8. Directional hearing

Axel Michelsen, Centre for Sound Communication, Institute of Biology, University of Southern Denmark, 5230 Odense M, Denmark, A.Michelsen@biology.sdu.dk (Ph.D. course 2006)

- The ability to determine the direction to sound sources has mainly been studied for sources in the horizontal plane, where two directional cues are potentially available: the amplitude and phase of sound at the ears, which vary as a function of the direction of sound incidence. The amplitude cue is determined by diffraction of sound by the body (and is thus not available at low frequencies). The phase cue is mainly determined by the distance between the ears. .

- Some animals use only the amplitude cue (examples: moths, bush crickets), but most hearing animals use both cues. In humans the phase cue dominates up to about 1,500 Hz, and the amplitude cue dominates at higher frequencies (duplex theory). Humans can also exploit directional dependent changes in the frequency spectra above 3.5 kHz for determining directions to sources outside the horizontal plane. Barn owls have a unique directional hearing, where phase cues are used for determining the position in the horizontal plane (azimuth) and amplitude cues are used for determining the elevation of the source.

- Birds and mammals can exploit the phase cue directly (this requires a sufficient number of auditory neurons and specialized mechanisms in the brain). Most other animals cannot perceive the phase of sound, but differences in phase can be transformed into differences in ear drum vibration, if sound can reach both the outer and inner surface of the eardrum (the pressure difference receiver).

- In most pressure difference receiving animals the eardrums of the two ears are connected by a sound guide (examples: grasshoppers, birds). Cricket eardrums have no less than four sound inputs.

- Recipe for analysing pressure difference receiving ears:
  - Determine the directional cues and eardrum vibration at several directions
  - Measure the transmission gain, i.e., the change of amplitude and phase for sounds propagating to the inner surface of the eardrum
  - Calculate the (relative) ear drum vibration at each angle of sound incidence
  - Compare the calculated and measured directional dependence of the eardrum vibrations. An agreement means that the transmission path(s) considered is/are the dominant sound guide(s) to the inner surface of the ear drum. A lack of agreement may indicate that sound may reach the eardrum through other routes (e.g., a sound-transparent body surface) or that there are non-linear elements.