POP BEAT
Latest edition of Idyllwild Jazz in the Pines festival will be dominated by San Diego-based artists. George Varga reports.
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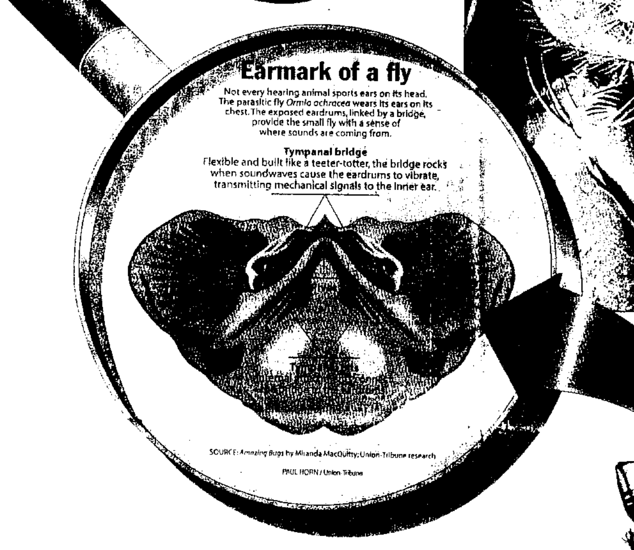
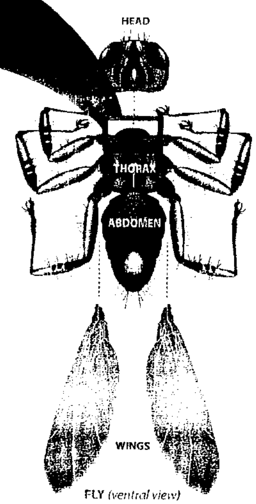
listening bugs





Chest ears
...red hea... system of Ormia ochracea just below head. One the two ex... eardrums be seen ab... fan-shape indentati... marked b... pattern of ridges.

A lowly fly inspires a hearing aid for humans

By Scott LaFee
STAFF WRITER

ITHACA, N.Y. — Loud and insistent, the cricket's love song wafts warmly on the breeze of a dusky summer evening. It's a series of rapid clicks, a crooning chirp to potential mates that reverberates at 5 kilohertz or 5,000 cycles per second.

In a back yard, a young boy listens to the nearby cricket's serenade but quickly returns to his play. A small female fly hears it, too, and twitches into action, lifting urgently into the air from its perch on a blade of grass.

The cricket has sung its death knell.

In most respects, *Ormia ochracea* looks like an ordinary if brightly colored housefly: bulbous orange-red eyes and a single pair of spindly wings on a mustard-colored body about the size of a pencil eraser. The female fly buzzes through the darkening sky, homing in on the cricket's vibrato until it locates the larger insect tucked beside a rock.

Lightly, the fly settles onto the cricket's back and deposits three or four small white larvae, each about 0.013 of an inch long, less than the nub of a dull pencil lead. Quickly and painlessly, the larvae 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. The hapless cricket will survive most of the experience, still able to carry out its own mating rituals until, on the seventh day of internal occupation, it will pitch over dead, a shell of its former self.

Their meal finished, the larvae will emerge, each now half an inch long and plump with cricket. In short order, the larvae will pupate and metamorphose into a

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Ear

Lowly insect inspires improved hearing aid

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new generation of adult flies. And the process will begin again.

Such tales, of course, are not new in nature, which is red in tooth and claw at even its lowliest levels. What intrigues some scientists isn't so much the cricket's mode of demise but the abilities of the fly. It can hear.

More precisely, the fly has devised a novel set of ears that can hear some of the same high-frequency sounds humans can — a fact that could eventually spell good news for hearing-impaired people.

MARIE READ / Cornell University

Movable feast: *The parasitic fly, Ormia ochracea, uses its directional hearing to home in on the mating call of male field crickets. Once located, a female fly lays larvae on the cricket's back, which in turn burrow inside and eat the cricket alive.*

Sound in the round

In the laboratory of Ron Hoy, a professor of neurobiology and behavior at Cornell University, a single specimen of *Ormia ochracea* is being driven to distraction.

Inside a small cage with speakers affixed at each end, the fly stands smack in the middle. Hoy turns on a tape recording of a cricket calling, then dials the sound so it is emitted only from the left speaker. The fly swivels on its six legs and walks rapidly toward the speaker. Hoy switches to the right speaker. The fly abruptly reverses course. Over and over, Hoy conducts this simple test. Left-right, left-right, the fly marches back and forth, sometimes almost spinning in a circle as it obviously attempts to zero in on the cricket's song.

Hoy and his colleagues, Ron Miles, a professor of mechanical engineering at State University of New York at Binghamton, and Daniel Robert, of the University of Zurich, believe the fly's ability to determine sound directionality could lead to dramatic improvements in the ability of human hearing aids to do the same.

