2. Sensory Processes/Systems

Chapter 12

1. Synapses, Neurotransmitters

Chapter 13

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1. Synapses, Neurotransmitters

Frequency and number!
SYNAPSES
- Communication between neurons or between neuron and effector organ

1-electrical (rapid)
2-chemical ('fast' or slow)

In postsynaptic neuron:
1. De- or hyper-polarize
2. Change # ion channels in membrane
3. Alter rate of ion channel activity
4. Modify sensitivity to activation signals

Electrical Synapse (rapid)
- Direct ionic coupling via gap junctions
- Examples in retina, CNS, smooth muscle, cardiac muscle, etc.

Agonist (mimics)
(e.g., heroin mimics natural opiates)

vs.

Antagonist (blocks)
(e.g., curare blocks ACh reception)

Chemical

1. Amplify
2. Excitatory or inhibitory
3. One-way
4. Modifiable

Electrical

Role of Ca

- Ionotropic
- Metabotropic
Postsynaptic Neurotransmitter Effects

NT role depends primarily on receptor characteristics on postsynaptic neuron

**e.g., ACh receptors**

1. Fast and direct
   1. Nicotinic (muscles, autonomic/sympathetic NS)
2. Slow and indirect
   2. Muscarinic (parasympathetic, indirect)

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**TABLE 12.1 Kinds of synapses**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Ionotropic</th>
<th>Metabotropic</th>
<th>Electrical synapse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanism and time course</td>
<td>Fast, ionotropic</td>
<td>Slow, metabotropic</td>
<td>Instantaneous current flow</td>
</tr>
<tr>
<td>Function effect</td>
<td>Signal transmission</td>
<td>Neuronal modulation</td>
<td>Electrical transmission</td>
</tr>
<tr>
<td>e.g., ACh receptors</td>
<td>Excitation (fast EPSP)</td>
<td>Excitation (slow EPSP)</td>
<td>Electrical coupling</td>
</tr>
</tbody>
</table>

*IPSP = inhibitory postsynaptic potential, EPSP = excitatory postsynaptic potential.

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**Postsynaptic Neurotransmitter Effects**

**e.g., indirect, metabotropic muscarinic ACh receptors acting to reduce heart cell excitability**
Postsynaptic Neurotransmitter Effects

1. Fast and direct e.g., fast nicotinic ACh receptors

Neuromuscular Junction

Nicotinic ACh receptor

Hill et al. 2004, Fig 12.16

Neurotransmitters:

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

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

Nematodes use a lot of the same neurotransmitters.
Synaptic Plasticity

- Change synaptic efficacy
- Alter rate of NT production and release
- Learning and Memory
- Facilitation vs. antifacilitation/depression
- Calcium-dependent
  - Research on-going

Long-term Potentiation

- Hippocampus
- Learning and Memory
- "Neurons that fire together wire together"
- NMDA glutamate receptors

Sensing the Environment

Sensory Reception
- Environment
- Within body
- Integrated and Processed by NS

Sensory Receptors send signals to brain so we 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

Hill et al. 2004, Fig 12.27
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Chapter 13
2. Sensory Processes/Systems

Doogie Mice?
Properties of Receptor Cells

- Specialized
- Selective for energy type and modality
- either is a neuron or
- Synapses immediately on a neuron
(1\textsuperscript{st} 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- Signal often amplified
3- Ion channels opened directly or indirectly
4- Current flows across membrane (often Na\textsuperscript{+})
5- Vm changes (aka receptor potential changes)
6- AP sent or NT released causing AP

Mechanisms and Molecules

Sensory Adaptation
- orders of magnitude different stimulus strength
- often controlled via Ca\textsuperscript{++} 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 $\uparrow [\text{Ca}^{++}]$
5. Accommodation of spike initiating zone
6. Sensory adaptation in downstream neurons (CNS)

Sensory Adaptation; Pacinian Corpuscle - Touch Example

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

Mechanisms and Molecules  
Lots of Evolutionarily Conserved Elements  
e.g., 7 transmembrane helices and G-protein intermediate  
e.g., Vision, olfaction, sweet and bitter taste (also muscarinic ACh receptors and many hormone receptors)

Mechanisms and Molecules  
Enzymatic Cascade to amplify  
Threshold of Detection  
e.g., 1 photon or hair cell movement of H diam.  
Sour ($\text{pH}+\text{H}^+$) and salt ($\text{Na}^+$) 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**
- Spontaneous basal activity
- Constant rate of APs
- Directionality if ↑ or ↓ AP frequency

**Tonic vs. Phasic receptors**
- Fast-adapting
- Slow-adapting

**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...

**Vision**
**FOCUS**
- light is focused by cornea to create an image on the retina
- refraction by cornea (85%) and by lens (15%)
- alter focal length by altering shape and curvature of lens
  (zonular fibers and ciliary muscle "sphincter")
- binocular convergence (both eyes on same part of retina)

**LIGHT INTENSITY**
- pupil for variable aperture via iris and radial muscle
Vision

- Receptor Cells
  - Rods: Dim light, low resolution
  - Cones: Bright light, high resolution

ANATOMY
- Sclera: White tough outer layer
- Choroid: Lots of blood vessels
- Pigment layer: With photoreceptors
- Fovea: Where highest acuity and highest number of cones

TRANSDUCTION
- Photoreceptors (rods and cones): Transduce photons (light) into electrical signal
- Rhodopsins (visual pigments):
  - Opsin (7-transmembrane lipoprotein)
  - Retinal (absorbs photon)
Rhodopsins (visual pigments) - located in stacked lamellae

Membranes hyperpolarize in response to light

When light hits, the Na+ current into the cell is stopped and membrane hyperpolarizes, stopping release of NT

Bleaching of retinal photoreceptors

Photoreceptors called cones respond to particular wavelengths of light. Their response involves “bleaching” of their responsive pigment, so that for some seconds they are unable to respond again.

Expectation after 15 seconds?

Rhodopsin mechanism:

cis-trans isomerization of retinal molecule

Changes conformation of opsin molecule and therefore initiates transduction

Activated retinal changes conformation of opsin molecule (opsin and retinal separate) and initiates transduction

Need to reconstitute the rhodopsin (night blindness)
Rod and Cone details

**Action spectrum** (where absorb light)
3 (e.g., humans, fish)-5 (e.g., birds) different photopigments

Different opsins, same retinal

Porphyropsins (different retinal) seem better than rhodopsins in freshwater

Sensitivity vs. Acuity

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Physiology Players

**Theatre**

-2 competing casts
-judge(s)
-accuracy
-enthusiasm

**Actors:**
1. Photon 4. Transducin 7. Ion channel
2. Retinal 5. PDE 8. Cation (Na+)
3. Opsin 6. cGMP

**Act I**
Photon enters stage right. Other players assembled within or near membrane. ...photo transduction...
Dark current reduced as curtain closes.