Introduction to Physiology for medical students 2021-2022

Sensory receptors

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Topics in this lecture

1) Requirements of sensory receptors to work
2) Receptor potential
3) Sensation
4) Summation
5) Adaptation
6) Sensory coding

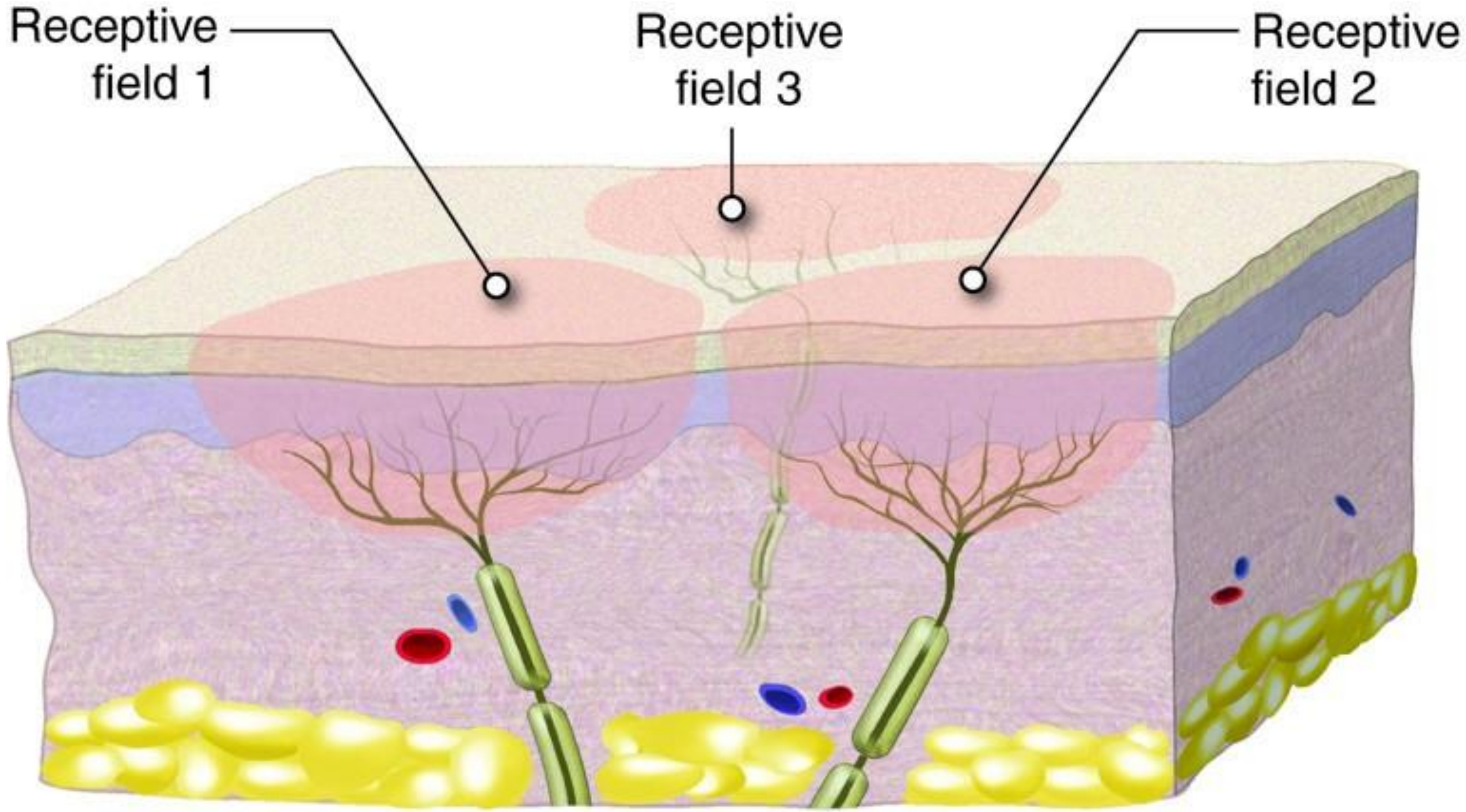
Sensory receptors

- For a sensation to arise, the following events typically occur:

- 1. **Stimulation of the sensory receptor**.

An appropriate stimulus must occur within the sensory **receptor's receptive field**, that is, the body region where stimulation activates the receptor and produces a response.

Receptive field

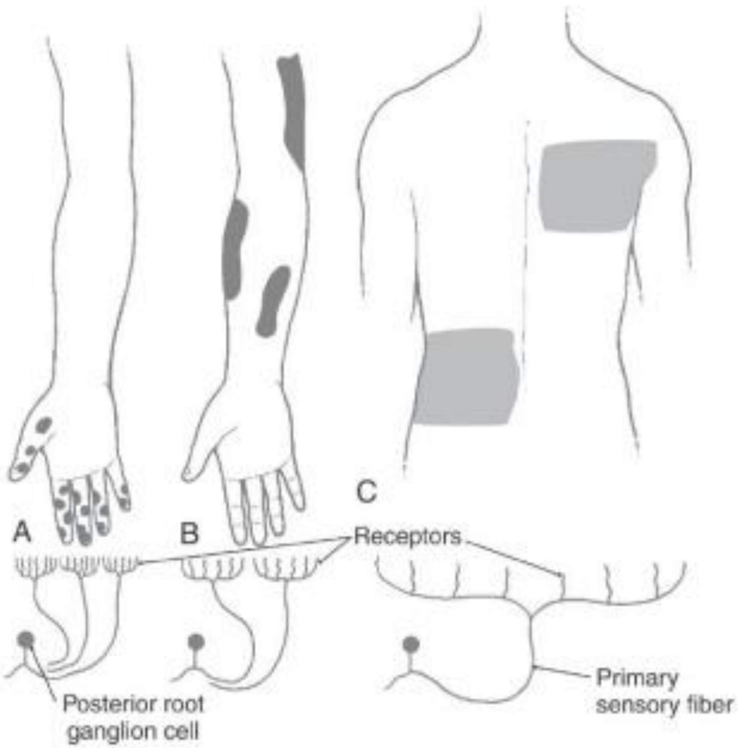


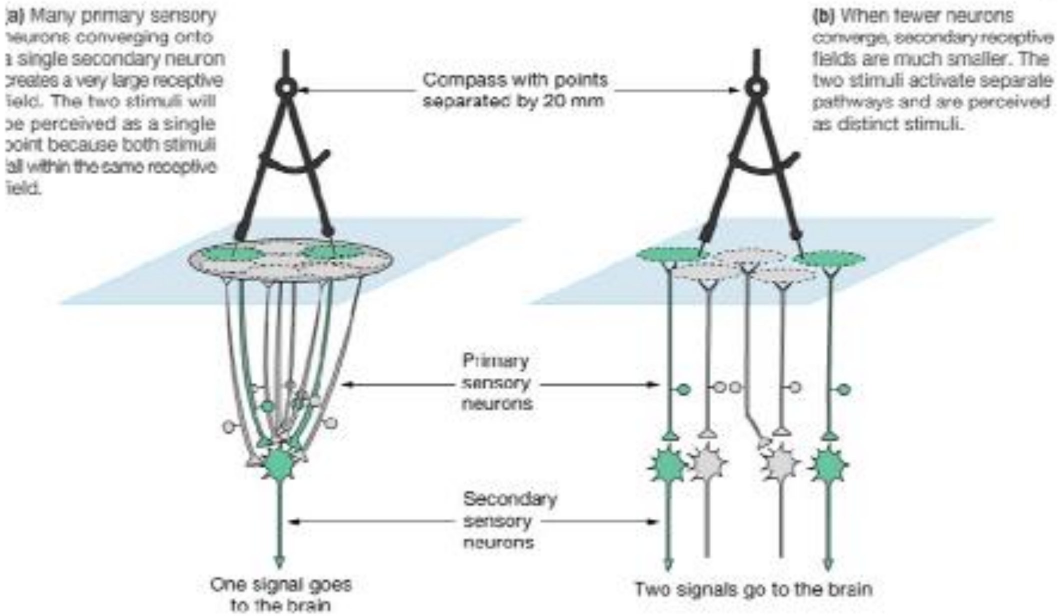
https://psychology.stackexchange.com/

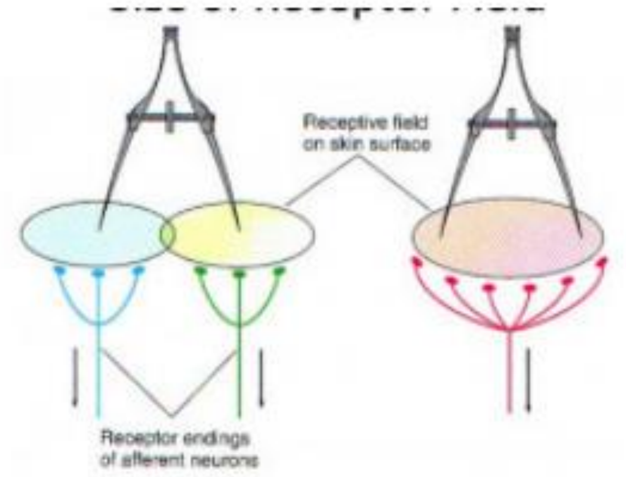
❑ Receptive field

Read Only

- ➢ Every receptor receives sensation from a certain area of the skin, (**receptive field)**
- The greater the density of receptors, the smaller the receptive fields of individual afferent fibers
- The smaller the receptive field the greater is the acuity or the discriminative touch







