Spinal Cord Functions & Reflexes

Color index

- Important
- Further Explanation

Explained wonderfully in:
Guyton
Ch.46 P.559 & Ch.54 P.655

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Contents

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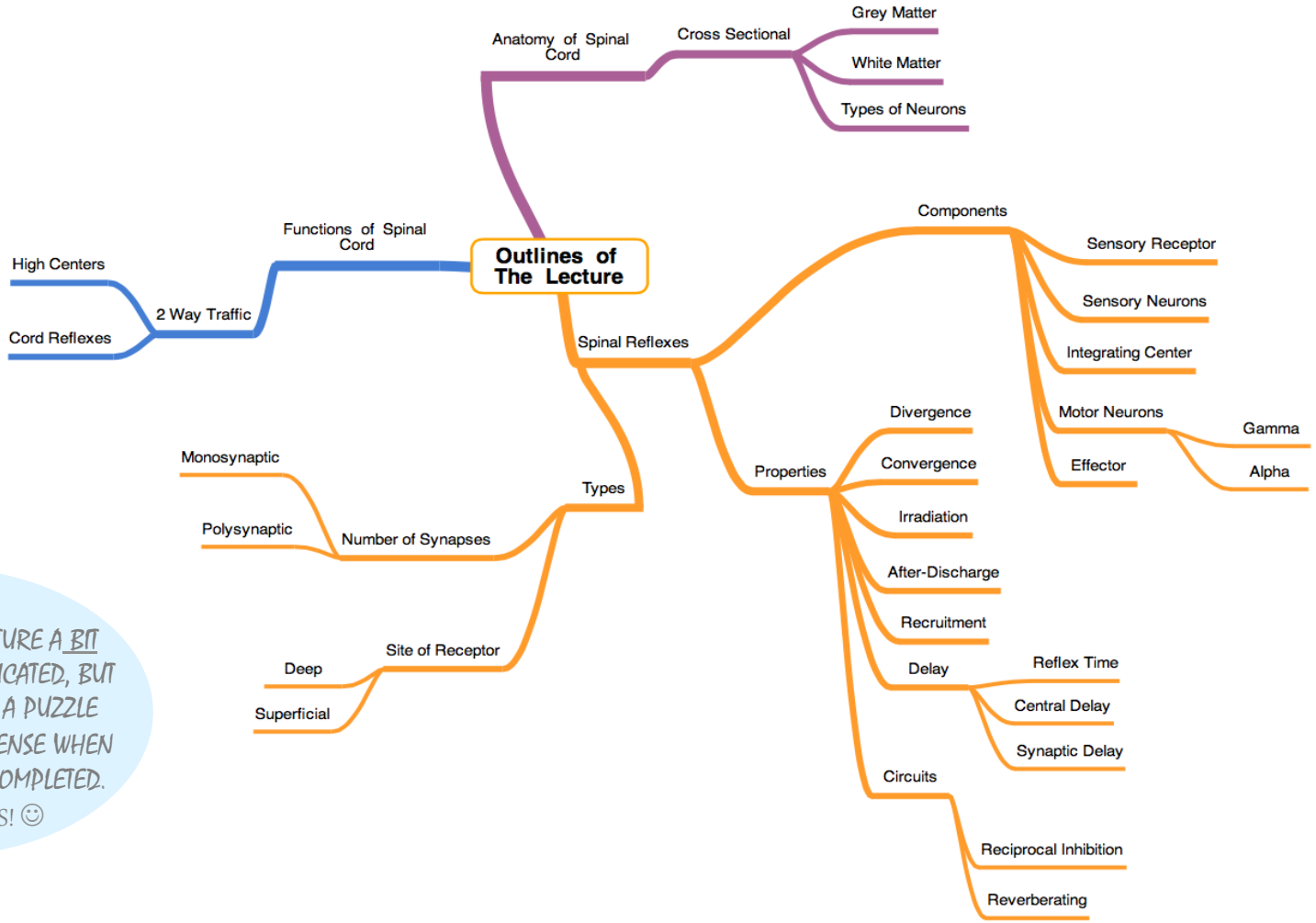


YOU MAY FIND THIS LECTURE A BIT –JUST A LITTLE BIT- COMPLICATED, BUT REMEMBER CNS IN LIKE A PUZZLE EVERYTHING WILL MAKE SENSE WHEN THE WHOLE PICTURE IS COMPLETED.

GOOD LUCK DEARS! ☺

Mind Map

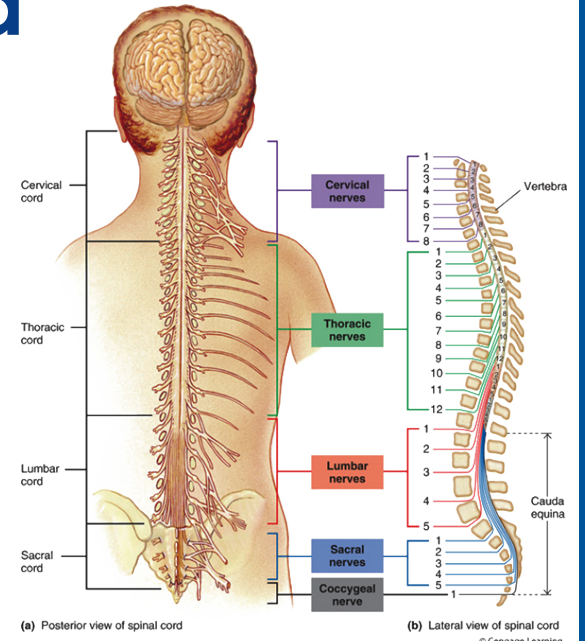
The Spinal Cord

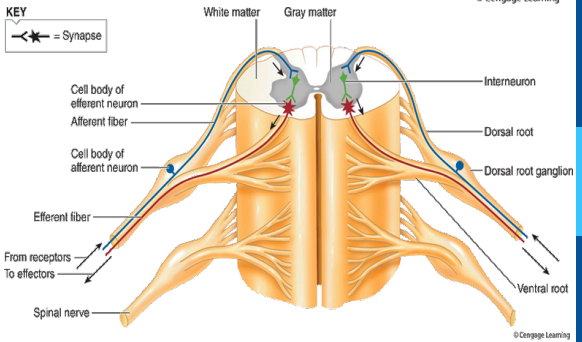
The spinal cord is composed of 100 million of neurons and even more neuroglia cells .

REMEMBER: NEUROGLIAL CELLS ARE MORE THAN NEURONS BECAUSE THEY ARE DIVIDABLE.

Spinal nerves: Are 31 pairs. Each spinal nerve has:	VenTral root (Anterior)	Carries EFFRENT fibers (MoTor).
		The cell body is located in the ventral horn of the spinal cord.
	DorSal root (Posterior)	Carries AFFRENT fibers (Sensory).
		Carries impulses from the sensory receptors.
		The cell body is located in the dorsal root ganglion (DRG).

MNEMONIC "SAME" = SENSORY AFFERENT , MOTOR EFFERENT





The sensory and motor tracts of the spinal cord are continuous with those in the brain.

Cross Section of the Spinal Cord

White Matter

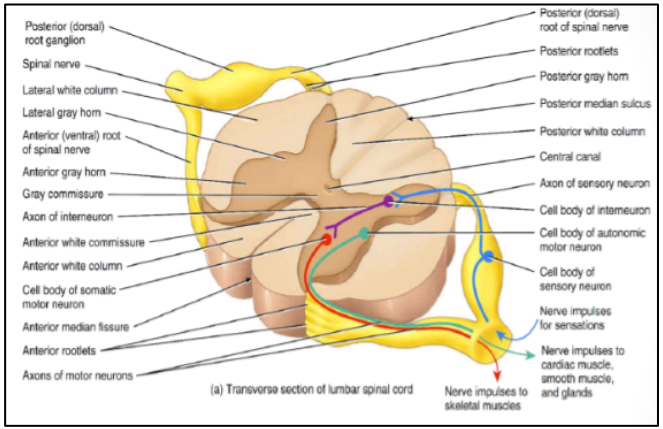
Is divided -by the anterior and posterior grey horns- into:

A. Anterior white column.
B. Posterior white column.
C. Lateral white column.

Each column contains a bundle of axons -tracts- having a common destination and similar information:

■Sensory tracts (ascending) conducting impulses toward the brain.

