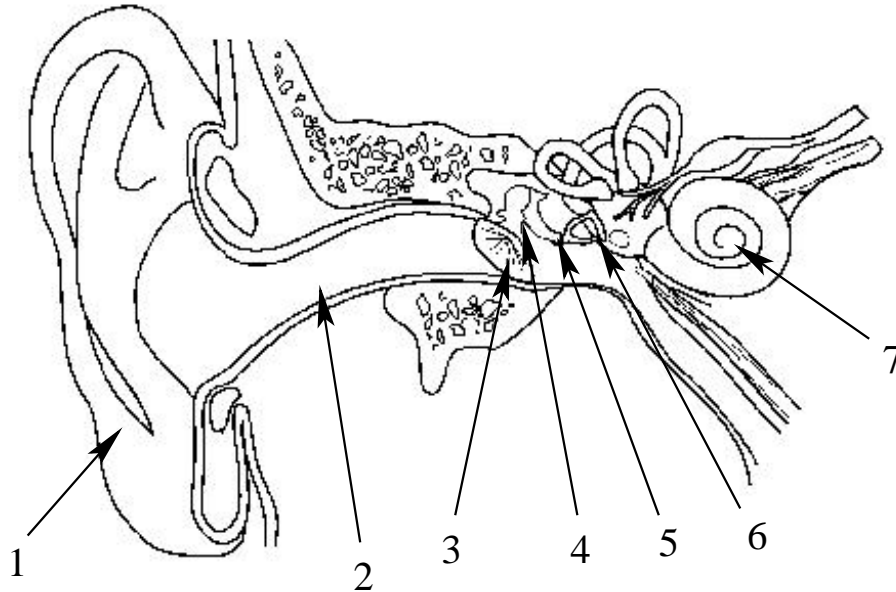


Lecture 3: The Ear

The ear is divided, semi-artificially, into three regions:



The Outer Ear consists of

1. the **Pinna**, or **external ear**,
2. the **Meatus**, or **ear canal**, and
3. the **Tympanic membrane**, or **eardrum**.

The eardrum separates outer and middle ears, so it counts as being in both.

The Middle Ear consists of

3. the **Tympanic membrane**, or **eardrum**,
4. the **Malleus**, or **hammer**,
5. the **Incus**, or **anvil**, and
6. the **Stapes**, or **stirrup**. 4-6 together are the **ossicles** or **earbones**.

The Inner Ear consists of

7. the **Cochlea**.

We will talk about the cochlea in another lecture, this lecture is just about the outer and middle ears.

Notice that in anatomy and medicine, everything has a Latin name. Most things also have common names. In every case here, the Latin name is just Latin for the common name; that is, Incus is Latin for anvil, etc.

What are these things? I assume everyone knows what the external ear and ear canal are. The eardrum is a membrane which forms an airtight seal between the ear canal and the middle ear. The middle ear is an air filled cavity containing the earbones, the hammer, anvil, and stirrup (named for their appearance). The cochlea is a snail-shaped soft tissue organ, embedded in the skull bone, touching the stirrup on one end and with a nerve (the aural nerve) emerging on the other.

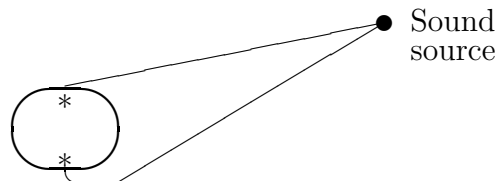
Now I go into more detail about each element of the ear.

Pinna

The pinna, or external ear (what we usually call “the ear”) serves several purposes. Obviously, it has a decorative role, often accentuated with earrings or other jewelry (in most cultures). In several animals, usually tropical ones (such as elephants and African wild dogs), the ears are “radiators” used for heat loss.

The main use of the pinna in hearing, though, is in the capture and localization of sound. To understand sound capture, think about what happens when you cup your hand to your ear, or use an ear horn. (Try sticking the small end of a funnel in your ear and see how it affects your hearing.) Doing so increases the amount of sound—especially sounds of certain frequencies—which enters your ear canal. Your pinna is a permanent device to do that, designed around a specific range of frequencies, presumably in the range 1000 to 5000 Hertz (frequencies and Hertz are explained in a later lecture).

