

The Human Auditory System

Music 175: Ear Physiology

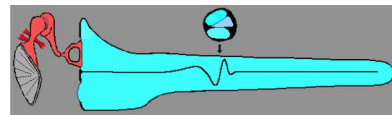
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- Hearing is accomplished via **auditory transduction**:

the ear *converts* sound waves into electrical impulses that are interpreted by the brain.

- the ear processes acoustic pressure by transforming it into mechanical vibrations on the *basilar membrane*.
- the pattern of these vibrations is represented by a series of pulses to be transmitted by the auditory nerve (to the brain).



see animation

- Sound interpretation or “signal processing” in the auditory system is done by BOTH the
 1. ear (peripheral auditory organs) AND
 2. brain (auditory nervous system).

1

Music 175: Ear Physiology

2

The Human Auditory System

- The Human Auditory System Consists of
 1. the Outer ear
 2. the Middle ear
 3. the Inner ear

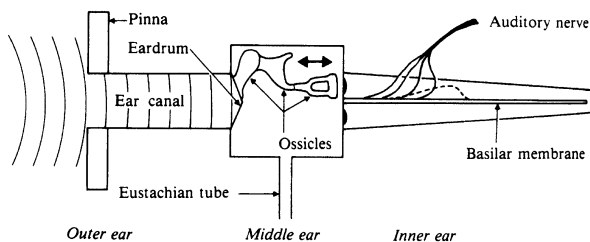


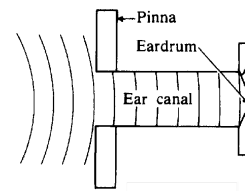
Figure 1: A schematic of the outer, middle, and inner ear (illustrations of the latter two have been enlarged) (from Rossing p. 81).

Music 175: Ear Physiology

3

The Outer Ear

- The outer ear consists of the *pinna*, the *auditory canal*, and the *tympanic membrane (eardrum)*.



- The *pinna*
 - “collects” sound and funnels to the ear canal;
 - acts as a *filter* helping us localize sounds.
- The *auditory canal*
 - acts as an acoustic tube closed at one end;
 - boosts hearing sensitivity in the range 2000-5000 Hz (the range of the human voice).
- The *tympanic membrane*
 - terminates the auditory canal;
 - vibrates in response to the produced sound.

Music 175: Ear Physiology

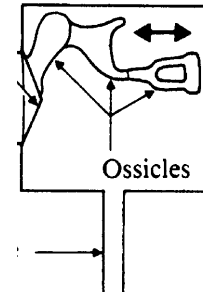
4

Sound in the Outer Ear

- The intensity of the sound in the auditory canal is dependent on
 - direction of sound reaching listener;
 - shoulders: can reflect sound toward the pinnae;
 - head: can cast an acoustical shadow;
 - pinna: “guiding” filtering effect increases with increasing frequency (though at high frequency rises and falls).
- Effects of pinna, the head, and shoulders is greatest when the sound’s wavelength is comparable to their size:
 - shoulders and head (6-8” wide) might influence a musical pitch of A6 (wavelength ≈ 7.7 ”)
 - the pinnae (2” wide) might influence a musical pitch of A8 (wavelength ≈ 1.9 ”)

The Middle Ear

- The middle ear consists of the eardrum, to which three small bones, called the **ossicles**, are attached.

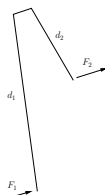


Middle ear

- The eardrum changes pressure variations of incoming sound waves (through the ear canal) into mechanical vibrations which are then transmitted via the ossicles to the inner ear.
- Since the eardrum seals the middle and outer ear, the Eustachian tube, which connects the middle ear to the oral cavity, is needed to equalize these two pressures.

The ossicles in the Middle Ear

- The ossicles transform small changes in pressure (sound wave) to a much greater pressure on the oval window using:
 1. **a lever action:** a small force acts through a larger distance resulting in a larger force acting through a smaller distance.



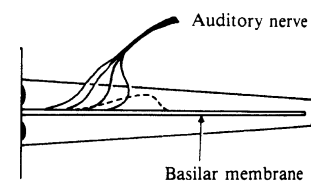
2. **a smaller oval window:** smaller area transmits greater pressure,

$$\text{pressure} = \text{force}/\text{area}.$$

- The lever action, a force factor of about 1.5, and the smaller oval window (1/20th the size of the eardrum), increase the pressure transmitted to the inner ear by a factor of $20 \times 1.5 = 30$.

The Inner Ear

- The cochlea transforms pressure variations into properly coded neural impulses.
- As a first approximation, consider an unraveled cochlea and only two main sections separated by the **basilar membrane**:
 1. the scala tympani (bottom)
 2. the scala vestibule (top)



Inner ear

- The oval and round windows are at the larger end of the cylinder, and a small hole (helicotrema) is at the smaller end to connect the two sections.

Basilar Membrane

- The basilar membrane stops just short of the end of the cochlea to allow the fluid to transmit pressure waves around the end of the membrane.
- When the stapes vibrates against the oval window, pressure waves are transmitted rapidly down the scala vestibuli, introducing ripples in the basilar membrane.
 - higher frequencies create higher amplitude ripples in the region near the oval window (where the basilar membrane is narrow and stiff).
 - lower frequencies create higher amplitude ripples in the region at the far end (where the membrane is slack).

Organ of Corti

- The mechanical vibrations of the basilar membrane are converted to electrical impulses in the auditory nerve via the *organ of Corti*.
 - the organ of Corti contains several rows of tiny hair cells called (*stereocilia*);
 - stereocilia bend when the basilar membrane responds to sound, generating nerve impulses;
 - nerve impulses travel to the brain at a rate dependent on the intensity and frequency of the sound.

Auditory System Summary

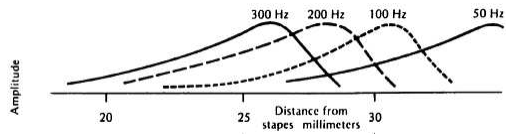
- Sound waves propagate through the ear canal and excite the eardrum.
- The stapes, the inner most ossicle of the ear, vibrates against the oval window and causes pressure variations in the cochlea, which in turn excite mechanical vibrations in the basilar membrane.
- The vibrations of the basilar membrane cause the stereocilia of the organ of Corti to transmit electrical impulses to the brain via the auditory nerve.
- Each auditory nerve fiber responds over a certain range of frequencies (and sound pressures) but has a characteristic frequency at which it is most sensitive.
- See video summary [here](#).

Signal Processing in the Auditory System

- Signal processing is done in the ears and in the auditory nervous system (the brain).
- Each auditory nerve fiber responds over a certain range of frequencies (and sound pressures) but has a characteristic frequency at which it is most sensitive.
- Two pure tones with frequencies 523 Hz and 1046 Hz (an octave apart) respectively, will each have a frequency response curve on the basilar membrane (i.e. an amplitude envelope).

Critical Bands

- A tone at a certain frequency will create a disturbance on the basilar membrane (BM) which will spread over a certain length on either side of the point of maximum displacement.



- The nerve endings in the BM are excited over this narrow region, called the critical band, which correspond to a range of frequencies above and below the frequency of the incoming sound.
- The critical band (bandwidth) varies with frequency:
 - it is about 90 Hz wide for a sound frequency of 200 Hz, increasing to a width of about 900 Hz for a 5000 Hz sound.
 - this corresponds to a region on the BM of essentially 1.2 mm (covering a range of about 1300 receptor cells).