General Physiology
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lecture 19
Receptor adaptation & Neural circuits in neuronal pool

Zuheir A Hasan

Department of Anatomy , Physiology and Biochemistry

College of Medicine

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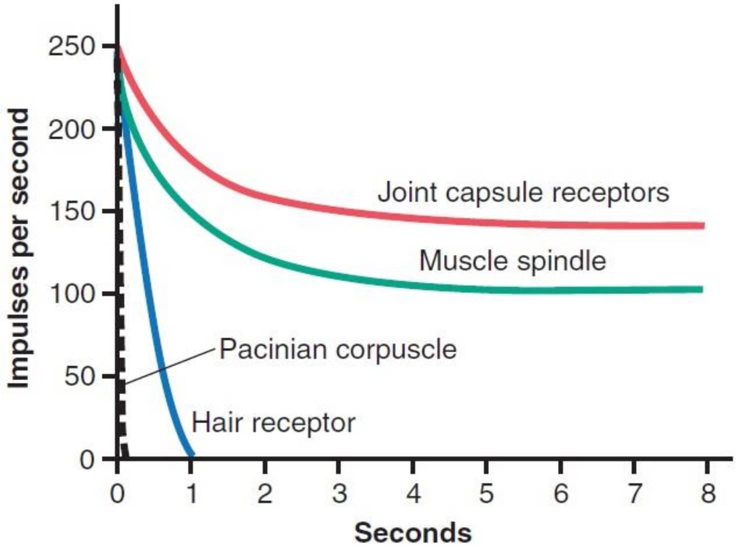
Lecture Objectives

- Define adaptation of receptors and describe the mechanism of receptor adaptation
- Define slowly adapting (Tonic receptors) and rapidly adapting receptors (Phasic receptors) and explain the differences between tonic and phasic receptors
- Describe the relationship between nerve fiber diameter and conduction velocity and the different types of fibers in a nerve trunk
- Differentiate between spatial and temporal summation of sensory signals .
- Recognize neural circuits, divergence, convergence, reverberating cycles and feedback circuits and their importance in integration of neuronal signals .

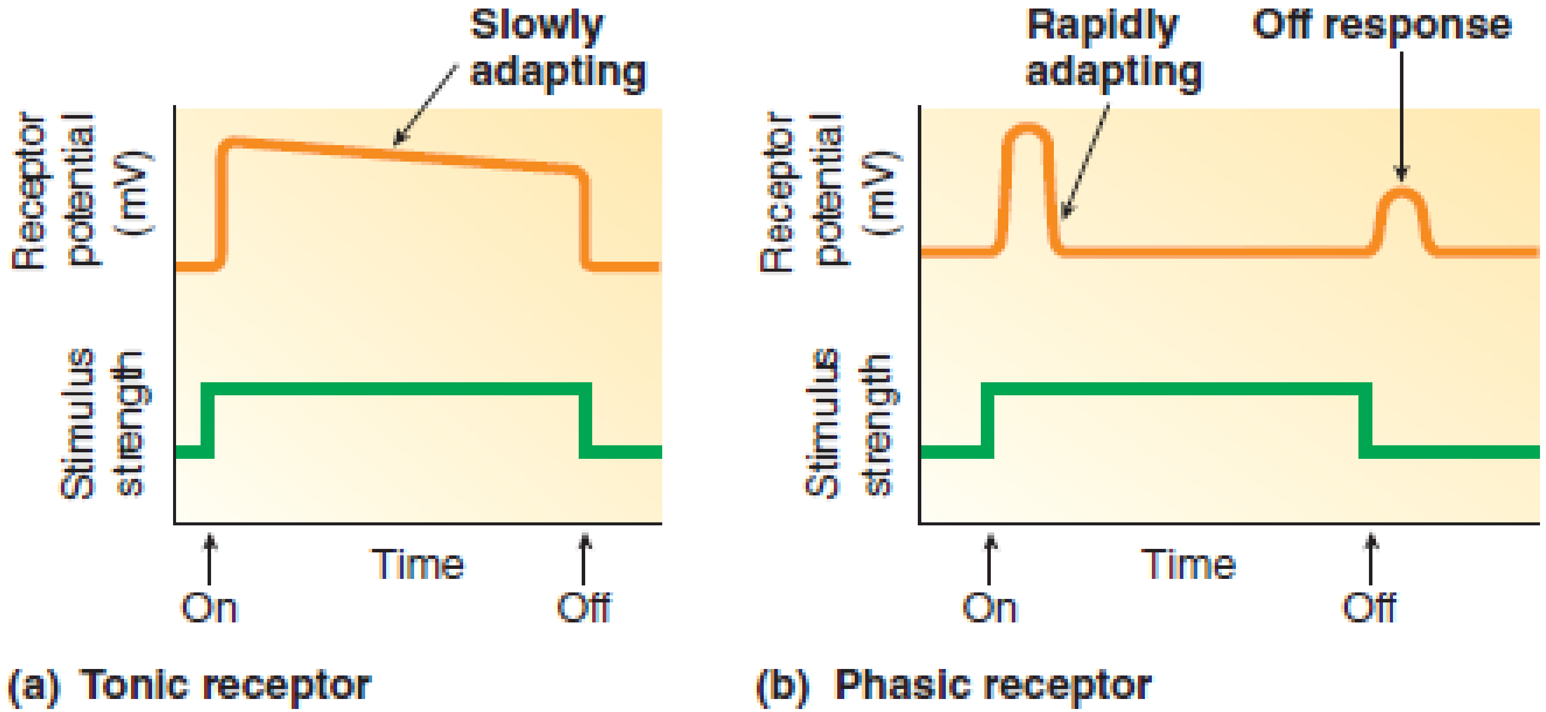
Adaptation of Receptors:

- **Adaptation** is the decline of the electric responses of a receptor neuron over time in spite of the continued presence of an appropriated stimulus of constant strength.
- 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.
- Some sensory receptors adapt to a far greater extent than do others. Example; the **Pacinian corpuscles** adapt to “extinction” within a few hundredths of a second. Whereas, some require hours or days to do so, for which reason they are called “nonadapting” receptors.
- A **mechanoreceptor** (such as carotid and aortic baroreceptors) adapts in about 2 days. Some of the non-mechanoreceptors (the chemoreceptors and pain receptors) probably **never adapt completely**.



