1. Synapses (Ch12)
2. Sensory Systems (Ch13)

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

Housekeeping, 06 February 2008

Upcoming Readings

today: Ch13
(see website for links to papers; "worksheet" via email)
Fri 08 Feb: Ch13
Mon 11 Feb: Ch13
Wed 13 Feb: Ch13
LAB Wed 13 Feb: none
Fri 15 Feb: Exam 1, through Ch13

Lab discussion leaders: 20 Feb
1pm – Virsheena, Matthew S. Arturo
3pm – Kat, Clif, Amber

Lab discussion leaders: 06 Feb
1pm – Rittner, Whitney
3pm – Roxanne, Maria
The Edges of Life

Wednesday, February 6
Life's Final Edge: The Origin and Extinction of Species in a Human-Dominated Earth
Michael Rosenzweig, Professor, Ecology and Evolutionary Biology
Today, Earth's treasury of species, its biodiversity, faces an existential challenge and its outcome depends on man. Science now knows we've taken away enough land from nature to precipitate a mass extinction like the one that exterminated the dinosaurs 65 million years ago. Using reconciliation ecology, we can prevent this - and preserve life.

Wednesday, February 13
Life's Cognitive Edge: The Role of the Mind and What it Means to be Human
Anna Dornhaus, Assistant Professor, Ecology and Evolutionary Biology
Our human mind distinguishes us from other animal life-or does it? Recent research has revealed culture and social learning, tool use, complex communication, self-recognition, and planning for the future are not unique to the human experience. With these new findings, science is finally getting closer to understanding exactly what makes us human.

Wednesday, February 20
Life's Human Edge: Changing Perspectives on the End of Life
Michael Gill, Associate Professor, Philosophy
Nothing looms with more certainty than the final edge of one's own life. But in fact, the edge between life and death is anything but clear. This lecture will address the attempts that have been made to define the line between life and death and will explore the biological, legal, ethical, and spiritual debates that have raged around that line.

Wednesday, March 5
Life's Technological Edge: The Singularity is Near: When Humans Transcend Biology
Ray Kurzweil, via Teleportec Teleporter
Founder, Chairman and Chief Executive Officer, Kurzweil Technologies
Humanity is on the edge of a vast transformation, when what it means to be human will be both enriched and challenged. Inventor and futurist Ray Kurzweil will introduce this radically optimistic singularity, an era when we break our genetic shackles to create a nonbiological intelligence trillions of times more powerful than today. In this new world, humans will transcend biological limitations to achieve entirely new levels of progress and longevity.

These do not count as physiology lectures.
**TABLE 12.3** Ionotropic and metabotropic receptors: Structural, functional, and mechanistic differences

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Ionotropic receptors</th>
<th>Metabotropic receptors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Receptor molecule</td>
<td>Ligand-gated channel receptor</td>
<td>G protein–coupled receptor</td>
</tr>
<tr>
<td>Molecular structure</td>
<td>Five subunits around an ion channel</td>
<td>Protein with seven transmembrane segments; no channel</td>
</tr>
<tr>
<td>Molecular action</td>
<td>Open ion channel</td>
<td>Activate G protein; metabolic cascade</td>
</tr>
<tr>
<td>Second messenger</td>
<td>No</td>
<td>Yes (usually)</td>
</tr>
<tr>
<td>Gating of ion channels</td>
<td>Direct</td>
<td>Indirect (or none)</td>
</tr>
<tr>
<td>Type of synaptic effect</td>
<td>Fast EPSP or IPSP</td>
<td>Slow PSPs; modulatory changes (in channel properties, cell metabolism, or gene expression)</td>
</tr>
</tbody>
</table>

(a) Topology of voltage-gated Na⁺ channels

Hill et al. 2004, Fig. 11.17

(b) Surface view of a Na⁺ channel

(c) Voltage-dependent conformational change
4 different domains

4 identical subunits

Voltage-gated channel superfamily

Proposed Evolution

Voltage-gated Channels

Hill et al. 2004, Fig. 11.18

Hill et al. 2004, pg. 301
Neurotransmitters:

1. **small-molecule neurotransmitters**  
   (often made in axon terminals; common)

2. **neuroactive peptides**  
   (often made in soma and shipped down axon)

Nematodes use a lot of the same neurotransmitters.

**TABLE 12.2** Some neurotransmitters and receptors of vertebrate central nervous systems  
These lists are not exhaustive; there are more neurotransmitters, and more receptors for each transmitter.