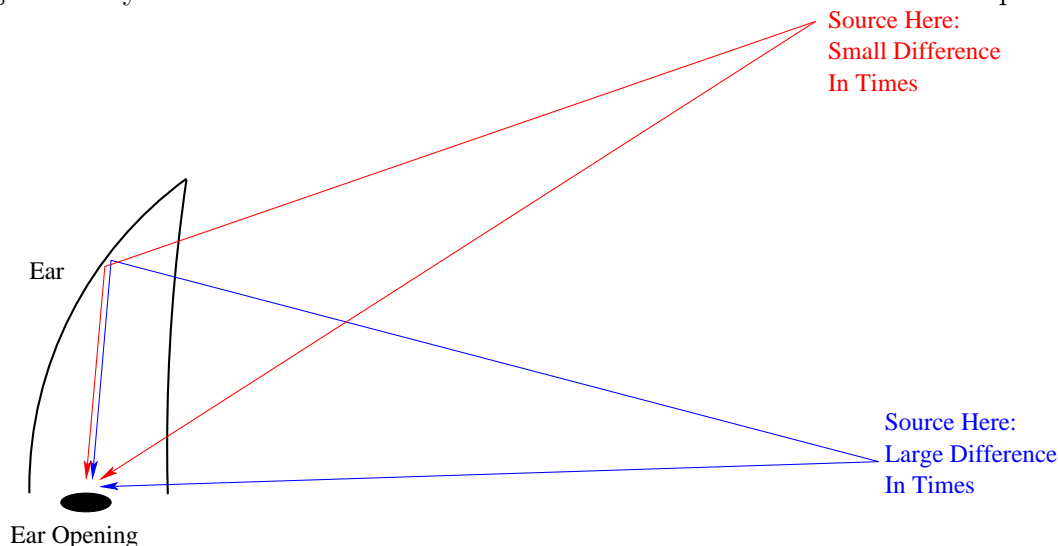
The pinna is also important in our ability to localize sound—that is, to tell where a sound is coming from. A clear example of this is the pointy ears on animals like bats and cats. First, let’s see that having two ears lets us tell which side of us a sound comes from. Here is a view from above, of sound arriving at your two ears (the *) from a source:



The distance sound has to go, to get to one ear, is shorter than to get to the other ear. Since it takes sound time to travel, it will take longer to get to the further ear. You can sense

the difference in time. The further to one side the source goes, the bigger the difference: that lets you judge the angle to the sound source. We will talk about this more in a future lecture.

This doesn't help us judge whether a sound comes from high up or low down, though. If the source is in front of you and above, it arrives at the ears at the same moment, just as if it is in front of you and below. However, a bat or cat ear can tell the height of the source by timing the delay between the sound and the reflection of the sound off of the cup of the ear:



the delay between the sound arrival, and the echo off the ear, depends on whether the sound source is above, even with, or below.

Our ears are not shaped like cat ears. Cat and bat ears work great for sources in front of them. Ours work reasonably for sources in all directions, what our ancestors needed in trees. They let us tell if a sound is from in front or behind, above or below, and so forth, but not with enormous accuracy.

Meatus

The ear canal is about $2.5 \text{ cm} = .025 \text{ meters}$ deep, basically a narrow tube into the side of your head. It also has a slight bend. The main purpose is to recess the delicate components of your ear into your head, so that they are not vulnerable if you get hit on the side of the head. It also plays a role in amplifying sounds at frequencies close to 3500 Hertz, a key hearing range. We will return to this later in the course.

The meatus is lined with hairs and wax producing glands. The hairs actually move the wax out along the walls of the canal to the opening. Any junk that gets inside becomes stuck in the wax and is carried out. It is a self-cleaning organ and it is not actually a good idea to clean it, except around the opening of the meatus. Shoving a q-tip in the meatus can remove some of the wax, but push the rest down against the eardrum, which can interfere with the proper function of the eardrum. If you have excessive wax buildup, there are gentle

drops you can put in your ear which loosen the wax and help it to get out—ask your doctor.