Adaptation of different types of receptors showing rapid adaptation of some receptors and slow adaptation of others.

Adaptation in receptors Slowly adapting and rapidly adapting receptors



The Tonic Receptors (Slowly Adapting Receptors):

* The slowly adapting receptors continue to transmit impulses to the brain as long as the stimulus is present. So, these receptors inform the brain about the **duration** of the stimulus.
* Therefore, they keep the brain aware about the status of the body and its relation to its surroundings. Example of tonic receptors are;
  1. Muscle spindles, Golgi tendon apparatuses, and joint capsule receptors.
  2. Receptors of the macula in the vestibular apparatus.
  3. Pain receptors.
  4. Baroreceptors of the arterial tree.
  5. Chemoreceptors of the carotid and aortic bodies.
  6. Skin mechanoreceptors such as Merkel's discs (detect pressure) and Ruffini corpuscles (detect skin stretch).
* Tonic receptors are given this name because they can continue to transmit information for many hours, or even days.

The Phasic Receptors (Rapidly Adapting Receptors, Rate Receptors, or Movement Receptors):

* These receptors react strongly while a change is actually taking place. Therefore, they inform the CNS about rapid changes in stimulus **intensity** and **rate**.
* Phasic receptors (such as the Pacinian corpuscle and Meissner's corpuscles) are important in informing the nervous system of rapid tissue deformations, but it is useless for transmitting information about constant conditions in the body.

Note:

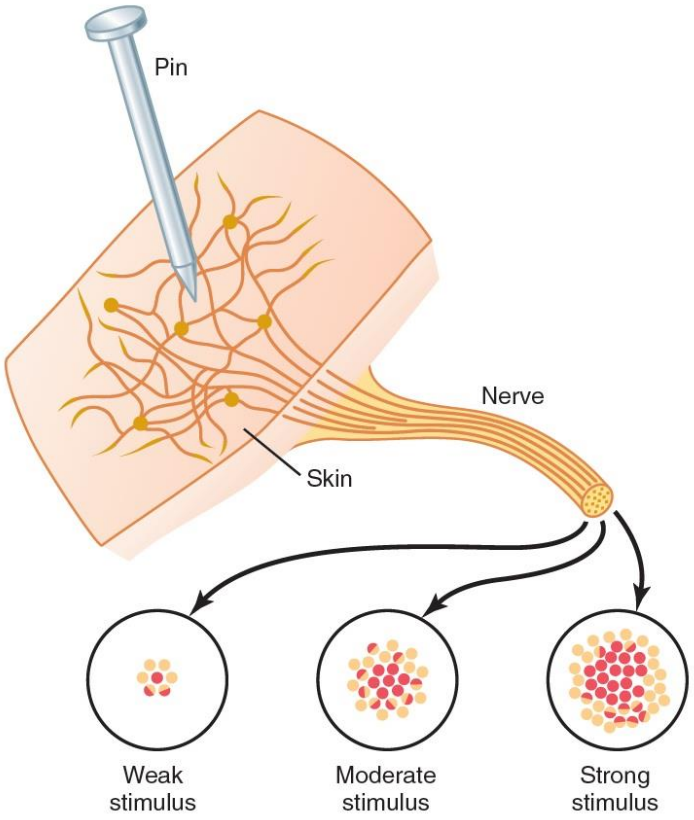
Many sensory neurons may unify both response properties and are called **phasic-tonic receptors**. They usually show a phasic response at stimulus onset, followed by a long-lasting, but lower tonic response. Example; **thermoreceptors**.

Mechanism of Receptor Adaptation:

- The mechanism of receptor adaptation is different for each type of receptor.
- Mechanoreceptors, for example, adapt because of readjustments in the structure of the receptor. Others, such as the rods and cones in the eye adapt by changing the concentrations of their light-sensitive chemicals.
- One of the adaptation mechanisms that is shared between receptors is the accommodation. Accommodation probably results from progressive “inactivation” of the sodium channels in the nerve fiber membrane.

Spatial Summation of Sensory Signal Transmission:

