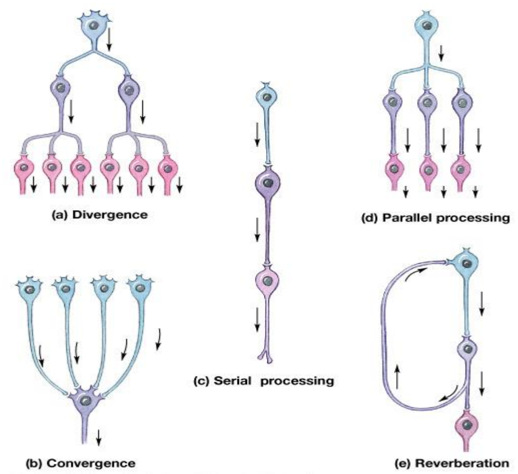
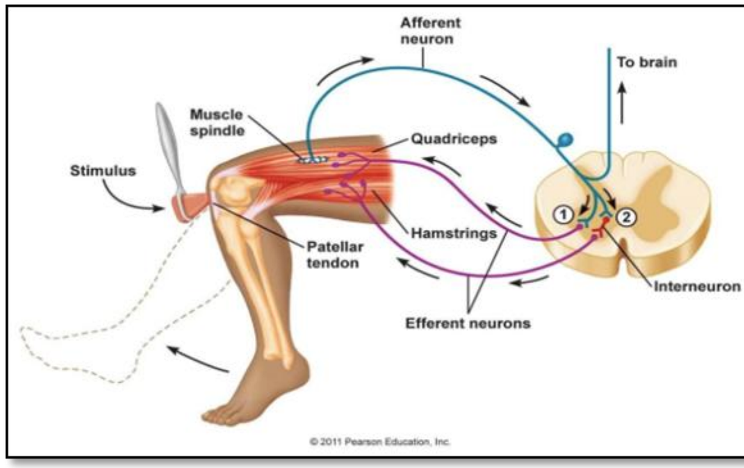
Unit VIII – Problem 2 – Physiology: The Motor System

- **Neuronal pool**: it is a group of neurons collected together to achieve a certain function which is represented by integrating the incoming information and forwarding it to its targeted destination.
- **A simple neuronal pool has:**
  - **A discharge zone**: in which neurons are most closely associated with incoming fibers
  - **Facilitated zone**: in which neurons are further away from incoming fibers.
- **The incoming fibers can provide either threshold or subthreshold stimulation to neuronal pool:**
  - **Excitation**: in which there is a threshold stimulation increasing the membrane potential above the firing levels in several cells and thus generating action potentials.
  - **Facilitation**: in which the membrane potential may be slightly depolarized but not quite enough to reach threshold (subthreshold). These cells are said to be facilitated; that is, they are more excitable because smaller excitatory potentials can bring the cells to threshold and cause the generation of action potentials.
- **There are 5 types of neural circuit patterns:**
  - **Divergence**: in which the action potential from incoming fiber is distributed to many neurons.
  - **Convergence**: in which action potentials from many incoming fibers are terminating in the same neuron.
  - **Serial processing**: in which the action potential is traveling from one neuron to another without converging or diverging.
  - **Parallel processing.**
  - **Reverberation**: in which the signal is continuously discharged.

