I. Announcements
Last Lab 6, Pulmonary Function Testing + optional notebook ✓ this Thurs. Exam II Tues, Dec 8, 8 am Q?

II. Nervous System Connections LS 7
A. Autonomic NS: Branches, neurotransmitters, receptors, actions, fight-or-flight stories ch 7 pp 179-85
B. Why are nerve & muscle unique? ch 4 p 71
C. How do excitable cells signal? ch 3 pp 62-7; ch 4 pp 74-83
D. How does the signal cross the nerve-muscle gap? ch 7 p 185-92 fig 7-5 p 190
E. What do black widow spider venom, botulism/Botox?, curare & nerve gas have in common? LS fig 7-5 p 190

III. Muscle Structure-Function & Adaptation LS ch 8 + DC Mod 12
A. Muscle types: cardiac, smooth, skeletal LS fig 8-1 pp194-6
B. How is skeletal muscle organized? LS fig 8-2, DC fig 12-2
C. What do thick filaments look like? LS fig 8-4, DC fig 12-4
D. Thin filaments? Banding pattern LS fig 8-5, 8-3, 8-7
E. How do muscles contract? LS fig 8-6, 8-10
F. What's a cross-bridge cycle? LS fig 8-11 +…
Hormonal Adrenaline Surge Reinforces Nervous Outflow & Accesses Tissues Not Directly Innervated!!

80% Epinephrine/Adrenaline (E)
20% Norepinephrine (NE)

Output → to blood

Adrenals = Paired organs above kidneys
<table>
<thead>
<tr>
<th>Organ</th>
<th>Effect of Sympathetic Stimulation</th>
<th>Effect of Parasympathetic Stimulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart</td>
<td>Increases heart rate and increases force of contraction of the whole heart</td>
<td>Decreases heart rate and decreases force of contraction of the atria only</td>
</tr>
<tr>
<td>Blood Vessels</td>
<td>Constricts</td>
<td>Dilates vessels supplying the penis and the clitoris only</td>
</tr>
<tr>
<td>Lungs</td>
<td>Dilates the bronchioles (airways)</td>
<td>Constricts the bronchioles</td>
</tr>
<tr>
<td>Digestive Tract</td>
<td>Decreases motility (movement)</td>
<td>Increases motility</td>
</tr>
<tr>
<td></td>
<td>Contracts sphincters (to prevent forward movement of tract contents)</td>
<td>Relaxes sphincters (to permit forward movement of tract contents)</td>
</tr>
<tr>
<td></td>
<td>Inhibits digestive secretions</td>
<td>Stimulates digestive secretions</td>
</tr>
<tr>
<td>Urinary Bladder</td>
<td>Relaxes</td>
<td>Contracts (emptying)</td>
</tr>
<tr>
<td>Eye</td>
<td>Dilates the pupil</td>
<td>Constricts the pupil</td>
</tr>
<tr>
<td></td>
<td>Adjusts the eye for far vision</td>
<td>Adjusts the eye for near vision</td>
</tr>
<tr>
<td>Liver (glycogen stores)</td>
<td>Glycogenolysis (glucose is released)</td>
<td>None</td>
</tr>
<tr>
<td>Adipose Cells (fat stores)</td>
<td>Lipolysis (fatty acids are released)</td>
<td>None</td>
</tr>
<tr>
<td>Exocrine Glands</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exocrine pancreas</td>
<td>Inhibits pancreatic exocrine secretion</td>
<td>Stimulates pancreatic exocrine secretion (important for digestion)</td>
</tr>
<tr>
<td>Sweat glands</td>
<td>Stimulates secretion by sweat glands important in cooling the body</td>
<td>Stimulates secretion by specialized sweat glands in the armpits and genital area</td>
</tr>
<tr>
<td>Salivary glands</td>
<td>Stimulates a small volume of thick saliva rich in mucus</td>
<td>Stimulates a large volume of watery saliva rich in enzymes</td>
</tr>
<tr>
<td>Endocrine Glands</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adrenal medulla</td>
<td>Stimulates epinephrine and norepinephrine secretion</td>
<td>None</td>
</tr>
<tr>
<td>Endocrine pancreas</td>
<td>Inhibits insulin secretion</td>
<td>Stimulates insulin secretion</td>
</tr>
<tr>
<td>Genitals</td>
<td>Controls ejaculation (males) and orgasm contractions (both sexes)</td>
<td>Controls erection (penis in males and clitoris in females)</td>
</tr>
<tr>
<td>Brain Activity</td>
<td>Increases alertness</td>
<td>None</td>
</tr>
</tbody>
</table>
Fight-or-Flight Stories!

or

...choose this!!
Time for a break! 😊
Why are nerve & muscle unique?

They are excitable!!
Action Potentials ≡ Spikes ≡ Impulses

Ultra-short reversal of membrane potential
Only in nerve and muscle cells
Maintains strength over distance
Primary way nerves & muscles communicate!
"Resting"/Membrane Potential?