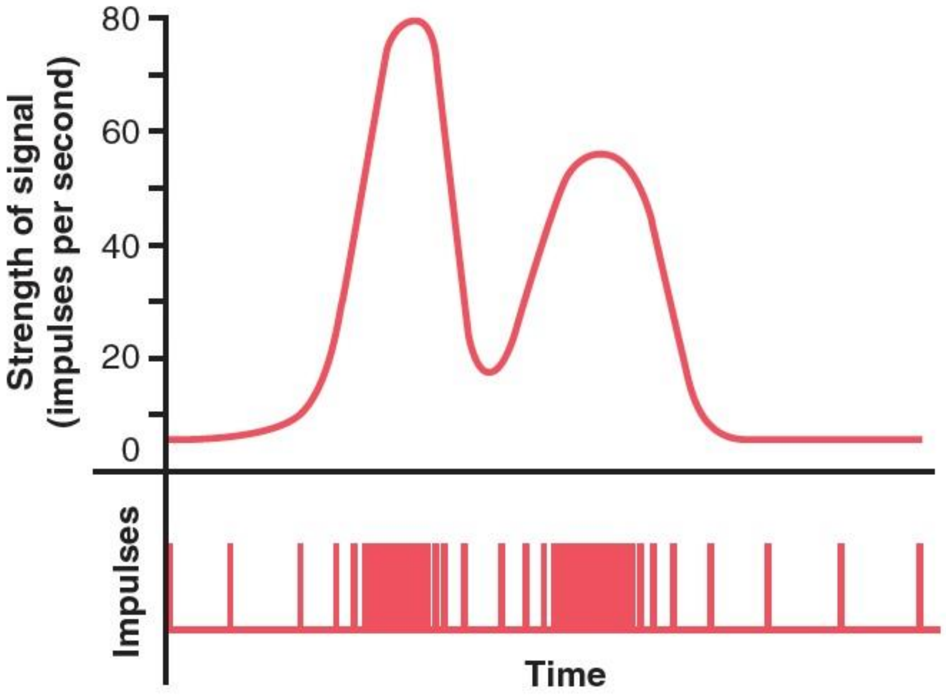
* Spatial summation is the increasing signal strength transmitted by using progressively **greater numbers of fibers**.
* The area of skin from which the entire cluster of fibers from one sensory fiber frequently covers is called the receptor field of that fiber.
* The **receptive field** is a portion of sensory space that can elicit neuronal responses when stimulated.
* The number of sensory endings is large in the center of the receptor field but diminishes toward the periphery.
* The arborizing fibrils of one sensory fibers **overlap** those from other fibers. Therefore, a pinprick of the skin usually stimulates endings from many different pain or tactile fibers simultaneously.



Pattern of stimulation of pain fibers in a nerve leading from an area of skin pricked by a pin. This pattern of stimulation is an example of *spatial summation*.

Temporal Summation of Sensory Signal Transmission:

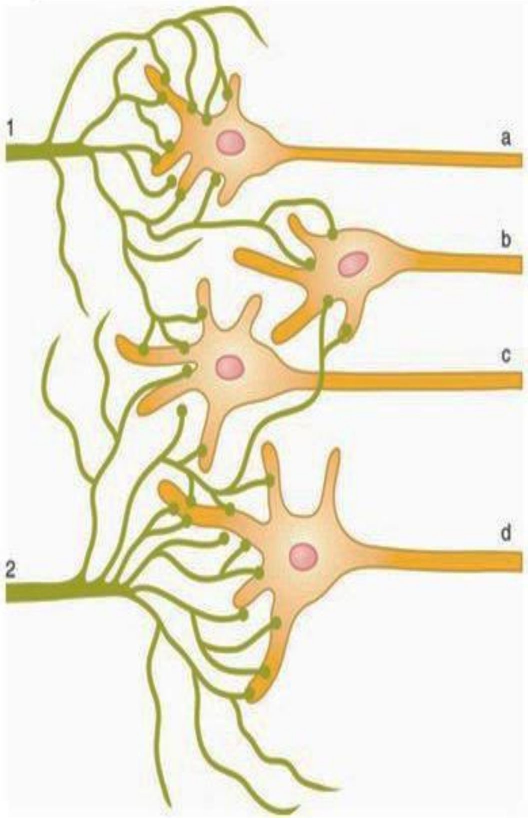
Temporal summation is a mean for transmitting signals of increasing strength by increasing the frequency of nerve impulses in each fiber.

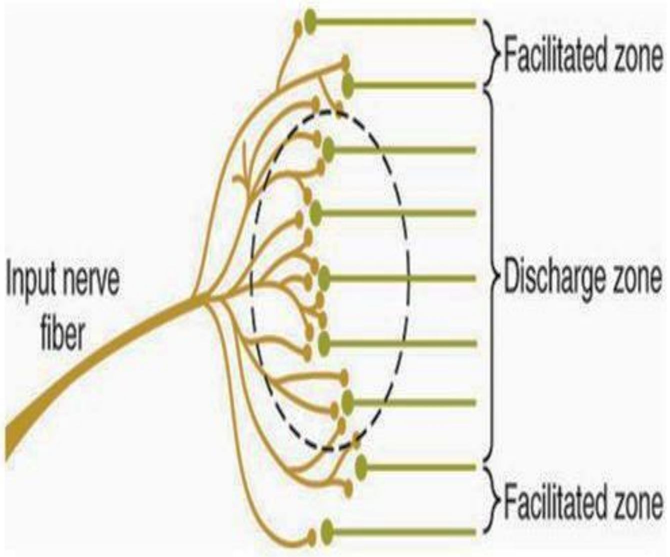


Translation of signal strength into a frequency-modulated series of nerve impulses, showing the strength of signal (*above*) and the separate nerve impulses (*below*). This illustration is an example of *temporal summation.*

