The Tiny Science Behind How We Hear and Feel

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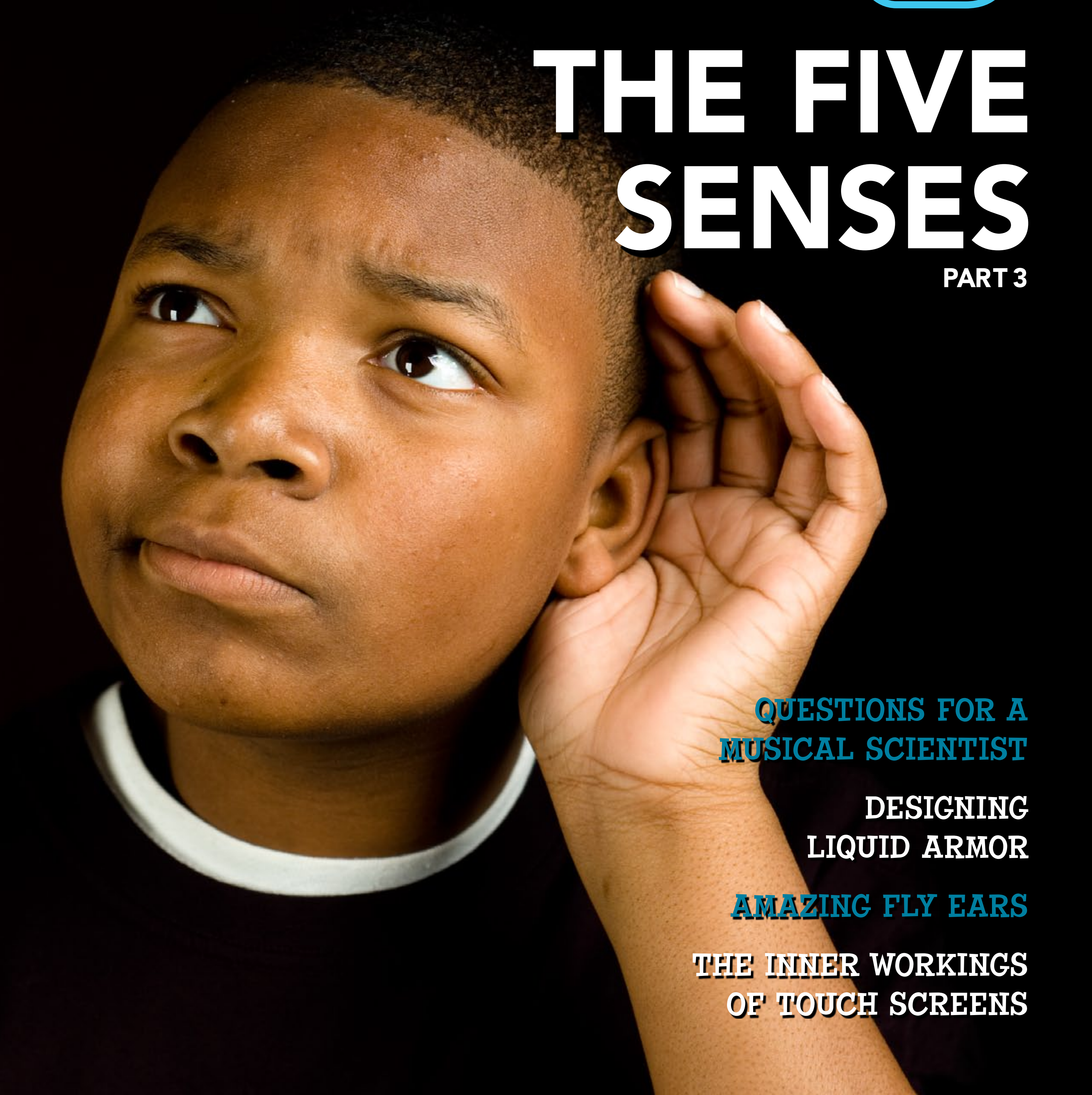
# NANOOZE



