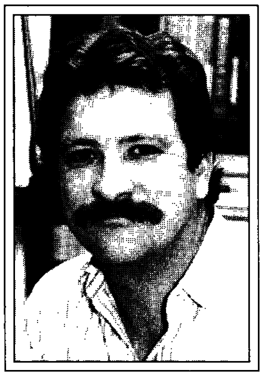
press) that could be considered his minority opinion. Frazer objected to headstarting on the grounds that it does nothing to address the primary causes of sea turtle mortality, while at the same time serving "as an attempt to relieve humans of the consequences of our actions. We may feel a little freer to degrade the habitat and over-harvest turtles either intentionally or incidentally if we have headstarting programs in place."



Thane Wibbles

Even the other panelists, though, found they could hardly give headstarting a ringing endorsement. In their consensus report, they conceded that headstarting had failed as a conservation measure: "Tag return, stranding, trawling, and nesting beach data recorded by NMFS, U.S. Fish and Wildlife Service, and the Instituto Nacional de Pesca collectively indicate that the mortality rate of Kemp's ridleys in the wild (both headstarted and nonheadstarted) is so high that few if any headstarted ridleys are likely to reach sexual maturity."

The bottom line, Wibbels later told *Science*, "was that this wasn't a successful program." Still, he says, the panel had been specifically directed not to "look at sea turtle conservation as a whole." As an experiment, he says, the program was still worth continuing: Once the turtles were protected from the shrimpers, he and his colleagues reasoned, the Galveston program would offer "the best chance ever to answer the question [of whether headstarting is an effective conservation measure]."

Turtle hatcheries. Headstarting not only had a new lease on life, it was threatening to expand dramatically. In the summer and fall of 1989, representatives of three shrimping states along the Gulf—Billy Tauzin of Louisiana, Gene Taylor of Mississippi, and Solomon Ortiz of Texas—introduced two turtle "stocking" bills before Congress. The first would have amended the Endangered Species Act, authorizing the secretary of the interior to make grants for projects for the propagation of endangered species by programs such as headstarting; the second would have established a headstarting program specifically for threatened and endangered turtles, to which as much as $2,750,000 would be earmarked yearly for construction and operating expenses—a tenfold expansion of the Galveston program.

Both bills died in committee, but they helped secure the future of the Galveston program last November. That was when NMFS's Southwest Fisheries Center sided with Woody and officially recommended that the program be phased out, and the decision was promptly overruled by NMFS head Fox. Besides citing the blue ribbon panel report, Fox argued that killing the experiment might result in a renewed, and perhaps successful, effort by the congressional supporters of the shrimping industry to authorize massive direct funding of turtle stocking programs. Fox did agree, however, to a review of the program if new evidence arises arguing against it.

The danger, say Woody and other sea turtle experts, is that such evidence may never materialize. Headstarting advocates are pinning their hopes on new tagging methods, which they say will give them a better chance of recognizing headstarted turtles if and when they return to breed. But Woody stresses that there is still no comparable way to tag the control group, the palm-sized hatchlings. The project is "a success only if the numbers showing up from the artificial deal are greater than if you had left [the turtles] alone," he says. "And we don't know. It will never be measurable."

Woody says he has learned one clear lesson from his 14-year experience with headstarting. Even a crash program to save a species should be designed so its success can be judged. "That's the first question you have to ask yourself before you go in and spend millions and millions of dollars that are pretty damn scarce."

–**Gary Taubes**

Gary Taubes is a free-lance writer in Santa Monica, California.

TECHNOLOGY

Virtual Acoustics Puts Sound in its Place

Think of how catching snippets of several different cocktail party conversations gets easier when the conversations are taking place on opposite sides of you. Or recall how the sound of footsteps behind you on a dark street commands your full attention, while the same sound coming from the other side of the street is easy to ignore. Our brains, it seems, rely on direction to untangle sounds and make sense of them.

Taking their cues from such real-life examples, a small group of psychologists, acoustic scientists, and engineers are applying the power of computers to turn the sound heard over headphones into a three-dimensional acoustic world. The technology, called virtual acoustics, is far more than an upscale version of a stereo headset. Whereas stereo sounds come from the same side of your headset whichever way you turn, the sounds of virtual acoustics seem to come from fixed points in the outside world: Turn your head to the right, and a sound that seemed to come from the left is now behind you. That kind of acoustic realism could improve the performance of anyone responding to sound on a headset.

