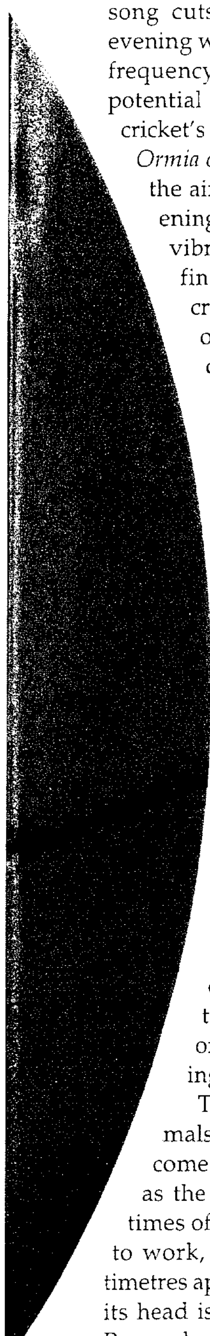
Inspired by a parasitic fly, engineers are designing a hearing aid that is smaller and more effective than anything around today. *Scott Lafee* reports



D. Robert

LOUD and insistent, the cricket's love song cuts through the dusky summer evening with chirping urgency. The high-frequency clicks are meant as a call to potential mates, but tonight they are the cricket's undoing. Nearby, a small female *Ormia ochracea* fly listens in, leaps into the air and buzzes through the darkening sky, homing in on the cricket's vibrato. Within seconds, the fly finds its target, settles on the cricket's back and deposits three or four small white larvae, which quickly burrow beneath the cricket's wing covers, then into the body itself.

Over the next week, the grubs will greedily consume the cricket's innards, until finally it will keel over dead, a mere shell of its former self. Their meal finished, the plump larvae will emerge, ready to form into the next generation of adult flies.

Such gruesome tales, of course, are not unusual in nature. *O. ochracea* looks like an ordinary, if brightly coloured, housefly with bulbous, orange-red eyes and a single pair of spindly wings on a mustard-coloured body about the size of a small pencil eraser. What is unusual about this fly is its ability to home in on the cricket's song with amazing accuracy.

This is no easy task. Most animals work out where a sound has come from using acoustic clues such as the difference between the arrival times of sounds at each ear. But for this to work, the ears must be several centimetres apart. How can a fly do this when its head is only a few millimetres wide? Researchers in the US think they know the answer. What's more, they say that by copying the fly's hearing mechanism it will be possible to build a hearing aid for humans that is dramatically better than those available today.

Worldwide, roughly 1 person in 10 has impaired hearing. In the US alone, this amounts to between 28 and 30 million. And although hearing-aid technology has come a long way since Grandpa's unsightly shirt-pocket device that shrieked with noisy feedback, today's hearing aids are basically the same. They rely on a microphone to pick up sounds, an amplifier to increase their volume and a speaker to redirect these louder sounds into the ear.

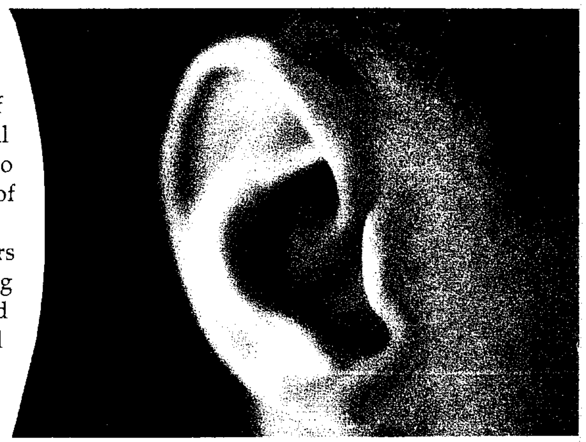
Rich and different

Humans can hear sounds with frequencies ranging from 20 hertz to 15 kilohertz, and we are most sensitive to noises in the 1 kilohertz to 6 kilohertz range. "High frequencies are vital because they are what make speech intelligible. In everyday conversation, consonants are high-pitched. Consonants are what make languages rich and different. They comprise the stopping sounds, the clicks," says Ron Hoy, a professor of neurobiology and behaviour at Cornell University in New York state who is studying the hearing mechanism of *O. ochracea*.