## THE FIVE SENSES

PART 3

QUESTIONS FOR A MUSICAL SCIENTIST

DESIGNING LIQUID ARMOR

AMAZING FLY EARS

THE INNER WORKINGS OF TOUCH SCREENS

# NANOOZE

ALL ABOUT THE THINGS TOO SMALL TO SEE

## Welcome to Nanooze!

*What is a Nanooze? (Sounds like nah-news.) Nanooze is not a thing, Nanooze is a place to hear about the latest exciting stuff in science and technology. What kind of stuff? Mostly discoveries about the part of our world that is too small to see and making tiny things using nanotechnology. Things like computer chips, the latest trends in fashion, and even important stuff like bicycles and tennis rackets. Nanooze was created for kids, so inside you'll find interesting articles about what nanotechnology is and what it might mean to your future. Nanooze is on the Web at **www.nanooze.org**, or just Google "Nanooze"—you'll find interviews with real scientists, the latest in science news, games and more!*

### HOW CAN I GET NANOOZE IN MY CLASSROOM?

*Copies of Nanooze are free for classroom teachers. Please visit **www.nanooze.org** for more information or email a request for copies to **info@nanooze.org**.*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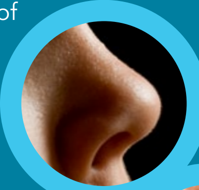
# THE FIVE SENSES PART 3

## THE LAST ISSUE IN OUR 3-PART SERIES DEDICATED TO THE FIVE SENSES: EXPLORING HEARING AND TOUCH

Most of the time we almost forget about them but there are five of them—smell, sight, hearing, taste and touch. A stinky sock, pizza, Red Hot Chili Peppers (the sound or the taste?), a bee sting (ouch). We get a stuffed nose and then we can't taste much of anything. These are our five senses. How do they work? And what does this have to do with science? Lots.

### WHAT IS ACTUALLY HAPPENING INSIDE OUR BODIES WHEN WE SENSE SOMETHING?

We have lots of different kinds of cells in our body. Some of these cells help with our different senses and each sense involves a special kind of cell. Cells inside our eyes detect photons of light, while tiny, delicate parts of our ears sense the different vibrations of sound waves. All those cells are hooked up to our central nervous system, which relays the signals triggered by those special cells to our brain where they're processed into a response. It may sound simple—touch an ice cube and your brain tells you "it's cold"—but it involves a lot of specialized cells and a complex transfer system to transmit signals to the brain. Then once the signal arrives, your brain needs to figure out what's going on and give you the right picture, sound, smell, taste or feeling. And it all happens at lightning speed!



### SO, WHAT DO OUR FIVE SENSES HAVE TO DO WITH NANOTECHNOLOGY?

Scientists study our five senses to learn more about how they work and are finding out that they are pretty complicated. Nanotechnology is helping us figure out what's really happening in the tiniest parts of our bodies and can help us develop new tools that can sense like we do.

## NANO KNOW-HOW

*Learning about nano stuff is fun but it can be complex, so it helps to keep these four important facts in mind:*

### 1. All things are made of atoms.

It's true! Most stuff, like you, your dog, your toothbrush, your computer, is made entirely of atoms. Things like light, sound and electricity aren't made of atoms, but the sun, the earth and the moon are all made of atoms. That's a lot of atoms! And they're incredibly small. In fact, you could lay one million atoms across the head of a pin.

### 2. At the nanometer scale, atoms are in constant motion.

Even when water is frozen into ice, the water molecules are still moving. So how come we can't see them move? It's hard to imagine that each atom vibrates, but they are so tiny that it's impossible to see them move with our eyes.