Receptive field

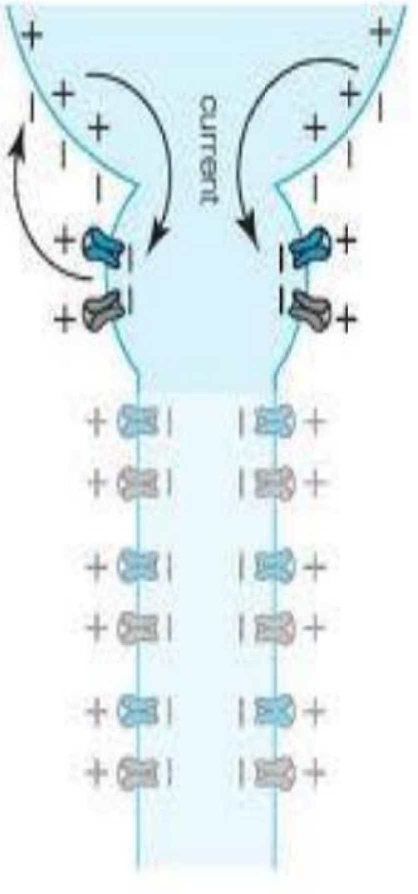
- Receptive fields vary in size. The smaller the receptive field, the more precisely the sensation can be localized or identified.

Sensation

- 2. **Transduction**: A sensory receptor transduces (converts) energy in a stimulus into a graded potential.

- Each type of sensory receptor exhibits selectivity: It can transduce only one kind of stimulus.

Action potential



Key:

1 Resting membrane potential: Voltage-gated Na^+ channels are in the resting state and voltage-gated K^+ channels are closed

2 Stimulus causes depolarization to threshold

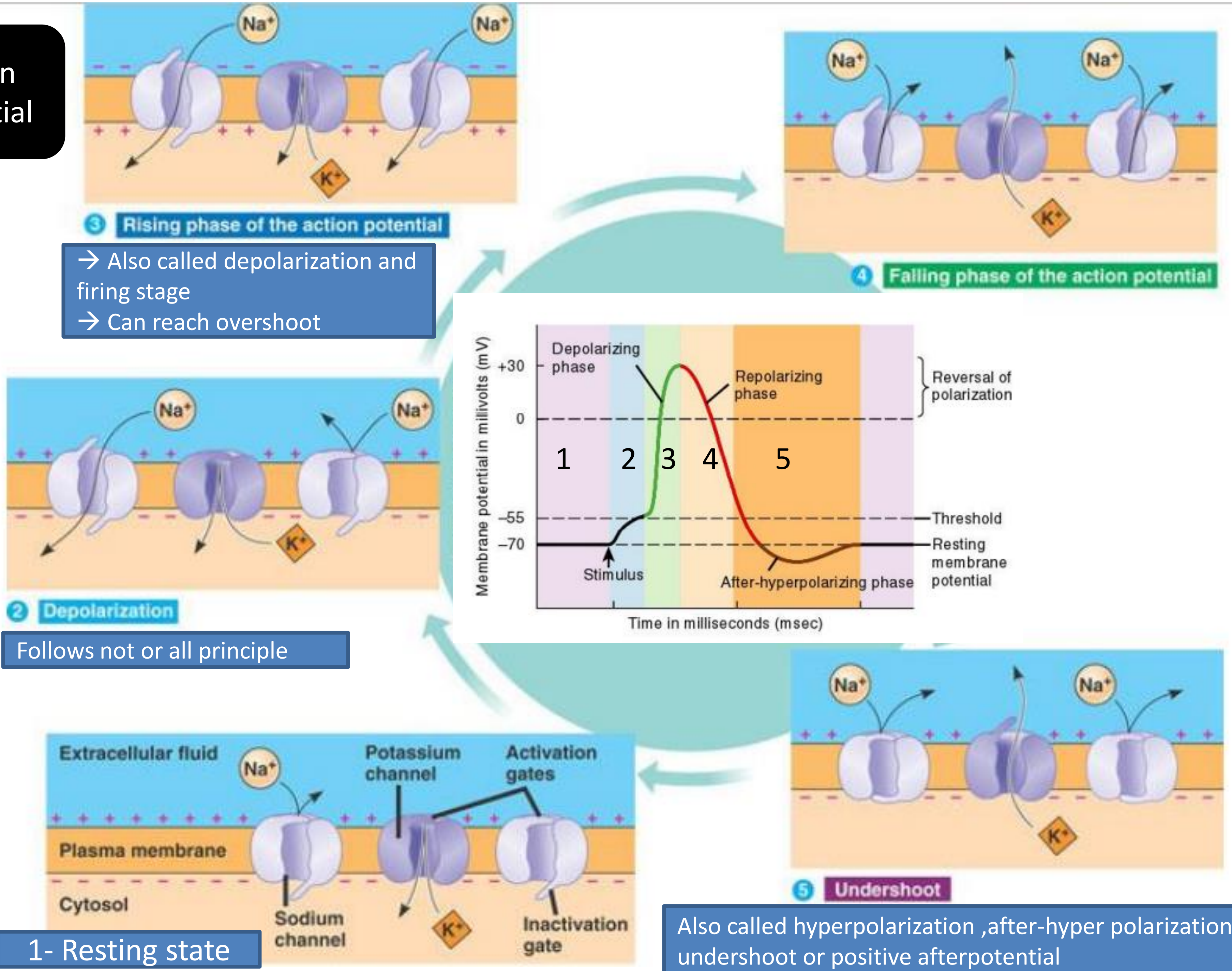
3 Voltage-gated Na^+ channel activation gates are open