Between 28 million and 30 million Americans are deemed "hearing impaired." Worldwide, the figure is roughly one in 10 people. Many of the afflicted simply cope with a world of semisilence. Others, though, use artificial hearing aids, which basically come in three styles:

- Behind-the-ear aids are used by people with the most severe but remedial hearing problems. They are the largest devices and most visible, hooking behind the auricle (the flaplike part of the ear) and connected to an earpiece by a small tube.
- In-the-ear aids cover a variety of models placed in the hollow of the ear. Size varies. Most are roughly the size of a thimble and less obvious than behind-the-ear models.
- In-the-canal aids, about the size of a pea, tend to be used for listeners with minor hearing loss. They are placed deeper into the ear and can be virtually impossible to see.

Hearing-aid technology has come a long way from Grandpa's unsightly shirt-pocket device that crackled with noisy feedback. Behind-the-ear and in-the-ear aids can now be digitally programmed to regulate frequencies so listeners can distinguish sounds better.

In-the-ear aids, including the smaller in-the-canal models, make up more than 57 percent of U.S. sales, said Sergei Kochkin, a marketing analyst for the Hearing Industries Association. Not surprisingly, most users choose the smallest aid capable of doing the job. Reduced size, though, comes at a cost.

In-the-canal aids, for example, cannot be digitally programmed. They amplify all sounds equally. And none of the aids, said Hoy, provides directional information comparable to a working human ear, especially the smallest aids.

"People who use these hearing aids tell me they can generally tell whether the sound is coming from the front or behind but they can't pinpoint it. It's all sort of mushy and disconcerting."

Hoy and colleagues think they may have found a solution in the structure of *Ormia ochracea's* ear. "Of all the thousands of flies in the world, these flies (and a related kind) are the only ones we know that have ever invented an ear," said Hoy.

"More importantly, they can hear at high frequencies. Humans have a hearing range of 20 Hertz to 15 kilohertz. Crickets produce sounds between 2,000 and 7,000 Hertz, and the flies are precisely tuned to hear them. High frequencies are vital because they're 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."

Most hearing loss occurs in the higher frequency range, leaving many hearing-impaired listeners able to pick up background noises like the general din of a cocktail party but deaf to the words spoken by a person inches from their ear.

Catching a wave

All tympanal auditory organs — that is, all hearing systems employing a membrane or eardrum to separate the external ear from the middle ear — function in one of two ways.

In larger mammals, including humans, each ear is a separate entity, acoustically isolated and independent of its partner. Such ears, called pressure receivers, work well in animals in which the individual ears can be set relatively far apart.

"Most vertebrates pretty much do it the way we do it," said Hoy. "If you've got one ear, you've got two and you look for them on the head."

Thus situated, the ears are separated by the dense, muffling tissues of the brain and each eardrum registers a sound wave at a slightly different moment, one ear before the other, like a pair of bicyclists sensing a passing automobile in sequence.

The brain measures the time elapsed between when the first eardrum registers a sound wave and when the second eardrum does, a phenomenon called interaural time difference (ITD). That information, combined with how strongly each sound wave strikes each eardrum (called interaural intensity difference or IID), helps humans and other vertebrates deduce where a sound is coming from.

"We say you have to have two ears to determine directionality," said Ross Roeser, director of the Callier Center for Communication Disorders at the University of Texas, Dallas. "Plug one ear and you'll immediately begin having problems figuring out where a sound is coming from, though in time you can get better at it."

In mammals like moles or in birds, frogs and insects, however, their comparatively small head size tends to rule out dual "pressure receiver" ears. There just isn't enough space. The gap between auditory organs is too short for an effective ITD measurement from isolated, pressure-receiving ears only.

The auditory organs of these creatures compensate by being intrinsically paired, acoustically coupled by an internal air passage. Sound waves strike the eardrums from both the outside and, transmitted through this inner passage, from the inside too. Data from these sound waves is thus doubled, and the animal determines a sound's direction from the pressure differences on each eardrum.

These animals also take advantage of interaural time differences — the gap between their ears — by placing their auditory organs as far apart as possible, sometimes with unusual effect. The elaborate hearing system of the cricket is a good example. It employs sound receivers on the tibiae of the four front legs, a location comparable to the shinbones of humans, which are connected to two eardrums (also on the legs) by a series of thoracic spiracles or air tubes.

The relative puniness of *Ormia ochracea*, however, means it cannot use either of these hearing systems. Neither would be effective in such a small insect. Instead, said Hoy, the fly has developed a novel hearing system of its own, a third kind of directional receiver for terrestrial animals.

"It's a spectacular example of convergent evolution," said Hoy, a new and different way to solve a common problem. "It's not unlike the way insects, birds and bats all developed different kinds of wings to achieve flight."

Ormia ochracea wears its ears on its chest, tucked beneath the head to protect them from dust and pollen but still exposed to ambient sound waves. The ears consist of a pair of circular tympana — eardrums — lying side by side like a pair of tiny, oddly shaped bongo drums just 450 to 520 microns or micrometers apart. (For comparison, a hair's width is between 25 and 100 microns.)