Neuronal Pools

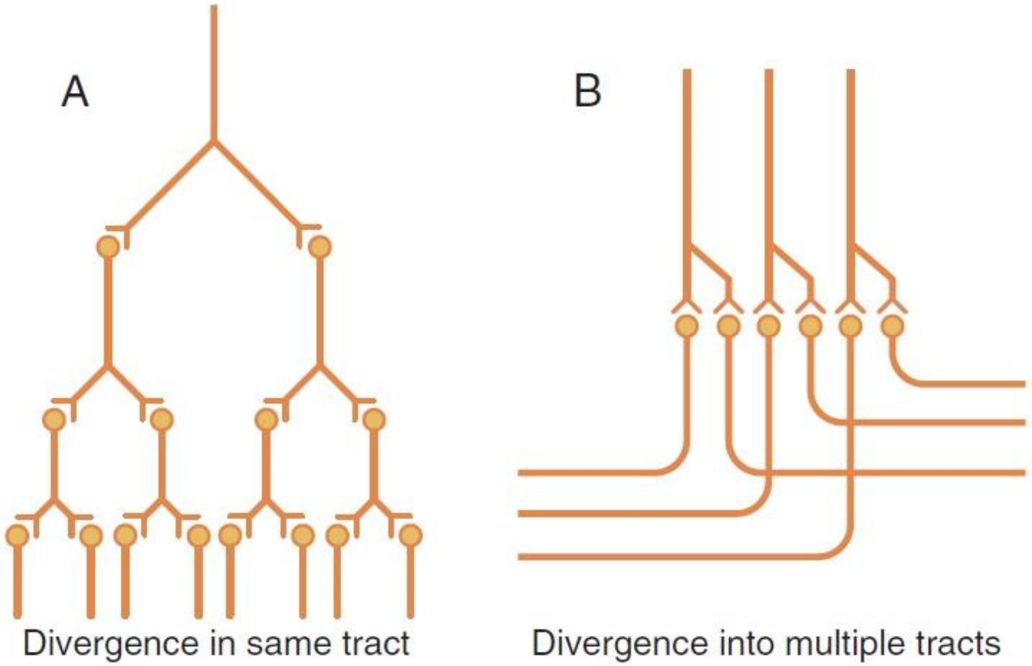
- The central nervous system is composed of thousands to millions of neuronal pools
- Neuronal pool : groups of neurons with special characteristics of organization comprise many different types of neuronal circuits that are important for integration of neuronal signals





Divergence of Neural Signals:

- A signal from a **single** presynaptic neuron may excite several postsynaptic neurons (or several muscle fibers or gland cells)
- This type of divergence is characteristic of the corticospinal pathway in its control of skeletal muscles, with a single large pyramidal cell in the motor cortex capable, under highly facilitated conditions, of exciting as many as10,000 muscle fibers
- It is the **amplification** of an input signal by exciting greater numbers of neurons as it passes through successive orders of neurons in its path.
- The divergence of the signal could run in a single tract or into multiple tracts.
- Example of multiple tract divergence is the divergence of sensory pathway which carries position sensations . Some fibers terminate in the thalamus and finally the cortex and another tract others terminate in the cerebellum



"Divergence" in neuronal pathways. *A*, Divergence within a pathway to cause "amplification" of the signal. *B*, Divergence into multiple tracts to transmit the signal to separate areas.

Divergence signal in the spinal cord an example of divergence sensory signal where a single sensory neuron is making synapses with multiple motor neurons

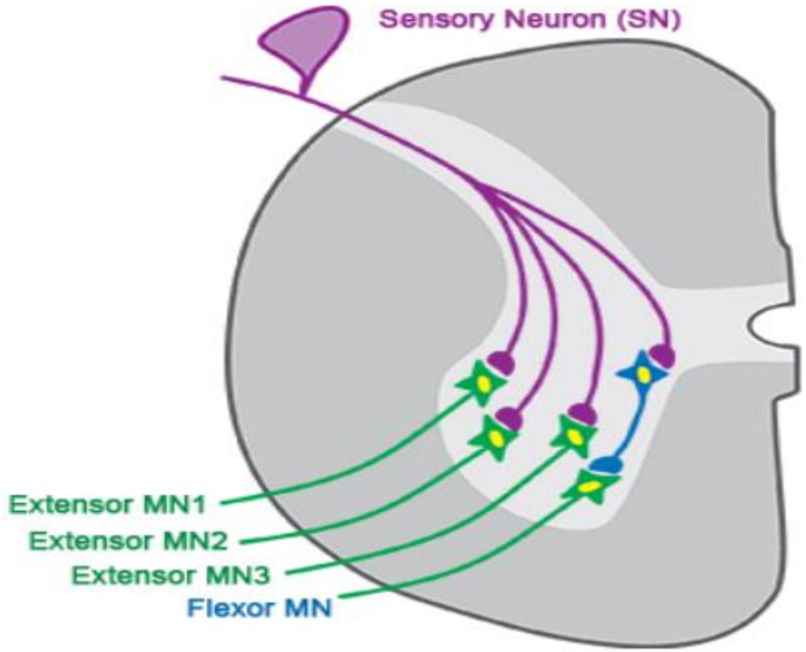
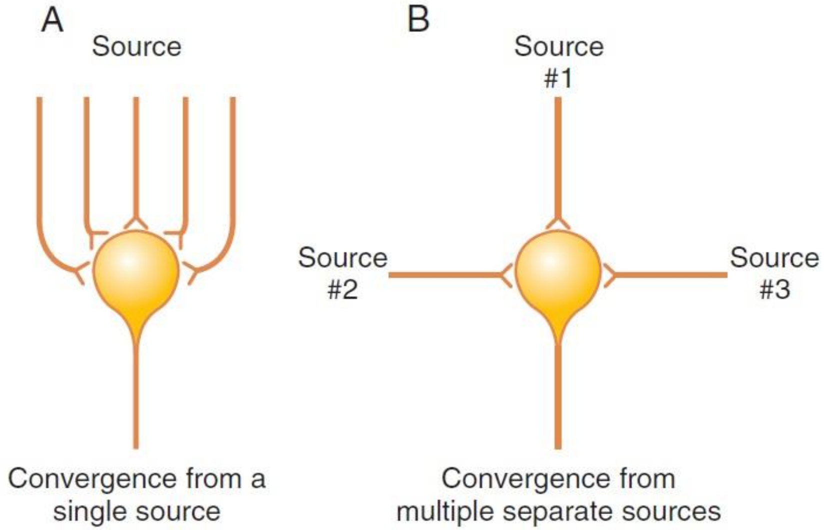


Figure 8

Convergence of Neural Signals:

* Convergence means signals from multiple inputs uniting to excite a single neuron.
* Convergence could be from a single source to provide enough spatial summation to bring the neuron to the threshold required for discharge.
* Or, Convergence can result from input signals (excitatory or inhibitory) from multiple sources. Such convergence allows summation of information from different sources, and the resulting response is a summated effect of all the different types of information.
* Example, a single motor neuron that synapses with skeletal muscle fibers at neuromuscular junctions receives input from several pathways that originate in different brain regions.