4 Voltage-gated K^+ channels are open; Na^+ channels are inactivating

(3–4) Absolute refractory period

5 Voltage-gated K^+ channels are still open; Na^+ channels are in the resting state

(5) Relative refractory period



→ Also called depolarization and firing stage
→ Can reach overshoot

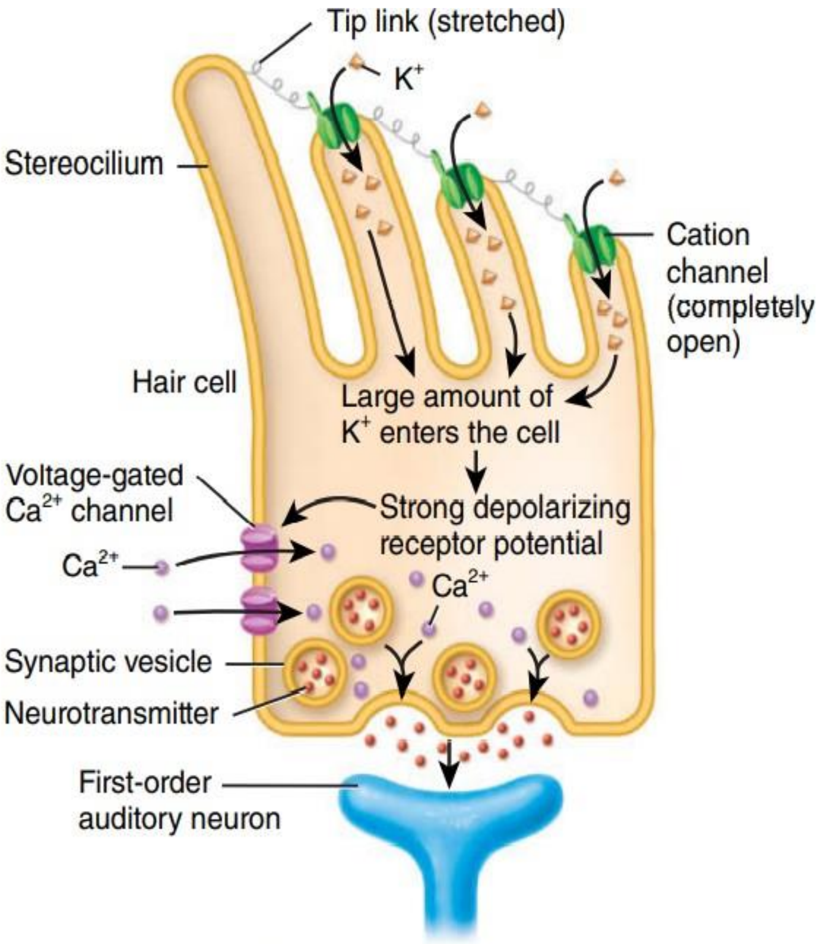
Follows not or all principle

1- Resting state

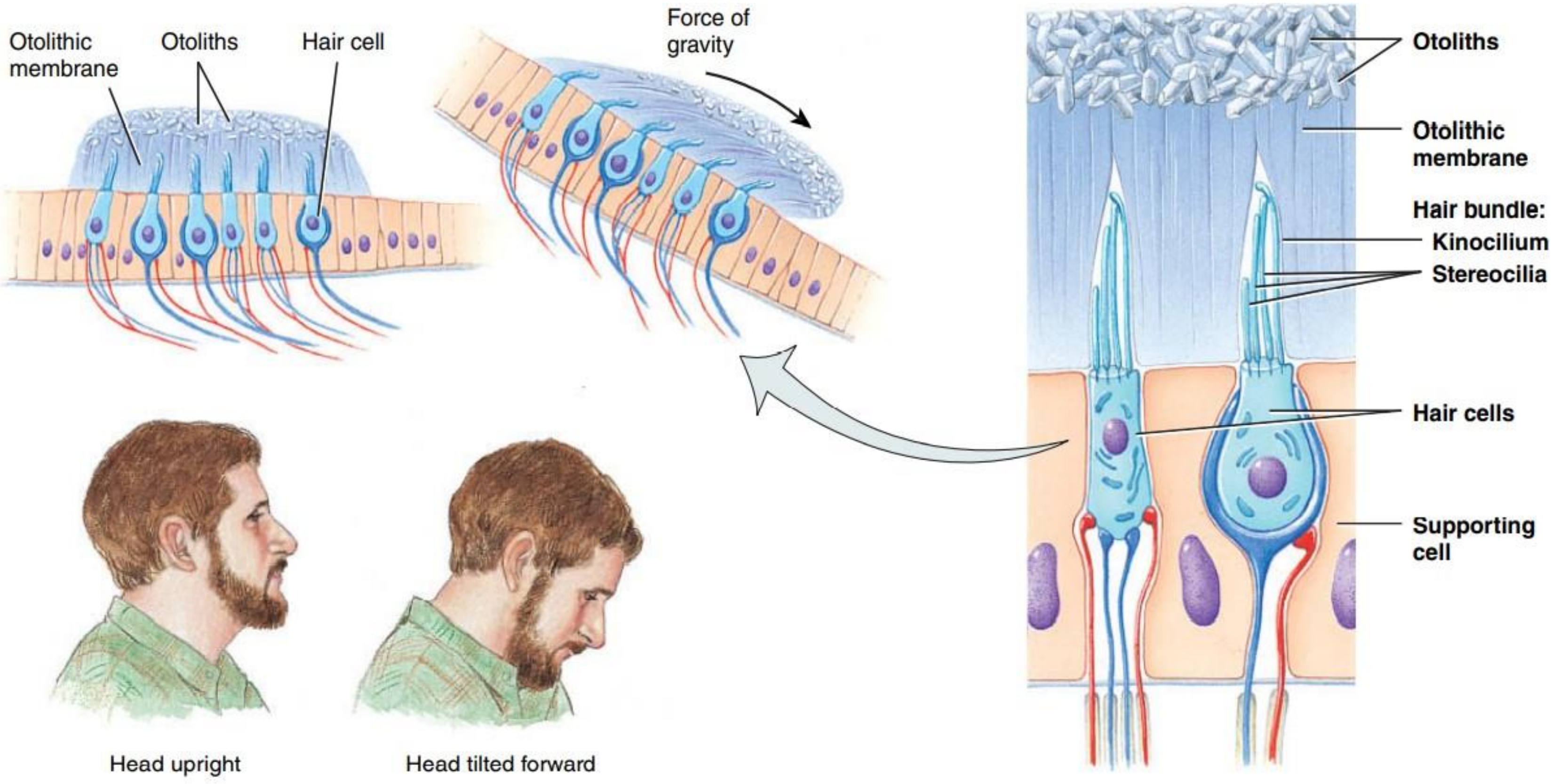
Also called hyperpolarization ,after-hyper polarization, undershoot or positive afterpotential

Remember!

Graded potential



(b) Strongly depolarized hair cell



(c) Position of macula with head upright (left) and tilted forward (right)

(b) Details of two hair cells

Receptor potential

All sensory receptors have one feature in common:

Whatever the type of stimulus that excites the receptor, its immediate effect is to change the membrane electrical potential of the receptor. This change in potential is called a receptor potential.

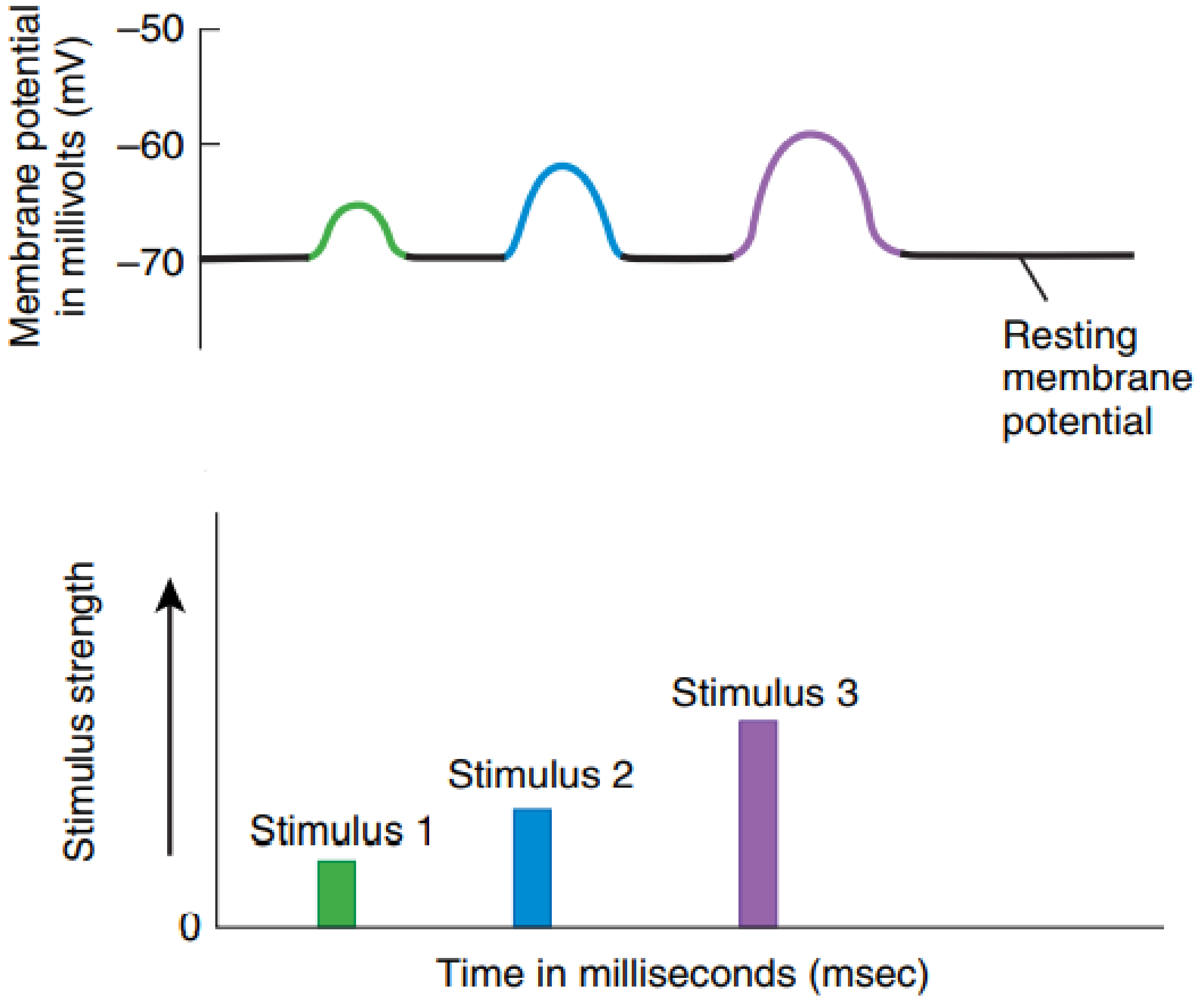
Receptor potential

- In all instances, the basic cause of the change in membrane potential is a change in membrane permeability of the receptor, which allows ions to diffuse more or less readily through the membrane and thereby to change the membrane potential.

