MOTOR System

Reflexes and sensomotor reactions

Movements
Reflexes and sensomotor reactions

- Unconditioned reflexes
- Conditioned reflexes
- Posture and gait

Don’t ring the bell every time you feed it. Yesterday it ate the postman.
Movements

PLANNING MOVEMENT  INITIATING MOVEMENT  EXECUTING MOVEMENT
The brain activates motor neurons in the spinal cord

Motor neurons are located in the ventral horn

(a) One segment of spinal cord, ventral view, showing its pair of nerves

White matter
Gray matter
Dorsal root: carries sensory (afferent) information to CNS
Ventral root: carries motor (efferent) information to muscles and glands

(b) Gray matter consists of sensory and motor nuclei

Visceral sensory nuclei
Somatic sensory nuclei
Dorsal root ganglion
Lateral horn
Ventral horn
Ventral root
Somatic motor nuclei

(c) White matter in the spinal cord consists of axons carrying information to and from the brain.

To the brain
Ascending tracts carry sensory information to the brain.
From the brain
Descending tracts carry commands to motor neurons.
Arrangement of motor nuclei of the spinal cord along a medial-lateral axis

Motor system I

Reflexes and sensomotor reactions
A single muscle fibre contains several myofibrils

The neuromuscular junction

1. Acetylcholine (ACh) is made from choline and acetyl CoA.

2. In the synaptic cleft ACh is rapidly broken down by the enzyme acetylcholinesterase.

3. Choline is transported back into the axon terminal and is used to make more ACh.
(b) The nicotinic cholinergic receptor binds two ACh molecules, opening a nonspecific monovalent cation channel.
The motor neuron

The motor unit

Source: Boron and Boulpaep, Medical Physiology, 3rd edition, Elsevier, 2017
Interneuron

Small-diameter motor neuron

$R_m$ is high... and conduction velocity is low.

Large-diameter motor neuron

$R_m$ is low... and conduction velocity is high.

Slow-twitch (type I) fibers

Fast-twitch (type II) fibers

efferent

Source: Boron and Boulpaep, Medical Physiology, 3rd edition, Elsevier, 2017
'small' tonic α–motoneuron

'big' phasic α–motoneuron

stretch
The motor unit

A motor neuron plus the muscle fibres which are synaptically activated by the nerve fibre

„Small-diameter motor unit“: a nerve fibre activates only one or a few muscle fibres
mainly involved in posture and small movements

„Large-diameter motor unit“: a nerve fibre activates many muscle fibres
mainly involved in large voluntary movements
Activating motor units: Forms of muscular contraction

(a) Single twitches: Muscle relaxes completely between stimuli (△).

(b) Summation: Stimuli closer together do not allow muscle to relax fully.

(c) Summation leading to unfused tetanus: Stimuli are far enough apart to allow muscle to relax slightly between stimuli.

(d) Summation leading to complete tetanus: Muscle reaches steady tension.

The amount of active contractile force depends on the degree of overlap of thick and thin filaments (myosin and actin filaments)
Activating motor units: contraction of the skeletal muscle

A  TYPE I (SLOW)
Twitch
2 g  
50 ms

Unfused tetanic force
2 g  
500 ms

Fatigability
4  
min

B  TYPE IIa (FAST, FATIGUE-RESISTANT)

10 g  
50 ms

20 Hz
250 ms

Fatigability
30  
min

C  TYPE IIx (FAST, FATIGABLE)

50 g  
50 ms

25 Hz
250 ms

Fatigability
50  
min

Source: Boron and Boulpaep, Medical Physiology, 3rd edition, Elsevier, 2017
Control of the strength of muscle contraction:

- Firing frequency of single motor neurons (Temporal summation)
- Recruitment of different numbers of motor neurons (Spatial summation)
Spinal control of muscle contraction: Spinal reflexes
<table>
<thead>
<tr>
<th>LOCATION</th>
<th>ROLE</th>
<th>RECEIVES INPUT FROM:</th>
<th>SENDS INTEGRATIVE OUTPUT TO:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spinal cord</td>
<td>Spinal reflexes; locomotor pattern generators</td>
<td>Sensory receptors</td>
<td>Brain stem, cerebellum, thalamus/cerebral cortex</td>
</tr>
<tr>
<td>Brain stem</td>
<td>Posture, hand and eye movements</td>
<td>Cerebellum, visual and vestibular sensory receptors</td>
<td>Spinal cord</td>
</tr>
<tr>
<td>Motor areas of cerebral cortex</td>
<td>Planning and coordinating complex movement</td>
<td>Thalamus</td>
<td>Brain stem, spinal cord (corticospinal tract), cerebellum, basal ganglia</td>
</tr>
<tr>
<td>Cerebellum</td>
<td>Monitors output signals from motor areas and adjusts movements</td>
<td>Spinal cord (sensory), cerebral cortex (commands)</td>
<td>Brain stem, cerebral cortex (Note: All output is inhibitory.)</td>
</tr>
<tr>
<td>Thalamus</td>
<td>Contains relay nuclei that modulate and pass messages to cerebral cortex</td>
<td>Basal ganglia, cerebellum, spinal cord</td>
<td>Cerebral cortex</td>
</tr>
<tr>
<td>Basal nuclei</td>
<td>Motor planning</td>
<td>Cerebral cortex</td>
<td>Cerebral cortex, brain stem</td>
</tr>
</tbody>
</table>
Spinal reflexes for the control of muscle contraction:

**Muscle spindle:** for control of muscle length  
**Golgi tendon organ:** for control of muscle tension

Other receptors (e.g. nociceptors..)
Muscle spindles parallel to the extrafusal muscle fibers: they measure the muscle length

Activation of gamma motor neurons during active contraction enables the muscle spindle to continue sensing changes in muscle length.

