the **photoreceptor, where light causes decreased inward current** and **hyperpolarization so there is no firing of the action potential .(also , dark will be depolarization and activation of photoreceptors)**
   - ***this exception as a protection for the eys and retina and adaptation .**

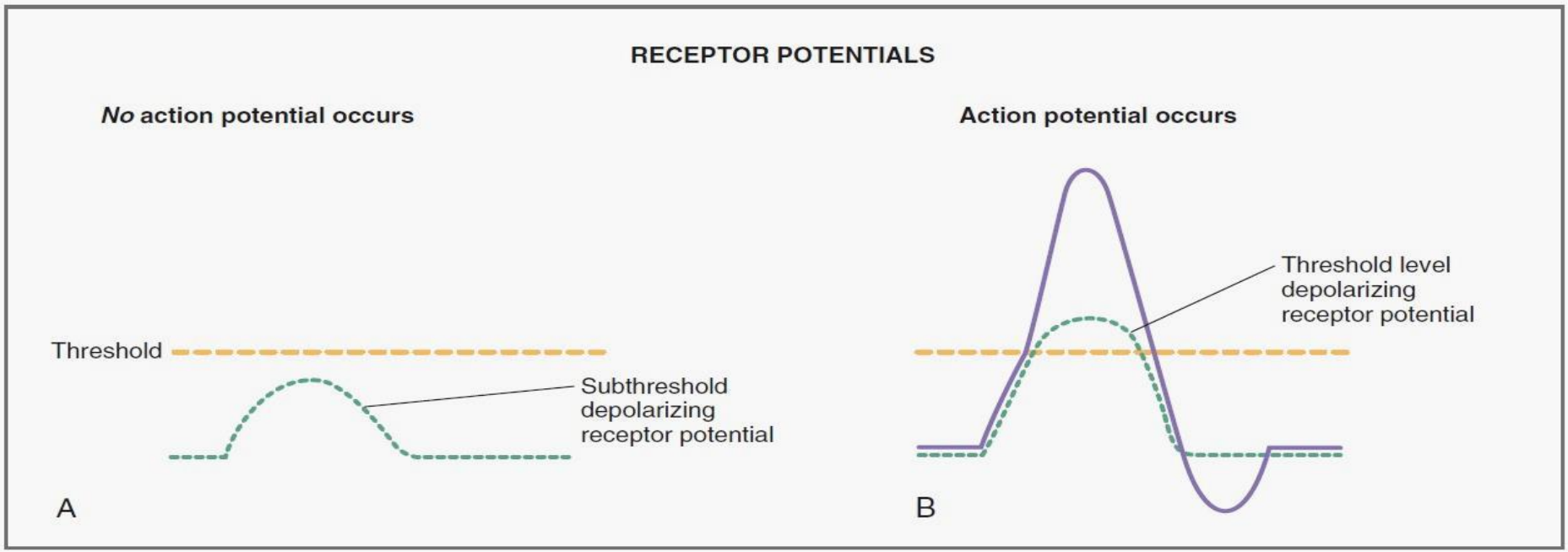
Steps in sensory transduction

- The change in membrane potential of the receptor produced by the stimulus is the **receptor potential,** or **generator potential.**

  - If the receptor potential is depolarizing, it brings the membrane potential closer to threshold. If the receptor potential is large enough, the membrane potential will exceed threshold, and an action potential will fire in the sensory neuron.(so if it is weak we can not continue this action potential)

  - Receptor potentials **size depend on the size of the stimulus.(stronger stimulus with large receptor involved in the detection of this stimulus so stronger action potential)**

Steps in sensory transduction



Receptor potentials in sensory receptor cells. Receptor potentials may be either depolarizing *(shown)* or hyperpolarizing *(not shown)*. **A,** If a depolarizing receptor potential does not bring the membrane potential to threshold, no action potential occurs. **B,** If a depolarizing receptor potential brings the membrane potential to threshold, then an action potential occurs in the sensory receptor.

*if the action potential reach the first order neurons are subthreshold (not enough to cause depolarization) so no action potential will propagate to the first order neurons.