Graded potential vs Action potential

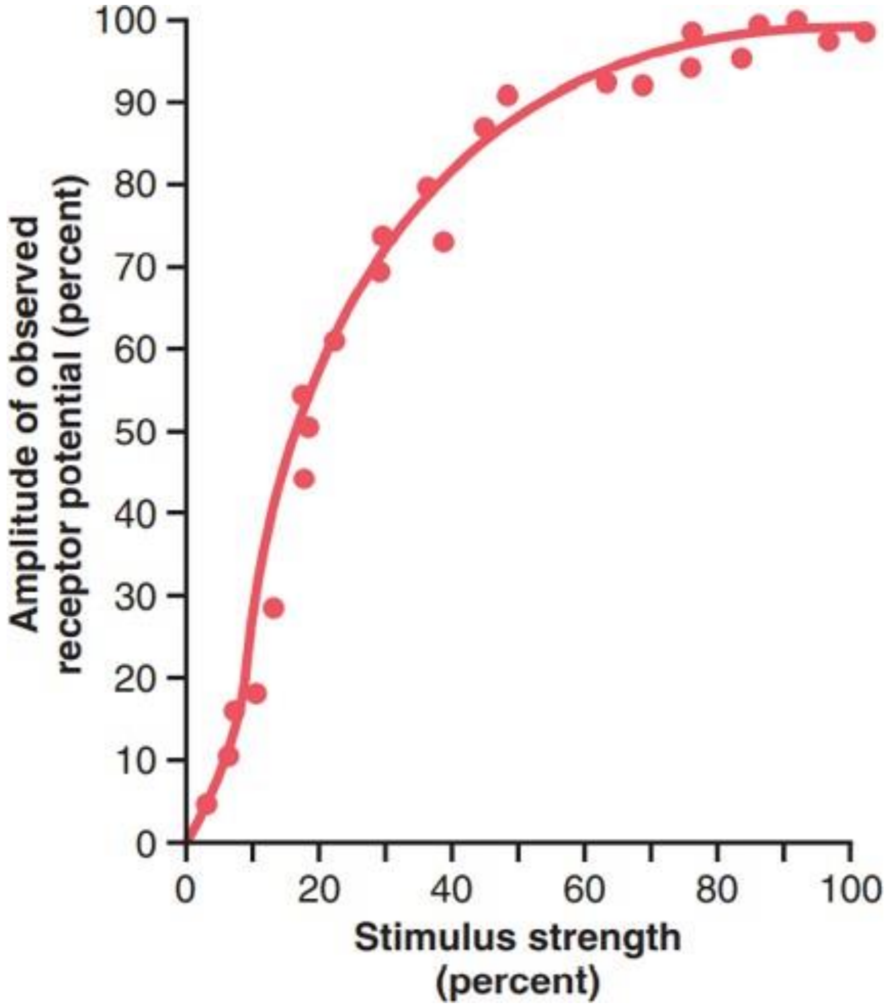
Comparison of Graded Potentials and Action Potentials in Neurons		
CHARACTERISTIC	**GRADED POTENTIALS**	**ACTION POTENTIALS**
Origin	Arise mainly in dendrites and cell body.	Arise at trigger zones and propagate along axon.
Types of channels	Ligand-gated or mechanically-gated ion channels.	Voltage-gated channels for Na^+ and K^+.
Conduction	Decremental (not propagated); permit communication over short distances.	Propagate and thus permit communication over longer distances.
Amplitude (size)	Depending on strength of stimulus, varies from less than 1 mV to more than 50 mV.	All or none; typically about 100 mV.
Duration	Typically longer, ranging from several milliseconds to several minutes.	Shorter, ranging from 0.5 to 2 msec.
Polarity	May be hyperpolarizing (inhibitory to generation of action potential) or depolarizing (excitatory to generation of action potential).	Always consist of depolarizing phase followed by repolarizing phase and return to resting membrane potential.
Refractory period	Not present; summation can occur.	Present; summation cannot occur.

The amplitude of a graded potential depends on the stimulus strength. The greater the stimulus strength, the larger the amplitude of the graded potential.



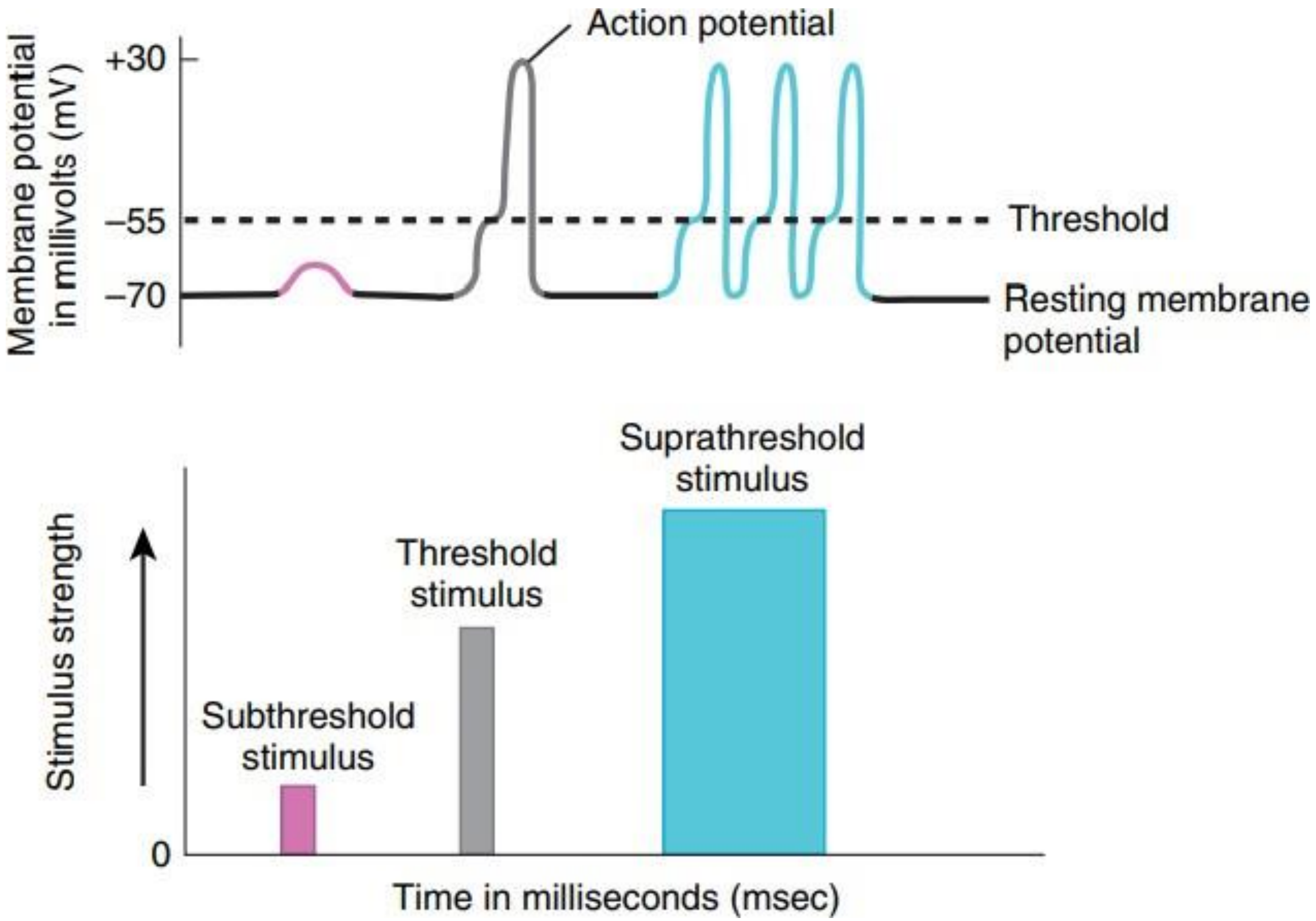
Stimulus intensity and Receptor potential

The amplitude increases rapidly at first but then progressively less rapidly at high stimulus strength.

