The Body Ear

To pinpoint a sound's direction, coqui frogs may lend not only an ear but a lung as well

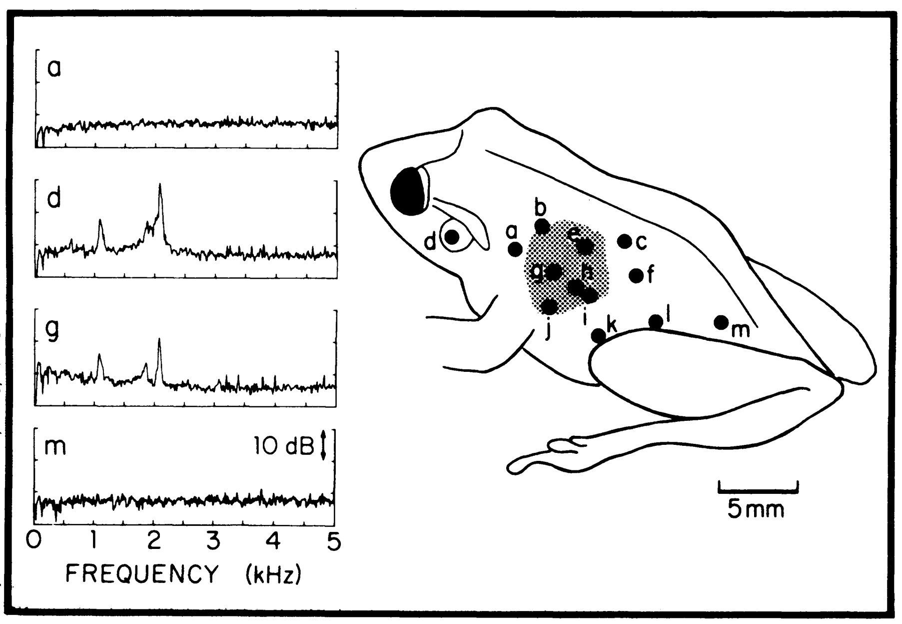
By STEFI WEISBURD

From dusk until midnight, nearly every day of the year, a deafening din floods Puerto Rico's rain forests. Every few seconds, male *Eleutherodactylus coqui* frogs trumpet their "co-qui" mating call in competition with the blaring advertisements of seven other frog species and the dissonant chorus of rasping, chirping, buzzing insects. The animal orchestra creates such a loud cacophony that researchers working in the forest say they have a hard time hearing themselves think. Yet the male and female coqui frogs and their amphibian compatriots somehow sort through the pandemonium, separating the melodious acoustic wheat of their own species from the chaotic chaff of other creatures' chants.

Exactly how the coqui and other frogs discriminate sounds in such noisy environments has long fascinated neuroethologist Peter M. Narins at the University of California at Los Angeles (UCLA). He and others have found that amphibians employ a variety of communication strategies, including divvying up sound frequencies among different species, creating a louder fracas than their neighbors or producing periodic, easily recognizable calls.

Most recently Narins and two associates have discovered that coqui frogs in particular may also be aided in pinpointing a sound's direction with an unusual sound pathway: through the lungs. They reported in the March PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES (Vol. 85, No.5) that when a sound wave hits a frog's side, it can travel through the air-filled lungs, up through the voice box, into the eustachian tubes and on to the eardrum.

"Peter and his colleagues have found what may be a totally unexpected medium for processing sound in these species of frogs," says Steven Greenberg, an auditory neurophysiologist at the University of Wisconsin in Madison. "This makes us rethink the ways in which sounds are localized in space, at least by frogs." This and findings in other animals are adding some interesting twists to the study of the evolution of hearing in vertebrates.



Adapted from Narins et al, PNAS, Vol. 85

When one frog hears another's "coqui" call, the body wall overlying the lungs (shaded area) vibrates in much the same way as the eardrum (d). The rest of the body is relatively still.

