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HOW AIR AND BONES CAN HELP YOU TO HEAR

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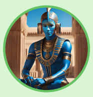
YOUNG REVIEWERS:


ADI
AGE: 13


DIYA
AGE: 13


NEIL
AGE: 8

Every day, you probably hear a lot of sounds: people chatting, instruments making music, bells ringing, and more. These sounds reach your ears through the air. However, when you talk, an important part of the sound is heard through your bones. This might surprise you, but in this article, we will tell you how to run an experiment that will hopefully convince you that this is true. So, be prepared to become a young scientist! You will also read about the structure of the ear and how you perceive voices and noise around you. This knowledge is important, as it can help scientists and doctors understand how to help people who have hearing problems.

LET US START WITH AN EXPERIMENT!

Here is an experiment—we hope you will have fun! To get ready, find an audio recorder (like on a cell phone) and ask a member of your family or your teacher to help you. Now, record your voice as you say any sentence you want. When you are done with the recording, play the recorded voice. Does it sound the same as when you spoke? Then, ask the person who is helping you with the experiment to say any sentence they like and record their voice when they talk. Then, play it back. Do you notice any difference between the sound of your helper's real voice and the recorded one?

When you do this experiment, you will probably observe that both recorded voices sound a bit different from the original ones, but there is quite a big difference when you hear your own voice in real time vs. coming out of the audio recorder. However, when you hear someone else's voice "live" or played back, they sound more similar. Did you experience this? Do you have any idea why this happens?

WE HEAR THROUGH THE AIR AND THROUGH OUR BONES

Thanks to hearing, we can identify people, animals, and objects by the sounds they produce. Even without seeing them, you can recognize your mother's voice when she calls you for dinner, your dog's bark when it sees you coming back from school, or the sound of the rain hitting the street. These sounds travel through the air and reach your ears where they are further transmitted (sent) to the brain. The ear has three main parts: the outer, middle, and inner ear (Figure 1) [1]. The outer ear includes the pinna (the only part we can see and that we usually call the "ear"), the ear canal, and the eardrum, which marks the beginning of the middle ear. The middle ear includes three small bones named ossicles, and the inner ear contains the cochlea, which is the snail shell-like structure that you can see in Figure 1.

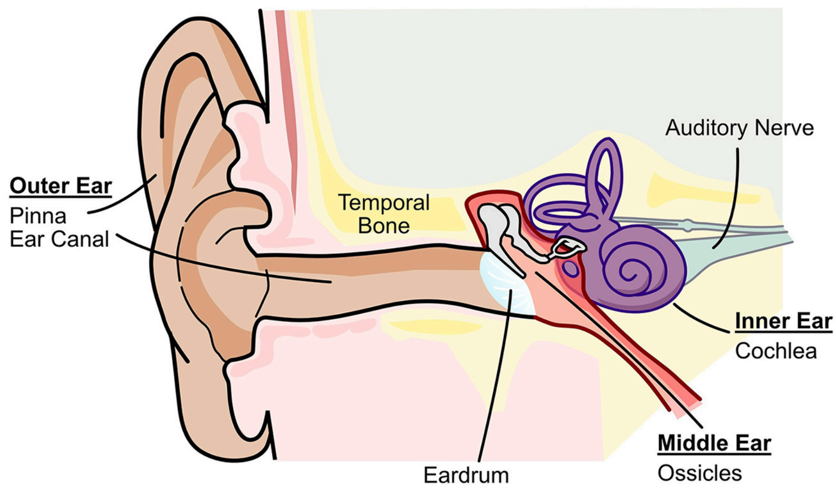


Figure 1

Figure 1

The ear is made up of three main parts: the outer, middle, and inner ear. The outer ear (pinna and ear canal) transmits sound to the eardrum, making it vibrate. Vibrations are amplified by the ossicles in the middle ear and transmitted to the cochlea (inner ear). The cochlea transforms the vibrations into electrical signals that are transmitted to the brain by the auditory nerve. The brain makes sense of the sounds we hear.