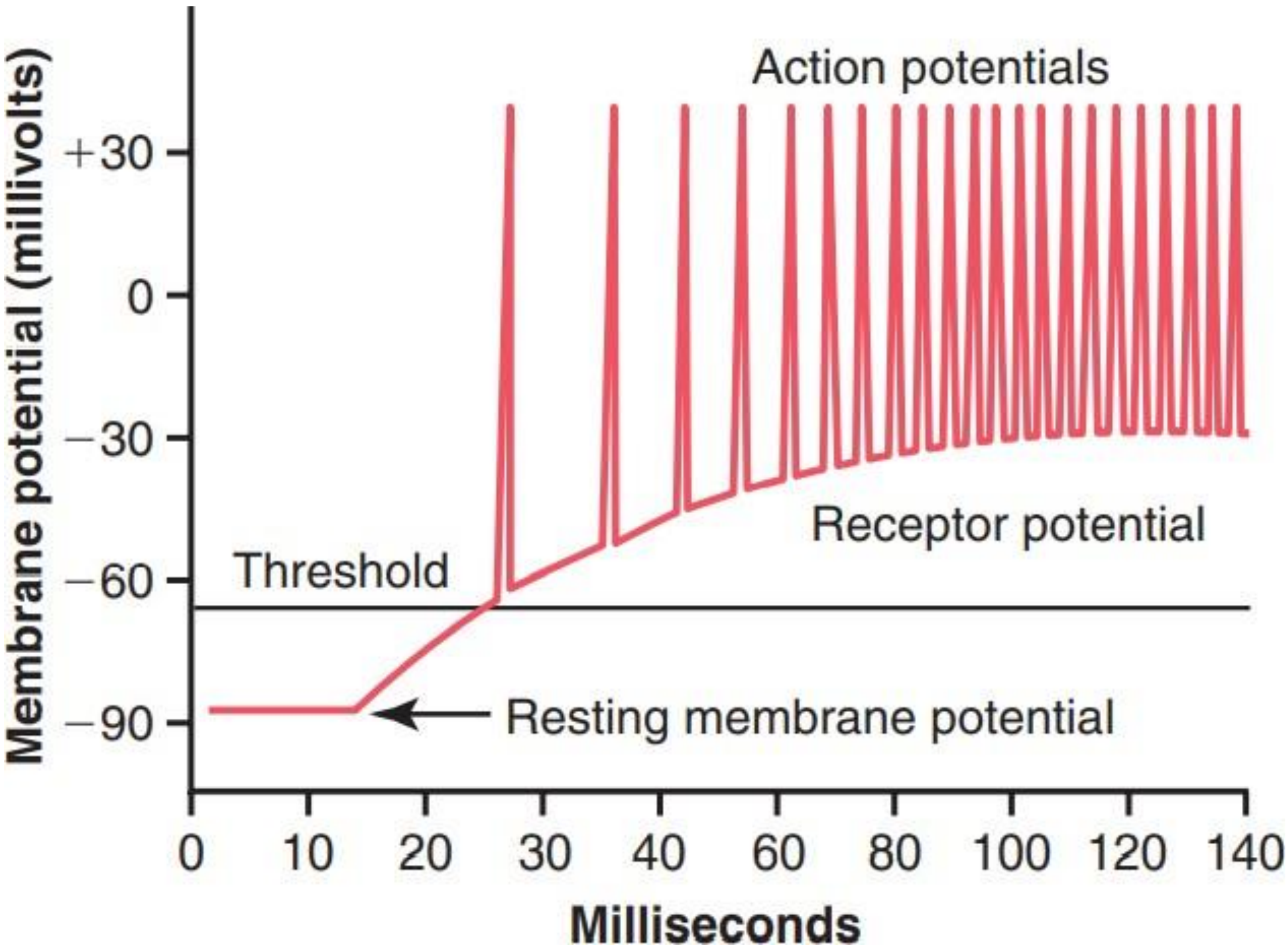


Sensation

- 3. Generation of nerve impulses. When a graded potential in a sensory neuron reaches **threshold**, it triggers one or more nerve impulses, which then propagate toward the CNS.



Action potential
+30
–55
–70
Threshold
Resting membrane potential
Membrane potential in millivolts (mV)
Suprathreshold stimulus
Threshold stimulus
Subthreshold stimulus
Stimulus strength
0
Time in milliseconds (msec)


Action potentials
Receptor potential
Threshold
Resting membrane potential
Membrane potential (millivolts)
+30
0
−30
−60
−90
0
10
20
30
40
60
80
100
120
140
Milliseconds

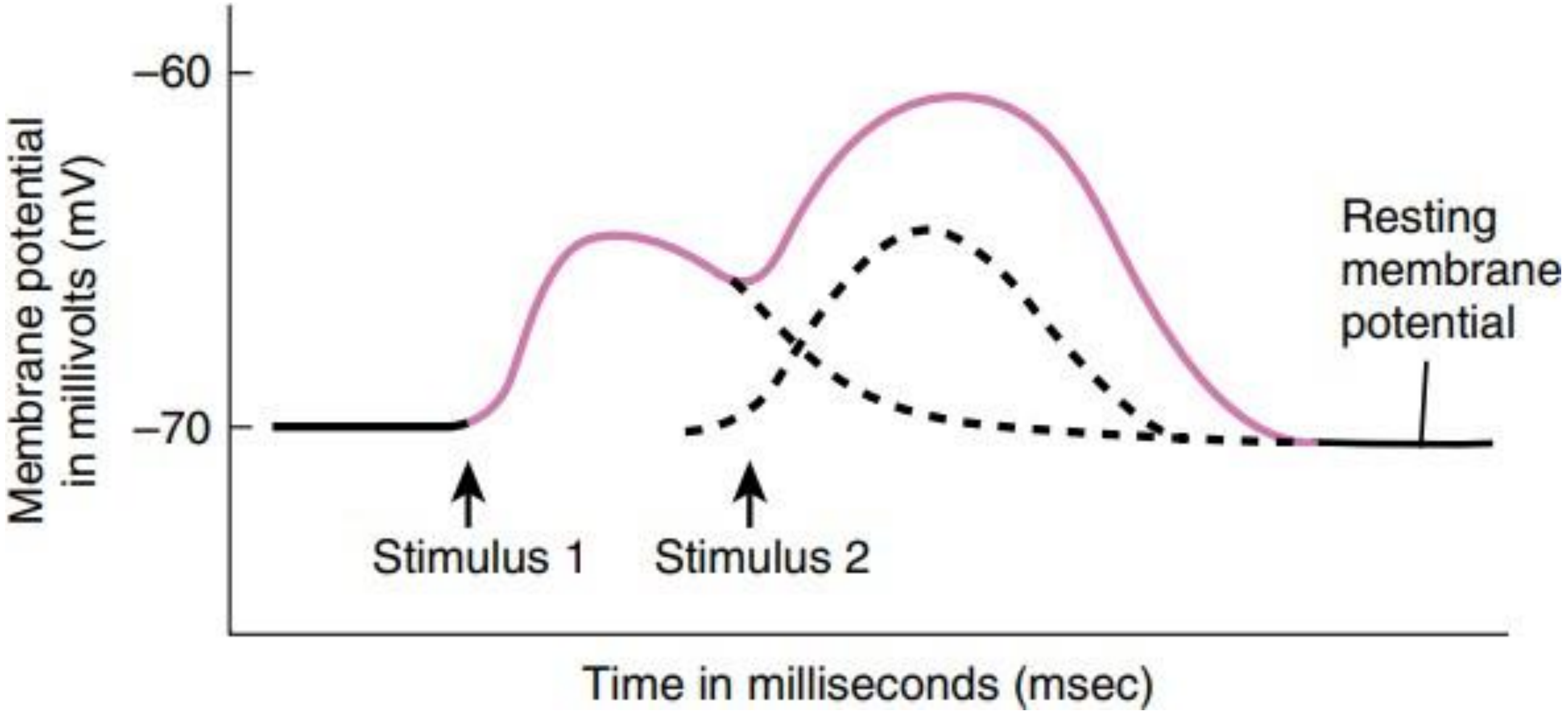
Stimulus intensity and Receptor potential

- The frequency of repetitive action potentials transmitted from sensory receptors increases approximately in proportion to the increase in receptor potential.