<table>
<thead>
<tr>
<th>Neurotransmitter</th>
<th>Receptor class</th>
<th>Direct/indirect</th>
<th>Indirect/metabotropic</th>
<th>Common mode of action</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Amines</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acetylcholine</td>
<td>Nicotinic</td>
<td>X</td>
<td>X</td>
<td>EPSP</td>
</tr>
<tr>
<td>Dopamine</td>
<td>M2, M3</td>
<td>X</td>
<td>X</td>
<td>G protein → IPSP</td>
</tr>
<tr>
<td>Norepinephrine</td>
<td>α1,2,3</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Serotonin</td>
<td>5HT1, 5HT2</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>5HT2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Amino acids</strong></td>
<td>(abundant and widespread)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glutamate</td>
<td>AMPA</td>
<td>X</td>
<td>X</td>
<td>EPSP</td>
</tr>
<tr>
<td>Glycine (IPSP)</td>
<td></td>
<td></td>
<td></td>
<td>G protein → IPSP IPSP</td>
</tr>
<tr>
<td>GABA (IPSP)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peptides</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Synaptic Plasticity

• Change synaptic efficacy
• Alter rate of NT production and release

• Learning and Memory

• Facilitation vs. antifacilitation/depression
• Retrograde messengers (i.e., NO)
• Calcium-dependent
  - Research on-going

Hill et al. 2004
Fig 12.24

1. Change $V_m$
2. ↑ calcium influx
3. ↑ # NT vesicles

Sensitization (facilitation) mediated by serotonin
Long-term Potentiation

• Often in Hippocampus  
  - Site of Learning and Memory

• “Neurons that fire together wire together”

• NMDA glutamate receptors...

NMDA = N-methyl-D-aspartic acid

Hill et al. 2004, Fig 12.27

Long term potentiation (LTP)

• NMDA glutamate receptors
  • role of Mg2+
  • voltage-dependent
Genetic engineers upregulated production of juvenile subunit of NMDA receptor in adult mice (Doogie mice).

Ethical?

Should we do this in humans or other animals?

Under what conditions?
Sensing the Environment

Sensory Reception
- Environment
- Within body

Integrated and Processed by NS

Sensory Receptors send signals to brain so perceive sensations

Sensory Receptor cells often organized into organs

Properties of Receptor Cells

Sensory Modality

Modalities include:
vision, hearing, touch, taste, smell, chemical, thermal, proprioceptors

Qualities within each modality
- e.g., Red or yellow;
  High or low-pitched
TABLE 13.1 Classification of sensory receptors, based primarily on the kind of stimulus energy that excites them (Part 1)

<table>
<thead>
<tr>
<th>Stimulus energy</th>
<th>Receptor modality</th>
<th>Stimulus perceived</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electromagnetic</td>
<td>Photoreceptors</td>
<td>Visible light</td>
<td>Some animals detect the polarity of visible and ultraviolet light</td>
</tr>
<tr>
<td>energy</td>
<td></td>
<td>Ultraviolet light</td>
<td>Infrared detection may be thermal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Infrared radiation</td>
<td></td>
</tr>
<tr>
<td>Electroreceptors</td>
<td>Electrical field</td>
<td>Electrical field</td>
<td>Animals may sense polarity or angle of inclination of magnetic lines of force (see Chapter 16)</td>
</tr>
<tr>
<td></td>
<td>or charge movement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Magnetoreceptors</td>
<td>Earth's magnetic</td>
<td>Earth's magnetic</td>
<td></td>
</tr>
<tr>
<td></td>
<td>field</td>
<td>field</td>
<td></td>
</tr>
<tr>
<td>Thermal energy</td>
<td>Thermoreceptors</td>
<td>Hot</td>
<td>&quot;Infrared receptors&quot; of rattlesnakes are actually sensitive heat receptors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cold</td>
<td></td>
</tr>
<tr>
<td>Chemical energy</td>
<td>Chemoreceptors</td>
<td>Olfactory stimuli</td>
<td>Chemical source is distant</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(distance chemoreceptors)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Taste (contact chemoreceptors)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Internal chemoreceptors</td>
<td></td>
</tr>
<tr>
<td>Mechanical energy</td>
<td>Mechanoreceptors</td>
<td>Touch, pressure</td>
<td>Internal chemoreceptors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Muscle length</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Muscle tension</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Joint position and movement</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sound (auditory stimuli)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Balance and acceleration</td>
<td></td>
</tr>
<tr>
<td>Osmoreceptors</td>
<td>Osmotic pressure</td>
<td>Osmotic pressure</td>
<td>Receptors detect mechanical stresses of osmotic swelling, etc.</td>
</tr>
</tbody>
</table>

Transduction

- Stimulus reaches receptor cells
- Receptor protein is activated
- Cascade of protein interactions modifies intracellular second messengers
- Ion channels open (or close)
- Change in conductance produces a receptor current
- Receptor current changes \( V_n \)

Amplification

- Change in \( V_n \) spreads electronically to spike-initiating zone
- Number and/or frequency of APs conducted along the axon changes
- Amount of transmitter released from receptor cell changes
- Number and/or frequency of APs conducted along axon of afferent neuron changes

Graded events

- All-or-none APs

7.5 Randall et al. 2002
Mechanisms and Molecules

Enzymatic Cascade to amplify

Threshold of Detection
- e.g., 1 photon or hair cell
  movement of H diam.