The pinna picks up the sound, and the ear canal transmits it to the eardrum. In response to the sound, the eardrum vibrates, which means it shakes (like a guitar string when you play it). The middle ear amplifies these vibrations, which means it makes them bigger, and then transmits them to the inner ear. The cochlea, which is the actual hearing organ, transforms the vibrations into electrical signals. Electrical signals are transmitted by the **auditory nerve** to a part of the brain called the auditory cortex. This brain area helps us to understand the meaning of the sounds we hear ("auditory/audio" means "related to sound").

AUDITORY NERVE

A bundle of long, thin biological "wires" that carry electrical signals from the cochlea to the brain.

The biggest contribution to hearing comes from sounds that travel through the air (blue waves in Figure 2). This phenomenon is called **air conduction hearing**. However, the cochlea also receives vibrations from the skull when a person is speaking. In fact, the sound of your voice is produced by vibration of the vocal cords, which are two small muscles in your throat. Vibrations are transmitted from the vocal cords, the mouth, and the teeth to both cochleae through the skull (red waves in Figure 2). Since the skull is made of bones, this part of hearing is called **bone conduction hearing**.

AIR CONDUCTION HEARING

Hearing due to sounds entering the ears through the ear canal and making their way to the inner ear.

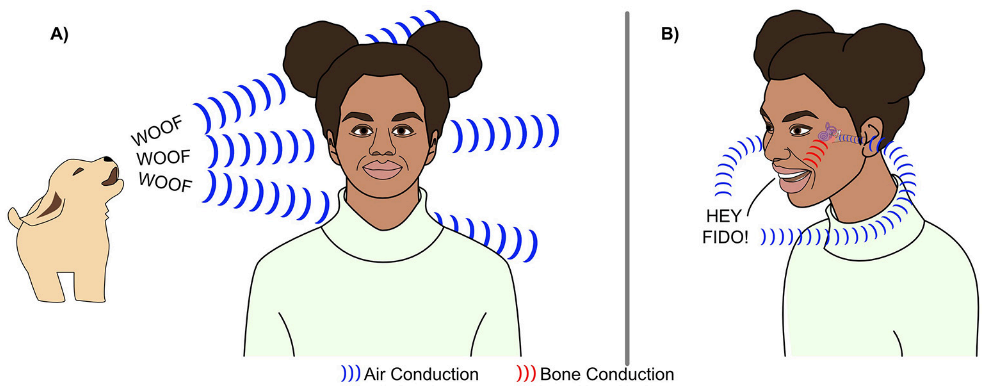


Figure 2

Figure 2

Sound travels to the cochleae in two ways: through air and through bones. **(A)** Fido barks to greet his owner, Sophia. The sound travels through the air (blue waves) and reaches her cochleae as it passes through the ear canal. **(B)** When Sophia greets Fido back, her voice reaches her ears via the air (blue waves), but also via the skull bones (red waves) that start vibrating in response to the sound produced by her vocal cords and mouth. The blue waves represent air conduction hearing and the red waves represent bone conduction hearing.

BACK TO THE EXPERIMENT!

Now that you have learned about how people hear, let us go back to our experiment! Can you guess why your voice sounds different when you speak and when you hear it played back? When you are talking, what you hear includes one component due to air conduction and one due to bone conduction. But when you record your voice, only the air conduction part is recorded, because the microphone is outside your head. So, when the sound is played back, you do not have vibrations traveling from the vocal cords, the mouth, and the teeth to the cochleae, through the bones. The bone conduction part is missing, which is why your voice sounds different from how it usually sounds to you. However, the spoken and recorded voices of your helper sound more similar because the bone conduction hearing component is missing in both cases.

BONE CONDUCTION HEARING

Hearing due to the bones in the skull passing vibrations into the inner ear.

Although your helper's recorded voice sounds more similar to their natural voice, the voices do not sound exactly the same. There are two main reasons for this. The audio recorder includes a microphone that picks up the sound and loudspeakers that play it back. Both the microphone and loudspeakers change the characteristics of voice sounds a little bit.

This experiment allowed you to hear the air conduction component of your voice (when you played back the recording of your voice) and the sum of the air and bone conduction components of your voice (when you heard your own voice while you were speaking). But are you curious to know how the bone conduction component sounds? Tiffany made a recording of the two components of her voice separately ("**air_conduction**" and "**bone_conduction**") and at the same time ("**air_and_bone_conduction**"). You may notice that it is more difficult to understand what she is saying if you listen to the bone conduction component compared to the air conduction. However, it is still possible.