Air traffic controllers and pilots, for example, have to match up voices in the cacophony coming over their headphones with the positions of airplanes visible from the tower or cockpit or on a radar screen. By giving each voice a direction matching that of the real plane, virtual acoustics could speed their response. It could also yield new audio navigation aids for the blind and even bolster the realism of the synthesized sounds in video games. Says Elizabeth Wenzel, a psychologist at the NASA Ames Research Center in Mountain View, California, who is studying the technology, virtual acoustics "is going to be very useful for any sort of task that's three-dimensional by nature."

The potential has sparked a lively research program, taking place at NASA Ames, the University of Wisconsin, and several other institutions. Some of the work is aimed at adding an acoustic dimension to the computer-generated visual environments known as virtual realities (*Science*, 3 April, p. 45). But more and more of this research is independent of the largely visual virtual reality simulations that have lately had so much attention. For one thing, virtual acoustics entails distinctive research challenges, which center on the psychology of how humans perceive sounds.

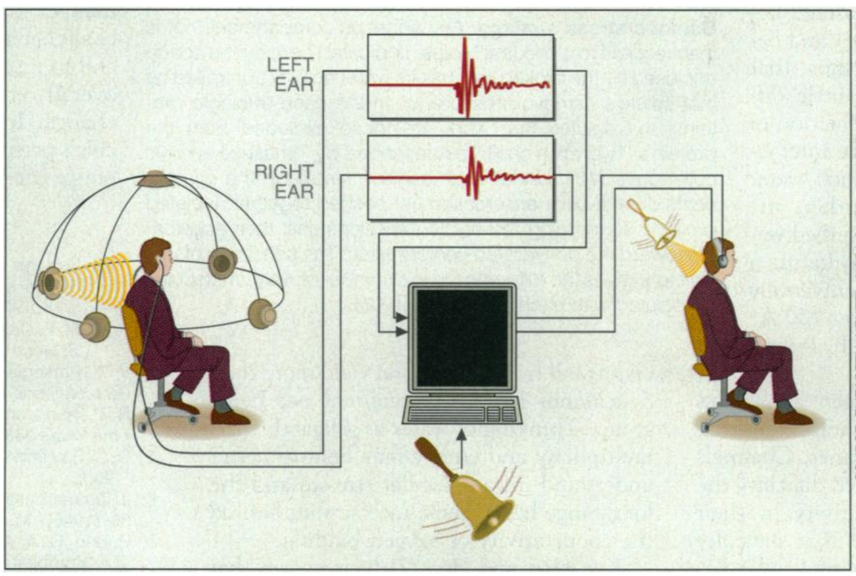
The ingredients of virtual acoustics are a set of sounds to be processed, headphones for the listener, and a package of computer hardware and software that alters the sound going to each ear to create the illusion of a specific direction. So that the system can keep the apparent direction of the sound constant when the listener turns, it tracks the orientation of the listener's head with the help of a magnetic device mounted atop the headphones. So far, such setups do a good job of accurately positioning synthesized tones, clicks, and noise bursts—at least for some listeners. But others perceive the sounds as coming from inside their heads rather than from the external environment. And these simulated sounds have been notably lacking in realism because they omit the rich blend of reflections, damping, and filtering that is typical of real-life sounds.

The key challenge in improving these results, say investigators, isn't building more sophisticated headphones or adding computer muscle. Instead, it lies in understanding and reproducing the sonic cues by which listeners pinpoint a sound's direction. On the simplest level, a sound coming from the left reaches the left ear a little earlier—and is also a little louder on the left. But sound waves hitting the outer ear are also modified by its curves and folds in ways that depend on the sound's direction.

To sort through this complex acoustic mixture, Frederic L. Wightman of the University of Wisconsin at Madison has been recording what the inner ears actually detect after sound is altered by the outer ears. Test subjects are seated in an anechoic (echoless) chamber and exposed to sounds from various directions while little microphones placed in their ear canals capture the timing and intensity of the sounds and the filtering effects of their outer ears. The microphone signals are fed into a computer, which analyzes them to produce a map of how these acoustic features—known as spatial location filters—change with sound location.

Then the experimenters turn the tables, using this information to add an illusion of position to sounds heard over a set of virtual-acoustics headphones. The researchers choose a sound position; based on the spatial location filters and the angle of the subject's head, the computer modifies the signal going to each earphone, and the subject reports which direction the sound seems to come from. By varying the spatial cues, Wenzel, Wightman, and other investigators have been able to home in on the most important ones for sound location. But the experiments have also turned up a potential sour note in virtual acoustics.