"Convergence" of multiple input fibers onto a single neuron. **A,** Multiple input fibers from a single source. **B,** Input fibers from multiple separate sources.

An example of convergence of sensory neurons with motor neurons in the spinal cord

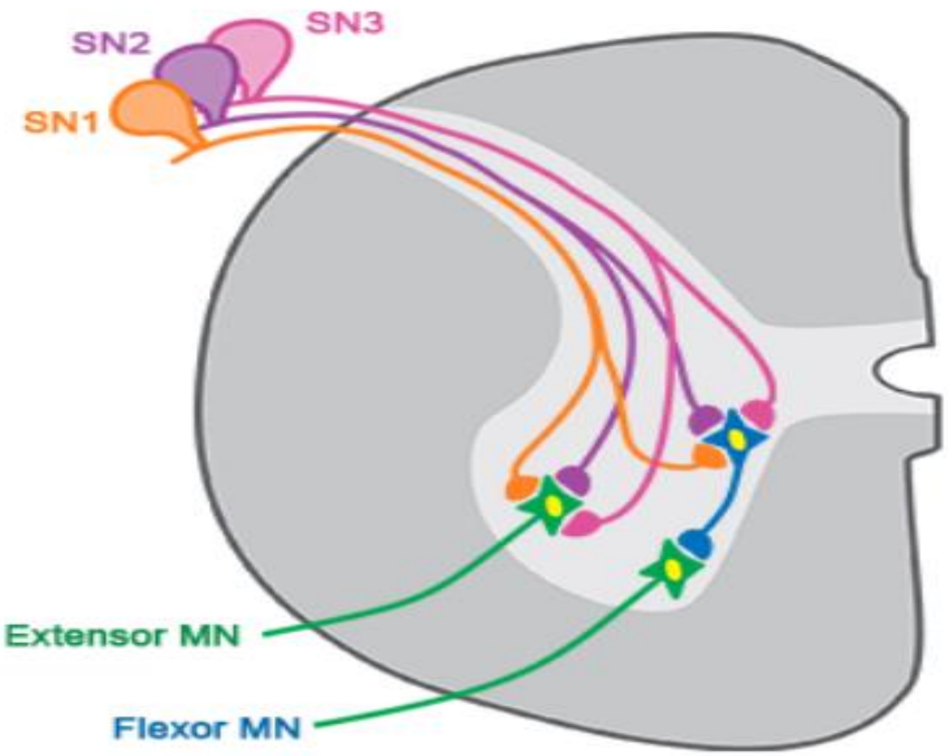
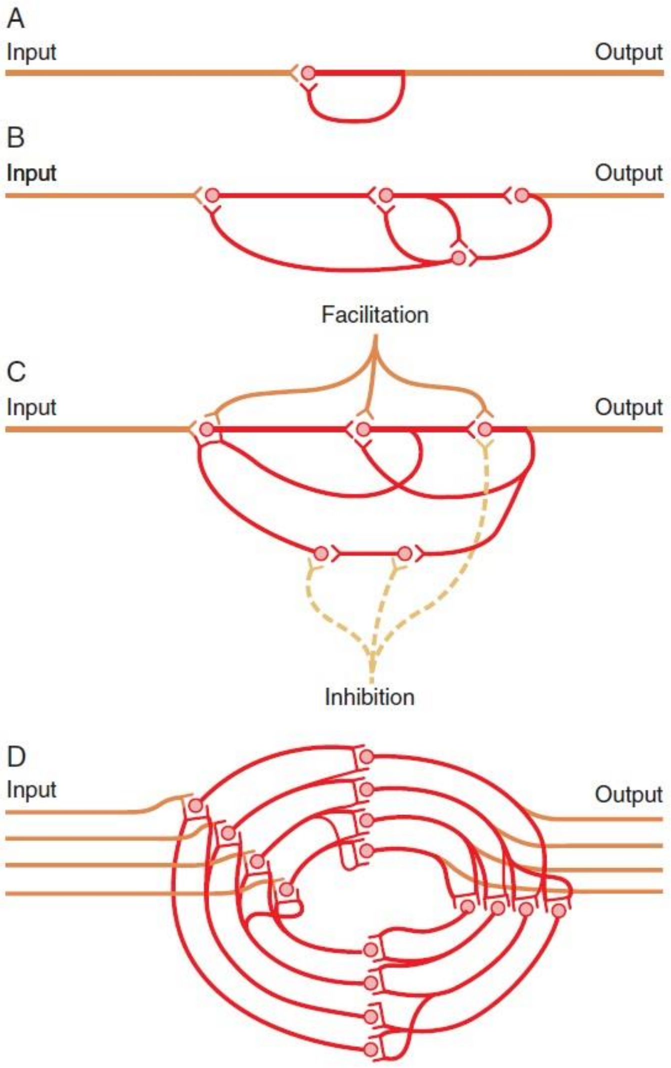


Figure 8

Neuronal Circuit:

