Introduction to Motor System & Spinal Control

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Motor System

- The nervous system that control body movements is called motor system.
- Motor system consists of all our muscles and the neurons that control them.
- It is responsible all of our movements and behavior!

Motor System

Hierarchy

- Highest level
  - Strategy
  - Neocortex and subcortial areas
- Middle level
  - Tactics
  - Motor cortex and cerebellum
- Lowest level:
  - Execution
  - Brain stem and spinal cord

Motor System

Hierarchy

- Highest level of hierarchy decide to do a specific action.

  ↓Send this information to middle level

- Middle level organize required pattern of required muscle activity for this action and create a model = motor program

  ↓Send this information to lowest level by descending tracts

- In the lowest level, motor neurons exit the spinal cord (or brain stem) and project to the muscles.

Motor System

Sensory and Motor System Relation

- Proper functioning of each level of hierarchy relies on sensory information
  - Sensory information (vision, auditory, vestibular etc) generates a mental image of the body and environment
  - Highest and middle level use this information
  - Sensory feedback about muscle length and tension are also used in lowest level
- «Sensorimotor system»

Somatic Motor System

- Three type of muscles: Smooth/Striated/Cardiac
- Striated (Skeletal) muscle is responsibe for voluntary movements.
- Each muscle fiber innervated by a single axon brach of a motor neuron
- Muscles and the nerves that control them are collectively called somatic motor system

Somatic Motor System

- Movement of bones around joints: Flexion/Extension
- Synergist muscle: Perform together for a movement
- Antagonist muscle: Act in opposition to the movement
- Reciprocal inhibition

Somatic Motor Neuron

- Somatic muscles are innervated by somatic motor neuron
- They are in the ventral horn of spinal cord and send their axons to muscles
- Also called *«lower motor neuron» and divide into two category:*
  - *Alpha motor neurons*
  - Gamma motor neurons

Alpha Motor Neuron

- Directly responsible for contraction of muscles
- One alpha motor neuron and the muscle fibers which innervated by alpha motor neuron is called «motor unit»
- *Motor unit is the elementary component of motor control*
- To control movements of muscles, alpha motor neuron pool controlled by various synaptic inputs

Alpha Motor Neuron

- There are three sources of input to an alpha motor neuron.

1. First input is from muscle spindle, sensory apparatus embedded within muscle
2. Second input is from upper motor neurons which placed in cortex or brain stem.
3. Third input is interneurons, which could be excitatory or inhibitory.

Spinal Control

- One of the input to alpha motor neuron in spinal cord, come from muscle itself.
- Some movements are generated by spinal cord without participation of brain.
- There is a big amount of neuronal circuit within the spinal cord for the control of movements.
  - Sensory feedback from the muscle (proprioception) integrated in spinal cord to create reflexive movements.
  - Other spinal reflexes
  - Certain motor programs (such as walking)

Proprioception

- Sense of self-movement and body position
- Component of somatic sensory system
- Informs us about how our body is positioned and moving in space
- Proprioceptors are mechanoreceptors within muscles, tendons, joints.
  - Muscle spindles monitors muscle length
  - Golgi tendon organs monitors muscle tension
  - Proprioceptive axons in joints monitors angle and direction of joint.

Muscle Spindle

- Specialized receptor that embedded deep within skeletal muscles.
- Consists of specialized skeletal muscle fibers in a fibrous capsule and group 1a sensory axons wrap around this specialized muscle fibers.
- It responsible for detection of changes in muscle length (stretch)
- Also called «stretch receptor»

Muscle Spindle

Definitions

- Regular skeletal muscle fibers are called extrafusal fibers
- Specialized muscle fibers in muscle spindle are called intrafusal fibers
- Extrafusal fibers are innervated by alpha motor neuron (and facilatete contraction)
- Intrafusal fibers are innervated by gamma motor neuron

Muscle Spindle

- Muscle spindles are inside the muscles and they are parallel to the extrafusal fibers.
- If the muscle (extrafusal fibers) stretch, it also pulls pulls the intrafusal fibers, so muscle spindle also stretch.
- Mechanosensitive ion channels open and 1a sensory neuron depolarize; send signal to the brain.
- With these signals, brain can monitor muscle length constantly.

Muscle Spindle

Alpha-Gamma Coactivation

- Muscle spindle send signal when it is stretched.
- Brain needs constant information about muscle length
- But if muscle get shorter (contracted) the tension on the spindle removes and the firing rate of the spindle slows.
- Alpha-gamma coactivation prevent losing signal.

Muscle Spindle

Alpha-Gamma Coactivation

- When muscle contracts, gamma motor neuron activates the intrafusal fibers and keep the spindle stretched
- With this coactivation, muscle spindle can send signal constantly; information about muscle length is continuously available.