The eardrums themselves are 150 to 200 microns in diameter, only 1 micron thick (about the width of a particle of tobacco smoke and nearly transparent) and ridged with mysterious radial corrugations resembling the base of an orange-juice squeezer. Hoy said researchers haven't yet deciphered the exact purpose of the corrugations but noted that they differ in spacing between fly species, each of which targets a different host insect with a different frequency song.

"We think this is no accident," said Hoy, "but we haven't done the work yet".

The drums are connected by an intertympanal bridge, a narrow bit of flexible cuticle balanced on a center pivot with its ends attached to the center of each drum. When a sound wave strikes the fly at an angle, the eardrums begin to vibrate, causing the bridge to move, either up and down like a seesaw or with both ends bowing in unison.

"The bridge serves as the internal attachment points for the tympanal receptor organs, so movements of the bridge activate the transducer," said Hoy. "And since the bridge connects both eardrums, the mechanical response is an interactive one. Directional sounds excite the near drum first, which excites the bridge, which responds as a vibrational system with two modes of vibration: in phase and out of phase."

In other words, a sound wave striking the closer eardrum causes a slightly different vibration than it does when it strikes the other eardrum. At 5 kHz, the frequency of cricket song, the result tends to be out of phase, with the bridge rocking like a flexible teeter-totter. Directional input comes from differences in both amplitude — the extent of vibratory movement in each tympanum — and time — the lag between when the first and second tympanum react to the same sound wave.

(Researchers say the fly's ear has evolved to respond most effectively to frequencies around 5 kHz, the call of the field cricket. Laboratory tests using a laser vibrometer, however, indicate the ear responds to a fairly broad range of frequencies, from 5 kHz to 25 kHz.)

Beneath *Ormia ochracea's* eardrums lies a single air-filled chamber housing the inner ear. This sensory organ is keyed to movements by the bridge. When the bridge rocks, it stretches membranes of receptor cells located inside the inner ear. Ion channels open and close, provoking a fluctuating cascade of positively or negatively charged atoms that are transmitted through auditory nerves as electrochemical signals to the fly's central nervous system.

The result is essentially the same as in any larger hearing animal. The fly hears something (usually a cricket), determines the direction of the sound and acts accordingly.

"It's really more than that," said Hoy. "It's not enough for the fly to simply say, 'Hey, there's a cricket out there.' It's got to be able to zero in on it, to find a single unseen insect out in the open."

Micro-microphones

Hoy and colleagues believe that by mimicking the construction of *Ormia ochracea's* ear, they can create a better directional hearing aid.

"The idea is to develop microphones copying the fly's ear that are small enough to fit inside a hearing aid," said Miles, a former Boeing engineer who worked on ways to eliminate noisy vibrations in aircraft.

"We want something more sensitive to sounds coming from the front than from the back," said Miles. "That way someone wearing the device will have an easier time communicating with a person in front of them. It'll help them focus on what presumably are the most important sounds, rather than feeling generally bombarded by sound coming in from everywhere."

The chief obstacles to building such a device are two, said Miles: size and power. Size is the lesser problem because emerging nanotechnologies continue to shrink the size of operable, practical micromachines.

"This is no different than what's being used now to create integrated silicon chips for computers," said 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 millimeters wide."

The greater challenge is power consumption. Modern hearing aids typically rely on tiny, internal batteries. In-the-canal aids use batteries so small that they frequently require weekly replacement.

"Obviously, manufacturers shoot for the lowest power consumption and voltages possible to extend battery life," said Miles. "That makes it hard to build effective electronic microphones, which is a well-known and advanced technology, because they require certain levels of power to process signals."

Here too *Ormia ochracea* offers a seeming solution: It's ear functions mechanically.

"The whole thing works passively, with sound waves instigating mechanical responses," said Miles. "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 (are) needed."

Hoy and Miles are putting the finishing touches on a proposal soliciting research and development funding from the National Science Foundation. They have also talked with commercial hearing-aid manufacturers. The companies, said Hoy, are interested and enthusiastic but have yet to offer any financial support.

But money or not, the scientists are optimistic about their project.

"I can't think of any hurdles to building something like this," said Miles. "We have the real advantage in that nature has already shown that the concept works. There's a working prototype out there. It just happens to be biological. I'm confident we can copy it effectively. We just have to understand how the animal does it, then do it ourselves."

A man-made version of *Ormia ochracea's* ear could be ready within five years, perhaps sooner, said Miles. If Miles is correct — and the device works as predicted — millions of impaired listeners may one day pick up the buzz of a cricket's call and cheer: Let's hear it for the fly!

- **Resources:** The nonprofit Better Hearing Institute in Annandale, Va., provides information on the nature of hearing loss and available medical, surgical, rehabilitative and amplification help.
- **Phone:** (800) EAR-WELL