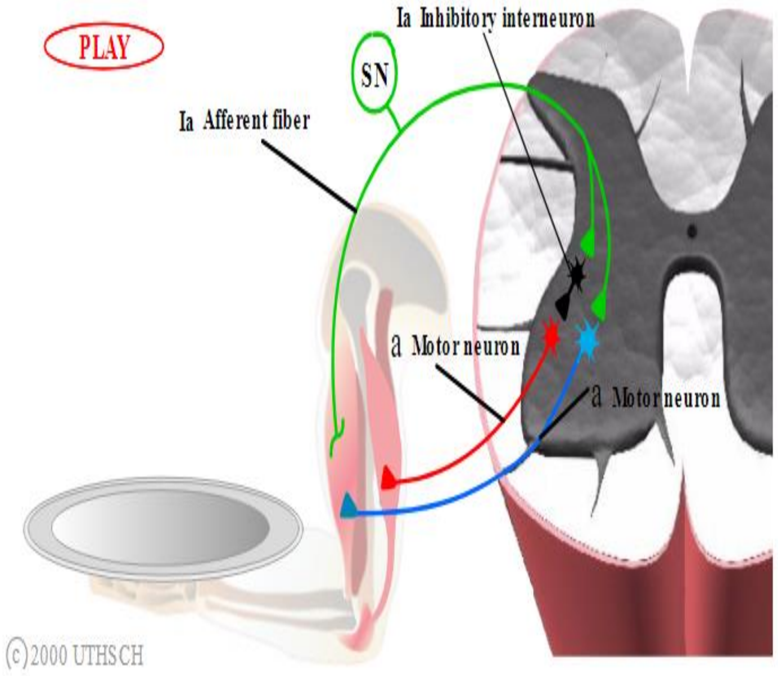
- **Afterdischarge**; is the state when stimulation of the presynaptic cell causes the postsynaptic cell to transmit a series of nerve impulses.
- Afterdischarge prolongs the output discharge of a single instantaneous input signal. The prolongation can last for few milliseconds to as long as many minutes or many hours after the incoming signal is over.
- The **reverberatory** or **oscillatory circuits** are the most common circuits within the CNS that explain the mechanism of the afterdischarge.
- In this circuit branches from later neurons synapse with earlier ones. This arrangement sends impulses back through the circuit again and again.
- As such, reverberatory circuits are caused by **positive feedback** within the neuronal circuit that feeds back to re-excite the input of the same circuit.
- The cause of this sudden cessation of reverberation is **fatigue** of synaptic junctions in the circuit.
- Among the body responses thought to be the result of output signals from reverberatory circuits are **breathing**, **coordinated muscular activities**, **waking up**, and **short-term memory**.

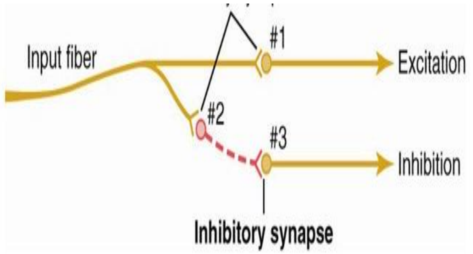


Reverberatory circuits of increasing complexity.

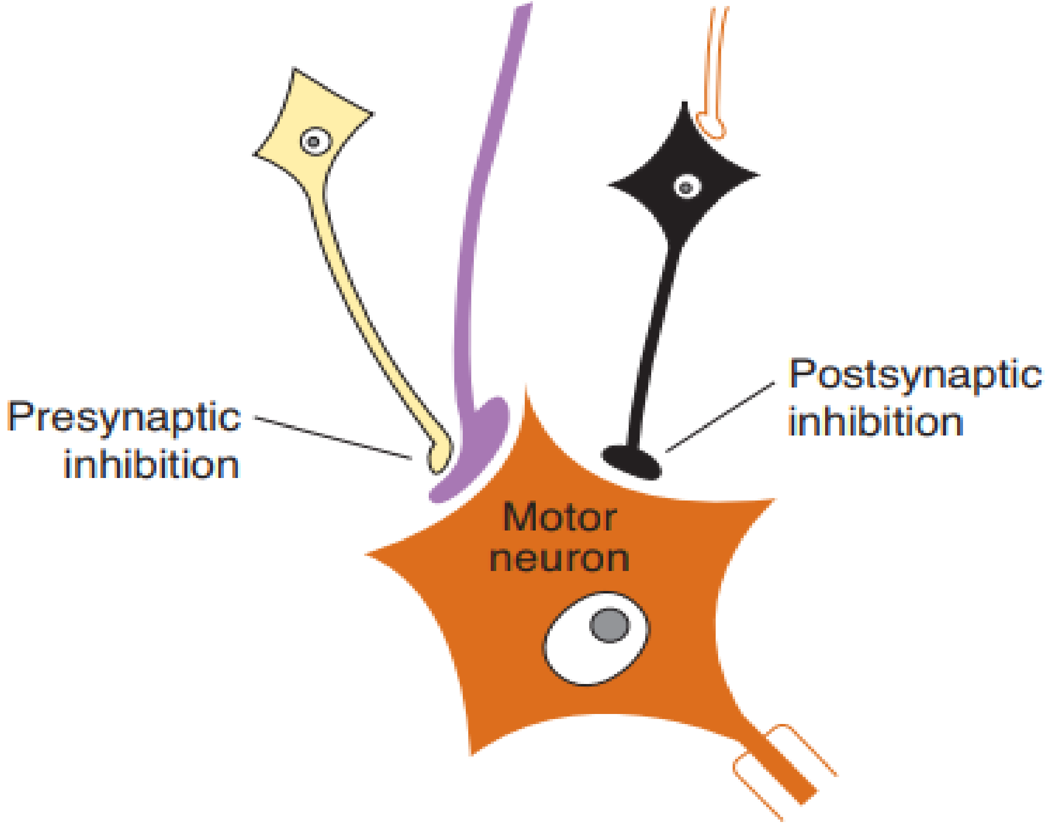
Neuronal Circuit With Both Excitatory and Inhibitory Output Signals

- An incoming signal to a neuronal pool causes an output excitatory signal going in one direction and, at the same time, an inhibitory signal going elsewhere.
- For example, at the same time that an excitatory signal is transmitted by one set of neurons in the spinal cord to cause excitation of flexor and an inhibitory signal is transmitted through a separate set of neurons to inhibit the extensor
- This type of circuit is characteristic for controlling all antagonistic pairs of muscles; it is called the reciprocal inhibition circuit.