Statische und Dynamische 
Ja - Atononeurone

Reizelektrode

dynam 
ja-MN

Reizung

Response of the 
Ia-Fiber

Reizung 
statiker Faser
Reizung 
dynamischer Faser

0.1 sec
Motor neurons

**alpha - motor neurons:**
activate synaptically extrafusal muscle fibres and cause contraction of the muscle

**gamma - motor neurons:**
activate synaptically intrafusal muscle fibres and cause contraction of the muscle spindles (dynamic response). This increases the sensitivity of the muscle spindles (static response).
Alpha and gamma motor neurons are coactivated during voluntary movements.
Golgi tendon organs in the tendon: they are activated during contraction of the muscle and measure muscle tension.
Inhibition of the α-motoneuron: protection + regulating force
The stretch reflex

Monosynaptic effect in same organ

The stretch reflex

Inhibition of the antagonist (reciproce)
Inhibitory reflex by inhibitory interneurons

Golgi tendon organs

The reflex inhibits—in the spinal cord—the motor neurons to the extensor muscle...

...and stimulates the motor neurons to the flexor muscle.

Source: Boron and Boulpaep, Medical Physiology, 3rd edition, Elsevier, 2017

**Muscle spindle reflex**: The addition of a load stretches the muscle and the spindles, creating a reflex contraction.

(a) Add load to muscle.

(b) Muscle and muscle spindle stretch as arm falls.

(c) Reflex contraction initiated by muscle spindle restores arm position.

**Golgi tendon reflex**: Protects the muscle from excessively heavy loads by causing the muscle to relax and drop the load.

(d) Muscle contraction stretches Golgi tendon organ.

(e) If excessive load is placed on muscle, Golgi tendon reflex causes relaxation, thereby protecting muscle.
Polysynaptic reflexes

1. Painful stimulus activates nociceptor.
2. Primary sensory neuron enters spinal cord and diverges.
3a. One collateral activates ascending pathways for sensation (pain) and postural adjustment (shift in center of gravity).
3b. Withdrawal reflex pulls foot away from painful stimulus.
3c. Crossed extensor reflex supports body as weight shifts away from painful stimulus.

Regulation of the strength of a reflex by changes in the transmission in the reflex pathway

Rhythmic activity pattern in the spinal cord

A. Alternating Contractions in a Single Limb

- When the extensors contract...
- The flexors relax...
- ...and the foot is planted.

B. Stepping Pattern of a Cat during Various Gaits

- Walk: Foot planted → Foot lifted
- Trot: LH → LF → RH → RF
- Pace: LH → LF → RH → RF
- Gallop: LH → LF → RH → RF

Source: Boron and Boulpaep, Medical Physiology, 3rd edition, Elsevier, 2017
Pattern generation in the spinal cord

Information on hip extension controls the transition from stance to swing.

Peripheral paresis/paralysis

- Reduced force of contraction / no contraction
- Muscle atrophies

Causes:

- Nerve lesions (injury..)
- Peripheral neuropathy
- Infections (e.g. poliomyelitis)
- Neurodegenerative diseases
  (amyotrophic lateral sclerosis)
- others
A Normal muscle

B Denervated muscle

C Myopathy

Motor neurons

Needle electrode

Rest

Slight contraction

Maximal contraction

Fibrillation

Giant unit

Small polyphasic units

Reduced interference pattern

Full interference pattern
Determination of motor nerve conduction velocity

H- (Hoffmann) Reflex

Electrical stimulation nervis tivialis, recording on musculus soleus

Low stimulus intensities: Ia- afferent fibers activated : H-wave

Higher stimulus intensities: higher threshold efferent fibers and/or muscle fibers activated: M-wave

Activation of stimulated Ia afferents hits refractory efferent structures
1. Lesion on the patient's right loss of all sensation, hypotonic paralysis (lemniscus pathway)

2. Spastic paralysis and loss of vibration and proprioception (position sense) and fine touch (Tractus corticospinalis)

3. Loss of pain and temperature sensation (Tractus spinothalamicus)
Brown Sequard syndrome

1. Loss of supraspinal innervation of motor neurons: spinal shock, areflexia
2. Hypersensitivity of motor neurons + new synapses
3. \[ \rightarrow \text{hyperreflexia} \]
   \[ \rightarrow \text{spastic movements (muscle spindles and tendon organs dominate action of } \alpha\text{-motoneurons)} \]
   Ipsilateral massive tonic contractions initiated by muscle spindles activate massively golgi tendon organs \[ \rightarrow \text{sudden tonus loss (pocket knife phenomenon)} \]

4. Damaged pyramidal fibers (normal dominance for flexors of leg and extensor of arm) causes now dominance of extensor of leg and flexor of arm leading to antigravity

5. Appearance of 'old' reflexes (Babinski reflex)