THE AUDITORY SYSTEM

Ralph Adolphs
### Read

| Chapter 30 & 31 | Auditory System (Adolphs) | **The auditory system**  
Anatomy: the ear, the brainstem, auditory cortex  
Details of middle ear, cochlea, transduction  
Audition is tonotopic (a map of the cochlea)  
Spatial audition requires making comparisons between the two ears  
Topography: there are centrally synthesized maps of auditory space  
There are special model systems (songbirds, owls, and bats) | Nov. 9 (today) |
| --- | --- | --- |
| Chapter 22: pp. 475-480, 491-495  
Chapter 23: pp. 498-504, 510-521  
Chapter 24: 530-535, 541-553 | Somatosensory System (Adolphs) | **Somatosensory system**  
There are many different kinds of touch/pain receptors and channels  
There are distinct spinal cord pathways for touch and pain  
Touch is somatotopic (a map of the body surface)  
Pain is represented in distributed brain regions  
Pain can be modulated, for instance by endogenous opioids | Nov. 11 |
| Discussion section | Sensory systems | Nov. 12 |
| Chapter 65, 66, 67 | Learning & Memory (Adolphs) | **Learning and Memory**  
There are multiple memory systems: declarative and nondeclarative  
There are stages of memory: encoding, consolidation, retrieval  
There are multiple physiological mechanisms implementing memory  
There are specific brain systems for different kinds of memory | Nov. 13 |
Sherrington (1948): senses classified as

--teloreceptive (vision, hearing)
--proprioceptive (limb position)
--exteroceptive (touch)
--chemoreceptive (smell and taste)
--interoceptive (visceral)
Anatomy of the auditory system
- peripheral
- central

Language

Model systems
Stages of Processing

1. Transduction
2. Perception (early)
3. Recognition (late perception)
4. Memory (association)
5. Judgment (valuation, preference)
6. Planning (goal formation)
7. Action
Similarities between audition and vision

- Processing streams
- Topographic maps
- Distortion/magnification
- Perception is inferential
- Perception makes comparisons
- Can be driven in the absence of sensory input
- Plastic periods in development
- Important role in social communication
## Differences between audition and vision

<table>
<thead>
<tr>
<th></th>
<th>Audition</th>
<th>Vision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transduction</td>
<td>Fast</td>
<td>Slow</td>
</tr>
<tr>
<td>Temporal Acuity</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Spatial Acuity</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Feedback</td>
<td>To cochlea</td>
<td>not to retina</td>
</tr>
<tr>
<td>Active sense</td>
<td>Somewhat</td>
<td>Very</td>
</tr>
<tr>
<td>Specializations</td>
<td>Language</td>
<td>Faces</td>
</tr>
<tr>
<td>Receptor Numb.</td>
<td>16k</td>
<td>100M</td>
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</tbody>
</table>
WHAT IS HEARING?

to know what is where by listening
Human listeners can:

--accurately judge the location of a sound and can tell the difference between sounds separated by a few degrees

--discriminate between two frequencies separated by 1-2 Hz over a range of nearly 10 Octaves

--discriminate between sounds with intensity differences of 1-2 dB over a range of $10^8$
Peripheral auditory system:
--external and middle ears and auditory nerve

Central auditory system:
brainstem, midbrain, and forebrain levels
(c) The middle ear

Ossicles:
- Malleus
- Incus
- Stapes

Tensor tympani muscle
Nerve to tensor tympani

Oval window
Tympanic membrane
Facial nerve
Branch to stapedius muscle
Stapedius muscle
Round window
Based on the properties of the basilar membrane, high frequency sounds localize to the cochlea base and low frequency sounds to the cochlea apex.

The Traveling Wave
Fibers in the 8th Nerve
- 95% from inner hair cells
- ~5% from outer hair cells
- Olivocochlear bundle
Hair Cells are Morphologically Polarized

- **Kinocilium**
- **Inhibition** → **Excitation**
- **Tip Links**
- **Stereocilium**
- **Rootlet**
- **Cuticular Plate**
- **Basal Body**
- **Excitation**
- **St**
- **K**
- **Afferent Nerve Fiber**
- **Efferent Nerve Fiber**
FUNCTIONAL POLARIZATION OF HAIR CELLS

K

Receptor potential

Nerve impulses

Depolarization

Hyperpolarization

Resting discharge

Increased firing

Resting discharge

Decreased firing

Resting discharge
RATE CODING

20 dB

30 dB

40 dB

50 dB

60 dB

70 dB

80 dB

Sound stimulus
TEMPORAL CODING IN THE AUDITORY NERVE
(Low frequency signals below about 4 kHz)

Action potentials

Low frequency sound
VOLLEY PRINCIPLE
(Low frequency below about 4 kHz)

Fiber 1

Fiber 2

Fiber 3

Fiber 4

Fiber 5

Fiber 6

Ensemble Output

Low frequency stimulus
Neural code:

- Rate
- Timing
- Place
MNTB – Medial Nucleus of the Trapezoid Body
- Inhibitory projections to the LSO

Output of LSO

Left LSO output

Right LSO output

70 40 20 0 -20 -40 -70

Left > right
Right > left

Relative loudness
Wernicke’s Area (left primarily) BA 22

Temporal pole

Temporal Visual Association Areas
Primary Auditory Cortex
BA 41, 42

Insula (not part of Temporal Lobe)
3 Model systems
Figure 31–14 Birdsong is learned through mimicry.

A. Distinct dialects of white-crowned sparrow song are recognizable in these sonograms of recordings from three locations on the northern California coast. Sonograms plot sound frequency against time, with amplitude indicated by density. Common structural elements such as whistles, buzzes, and trills differ in length and frequency in the dialects. Birds learn their dialect early in life from a local tutor, and develop some individual song features as well.

B. White-crowned sparrows raised without tutors sing isolate songs, which resemble normal sparrow song in duration and whistle-like features but are otherwise much simpler.

C. Songs of birds that were deaf before sensorimotor learning of song are even more abnormal than isolate songs. This is true whether the animals were tutored or not, so the abnormal song reflects the lack of auditory feedback as birds attempt to produce sounds. (Modified, with permission, from Marler 1970; modified, with permission, from Konishi 1985).
Figure 31–15 Song-selective neurons in the songbird brain.

A. A side view of the songbird brain illustrates some of the major components of the song system. The premotor nucleus HVC and robust nucleus of the arcopallium (RA) form the motor pathway for producing song. The RA motor nucleus projects to peripheral effectors that include the hypoglossal nucleus (nXII). The anterior forebrain pathway connects the HVC and RA through the rostral part of the brain, and includes the basal ganglionic nucleus area X, the medial nucleus of the dorsolateral thalamus (DLM), and the lateral magnocellular nucleus of the anterior nidopallium (LMAN), an outflow region that connects back to RA.

B. Peristimulus time histograms of recordings from an LMAN neuron in an adult zebra finch show that the neuron responds more vigorously to the bird’s own song than to a reversed version of the song or even to a conspecific song. The song is displayed beneath each histogram as a sonogram, or plot of frequency against time. Such song-selective neurons are found throughout the song system.

C. An LMAN neuron is much more sensitive to a complete song “abcdef” than to isolated components “abcd” or “ef”. In this panel the song is portrayed as an oscillogram, or plot of sound pressure against time. (Modified, with permission, from Doupe 1997)