1. Intro Nervous System Fxn (slides 32-60 from Mon 28 Jan; Ch10)
2. Neurons & Action Potentials (Ch11) (slides in this file)

http://eebweb.arizona.edu/eeb_course_websites.htm

Housekeeping, 30 January 2008

Upcoming Readings

today: Ch 10&11
LAB Wed 30 Jan: Bisbal & Specker, plus two optional papers
(see website for links to papers; “worksheet” via email)
Fri 01 Feb: Ch11
Mon 04 Feb: Ch 12, Slowinski article

Lab discussion leaders: 30 Jan
1pm – Josh, Seth
3pm – Aaron, Adam

Lab discussion leaders: 06 Feb
1pm – Rittner, Whitney
3pm – Roxanne, Maria
1. Neurons & Action Potentials

Changing Membrane Potentials…

(c) Membrane resistance and capacitance

channels

membrane bilayer

Hill et al. 2004, Fig 11.5c
**Membrane Potentials and Electricity**

Conductance = reciprocal of resistance

\[ \text{deltaV} = \text{IR} \]
Change in Voltage = current x resistance

- **Tau** = time constant
- (2 - 20 ms)
- (time to reach 63% max)

Current from + to –
(follow cations)
Hill et al. 2004, Fig 11.6a,b

Lambda = length constant
(distance at which 37% voltage change)

Hill et al. 2004, Fig 11.6c
Nervous System

Synapse
- Presynaptic
- Postsynaptic

1 Sensory Neurons
receive stimuli

2 Interneurons
entirely in CNS

3 Motor Neurons
effector organs
 incl. muscle, gland
- Presynaptic
- Postsynaptic

Action Potential

All-or-None from
spike-initiating zone

- Changes in ion
 permeability...
- Changes in membrane
 potential

-Voltage-gated ion channels
 vs. ligand-gated

- Na⁺, K⁺, (Ca²⁺)
**Action Potentials**

- Moves information; high-speed communication

- Thoughts, Sensations, Memories, Movements etc.

- Moves SIGNAL without decrement

- AP possible because:
  1. Ionic gradients across membrane
  2. Creates electrochemical gradient and therefore source of potential energy
  3. When ion channels open, ions move down their electrochemical gradients and rapidly change the membrane potential ($V_m$)

- Na+ and K+ responsible for AP character...
- Threshold
- Voltage gated
- Many channels for Na+
- Then many channels for K+
- +60 vs. -100 emf

Membrane Potential

Terms:
- Hyperpolarization 1 and 2
- Depolarization 3 and 4
- Threshold Potential see 4 (50% time get AP)
- Repolarization 3 and 4
(a) An action potential

<table>
<thead>
<tr>
<th>Channel</th>
<th>Current through channel</th>
<th>Characteristics</th>
<th>Selected blockers</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leak channel (open in resting axon)</td>
<td>$I_{K}^{(leak)}$</td>
<td>Produces relatively high $I_{K}$ in resting cell</td>
<td>Partially blocked by tetraethylammonium (TEA)</td>
<td>Largely responsible for $V_{Na}$</td>
</tr>
<tr>
<td>Voltage-gated Na(^+) channel</td>
<td>$I_{Na}$</td>
<td>Rapidly activated by depolarization, inactivated at $V_{Na}$</td>
<td>Tetrodotoxin (TTX)</td>
<td>Produces rising phase of AP</td>
</tr>
<tr>
<td>Voltage-gated Ca(^{2+}) channel</td>
<td>$I_{Ca}$</td>
<td>Activated by depolarization but more slowly than Na(^+) channel; inactivated as function of cytoplasmic $[Ca^{2+}]$ or $V_{Na}$</td>
<td>Verapamil, D600, $Ca^{2+}$, $Cd^{2+}$, $Mg^{2+}$, $Ni^{2+}$, $La^{3+}$</td>
<td>Produces slow depolarization that allows Ca(^{2+}) to enter the cell, where it can act as a second messenger</td>
</tr>
<tr>
<td>Voltage-gated K(^+) channel (delayed rectifier)</td>
<td>$I_{K(V)}$</td>
<td>Activated by depolarization but more slowly than Na(^+) channel; inactivated slowly and not completely if $V_{Na}$ remains depolarized</td>
<td>Intra- and extracellular TEA, amino/glycylides</td>
<td>Carries current that rapidly repolarizes the membrane to terminate an AP</td>
</tr>
<tr>
<td>Ca(^{2+})-dependent K(^+) channel</td>
<td>$I_{CaK}$</td>
<td>Activated by depolarization plus elevated cytoplasmic $[Ca^{2+}]$; remains open as long as cytoplasmic $[Ca^{2+}]$ is higher than normal</td>
<td>Extracellular TEA</td>
<td>Carries current that repolarizes the cell following APs based on either Na(^+) or Ca(^{2+}) and that balances $I_{Na}$, thus limiting depolarization by $I_{Ca}$</td>
</tr>
</tbody>
</table>