Hearing loss in humans usually occurs in the higher frequency ranges, leaving many people able to pick up background noises like the general din of a cocktail party but deaf to the words spoken by the person standing next to them. Although hearing aids can be designed to preferentially amplify the high frequencies in speech, there's still a big problem. None of the aids provides directional information comparable to a pair of working human ears, says Hoy. For anyone who has difficulty distinguishing sounds, a hearing aid would be much more useful if they could tune into sounds produced in front of them, while ignoring those that come from behind. With today's technology, such a hearing aid would be bulky and power hungry, but *O. ochracea* may have the answer.

"Crickets produce sounds between 2 kilohertz and 7 kilohertz, and the flies are precisely tuned to hear them," says Hoy. "But it's not enough for the fly to simply say: 'Hey, there's a cricket out there.' It has to be able to zero in on it, to find a single, unseen insect out in the open." There is no doubt that the flies are tuned in to the sound of a cricket. In his lab, Hoy has built a specially adapted cage with speakers at each end through which he can play the sound of a cricket. The behaviour of *O. ochracea* in Hoy's experiments show that the flies always follow the sound. Clearly, they are using a hearing mechanism that is entirely different to the ones other animals use.

In humans, as in other large mammals, the ear consists of a membrane or eardrum that separates the external ear from the middle ear. This membrane



Tony Stone Images

vibrates in response to the changes in air pressure that we perceive as sounds. Each ear is a separate entity, acoustically independent from its partner on the opposite side of the head and separated from it by the dense, muffling tissues of the brain. An approaching sound wave arrives at each at a slightly different moment, depending on which one is closer to the sound's source. The brain is able to detect this time difference, which is called the interaural time difference. That information, combined with how strongly the sound wave strikes each of the eardrums, called interaural intensity difference, helps us work out where a sound is coming from.

"Most vertebrates pretty much do it the way we do it," says Hoy. But there are

'The fly has developed a novel hearing system of its own and wears its ears on its chest'

some exceptions. The ears of smaller animals like moles, and some birds and frogs, are linked by an internal air passage. These animals hear sounds not only from the outside of their ears, but also from the inside, as this air passage transmits sounds from one ear to the other through the head. Sensing the time it takes for the sound to travel along this passage relative to its arrival time at each ear helps them to work out where the sound came from. Insects' hearing organs are set up in a similar way.

Leggy eardrums

Some of these creatures try to improve their directional hearing by placing their auditory organs as far apart as possible. The elaborate hearing system of the cricket is a good example. It employs sound receivers on the tibiae of the front legs, a location comparable to the shin bones of humans. These four receivers are connected to two eardrums, which are also on the legs, by a system of thoracic spiracles or air-tubes.

But *O. ochracea* is too small to use either of these hearing systems. Instead, says Hoy, it has developed a novel hearing system of its own. The fly wears its ears on its chest, tucked beneath the head to protect them from dust and pollen but where they are still exposed to incoming sound waves. The ears consist of a pair of circular tympanums, or membranes, lying side by side, like a pair of tiny, oddly shaped leaves just half a millimetre apart (see Diagram).

The membranes themselves are about 150 to 250 micrometres in diameter, which is no more than twice the width of a human hair, and only one micrometre thick. This is about the width of a particle of tobacco smoke, so not surprisingly the membranes are nearly transparent. They are ridged with mysterious radial corrugations resembling the base of an orange squeezer.

