

# THE NEW YORKER

MEDICAL DISPATCH

## THAT BUZZING SOUND

*The mystery of tinnitus.*

by Jerome Groopman

FEBRUARY 9, 2009



Tinnitus is one of the most common clinical conditions in the United States.

I noticed the sound one evening about a year ago. At first, I thought an alarm had been set off. Then I realized that the noise—a high-pitched drone—was mainly in my right ear. It has been with me ever since. The tone varies, from a soft whoosh like a shower to a piercing screech resembling a dental drill. When I am engaged in work at the hospital or in the laboratory, it seems distant. But in idle moments it gets louder and more annoying, once even jarring me from a dream.

Tinnitus—the false perception of sound in the absence of an acoustic stimulus, a phantom noise—is one of the most common clinical syndromes in the United States, affecting twelve per cent of men and almost fourteen per cent of women who are sixty-five and older. It only rarely afflicts the young, with one significant exception: those serving in the armed forces. Tinnitus affects nearly half the soldiers exposed to blasts in Iraq and Afghanistan.

This past August, I visited the University of Buffalo, which houses one of the major clinical and research centers for the evaluation and study of tinnitus. After filling out a detailed questionnaire, I met with Christina Stocking of the Speech-Language and Hearing Clinic, who has a doctorate in audiology and specializes in the condition. Stocking thought that I might have suffered noise trauma during a youth spent on the New York City subways. Sitting in the first row of a rock concert exposes you to between a hundred and ten and a hundred and twenty decibels; the screech of the New York subways can reach about a hundred and fifteen decibels. Moreover, since much of the New York subway system is underground, the noise reverberates in the tunnels, unlike in Boston, where many of the trains are above ground and noise dissipates, or in Paris, where several metro lines run on rubber wheels.

Normally, the outer ear, known as the pinna, collects sound waves and directs them into the ear canal, which carries the sound waves to the eardrum. In turn, the eardrum vibrates, and these tremors are picked up by the three tiny bones in the middle ear: the malleus (resembling a club), the incus (shaped like an anvil), and the stapes (similar to a stirrup). These bones amplify the sound vibrations and transmit them to the inner ear, where the cochlea converts the vibrations into electrical impulses, which travel from the acoustic nerve to the part of the brain that processes sound, the auditory cortex. Tinnitus can be temporary, caused by excess wax, an infection of the inner ear, or the toxic effects of drugs like aspirin (which appears to weaken the neural signals from the ear to the brain) or those used to treat cancer. Some people with normal hearing develop spontaneous tinnitus when placed in total silence; this is believed to be a response of the auditory cortex to the abnormal absence of all ambient sounds. But the majority of people with chronic symptoms develop them in conjunction with hearing loss. With the

recent proliferation of MP3 players, rates of hearing loss and tinnitus may rise sharply in the coming years. A recent European Union study has projected that as many as ten million Europeans may be at risk of developing severe hearing loss as they age; and, according to the American Academy of Audiology, noise-induced hearing loss affects about one out of every eight children in the United States.



*"Don't mind me, Richie—it's just the rabies talking."*

The range of tinnitus's severity is as wide as the ways of describing the syndrome. Martin Amis, in "Money," characterizes the tinnitus that his character John Self suffers as "jet take-offs, breaking glass, ice scratched from the tray." In "A Pair of Blue Eyes," Thomas Hardy's William Worm complains of "people frying fish: fry, fry, fry, all day long in my poor head." Some patients also suffer from hyperacusis, in which certain sounds are amplified in a painful way. As part of a standard evaluation, patients are given a series of tests: a tympanogram, to determine how the eardrums respond to air pressure; an assessment of the cochlea's response to sound; and a standard audiogram, to test the frequency and intensity of sounds that define the span of hearing. Although my eardrums functioned well, Stocking said, the last two tests showed signs common to hearing loss at high frequencies, usually owing to age and noise trauma.