■Motor tracts (descending) carry nerve impulses from the brain.



Type of neurons	Location
Interneurons	Posterior grey horn
Sensory neurons	Dorsal root ganglion + axons of the interneurons (synapses)
Somatic motor	Ventral grey horn
Autonomic motor	Lateral grey horn

Grey Matter

REMEMBER:THE GREY MATTER-IN THE BRAIN AND THE SPINAL CORD - IS COMPOSED OF CLUSTERS OF NEURAL CELL BODIES(NUCLEI).

■Sensory nuclei: receives input from sensory receptors via sensory neurons AFFERENT.

■Motor nuclei: provides output to the suspected effector via motor neuron EFFERENT.

Functions of the Spinal Cord

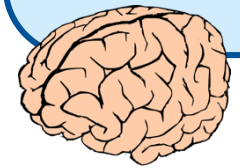
1- The The two-way traffic along the spinal cord (see the two pathways below).

2- Generating the spinal reflexes.

2. Transmits signals to higher levels in the cord, or to the brain stem, or even to the cerebral cortex through spinal ascending sensory tracts as :

- Dorsal Column Tracts (Gracile Or Cuneate)
- Lateral Spinothalamic Tract
- Anterior Spinothalamic Tract.
- Spinocerebellar Tracts

WILL BE EXPLAINED IN A SEPARATE LECTURE



- **Pathway of a sensory tracts:**

Sensory receptors → **Sensory posterior roots** → **Enters the spinal cord** → **Has two separate destinations**

- **Pathway of motor tracts:**

Motor signals & brain motor commands pass through descending motor tracts & spinal efferent motor nerves to skeletal muscles to execute motor functions

1. Transmits in the gray matter of the cord and elicits local segmental cord reflexes.

The Organization of The Spinal Cord For Motor Functions

(anterior horn cells , interneurons & neuronal pools)

Ventral (Anterior) horn cells:

- Located in each segment of the anterior horns of the cord gray matter
- 50 to 100 % larger than others neurons.
- It gives rise to the nerves which directly innervate skeletal muscle fibers.

Alpha Motor neurons	Gamma Motor neurons
They give rise to large type A alpha (Aa) motor nerve.	They transmit impulses through much smaller type A gamma motor nerve fibers.
14 micrometers in diameter	5 micrometers in diameter
innervates skeletal muscles (Extrafusal fibers[1]) *Together the skeletal muscle fibers innervated by the alpha motor neuron fiber and the fiber itself are called **motor unit.**	Innervated special skeletal muscle fibers called Intrafusal fibers.

1: Make up large mass of skeletal (striated) muscle and responsible for contractibility of a muscle.
2: Contain muscle spindles -WILL BE EXPLAINED NEXT LECTURE--, attached to extrafusal fibers to sense the muscle tone and stretch.

Spinal Reflexes

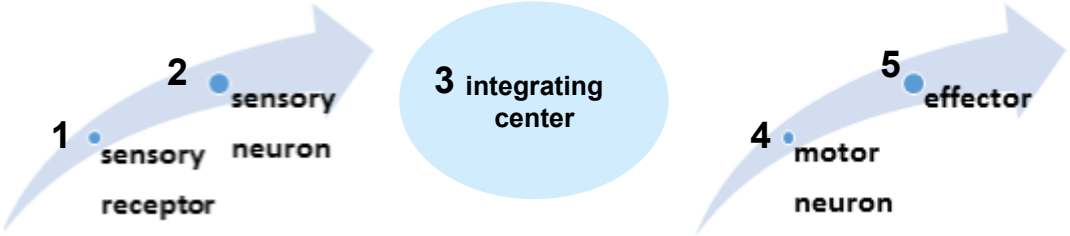
What is a reflex ?
Functional unit of CNS, rapid, automatic , involuntary response to a stimulus.

- The spinal cord and it's associated nerves contain neural circuits -WILL BE EXPLAINED IN COMING SLIDES- that controls reflexes.
- Spinal reflex involves neurons in the spinal cord and spinal nerves.

Example : Pinprick causes withdrawal.

What is the reflex arc? Reflex arc is the pathway followed by nerve impulses that produce a reflex is a reflex arc (reflex circuit)

Components Of The Reflex Arc



1. Sensory Receptor

the distal end of a sensory neuron (dendrites) and an associated sensory structures serves as a sensory receptor.

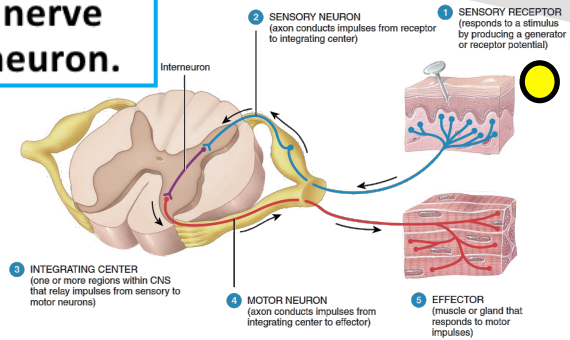
it responds to a specific stimulus by potential called a generator or receptor potential.

if a generator potential reaches the threshhold level of depolarization it will trigger one or more nerve impulses in the sensory neuron.

The nature of receptors varies from one sensory modality to the next .Regardless, the basic function of the receptors is the same.

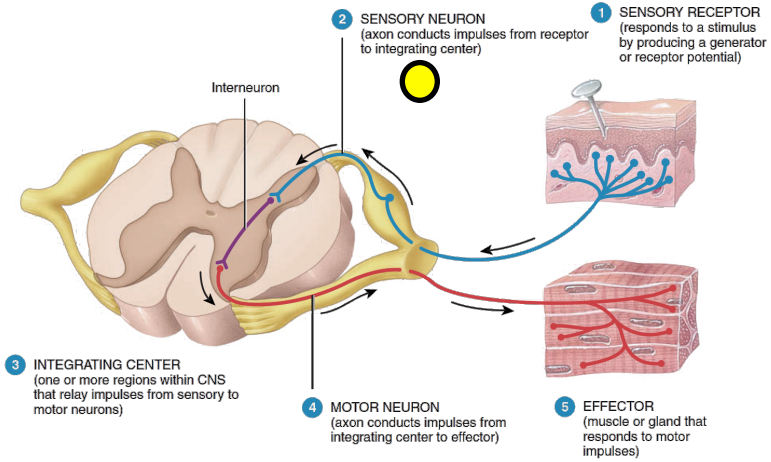
The stimulus is triggered from changes in the environment pressure, temperature, chemicals, wave, sound, light..etc

Sensory transduction : is the basic function of the receptors. Which involves the process of converting a stimulus to an electrochemical energy through opening and closing specific ion channels.



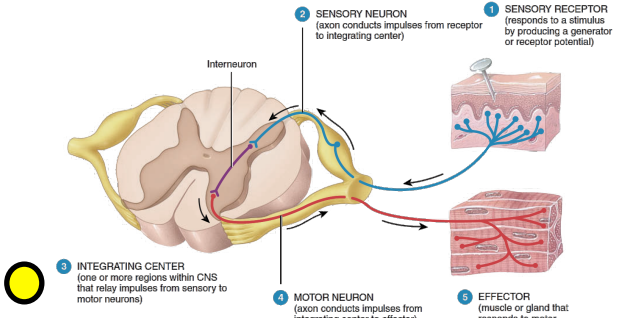
2. Sensory Neurons

- The nerve impulses propagate from the sensory receptor along the sensory neuron to the axon terminals which are located in the grey matter of the spinal cord or the brain stem.
- Relay neurons send nerve impulses to the area of the brain that allows conscious awareness that the reflex has occurred .Or it sends to motor neuron or interneuron.