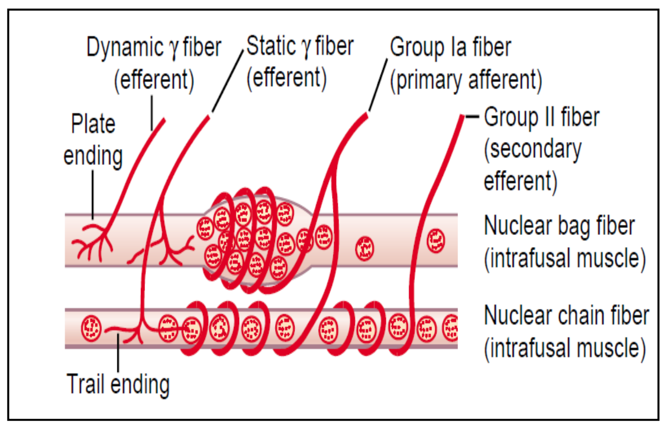


- **Motor unit**: it is a one motor neuron and all muscle fibers which are supplied by it.
- **Motor neuron pool**: all motor units supplying one muscle.
- **A muscle is following the type of its innervations (How?)** → if the motor neuron going to the muscle is rapidly conducting, the muscle becomes white (fast-muscle type) and the opposite is true.
- **α-motor neurons are under the control of inputs from 3 sources:**
  - **The corticospinal tract.**
  - **Sensory fibers from the muscle.**
  - **And spinal interneurons.**
- **Organization of the motor system: it is composed of:**
  - **The motor cortex (pre-central gyrus):** which can directly go and stimulate α-motor neurons (which are terminating in the neuromuscular junctions and thus causing contraction of the muscle).
  - Or the motor cortex might indirectly stimulate the **brain stem** which in turn is going to stimulate:
  - The **spinal cord** that will activate α-motor neurons (these are known as the final common pathway).
- **The stretch reflex (a monosynaptic reflex):**
  - **Functions of the stretch reflex:**
    - ✓ Maintains body posture (static).
    - ✓ Generation of muscle tone (static).
    - ✓ Smoothing of muscle contraction (during movement).
    - ✓ Load reflex: stabilize joint posture (dynamic).
    - ✓ Proprioceptive function (sensation).

- **Dynamic stretch reflex:**



  - ✓ Stimulus: fast/sudden stretch of the muscle; clinically this is produced by a brief sharp tap on a muscle tendon (this results in sudden small lengthening of muscle, not in stimulation of tendon receptors).
  - ✓ Sense organ excited: this strongly excites muscle spindle primary (Group Ia) afferents.
  - ✓ Primary response: muscle that is stretched contracts rapidly
  - ✓ Synapses: Group Ia muscle spindle sensory neurons make strong monosynaptic excitatory connections with α-motor neurons of homonymous muscle (same muscle in which spindle is located).
    - ❖ *Note*: Monosynaptic reflex is the fastest reflex known with a delay of about 1 msec at the synapse.
  - ✓ Other effects
    - ❖ *Excite synergist muscles.*
    - ❖ *Inhibit antagonist muscles (reciprocal inhibition):* Spindle sensory neurons also produce inhibition of motor neurons to antagonistic muscles (ex. biceps spindle neurons produce inhibition of triceps motor neurons); these connections are polysynaptic. The spindle afferent excites interneurons, which then fire and produce inhibitory synaptic potentials in motor neurons to the antagonistic muscle.
- **The muscle spindle**:



  - ✓ It has 2 types of sensory fibers:
    - ❖ *Primary afferents (Ia)* originating from both nuclear bag and nuclear chain fibers.
    - ❖ *Secondary afferents (II)* originating only from nuclear chain fibers.
  - ✓ It has 2 types of motor neurons:
    - ❖ *α-motor neurons*: which are innervating extrafusal fibers.
    - ❖ *γ-motor neurons*: which are innervating intrafusal fibers.
- **Static stretch reflex (static response):**
  - ✓ Function: maintaining posture of the body especially in antigravity muscles (e.g. When muscle spindle in the muscles of the back are stretched → they will be slowly and continuously corrected by the static response).
  - ✓ Characteristics of static response:
    - ❖ Polysynaptic (while dynamic stretch reflex is monosynaptic).
    - ❖ Non-synchronized (while dynamic stretch reflex is synchronized).
    - ❖ Transmitted by type Ia and II afferent fibers from the muscle spindle (while dynamic stretch reflex is transmitted only by type Ia afferents).
    - ❖ Maintaining the tone of the muscle.
    - ❖ The static response is regulated by higher centers in the brain:
      - If there is a lesion in upper motor neurons → this will lead to hypertonicity of the muscle (spastic).

- If there is a lesion in lower motor neuron → this will lead to hypotonicity of the muscle (flaccid).

