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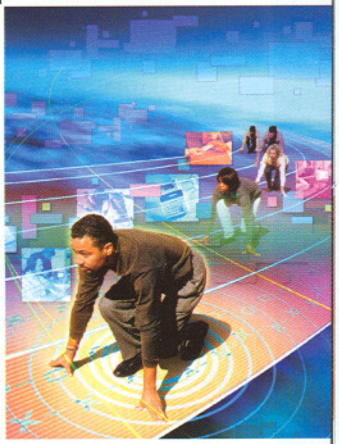


Inspired by a Fly

In the near future, you could be thanking an insect and the NIH for better hearing in noise and increased satisfaction for your patients.

BY JENNIFER SCHESTOK

What do a fly, a microphone and hearing aid technology have in common? Give up? Ronald N. Miles, PhD, hasn't. With the previous discovery of the directional hearing capabilities of a small parasitoid fly (*Ormia ochracea*), Dr. Miles, a Binghamton (NY) University professor, couldn't stop thinking about how he could use the information about the natural occurrence of a directionally hearing fly to improve hearing aid technology for people with hearing loss.

The National Institute on Deafness and Other Communication Disorders (NIDCD), part of the National Institutes of Health (NIH), must have been just as curious as Dr. Miles, since NIDCD awarded him $6.5 million in support of his biomimetic acoustic sensor research. That research is expected to lead to a revolution in hearing aid technology within the next few years.

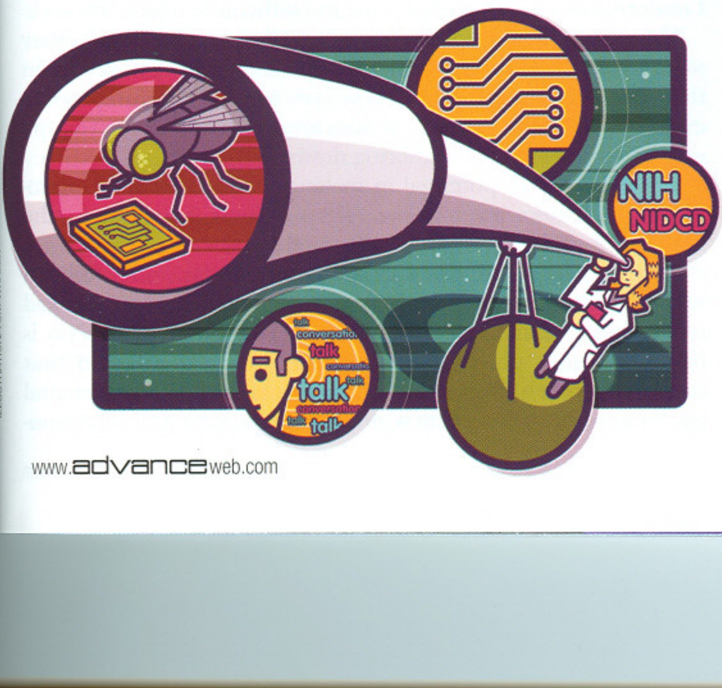
The idea for this directional hearing aid research started when Dr. Miles collaborated with two biologists—Ronald R. Hoy, PhD, professor of neurobiology and behavior at Cornell University, in Ithaca, NY, and Daniel Robert, PhD, now a professor at the School of Biological Sciences, University of Bristol, UK—for studies of the auditory systems of small animals.

These researchers discovered that this one type of fly has unique ears and asked Dr. Miles to help them figure out how their hearing worked.

As an engineer with a background in structural vibrations and acoustics, Dr. Miles was happy to assist. "At that time, I had some tools in my lab for studying the vibration of really small things...We tried to understand how the ear of this fly worked." The team found that it was able to localize sound very well. "The ears basically function like a really good, tiny microphone," he recalled.

Application Sought

After some analysis, the engineer started thinking about what he could do with the information gathered from this wee fly. For Dr. Miles, "the ears looked like an interesting way to make a directional microphone that, as far as I could tell, was different from any other directional microphone that had been made, and was really small." He learned that with hearing aids, which obviously need very tiny microphones, there is a lot of interest in those microphones being directional to improve speech intelligibility.