*While if the depolarization is enough to reach the threshold so there will be generation of action potential that will reach the first order neurons

* This will depend on : 1) type of the stimulus 2) number of sensory receptors involved in detection this stimulus

Sensory encoding

- Sensory neurons are responsible for encoding stimuli in the environment.
- Coding begins with a stimulus and continues as the information is transmitted to progressively higher levels of the CNS.
- Each charsactaristics of the external stimuli will be encoded as electrical stimuli.

- Example,: in seeing a red ball, its **size**, **location**, **color**, and **depth** all are encoded and reach the cerebral cortex of CNS

Sensory encoding

- **Modality** → consist of pathways of sensory neurons dedicated to that modality.
  - *يعني عندي مجموعة من المستقبلات الحسية بتكون متخصصة ب model معين مثلا اللمس او الالم او القوة او التذوق .
  - فيه بعض المستقبلات مسؤولة عن اكثر من اشي اسمها polymodal مثال عليها ال nocireceptors المسؤولة عن extreme temprature and pain ولكن بالعادة كل stimuli بتخصص فيه مجموعة من المستقبلات والاعصاب
- **Location** → encoded by the *receptive field* of sensory neurons.
- **Threshold** → is the minimum stimulus that can be detected.
- **Intensity** → encoded in:
  - Number of receptors activated
  - Differences in firing rates of sensory neurons in the pathway
  - Activating different types of receptors.

- Stimulus information also is encoded in **neural maps**

  → formed by *arrays of neurons* receiving information from different locations on the body.

  - يعني الخلاصة انو كل stimuli يوصل للمنطقة المخصصة اله بالدماغ

- However, receptors may **adapt** to stimulus and change their firing rates.

Adaptation of sensory receptors

1. **Slowly adapting, or tonic, receptors (muscle spindle; pressure; slow pain)**

   - respond repetitively to a prolonged stimulus.
   - detect a **steady stimulus.**
   - هون بستجيب للمستقبل بنفس ال **rate** ونفس ال **firing** زي ال **steady state**

2. **Rapidly adapting, or phasic, receptors (pacinian corpuscle; light touch)**

respond maximally but briefly to stimuli; their response decreases if the stimulus is maintained.

كل ما تعرضوا للمحفز بتقل الاستجابة .