- The more the receptor potential rises above the threshold level, the greater becomes the action potential frequency.

- Very intense stimulation of the receptor causes progressively less and less additional increase in numbers of action potentials.

Summation in graded potential



Summation

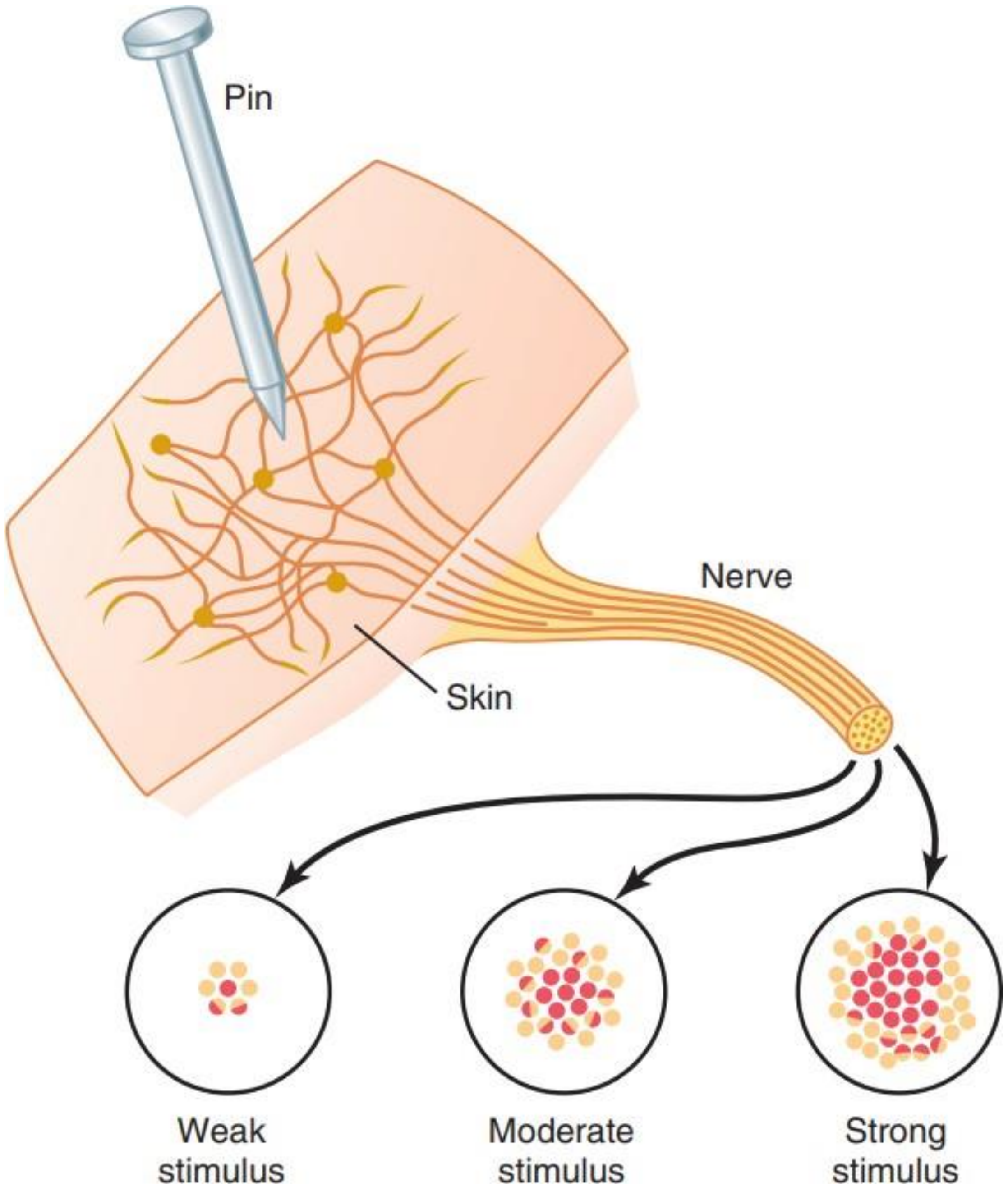
- One of the characteristics of each signal that always must be conveyed is signal intensity—for instance, the intensity of pain.

- The different gradations of intensity can be transmitted either by using increasing numbers of parallel fibers or by sending more action potentials along a single fiber. These two mechanisms are called, respectively, spatial summation and temporal summation.

Spatial summation

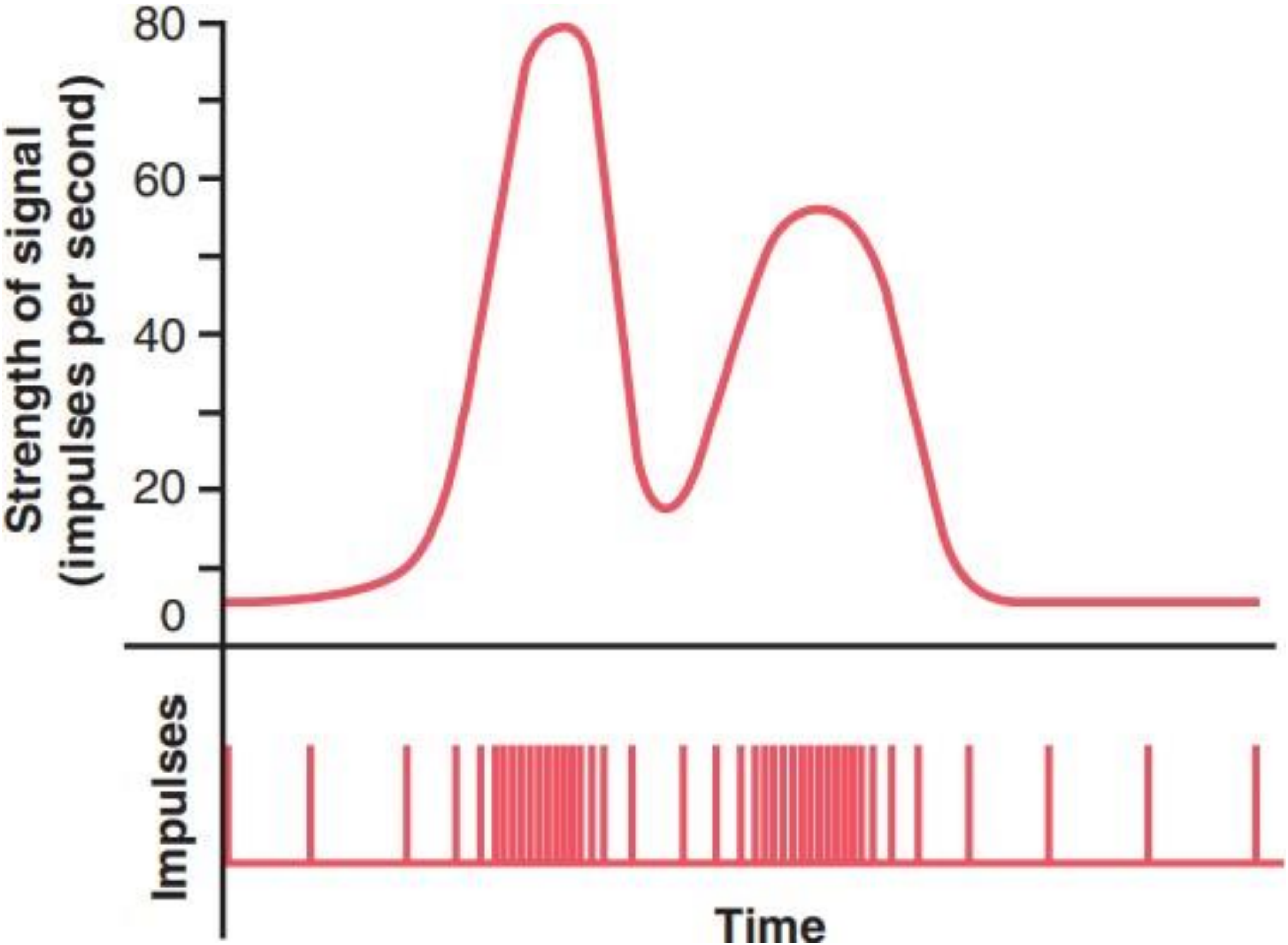
- Increasing signal strength is transmitted by using progressively greater numbers of fibers.

- When the pinprick is in the center of the receptive field of a particular pain fiber, the degree of stimulation of that fiber is far greater than when it is in the periphery of the field because the number of free nerve endings in the middle of the field is much greater than at the periphery.