### 3. Molecules have size and shape.

Atoms bond together to form molecules that have different sizes and shapes. For instance, water is a small molecule made up of two hydrogen atoms and one oxygen atom, so it is called $H_2O$. All water molecules have the same shape because the bonds between the hydrogen atoms and the oxygen atom are more or less the same angle. Single molecules can be made up of thousands and thousands of atoms. Insulin is a molecule in our bodies that helps to control the amount of sugar in our blood. It is made up of more than one thousand atoms! Scientists can map out the shapes of different molecules and can even build most types of molecules in the lab.

### 4. Molecules in their nanometer-scale environment have unexpected properties.

The rules at the nanometer scale are different than what we usually encounter in our human-sized environment. For instance, gravity doesn't count because other forces are more powerful at the molecular level. Static and surface tension become really important. What is cool about nanotechnology is that we can make things that don't behave like we expect. Things are really different down there!!

# Q&A *with* Catherine Oertel

*Scientist, teacher and...organist!*

*Tell us a bit about your background.* I grew up near Cincinnati, Ohio, and went to Oberlin College, also in Ohio. It is a small school with programs in the sciences as well as in music and the arts. I went to graduate school in chemistry and got my PhD at Cornell University, and afterward I spent some time doing research in Sweden. In 2006 I got the opportunity to begin teaching at Oberlin, the same place where I had been a college student!

*When you were a kid what interested you about science? What was the first experiment that you did?* I have always been interested in making things and doing things like building models and working on crafts. Science also often involves inventing something new, figuring out how to build a device or designing an experiment. I think that the first experiment I ever did was probably the "kitchen chemistry" reaction of mixing baking soda and vinegar and watching the transformation.

*So what happened when you mixed this stuff up? Did it make a mess?* The mixture began to bubble and fizz and it almost ran over the sides of the container.

*What are your days at work like being a professor?* I spend at least some time teaching every day. I teach chemistry classes, and I also work with students who are doing research in my laboratory. I also spend time planning my classes and preparing demonstrations and activities for my students.

*Is that fun? Is it what you imagined it would be?* In most ways, it is how I expected it would be. It is interesting to learn about what happens "behind the scenes" at a school and to be part of some of the planning and decision-making that goes on. I find that it is a lot of fun to work with students, and I also enjoy the fact that this is a job where I am always continuing to learn new things, too.

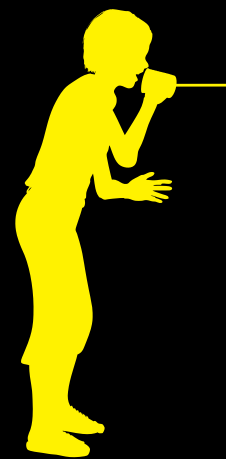
*Where do you come up with your ideas?* I get a lot of ideas from reading articles that other scientists have written about their research and from meeting other scientists at conferences.

*Part of your research is studying pipe organs. Are you a musician?* I actually play the organ, which is how I got interested in this research project. I found out that very old organs are often damaged by corrosion, which causes holes to form in their pipes. I was able to become part of a group of scientists that is trying to find out why this happens and how it can be prevented. It turns out that the cause of the corrosion is acid that comes from the wood that is used to build the organs. The acid is released as part of the natural aging process of wood, and it attacks the metal to first form small pits and later much bigger cracks and holes. There might be ways to stop this by protecting the metal from the acid or by finding a way to reduce the amount of acid in the organ.

*When you hear a sound do you think about the science behind the sound and try to figure out what materials are involved? Like you hear a bell and think, hm, that sounds like copper?* It's very interesting to think about how materials affect sound. You've probably noticed that hitting a piece of metal, like a bell, makes a very different sound than tapping a wooden box or a plastic container. If you were to look at these materials under a strong microscope, you would see that their structures are different. The differences in their structures cause them to interact with sound waves in different ways. You've probably noticed that the sounds people's footsteps make as they walk down the hallway are not all the same. This is partly because of the different materials used to make the soles of their shoes!

*If you weren't involved in science, what do you think you might be doing?* I really enjoy teaching, so I think that I would be still be a teacher or professor, but in a different subject.