Cells are slightly negative inside!
Stimulate Cell @ Rest

Thermal

Mechanical

Electrical

Chemical
Tap! Tap!..
Changes Cell Membrane Permeability to Sodium/Na+!

+ Charges/Na+ Rushes In!
Action Potential has occurred!

Brief (1-2 ms) reversal to + inside cell!
Triggering event

Depolarization (decreased membrane potential)

Influx of Na$^+$ (which further decreases membrane potential)

Opening of some voltage-gated Na$^+$ channels

Mechanical
Chemical
Electrical
Thermal

Positive-feedback cycle!
= Action potential = After hyperpolarization

Na⁺ equilibrium

Threshold

Resting potential

K⁺ equilibrium

stimulus

1 msec

Time (msec)
Threshold

Resting potential

Caused by Na⁺ entry

Caused by K⁺ exiting

↑P_Na⁺, ↑P_K⁺

Membrane potential (mV)

Time (msec)

Threshold

Resting potential
**Synapse** = Generic term = connection between excitable cells!
Neuromuscular junction
= Nerve-muscle connection

H Howard 1980
Synapse Animation

http://outreach.mcb.harvard.edu/animations/synaptic.swf

NT Balance!

Uptake

Release

LS 2012 fig 4-14
Skeletal Muscles

Body systems maintain homeostasis

Homeostasis
Skeletal muscles contribute to homeostasis by playing a major role in the procurement of food, breathing, heat generation for maintenance of body temperature, and movement away from harm.

Homeostasis is essential for survival of cells

Cells make up body systems

Cells

LS 2012 ch 8 vignette
Muscle fiber or cylindrical cell

“Threads” ≡ Myofibrils

Nuclei

Dark-Light...bands ≡ Overlapping thick & thin filaments

x1000
Organ = Muscle → Cell = Myocyte = Fiber

Subcellular = Cytoskeleton

Molecules = Actin & Myosin

DC 2013 fig 12-3
Whole Muscle

Myocyte or Muscle Fiber

Myofibril

Thick & Thin Filaments

Myosin & Actin

Organ

Cell

Cytoskeleton

Molecules
**Golf Club Analogy?**

(a) Actin binding site
Myosin ATPase site

(b) Cross bridges
Myosin molecules

LS 2006, cf:
LS 2012 fig 8-4
Broccoli Analogy?

Myosin Heads

Myosin Tails

Bare Zone

Myosin Heads
Actin molecules

Actin helix

Tropomyosin

Troponin

Thin filament

Triad $\equiv$ T tubule abutting cisternae

Mitochondria

Sarcomere

Myofibril
A Band = Dark Band
Anisotropic = Light Can’t Shine Through

I Band = Light Band
Isotropic = Light Can Shine Through
What do we guess happens at the molecular level?
Cross-Bridge Cycle

1. Energized
   - Energy ADP P_i
   - No Ca++

2a. Binding
   - Ca++ present (excitation)

2b. Resting
   - Energy ADP P_i

3. Bending (power stroke)
   - Fresh ATP available
   - Energy ADP P_i
   - No ATP (after death)

4a. Detachment
   - ATP (Mg++)

4b. Rigor complex
Relaxed: No Cross-Bridge Binding

(a) Relaxed

1. No excitation.

2. No cross-bridge binding because cross-bridge binding site on actin is physically covered by troponin–tropomyosin complex.

3. Muscle fiber is relaxed.
Excited: Calcium Triggers Cross-Bridge Binding

(b) Excited

1. Muscle fiber is excited and $\text{Ca}^{2+}$ is released.

2. Released $\text{Ca}^{2+}$ binds with troponin, pulling troponin–tropomyosin complex aside to expose cross-bridge binding site.

3. Cross-bridge binding occurs.

4. Binding of actin and myosin cross bridge triggers power stroke that pulls thin filament inward during contraction.
Rope Climb or Tug of War
Grasp, then Regrasp!
Summary
We are almost there!
1. Acetylcholine released by axon of motor neuron crosses cleft and binds to receptors/channels on motor end plate.

2. Action potential generated in response to binding of acetylcholine and subsequent end plate potential is propagated across surface membrane and down T tubules of muscle cell.

3. Action potential in T tubule triggers Ca\(^{2+}\) release from sarcoplasmic reticulum.

4. Calcium ions released from lateral sacs bind to troponin on actin filaments; leads to tropomyosin being physically moved aside to uncover cross-bridge binding sites on actin.

5. Myosin cross bridges attach to actin and bend, pulling actin filaments toward center of sarcomere; powered by energy provided by ATP.

6. Ca\(^{2+}\) actively taken up by sarcoplasmic reticulum when there is no longer local action potential.

7. With Ca\(^{2+}\) no longer bound to troponin, tropomyosin slips back to its blocking position over binding sites on actin; contraction ends; actin passively slides back to original resting position.

LS 2006 cf: LS 2012 fig 8-10
Relaxation Phase

1. Excitation by nerve fiber
2. Conduction by T-tubules
3. Ca^{2+} release by SR

Contractile Phase

D Liang & VP
Lombardi 1989