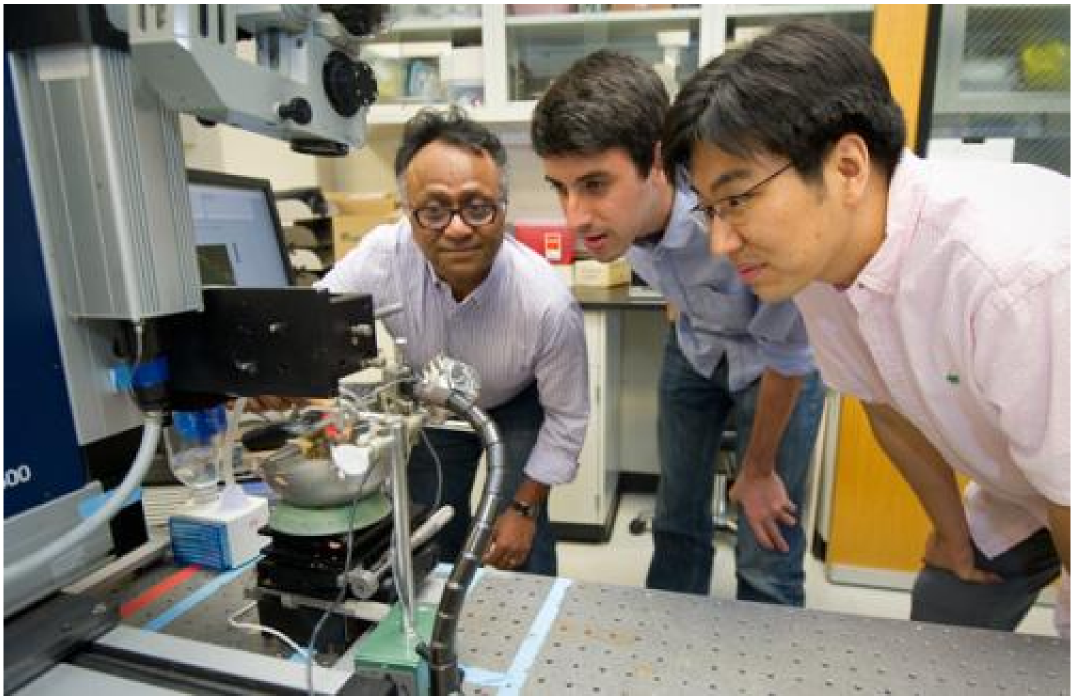
Scientist looks for a deeper understanding of hearing through the bones in our heads

August 6 2013, by Glen Martin



Consulting Associate Professor Sunil Puria, graduate student Peter Gottlieb and postdoctoral scholar Nam Keun Kim use a 3-D laser Doppler vibrometer to measure motions in a human cadaver ear.

(Phys.org) —Stanford mechanical engineer Sunil Puria is unraveling the mysteries of bone conduction hearing, which could lead to a better understanding of hearing – and some types of hearing loss.

It is a question that has long perplexed paleontologists and auditory scientists – and mechanical engineer Sunil Puria, a consulting associate professor at Stanford: Why do mammals have three middle ear bones?

"Reptiles don't have them," Puria muses in his office in Durand Hall. "Birds don't have them. If you find a fossil in the field, the surest way to determine if it's a mammal is to look for those three ear bones. But why are they there? Why do we need them?"

Puria, whose research centers on middle and inner ear biomechanics, has begun focusing on this conundrum in earnest. If anyone can identify the precise biological imperative dictating mammalian ear structures, it could well be Puria. Auditory mysteries, to a very large degree, are his life; his latest research, for example, has led to a far more textured understanding of the role bone conduction plays in hearing.

"We hear sound through two pathways," Puria explains. "The first is air conduction – sound passes through the air and into the ear canal, where it vibrates the eardrum. These vibrations are transferred to a sensory organ – the cochlea – through a chain composed of three tiny bones: the malleus, incus and stapes."

But we also hear through bone conduction, Puria explains – at least, we hear our own voices. When we speak, vibration of the vocal cords engenders a companion vibration in the bones of the skull, stimulating the cochlea. This pathway augments the air conduction pathway.

"That's why your recorded voice sounds so different to you," says Puria. "The bone conduction pathway is eliminated."

As he talks, Puria produces a pair of earphones with metal contacts rather than the usual earbuds. "You can also experience the opposite effect with these," he says, placing the contacts on the mastoid bones of his interviewer. "They allow you to hear solely through the bone conduction pathway."

