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What Happens When We Hear?

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Abstract

What happens when we hear? Where does the sound go when it enters our ears? Our ears sense the vibrations of the air and convert them into electrical signals the brain can process. But that is only the start. The brain uses tens of thousands of nerve cells to hear even the quietest or simplest sound. With those nerve cells, the brain is solving a never-ending puzzle: figuring out what is going on in the world. To do that, the brain must separate out sounds that are occurring at the same time, recognize them, and describe them in lots of ways, such as how loud a sound is and where it is coming from. This article gives an overview of how the ears and brain work together, so we can live in a world of sound.

Imagine you are sitting by a very still lake. Now imagine you place two small toy boats on the water's edge, about a meter apart, like the boy in the picture above. You throw a stone into the water, farther out than the boats. When the stone hits the water, it creates ripples that move outward in a circle from where the stone sank. When the waves reach your boats, the boats bob up and down. If your stone landed an equal distance from each boat, both boats will start moving at the same time. But if your stone was closer to the left boat, it will start to bob around before the boat on the right.

Now imagine the lake is busy. A dog splashes nearby, a jet ski whizzes past in the distance, and ducks swim around. Each moving thing creates more waves of various sizes, coming from lots of directions—and each wave will move your boats in a specific way.

What if you could not see the entire lake, but could only see the two boats? You might know that *something* is creating ripples, but it would be difficult to work out what was causing them. This is exactly what you do when you listen to sounds. When people talk, birds sing, or cars go by, they create invisible ripples of air that spread outwards like the ripples on the lake. When those ripples reach your ears, they cause moving parts inside your ears to "bob" about, just like those toy boats, and nerves inside your ears send signals about this bobbing motion to your brain. Your brain then works out what those sounds are and where they are coming from—even if you cannot see what is making the sound! Hearing can create a vivid picture of the world around you, and most of the time you do not even notice you are doing it! Scientists are still figuring out how this happens [1].

What Happens Inside Your Ears?

If you could see air move in slow motion, you could watch sound vibrations travel from someone's hands when they clap, through the air, to your ears. Of course air is invisible, and it vibrates much too fast for our eyes to follow, but some scientists have devised a clever way for you to see the sound waves. To learn more about the physics of sound in the air, read this Frontiers for Young Minds article.

Your ears are made up of several parts (Figure 1). The flappy bits on the sides of your head are called your outer ears. The outer ear collects the sound waves traveling through the air and funnels them into the ear canal, where they bounce against a thin piece of skin about 8 mm across (a little smaller than an M&M candy), called the eardrum, which is stretched across the end of the ear canal. Your eardrum vibrates to the sound waves that hit it. Attached to the other side of the eardrum are three tiny bones—the tiniest bones in your body. They pick up the vibrations from the eardrum, and send them into the inner ear, or cochlea. The cochlea is a spiral tube filled with sa liquid that moves rapidly back and forth based on the vibrations of the air.

