The Senses: Hearing

Written by Carl Sherman

Words of love, or wisdom; the timeless murmur of wind in the trees; the warning blare of a car horn; the sublime harmonies of Mozart—our sense of hearing informs, enriches, and all too often disrupts our lives. It connects us to a world in motion.

Such motions as objects striking or rubbing against each other, air agitated by vocal cords, or gases rushing through a car's muffler produce cyclical pressure variations in the air: sound waves. Frequency—how many cycles per second—determines the pitch of the sound. Amplitude—how wide the pressure variations—determines volume.

Hearing is a mechanical sense. It turns physical movement into the electrical signals that make up the language of the brain, translating these vibrations into what we experience as the world of sound.

The diversity of sounds we can hear typically ranges from 20Hz (cycles/second) to 20,000Hz. The loudest we can handle without immediately damaging our hearing (for example, standing 100 feet from a jet at takeoff) carries about a million million times more energy than the barely audible.

A Biological Microphone

The sounds we hear represent a richly layered mix of frequencies and amplitudes, faithfully transmitted through a finely engineered apparatus.

Sound waves enter the hearing system through the outer ear, traveling down through the inch-long ear canal to strike the tympanic membrane, or eardrum, and making it vibrate.

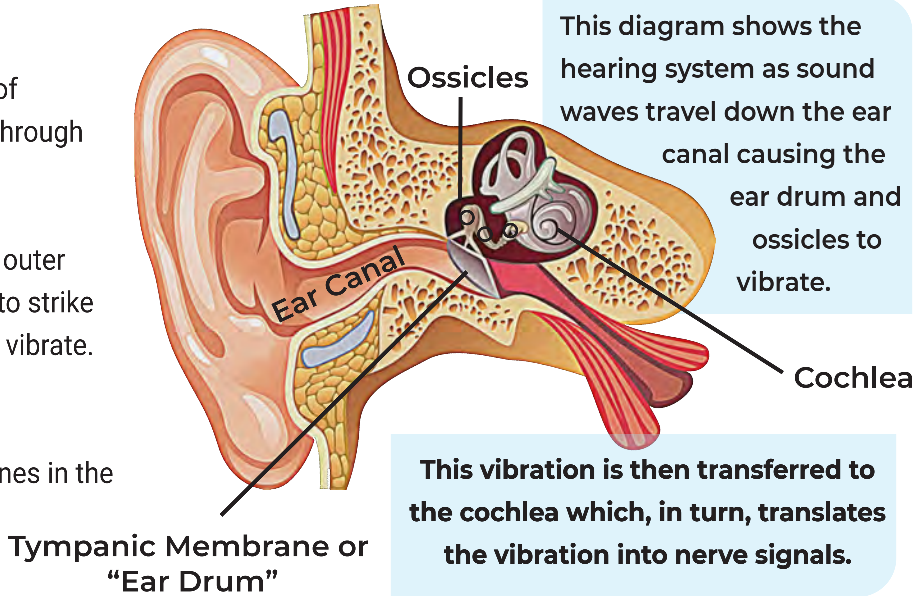
In the middle ear, the vibrations are transmitted to three linked bones. These ossicles, the smallest bones in the body, magnify the motion of the eardrum some twentyfold.

At their other end, the ossicles transmit their tiny movements to the cochlea, the organ of the inner ear that actually translates the energy of sound waves into nerve signals.

The cochlea is shaped like a spiral snail shell and contains fluid-filled canals. The vibration of the ossicles against a window at its base generates waves that ripple through this fluid, pushing against a membrane that is lined with thousands of tiny (about a thousandth of an inch long) hair cells—the receptors of the auditory system.

This movement opens tiny pores in the hair cells, allowing charged particles (ions) to enter, generating electric impulses that are picked up by nearby filaments of the auditory nerve, which carries them to the brain.

The cochlea thus translates sound waves into the language of the brain. But there is some controversy over just how. Some frequencies of sound may be encoded by which hair cells respond: cells at the base of the cochlea are moved by high-pitched sounds, while those that line the cochlea as it winds toward its apex respond to increasingly lower frequencies. This explanation is called "place theory."



This diagram shows the hearing system as sound waves travel down the ear canal causing the ear drum and ossicles to vibrate.

This vibration is then transferred to the cochlea which, in turn, translates the vibration into nerve signals.

The “rate theory,” on the other hand, contends that some sounds, perhaps those at the low end of the frequency spectrum, are encoded by the rate of neuron activation: within this range, higher-pitched sounds stimulate neurons to fire more rapidly.

The Brain Gets — and Sends — Messages

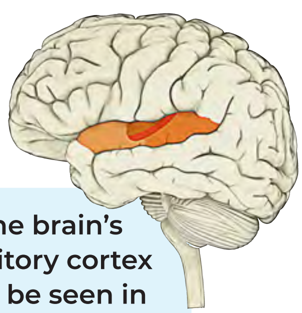
Signals from the ear carry the bare sensation of individual components of sound. It is in the brain that we perceive sounds—become conscious of them and interpret what they mean. The process begins as information from the cochlea travels through the olive and inferior colliculus in the brain stem, then on up through other structures to the thalamus, a kind of central switching station for the senses. These lower brain centers coordinate signals from our two ears, allowing us to locate sounds, and respond to sounds of danger so we can take immediate action even without conscious thought.

But most conscious perceptual processing occurs in the auditory cortex, a part of the brain’s evolved outer layer that lies along the side of the head, in the temporal lobe. It appears that specific parts of the auditory cortex decode information from the cochlea about sound volume, rhythm, and pitch. With connections to parts of the brain that store memories and regulate emotion, we understand and respond to what we hear.

Information flows both ways. Feedback from cortex to cochlea amplifies some signals while blocking others. This fine-tuning allows us to hear distinct conversations despite background noise, rather than a cacophony of sound.

Words and Music

A key function of human hearing is response to speech, the principal way we connect and communicate, emotionally and intellectually.



The brain’s auditory cortex can be seen in orange and red

Language highlights the vital importance of hearing in brain development. There is good evidence that infants who hear more words from their parents learn to read earlier and do better in school than their peers.

Speech sounds are largely processed as words in Wernicke’s area, the part of the dominant (usually left) brain hemisphere devoted to language. But signals also go to the corresponding area on the opposite side of the brain, where tone and rhythm—the “music” of speech—are decoded.

Music itself graphically illustrates how complex and powerful hearing perception can be. We’re often deeply affected as melody, harmony, and rhythm engage widespread brain areas involved in movement, attention, memory, emotion, and language.

The effect of music on the brain has been harnessed therapeutically for rehabilitation after stroke and brain injury, and to improve the lives of people with brain disorders from autism to Alzheimer’s disease.

Hearing Loss — Avoidable and Otherwise

With age, progressive loss of hair cells means less acute hearing, particularly in the higher frequencies. The decline is typically more pronounced in men than in women.

The process is greatly accelerated by exposure to loud sounds. Approximately 5.2 million children and 26 million adults have significant noise-induced hearing loss. Some studies have found, even in 20- to 30-year-olds, a link between blunted hearing and the incautious use of listening devices with headphones and earbuds.

Hearing is worth protecting for more than its own sake: a number of studies associate hearing loss and cognitive decline, and link it to an increased risk of falls.

Avoid noise-induced hearing loss by reducing exposure to sounds loud enough that you must raise your voice to be heard. When you must be in a very noisy environment (such as operating a lawn mower or leaf blower, or attending a rock concert), wear earplugs. If you use a personal listening device, keep the volume moderate.