He plays a track: Pink Floyd's "Money." The music sounds radically different from the Pink Floyd one normally hears solely through air conduction. The low tones seem somewhat washed out, while the high tones are richer, more resonant.

Though air conduction is the most important hearing pathway, bone conduction plays an essential secondary role – and is particularly important from the perspective of technology. Some hearing aids are based on it, and it is playing an expanding role in the design of personal computing devices. Google Glass, for example, harnesses the bone conduction pathway to eliminate the need for earbuds.

Credit: AI-generated image (disclaimer)

Understanding bone conduction, Puria continues, is predicated on understanding the role the stapes – the smallest bone in the human body – plays in this pathway. The stapes connects to the cochlea through the stapes annular ligament (SAL) – a minute gasket of tissue. It is essential that this ligament remains soft and pliable to function properly, Puria says.

Solving a riddle

A disease known as otosclerosis provides insight into the mechanisms of bone conduction, particularly in regard to the stapes, Puria says. Otosclerosis causes the SAL to ossify, which inhibits motion of the stapes, restricting the transmission of vibrations to the cochlea.

In 1950, audiologist Raymond Carhart demonstrated that otosclerosis patients suffered hearing loss of 10 to 20 decibels in the 1- to 2-kilohertz range, with no major loss at either higher or lower frequencies. This lost frequency range has since been known as "Carhart's Notch," and its manifestation is considered a prime indicator of otosclerosis.

Generally speaking, experiments have confirmed that Carhart's Notch can be attributed to the loss of middle ear bone movement because of ossification of the SAL; the bones can't move freely and hence can't transmit vibrations efficiently to the cochlea.

But there's a riddle here, Puria says. When stimulated by vibrations, especially low-frequency vibrations, every part of the skull shakes by the same degree. But the middle ear's "ossicular chain" – which includes the stapes – is suspended by the eardrum, two tendons and several ligaments; it essentially hangs free from the skull, creating a kind of inertial lag in the bone conduction pathway. The middle ear bones still vibrate – ultimately stimulating the cochlea – but the resulting auditory sensation is more akin to normal air conduction hearing than bone conduction hearing, meaning there should be some bone conduction low-frequency hearing loss in otosclerosis patients. There isn't. Why?

To answer the question, Puria and his colleagues created a 3-D computer model of the human inner ear and the middle ear. They then ran scenarios on the model. First, they subjected the model ear to inertial motion only; they then ran tests that simulated both inertial motion and the compression on the inner ear bones that such motion could be expected to generate.

"When only inertial stimulation was applied, a Carhart Notch showed up at 1 to 2 kHz. But there was also low-frequency hearing loss," Puria says, "and that went against known clinical experiments, which showed no low-frequency loss."

But when the researchers included bone compression into the simulation, bone-conducted low frequency hearing jumped up, confirming the clinical data.

"Previously, researchers didn't think bone compression played much of a role in bone-conducted hearing at low frequencies," Puria says. "We showed that in all likelihood it is a significant factor."

What are the possible applications of the discovery? Given that Google Glass already exploits the bone conduction pathway, any research that can further elucidate the process is likely to attract attention in the biomechanics realm. But a tech payoff isn't what attracted Puria to his work.

"We can't forget the necessity for pure research, for inquiry that's undertaken simply to discover how things work," he says. "This kind of research often leads to breakthrough technologies, of course – but there's a larger value, a social value. That's what really excites me about it."

And the mystery of the three ear bones in the mammalian skull? Puria says a disease called semi-circular canal dehiscence may provide a clue. The disease causes thinning of one of the semi-circular canals in the ear, a phenomenon discovered by Stanford's current medical school dean, Lloyd Minor.

"When that happens, the bone conduction pathway is greatly augmented – sometimes patients may hear their heartbeats or their eyeballs move in their sockets. That could pose a risk for mammals," Puria says. "You may not be able to hear some sounds in your environment via the air pathway, sounds that could indicate, say, prey or predator. You may not eat or you may get eaten as a result."

So those three middle ear bones in mammals, he theorizes, may moderate bone conduction hearing. It's a mystery he's still working to solve, testing hypotheses with support from the National Institutes of Health.

Provided by Stanford University

Citation: Scientist looks for a deeper understanding of hearing through the bones in our heads (2013, August 6) retrieved 28 April 2024 from https://phys.org/news/2013-08-scientist-deeper-bones.html