The Infinite Mind: *Hearing*

KATINA KAELIN (Announcer): Major underwriting for THE INFINITE MIND is provided by the John D. and Catherine T. MacArthur Foundation, the National Science Foundation, the National Institute of Mental Health and the Non-Profit Finance Fund.

Dr. FRED GOODWIN, host:

I'm Dr. Fred Goodwin, and this is THE INFINITE MIND.

This week we'll hear about our sense of hearing. It's vital to how we communicate. But in such a noisy world, how do we pick out what's important? We'll explore exciting new findings about how we tell one sound from another.

Dr. ALBERT BREGMAN (Professor, McGill University, Montreal, Canada; Author, "Auditory Scene Analysis: The Perceptual Organization of Sound"): If you look at what's happening actually, say, on the eardrum, there is no separate set of sounds.

GOODWIN: We'll meet the activist behind a new law requiring that ear protection be available in loud clubs, and hear why rockers, from Joe Satriani to Metallica, are endorsing her work.

Ms. KATHY PECK (HEAR): It's insidious. Hearing loss is insidious. It just creeps up on you.

GOODWIN: Plus, we'll learn what's going on in the brain when people with schizophrenia hear things that aren't there.

Ms. EDITH SHUTTLEWORTH: Like, I'll be on the subway downstairs, and they'll--says, `Do you want to jump?'

GOODWIN: All this, plus the Oscar-winning sound designer of films, including "Cast Away," "Forrest Gump" and "Harry Potter and the Chamber of Secrets," reveals some of the tricks of the trade. And commentator John Hockenberry.

JOHN HOCKENBERRY (Commentator): Big screen, little screen--it's not real without good speakers and a subwoofer.

GOODWIN: Today as we explore the sense of hearing right here on THE INFINITE MIND.

I'm Dr. Fred Goodwin.

The topic of hearing hits home for me. My father, one of my sons and yours truly suffer from a congenital right-sided hearing loss. I'd like to offer a few personal stories that illustrate many of the issues we'll cover in today's program. I think they'll show just how vital unimpaired hearing is for connecting with other people and interacting with the world around us.

My dad never did anything about his hearing problem. In his day, hearing aids were quite large, and people with moderate hearing loss on just one side generally didn't consider them. But as my dad got into his 80s and 90s, the congenital problem was made worse by some normal age-related hearing loss, and it really began to handicap him. As you'll hear today, for many with hearing loss, the biggest problem is often hearing speech in a noisy background. For my dad, this deficit became obvious when our extended family gathered for dinner. There were intense, multiparty conversations, plus lots of little ones producing their own kind of background music--or perhaps I should say noise. I'd watch my dad start participating in a conversation with great interest. Clearly, his mind was still sharp, and he had interesting things to say, but after a few minutes, he'd drop out. He couldn't keep up with the conversation simply because he couldn't hear much of it.

As for my own hearing loss, I, too, lived with it for years without doing anything about it. As a young man, it only affected me at certain times, such as when driving in my un-air-conditioned car in the summer, with the driver's side window down, while trying to listen to my date with my impaired right ear. When I didn't catch something she said, I'd try to take the pieces I did hear and fill in the rest with guesswork. Now I think I understand why some of those summer dates never worked out. I must have come across as at least insensitive or even disconnected and a little weird. A few years ago, just like for my dad, age began to make my impairment worse, so it wasn't just wind noise that brought it out. For example, when I held staff meetings as director of the National Institute of Mental Health, I would not consistently hear what was said by people on my right, so most of my responses were to the people on my left. This must have produced some consternation, since, of course, everyone wanted the director's ear, so to speak.

But I've been more fortunate than my dad. By the time my loss became a real problem a few years ago, hearing aid technology had come a long way. Call it vanity, but when I learned that there were devices that fit completely into the ear canal and were essentially invisible, my resistance was overcome. More recently, I've moved to the new digital hearing aids, which selectively amplify the sound frequencies that represent each wearer's particular kind of loss. In my case, it's the frequencies of most female voices. The new hearing aids are great, and my wife is very pleased.

For insight into just how powerfully our hearing affects us, we look to somebody whose job it is to use sound to stir our emotions. Randy Thom is a true master of movie sound design. Since 1979, he's been working as a re-recording mixer and sound designer for Skywalker Sound, a division of Lucas Digital and one of the largest and most versatile audio post-production facilities in the industry. Mr. Thom won an Academy Award for his work on "The Right Stuff," and he's been nominated for numerous others for films including "Cast Away," "Contact," "Forrest Gump" and "Return of the Jedi." Most recently, he did the sound design for "Harry Potter and the Chamber of Secrets." He'll demonstrate some of the tricks of the trade.