3. Integrating Center :

Location	Group of neurons are located in the grey matter of the spinal cord.
Monosynaptic Reflex Arc	Is a reflex pathway having **only one synapse** in the CNS. in which a single synapse between a sensory neuron and a motor neuron takes place. **It is the simplest type of reflexes**
Polysynaptic Reflex Arc	Is the pathway having more than two types of neuron and **more than one synapses in the** CNS. Impulses are transmitted to a motor nerve and neighboring interneurons. **It is more common.**



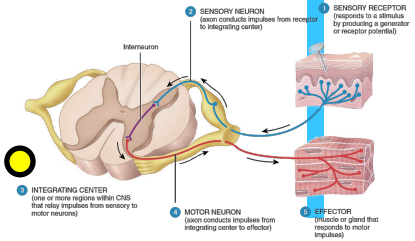
Interneurons & Interneuron Pool

- **Location**: Interneurons are present in the gray matter in the dorsal horns, the anterior horns, and the intermediate areas between them.

- **Function**: They are (**excitatory or inhibitory**).

- These cells are about 30 times as numerous as the anterior motor neurons, small and highly excitable, often exhibiting spontaneous activity.

- Different types of neuronal circuits are found in the interneuron pool (parallel and reverberating circuits), diverging, converging, and repetitive-discharge – WILL BE EXPLAINED IN COMING SLIDES-.



Renshaw Cells

- **Location:** located in the anterior horns of the spinal cord, in close association with the motor neurons.

- **Function: inhibitory** cells.

- As the anterior motor neuron axon leaves the body of the neuron, sends collateral branches to adjacent Renshaw cells.

- Renshaw cells sends inhibitory signals to the surrounding motor neurons BY Lateral inhibition/ stimulation of each motor neuron tends to inhibit adjacent motor neurons.

- This lateral inhibition helps to focus or sharpen the signals from each motor neuron

- allow transmission of the primary signal in the desired direction while suppressing the tendency for signals to spread laterally

4. Motor Neurons :

it is the efferant neurons also its called anterior horn cells.

impulses trggerd by the integrating center propagate out of the CNS along a motor neuron to the part of the body will repond (skletal muscle for example)

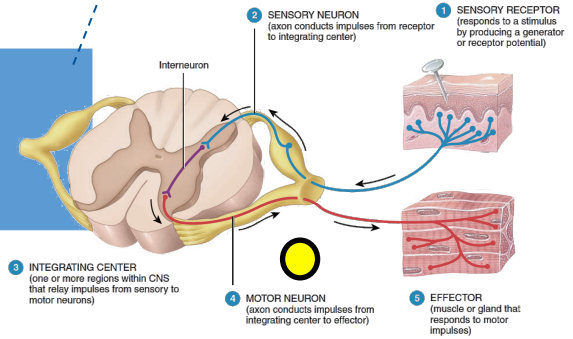
motor neurons which supplyin skletal muscles are :

* alpha motor
* gamma motor

RECALL!

Aalpha motor neurons :- large cells, with large myelinated fibres (axons) form 70% of ventral root - supply extrafusal muscle fibres (2/3 Of skeletal muscle fibers)

Gamma motor neurons :- smaller cells- with small axons form 30 % of ventral root - supply intrafusal muscle fibres (muscle spindles=1/3 Of skeletal muscle fibers)



5. Effector :

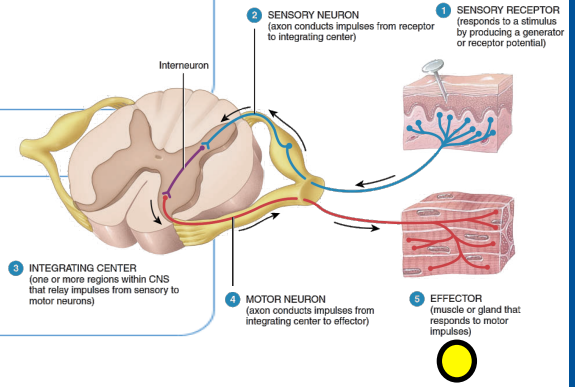
definition

- The part of the body that responds to the motor nerve impulses such as skeletal muscles or gland

- it's action is called a REFLEX

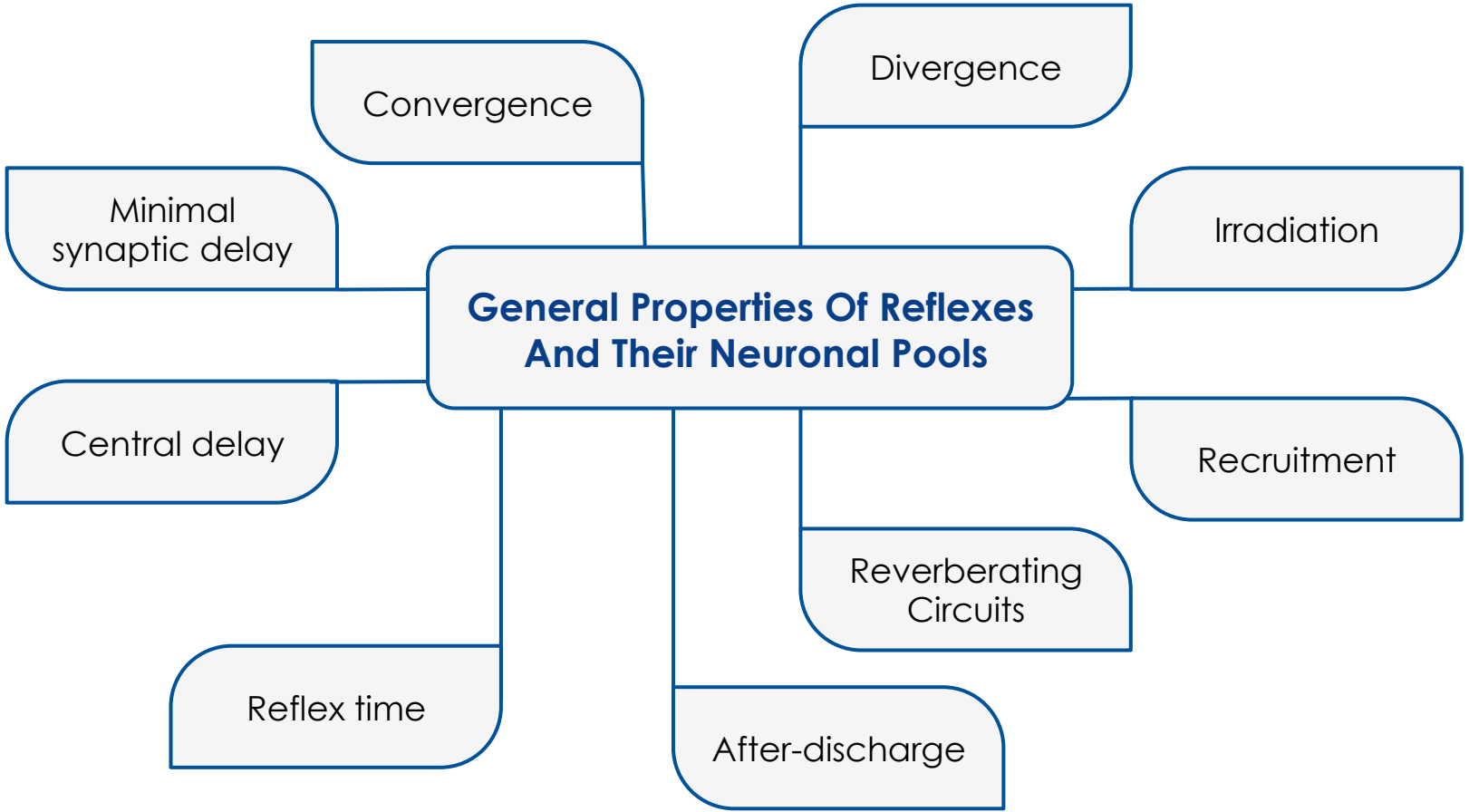
somatic reflex.