Sour (pH; H+) and salt (Na+)
move directly – no amplification

To measure quality need many receptors grouped into organ; different ‘tunage’ (e.g, wavelength of light or frequency of sound)

Enhancing Sensitivity

- Efferent Control
- e.g., stretch receptors in muscle
  control length so can perceive stretch

- Feedback Inhibition
  Auto (helps keep in dynamic range)
  vs.
  Lateral...
Properties of Receptor Cells

**Receptor Cells**
- Specialized
- Selective for energy type and modality
- either is a neuron or Synapses immediately on a neuron

*(1° afferent neuron to CNS)*

Stimulus modifies conformation of receptor

**Transduction**
Stimulus energy converted to nerve impulse

**Example**
Mechanoreceptors (touch)

1- Proteins respond to membrane distortion
2- Ion channels opened directly or indirectly
3- Current flows across membrane *(often Na⁺)*
4- Vm changes (aka receptor potential changes)
5- Signal often amplified
6- AP sent or NT released causing AP
Mechanisms and Molecules

Sensory Adaptation
- orders of magnitude different stimulus strength
- often controlled via Ca++ availability
- local control or feedback from CNS

Type of stimulus received depends on where in CNS (~brain) AP arrives (LABELED LINES).

Rub eyes and see light!

Intensity signalled by frequency of APs, but...

Stimulus Intensity and Dynamic Range
From lowest threshold, to upper limit imposed by refractory period:

Note log axis
Dynamic Range

Shifting range of appropriate AP frequency
Detectable light intensity varies over 9 orders magnitude
Detectable sound intensity varies over 12 orders magnitude

Range Fractionation
- Function of sensory adaptation
- Also recruit receptors with different ‘tunage’ or sensitivity (e.g., rods and cones in eye)

Sensory Adaptation Possibilities:

1. Receptor cell mechanical properties may filter
2. Receptor cells may be depleted (e.g., visual pigments; need to be regenerated)
3. Enzyme cascade (during amplification) may be inhibited by (intermediate) product
4. Electrical properties change b/c $\uparrow$ [Ca++]
5. Accommodation of spike initiating zone
6. Sensory adaptation in downstream neurons (CNS)
- Accommodation

Enhancing Sensitivity

- Spontaneous basal activity
- Constant rate of APs
- Directionality if $\uparrow$ or $\downarrow$ AP frequency
Tonic vs. Phasic receptors

(a) Phasic response

(b) Tonic response

Hill et al. 2004, Fig 13.5

Randall et al. 2002
Sensory Adaptation; Pacinian Corpuscle - Touch Example

Movement of Oil between layers is what triggers APs
Signal changes in pressure, not steady pressure

7-10 Randall et al. 2002

Star-Nosed Mole
(↑ # neurons, ↑ subtlety)
(receptor field size?)
External Chemoreception (Taste and Smell)

- **Taste**
  - direct contact

- **Smell**
  - distant signal source

- **Chemoreception** very sensitive

  - *Bombyx* moth antenna example:

    Male responds to female pheromone at low \[ \] of 1 molecule in \( 10^{17} \)!

---

**Taste Chemoreception**

- **Taste**

  Usually oral cavity
  Some fish fins!

  4-5 qualities:
  1. Salt
  2. Sour
  3. Sweet
  4. Bitter
  5. **Umami**
     ("savory" or "meaty")

**Differing Receptor Properties**
Taste

- microvilli
- basal cells give rise to new receptor cells every **10 days**
Taste

- Quasi Labelled lines
- multiple receptor types/neuron

Facial nerve

<table>
<thead>
<tr>
<th>Type</th>
<th>Type A</th>
<th>Type B</th>
<th>Type C</th>
<th>Type D</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>20</td>
<td>42</td>
<td>17</td>
<td>1</td>
</tr>
</tbody>
</table>

Chorda tympani nerve

<table>
<thead>
<tr>
<th>Type</th>
<th>Type A</th>
<th>Type B</th>
<th>Type C</th>
<th>Type D</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>20</td>
<td>42</td>
<td>17</td>
<td>1</td>
</tr>
</tbody>
</table>

Glossopharyngeal nerve

<table>
<thead>
<tr>
<th>Type</th>
<th>Type A</th>
<th>Type B</th>
<th>Type C</th>
<th>Type D</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>8</td>
<td>4</td>
<td>52</td>
<td>19</td>
</tr>
</tbody>
</table>

- Sucrose (sweet)
- NaCl (salty)
- HCl (sour)
- Quinine (bitter)
Smell

Smell/ Olfaction

- 1 Nasal Cavity
- turbinates (↑s.a.)

- 2 Vomeronasal organ
- usually conspecific communication
Smell/ Olfaction

-Nasal and Vomeronasal:

- Epithelial tissue origin
  - Cilia or Microvilli covered in mucus
- Receptor proteins with 7-transmembrane helices
  - Coupled to G-protein cascade

---

Smell/ Olfaction

- Nasal and Vomeronasal:

- Thousands of receptor proteins (general & special)
  - but different for nasal and vomeronasal
- Receptor cells contain axons
  - Glomeruli in olfactory bulb/accessory olfactory bulb

---
Sensory neurons (~ odor specific)

Olfactory bulb (info processing in brain)

Glomeruli (similar odor receptor synapses)

Mucus from epithelial glands
Olfactory Neurons

In humans, $10^7$ olfactory receptor neurons

In dogs, $2 \times 10^8$

Human auditory nerve: $10^4$
Human optic nerve: $10^5$