Table 5-1 Examples of ion channels found in axons

Randall et al. 2002
Action Potential

Hill et al. 2004, Fig. 11.12
Voltage-gated Na+ channels

local current flow causes Vm change

AP is regenerative

Hodgkin Cycle (~Feed Forward)

Initial depolarization

(a)

Further membrane depolarization

(c)

Opening of voltage-gated Na+ channels increases $P_{Na}$

(b)

Increased Na+ flow

Hill et al. 2004, Fig. 11.13
- Refractory Periods

- Absolute
- Relative

≈ Toilet Analogy...

Voltage-gated Na+ channels

Closed

Inactive

Open

Voltage - top

Current - bottom
How would you make the membrane in the axon hillock/spike initiation zone more, or less, likely to send an AP?
(c) Subthreshold responses and action potentials

Hill et al. 2004, Fig. 11.11

Silverthorn 2001. 2nd ed. Human Physiology. Prentice Hall
- Role of local current flow

(no APs past here)

- But can see local graded potential diminishing
- Receptor potential is graded and decremental

- Magnitude of graded receptor potential determines frequency of APs (~all of the same size)

- Neurotransmitter Release

- Alternate between graded pspS and all-or-none APs

\[ \text{ PSP = postsynaptic potential} \]
EPSP and IPSP

Excitatory or Inhibitory Postsynaptic Potentials

Graded current causing graded potential:

Integration

Hill et al. 2004, Fig 12.5
How can you have IPSP where \( E_x \) greater (more +) than \( V_{\text{rest}} \)?

Reversal Potential

Opening channel for a given ion species \( X \) means \( V_m \) will move toward \( E_x \)

\( E_{\text{rev}} \) is the reversal potential

Can’t change membrane potential beyond \( E_{\text{rev}} \) for a given ion(s) and its channels

Use Nernst to calculate for one ion species

Goldman equation for multiple ions

ACh opens for K+ and Na+, so \( E_{\text{rev}} \) between \( E_K \) and \( E_{Na} \)

EPSP and IPSP
Synaptic Efficacy

e.g., Cl⁻, K⁺ or alter Ca²⁺

NT release via exocytosis: the role of Ca²⁺
Presynaptic inhibition

GLIAL:
- Schwann cells in peripheral nerves
- Oligodendrocytes in CNS
- How increase conduction velocity?

1 - Diameter

2 - Insulation

- Long axons require insulation (support cells) and glial cells for myelination (fatty tissue) aka:

- Schwann cells in peripheral nerves
- Oligodendrocytes in CNS
longitudinal current vs. cross membrane

### Table 6-1

<table>
<thead>
<tr>
<th>Fiber type</th>
<th>Average axon diameter (µm)</th>
<th>Conduction velocity (m·s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Myelinated fibers</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aα</td>
<td>18.5</td>
<td>42</td>
</tr>
<tr>
<td>Aβ</td>
<td>14.0</td>
<td>25</td>
</tr>
<tr>
<td>Aγ</td>
<td>11.0</td>
<td>17</td>
</tr>
<tr>
<td>B</td>
<td>Approximately 3.0</td>
<td>4.2</td>
</tr>
<tr>
<td><strong>Unmyelinated fibers</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>2.5</td>
<td>0.4–0.5</td>
</tr>
</tbody>
</table>

Source: Erlanger and Gasser, 1937. Randall et al. 2002

Multiple sclerosis caused by demyelination