- if the effector is skeletal muscle



autonomic reflex

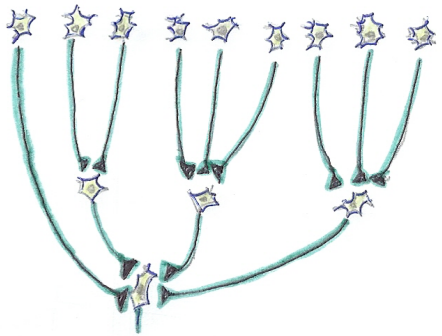
- if the effector is gland or smooth muscles and cardiac muscle.
- also called visceral reflex



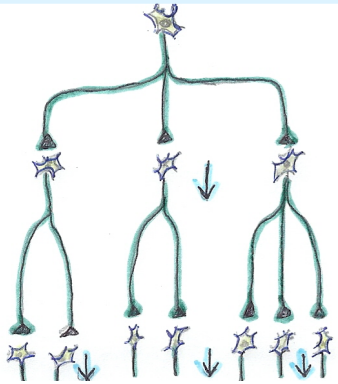
Neuronal Pools: A motor pool consists of all individual motor neurons that innervate a single muscle.

Convergence & Divergence:

Convergence: signals from multiple inputs (neurons) unite to excite a single neuron's multiple action potentials. This will provide enough spatial summation[1] to bring the neuron to the threshold required for discharge.

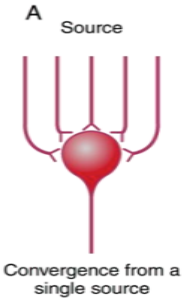
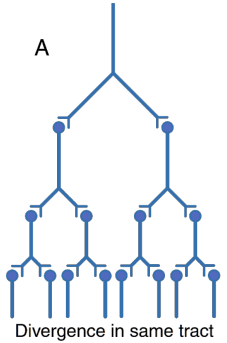
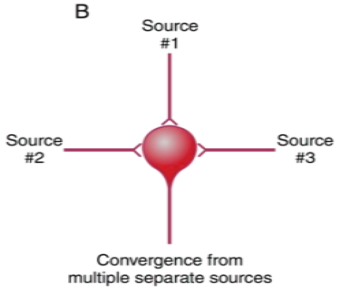
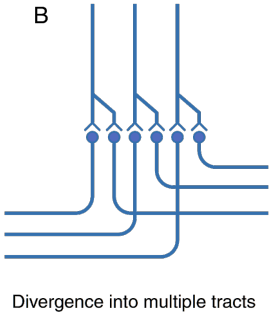


Divergence: helps to spread a single stimulus to a wide area of the spinal cord, it is important for weak signals entering a neuronal pool to excite far greater numbers of nerve fibers leaving the pool.



1: Spatial Summation الجمع المكاني: At any given moment, a neuron may receive postsynaptic potentials from thousands of other neurons. Whether or not threshold is reached, and an action potential generated, depends upon the **spatial** (i.e. from multiple neurons) **summation** of all inputs at that moment.

Convergence & Divergence cont.

Convergence		Divergence	
Multiple input fibers from a single source.		Divergence within a pathway to cause amplification[1] of a signal.	
Input fibers from multiple separate sources.		Divergence into multiple tracts to transmit the signals to separate areas	

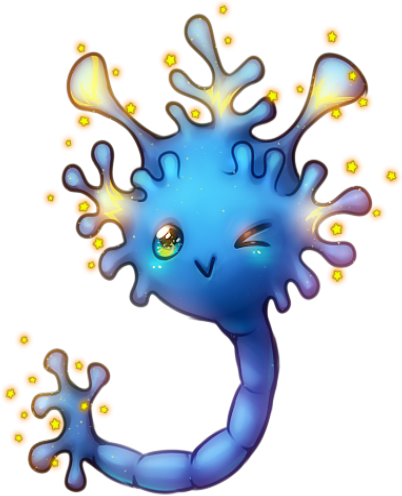
1: توسيع

Circuits

Reciprocal[1] Inhibition Circuits

Reverberating -Oscillatory[2]- **Circuit**

Parallel Circuit

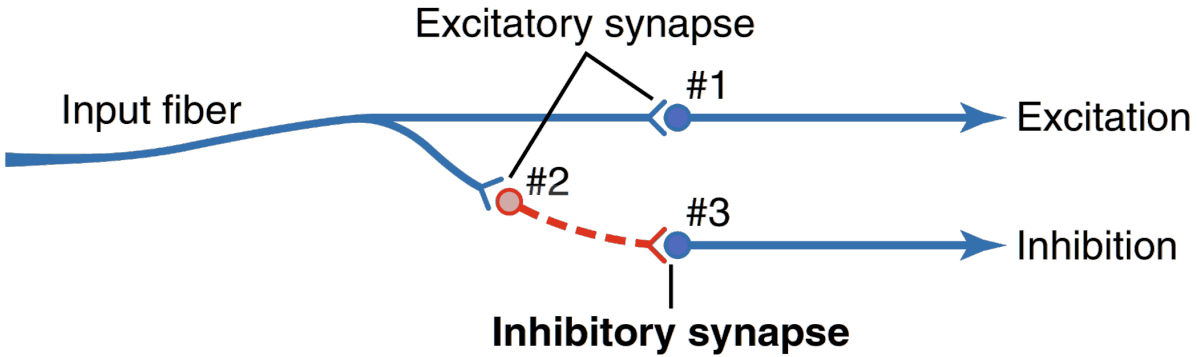


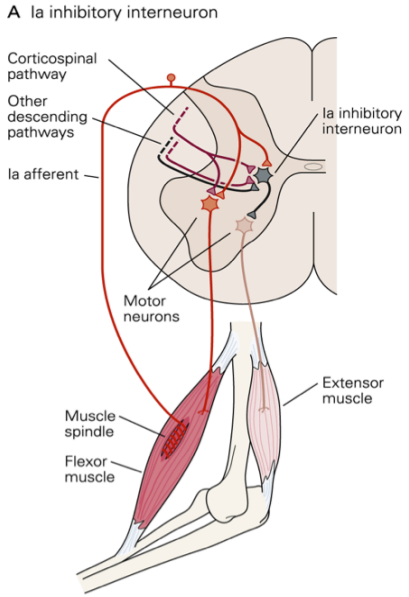
1: متبادل , 2: تذبذبي

What are Reciprocal Inhibition Circuits?

Definition: Reciprocal innervation is the stimulation of flexors muscles accompanied by inhibition of extensors through inhibitory interneurons.

The process: The input fiber directly excites the excitatory output pathway, but it stimulates an intermediate inhibitory neuron (neuron 2), which secretes a different type of transmitter substance to inhibit the second output pathway from the pool. The objective is to prevent over activity in many parts of the brain.



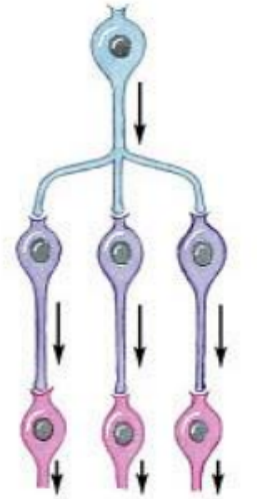


Result: Reflex contraction of an agonist muscle is accompanied by inhibition of the antagonist.

Parallel and Reverberating Circuits

Parallel

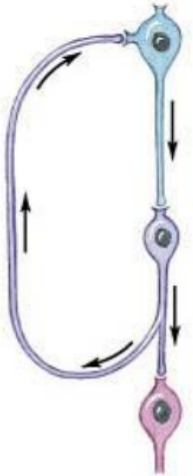
Notice that the fibers are *parallel* to each other.



(d) Parallel processing

Reverberating
-Oscillatory-

The simplest reverberatory circuit involves only a single neuron, the output neuron sends a collateral nerve fiber back to its own dendrites or soma to re-stimulate the input neuron itself & once the neuron is stimulated, the circuit may discharge repetitively for a long time and causes signal *prolongation*.