At that point, Dr. Miles applied to the NIH for funding for his research, since this organization has a history of funding research for hearing technology. The NIH/NIDCD grant will support the project, titled, "Sensing and Processing for Directional Hearing Aids."

"NIH has funded some very basic research in fly ears," Dr. Miles quipped. "But this research is paying off, because what we ▷

are doing is converting what we've learned about these fly ears into useful technology for the hearing-impaired." Dr. Miles, a mechanical engineer at Binghamton's Watson School of Engineering and Applied Science, will use a tiny structure found in the ear of the fly as a model to develop the world's smallest directional microphones.

His aim is to dramatically improve the ability of people with hearing loss to understand speech in noisy environments.

"Our focus is to improve the technology of acoustic sensing and signal processing so that we can minimize the influence of unwanted sounds," he said. "Research shows that hearing in noisy environments remains the No. 1 unsolved problem faced by hearing aid wearers."

His work, which is based on discoveries about the directional hearing capabilities of the tiny fly, holds promise in any number of civilian and military applications where microphones and acoustic sensing systems are or could be employed.

Replacements, Improvements

As principal investigator for the project, Dr. Miles will partner with researcher Douglas L. Jones, PhD, and F. Levent Degertekin, PhD. Dr. Jones is an electrical engineer at the University of Illinois at Urbana-Champaign and an expert in signal processing algorithms. Dr. Degertekin is an electrical engineer at the School of Mechanical Engineering at Georgia Institute of Technology, in Atlanta, and an expert in optical sensors. The sensors will replace and improve upon the capacitive sensing scheme used in traditional hearing aid technology.

Others working and consulting on Dr. Miles' research include Peter Loeppert, PhD, Knowles Acoustics, and Stephen C. Thompson, PhD, Knowles Electronics, both headquartered in Itasca, IL; Stefan Launer, PhD, Phonak Inc., in Staefa, Switzerland; and Todd A. Ricketts, PhD, CCC-A, assistant professor and director at Vanderbilt University Medical Center's Dan Maddox Hearing Aid Research Laboratory, Nashville, TN.

Drs. Loeppert and Thompson are experts in acoustics and microphone technology. Knowles is a leading manufacturer of microphone technology, and sells Knowles technologies to various hearing aid companies. "Having [Knowles representatives] as a part of our team is extremely beneficial," said Dr. Miles. "It's great to have their expertise...they have been working on silicon microphones for [almost] 15 years."

Dr. Miles reported that Phonak Inc. "is very interested in our technology...to take our fabricated prototypes and to develop that into a hearing aid." Dr. Miles asked for Dr. Ricketts' help since "he has lots of experience in directional microphones and knows how to test them."

The Mic and the Mechanics

So, why is this new microphone creating such a buzz in the electronics and hearing technology industries? Dr. Miles explained that improving the directionality of hearing aids, enhancing their ability to filter out unwanted noise, and producing microphones that create less self-noise will mean major enhancements to speech intelligibility in noisy environments. For audiologists, improving directional microphone technology in hearing aids and increasing understanding of speech in noise has been a highly sought-after goal for a number of years. Drs. Miles, Jones and Degertekin are attempting to make these improvements by developing three interrelated areas of technology: novel directional microphones, optical electronic sensors and signal processing.

Improved Sensitivity

By "reading out" sound waves hitting the microphone's diaphragm through signals created by changes in light rather than in electronic voltage, much thinner and more sensitive microphone diaphragms can be used.

"This will remove some of the key design constraints that have limited the development of small microphones," Dr. Miles said. "It should permit a revolution in microphone designs and enable the achievement of much greater sensitivity and lower noise."

The signal processing algorithms will allow for customization of hearing aid sensitivity, and hopefully reduce unwanted sounds beyond what is possible with current hearing aids.

Dr. Miles' microphone diaphragms will be made of silicon, which is a robust material that can be manufactured inexpensively and quickly. Many computer chips can be made on a single silicon wafer; using that same method, so can microphones.

Traditional microphone diaphragms (the moving part that picks up the sound wave) are made of Mylar, said Dr. Jones. However, with silicon, production costs can be cheaper and faster, and since it is a sturdy material, microphones will better withstand a variety of environmental conditions.

