The Auditory System

Reading:
BCP Chapter 11
Function of the Auditory System

The function of the auditory system is to perceive sounds (i.e., to localize and to identify sounds in space). Physical dimensions of sound relate to perceptual dimensions.

*Figure 1*

- **Amplitude**
  - Low
  - High
  - Physical Dimension: **Loudness**

- **Frequency**
  - Low
  - High
  - Physical Dimension: **Pitch**
Natural sounds are complex patterns of vibrations, but most consist of a harmonic sequence of tones (integer multiples of the fundamental).

Fourier analysis breaks a natural sound down into its component sine waves → the auditory system will do the same.
The Ear

Sound propagation:
• wave enters auditory canal
• strikes the eardrum (or tympanic membrane)
• ossicles (hammer, anvil and stirrup) vibrate
• oval window vibrates
• fluid in cochlea set in motion
• vibrations of fluid dissipated at round window
The cochlea is divided into three chambers (scala) by Reissner’s membrane and the basilar membrane. The auditory receptor apparatus, the organ of Corti, sits on the basilar membrane in the middle scala.
Motion of the Basilar Membrane

Pressure changes in the cochlea set up a traveling wave on the basilar membrane which peaks at one place for each frequency in the input.

The basilar membrane “performs” a Fourier analysis of the incoming sound waves by virtue of its biomechanical properties.
There are two types of hair cells (short receptors) in the organ of Corti:
- inner hair cells, ~3,500
- outer hair cells, ~14,000

All hair cells have stereocilia on their upper surfaces which are in or near the tectorial membrane.

Up-down motion of basilar membrane converted to side-to-side motion of stereocilia
Transduction and Transmission

Mechanotransduction: conversion of mechanical stimulus to an electrical receptor potential is direct.

Outer hair cells change length and augment basilar membrane motion.

Inner hair cells release transmitter onto axons of the auditory nerve (indirect transmission).
Like the cochlea, most structures of the auditory system are arrayed according to frequency (i.e., in a tonotopic manner).
The axons of auditory nerve fibers synapse in the cochlear nuclei on the same side (ipsilateral)

From there, projections lead to the superior olives on both sides of the brain stem (binaural)

Cochlear nuclei and superior olives → inferior colliculi → ipsilateral medial geniculate nuclei of the thalamus → ipsilateral primary auditory cortex
The auditory cortex is located in the temporal lobe.

The auditory cortex includes:
- a core (primary; A1) and
- up to 10 belt (secondary) regions

Each area appears to be organized on the basis of frequency (tonotopic).
Auditory Scene Analysis

Fan

Speech

Printer

![Graph showing frequency distribution with dB scale from 0.1 to 5 kHz]
Sounds located off the midline reach the two ears at different times and different intensities, creating interaural (between-the-ears) time (ITD) and level differences (ILDs).

The superior olive receives inputs from the two ears and responds to ITD and ILD cues in the medial (MSO) and lateral superior olive (LSO) nuclei, respectively. Thus, the superior olive computes an implicit map of space.
One small area just anterior to the primary auditory cortex has neurons that respond to pitch rather than frequency (responds to a stimulus even if the fundamental is missing).
Auditory signals are conducted to two areas of association cortex:
- Posterior parietal cortex
- Prefrontal cortex

Posterior vs Anterior:
- “where” vs “what”
- in register with visual pathways
Cortical Laterlization of Language

Numerous fMRI and PET studies of healthy volunteers engaging in various language-related tasks suggest that the brain mechanisms of language predominate in the left hemisphere.

The results above represent activity averaged over all trials and participants. At the individual level, areas of activity were patchy, variable from trial to trial, and widespread.
Cortical Localization of Language

Localization refers to the locations within a (the left) hemisphere that participate in language-related activities.

There are seven main areas of cortex thought to contribute to our ability to comprehend and to produce spoken and written language:
• primary auditory cortex;
• primary visual cortex;
• angular gyrus;
• Wernicke’s area;
• arcuate fasciculus;
• Broca’s area; and
• primary motor cortex.
In this model, spoken language (green) is processed by the auditory cortex, and then conducted to Wernicke's area, where its meaning is understood. A similar process occurs for written words (black), where information flows from the visual cortex to the angular gyrus (which translates the visual code into an auditory code) before passing to Wernicke's area. Then, if a response is necessary, Wernicke's area further translates thought processes into verbal responses, which are transmitted to Broca's area via the arcuate fasciculus. In Broca's area, this signal activates the appropriate programs that drive the neurons of the primary motor cortex and ultimately the muscles of articulation or of the hands.
Deficits in language and speech functions can be of numerous types:
• aphasias due to brain damage including …
  1. Wernicke-fluent-receptive-comprehension
  2. Broca-nonfluent-expressive-production
  3. conduction (arcuate fasciculus) – hallmark is inability to repeat unfamiliar words
• disorders due to genetic factors including …
  1. dyslexia (angular gyrus) – reading difficulty
  2. verbal dyspraxia (Broca) – impaired speech

Genetic linkage analyses have implicated mutations in the gene KIAA0319 (6p22.3) with dyslexia. This gene (expressed selectively in and around the angular gyrus) is thought to be critical for neuronal migration during development as well as normal function of adult neurons.

Genetic linkage analyses have implicated mutations in the gene FOXP2 gene (7q31) with verbal dyspraxia. This gene encodes a transcription factor that appears to effect the development (grey matter density) of Broca’s area, the motor cortex, basal ganglia and cerebellum.