Mr. RANDY THOM (Sound Designer, Skywalker Sound): I--it's funny that when I'm introduced to people at parties as `a film sound designer,' you know, often the thing they say is, `Well, you know, sound is so important to film,' and I always feel like I'm being patronized because they would never say, if they were introduced to a cinematographer, `You know, visual images are so important to a film.' But, in fact, sound actually is very important to film. It's just that sound tends to affect us in ways that we don't realize, and it's--the cliche is that it sneaks in the side door to the brain. The great thing about that in movie sound is that it gives the filmmaker an enormous latitude to, you know, pull the puppet strings, as it were, and affect the emotions of the audience with sound in ways, if it's done artfully, that they won't recognize.

But I'll give you a fairly specific example. It's fairly common for a director to come to me and show me a scene in which there's a conversation on somebody's front porch, and the director says, `You know, this scene is a little darker, a little more sinister or depressing than I'd like for it to be. What can you do with sound effects to lighten the mood a little bit?' And just about the only sound--natural sound that I can put into a scene like that that'll have that effect is songbirds.

(Audio of songbirds)

Mr. THOM: On the other hand, I have lots and lots of sounds that will suggest danger or reason to be concerned or something sinister.

(Audio of rain)

Mr. THOM: Before "Star Wars"--and I had nothing to do with the first "Star Wars" film. This is a--a--Ben Burt's great work. The sound for previous science fiction films--that is, the sound effects, the special sound effects--had been generated with oscillators generating pure tones in reverb chambers, echo chambers, etc. And Ben and George thought, `Maybe, instead, we should start with real-world sounds that have this kind of gritty experiential feel to them that will be familiar, but then we'll take those sounds and we'll modify them electronically and mechanically to give them a kind of exotic edge that will also make the audience feel like, "Wow, that's not quite like anything I've ever heard before."' And that was the big creative breakthrough on the sound of "Star Wars."

I'll give you a specific example. The sounds of some of the evil empire's ships were made using animal sounds; that is, the sounds of them flying by are made from things like elephants. If you combine those sounds...

(Audio of elephants)

Mr. THOM: ...with the sound of an airplane flying by or a--or a rocket flying by, what you get is this kind of amalgam that ha--has a double edge to it.

(Excerpt from a "Star Wars" episode)

Mr. THOM: When Bob Zemeckis was beginning to direct "Cast Away," he said that he was thinking maybe there shouldn't be any music in the sequence when Tom Hanks is alone on the island, and that's a very long sequence. It's about an hour of the film. And at first, I thought, `Wow, my dream has come true. I finally--I don't have to compete with the music department to make the sound effects heard.' And then the reality of it sort of dawned on me, and I thought, `Oh, my God, I've finally gotten what I've been asking for all these years, and now I have to actually pull it off with sound effects.' And what made it even tougher is that not only did Bob not want any music on the island, he didn't want to hear any insects or birds or frogs because he thought that, also, would make it seem like the Tom Hanks character was less lonely. So that's when I really panicked.

Basically, all we had was the sound of him walking around, his movement sounds, and the sounds of the water, the waves lapping and other kinds of surf, and the sound of the wind: the wind blowing across the rocks, the wind blowing through the cave, the wind blowing through the palm trees. And we decided we could make the palm trees a little more evocative if we made them creak, and so we recorded squeaky wicker cat carriers, among other things, to give the palm trees a squeaking sound as they swayed back and forth in the wind.

(Audio of squeaking palm trees in the wind)

Mr. THOM: When you're learning to be a sound designer in movies, the main thing you need to do is to divorce yourself from what things really sound like or what things really would sound like, and you need to think in purely dramatic and emotional terms about what they should sound like in the film in order to tell the story.

GOODWIN: I'm Dr. Fred Goodwin, and you're listening to THE INFINITE MIND.

There are some basic questions when it comes to hearing: How does the ear work? Why do some people lose their hearing? We have pretty good answers for these, but there are other questions, too, with answers we're only beginning to discover: How do we distinguish one sound from another? Can lost hearing be restored?

Joining me now for a primer on hearing as well as to explore some of the remaining mysteries are two distinguished guests: Dr. Brenda Ryals, a professor and a hearing researcher at James Madison University; and Dr. Albert Bregman, a professor of psychology and a hearing researcher at McGill University in Montreal, Canada. He's the author of "Auditory Scene Analysis: The Perceptual Organization of Sound," and he's the creator of a CD that gives examples of how we hear and pick out sounds in the environment. We'll hear excerpts from that CD today.