This can be good news for hearing aid wearers who currently need to protect an aid's microphone from water and earwax buildup.

"Silicon is quite robust when it comes to shock, vibration, environmental changes like temperature and humidity...If you take a typical microphone used in a hearing aid today, it's quite responsive to temperature changes and humidity changes...Silicon just doesn't take up any moisture," explained Dr. Loeppert.

Diaphraghm Design

Dr. Miles said his team is using silicon microfabrication technology to make the microphone diaphragms. "What we do is very carefully design these microphone diaphragms, analyze how well the designs are supposed to work when they are driven by sound, and then develop a fabrication process using silicon in order to make them."

Dr. Jones explained how the use of silicon could make production costs cheaper. A microphone is what you call a capacitor, with a very thin backplate and a very flexible sheet, usually made of Mylar, which is metalized. The Mylar diaphragm is placed a small distance away from the backplate. "You have this very thin and flexible piece [that] moves when sound waves hit it. The problem with it is that they usually have to be hand-assembled. As I understand, it's rather expensive and difficult to make," he said.

However, "if microphones were made out of silicon...they would be really cheap and able to be produced by the millions in the same way that computer chips [are made]," Dr. Jones pointed out. Eventually, once the production process has been adapted for hearing aids, it could bring down the cost.

There is a lot of potential in making a low-cost silicon microphone, but there are also possible problems. Fortunately, the team has found solutions for these challenges.

Silicon is really stiff and like a crystal, said Dr. Jones. Silicon microphones currently on the market in tape recorders and other devices have terrible sensitivity. Working with silicon is like bending a piece of concrete, Dr. Jones said, and that doesn't do much for sensitive microphones. It's a fundamental problem with creating a new, high-performance and directional microphone, but one that Dr. Miles has overcome.

Problem Solved

"Ron's idea is basically brilliant," remarked Dr. Jones. "Instead of making a regular microphone by trying to bend an inflexible sheet of crystalline silicon, what Dr. Miles did was essentially make a teeter-totter. The rigid silicon now doesn't have to bend like a sheet of metal, but it will rock like a teeter-totter. By making little supports where the teeter-totter is hooked on in the middle, and making them very small, the supports will just have to flex or twist it," said Dr. Jones.

The unusual nature of the microphone diaphragm enables the researchers to overcome some of the limitations of conventional directional microphones.

Furthermore, Dr. Degertekin's optical sensors can pick up the teeter-totter motion, giving consumers a sensitive microphone, Dr. Jones explained.

"I realized that an optical sensor would be an ideal way to pick up the motion from these novel microphone diaphragms that I have been working on. This would avoid a lot of the design hassles imposed by capacitive sensing and would provide a great way to convert the flexible diaphragm motion into an electrical signal," said Dr. Miles. What these researchers are doing is combining a novel way of making a microphone diaphragm "with a very promising method for converting the motion of the diaphragm into an electrical signal," he explained. With the new technology, he can control the sensitivity of the microphone by how much it moves relative to the sound coming in, and set it exactly how he wants it.

The team has tested the response of the silicon microphone diaphragm to sound and compared responses with design models. "So far, all of that has gone extremely well," he reported.

Optimizing Optical Sensors

The work that Drs. Miles and Jones are pursuing now with Dr. Degertekin in the fabrication of the microphone is to develop a way to marry optical sensing with microphone diaphragm technology—one of the main tasks for the NIH grant. To do it, the team needs to incorporate an optical grating on the microphone diaphragm, Dr. Miles said.

What they have developed so far—given their initial funding up to now—is a fabrication process to connect Dr. Degertekin's optical device to the microphone diaphragm. The team then plans on optimizing the performance of the microphone diaphragms so they meet the project's standards.

Combining these two methods together makes sense because the microphone diaphragm automatically provides more directional information and reduces internal noise, according to Dr. Degertekin.

"You don't want any mechanical structure close to that diaphragm, and optical detection enables you to do that...We get a very sensitive measurement using a light beam, and we don't introduce any extra mechanical noise into the system," he said.