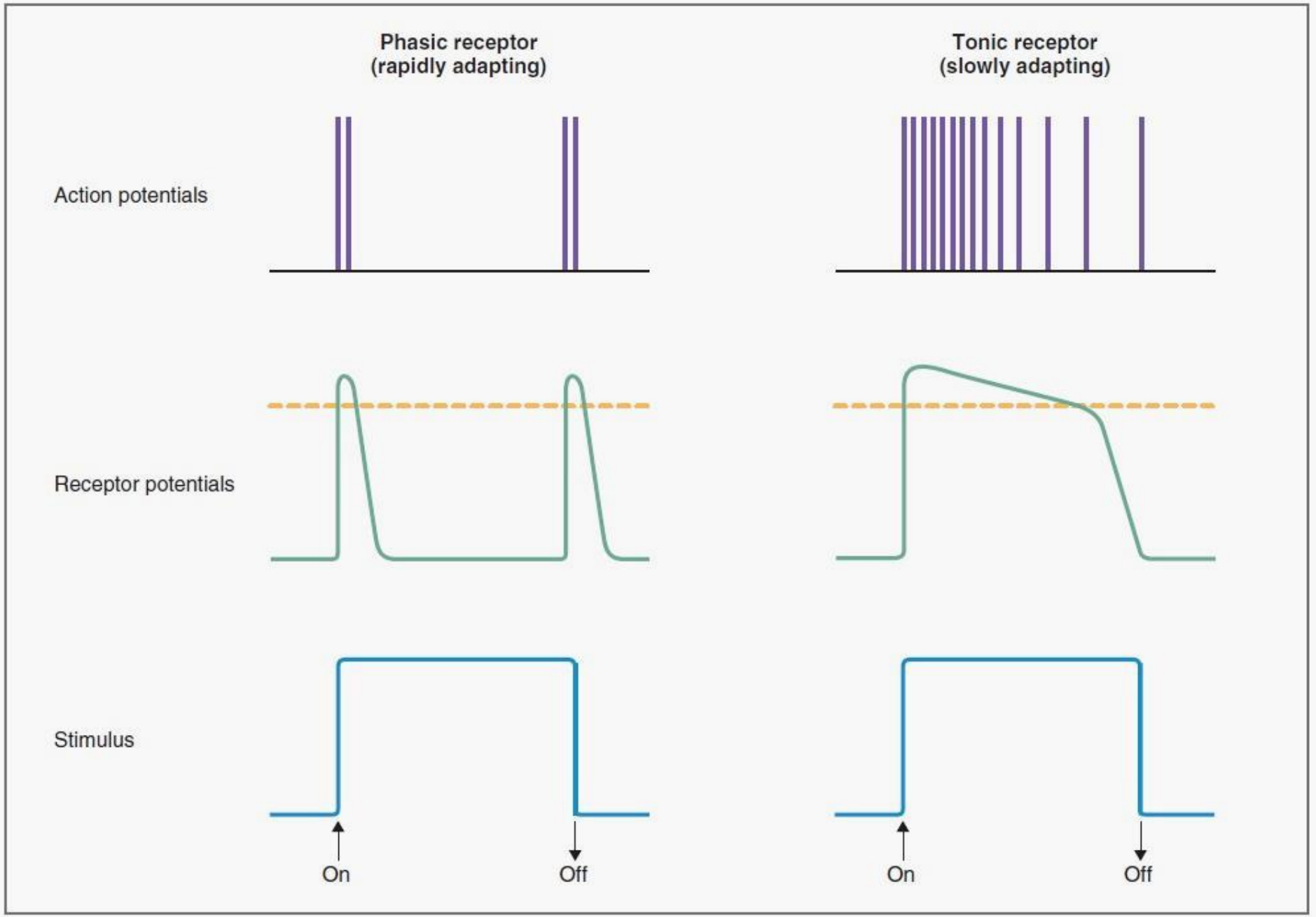


Fig. 3.8 Response of phasic and tonic mechanoreceptors.

- شرح السلايد السابق :

*rapidly adapting receptors :

*هذول رح يستجيبوا للمستقبل باقصى حد ولكن لما يضلوا يتعرضوا لنفس المستقبل رح يقل ال firing rate فرح يصيروا يستجيبوا بس لل onset and the end of the stimulus رح يعطوا بس هون action potential

مثلا ال Pacinian corpuscle الهم علاقة بال vibration هدول كل ما تعرضوا لنفس المحفز رح يقل ال firing rate وبس رح detect the onset and offset of the stimulus لهيك ممكن احتاج stronger stimulus او اغير طبيعته او خصائصه حتى ازيد ال firing rate تبعهم .

*slowly adapting stimulus :

*هذول كل ما تعرضوا لل stimuli رح يضلوا يعطو action potential in each stage of this stimulus مش زي يلي قبل بس بالاول والاخر لهيك الاسجابة تبعتهم ما بتتغير steady

- مثلا العضلات بضلوا يستجيبوا بنفس المستوى والالم
- *ملاحظة : بالنهاية النوعين رح يصيرلهم adaptation ولكن الوقت مختلف مثلا chronic pain هذا يعتبر slowly adapting بدنا وقت طويل حتى يصيرلة adaptation زي وجع الدسك رح يضلو يعانو من نفس الالم الم ثابت ومستمر لحد ما يصيرلهم adaptation
- *ملاحظة : الادوية لما تتدخل بكون الوجع موجود ولكن ما بنحس فيه وهذا لا يعني انو صارلها adaptation يعني هاد موضوع مختلف(مش متأكده حسب يلي فهمته من الدكتوره)