Personal space. So far, Wenzel and Wightman have found that a listener gets the strongest sense of acoustic "reality" when the computer is programmed with spatial location filters measured earlier for the same subject. Slight differences in the shapes of people's external ears apparently result in individual differences in some important cues for spatial sound perception, for example those that distinguish sounds coming from the front from those coming from the rear. That individual variability could spell trouble for applications of virtual acoustics. Clearly it would be impractical to measure a set of spatial location filters—a process that takes a couple of hours—for each new person who would use a virtual acoustics headset. But Wenzel thinks the problem isn't fatal.



Fooling the ears. By recording how the ears capture sounds *(left)*, investigators learn how to create the illusion of position in an artificial sound.

SOURCE: ELIZABETH WENZEL, NASA AMES ILLUSTRATION: J. CHERRY

Just what to do about it, though, is a matter of debate. Wenzel suggests adopting "a sensible average" spatial filter that would yield enough sensory cues for most people to pinpoint sounds with reasonable accuracy. Wightman thinks "some individualized tailoring of the equipment will probably always be necessary"—perhaps using the shape of each listener's ears as a guide. But Nathaniel Durlach of Massachusetts Institute of Technology's Sensory Communication Group believes the issue of individual differences can be largely bypassed by exaggerating the location cues to make up for any listener's quirks.

Durlach's approach magnifies the intensity and timing differences of the sound waves sent to each ear—as if the ears had been moved farther apart. "There's little doubt that these kinds of techniques can improve resolution [of narrowly spaced sound sources]," Durlach says. Still unknown, he concedes, is whether a listener still gets an accurate impression of a sound's position in this distorted aural world.

But give us 10 years to solve such problems, predicts acoustic engineer Scott H. Foster, president of Crystal River Engineering in Groveland, California, and "we'll have [virtual acoustics] displays so good that people will think they're real." If so, Foster's firm, which supplies much of the hardware and software to the virtual acoustics research community, will be riding a boom in several fields at once.

In air traffic control, for example, the potential safety benefit of an experimental virtual acoustics system being developed at NASA Ames has already caught the eye of the Federal Aviation Administration, which is planning to test it. Air safety might also benefit from a collision-avoidance system being tested by acoustics specialist Durand Begault at NASA Ames. A pilot wearing a virtual acoustics headset would hear the word "traffic" repeated from a direction that tracks an oncoming plane. In cockpit simulations, the system has sped up pilots' responses by 1 to 2 seconds compared to conventional collision-avoidance systems—enough time, perhaps, to make the difference between a collision and a near miss.

Predictably, the military is intrigued by virtual acoustics' potential for improving the performance of everyone from submarine sonar operators to fighter pilots. But the technology may also find its way into some more surprising domains. Jack Loomis, a psychologist at the University of California, Santa Barbara, thinks it could serve as a navigation aid for the blind. The idea would be to feed the radio signals from the GPS (global positioning system), a network of navigation satellites that can pinpoint positions on Earth's surface to within a few meters, into a pocket-sized computer equipped with a map of a city or neighborhood. The computer could then tell a blind user just where he or she stood relative to a particular landmark—a park, say, or an intersection—by generating sounds that seemed to come from the true position of the landmark relative to the listener.

Audio Atari. Such power to create a separate reality has naturally attracted the attention of the entertainment industry. Crystal River's Foster, for example, says he's been talking informally with such companies as Sega, Nintendo, and Atari about applying his firm's virtual acoustics circuitry, trade-named the Convolvotron, in new video systems. Imagine the appeal of a headphone-equipped video game in which you could hear the clank of an android approaching from the northeast sector of hyperspace. "I think it's inevitable that you'll see this technology used in entertainment," Foster says. "By 1995 or 1996," he adds, "I bet it will show up at the consumer level, probably in arcade games."

Not at present prices, though. A single Convolvotron, for instance, costs $15,000. And besides the problem of tailoring simulations to individual ears, many features of acoustic reality still lie beyond the technology: not just echoes and reflections but also the complex sound waves required to reproduce many background noises—"say, something as simple as dropping a shoe," says Durlach. But the challenges are manageable, Foster and other proponents think, now that the interest in virtual acoustics has propelled it out of its former rank as poor cousin to vision-based virtual reality systems. In fact, Foster believes that virtual acoustics will create a truly life-like world a lot sooner than visual systems. "Compared to the eyes, the ears are simpler devices," he says, "so they'll be easier to fool."

–**Gordon Graff**

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