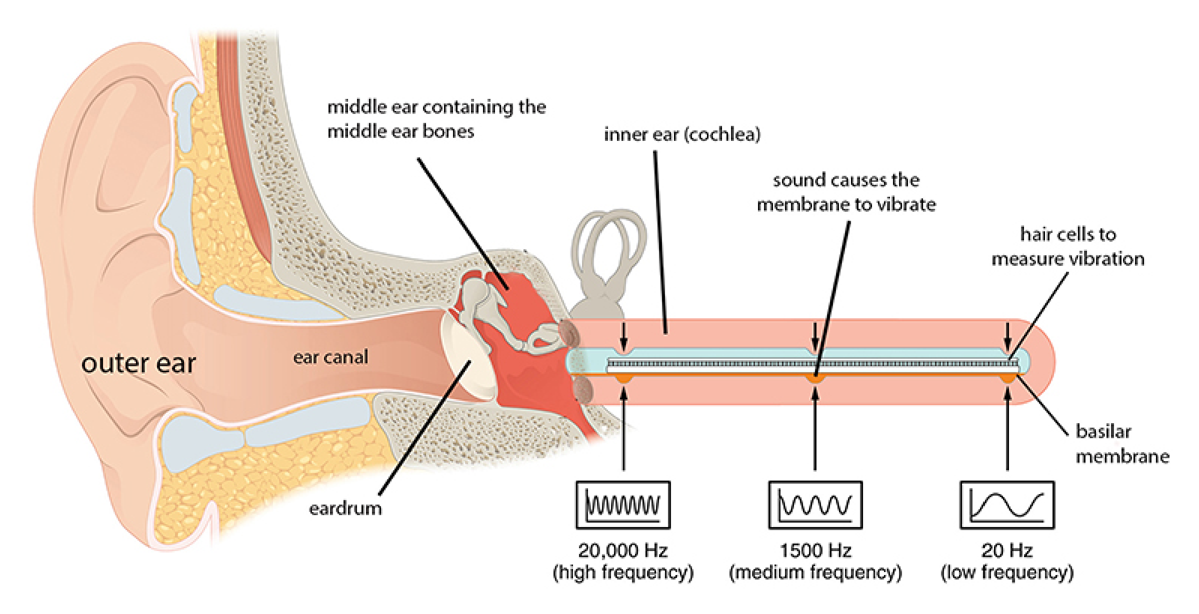

Figure 1 - The parts of the outer, middle, and inner ear are shown.
In the inner ear, the cochlea is cut away to show the basilar membrane. The inner ear is also shown as straight, so you can see how the membrane works to separate high- and low-frequency sounds, which are measured in Hertz (Hz). In reality, the cochlea is coiled up inside the skull (see Figure 2).

The cochlea is divided into two sections by a skin-like layer called the basilar membrane. Sound vibrations entering the ear cause this membrane to vibrate up and down. The membrane closest to the outer ear is more sensitive to high-frequency sounds—as high as 20,000 vibrations per second or Hertz (Hz). If you are not sure what frequency is, you can read more about it here. This is far higher than even the highest musical notes, like those made by a piccolo or a whistle, which can be as high as 4,000 Hz. Generally, only young people can hear this well: most older adults aged around 60 can only hear up to about 10,000 Hz. The other end of the basilar membrane vibrates most to low-frequency sounds such as those made by a double bass, which can be as low as 40 Hz—close to the lowest we can hear (20 Hz). Speech falls mostly in the middle range of frequencies, from 100 to 2,000 Hz. So, the cochlea "sorts" sounds according to frequency. This helps us to know what frequency a sound is (e.g., what musical notes) but also to separate out sounds of different frequencies which occur at the same time!

All along the basilar membrane are tiny hair cells that measure these vibrations and turn them into electrical signals. Each cell is connected to a nerve fiber, which carries the electrical signals to the brain. The brain then decodes, or interprets, these signals and works out what the sound is and where it is coming from. Of course, there is still much more to how the ear works. You can find out more in other Frontiers for Young Minds articles here, or here.

You Hear With Your Brain

called auditory nuclei (Figure 2). Within the auditory nuclei, brain cells sense specific types of sounds. Some brain cells like low-frequency sounds, such as car engines, and others like high-frequency sounds, such as birdsong. The brain cells that like low-frequency sounds often cluster together, and those that like high-frequencies do the same. We say they are arranged into a "map" of frequency, which helps you to know what frequency of sound you are hearing.