Humans and most other mammals can tell a sound's direction by comparing the vibrations the sound waves induce in each eardrum. The waves entering the ear nearest the source are more intense and arrive sooner than do those entering the far ear. But to exploit this intensity and timing difference, the sound's wavelength must be much smaller than the distance between the ears. Since the upper audible limit of most mammals falls within 20,000 to 60,000 hertz, this condition is usually met in even the smallest mammals.

Reptiles, birds and amphibians, however, generally do not hear sounds above 10,000 hertz, and for many of these creatures, including coqui frogs, the distance between the ears is too small to localize sound the mammalian way. Instead, these animals use a "pressure-gradient system." In humans — and other mammals whose middle ear cavity is separated from the outside world by bone — sound usually strikes the eardrum from the outside only. In contrast, a reptile, bird or amphibian eardrum vibrates in response to sound waves coming at it from *both* sides. For instance, a frog's anatomy is such that its right eardrum will be hit by sound directly entering the right ear and by sound traveling through the *left* ear, then down the left eustachian tube, across the mouth cavity, up the right eustachian tube and into the right eardrum.

Since this second route — the contralateral ear pathway — is generally longer than the direct approach, waves traveling along the two paths will be out of phase with one another at the eardrum. A frog can sense a sound's direction from the way the two waves then interfere, because the exact interference pattern depends the angle between the frog and the sound source.

What Narins, Günther Ehret and Jürgen Tautz at West Germany's Konstanz University discovered is that sound can also travel through the lungs of a coqui frog to its eardrums. Originally, Narins wanted to learn why coqui frogs — whose extremely loud calls have sound pressure levels as high as 100 decibels 1 meter away — don't deafen themselves when they blast out their territorial and mating announcements. So he collected the loudest frogs he could find in Puerto Rico and brought them to Ehret and Tautz, who use laser beams to measure eardrum vibrations. In Germany, however, the frogs turned shy, and, unable to coax them into calling, the researchers instead measured their eardrum movements as the frogs listened to recorded coqui calls.

"It was all pretty boring because we were getting just what we expected," Narins recalls. Then, late one night, Narins' hand slipped and the laser beam moved to the side of a frog over one lung, which by all accounts should have been impervious to sound. But this spot vibrated.

"We couldn't believe it," says Narins. "We then mapped the whole frog to find vibrating places. It turns out it's just a little [25 square millimeters] localized region over the lung which vibrates, and that's where the laser just happened to slip that night."

The researchers suspect but are not yet certain that the frogs use the lung pathway for locating sound. Narins has shown that the pressure in the frogs' mouth cavity does indeed change when sound impinges on the lungs. And Ehret and Tautz further demonstrated that sound traveling through the lungs actually makes the eardrum vibrate.

"I think the level of sound arriving at the inside surface of the [eardrum] is going to be greater from the contralateral ear than from the lungs," says Narins. "So what we found is not the principal pathway to the inside of the eardrum, but rather a complementary one. I think it's going to be important, but to what extent I don't yet know."

Coqui frogs, apparently, are not alone in using body parts other than their ears to pinpoint sound. A researcher in Denmark has since discovered the same lung pathway in green tree frogs; another scientist had previously shown that snakes, too, transfer sound through their lungs to their ears. According to Narins, porpoises and dolphins transmit sound through oil-filled lower jaws.

In addition, John J. Rosowski at the Massachusetts Institute of Technology in Cambridge and his colleagues recently reported that at frequencies below 800 hertz, sound is conducted across the throat walls of the alligator lizard and on to its eardrums when the animal's head is raised. (At higher frequencies, sound gets to the inside eardrum via the contralateral ear.) Like Narins, Rosowski has no direct evidence that the lizards indeed use this to localize sounds, but it seems a reasonable possibility. He notes that the throat path might also be used by alligator lizards to detect ground vibrations when they are basking with their heads resting on the ground.

Researchers do not know how many other animals may possess unusual sound passages and how important these alternative pathways are for hearing and survival. But the intriguing recent discoveries "emphasize the fact that many structures in the body serve more than one purpose," says Greenberg. "Evolution has been very efficient in maximizing the amount of work or the function that an individual structure can do." □