Stretch Reflex

- Reflex; involuntary, automatic and fast response to a stimuli
- Reflex arc; neural pathway that control reflex
- Reflex arc consists of 5 components:
    1. Receptor,
    2. Sensory neuron,
    3. Center,
    4. Motor neuron,
    5. Effector

➢ Stretch reflexes is a muscle contraction in response to stretching the muscle.

➢ Receptor of stretch reflexes is muscle spindle.

Stretch Reflex

- Important in maintaining balance and posture
  - Muscle stretched, muscle spindle gets activated and send signal
  - 1a sensory fibers go up to spinal cord and make synapse with alpha motor neuron of the muscle
  - Alpha neuron send signal to the muscle and muscle contracted.
- Most familar one is knee-jerk reflex (patella reflex)
- *Monosynaptic reflex*

Stretch Reflex

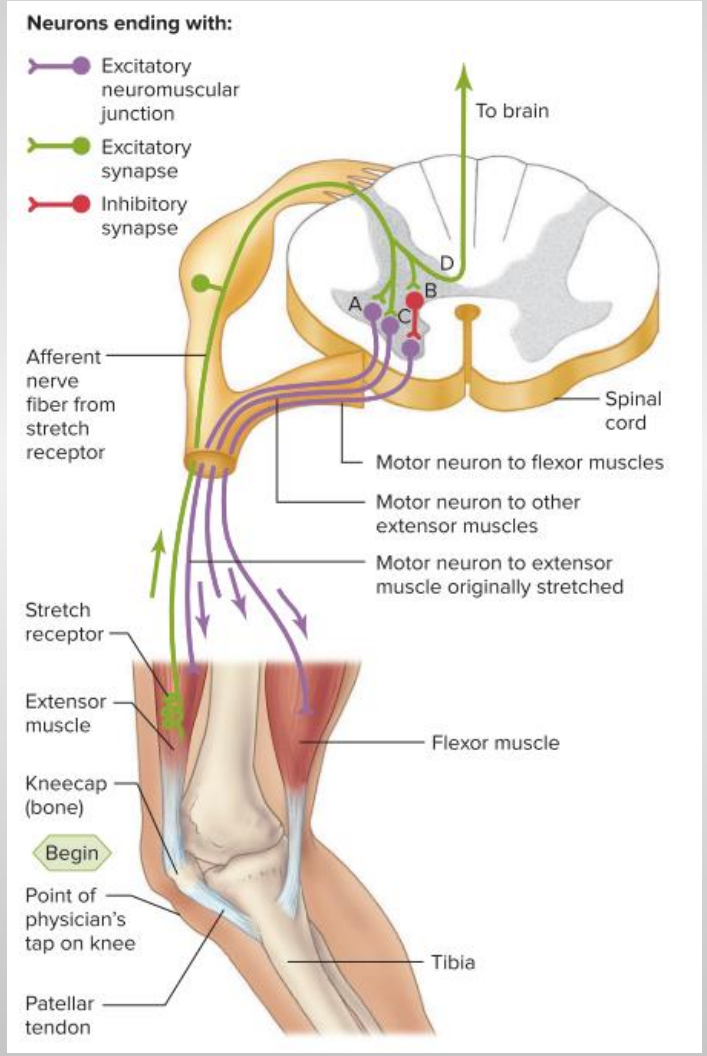
- 1a sensory neuron from muscle spindle have branches:

  A) Directly synapse with alpha motor neuron (monosynaptic arc)

  B) End on inhibitory interneuron; these neuron inhibit antagonistic muscles (Reciprocal innervation)

  C) Activates motor neuron of synergistic muscle

  D) Send information about length of muscle to higher center



Golgi Tendon Organ

- Proprioceptive inputs:
  - Muscle spindle → Muscle length
  - Golgi tendon organ → Muscle Tension
- Golgi tendon organs are located in junction of muscle and tendon; innervated by group 1b axons
- Thin branches of the 1b axons are among of the coils of collagen fibrils.
  - When muscle contracts, tension on the collagen fibrils increases. Fibrils squeeze the 1b axons and their mechanosensitive ion channels are activated; axons send signal.

Golgi Tendon Reflex

- If the muscle tension increase, GTO activates.
- 1b axon from GTOs, enter the spinal cord and synapse on inhibitory interneurons.
- These interneurons inhibit alpha motor neuron that innervates same muscle and muscle relaxed.
- This reflex protect the muscle from being overloaded.

Other Spinal Reflexes

Withdrawal reflex

- Withdraw a limb from an aversive stimulus
- Complex, polysynaptic reflex arc

1. Pain receptor,
2. Aδ nociceptive axon,
3. Spinal cord,
4. Alpha motor neuron,
5. Flexor muscle

Other Spinal Reflexes

Crossed-extensor reflex

- If withdrawal reflex happens in the leg;
- Stepping on a needle
- Leg pull away from painful stimuli; flexors activated, extensor inhibited (Withdrawal reflex).
- But this would cause losing balance.
- An additional component is recruited:

➢ *On the opposite side the extensors are activated and flexors inhibited.*

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