- **Skeletal muscle tone is regulated by:**
  - ✓ Supraspinal centers which can be facilitatory or inhibitory:

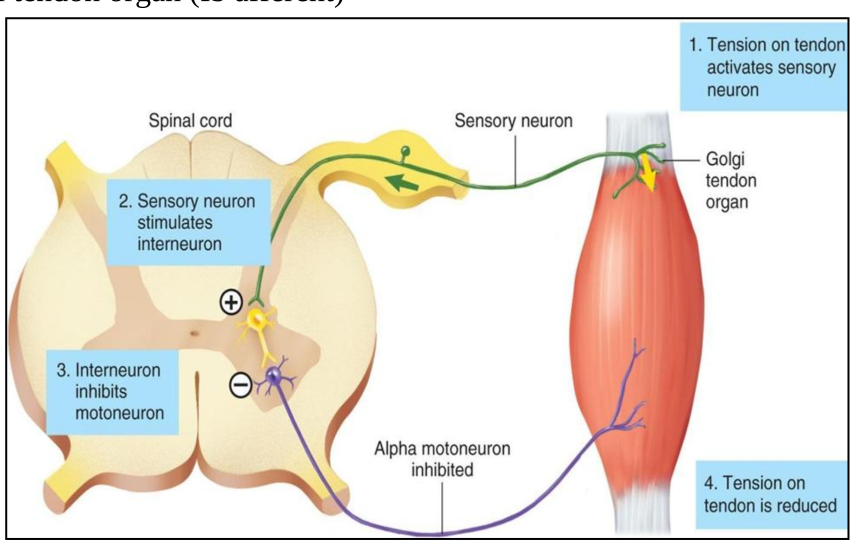
Facilitatory	Inhibitory
Area 4	Area 6
Cerebellum	Basal nuclei
Excitatory RF	Inhibitory RF
Vestibular nucleus.	Red nucleus

  - ✓ Normally, the corticospinal tract inhibits stretch reflexes but stimulate abdominal and cremasteric reflexes (Why?) → because we need to protect our internal organs by abdominal reflexes (the same concept applies for protection of testes by cremasteric reflex).
- **Comparison between dynamic response and static response:**

	Dynamic response	Stretch response
Stimulus	Sudden stretch	Steady stretch
Receptors	Nuclear bag	Nuclear chain
Afferents	Ia (primary)	Ia & II (primary & secondary)
Response	Rapid contraction followed by rapid relaxation	Maintained subtetanic contraction
Examples	Tendon jerk	Muscle tone

- **Pyramidal tract stimulates both α and γ motor neurons so both the intrafusal fibers and the extrafusal fibers contract to the same extent (the stretch receptor does not feel anything).**
  - ✓ If the load is too big for the muscle to lift, what happens to the stretch receptor?
    - ❖ *It becomes stretched (the muscle does not shorten) and increases the frequency of action potentials along the stretch receptor afferent → this stimulates only the α-efferent causing the extrafusal muscle fiber to generate greater amounts of tension.*

- **Golgi tendon organ reflex:**
- **Golgi tendon is measuring the tension of the muscle.**
- **Different muscles have different tensions** (these tension are in turn decided by the cortex).
- **If Golgi tendon organ is not present** → tension in muscles will be the same and will not change according to function (e.g. You will hold a paper cup with the same force/tension in which you hold a cup made of glass).
- **The reflex:**
  - ✓ Stimulus: contraction of the muscle.
  - ✓ Sense organ excited: Golgi tendon organ (Ib afferent)
  - ✓ Primary response: muscle attached to tendon relaxes
  - ✓ Synapses: disynaptic; Ib afferent makes an excitatory synapse upon an interneuron; the interneuron makes an inhibitory synapse upon the motor neuron from the same muscle in which the tendon organ is located.



- **Comparison between muscle spindle and Golgi tendon organ:**
  - ✓ During active contraction of a muscle: spindles inhibited, Golgi stimulated.
  - ✓ During passive contraction of a muscle: both spindles and Golgi are stimulated.