The audiologists at the Buffalo clinic see between a hundred and fifty and two hundred tinnitus patients a year, nearly all of them referred by physicians because the noise is disrupting their lives. Last May, David Nowak, a sixty-four-year-old retired machine repairman, had an ear infection that his doctor treated with antibiotics. Shortly thereafter, he heard a loud horn in the street, and has been plagued by tinnitus ever since. "It's so loud that I can't drown it out," he told me. "It is a high-pitched squeal most of the time." Nowak said that, before the tinnitus, "I didn't have a care in the world—I cut the grass and I played with my granddaughter." Now, he said, "My life has come to a halt. I can't do anything. I can't concentrate." One Sunday, he told me, he went out and stood by a metal flagpole during a storm, hoping that lightning would strike, and that he had gone to the cemetery and "begged my mother to take me. I wish I would pass away."

Tinnitus may have been described as early as the Seventeenth Dynasty, in Egypt (1650-1532 B.C.): an ancient Egyptian text, the Medical Book from Crocodilopolis (circa 150 B.C.), contains references to a "humming in the ear." Treatment involved pouring herbs, oil, frankincense, tree sap, and soil into the ear using a reed stalk. The earliest undisputed description of the condition comes from Hippocrates, who used three words to describe the problem: *echos*, meaning sound; *bombos*, denoting buzzing; and *psophos*, indicating a slight sound. (Our word "tinnitus" derives from the Latin *tinnire*, meaning to ring.) The Greco-Roman therapy ranged from holding one's breath in an effort to expel offending humors from the ear to placing honey, vinegar, cucumber juice, and radish extract in the ear. Hippocrates did make an observation that serves as the foundation for modern therapy: "Why is it that the buzzing in the ear ceases if one makes a sound? Is it because the greater sound drives out the less?"

In the modern era, people with tinnitus were thought to be suffering from anxiety or delusion, or to be subject to the transmission of spontaneous impulses from the nerve within the ear. Researchers have only recently begun to explore the neurological basis for tinnitus. Richard Salvi, a professor at the University of Buffalo, is one of the leading experts in the field. As a graduate student at Upstate Medical Center, in Syracuse, Salvi had set out to identify the "neurological signature" for tinnitus by treating rats and mice with drugs that injured the auditory nerve; conventional wisdom held that, after damage to the hearing apparatus in the inner ear, increased output from the cochlea would create the constant ringing or buzzing sound perceived as tinnitus. Salvi recalled, "Instead of seeing hyperactivity, which was the prevailing opinion about tinnitus, it was just the opposite. Output would actually slow down. You had a severely deafened animal, and nothing coming out of the inner ear—no spontaneous activity at all."

Salvi moved to the University of Buffalo in 1987. He had begun to consider a new theory, in which hyperactivity originated in the central nervous system rather than in the inner ear. He collaborated with Dr. Alan Lockwood, a neurologist at the University of Buffalo. "Initially, we were going to do images of the brains of people who are normal and people with tinnitus," Salvi recalled. "But when you are doing any sort of brain-imaging project what you have is all the other confounding variables"—such as age, gender, and head size. Shortly after Salvi's arrival, he met with a group of local residents who had formed a tinnitus support group. One person, Salvi recalled, got up and said, "'Dr. Salvi, I stick my tongue out and my tinnitus gets louder.' I looked at the person, and my eyes started to wobble around in my head, and I thought, 'What's going on with this person?'" Then a second person got up and said, "When I clench my jaw, my tinnitus gets quieter." Salvi told me, "A light bulb went off in my head. It seemed like what we should be doing with imaging studies was not comparing normal people to those

with tinnitus but, rather, having these people come in and get scanned when their tinnitus was quiet, and then again while doing something like sticking out their tongue, which made it louder. In the same patient we can determine what part of the brain was changing.”

The first PET-scan results were unexpected. Whereas a real sound will activate areas on both sides of the brain, “we found a big increase in activity in just one side of the brain,” Salvi told me. If the origins of tinnitus were in the ear, it would activate both sides of the brain; when only one side appeared active, it suggested that the tinnitus originated in the central nervous system. The brain became hyperactive in an effort to compensate for the reduced input, generating phantom sounds. This conclusion, which was published in the journal *Neurology* in 1998, began to change the way that researchers approached tinnitus. Still, there is no convincing explanation for why only one side of the brain shows activity in people with tinnitus, particularly since it doesn’t appear consistently on either the right or the left side.