(e) Reverberation

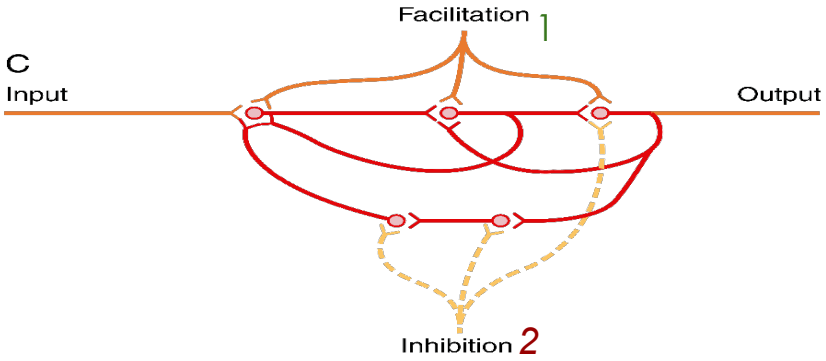
More about Reverberating Circuits

-Oscillatory Circuits-

Objective of the circuit: Is to allow prolonged discharge of the same motor neurons by a single stimulus.

Complex reverberating circuits: Both *facilitatory* and *inhibitory* fibers are involved on the reverberating circuit. 1. A *facilitatory* signal enhances the intensity and frequency of reverberation, whereas 2. An *inhibitory* signal depresses or stops the reverberation.

Relation to parallel fibers: Most reverberating pathways are constituted of many *parallel fibers* & can be weaken or strengthen, depending on how many parallel nerve fibers are involved in the reverberation.

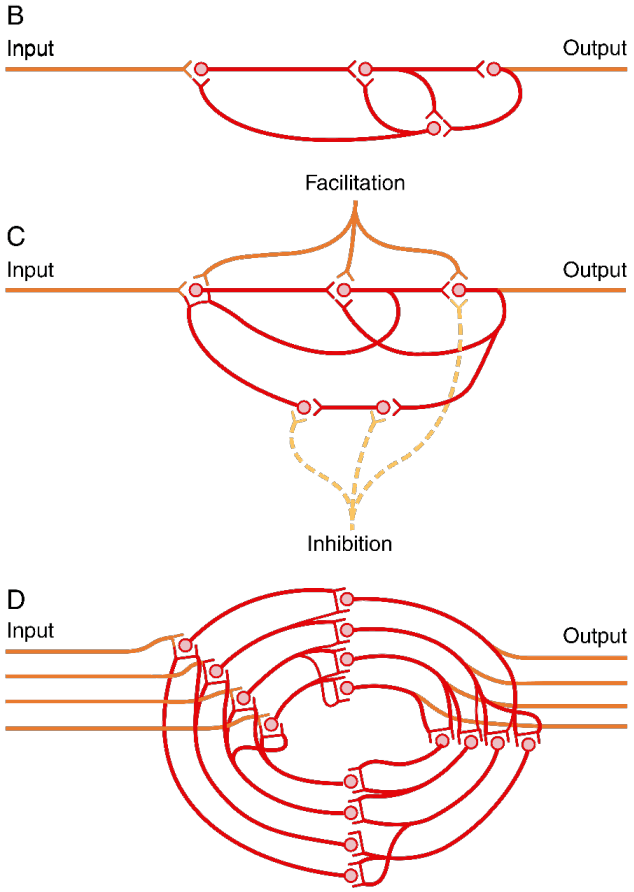


Cont.

B shows a few additional neurons in the feedback circuit which causes a longer delay between initial discharge and feedback signal.

C shows a complex system in which both facilitatory and inhibitory fibers interact in the reverberating circuit.

D shows that most reverberating pathways contain many parallel fibers.



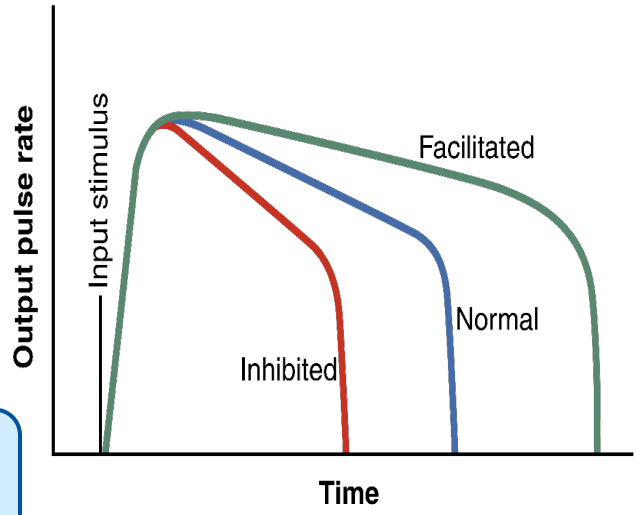
Which one of them you think will be stronger and last longer? Obviously D.

Characteristics of Signal Prolongation from a Reverberatory Circuit & Fatigue of Synaptic Junctions

GENERAL CONCEPT: The intensity of the output signal increases to a high value early in reverberation and then decreases to a critical point & suddenly ceases[1] due to fatigue of synaptic junctions, this lowers the stimulation of the next neuron & the circuit feedback is suddenly broken.

- The figure shows that the intensity of the output signal usually increases to a high value early in reverberation & then suddenly decreases to a critical point then suddenly ceases entirely. The cause of this sudden cessation is ***fatigue*** of synaptic junctions in the circuit.

- Fatigue beyond a critical level lowers the stimulation of the next neuron below its threshold level so that the circuit feedback is suddenly broken.



The duration of the total signal before cessation can also be controlled by signals from other parts of the brain.

1: يتوقف

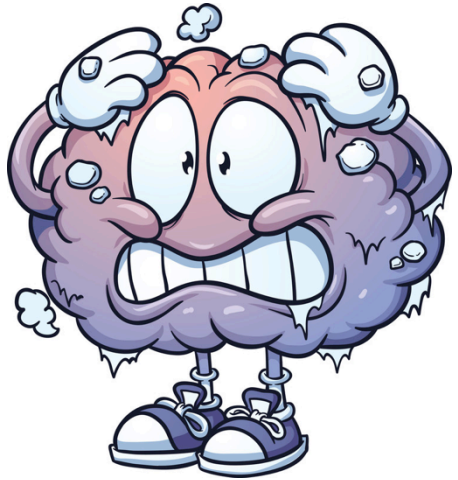
Fatigue of Synaptic Transmission

Objective of fatigue: When areas of the nervous system become **overexcited**, fatigue allows them to lose this extra "excitability" after a while. It's also very important in putting an end to epileptic seizures.

Fatigue of *Synaptic Transmission*: When excitatory synapses are repetitively stimulated at a rapid rate, the number of discharges by the postsynaptic neuron are great at first but the firing rate becomes *progressively less.*

Remember: Fatigue is a protective mechanism against excessive neuronal activity!

Logically: A reverberating circuit that does not fatigue enough to stop reverberation is a source of continuous impulses.



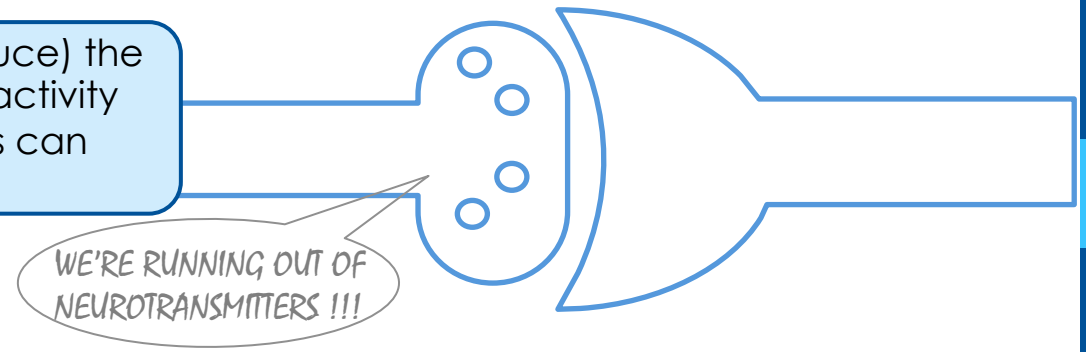
Causes Fatigue Of Synaptic Transmission

1) **Exhaustion -or partial exhaustion- of the stores of transmitter substances in the presynaptic terminals. Terminals can store enough transmitter to cause about 10,000 action potentials, and the transmitter can be exhausted in a few seconds/ minutes of rapid stimulation.**

2) **Inactivation of postsynaptic membrane receptors.**

3) **Slow development of abnormal ion concentrations inside the postsynaptic cell.**

It takes time to replenish (reproduce) the reserves of neurotransmitter. IF activity was too high synaptic vesicles can become depleted.