- **Upper motor neurons**: are the ones which are present within the spinal cord and above the ventral horn of the spinal cord. UMNs divided into:
  - **Pyramidal**: which is represented by the corticospinal tract.
  - **Extra-pyramidal**: represented mainly by the basal ganglia.
- **What are the differences between upper motor neurons (UMNs) lesions and lower motor neurons (LMNs) lesions:**

UMN paralysis	LMN paralysis
No wasting of muscles	Wasting of muscles
Increased tone (spasticity/ clasp-knife)	Decreased or lost tone of muscles
Hyper-reflexia	Decreased or lost reflexes
Fasciculations are absent	Fasciculations are present
Babinski sign present + clonus	Babinski sign absent

- **In UMN lesion** → Babinski sign will be present → and it is represented by dorsiflexion of the great toe with spread of other toes.
  - **Why is Babinski sign present in babies?**
    - ✓ Because their pyramidal tract is still not developed (so they will be behaving as there is a lesion to the pyramidal tract). Babinski sign is also present in elderly due to weakness of the pyramidal system.
- **In UMN lesion** → there will be increased tone of the muscles → this will be represented as:
  - **Spasticity:**
    - ✓ Due to a lesion in the pyramidal system.
    - ✓ Speed-dependent (which means that there will be increased resistance when the examiner is trying to passively and rapidly move the arm of the patient).
    - ✓ Single group of muscles (antigravity).
    - ✓ Also described as clasp-knife: that is resistance will suddenly disappear due to activation of Golgi tendon organs leading to sudden relaxation in the muscle which is being stretched.
  - **Rigidity:**
    - ✓ Due to a lesion in the extra-pyramidal tracts.
    - ✓ Group of muscles will be showing rigidity.
    - ✓ In patients suffering from Parkinson's disease:
      - ❖ *Lead-pipe is present*: in which resistance will always be present when the arm is stretched (there will be no sudden relaxation).
      - ❖ *Cog-wheel*: due to a mixture of lead-pipe phenomenon and tremors.
- **Sensations of movement and joint position are provided to the cortex by the following receptors:**
  - Joint-receptors.
  - Muscle spindles.
  - Golgi tendon organs.
  - Tactile (Ruffini) → providing a sense of how much the skin over the joint is stretched.

  If there is a patient with artificial joint → he will still be able to know the position of his leg (Why?) → although joint-receptors are lost but still other receptors (muscle spindles, golgi tendon organs and Ruffini) are present.

  This same concept applies anesthetized skin → in which Raffini are lost but other receptors will provide the missing information.

  If one has no afferent input at all → he has a sense of position from the motor commands (corollary discharge). If a command to move the arm to the left is sent out, the person assumes that the arm will move to the left exactly at the site where he ordered it to move to.

- **Withdrawal reflex and reciprocal inhibition:**
  - It has a complex organization in which there will be contraction of flexor muscles in the leg which has been exposed to a painful stimulus and reciprocal inhibition of extensors in the same leg. There will also be crossed extensor reflex → in which extensors of the contralateral leg will be stimulated (so the body can still be supported and maintain balance instead of falling).
- **Central pattern generators:**
  - **Animals are moving by spinal reflexes which are not under the control of the cortex** → thus when a lesion is induced in the cortex of an animal, it will still be able to move.
  - **This concept does not applies on humans where the cortex has to be functioning in order of movement to occur.**
- **There are 3 levels of motor system control:**
  - **Represented by**: the motor cortex, the brain stem and the spinal cord.
  - All of these levels will eventually terminate in α-motor neurons (their final common pathway).
- **The spinal cord:**
  - **It has α-motor neurons which are connected to propriospinal tract. The propriospinal tract is classified to:**
    - ✓ Lateral part:
      - ❖ Controlling distal muscles (for fine/accurate movements).
      - ❖ It is a small tract.
      - ❖ It is ipsilateral (cannot control both sides of the body).
    - ✓ Medial part:
      - ❖ Controlling proximal axial muscles (does not provide precise movements but is involved in maintaining posture and balance of the body).
      - ❖ It is longer than the lateral part because it is controlling all axial muscles and thus must involve more spinal segments.
      - ❖ It is controlling both sides the body (axial muscles of both sides must contract together to maintain balance).
  - **Size principle of motor units**: this states that when contraction occurs → small motor units are the ones which will be activated first → if the tension generated by them is not enough → larger motor units will be activated.
    - ✓ Note that as a large motor unit is activated → precision will be lost (because in this case, 1 motor neuron is innervating thousands of muscle fibers).
    - ✓ Example: when you want to write something → small motor units are activated because they are more precise.
- **Brain stem:**
  - **Several brain centers serve in:**
    - ✓ Orientation toward stimuli:
      - ❖ *Superior colliculus* → if the stimulus is visual.
      - ❖ *Inferior colliculus* → if the stimulus is audible.