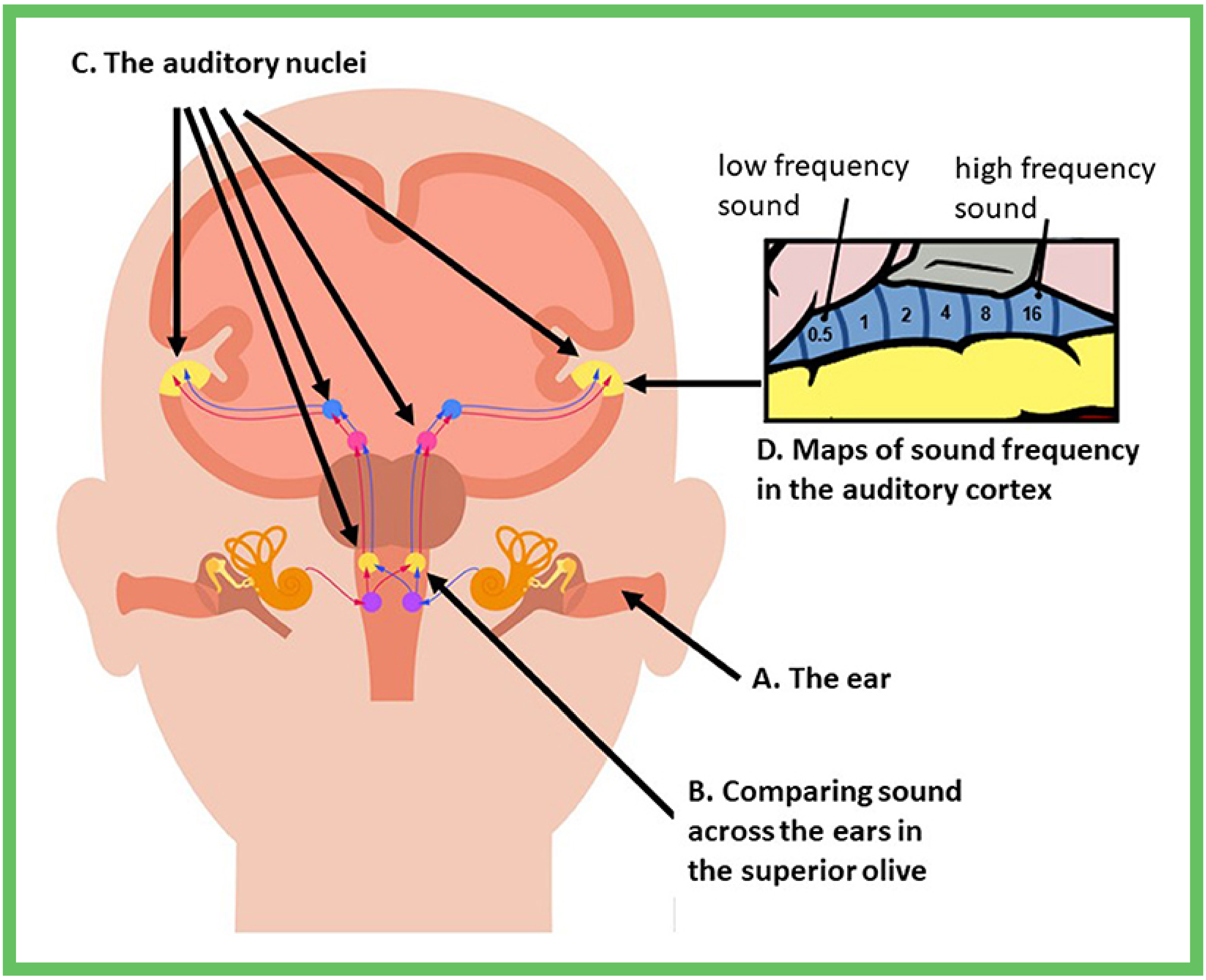

Figure 2 - **(A)** The ear, where sound enters.
(B) The "superior olive" where sound from the two ears is compared. **(C)** Other auditory nuclei. Information about sound passes through these, and each nucleus has a different job to do, processing the sound so we can understand it. Scientists are still figuring this out. **(D)** The close-up shows a frequency map in the auditory cortex, another part of the brain important for processing sound. In the close-up the upper layer of the brain has been lifted back to reveal the map (Image credit: Modified from Wikipedia Commons).

Some auditory nuclei have extra special jobs that no other parts of the brain can perform. One nucleus, called the medial superior olive, compares the times that a sound arrives at each ear [2]. Just like our example of the toy boats on the lake, sounds from the left will arrive at the left ear first and will take a little longer to arrive at the right ear the sound comes from in front, it will arrive at both ears at the same time. This is one c

The brain does lots of other jobs to help you understand the sounds around you. For example, it can work out how loud a sound is, or spot new and unexpected sounds. It can recognize words, and can work out how an object is moving from the changes in sound waves over time. Imagine almost any aspect of sound or how it can change, and you can probably find brain cells that can measure it!

Making Sense of Sounds

The job of the brain is to turn sounds into information about the world around us that makes sense. For example, when you hear a person talking and understand the words they say, you are not just working out whether the sounds are loud, quiet, close, distant, still, or moving. Your brain is also trying to identify the sounds. It does this by drawing on all the knowledge it already has about those sounds (Figure 3A). We understand words because we have already learned the language and know what many words sound like; so you hear not just sounds, but words that have meaning to you. So, how we understand sounds is partly dependent on what we already know! Even the things you see can affect the way you perceive sound. This is extremely important when you are listening to someone talking—seeing a person's face makes them easier to understand (see this Frontiers for Young Minds article for more about how what we see affects our hearing).