Just what these ridges do, Hoy is not yet sure. For the moment he is concentrating on working out exactly how *O. ochracea* hears so well. The tympanums are connected by an intertympanal bridge, a narrow piece of flexible cuticle balanced on a central pivot. Each end of this bridge is attached to the centre of one of the two membranes, like a set of scales. "Directional sounds excite the nearest drum first," says Hoy. The eardrum farthest from the sound begins to vibrate a fraction of a second later. This motion also sets the flexible bridge vibrating. "Since the bridge connects both eardrums, the mechanical response is an interactive one," says Hoy. The patterns of movement are complex but the structure is cleverly designed so that many of the vibrations cancel out in a way that produces the most vibration on the side from which the sound arrived. "This is a spectacular example of convergent evolution—not unlike the way insects, birds and bats all developed different kinds of wings to achieve flight."

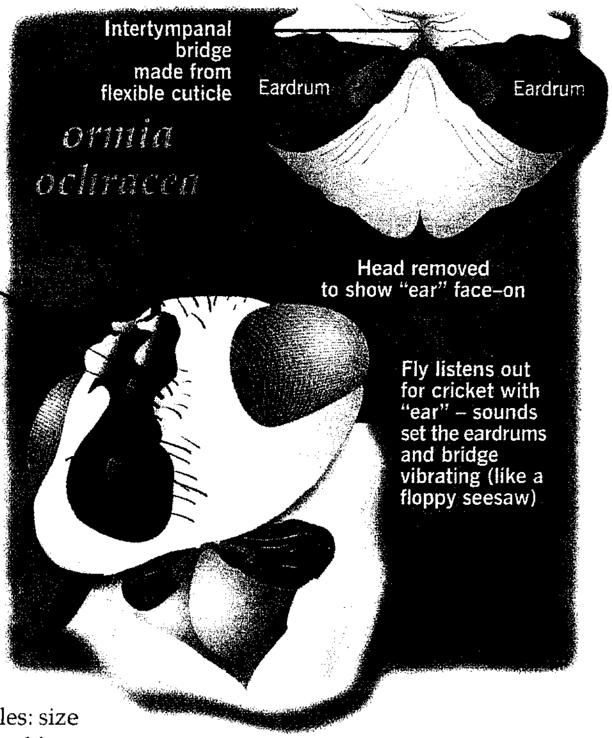
Hoy and his colleagues Ron Miles, a professor of mechanical engineering at Binghamton University in New York state, and Daniel Robert of the University of Zürich, believe that by mimicking this exquisite design they will be able to create a hearing aid. "The idea is to develop microphones that copy the fly's ear and are small enough to fit inside a hearing aid," says Miles, a former Boeing engineer. "But we also want something more sensitive to sounds coming from the front than from the back," he says. This can be done by monitoring the movement of the membrane on only one side of the ear so that only the sounds from that direction are amplified.

Small and powerful

The chief obstacles to building such a device are twofold, says Miles: size and power. Size is the lesser problem because nanotechnologists continue to shrink the size of functioning micromachines. "This is no different than what's being used now to create integrated silicon chips for computers," says Miles. "And we don't even need to make our device as small as the fly's ear. We can probably build it a couple of millimetres wide."

The greater challenge is power consumption. Modern hearing aids typically rely on tiny internal batteries, which are being drained constantly while the aid is switched on and often need to be replaced every week or so. "Obviously manufacturers aim for the lowest power consumption and voltages possible to extend battery life," says Miles. "That makes it hard to build effective electronic microphones, because they require certain levels of power to process signals."

Here too *O. ochracea* offers a potential solution since its ear functions mechanically. "The whole thing works passively, with sound waves instigating mechanical responses," says Miles. This mechanical motion can be used to switch on the amplifier so that power is only used when sound is passing into the ear. "Instead of building a hearing device that requires significant amounts of power, we can build one that operates only when sound waves move it. That means less power and less circuitry is needed," says Miles.



Hoy and Miles are putting the finishing touches to a proposal for research and development funding from the US National Science Foundation. They have also been talking to commercial hearing aid manufacturers. The companies are interested, Hoy says, but have yet to offer any financial support.

Wherever the money is going to come from, the scientists are optimistic about their project. "An artificial version of *Ormia ochracea*'s ear could be ready within five years, perhaps sooner," says Miles. "We have the real advantage in that nature has already shown that the concept works. Now we just have to do it ourselves." □

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