# Listen Up!



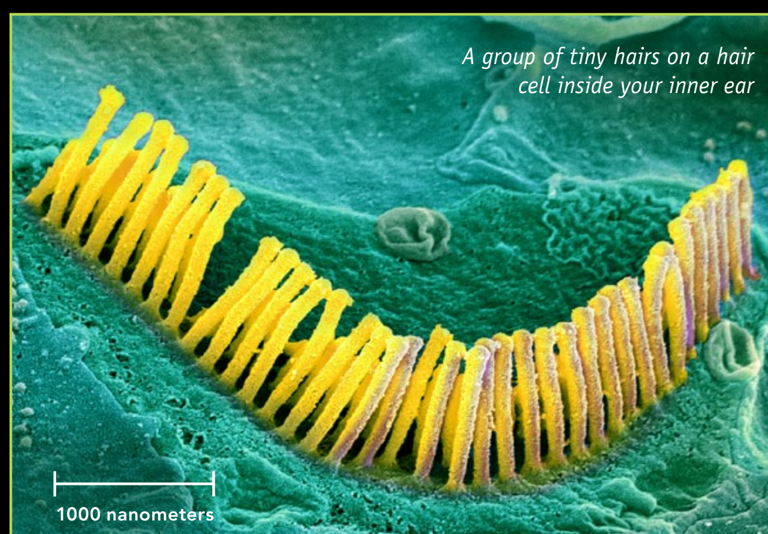
**Hearing and touch both involve a physical stimulus that is picked up by a special set of cells in our bodies. These cells then signal our brain, which tells us, "Oh, I can hear my dog barking," or "That's my dog's wet tongue licking my face."**

The sounds we hear can start from someplace close, such as a friend whispering, or from very far away, like a distant clap of thunder. When a sound is made a physical vibration is created.

If a drummer whacks the top of a drum, vibrational movement from the drum forces air molecules to move and that movement then forces neighboring air molecules to bump into other molecules and so on and so on. It's the air molecules moving only a few nanometers that carries the sound from the drum to your ear.

Sound waves are happening all the time, all over the place. Close your eyes and listen. How many different sounds can you hear right now?

Once the sound reaches you, your outer ear is shaped perfectly to collect the sound waves and direct them into your inner ear. The sound waves make your eardrum, called the **tympanic membrane**, vibrate and that vibration is amplified over 20 times by different parts of your ear. Finally, a set of very special cells buried deep inside your ear, **hair cells**, take these vibrations and translate them into electrical signals that are sent to your brain, which perceives these signals as sounds. Each hair cell has a group of tiny hairs projecting off of it. The tiniest parts of these hairs are very, very small, about 250 nanometers across. That's about 400 times smaller than a hair on your head!



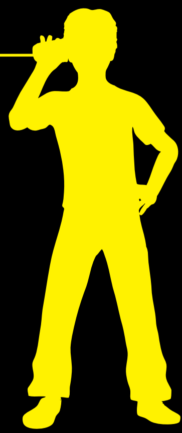

*A group of tiny hairs on a hair cell inside your inner ear*



*The tiny hairs that project from the hair cells in your inner ear are much, much smaller than the hairs on your head. The smallest, sound-sensitive parts of the hairs are only about 250 nanometers across. Very loud sounds can damage your hair cells, causing permanent hearing loss.*

## The many speeds of sound

*Sound travels at a certain speed depending upon what it is traveling through. So in the air, sound travels at 767 miles per hour. In water it moves faster, over 3,000 miles per hour and in steel even faster still, more than 13,000 miles per hour.*



## Did you feel that sound?

*Sound waves travel through air and through a lot of different kinds of matter. They don't travel through outer space because there aren't enough molecules to carry the sound waves. Sound waves can even travel through a string with two cans on the ends. But you can also "hear" something by feeling the vibrations. Crank the stereo up and go into another room. Then put your hands on the wall and see what you can feel. Then turn it down before the neighbors start to complain.*