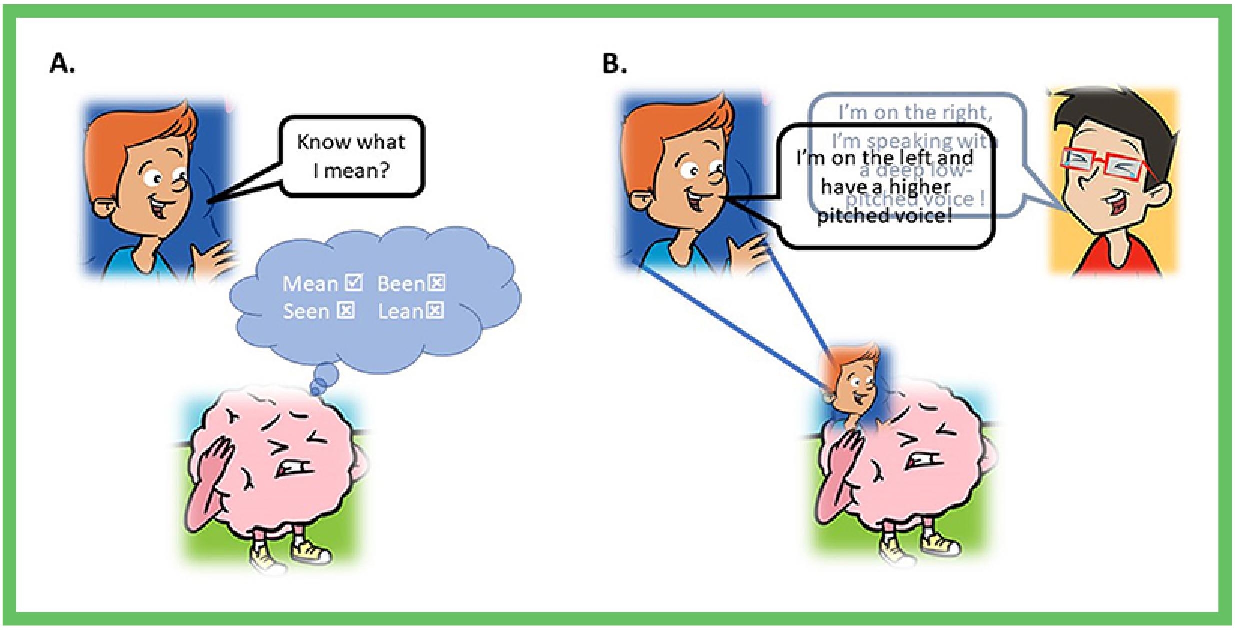

Figure 3 - **(A)** What you know about sounds affects what you hear and helps you to understand. **(B)** How you listen affects what you hear and helps you separate and understand sounds (Figures adapted from here, here and here).

Untangling All The Sounds You Hear

the same time. You can usually pick out one of the voices to listen to, and not get both friends' words mixed up. The brain uses "tricks" to separate out sounds. For example, if your friends are sitting in separate places, your brain can work out where each voice is coming from by using your medial superior olives! You do not need to think about where the voices are coming from—your brain is wired to do this automatically. *Choosing* which of your friends to listen to is not automatic, and *how* you listen also helps your brain to separate out the voices (Figure 3B). Amazingly, if you *pay attention* to one of the voices, your brain responds more strongly to that voice and you hear it more clearly [3]! For more information, see this Frontiers for Young Minds article.

Hearing: A Lot More Than Meets The Ear!

By now, you probably agree that there is a lot more to hearing than just your ears. Your ears convert sounds into signals your brain can deal with. That is not an easy job! But by the time you make sense of those sounds, they have passed through many thousands of brain cells. Your brain and the cells in it work hard to help you make sense of sounds and the information that sounds are telling you about the world. Understanding how we hear is critical to treating hearing problems effectively, which become worse with age. This understanding has also led to technologies such as mp3 files and innovations in artificial speech recognition by computers. If you want to learn more about the exciting world of sound and how we hear it, be sure to check out the other articles in this Collection.

Glossary

Ear Canal: ↑ A tube that carries the sound to the ear drum.

Eardrum: ↑ A skin-like membrane that vibrates in response to sound, converting the vibrations in the air to motion of the middle ear bones.

Cochlea: ↑ A spiral chamber, made of bone and filled with fluid, that moves in time with the middle-ear bones and ear drum. In turn, this moves the basilar membrane.

Basilar Membrane: ↑ A flexible membrane in the inner ear that moves in time with the movement of the surrounding fluid. The part that moves most depends on the frequency of the sound.

Frequency: ↑ The rate of vibration of sound waves in the air. The number of times per second that air molecules complete a cycle of being squashed together, expand out, and back.

Hair Cells: ↑ Cells on the basilar membrane that convert movement into electrical signals, which are sent to the brain via nerves. They have tiny hairs that move around with the fluid.

Auditory Nuclei: ↑ A collection of brain cells close together in the brain that are dedicated to processing sound. The medial superior olive and auditory cortex are examples of auditory nuclei.

Medial Superior Olive: ↑ A nucleus of the brain that is dedicated to processing information about sounc and is important for knowing where sounds come from.

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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