Hidden Mechanisms at the Heart of Hearing

Deep in Your Ear Is a Place Where Physics, Biology, and Psychology Meet

by Hugh McDonald

A mosquito drones past as you hover between waking and sleep—and you flinch instinctively. Brakes screech in the street, and without thinking, you turn your head, spot the oncoming car, and leap to safety. A friend softly says your name, and you recognize her voice in an instant. Although they're very different, we experience such common acts of listening as unitary events: reception, identification, and understanding all seem to happen at once.

But even the simplest perceptions are made up of multiple steps, most of which occur without our conscious awareness. And no sensory modality hides more amazing activity than our faculty of audition. Our ears might appear to be passive portals for sound, but our auditory systems rely on a chain of tiny mechanisms, each a marvel of biological engineering, to turn sound into thought. At the core of this chain, buried deep in your inner ear, is your *cochlea*. It's only about the size of a pea, but it's one of the most exquisitely sensitive and finely tuned parts of your body.

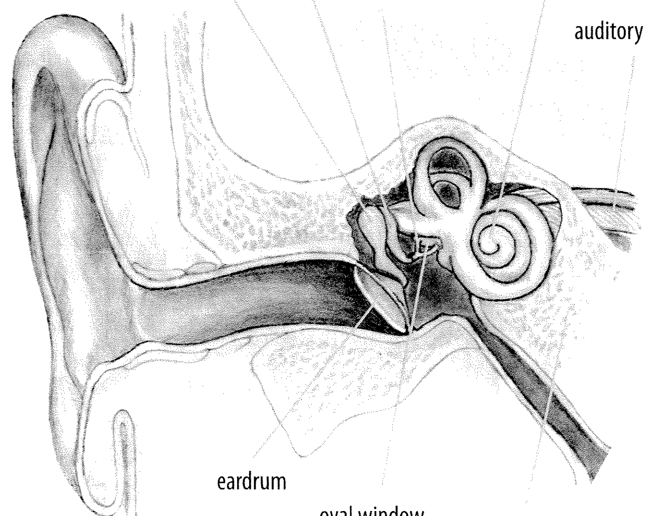
Conceptually, the cochlea (from the Greek *kochlias,* for "snail shell," a nod to the organ's shape) is where physics, biology, and psychology come together. Here, sound waves are turned into the nerve impulses that carry information to our brains for decoding and interpretation.

This fundamental transformation—from the physical motion of air to the chemical and electrical signals of neurons—starts when sound waves traveling through space reach your eardrum. The vibrations of this drumhead-tight membrane are amplified and transmitted by three tiny bones (the *hammer, anvil,* and *stirrup*) to the *oval window,* a sheet of tissue that serves as the gateway to the cochlea. The motion of this membrane creates pulses in the fluid inside the cochlea.

The cochlea's construction gives rise to one of its most important functions: organizing incoming sound waves according to pitch. Pulses in the cochlear fluid set in motion a flexible structure called the *basilar membrane.* Picture yourself on laundry day, snapping a freshly washed sheet over your bed, holding one edge while the opposite side flies like a flag. Like your bedsheet, the basilar membrane is taut at one end and looser at the other. Closely spaced liquid ripples produced by high-pitched sounds make bigger waves at the taut end, while farther-apart ripples from lower-pitched sounds make the loose end flap. In other words, different sections of the basilar membrane respond to different frequencies of sound waves.

Like the next devices in a Rube Goldberg contraption, the membrane's disturbance sets a number of structures in motion, which leads to the animation of tiny fiber bundles at the tips of *hair cells.* The hair cells react by activating adjoining nerve cells, which then send signals along the auditory nerve to the brain. The cochlea's separation of sound waves by frequency is mirrored in the brain's auditory cortex, where different groups of cells respond to different pitches.

A view of the cochlea. The protective bony wall has been removed, revealing the cochlea's internal spiral shape.
Image courtesy of Physiological Acoustics and Communication, ENT Department, University Tübingen



Our hair cells are among the most sensitive instruments in biology, reacting to soft sounds that barely ripple the cochlear fluid. In fact, they respond when their hairlike fibers are deflected less than a nanometer—a billionth of a meter. Some hair cells may also strengthen extremely quiet sounds by enhancing very weak pulses in the cochlear fluid. But hair cells are extremely delicate, too: They can be damaged by constant noise and destroyed by loud sounds. And although researchers are working on ways of using stem cells to grow new hair cells, a damaged hair cell cannot currently be regenerated.

All of these actions—the thrum of the eardrum, the insistent lever action of the middle ear's bones, the tiny pulses in the cochlear fluid—are essential components of your sense of hearing, whether you're straining to catch a whispered conversation or cringing from a passing jet. Yet though they're in nearly constant motion, these mechanisms remain perpetually hidden from your awareness. Indeed, the cochlea's location within a hard sheath of bone protects it not only from damage but also from excessive and distracting sound; paradoxically, its extreme sensitivity means it must be isolated from sounds you don't need to hear—even sounds made by the workings of your own body.

So the next time you hear something soft or stirring, faint or frightening, think for just a moment of all the silent activity of bone and fluid and fiber and nerve inside your head, ceaselessly turning the unseen movement of air molecules into the universe of sonic experience in which you live.

Cochlear Implants

In some cases, damaged or destroyed hair cells can be bypassed with a cochlear implant. Unlike a hearing aid, which amplifies sound as it enters the ear and improves hearing for people with functioning hair cells, cochlear implants can provide some hearing for people without working hair cells. With an implant, an external microphone captures sound; key sounds, such as speech, are recognized by a processor. The processor turns these sounds into electrical signals and feeds them directly into the auditory nerve and on to the brain.