HELPING PEOPLE WITH HEARING PROBLEMS

Doctors and scientists can take advantage of the bone conduction phenomenon to help people with some types of hearing problems. Hearing aids are devices used to improve hearing, but they cannot fully restore it. There are different types of hearing aids depending on the hearing problem. If a person hears loud sounds as if they were quiet, hearing aids can be placed behind the pinna, in the pinna, or in the ear canal, to pick up sounds with a microphone and amplify them (that is, make them louder) before the sounds reach the cochlea. These devices are based on the air conduction principle.

We mentioned earlier that the cochlea is the real hearing organ, and the middle ear amplifies the sounds that reach the cochlea. A person can have hearing problems because the cochlea is damaged and/or because the sound cannot reach the cochlea. If the cochlea is severely damaged, a cochlear **implant** can be used as hearing aid (see Figure 2 of this Frontiers for Young Minds article). Cochlear implants transmit sound from outside the head directly to the auditory nerve. The cochlear implant includes a microphone placed behind the ear to pick up the sound; a transmitter, which transmits the sound signal to a stimulator implanted under the skin; a stimulator that converts the sound into electrical signals; and electrodes placed in the cochlea that stimulate the auditory nerve with the electrical signals. As usual, the auditory nerve sends the signals to the auditory cortex, which makes sense of the sounds [2].

If a person does not have an outer ear, or if the sound cannot reach the cochlea for other reasons, bone conduction hearing aids can be useful. As we explained, the cochlea's job is to convert vibrations into

AIR_CONDUCTION

Press the speaker icon to hear the air conduction component of sound when the following sentence is pronounced: "In this voice recording, you can only hear the air conducted sound of my voice as it is being recorded by a microphone positioned just in front of my mouth as I speak. When I listen to this recording, it sounds different from how I think my voice sounds when I speak to other people".

BONE_CONDUCTION

Press the speaker icon to hear the bone conduction component of sound when the following sentence is pronounced: "In this recording you now hear only the bone conducted sound of my voice as a bone conduction microphone is positioned on my forehead and isolated from any other sound in the room. You may notice that it sounds a bit deeper and less clear, and this is due to the absence of air conducted sound".

AIR_AND_BONE_CONDUCTION

Press the speaker icon to hear the air and bone conduction components of sound when the following sentence is pronounced: "In this recording of my own voice, both the air and bone conducted sound are recorded simultaneously, so it is a good representation of what my voice sounds like to me. As you may hear, this sounds very different from only the air conducted sound that other people hear when I speak".

IMPLANT

A device inserted into the body by a surgeon, for example, the cochlear implant or bone conduction implant.

TRANSDUCER

A device that transforms a signal of a certain type (like sound) into a signal of another type (like electrical activity).

Figure 3

Bone conduction implant. The implant includes a microphone that picks up the sound, a receiver that receives the sound, and a transducer implanted in the temporal bone of the skull that transforms the sound into vibrations. Bone vibrations reach the cochlea, which processes the signals so that a person can hear through bone conduction.

electrical signals that can be interpreted by the brain. If the outer or middle ear cannot transmit sounds to the cochlea, bone conduction hearing aids can replace this function. The device is positioned behind the ear to vibrate the skull close to the cochlea. It can be kept in place by a soft band [3], attached by a surgeon to the skull with a metal screw [4], or inserted by a surgeon into a small hole in the skull (Figure 3) [5]. A microphone picks up the sound from outside the head, a receiver receives the sound signal, and a **transducer** converts the sound signal into vibrations and vibrates the skull. Bone conduction transmits these vibrations to the cochlea, which processes them as usual, allowing the person to hear! Of course, a person with a bone conduction hearing aid hears sounds differently from the way a person with an intact hearing system does. However, this is a big help for people who cannot hear via the ear canal!

