Systems Neuroscience
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Motor systems

Daniel C. Kiper
kiper@ini.phys.ethz.ch

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Why is the Motor System Important

• All observable behavior is directly related to activity in the motor system.

• Without the motor system, we could experience sensation, think, reason, problem solve, read, write, and do mental math, but we would not be able to communicate our thoughts and abilities to anyone.
Overview of Motor Systems

• Spinal reflexes
• Corticospinal and corticobulbar tracts
• Cortical-subcortical-thalamo-cortical systems
  Involving basal ganglia
  Involving pons and cerebellum
Skeletal Muscles (vs. smooth muscles)

- striated (striped) appearance because they are comprised of muscle fibers
- move through a pull action (contraction)
- work in pairs with a reciprocal muscle (bicep contracts & triceps relaxes)
- stimulated by a Motor Neuron
The Biceps and Triceps

Elbow joint flexion
- Biceps contract
- Triceps extend

Elbow joint extension
- Biceps extend
- Triceps contract

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Anatomy of the Muscle

Striated muscles are made of muscle fibers that have two parts, outer and inner:

- **Outer fiber** = extrafusal fiber
- **Inner fiber** = intrafusal fiber

Wrapped around the intrafusal fiber is a sensory nerve that picks up the sensation of stretch.

This represents only one muscle fiber - a muscle has many fibers.
Outer fiber = extrafusal fiber

Inner fiber = intrafusal fiber

Each muscle fiber has a gamma motor neuron that synapses on the intrafusal fiber. The alpha motor neuron synapses on the extrafusal fibers. One alpha motor neuron can stimulate numerous fibers. This is called the motor unit. The neural link between the alpha motor neuron and the muscle fiber is called the neuromuscular junction.
The Muscle-Spindle Feedback Circuit

- Dorsal horn for sensory input
- Ventral horn for motor output
• The ratio between the alpha motor neuron and the number of muscles fibers it innervates is associated with the degree of dexterity needed in the movement.

  high ratio (1:150) = contraction of large muscles
  low ratio (1:10) = contraction of small muscles needed for fine movements

Motor Homunculus is related to the number of alpha motor neurons needed to innervate muscles of various regions of our body.
Comparing the Anatomy of the CNS with the Anatomy of the Neuromuscular Junction

<table>
<thead>
<tr>
<th>Motor Unit</th>
<th>CNS Synapse</th>
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<tbody>
<tr>
<td>Alpha Motor Neuron</td>
<td>Presynaptic Neuron</td>
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<tr>
<td>Muscle Fiber</td>
<td>Postsynaptic Neuron</td>
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<tr>
<td>Endplate</td>
<td>Dendrite</td>
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<tr>
<td>NT is Acetylcholine</td>
<td>Many different NTs</td>
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<tr>
<td>Nicotinic Receptors</td>
<td>Many different receptors</td>
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<td>Calcium enters</td>
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<td>Endplate Potential (EPP)</td>
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<td>Muscle Contraction or Muscle</td>
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<tr>
<td>Action Potential &amp; movement</td>
<td>NT</td>
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</tbody>
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How is limb position maintained?

• **Involuntary movement** (i.e. posture): continual contraction and relaxation of the muscles in our feet and calves.

• **Voluntary movement:**
  
  Stretch of the intrafusal fiber causes contraction of the extrafusal fiber via alpha motor neuron. Keeping the movement at this position requires a direct signal from the brain.
Automatic Maintenance of Limb Position (Continued)

The unexpected force (i.e., my cat Arnold) elicits an increase in firing of the biceps spindle afferent neurons.
Automatic Maintenance of Limb Position

The increase in the firing of the biceps spindle afferent neurons increases firing in the biceps motor neurons, thus keeping the arm in its original position.
Without intrafusal motor neurons, the spindles of a skeletal muscle would become slack and unresponsive to stretch during a muscle contraction.

The function of intrafusal motor neurons is to adjust the length of intrafusal muscles, thus maintaining an appropriate degree of tension on muscle spindles, regardless of the length of the skeletal muscle.
Remember, muscles work in pairs, so if one contracts the other relaxes.

This is referred to as **reciprocal innervation**. What if both muscles contracted at the same time?
Reciprocal Innervation of Antagonistic Muscles

1. The thumb tack produces a burst of firing in sensory neurons.

2. The burst of firing in the sensory neurons excites excitatory spinal interneurons that excite biceps motor neurons.

3. At the same time, the burst of firing in the sensory neurons excites inhibitory spinal interneurons that inhibit triceps motor neurons.

4. The simultaneous contraction of the biceps muscle and relaxation of the triceps muscle causes a rapid flexion of the elbow joint.
The Elicitation of a Stretch Reflex

The rap on the knee tendon stretches the spindles of the thigh muscle and elicits a burst of firing in their spindle afferents.