Somatosensory system

- includes the sensations of:
  - touch
  - movement
  - temperature
  - pain

Mechanoreceptors for touch and pressure

Type of Mechanoreceptor	Location	Adaptation	Sensation Encoded
Pacinian corpuscle	Subcutaneous; intramuscular	Very rapidly	Vibration, tapping
Meissner corpuscle	Nonhairy skin	Rapidly	Point discrimination, tapping, flutter
Hair follicles	Hairy skin	Rapidly	Velocity, direction of movement
Ruffini corpuscle	Hairy skin	Slowly	Stretch, joint rotation
Merkel receptors	Nonhairy skin	Slowly	Vertical indentation of skin
Tactile discs	Hairy skin	Slowly	Vertical indentation of skin

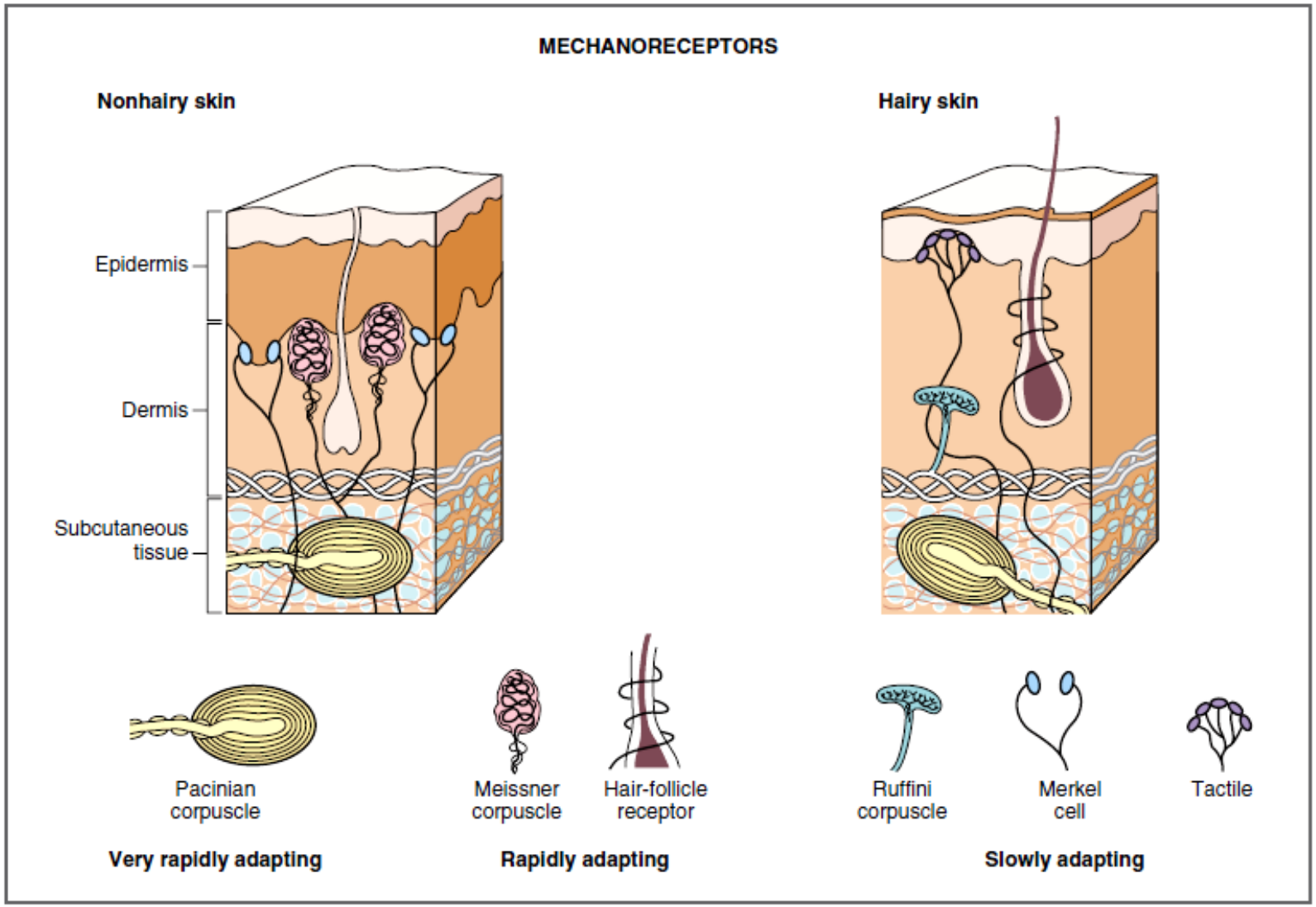
مطلوب حفظ

*note : merkel and tactile receptors responsible for detecting low frequency vertical indentation of skin