After-Discharge

Definition: A signal entering a pool causes a prolonged output discharge of AHCs[1] (MOTOR) called *afterdischarge*, it lasts a few milliseconds-minutes after the incoming signal is over.

Causes:

1) Synaptic After-discharge:

PROCESS: When excitatory synapses discharge on the surfaces of dendrites or soma of a neuron, a postsynaptic electrical potential (PSP)develops in the neuron and lasts for many milliseconds. As long as this potential lasts, it can continue to excite the neuron, causing it to transmit a continuous train of output impulses. - Thus, it is possible for a single input signal to cause a sustained signal output (a series of repetitive discharges.) This causes maintained reflex action & response continue for some time after cessation of stimulus

2) Reverberating circuits

Presence of reverberating circuit re-stimulate AHCs

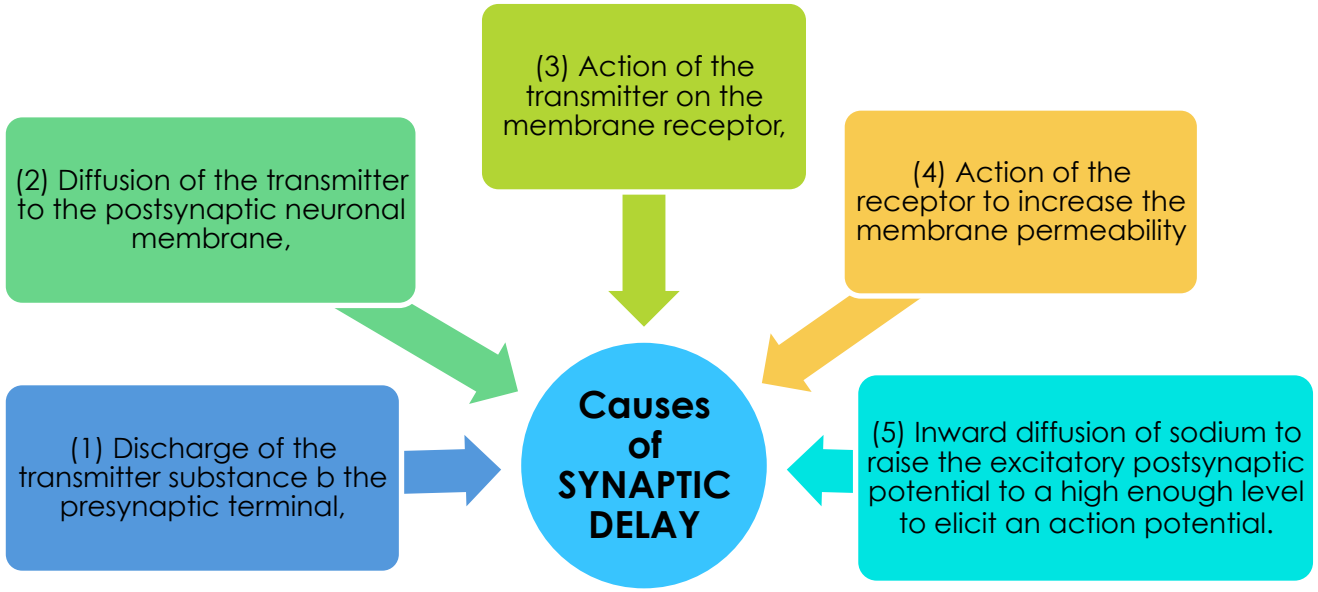
1: Anterior Horn Cells

Synaptic Delay (Central Delay)

Definition: The minimal period of time required for transmission of a neuronal signal from a presynaptic neuron to a postsynaptic neuron, & = 0.5 ms/synapse. (It's long in polysynaptic reflexes -DISCUSSED IN COMING SLIDES-) This synaptic delay is > 2ms in withdrawal reflex -DISCUSSED IN COMING SLIDES- and for knee jerk = 0.6 ms.

GENERAL RULE: Number of synapses = central delay / 0.5ms

Example:
Measure the central delay if there're 5 synapses?
Central delay = number of synapses X 0.5
= 5 X 0.5 = 2.5 ms



Reaction Time (Reflex Time)

Definition: Reflex Time **=** Central Delay **+** Time spent in conduction of impulses along the afferent and efferent nerves.

The time between the application of the stimulus and the response is called the

Reaction Time

In humans, the reaction time for a stretch reflex such as the knee jerk is 19–24 ms.

The conduction velocities of the afferent and efferent fibre types are known and the distance from the muscle to the spinal cord can be measured

- This is responsible for most of the reaction time

CENTRAL DELAY

It is possible to calculate how much of the reaction time was taken up by conduction to and from the spinal cord.

When this value is subtracted from the reaction time, the remainder, called the **central delay** ,

This is the time taken for the reflex activity to traverse the spinal cord.

The central delay for the knee jerk reflex is 0.6–0.9 ms

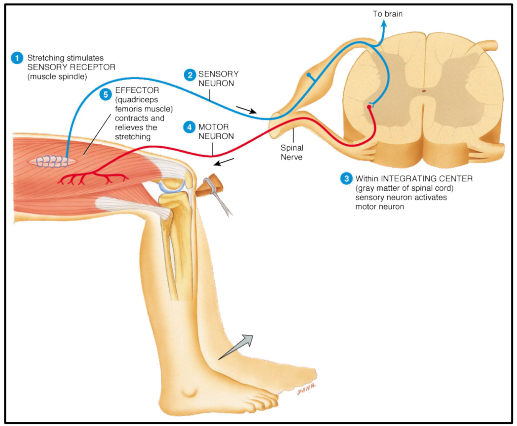
Because the minimum synaptic delay is 0.5 ms, only one synapse could have been traversed

Spinal Reflexes
Types Of Spinal Reflexes

According to Number of Neurons

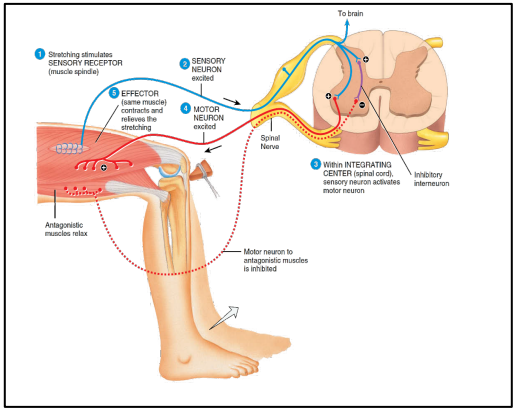
1. Monosynaptic
Sensory axon (afferent) synapse directly with anterior horn cell- (No interneuron)
Ex. Stretch reflex.

1



2. Polysynaptic
Sensory axon (afferent) synapse with one or more interneuron
Ex.Withdrawal, abdominal, and visceral reflexes.

2



Types Of Spinal Reflexes cont.