Inhibition in the nervous system : post synaptic and presynaptic inhibition



Inhibitory Neuronal Circuits in the Nervous System

- There are 3 types of inhibitory circuits:

1. Feed-forward inhibitory circuit.
2. Feed-back inhibitory circuit.
3. Lateral inhibition.

Feed-back inhibitory circuit.

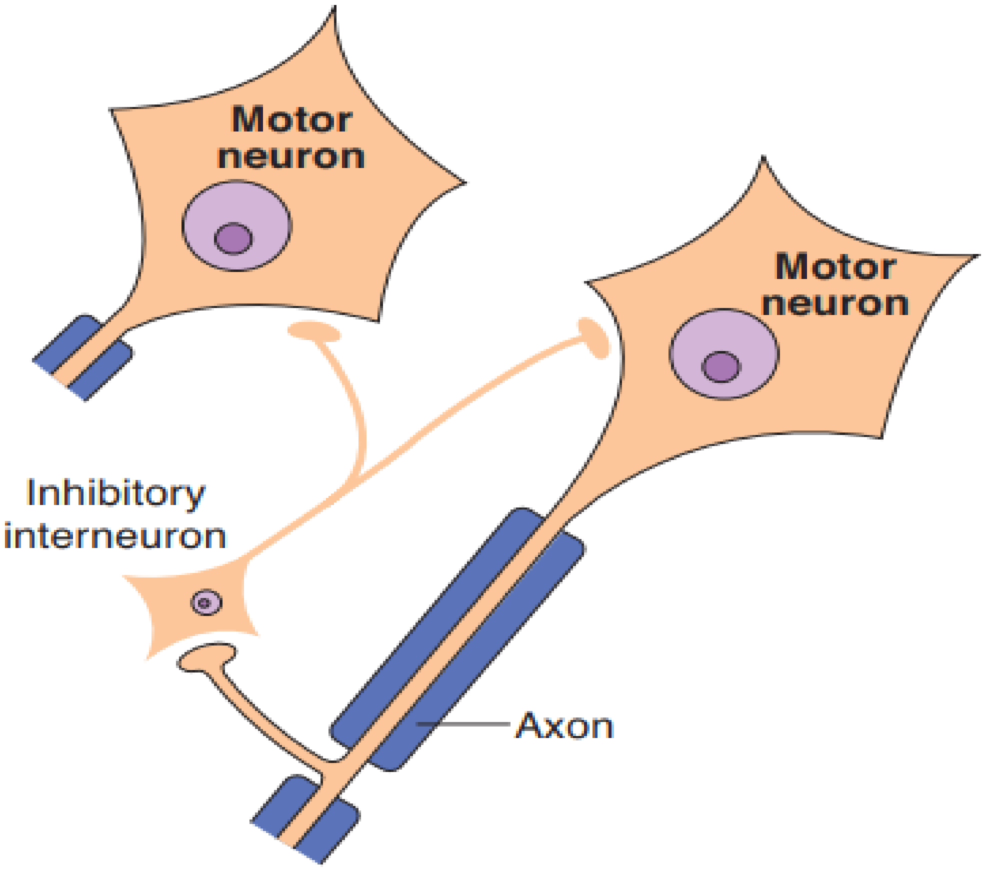
- Collateral branches of the excitatory efferent fibers excite inhibitory interneurons that **inhibit neurons by the feedback mechanism**.
- Example: axon of a spinal motoneuron sends collateral to a Renshaw cell that inhibits the action of the same and neighboring motoneurons → the more intensely the motoneuron fires impulses, the more it turns itself off by the negative feedback.
- Similar function have the basket cells in the hippocampus and other interneurons in the cerebral cortex.

Negative feedback inhibitory circuits

Examples

Inhibition of a spinal motor neuron via an inhibitory interneuron (Renshaw cell).

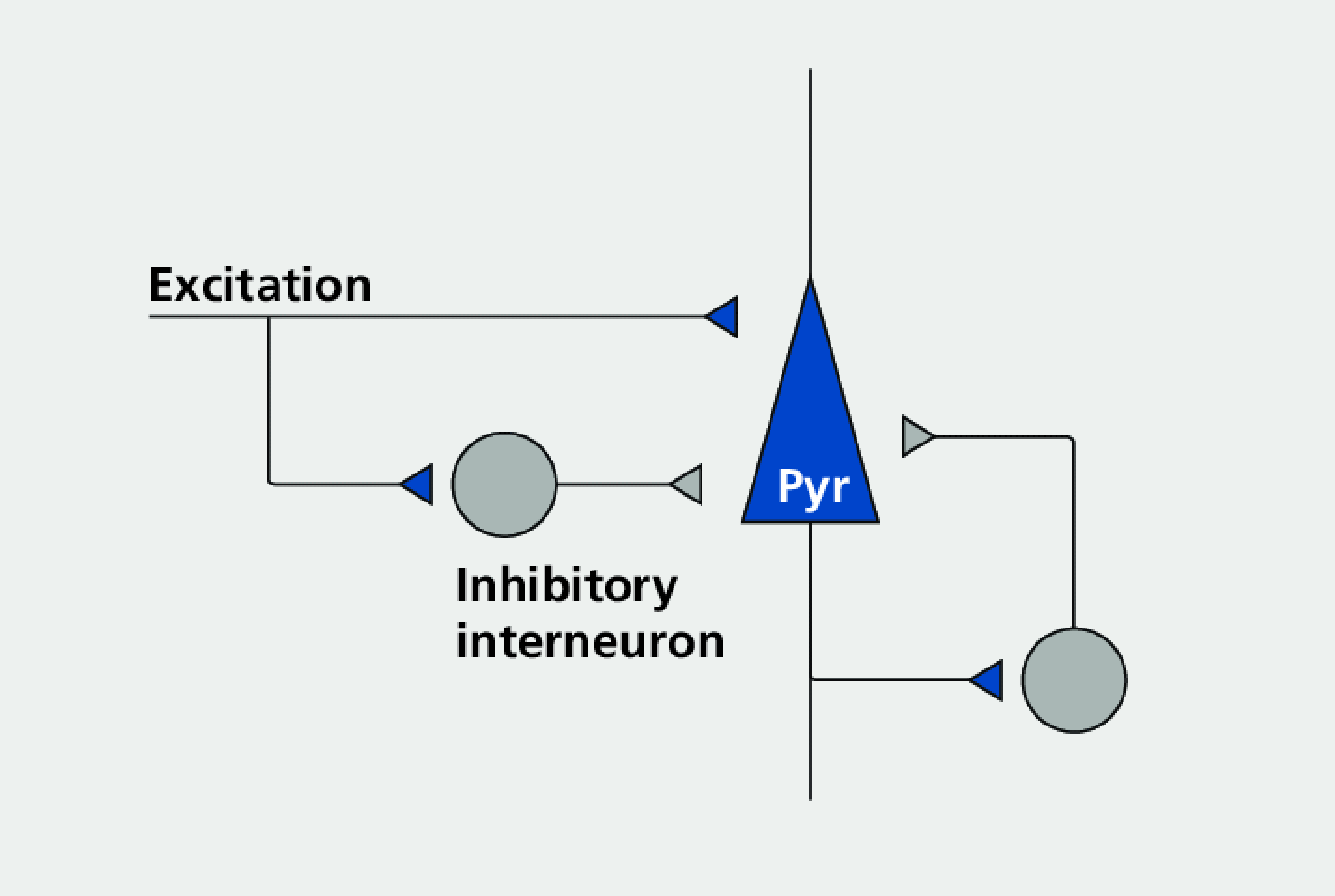
Inhibition of pyramidal cells in the in the cerebral cortex by basket cells inhibitory interneurons