Pin
Nerve
Skin
Weak stimulus
Moderate stimulus
Strong stimulus

Temporal summation

- A second means for transmitting signals of increasing strength is by increasing the frequency of nerve impulses in each fiber, which is called temporal summation.



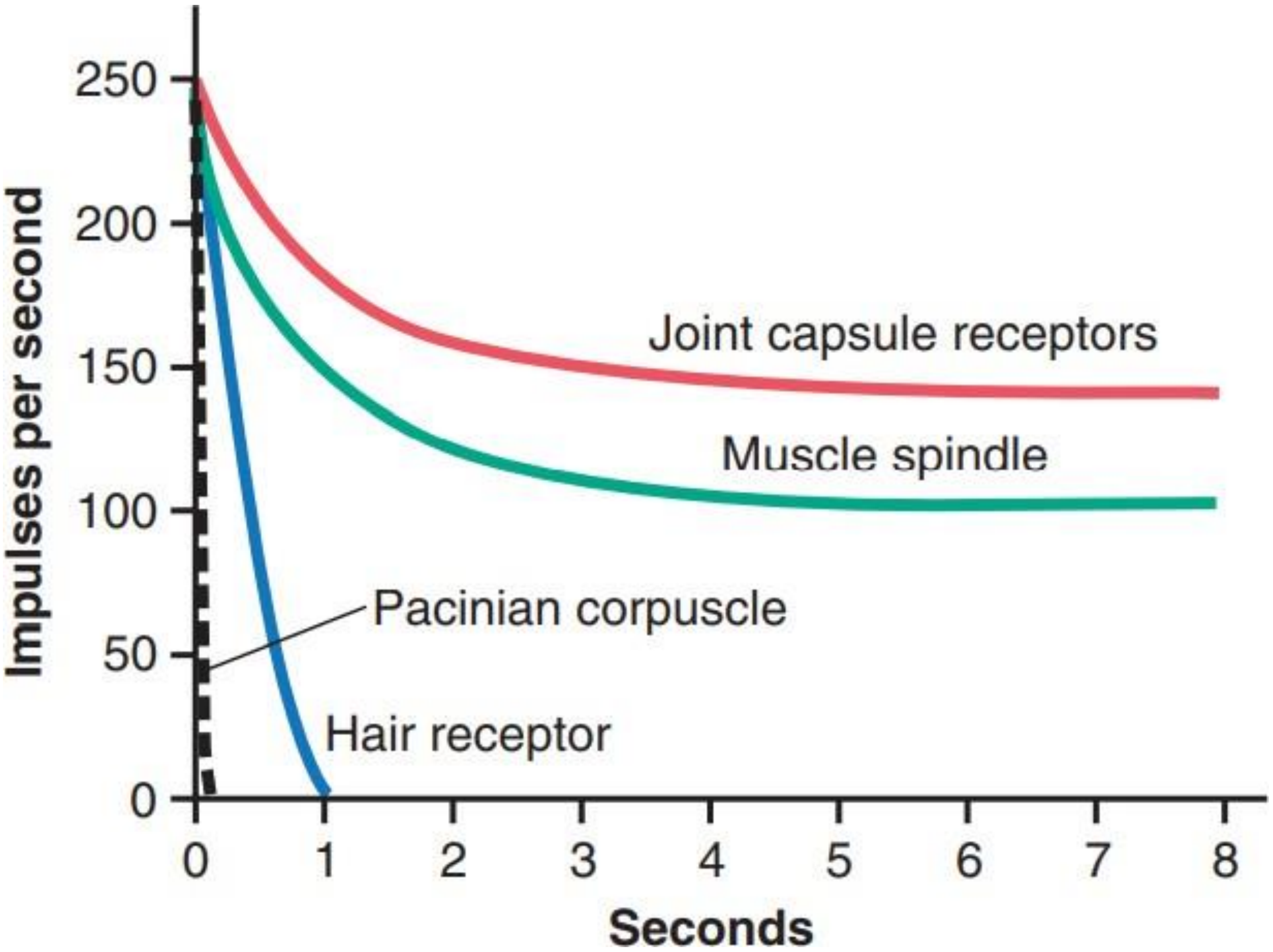
80
60
40
20
0
Strength of signal (impulses per second)
Impulses
Time

Adaptation

- A characteristic of most sensory receptors is adaptation, in which the receptor potential decreases in amplitude during a maintained, constant stimulus.

- This causes the frequency of nerve impulses in the first-order neuron to decrease.

- Because of adaptation, the perception of a sensation may fade or disappear even though the stimulus persists.



Impulses per second
250
200
150
100
50
0
0
1
2
3
4
5
6
7
8
Seconds
Joint capsule receptors
Muscle spindle
Pacinian corpuscle
Hair receptor

Adaptation of sensory receptors

- When a continuous sensory stimulus is applied, the receptor responds at a high impulse rate at first and then at a progressively slower rate until finally the rate of action potentials decreases to very few or often to none at all.

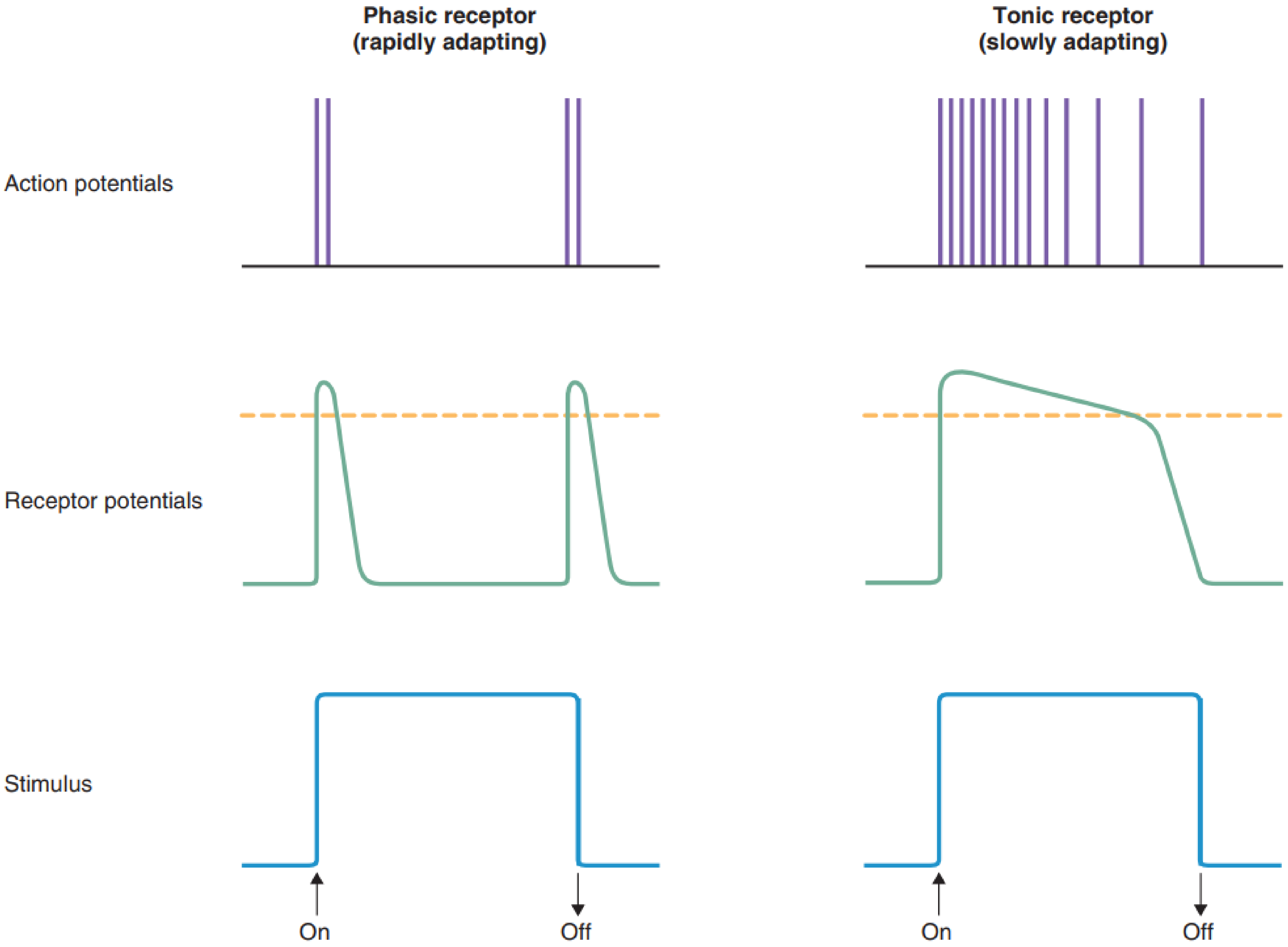
- Sensory receptors adapt either partially or completely to any constant stimulus after a period of time.