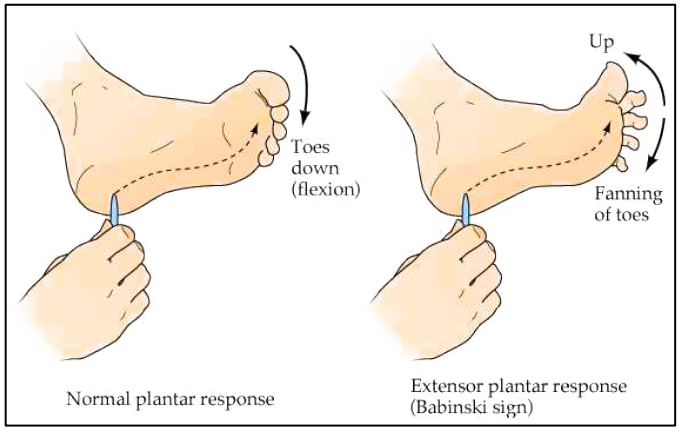
GO BACK TO RECOMMENDED VIDEOS FOR FURTHER EXPLANATION!

According to Site of the Receptor

Deep Reflexes: by stimulation of receptors deep in muscle and tendons.

(1) Stretch Reflexes (Tendon jerks) ,they are monosynaptic, such as knee-jerk (patellar reflex) and ankle jerk . The receptor for all these is the muscle spindle (located deep within the muscle itself)
(2) Inverse Stretch Reflex (Golgi Tendon organ reflex) polysynaptic. The receptor is called Golgi Tendon Organ & is present deep in the muscle tendon.

Superficial Reflexes: are polysynaptic reflexes. The receptor are superficial in the skin.
Ex. withdrawal, abdominal and plantar reflex (as shown in the picture)



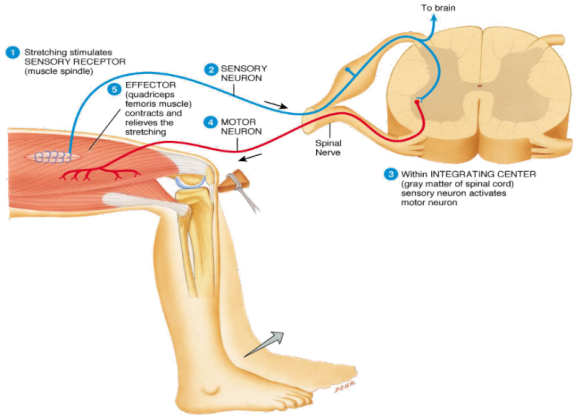
Visceral Reflexes: by stimulation of receptors in wall of viscera.
Ex. micturition & defecation.

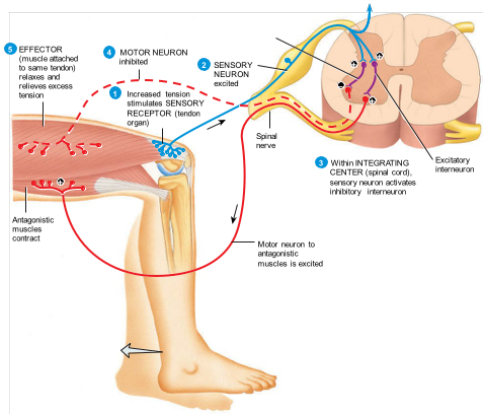
Will Also Be Discussed in More Details Next Lecture

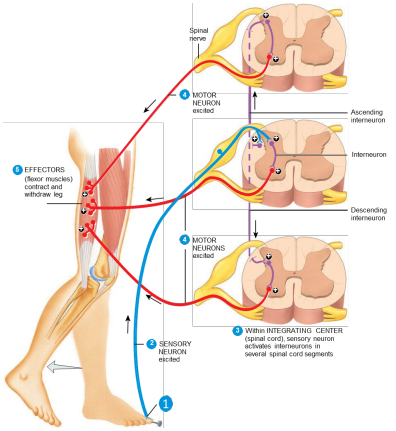
Types Of Spinal Reflexes cont.

According to Site of the Receptor

Reflex	Stimulus	Clinical test
Stretch (myotactic) reflex	Rapid stretch of muscle	Tap on muscle tendon
Inverse stretch reflex (autogenic inhibition)	Large force on tendon	Pull on muscle when rested
Flexor reflex (withdrawal)	Sharp painful stimulus	None – stepping on nail







Will Also Be Discussed in More Details in Coming Lectures

1) Withdrawal Reflex

–Nociceptive reflex OR Flexor Reflex-

- **Type:** A superficial polysynaptic reflex.

- **Process**: Stimulation of pain receptors of hand (a pinprick, heat, or wound) ➔ impulses A delta or C fibers ➔ interneurons pool ➔ motor neurons ➔ stimulate hand flexor muscles ➔ move the hand away from the injurious stimulus.

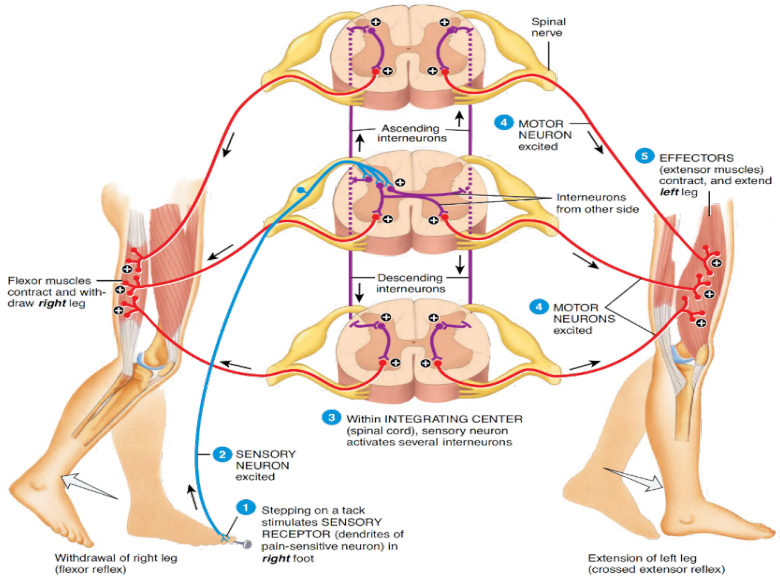
- **Characteristics:**

It involve the following basic types of circuits:

1- Diverging circuits to spread the reflex to the necessary muscles for withdrawal.

2- Reciprocal inhibition circuits to inhibit the antagonist muscles.

3- Circuits that Causes After-Discharge



Circuits to cause afterdischarge lasting many fractions of a second after the stimulus is over.

Process: The duration of afterdischarge depends on the intensity of the sensory stimulus that elicited the reflex. Because of afterdischarge, the reflex can hold the irritated feeling for 0.1 to 3 seconds after the irritation is over.

Cause: Presence of a reverberating circuit re-stimulate AHCs.

Objective: Prolong the protective response of reflex.

Will Also Be Discussed in More Details in Coming Lectures

1) Withdrawal Reflex Characteristics cont.

4- Recruitment

Definition: Gradual[1] activation of more number of motor neurons (AHCS) in a reflex arc by maintained, repetitive stimulus.

Causes:

1- **Different conduction velocities of afferents some are slowly & others are rapidly conducting fibers.**

2- **Different number of interneurons with short & long pathways to the motor neurons (AHCs) (impulses do not reach AHCs at same time but reach them gradually, so maintained stimulation allow more neurons to be stimulated)**

LOGICALLY: In motor unit recruitment: If a repetitive & stronger stimulus is maintained, there will be gradual increase in the force of the muscle contraction until the maximum force is reached due to *gradual recruitment/ activation* of more and more motor neurons.

1) Withdrawal Reflex Characteristics cont.

5- Irradiation

Spread of impulses up & down to different segments and motor neurons in the S.C (subcutaneous) due to a strong stimulation in sensory afferent fibers irradiate to many segments of spinal cord due to divergence.

LOGICALLY: The extent of the response in a reflex depends on the intensity of the stimulus.

Process:

- Weak stimulation → irradiates to small number of neurons, so it causes weak flexion of limb ONLY.
- Strong stimulation → irradiates to large number of neurons, so it causes withdrawal of affected limb AND extension of opposite limb.