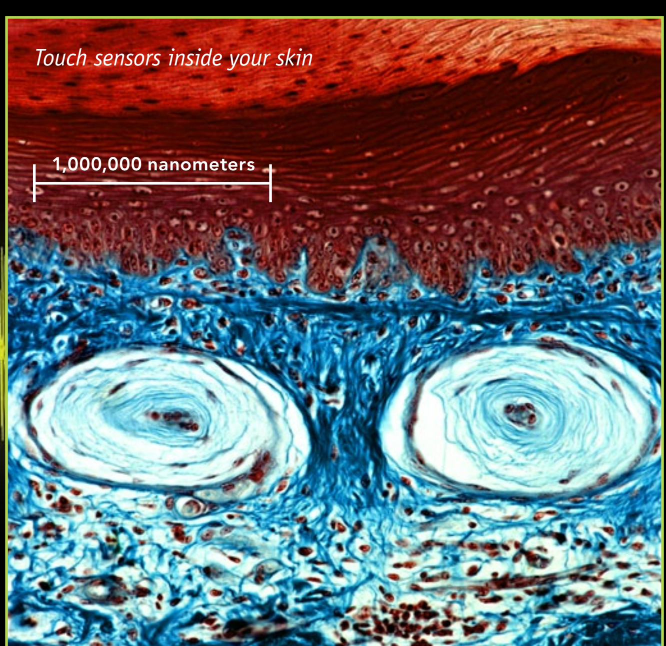
# The Power of Touch

**Like hearing, your sense of touch responds to physical stimuli. The big difference with your sense of touch is that it is happening all over your body, all the time.**

Hearing, seeing, tasting and smelling all involve only specialized parts of your body. But your sense of touch is extraordinarily complex—you can "feel" temperature, pressure and pain.

There are cells inside our bodies called **mechanosensors**. These cells take something physical—like a finger pressing a key on a laptop—and convert that action into a signal that is transmitted to the brain. There are about 50 sensors in every square centimeter of your skin, and about five million total all over your body. Some places, like the tips of your fingers, have a lot more sensors than, let's say, the skin on your back. This makes your fingers more sensitive than other parts of your body. All five million of these sensors are wired to your brain and are working all the time to sense the environment around you.

Five million sensors is a lot, but compare that number to the amount of transistors in an average computer chip. A little chip that is smaller than one inch square can have over 100 million transistors! These tiny transistors are all wired together and processing data at rapid speeds to keep your computer working properly.






*This cross-section of human skin shows the outer layer, the "epidermis" (red), and the underlying "dermis" (blue). The two circular shapes are "Pacinian corpuscles," sensory organs that are found deep in the skin that respond to pressure, vibration and tension.*

# Pour on the Armor!

Can nanotechnology help to protect soldiers in combat? Maybe some day. In the old days, knights would walk around with really heavy, clunky armor for battle. It offered lots of protection against swords and arrows, but it made it hard to do much of anything else!

## Armor needs to be strong, but also light-weight and flexible.

So scientists are working on a material they call liquid armor. One possible way to make better armor is to use something called a **shear thickening fluid**. What does that mean? It is a liquid that the harder you push on it the tougher it becomes.

## Liquid armor is made by suspending a lot of special nanoparticles in a liquid.

When you push on the nanoparticles-liquid mixture, the interaction between the particles seems to make the liquid thicker. So liquid armor isn't rigid until it is hit with significant force.

### Try it Yourself!

You can make a **shear thickening fluid** at home with cornstarch and water. Empty half a box of cornstarch into a large bowl. Add water slowly and stir to make a thick paste. Can you roll the paste into a ball? Try cutting it with a knife. What happens when you poke it slowly? What about when you poke it fast?

Now, you can't easily make liquid armor but you can make a shear thickening fluid at home. Take corn starch and mix in water slowly to make a thick paste. If you get it just right you will see that the faster you push your finger into it the thicker it gets. Slap the mixture hard and it will feel like a solid. Pick it up slowly and it will run through your fingers.