"By using semi-conductor laser diodes, we can actually package the whole microphone into a volume of two cubic millimeters...That's what's enabling us to put these [small microphones and optical sensors] into hearing aids," Dr. Degertekin explained.

A second concern with optical detection schemes is power consumption, because standard lasers consume a lot of power. "To solve that problem, we are using small lasers that are developed for optical communications.

"It's like our eyes," Dr. Degertekin continued. "In a movie, you see 25 frames per second. When you move the discrete pictures very fast, you think that it's a continuous movie. So basically, we are taking snapshots of the vibration, rather than using the laser all the time...you get a continuous wave at the output."

The research team is hoping to use regular power batteries for the BTE or ITE style hearing aids. "The advantage of the semiconductor small lasers is that they can be turned on and off with one volt," Dr. Degertekin said.

Meeting Microphone Challenges

The unusual nature of the microphone diaphragm enables the researchers to overcome some of the limitations of conventional directional microphones, Dr. Miles told *ADVANCE*. One challenge with current directional microphones arises from the fact that there tends to be a pair of microphones, and the processing of the signals from these microphones produces a directional signal. The directionality of the system depends on how well these microphones are matched; if the sensitivity of one microphone shifts relative to that of the other microphone, the performance suffers, he said.

With Dr. Miles' prototype, the microphone is essentially self-matched. "In itself, it provides the directionality so there isn't a need for this careful matching between the microphones."

Better Directionality

"Our predictions are that the directionality of the microphone will provide better directionality over the entire frequency range that is important for speech, particularly at the lower frequencies," he said.

Sometimes in going to the lower frequencies, directionality tends to degrade. The team predicts that the noise performance of the microphone will be significantly better than what can be achieved now with the existing directional systems. ▷

Dr. Thompson added that Knowles is particularly interested in reducing internal noise levels. "There are some situations where that noise can be audible in hearing aids," said Dr. Thompson. "If [Dr. Miles'] most optimistic projections turn out to be right, we'll have a significant reduction in noise level," he said, adding that "the optical detection methods that [Dr. Degertekin and Dr. Miles] would be using are completely different sensing mechanisms than [what] has ever been used in hearing aid microphones before."

A reduction in self-noise, added Dr. Miles "is accomplished because this microphone overcomes the frequency dependence of existing directional microphones, [and] there tends to be a low frequency roll-off in their response. These microphones can be designed so that they are more sensitive in the frequency range where you really need to use them for speech."

Hopeful Changes

"If we can provide silicon microphones that are bulk fabricated/mass produced that are good enough for hearing aids, that could lead to significant cost reductions in the hearing aid market for hearing aid microphones," Dr. Miles projected.

"There are three microphones in our system for the directional acoustic sensing, but they are all built on a single chip, which is built with standard computer chip technology," said Dr. Jones. Because chip-building has become a sophisticated process, this could mean cheaper manufacturing of microphones, compared to how they're normally made for hearing aids.

In four years, the team hopes to have built the prototype. In Dr. Jones' experience, however, it usually takes two or three years for companies to want to pick up the technology and actually design and build a product around it.

"We would certainly prefer to be selling microphones that had those better properties if it's technically feasible to do so," said Dr. Thompson, commenting that the new technology looks good for improving some of the difficulties hearing aid wearers have experienced with a number of traditional microphones.

Knowles works with all hearing aid manufacturers on any of the microphone products that they sell, said Dr. Thompson. However, Knowles does not have any special relationship with manufacturers to produce or sell Dr. Miles' directional microphone, since this is not currently in Knowles' product line.

The Future

Ultimately, signal processing could be tuned in a hearing aid based on any of a number of criteria, including directionality, frequency, or volume of sounds, according to Dr. Miles. Dr. Degertekin believes the optical detection schemes could be used in other micro-machined devices, and perhaps medical ultrasound imaging.

Dr. Miles and his team hope that the technology will revolutionize the microphone market in general. By providing silicon microphones that are bulk-fabricated or mass produced, it could lead to a significant cost reduction in the hearing aid market for hearing aid microphones. Ultimately, the lower production costs and the improved speech intelligibility of the new directional microphone technology may lead to more hearing aid purchases and the *coup de grâce:* patient satisfaction.

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