Eardrum

The tympanic membrane is a thin, somewhat stiff membrane separating the outer and middle ears. The area of the membrane is about 0.2 cm^2 , or $.00002 \text{ m}^2$. The middle ear is an air filled cavity in the skull, with a tube, called the Eustatian tube, which connects it to the throat. This lets air in and out, and can drain any fluid which forms in the middle ear (when you are sick, for instance). The pressure in the middle ear should be the same as outside. When it is not, air should pass through the Eustatian tube. When the air pressure changes (takeoff and landing in an airplane, say) the tube can become closed and a pressure difference builds up. You yawn or swallow to force open the tube and “pop,” air flows through and equalizes the pressure. Such pressure differences change the tension on the eardrum, affecting hearing and sometimes causing pain.

The role of the tympanic membrane in hearing is to transmit sound—pressure variations—at the back of the ear canal, to the bones of the middle ear. The changing air pressure bends the eardrum in and out, pulling the malleus back and forth.

Ossicles

The malleus touches the eardrum on one side. Then the three bones form a chain, with the stapes touching a soft spot on the cochlea called the **oval window** on the far side. Each bone is also anchored by ligaments, so it can pivot but is not loose to move freely. The ossicles’ role is the following:

The malleus is pushed on one side by the eardrum. It moves back and forth, pushing the incus on the other side.

The incus is pushed back and forth by the malleus. It moves back and forth, pushing the stapes.

The stapes is pushed back and forth by the incus. It moves back and forth, pushing the oval window.

This sounds like a Rube Goldberg device. Why not just have the eardrum push straight on the oval window? This is actually what happens in fish. However, for animals which live in the air, it is not a good method, because the cochlea is full of fluid, whereas the sound arrives down the meatus through air. Air is “thin”—it takes a small pressure to move it a large distance. The pressures involved in hearing are not large. Fluid is “thick”—it takes a large pressure to move it a small distance. Without the earbones, the sound reaching the ear would barely be able to move the fluid in the cochlea. This means that almost all of the sound energy would bounce off the eardrum and go back out the ear. The role of the ossicles is to make an efficient conversion of the sound energy, from a small force on a big area to a large force on a small area. The motion of the oval window is about $1 \frac{1}{2}$ times the motion of the eardrum, and the pressure on the oval window is about 14 times the pressure on the

eardrum. This difference is made up for by the oval window being much smaller than the eardrum. An air pressure of 30 Pascals in a sound wave is the threshold of pain. The limit of hearing is about $3 \times 10^{-5} = .00003$ Pascals. Therefore this factor of 14 is important!

[Technically, the ossicles are an impedance matching device. Impedance matchers are more efficient as they include more components or a more gradual taper. They become inefficient at very low frequency, which is also the case for the ossicles—we will discuss this in future asides.]

Fish have no ossicles, but 7 jawbones. Birds, reptiles, and amphibians have a single ossicle in each ear, the stapes, and 5 jawbones. ($5 + 2 \times 1 = 7$.) Mammals have 3 ossicles per ear, and 1 jawbone. ($1 + 2 \times 3 = 7$.) Evolution preserved the number of bones, but changed their role. This allows the reptilian jaw to perform feats impossible for a mammal. However, mammalian ears yield superior hearing because of the ossicles.

Safety mechanisms of the Ear

There is a set of muscles attached to the eardrum, and another set attached to the malleus. When these muscles contract, they tighten the eardrum, reducing the efficiency of sound transmission, and draw the malleus back from the eardrum, reducing the efficiency of transmission between the eardrum and the malleus. That is, these muscles can partially “turn off” the propagation of sound from the outside into your ear.

When there is a loud sound, a reflex called the **acoustic reflex** activates these muscles. This reduces the danger that a loud sound will cause damage to your ear. For future reference, the reflex usually occurs for sounds louder than about 85 decibels (dB).

However, like all reflexes, there is a delay before the reflex starts. In this case, it is about 30–40 milliseconds, or 0.03 to 0.04 seconds. This delay means that sudden loud sounds go through before the reflex can act. This means that sudden loud sounds (gunshot) are much more likely to damage hearing than steady loud sounds (jackhammer). Also, sudden loud sounds are more likely to be in the upper register of hearing, which is part of the reason that deafness usually progresses from high to low pitch.