Another oddity is a type of tinnitus called “gaze-evoked,” in which ringing in the ears is occasioned or worsened by moving one’s eyes to the right or left, or up or down. Case studies reported gaze-evoked tinnitus in patients who had had a tumor on the auditory nerve which was surgically removed. “The patient goes completely deaf in that ear, and then he starts hearing the phantom sound of tinnitus in the ear which is deaf,” Salvi explained. “The ear isn’t even connected to the brain anymore.” When patients with gaze-evoked tinnitus were given PET scans, some showed activity in the angular gyrus, an area of the brain near the auditory cortex; others had activity in the brain stem. “The bottom line was that you perceive tinnitus in your deaf ear but there is no nerve there, no input,” he went on. “So it has to come from various parts of the brain.”

Jean-Luc Puel, a professor of neuroscience in Montpellier, France, is not convinced that tinnitus always originates as a phantom sound in the brain. He has studied rats and guinea pigs that were treated with high doses of aspirin or exposed to noise trauma. Puel believes that glutamate, a neurotransmitter, is inappropriately processed in the cochlea, which causes abnormal impulses from the acoustic nerve, and that by infusing the animal’s ear with a drug that blocks the action of glutamate he can reduce the tinnitus. More broadly, Puel argues that the disorder may have multiple causes. “This conflict between peripheral and central origin of tinnitus is simplistic,” he said. “To have perception of tinnitus, which is subjective, you need a brain.” Puel allows that his view is contrarian, adding, “I like to arrive at scientific meetings and disturb people.” But he also believes that different causes of tinnitus may reflect differences in biology. “There is no one type of tinnitus,” he told me.

When I visited Salvi’s laboratories, Edward Lobarinas, a researcher, was conducting experiments on rats that had been subjected to acoustic trauma. Lobarinas showed me a Plexiglas platform with an embedded pressure sensor attached to a computer. On top of the Plexiglas was a metal mesh canopy. First, a normal rat that served as a control was caged under the canopy and the entire apparatus was placed inside an acoustic chamber, into which Lobarinas delivered a steady noise with a narrow frequency range. “It’s a continual sound in the background, a sort of *sh-h-h*,” he said. This was interrupted by a loud bang. “The animal startles,” he said, and this sent a measurement of the movement through the pressure sensor to the computer screen, which showed a sharp spike.

In the next step, the sudden bang was preceded by a silent gap in the noise. This time, the rat had a much smaller startle reflex, seen on the computer as a low peak. “When you have a silent gap before the loud noise, you’re less startled,” Lobarinas said. “It’s like when it’s dark and you’re in your room and a bogeyman jumps out at you. You have a maximum startle. But if, before the bogeyman jumps out, the door is slowly creaking open, you sort of know the bogeyman is going to come out, and that decreases your startle.”

When a rat with induced hearing loss underwent the same experiment, it had a robust startle reflex even when the loud noise was preceded by silence. “The rat has tinnitus,” Lobarinas said. “It can’t tell us, of course, but it has constant buzzing in the ear, and we know that although it hears, it doesn’t perceive the silent gap because of tinnitus. So its startle reflex is not attenuated. It doesn’t hear the door slowly creaking open, just the bogeyman.”

Total funding for tinnitus research in the United States has recently been little more than three million dollars. “People don’t realize how complicated tinnitus really is,” Salvi said. “It’s in the same league as epilepsy and many neurological disorders. But so little money is spent on it, so there is almost no scientific database you can build on.”

Perry Jefferies, now a forty-eight-year-old retired Army first sergeant, entered Iraq with the 4th Infantry Division in April, 2003, as part of the initial invasion of Operation Iraqi Freedom. “We moved from Kuwait to Baghdad,” he told me, when we spoke by phone, “and then went up to Tikrit, until we were posted at the Iran border.” Jefferies escorted and resupplied units moving into battle. After one firefight, as his convoy was evacuating an injured Iraqi soldier, U.S. helicopters fired missiles into enemy ammunition bunkers. “We were right there at the explosions,” he said. Later, as his convoy was resupplying a unit near the border with Iran, a massive explosion at a nearby Iraqi fort rocked his Humvee. “We think that looters set it off,” he said. “It fried the fort.”