Adaptation

- Receptors vary in how quickly they adapt, and some sensory receptors adapt to a far greater extent than do others.
- Rapidly adapting receptors adapt very quickly. They are specialized for signaling changes in a stimulus.
- Receptors associated with pressure, touch, and smell are rapidly adapting.

Adaptation

- Receptors vary in how quickly they adapt.
- Slowly adapting receptors adapt slowly and may continue to trigger nerve impulses as long as the stimulus persists.
- Slowly adapting receptors monitor stimuli associated with pain, body position, and chemical composition of the blood.


Phasic receptor
(rapidly adapting)
Tonic receptor
(slowly adapting)
Action potentials
Receptor potentials
Stimulus
On
Off
On
Off

Costanzo

Slowly adapting receptors

- Detect Continuous Stimulus Strength: **Tonic Receptors**.

- Slowly adapting receptors continue to transmit impulses to the brain as long as the stimulus is present (or at least for many minutes or hours). Therefore, they keep the brain constantly apprised of the status of the body and its relation to its surroundings.

Slowly adapting receptors

- Impulses from the muscle spindles and Golgi tendon apparatuses allow the nervous system to know the status of muscle contraction and load on the muscle tendon at each instant.

- Some of the non-mechanoreceptors (the chemoreceptors and pain receptors) probably never adapt completely.

Slowly adapting receptors

- Slowly adapting receptors include:

- (1) receptors of the macula in the vestibular apparatus.
- (2) pain receptors.
- (3) baroreceptors of the arterial tree.
- (4) chemoreceptors of the carotid and aortic bodies.
- (5) proprioceptors such as muscle spindle and Golgi tendon organ.

Rapidly adapting receptors

- Detect Change in Stimulus Strength. Also called Rate Receptors, Movement Receptors, or Phasic Receptors.

- Receptors that adapt rapidly cannot be used to transmit a continuous signal because they are stimulated only when the stimulus strength changes. Yet, they react strongly while a change is actually taking place.

Predictive function of the rate receptors

- If one knows the rate at which some change in bodily status is taking place, the state of the body a few seconds or even a few minutes later can be predicted.

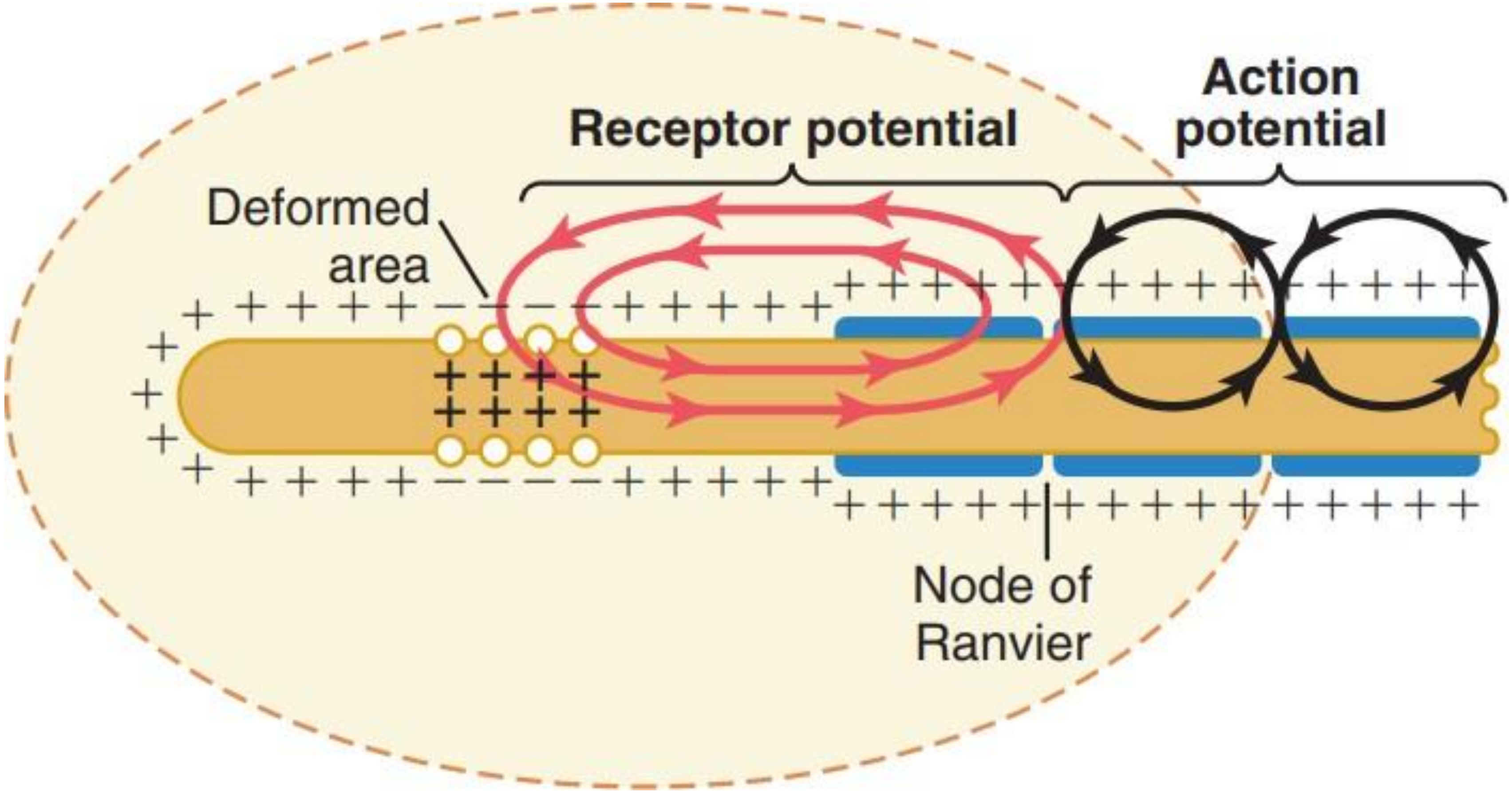
- For instance, when one is running, information from the joint rate receptors allows the nervous system to predict where the feet will be during any precise fraction of the next second. Therefore, appropriate motor signals can be transmitted to the muscles of the legs to make any necessary anticipatory corrections in position so that the person will not fall.

Adaptation of sensory receptors

- The **mechanism** of receptor adaptation is different for each type of receptor, in much the same way that development of a receptor potential is an individual property.

- For instance, in the eye, the rods and cones adapt by changing the concentrations of their light-sensitive chemicals.

Pacinian corpuscle



Rapidly adapting receptors

- In the case of the Pacinian corpuscle, sudden pressure applied to the tissue excites this receptor for a few milliseconds, and then its excitation is over even though the pressure continues. Later, however, it transmits a signal again when the pressure is released.

Rapidly adapting receptors

- Pacinian corpuscle is exceedingly important in apprising the nervous system of rapid tissue deformations, but it is useless for transmitting information about constant conditions in the body.

Adaptation of Pacinian corpuscles

- Adaptation occurs in this receptor in two ways.

- First, the Pacinian corpuscle is a viscoelastic structure, so that when a distorting force is suddenly applied to one side of the corpuscle, this force is instantly transmitted by the viscous component of the corpuscle directly to the same side of the central nerve fiber, thus eliciting a receptor potential.

Adaptation of Pacinian corpuscles

- However, within a few hundredths of a second, the fluid within the corpuscle redistributes and the receptor potential is no longer elicited.

Adaptation of Pacinian corpuscles

- The second, much slower mechanism of adaptation, results from a process called accommodation, which occurs in the nerve fiber itself.

- This probably results from progressive “inactivation” of the sodium channels in the nerve fiber membrane, which means that sodium current flow through the channels causes them gradually to close, an effect that seems to occur for all or most cell membrane sodium channels.

Adaptation of Pacinian corpuscles

- These same two general mechanisms of adaptation may apply also to the other types of mechanoreceptors.

- That is, part of the adaptation results from readjustments in the structure of the receptor, and part results from an electrical type of accommodation in the terminal nerve fibril.

Sensory coding

CNS can distinguish 4 stimulus properties:

- 1. sensory modality: labeled line principle
- 2. location: receptive field
- 3. intensity: spatial and temporal summation
- 4. duration: rapidly vs slowly adapting