# Medical Neuroscience | Tutorial Notes

## Lower Motor Neuronal Control—Segmental Reflexes

### *MAP TO NEUROSCIENCE CORE CONCEPTS*[1]

NCC1. The brain is the body's most complex organ.

NCC3. Genetically determined circuits are the foundation of the nervous system.

### *LEARNING OBJECTIVES*

After study of the assigned learning materials, the student will:

1. Discuss the critical components of the myotatic reflex and how they interact to monitor and adjust muscle length.
2. Characterize the role of gamma motor neurons in spindle gain adjustment.
3. Discuss the factors that account for muscle tone.
4. Discuss the critical components of the golgi tendon reflex and how they interact to monitor and adjust the force of muscle contraction.
5. Discuss the critical components of the flexion/crossed-extension reflex and how they interact to withdraw a limb from a harmful stimulus.

### *TUTORIAL OUTLINE*

I. lower motor circuits

   A. Overall organization of the neural centers that control movement (see **Figure 16.1**[2])

      1. spinal cord circuits: "final common pathway" or "basic motor system"

         a. **segmental reflexes** involving alpha (and gamma) motor neurons (i.e., **"lower motor neurons"**), local circuit interneurons, and afferent somatic sensory input (e.g., myotatic or "knee-jerk" reflex)

         b. **intersegmental reflexes** mediated by interneurons that coordinate the activities of segmental circuits at multiple levels of the spinal cord (and brainstem) (e.g., central pattern generators for locomotion)

   B. segmental sensorimotor reflexes

      1. **myotatic** (muscle spindle) **reflex**: a system that monitors and maintains *muscle length* (see **Figure 16.10**)

         a. stimulus: *stretch of muscle*

---

[1] Visit **BrainFacts.org** for *Neuroscience Core Concepts* (©2012 Society for Neuroscience ) that offer fundamental principles about the brain and nervous system, the most complex living structure known in the universe.

[2] Figure references to Purves et al., *Neuroscience, 5th Ed.*, Sinauer Assoc., Inc., 2012. [click here]

b. sensor: **muscle spindle**; specifically, sensory endings (group Ia and II fibers) coiled around the intrafusal fibers of the muscle spindle

c. muscle spindles (see **Figure 16.10A**)

  (i) within skeletal muscle are encapsulated, **muscle spindles**, which contain a small number of **intrafusal muscle fibers** in parallel with the extrafusal, striated muscle fibers

  (ii) two types of intrafusal fibers: **nuclear bag fibers** and **nuclear chain fibers**, so-named because of the arrangement of nuclei within each type of fiber

  (iii) primary sensory endings from **group Ia afferent fibers** encircle both types of intrafusal fibers; **group II afferent fibers** innervate nuclear chain fibers

  (iv) stretch can activate the spindle fibers in one of two ways:

    - passive stretch of the entire muscle (both intrafusal and extrafusal fibers are stretched)

    - contraction of the intrafusal muscle fibers themselves by stimulation of the **gamma motor neurons** that innervate the contractile segments of intrafusal fibers

  (v) nuclear bag fibers respond *phasically* to dynamic changes in muscle length

  (vi) nuclear chain fibers respond *tonically* and proportionally to muscle length

  (vii) muscle spindles provide feedback signals to the cerebellum that helps to regulate the strength of contraction (via dorsal spinocerebellar and cuneocerebellar tracts)

  (viii) muscle spindles also provide feedforward signals to the cerebral cortex that contributes to conscious proprioception, (via the dorsal column-medial lemniscal pathway) (see Lab Guide, Appendix 1, **Figure A1.6**)

  (ix) group Ia afferents also provide direct feedback to alpha motor neurons in the ventral horn

d. central effects of afferent activity (see **Figures 1.7** & **16.10**; see also **Chapter 16 Animation 16.1** click here)

  (i) **monosynaptic excitation** of motor neurons that innervate the extrafusal fibers of the homonymous (same) muscle

  (ii) **monosynaptic excitation** of motor neurons that innervate the extrafusal fibers of synergistic muscles

  (iii) **disynaptic inhibition** of the alpha motor neurons that innervate the extrafusal fibers of antagonistic muscles (*reciprocal innervation*)

e. gain control

(i) **gain**: the amount of extrafusal contraction elicited by a given stretch (load) applied to the muscle (output/input)

- if gain is low, a moderate stretch will induce a low rate of firing in spindle afferent fibers and result in a low degree of extrafusal contraction
- if gain is high, the same degree of stretch will induce a higher rate of firing in spindle afferent fibers and result in a higher degree of extrafusal contraction

(ii) gain adjustments may be made by alterations in the firing of **gamma motor neurons** (see **Figure 16.11**)

- gamma motor neurons innervate the contractile segments of intrafusal muscle fibers
- activation of gamma motor neurons leads to contraction and shortening of intrafusal fibers
- changes in the length of intrafusal fibers "re-sets" the sensitivity of the muscle spindle to stretch of the whole muscle