        Note: both of these colliculi are present in the midbrain.
    - ✓ Locomotion: be mesencephalic locomotor area.
    - ✓ Postural control by:
      - ❖ *Vestibular nuclear complex.*
      - ❖ *Reticular formation.*
  - **Medial brainstem pathways: these include:**
    - ✓ Tectospinal tract.
    - ✓ Reticulospinal tract:

        - It functions in anticipated disturbed movement correction. Example: a person is placed in front of a wall which has a rope → the subject is asked to pull that rope → normally, the reticular formation will predict that a disturbance to the balance of the body will occur by this action and thus it will correct it by causing contraction of the muscles in the leg (even before the subject pulls the rope) and thus balance will be maintained.
        - *Reticulospinal tract is divided into:*
            - Pontine reticulospinal tract: which is stimulating extensors of lower limb.
            - Medullary reticulospinal tract: which is stimulating flexors.
    - ✓ Vestibulospinal tract.

      Note: these tracts are going to the medial part of propriospinal tract in the spinal cord.
- **Lateral brain stem pathway: including:**
    - ✓ Rubrospinal tract: from red nucleus in the midbrain – it is crossing – going to the lateral part of propriospinal tract in the spinal cord – more functional in animals.

- **The cortex:**
    - **It has 2 systems:**
        - ✓ One which is indirect and going to the medial part of the ventral horn in spinal cord:
            - It is not precise.
            - Represented by the ventral corticospinal tract (its fibers doesn't cross).
        - ✓ Another one which is direct and going to the lateral part of the ventral horn in the spinal cord:
            - It is very precise.
            - Represented by the lateral corticospinal tract (its fibers cross in the medulla).
            - *Containing Betz neurons*: the largest neurons in the nervous system (1mm) – they are few in number – function in very precise movements (example: movements of the fingers).
            - Receiving 40% of information from area 2 in the post-central gyrus.

          Note:
            - Corticospinal tract → controlling muscles of the body.
            - Corticobulbar tract → controlling muscles of the face (going to cranial nuclei).
    - **Hemiplagia (paralysis of half of the body)** → is caused when the artery supplying the internal capsule gets ruptured.
    - **Area 4 (primary motor area):**
        - ✓ Stimulation of which leads to contraction of group of muscles.
        - ✓ Deciding the type of movement, goal of movement and the direction of the movement.
        - ✓ All these detailed commands regarding movement will descend to lower motor neuron in the ventral horn of spinal cord which will distribute them to different muscles.
    - **Area 6 (pre-motor area):**
        - ✓ It is the area concerned with programming of the movement.
        - ✓ Receiving fibers from the cerebellum.
        - ✓ Sending the program to primary motor area.
        - ✓ Lateral portion of pre-motor area: is further divided to:

- *Ventrolateral (mirror motor neurons):* important for learning motor activity (imitation of movement), social communications, language and empathy.
- *Rostral-lateral*: which contains Broca's area (for speech).

- Medial portion of pre-motor area:
  - Mediates selection and initiation of movements specified by internal cues (from memory)
  - *Containing:*
    - Frontal eye-fields: directing visual gaze.
    - Cyngulate sulcus: expression of emotional behavior.