The burst of firing in the spindle afferents triggers a burst of firing in the thigh muscle motor neurons, which causes the thigh muscle to contract.
• Alpha Motor Neuron is the **Final Common Path** for all movement. Movement can be generated from:
  - sensory signals in the muscle spindle like the stretch reflex
  - sensory signals from skin as in the pain withdrawal response
  - involuntary signals from the brainstem for posture, keeping us upright without conscious attention
  - signals from the brain for voluntary movement
But, regardless of where the signal originates, all movement is the result of activity in the alpha motor neuron – making this the Final Common Path.
The Two Divisions of the Dorsolateral Motor Pathway

- **Dorsolateral Corticospinal Tract**
  - Medullary pyramid
  - Dorsolateral portion of the spinal cord
  - To contralateral distal limb muscles

- **Dorsolateral Corticorubospinal Tract**
  - To muscles of contralateral face
  - Red nucleus
  - Nuclei of cranial nerve motor neurons
  - To contralateral distal limb muscles
Corticospinal tract

• Origins: primary motor cortex (MI), premotor cortex, supplemental motor cortex, anterior paracentral gyrus, parietal lobe (including SI) and cingulate gyrus

• collaterals: small percentage of corticospinal neurons
  – 1. midbrain (primarily red nucleus)
  – 2. trigeminal nuclei
  – 3. pontine nuclei
Corticospinal tract

- Termination in spinal cord: mostly laminae 3-7, few in ventral horn and laminae 1-2; mostly innervating interneurons, although some innervation of alpha motor neurons
- Neurotransmitter: glutamate and/or aspartate
Pyramidal tract origin
Corticobulbar tracts

- A. control over facial muscles; bilateral input to motor neurons controlling muscles in upper face, but contralateral input to motor neurons controlling lower face (in humans, not sure about rodents)
- B. control over muscles of mastication: motor trigeminal, and RF
- C. control over external eye muscles: input comes from frontal and parietal eye fields, rather than from MI; projection to midbrain and paramedian pontine RF
- D. control over tongue: hypoglossal and RF
- E. control over swallowing reflexes: nucleus ambiguus and RF
Voluntary Movement: Instructions from Cerebral Cortex

• Dorsolateral Prefrontal Cortex: directs movement of our limbs (as in reaching) and movements of our fingers.
• Actual signal for movement must go through pre-motor cortex, then motor cortex.
• From motor cortex, signal travels down spinal cord eventually reaching the alpha motor neuron.
• BUT, the instructions for this movement ultimately comes from our Parietal lobe, which receives sensory input.
Pathways of the Dorsolateral Prefrontal Association Cortex

Dorsolateral prefrontal association cortex

Posterior parietal association cortex
Four Areas of the Secondary Motor Cortex

- Primary motor cortex
- Premotor cortex
- Supplementary motor area
- Cingulate motor areas
(a) Lateral view of brain showing location of primary motor cortex

Central sulcus

(b) Representation of the body in primary motor cortex

Elbow  Wrist  Shoulder  Trunk  Hip  Leg
Digit V  Digit IV  Digit III  Digit II  Thumb  Neck  Knee  Ankle  Feet  Toes
Brow  Eyelids  Hand  Eyeballs  Face
Lips  Jaw  Tongue  Mastication  Salivation
Throat  Genitalia

(c) Motor homunculus
Control of movement by motor cortex

• A. microstimulation studies: in MI movements of particular contralateral joints (e.g. distal finger) can be elicited by microstimulation; in MII contractions of groups of muscles sequentially to produce overall movements of limbs, often bilaterally
Control of movement by motor cortex

- B. electrical activity during movement: corticospinal neurons active just before initiation of a movement; activity related to amount of force necessary to produce the movement; directionally-sensitive corticospinal neurons; higher-order motor cortex involved in calculating trajectories in space (probably in close communication with cerebellum) and in planning larger-scale movements (probably in close communication with the basal ganglia)
Control of movement by motor cortex

- C. imaging studies in humans: random movements of digits activates MI (precentral gyrus); planned movements activate MI and supplemental motor cortex; thinking about planned movements activates supplemental motor cortex, but not MI
Sequences of Finger Movements Recorded by a PET

Sensorimotor areas activated by performing a well-practiced sequence of finger movements

- Supplementary motor area
- Premotor cortex
- Primary somatosensory and motor cortex
- Posterior parietal cortex
- Cerebellum

Very active
Active
Sequences of Finger Movements Recorded by a PET (continued)

Sensorimotor areas activated by performing a newly learned sequence of finger movements.
Of course, this is really too simple…

• Other brain areas involved in movement:
  1. ventromedial frontal cortex – involved in body control, posture and whole body movements
  2. Cerebellum
  3. Basal Ganglia
  4. Brainstem

• In the end, all movement funnels through the alpha motor neuron (final common path)
Motor Hierarchy and Loops

- Cerebral Motor Cortex
- Thalamus
- Cerebellum
- Basal Ganglia
- Brain Stem
- Spinal Cord
- Final Common Pathway

Control Circuits

Indirect Activation Pathways

Direct Activation Pathways
Disorders of the Motor System

- Amyotrophic lateral sclerosis – motor neurons of the brainstem & spinal cord are destroyed.
- Huntington’s Disease – progressive destruction of the basal ganglia (GABA).
- Muscular Dystrophy – biochemical abnormality affecting the utilization of Ca++ causing wasting away of muscles.
- Myasthenia gravis – autoimmune disorder that destroys Ach receptors (starts with head as in drooping eyelids then progresses to swallowing & respiration).
- Parkinson’s disease – degeneration of neurons in the striatum due to loss of cells in the substantia nigra that synthesis/release dopamine.