*Pacinian responsible for detecting high frequency vibration and also detect pressure

*الاول هو اهم واحد بالجدول

Mechanoreceptors for touch and pressure



Types of mechanoreceptors found in nonhairy skin and hairy skin.

Thermoreceptors

- Thermoreceptors are *slowly* adapting receptors that detect changes in skin temperature.
  - cold receptors (most abundance)
  - warm receptors

- Each type of receptor functions over a broad range of temperatures, with some overlap in the moderate temperature range (e.g., at 36°C, both receptors are active).
  - When the skin is warmed above 36°C, the cold receptors become quiescent(in G0 so no activation dormant), and when the skin is cooled below 36°C, the warm receptors become quiescent and cold receptors will be activated .

Thermoreceptors

- If skin temperature rises to damaging levels (above 45°C), warm receptors become inactive; thus warm receptors do not signal pain from extreme heat.
- At temperatures above 45°C, polymodal nociceptors will be activated. Likewise, extremely cold (freezing(درجات حرارة سالبة)) temperatures also activate nociceptors.
- ملاحظة : هذا النوع من المستقبلات رح ينقل مش بس الحراره العالية وانما كمان الالم المصاحب الها ممكن الجلد ينسلخ ويصير دمار للانسجة .

Thermoreceptors

- Transduction of temperatures involves **transient receptor potential (TRP) channels** in the family of vanilloid receptors (i.e., TRPV).
- هذول ال TRP همه يلي بعطونا الشعور بالبرد او الحرارة حسب البروتينات المكونة الها

- compounds in the vanilloid class, which includes *capsaicin*, an ingredient in spicy foods gives warm sensation.

- compounds like menthol (which gives a cold sensation).

Table 7-1. TRP Family Proteins Involved in Thermal Transduction

Receptor Protein	Threshold or Temperature Range for Activation (°C)	Other Characteristics
TRPV1	>42	Activated by capsaicin
TRPV2	>52	
TRPV3	34-38	Activated by camphor
TRPV4	27-34	
TRPM8	<25	Activated by menthol
TRPA1	<18	Activated by mustard oil

مطلوب حفظ

*اخر عمود بعطي امثلة لمركبات لو تعرضت الها رح يحفز نفس هذول المستقبلات وبعطوا احساس كانه تعرضت ل worm sensation or called sensation

*اخر اثنين من اهم البروتينات يلي بتعمل ال cold receptors وبتعاملوا مع درجات حراره قليله

*كل مستقبل المختص بدرجة حرارة معينة بكون اله مكونات معينة من الTRP

*اي خلل او طفرة بهذول البرةتينات بصير خلل بشعورنا لدرجات الحرارة فهمه بتعرضوا ل genetic disturbances

Nociceptors

- Nociceptors respond to noxious stimuli that can produce tissue damage(pain and extreme temperature >45 or freezing temperature)

- سؤال ساله طالب عن المحاضرات السابقة مهم

- Why H+ doesn't have a role in the generation of action potential ?

Because chemically H+ is very reactive ions (doesn't have specific state) and for action potential we need good separated abundant in the ionic form to generate the action potential .Also the small size of the action potential and because the H+ has very important role in all cells in the body not only neurons for example the ph , so if the h+ involved in the action potential by diffusion ,leaking of these h+ pumps so we will interrupt the ph of the body so the H+ doesn't participate in the action potential .

Note : the exact reason for selecting NA+ and K +in the action potential generation not unknown .