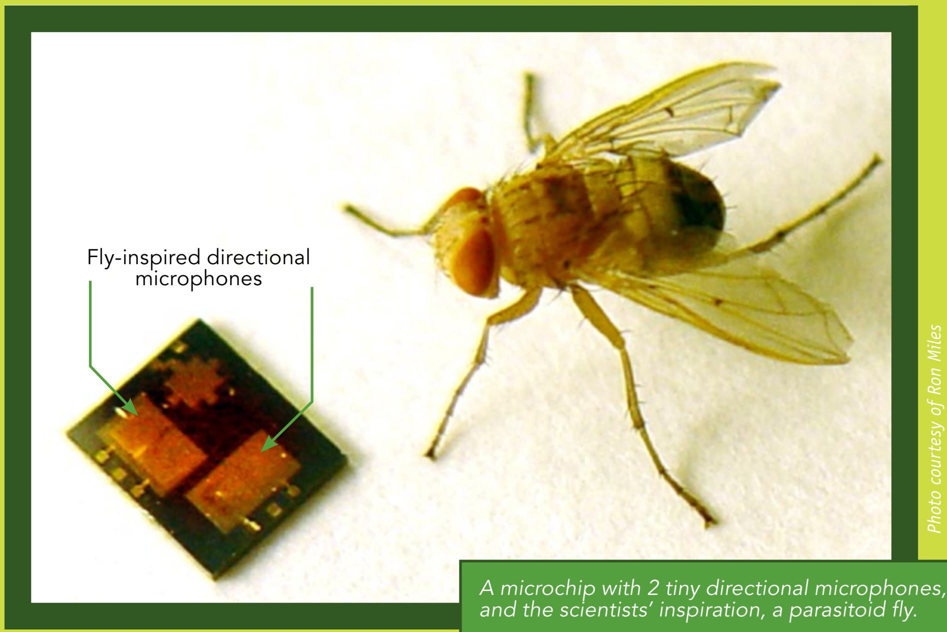
Instead of cornstarch, scientists are experimenting with different kinds of nanoparticles—particles made from calcium carbonate, the same material that oyster shells are made of, or silica.

Because of their shape, these particles have a hard time slipping past each other, especially if they are moving fast. To make liquid armor, scientists are experimenting with strong materials, like Kevlar®, that are treated with a solution of nanoparticles.

Liquid armor is still in the testing phase but it shows promise and maybe one day will protect soldiers and police officers from getting hurt.

# Hearing Like a Fly on the Wall


Most of us take our hearing for granted. We hear something and we are able to figure out where the noise is coming from. This is called **directional hearing** and it's important in the design of hearing aids. Hearing aids help people to hear but also make it hard for them to figure out where the sounds are coming from. Scientists are trying to make a better hearing aid to help people who need them.




*A microchip with 2 tiny directional microphones, and the scientists' inspiration, a parasitoid fly.*

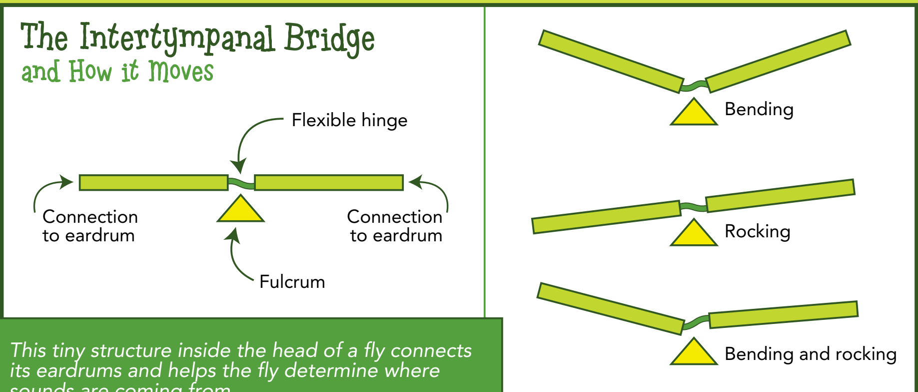
Ron Hoy, a biologist from Cornell University, Daniel Robert, of the University of Bristol, and Ron Miles, an engineer from Binghamton University, got together to study a specific fly species with great directional hearing. Most flies can hardly hear at all, but the flies that these scientists study (*Ormia ochracea* or the parasitoid fly) need special hearing to locate the crickets they use to help incubate their offspring.