Feed-forward inhibitory circuit.

- Collateral branches of the excitatory afferent fibers excite inhibitory interneurons that **inhibit neurons in the forward direction**.
- Inhibitory pathways keep down the level of excitation and suppress discharges from all weakly excited neurons.
- Example: Iα afferent fibers from muscle receptors → spinal motor neurons.

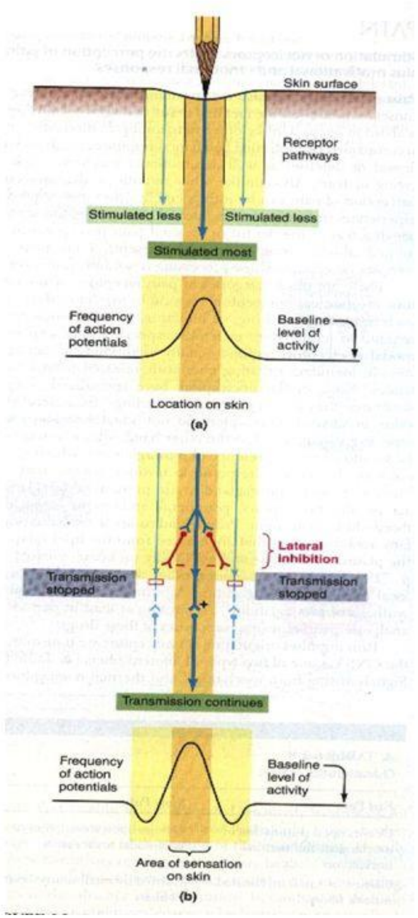
Scheme of feedforward and feedback inhibition in the nervous system



Lateral inhibition

- Also known as: surround inhibition.
- A higher-order neuronal action which employs **both feed-back and feed-forward inhibition** and requires more complex neuronal systems.
- It is primarily designed to **block the lateral spread** of the excitatory signals and therefore increase the degree of contra

Lateral Inhibition in the sensory System as a way of sharpening of the stimulus



Nerve fiber types and conduction velocity of action potential

- The larger the nerve fiber diameter the faster the rate of transmission of the signal
- Velocity of transmission can be as fast as 120 m/sec or as slow as 0.5 m/sec
- Nerve fiber classification
- Myelinated fibers –Type A (types I, II and III)
  - A α- A β- A γ- A δ-
- Unmyelinated Fibers-Type C (type IV)
- The C fibers constitute more than one half of the sensory fibers in most peripheral nerves, as well as all the postganglionic autonomic fibers.

Stabilization of neuronal discharge

- Inhibitory circuits in widespread areas of the brain help prevent excessive spread of signals. Examples of these circuits :
- (1) Inhibitory feedback circuits that return from the termini of pathways back to the initial excitatory neurons of the same pathways Example inhibitory feed back signals from the sensory cortex to various relays of sensory path
- (2) Some neuronal pools that exert gross inhibitory control over widespread areas of the brain (e.g., many of the basal ganglia exert inhibitory influences throughout the muscle control system)

Stabilization of neuronal discharge

- (3) Synaptic fatigue means simply that synaptic transmission becomes progressively weaker the more prolonged and more intense the period of excitation. This is important for automatic short-term adjustment of neuronal pathway sensitivity
- (4) Automatic downregulation or upregulation of synaptic receptors This is along term stabilization through modification of receptors availability

Practice Test Question:

Which one of the following statements concerning sensory neurons or their functional properties is true?

A. All sensory fibers are unmyelinated

B. In spatial summation , increasing signal strength is transmitted by using progressively greater numbers of sensory fibers

C. Increased stimulus intensity is signaled by a progressive decrease in the receptor potential

D. Continuous subthreshold stimulation of a pool of sensory neurons results in disfacilitation of those neurons

E. Temporal summation involves signaling of increased stimulus strength by decreasing the frequency of action potentials in the sensory fibers