-as in crossed extensor reflex DISCUSSED IN COMING SLIDES-

6- Pattern of Withdrawal

The pattern of withdrawal that results when the flexor reflex is elicited depends on *which sensory nerve is stimulated*.

Example: When a pain stimulus targets the inward side of the arm causes not only contraction of the flexor muscles of the arm *but also* contraction of abductor muscles to pull the arm outward. • This is called the principle of "local sign."

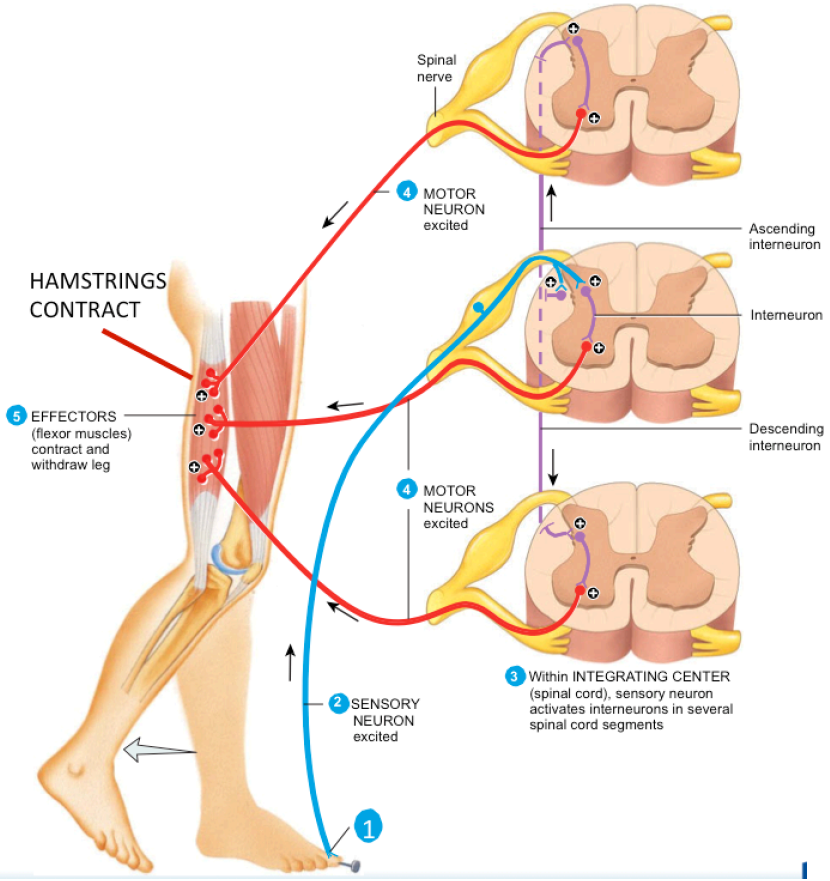
1) Withdrawal Reflex cont.

Irradiation & Recruitment (The Big Picture)

Strong stimuli can generate activity in the interneuron pool that spreads

This spread of excitatory impulses up and down the spinal cord to more and more motor neurons is called **irradiation** of the stimulus

The increase in the number of active motor units is called **recruitment** of motor units

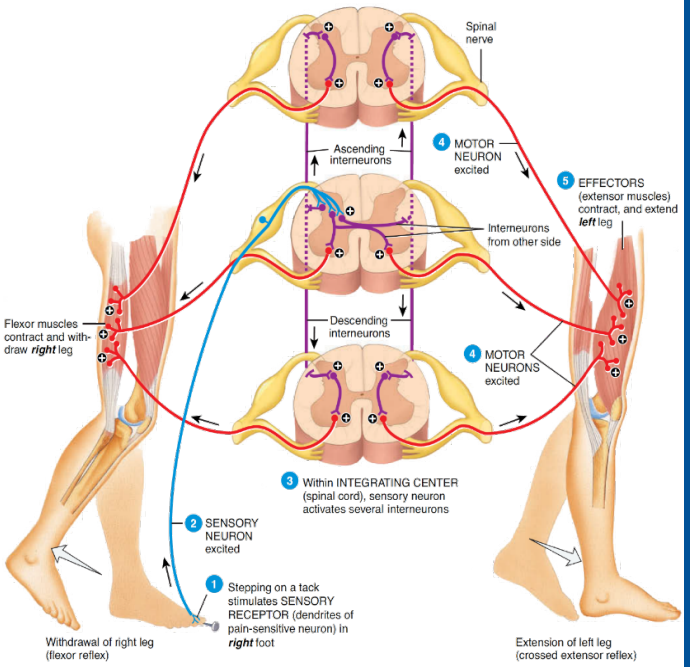


2) Crossed extensor reflex

(It's simply a continuation of the withdrawal reflex if the pain stimulus was strong enough.)

- **Definition:** Flexion and withdrawal of the stimulated limb → extension of the opposite limb and this occurs with strong stimulus.

- **WHY/HOW DOES THIS HAPPEN?** (Understand the mechanism)
  • Signals from sensory nerves cross to the opposite side of the cord to excite extensor muscles. ➔ It does not begin until 200 to 500 milliseconds after onset of the initial pain stimulus because many interneurons are involved in the circuit between the incoming sensory neuron and the motor neurons of the opposite side of the cord (so it takes time) ➔ After the painful stimulus is removed, the crossed extensor reflex has an even longer period of afterdischarge, results from reverberating circuits among the interneuronal cells.➔ The prolonged afterdischarge is of benefit in holding the pained area of the body away from the painful object. Occurs mostly in the lower limb to support balance.



REMEMBER RECIPROCAL INNERVATION? Reciprocal innervations occurs also in crossed extensor reflex. How? -flexors in the opposite limb are inhibited while extensors are excited because while pushing the body away from the injurious agent by withdrawal reflex, the crossed extensor reflex supports the body weight against gravity.

Will Also Be Discussed in More Details in Coming Lectures

1- Renshaw Cells are :
A. Excitatory cells
B. Inhibitory cells
C. Both A&B
D. Neither

2- The soma -cell body - of the sensory neuron is located in the :
A. Dorsal horn of the grey matter
B. Ventral horn of the grey matter
C. Lateral horn of the grey matter
D. Dorsal root ganglion

3- The objective of *Convergence* is to
A. Provide enough spatial summation to bring the neuron to the threshold required for discharge.
B. Spread a single stimulus to a wide area of the spinal cord
C. Protective mechanism against extra neuronal activity.
D. None of the above.

4- Reverberating circuits can be weaken or strengthen depending on:
A. Firing rate
B. Reflex time
C. Number of parallel nerve fibers involved.
D. None of the above.

5- What is true about fatigue of synaptic transmission?
A. Lowers the stimulation of the next neuron below its threshold level.
B. The number of discharges by the postsynaptic neuron are great at first but the firing rate becomes progressively less.
C. It's not affected by neurotransmitter reservoirs.
D. None of the above.

6- If the central delay= 0.6, what are the number of synapses?
A. 1.2 so roughly = 1
B. 2
C. 5
D. None of the above.

7- Which of the following is NOT true about motor neurons :
A. They sends impulses to the integrating center
B. They are inhibited by renshaw cells
C. They are located in the anterior horn of the spinal cord
D. Provide the effectors with the impulse needed to do the action

1.B
2.D
3.A
4.C
5.B
6.A
7.A

MCQs

1-which kind of muscle fiber is supplied by Gamma motor neuron?

Intrafusal muscle fibers

5- What type of reflex is the withdrawal reflex?

A superficial polysynaptic reflex.

6- When does crossed reflex take place?

As a continuation of withdrawal reflex IF the pain stimulus was strong enough.

7- Characteristics of withdrawal reflex?

1- Diverging circuits to spread the reflex to the necessary muscles for withdrawal.
2- Reciprocal inhibition circuits to inhibit the antagonist muscles.

THANK YOU FOR CHECKING OUR WORK!

BEST OF LUCK

{ والله في عون العبد ما كان
العبد في عون أخيه }

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