Race Gear: The Ear

How We Hear

We hear by sensing differences in air pressure. It is a common misconception to think that the molecules near a sound source move from the sound source to the listener, but that's not quite how things work. When a person speaks, their vocal cords cause the air molecules in their windpipes to oscillate back and forth. Those air molecules cause the air molecules nearest them to start moving in the same oscillating pattern. This movement continues to be passed along and eventually the air molecules near your ear move in the same oscillating pattern.

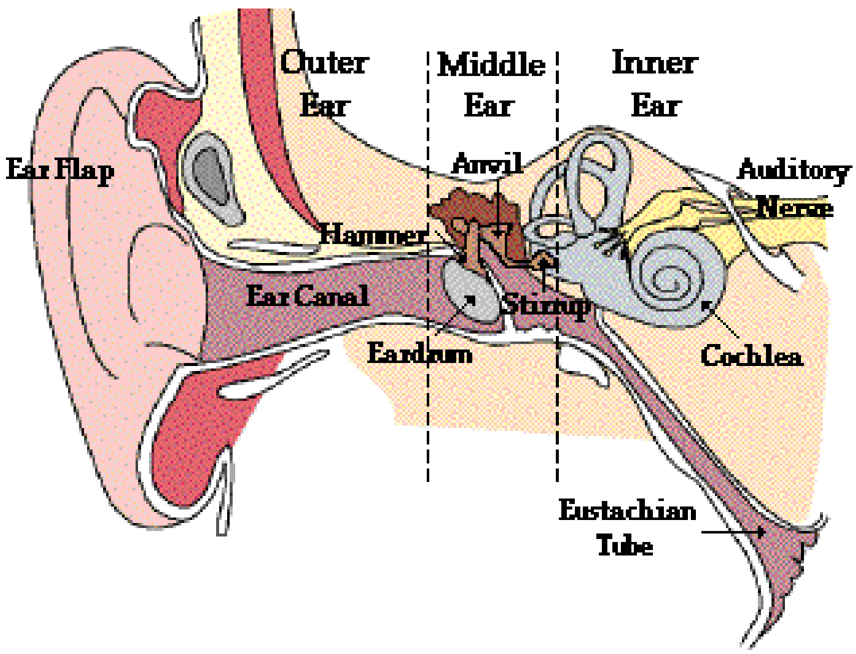

Figure 0.1: An overview of the ear. From http://www.physicsclassroom.com/Class/sound/U11L2d.html

The figure above shows the internal structure of the ear. The outer ear is responsible for intercepting and, to some extent, focusing sound. The shape of the ear flap focuses sound waves and also helps protect the more sensitive parts of the ear. The ear's structure make it selective as to which sounds are detected. The ear is about 1000 times more responsive at a frequency of 1 kHz than at 100 Hz. There is a natural filtering out of low-frequency sound with a preference for amplifying sounds around 3000 Hz – that frequency is determined by the length of the ear canal.

The eardrum is a tightly stretched membrane (like that on a drum) located where the outer and middle ears meet. The eardrum vibrates when sound waves hit it. A compression (high pressure) forces the eardrum inward and a rarefaction (low pressure) forces it outward. The result is that the membrane vibrates in the same pattern as the sound wave. If a sound wave has too large an amplitude, it stretches the eardrum too much and can physically break the eardrum. (You can also damage the eardrum by sticking things in your ear). Broken eardrums usually heal, although they may have scar tissue that impairs their frequency response.

The eardrum is connected to the hammer, anvil and stirrup bones, which vibrate with the same pattern and amplify the sound. The force of the vibrating stirrup is about 15 times larger than the force of the vibrating eardrum.

The middle ear is an air-filled cavity and is connected by the Eustachian tube to the mouth. This tube allows the pressure to change by bringing more or less air into the middle ear. When you get a cold, the Eustachian tube can get clogged and you get earaches because you cannot equalize the pressure inside the ear with that outside the ear.

The inner ear coverts the mechanical pressure input (the sound waves) into an electrical nerve output. The cochlea is a fluid-filled coiled cavity that contains the basilar membrane, which in turn has over 20,000 strands of hair-like receptor cells (which are called hair cells). These receptor cells have slightly different lengths, and the different lengths allow different cells to detect different frequencies. When the frequency of the sound wave matches the natural frequency of the nerve cell, the nerve cell resonates with a larger amplitude vibration, which in turn stimulates the cell to release an electrical impulse that travels along the auditory nerve towards the brain. How the brain translates these electrical signals into the perception of sound is not well understood, in part because it differs from person to person. The more pressure coming from the middle ear, the larger the fluctuations in the basilar membrane and the louder the sound.

We are born with about 30,000 hair cells. Loud noises, chemicals and the normal aging process all kill hair cells slowly over time. A very loud noise (like a mortar shell) can kill all the hair cells in your cochlea, which would make you instantly deaf. Mammals cannot regenerate their hair cells; however, birds and reptiles can. There is a lot of research going on trying to figure out how mammals might be able to regenerate hair cells and thus address issues profound about hearing loss, as well as the normal loss of hearing with age.

Other Resources

Animations showing the hearing process:

- http://www.innerbody.com/anim/ear.html
- http://www.neurophys.wisc.edu/animations.

 The development of these materials was funded by the National Science Foundation through grant PHY-0839180. The opinions and conclusions expressed here do not necessarily represent those of the National Science Foundation. More information is available at www.buildingspeed.org.