Although hearing trauma was most intense in combat, Jefferies said, he had been exposed to repeated noise during his many years in the military. During basic training, while on the weapons range, “we only wore one earplug, so you could hear the instructor when he yelled at you.” While learning how to fire a .50-calibre gun from an armored personnel carrier, he recalled,

“we had no hearing protection. Afterwards, blood was coming out of one of my ears.” He had ruptured his right eardrum. Even so, the close-range explosion at the fort was different from anything he had experienced before. “I felt like I was under water for a few minutes,” he said. Since that time, he has been afflicted with tinnitus. “It is a high, steady electronic tone,” he told me. “And my ears feel heavy and blocked.”

As a first sergeant, Jefferies acted as an adviser to soldiers during their deployment. “One of my jobs was to try to find answers,” he said. “But I don’t remember any discussion about hearing protection.” The soldiers in his unit were required to carry earplugs, but many of them would simply attach the case to the front of their protective vests. “I had to listen sometimes to three different radios in the Humvee and respond,” Jefferies went on. No one, he told me, wore hearing protection, even when machine guns were test-fired on the base. In 2004, Jefferies retired from active service and was awarded the Bronze Star and the Legion of Merit.

Jefferies’s hearing fluctuates, at times diminishing to thirty-five per cent below normal, and he is now receiving ten-per-cent disability compensation for tinnitus. He is active in the Iraq and Afghanistan Veterans of America and works as a blood-donor recruiter at Robertson Blood Center, at Fort Hood, in Texas. “It is hard to hear in a bar or restaurant, hard to discern certain words, and I have to turn up the TV,” he told me. At times, the high-pitched drone of his tinnitus wakes him in the middle of the night.

A recent report from the Department of Veterans Affairs estimated that nearly seventy thousand of the 1.3 million soldiers who have served in Iraq and Afghanistan are collecting disability for tinnitus, and more than fifty-eight thousand are on disability for hearing loss. In 2006, the V.A. reportedly spent five hundred and thirty-nine million dollars on payments to veterans with tinnitus. A survey of more than a hundred and forty-one thousand Army active-duty, reserve, and Guard members who were examined in audiology clinics from April, 2003, through March, 2004, showed that tinnitus accounted for more than thirty per cent of post-deployment-related diagnoses. The study, from the U.S. Army Center for Health Promotion and Preventive Medicine, concluded, “There were not adequate supplies of earplugs to fit all deploying soldiers. There was also failure of an Army medical readiness automation system . . . to provide unit commanders with information regarding troops having adequate hearing protection. . . . Finally, there is evidence . . . that soldiers having blast injuries may not have been referred to audiology for adequate evaluation and treatment.” As with body armor and protective shielding on Humvees, the Pentagon had failed to anticipate the kind of hearing-protection devices that were needed. Even soldiers who were provided with earplugs were given insufficient instruction in their use; mistakenly believing that the earplugs could interfere with low-frequency sounds, like whispered commands during search-and-destroy operations, many chose not to use them.

Theresa Schulz, an audiologist who served in the military for twenty-one years, told me that hearing loss accompanying tinnitus is now the No. 1 cause of disability among veterans of the conflicts in Afghanistan and Iraq. “I think it’s probably because of the nature of urban warfare,” she said, given that gunfire and mortar and grenade explosions occur in relatively confined and often closed areas. After Schulz left the military, she worked for the National Institute for Occupational Safety and Health, in the field of hearing conservation among workers, and she is now employed in the private sector, developing devices that can protect against noise trauma. For civilians, Schulz noted, extraordinary noise like construction blasts or jackhammering can often be anticipated and protected against, but “in the military that’s not the case. It can come up anytime.”