(iii) gain adjustments are necessary when the muscle is shortening to prevent the muscle spindle from being "unloaded"

(iv) gain adjustments may be context dependent

- gamma motor neuron activity may be adjusted independently of alpha motor neurons by descending projections from higher motor centers
- in anticipation of a difficult motor task or in preparation for "fight or flight", gamma motor neuron activity increases, as does spindle sensitivity
- reflex gain is also dependent upon the excitability of alpha motor neurons, which can also be modulated by descending inputs from the brainstem reticular formation (biogenic amine neurotransmitters)
- the synaptic terminals of Ia afferent fibers are subject to axo-axonal (presynaptic) inhibition by local inhibitory (GABAergic) neurons in the ventral horn

f. muscle tone (see Chapter 17, **Box 17E**)

1. resting level of tension in a muscle
2. depends upon the resting firing rate of alpha motor neurons

   (i) in turn, this is dependent mainly upon the activity of muscle spindle afferents

(ii) gamma motor neuron activity establishes the gain of the muscle spindle, which then influences the overall level of muscle tone

Consider whether you think psychological stress might cause an increase in firing of cervical gamma motor neurons. Might PT (e.g., massage) provide tools for resetting the gain of spindle activity?

3. damage to the dorsal roots (spindle afferents), ventral roots (alpha and gamma motor neurons) or the spinal cord itself generally results in *loss* of muscle tone, termed **hypotonia** (lower motor neuron sign)

4. damage to descending pathways that modulate spinal reflexes generally produce an *increase* in muscle tone, termed **hypertonia** (upper motor neuron sign)

2. **Golgi tendon organ reflex**: a system that monitors and maintains *muscle force* (see **Figure 16.12** & **16.13**)

   a. stimulus: *tension* due to muscle contraction (insensitive to stretch)

   b. sensor: golgi tendon organ, which consists of nerve endings of group Ib afferents woven into the "fabric" of the collagen fibrils near the junction of the muscle and tendon (in series with muscle fibers)

   c. central effects of afferent activity

      (i) **disynaptic inhibition** of the alpha motor neurons that innervate the extrafusal fibers of the homonymous muscle
      (ii) **disynaptic excitation** of alpha motor neurons that innervate the extrafusal fibers of antagonistic muscles
      (iii) because of some level of tonic activity in Ib afferents, Golgi tendon organs help to maintain a steady level of muscle force (e.g., counteracting the effects of fatigue)
      (iv) as large forces are generated by muscle contraction, Golgi tendon organ activity provides negative feedback signals that protect against excessive (potentially damaging) tensions

   d. subject to modulation by descending systems and input from other sensory fibers (via group Ib interneurons)

      (i) descending control from higher motor control centers provides a means of allowing for maximal force generation, when the risks are justified (e.g., "fight or flight" conditions, athletic performance, resistance training)

   e. compare function of muscle spindles and Golgi tendon organs with passive stretch and active contraction of a muscle (see **Figure 16.12**)

3. flexion/crossed-extension reflex pathways: a system for withdrawing the limb from a noxious stimulus (see **Figure 16.14**; see also **Chapter 16 Animation 16.2** click here)

   a. stimulus: activation of peripheral *nociceptors*

b. sensor: sensory endings (group Aδ) in skin, joints, periosteum, etc.

c. central effects of afferent activity: ipsilateral flexion & contralateral extension (for postural stability)

  **(i)** **disynaptic excitation** of alpha motor neurons that innervate the extrafusal fibers of flexor muscles in the same limb

  **(ii)** **disynaptic inhibition** of alpha motor neurons that innervate the extrafusal fibers of extensor muscles in the same limb

  **(iii)** **polysynaptic excitation** of alpha motor neurons that innervate the extrafusal fibers of extensor muscles in the opposite limb

  **(iv)** **polysynaptic inhibition** of alpha motor neurons that innervate the extrafusal fibers of flexor muscles in the opposite limb

d. also subject to descending modulation (e.g., fire-walkers)

## *STUDY QUESTION*

Q1. Make a fist. Now squeeze harder. What just happened?

A. Activity in the Ia afferents associated with the contracting muscles were increased substantially.
B. Activity in the Ia afferents associated with the contracting muscles were decreased substantially.
C. Activity in the Ib afferents associated with the contracting muscles were increased substantially.
D. Activity in the Ib afferents associated with the contracting muscles were decreased substantially.
E. Activity in the alpha motor neurons associated with the contracting muscles were decreased substantially.

Q2. What change in neural activity is associated most directly with an <u>increase</u> in the gain of myotatic (muscle spindle) reflexes?

A. Increase in the firing of gamma motor neurons.
B. Increase in the firing of alpha motor neurons.
C. Decrease in the firing of Ia afferent neurons.
D. Decrease in the firing of Ib afferent neurons.