Using powerful microscopes, scientists figured out that the fly has a tiny structure called an **intertympanal bridge** that connects its ear drums. The bridge makes the ears act like two end-to-end diving boards that are hinged together. The tiny differences in the way they respond to sounds (depending on if the sound is coming from the left or the right) is used by the fly to figure out where the sound is coming from.

What was next for the scientists? They went into the laboratory and built devices that mimic the ear of the fly. To do that, Ron Miles and his team made tiny microphone diaphragms (the diaphragm is the part that picks up sound) that work just like the fly's coupled ears and hooked them up to some sophisticated electronics. The microphone diaphragms are about 2 millimeters long and about 1 millimeter wide. They were created using nanotechnology, a lot of the same techniques used to make the little devices in cars that trigger air bags.

The result? A tiny directional microphone—and it works much better than the current hearing aids. There is still a lot of work to be done, because making tiny fly ears out of silicon (the stuff they use to make computer chips) isn't rugged enough. But some day hearing aids will be a lot better because of the inspiration these scientists got from a tiny little fly!

## The Intertympanal Bridge and How it Moves




*This tiny structure inside the head of a fly connects its eardrums and helps the fly determine where sounds are coming from.*

# Just a Touch Away...


Photo courtesy of Apple

**Apple iPhone**

*The iPhone's touch screen can recognize swiping movements and two-finger zooming.*

Step on a tack—ouch, it hurts! But what if the tack is only 100,000 nanometers tall (about the width of a hair) instead of 10,000,000 nanometers (the height of a normal tack)? Can you feel it? Probably not, it's too tiny and your feet aren't sensitive enough.

Touch is one of the most complex of the senses. Your sense of touch involves lots of different sensors in your body that respond to temperature, pressure and pain. In the laboratory, scientists have been developing different kinds of things that help measure touch or are controlled by touch. Some of these things are even more sensitive than our own sense of touch.

One of the most well-known devices is a touch screen—it's what we use to control the Apple iPhone, the iPod touch, and other devices. Touch screens have three parts: some kind of sensor, a controller, and then software that tells the device where you have touched the screen.

One kind of touch screen has tiny wires in layers that are separated by a layer of insulation that is only a few thousand nanometers thick. When you touch the screen the insulating layer between the two layers of wires gets squished and a tiny amount of electricity moves from one layer of wires to the other. The closer the wires are together the more accurate the touch screen is at figuring out where you have touched it. The newest touch screens can even figure out if you are using one or two fingers. That is cool because then you can do so many more things on a touch screen with different kinds of gestures. Use two fingers and spread them apart, the image gets bigger. Whirl two fingers around, and the image rotates.

Another kind of touch screen developed by Jeff Han at New York University doesn't use electrons but bounces light between two layers of plastic that are less than 500 nanometers apart—that's really small, about 1/200th the width of a hair! Press on the top of the plastic with your finger and it changes the gap between the plastic layers, which changes the way the light bounces around between the layers. By using software that takes a picture of the screen about 30 times a second, the touch screen can record the position of everything that touched the screen—one finger, two or all ten.

A more sensitive touch screen gives us a lot of ways to use some cool finger gestures to tell the computer or whatever the touch screen is connected to what to do. Imagine editing a photograph with just your hands, directing a bunch of robots in a warehouse with just your fingers, or playing a game where you don't even need a separate controller!


Photo courtesy of HP

**HP TouchSmart PC**

*With this touch screen computer, you can share photos, listen to music, check email and watch TV, all without touching the keyboard!*