In the fall of 2004, in an article for *Hearing Health* titled “Troops Return with Alarming Rates of Hearing Loss,” Schulz wrote, “Unfortunately, the resources required to accomplish the hearing conservation mission throughout the armed forces are diminishing just as the problem worsens.” Positions for active-duty audiologists, Schulz noted, were quickly being eliminated; since 1990, these positions had dwindled from seventy-three to twenty-five, with six more posts expected to be eliminated in the coming years. Meanwhile, Schulz wrote, “In the Army . . . only forty-six per cent of those soldiers who require an annual hearing evaluation—because they are exposed to hazardous noise as a part of their routine duties—received one last year.”

The military has attempted to make hearing protection more widely available. The combat-arms earplug currently in use was originally developed in France, in the late nineteen-nineties, and contains a unique acoustic filter that is about the size of a grain of rice. The filter creates acoustic friction to capture potentially harmful sound waves and turn them around, so that the noise doesn’t send signals into the ear canal. Schulz described it as low-end, explaining, “It’s basically just a fairly traditional earplug that has a filter in it, that allows through most of the sounds that you would normally hear,” while blocking sharper noises, like gunfire. A more sophisticated device, called QuietPro, is a lightweight digital tactical-communication headset with high-level hearing protection. Continuous low-frequency rumbling noises above eighty-five decibels, such as those produced by helicopters and armored vehicles, are attenuated by more than thirty decibels. Outer microphones amplify surrounding sound, but very loud impact noises from I.E.D.s are instantly blocked by a digital processor; normal amplification is restored immediately after the impact sound has passed. “It’s essentially a hearing aid and a hearing protector in one,” Schulz said. “It’s a device that allows you to turn up the sound so that you can hear what’s on the other side of a door, what’s around the corner. . . . It basically shuts down and protects you during the blast and then comes back on so that you can hear what’s going on after the blast.” The Marines have adopted the QuietPro, but the Army and the Air Force, Schulz said, are taking a “wait-and-see approach,” particularly since each QuietPro unit costs about a thousand dollars. But, Schulz noted, hearing loss and tinnitus can

prevent soldiers from being redeployed and qualifies as a disability. "It's one of those pay-me-now, pay-me-later" situations, Schulz said. "Pay-me-now is really less."

Colonel Kathy Gates, the director of the Army Audiology and Speech Center in Washington, D.C., serves as the audiology consultant to the Army Surgeon General, working to redesign the hearing program in that branch of the service. In 2004, Gates instituted an annual surveillance hearing test for soldiers about to be deployed, and last year mandated a similar evaluation of those returning from service. All soldiers must now be instructed in the use of the combat-arms earplugs. Gates has helped develop a strategy for persuading Army personnel to wear the earplugs in combat by linking their use to success in battle rather than to long-term health. "A soldier with hearing loss is impaired in battle," Gates said. "We are linking hearing not to quality of life per se but to survivability and completion of the mission." Gates said that QuietPro is being field-tested in Iraq and Afghanistan, and that the Army had increased the number of positions for audiologists in the battle theatre and in regional hospitals in Iraq. Even so, recruitment was slow, and the military is not yet fully staffed despite the restoration of funding for the hearing program.

The efforts to provide proper training and equipment have had some success. Specialist Joseph McLosky, who is twenty-four, is a member of the military-police reserve; in September, 2006, his unit was sent to Fort Dix to prepare for urban combat, and he was issued the newly requisitioned combat-arms earplugs. Two-sided and color-coded (the green side for use when actively shooting—on a range, for instance—and the yellow side for missions), the earplugs, McLosky said, were to be used in addition to the radio headsets that soldiers wear in convoys. "A lot of guys thought it was ridiculous to use both," he told me, when we spoke in September.