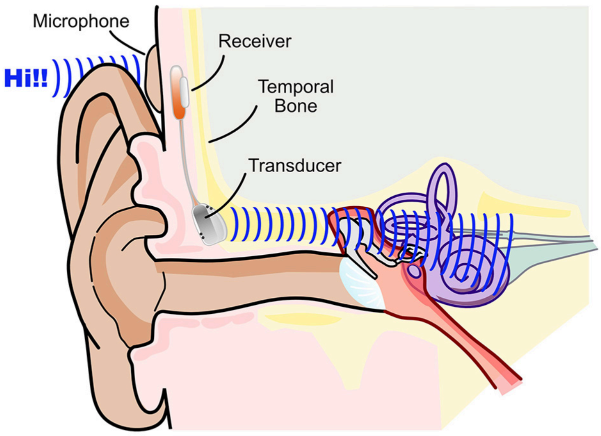


Figure 3

Bone conduction is also helpful for those who can hear properly. For instance, there are some headphones that, instead of earphones or earmuffs, use transducers on the skull bone close to the ears—very similar to bone conduction hearing aids. Their vibration allows users to enjoy music while leaving their ear canals free to hear what is happening around them! This can make it safer to wear headphones while doing other tasks, like exercising outdoors, because users listen to the music by bone conduction and listen to the noises in their environment by air conduction.

In summary, we hear sounds thanks to air and bone conduction. These two sound conduction principles can be used to build hearing aids that can help people with many different hearing problems, in the way that is best for each person.

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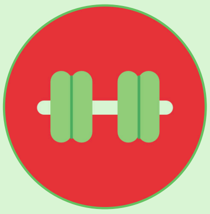
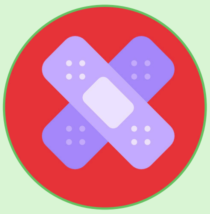
YOUNG REVIEWERS



ADI, AGE: 13

I am a Lego enthusiast who loves science and math. I also enjoy making 3D prints of airplanes and gears. The most fun thing for me to do when not coding or 3D printing is to read about new topics in science and technology. I enjoy immersion in projects and videos of these topics that allow him to learn more about them in a fun way. I play percussion instruments and am just learning a Tenor Saxophone.



DIYA, AGE: 13

I am a proud twin who loves to listen to music and enjoy art. I am passionate about helping people who do not have access to resources that help enhance STEM learning. I help run an engineering summer camp every year and visit countries where I can share my learning. I am also a dancer and love to spend time with my fluffy dog.

NEIL, AGE: 8

I have a big passion for art, from drawing to shaping ceramics. I am also a fan of fantasy books, especially *The Mysterious Benedict Society*. Outside of art and books, I am dedicated to gymnastics and am a member of a professional gymnastics school. I have a younger brother and sister, who are also my friends, and we play together every day.

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I am an associate professor of neural engineering at Chalmers University of Technology in Gothenburg in Sweden. I am an engineer who collaborates with students and doctors to study how the brain and muscles help us to move, to help people who have movement problems. I have been interested in science since I was a child, and I would like to share what I learned with young people. During my spare time, I like to travel and visit new countries. *muceli@chalmers.se

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I am a Ph.D. student researcher at Chalmers University of Technology in Gothenburg in Sweden. I study how humans control complex hand movement by measuring and analyzing the electrical activity of muscles during movement. I am interested in how human movement control redevelops after a traumatic injury or brain problem. If we can understand this better, we can improve medical care for these conditions, to help patients return to the activities they enjoy. This is a fascinating field that requires close cooperation between engineers, scientists, doctors, and patients living with neuromuscular problems.

KARL-JOHAN FREDÉN JANSSON

I am working as a researcher in biomedical engineering at Chalmers University of Technology in Gothenburg in Sweden, and I have been working in the bone conduction field since 2012. I graduated with a Ph.D. in 2017 and my research is focused on bone conduction technologies. I also teach electronics classes at the university for undergraduate students in electrical and biomedical engineering.

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I am an associate professor in biomedical engineering at Chalmers University of Technology in Gothenburg in Sweden. I am an engineer and divide my time between research and teaching. My research is in bone conduction hearing, and I have been studying how the vibrations travel through the skull bone. Together with my colleagues, I have been working on different applications within bone conduction hearing, such as hearing aids, investigations on how well people hear, and also investigations of dizziness. When I am not working, I like to spend time with my family and I also like traveling and dancing.