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How do the hammer, anvil and stirrup bones amplify sound into the inner ear?

Douglas E. Vetter, Assistant Professor of Neuroscience at the Tufts University Sackler School of Biomedical Sciences, sounds out an answer to this query.

The hammer, anvil and stirrup—also known as the malleus, incus, and stapes, respectively, and collectively, as "middle ear ossicles"—are the smallest bones in the human body. Found in the middle ear, they are a part of the auditory system between the eardrum and the cochlea (the spiral-shaped conduit housing hair cells that are involved in transmitting sound to the brain). To understand the role of these bones in hearing requires an understanding of levers. This is because the middle ear ossicles are arranged and interact with each other as a lever system.

All levers generate a mechanical advantage. They are used to exert a large force over a small distance at one end of the lever by applying a smaller force over a longer distance at the opposite end. The leveraging capabilities of the middle ear ossicles are needed to generate the large forces that allow us to hear.

As terrestrial animals, we live in a gaseous environment. But, our inner ear is filled with fluid, and this represents a problem. As an example, most people have first hand knowledge of hearing underwater. If someone screams at you from above the water's surface, the sounds are tremendously muted, making it difficult to understand or even hear at all. That is simply because most of the sound is reflected off the water's surface.

So how do we take in airborne sounds, which are simply vibrations of the air molecules, and get them past the air-fluid interface between our ear canal and the inner ear? We need a system to use those air vibrations to push against the surface of the inner ear fluid.

When the eardrum vibrates as sound hits its surface, it sets the ossicles into motion. The ossicles are arranged in a special order to perform their job. Directly behind and connected to the eardrum—which is essentially, a large collector of sound—is the hammer. The hammer is arranged so that one end is attached to the eardrum, while the other end forms a lever-like hinge with the anvil. The opposite end of the anvil is fused with the stirrup (so anvil and stirrup act as one bone). The stirrup then connects with a special opening in the cochlea called the "oval window." The footplate of the stirrup—the oval, flat part of the bone that resembles the part where one would rest ones foot in an actual stirrup—is loosely attached to the oval window of the cochlea, allowing it to move in and out like a piston. The piston-like action generates vibrations in the fluid-filled inner ear that are used to signal the brain of a sound event. Without the middle ear ossicles, only about 0.1 percent of sound energy would make it into the inner ear.

Overcoming the problem of getting airborne sound into the fluid-filled inner ear is solved by two main mechanisms: the concentration of energy from the large eardrum onto the small stirrup footplate situated in the oval window; and the lever-like action between the hammer and the anvil-stirrup complex. In cats, for example, the simple concentration of forces from the eardrum to the stirrup increases pressure at the oval window to about 35 times what is measured at the eardrum. The lever action of the middle ear bones imparts a further mechanical advantage to the system—occurring because the anvil is shorter than the hammer—and further increases pressure by roughly 35 percent. In this way we overcome the problem of getting airborne vibrations into the pressurized, fluid-filled inner ear.

Not all animals have this same middle ear bone configuration. In fact, reptiles, amphibians and birds, have a middle ear that contains just one bone, called the columella, which connects the eardrum directly to the oval window of the cochlea. When we examine the most sensitive frequency for hearing in these animals, they do very well for sounds around 1,000 hertz (1 kHz) but quickly lose their ability to hear well at higher frequencies. On the other hand, animals with three middle ear bones tend to hear at much higher frequencies. For humans, our hearing can extend to 20 kHz, although most of our lives are spent attending to sounds between 4 and 8 kHz.