In December, 2006, McLosky was deployed to the city of Bayji, between Baghdad and Mosul, in the north of the country, to train Iraqi police recruits in the use of firearms, surveillance missions, and the pursuit of insurgents. "We went from police station to police station along the same roads, spending eight to sixteen hours a day in the convoy," he said. They encountered about one I.E.D. a week. In June, 2007, his squad was passing a checkpoint when a car bomb exploded. "Dirt and smoke and debris were flying past my head," he went on. "We had been up all night, and I thought I was dreaming." Although he was only a few yards away from the explosion, McLosky said, "My ears weren't ringing." In October, an I.E.D. detonated underneath McLosky's truck. "I was ejected from the vehicle," he said. "It broke my pelvis, left leg, and ankle. I had to have my left foot amputated." Despite the severity of his injuries, McLosky emerged with his hearing intact; he now plans to become a physical therapist. Throughout his deployment, McLosky told me, it had been easy to tell which soldiers weren't wearing their earplugs. "They were the ones saying, 'What? What?'"

Tinnitus patients desperate for relief sometimes turn to folk remedies. Christina Stocking routinely hears of patients using herbal supplements like ginkgo biloba or high doses of Vitamin B, neither of which has been proved effective in large controlled studies. Antioxidants are commonly recommended—because the aging process is believed to be related in part to oxidized damage to tissues, including the auditory nerve—although no practical benefit has been documented. Some of the more extreme approaches that Stocking has encountered include the neti pot, a device that resembles a teapot with a long spout; the device is filled with warm salt water and used to irrigate the nasal passages. "You get yourself into a position to pour up one nostril, and it gets up to your sinus and drains out the other side," Stocking explained. Another is "ear candling," she told me. "People actually take wax paper, roll it up, stick one end into the ear canal, and light the other end."

Stocking trained under Pawel Jastreboff, now a professor at Emory University, who developed a treatment plan called tinnitus retraining therapy. It combines counselling, to reduce the anxiety caused by the phantom sounds, with sound therapy, using a neutral background noise. Stocking first determined the decibel level of my tinnitus, then transmitted a noise similar to rushing water to both ears through headphones. For the first time in a year, I couldn't hear the dental drill even when I tried.

The device currently approved by the F.D.A. for tinnitus treatment, produced by a company called Neuromonics, resembles an MP3 player. I put the earbuds in and listened to a soothing piece of classical music. "That is meant to induce relaxation," Stocking explained, a key component of the tinnitus management strategy. Then I noticed a soft white noise that was programmed to mask my own tinnitus. Again, within moments, the tinnitus was gone. The theory, elaborated by Jastreboff, is that when more sounds are fed to the brain sensitivity and spontaneous activity decline—the effect Hippocrates remarked upon.

A simple hearing aid may reduce some tinnitus by amplifying background noises, but other strategies include using sounds in the environment, like soft background music from a stereo or more directed sounds that come from a fan or a small desktop sound machine. Similarly, a device called a sound generator, which is worn on the ear, can supply a white noise that partially interferes with the tinnitus. "It really provides a sense of relief and control over the tinnitus," Stocking said. "Patients feel they are able to do something about it. And, by providing additional sound, it seems to bring down the sensitivity of the auditory system."

Recently, I met with Dr. David Vernick, an ear-nose-and-throat specialist at my hospital, Beth Israel Deaconess. He reviewed the tests done in Buffalo and concurred that I needed hearing aids. "They will certainly help you with what you are missing now," he said. "It's hard to know how much benefit you will get with regard to your tinnitus." He added that hearing

aids often act simply as a placebo.

Ann Stockwell, an audiologist in Vernick's office, entered the data from my audiogram into a computer, then used earbuds to transmit sounds generated by the computer—in essence, programming the hearing aids. I listened to a range of tones, which Stockwell compared with the data provided by the audiogram. Once the hearing aids were fitted, she asked me to turn my back. From about sixteen feet away, she spoke in a normal voice that I heard with no difficulty. “The aids will amplify background sounds, like the noise from the refrigerator or a heater,” she said. “Initially, there will be increased sensory awareness, and then you will adapt. I like to say that we are entering the auditory closet and throwing out what the brain can't hear. We will fill the closet with a new set of sounds. And, hopefully, your brain will change so that there is less tinnitus.”

The hearing aids aren't a cure: in a quiet room, my tinnitus is as persistent as ever. But when I returned to my office, with the hearing aids in place, I could hear the noise of the air vents, which previously had been inaudible. I tried to catch the high-pitched drone that has accompanied me in the past year. I couldn't hear it. ♦

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