Dr. Bregman, Dr. Ryals, welcome to THE INFINITE MIND.

Dr. BRENDA RYALS (Professor, Hearing Researcher, James Madison University): Hello.

Dr. BREGMAN: Glad to be here.

GOODWIN: Nice to have you. Dr. Ryals, let me begin with you. How does the ear work? Just the mechanics, I mean, how does the ear actually receive and--and then transmit the sound into the brain?

Dr. RYALS: Well, in its simplest form, sound is transmitted through the middle ear to the inner ear, and there are small sensory cells we call hair cells in the cochlea or the inner ear that are mechanotransducers--they send electrical impulses through the auditory nerve to the brain, where the sound is perceived and interpreted.

GOODWIN: Dr. Bregman, your work is all trying to figure out how and why we hear the way we do. So what are the major questions that you address in--in that? I mean, how--how is that--that field progressing?

Dr. BREGMAN: The major question is how we hear sounds in a mixture. If you ask somebody how they do it, they just say, `Well, I just listen to the sound.' But if you look at what's happening actually, say, on the eardrum, there is no separate set of sounds. All you have is the sum of all the sounds, and so you have a wave pattern on the eardrum that is the sum of the--all the wave patterns that created that mixture or that sum. And then the problem is: How do you decompose that sum back into the original wave patterns that were the origin of the--of that mixture? So that process is called auditory scene analysis, going from the mixture of sounds that get into the ear and then inferring what the original sounds must have been. And what we've been doing is trying to find out all the tricks that the auditory system uses to solve that problem.

GOODWIN: How did you get started in this interesting area?

Dr. BREGMAN: Purely by accident, actually. I was making some sounds for a memory experiment, and then I noticed--I used very rapid patterns of short sounds, and I noticed that I wasn't actually hearing them in the order that they were on the tape. I was actually grouping them differently. I started off with a very simple alternation of high and low tones and found that you heard two separate steams of sound, a high stream and a low stream, and you didn't seem to f--hear any connection between them. And this was the beginning of the--the research on that area.

GOODWIN: You know, it might make our listeners understand this better and get a real feel for it if we had some examples. You notice, in the introduction, I mentioned your CD, and I think your CD gives examples of the kind of processing a brain does to sort out sound. So maybe we can listen to one of these now, and maybe you could describe it for us. Can you play it?

Dr. BREGMAN: OK.

(Excerpt from CD)

GOODWIN: So, Dr. Bregman, what does this mean? What's the significance of--of these broad--these clear differences we were hearing?

Dr. BREGMAN: In the first example, eventually, as you speeded it up, you got grouping by frequency; that is, the high tones were close enough in time that they preferred to group with each other than to group with the low tone.

(Excerpt from CD)

GOODWIN: This is the brain processing which--we hear it in a way that's different than the way it's actually being produced.

Dr. BREGMAN: Yes. It's a--it's an interpretation. Now in the second example, the frequencies were all very close together, and when you speed that up, there was no preference for grouping with the same frequency than--rather than with the one that was, say, lower or higher. So we continue to hear the galloping to a high speed.

(Excerpt from CD)

GOODWIN: That's a pretty dramatic demonstration, isn't it, of how we impose our own reality on what's coming from the environment?

Dr. BREGMAN: Yeah, but that reality that we're imposing is an attempt to reconstruct what's happened in the environment. It's as if the brain had said, `Look, if there are these things that are so similar to each other and separated by such a small time interval, they must be part of the same event. And the one that's different and further away in frequency is probably part of some other sequence.'

GOODWIN: Now I imagine that has meaning in terms of how we listen to words and perhaps not listen to background noise. I mean, is that the real-world translation of this kind of thing?

Dr. BREGMAN: Eventually, yes. I mean, this is just one of the many mechanisms that we have for separating sounds.

Dr. RYALS: We do know that if there's a background babble of noise, there are gaps in that noise of silence, and so if you're listening to a speaker in a babble or in a background of noise, one of the things that we know people do is to listen in the gaps and fill in, in their brains, what would probably be in that stream of speech. And we know that as you get older, people who have some hearing loss, but not very much hearing loss, tend to really have more and more difficulty hearing in background noise, and one of the things that we think they're having difficulty with is hearing in those gaps. And we think that probably older people tend to ta--to start using a different mechanism for hearing in background noise.

GOODWIN: What about other animals? I mean, we have ears. We're pretty familiar with them. Are there significant differences in--in that kind of external structure that--let's say between us and other mammals, let's say dogs?

Dr. RYALS: I would say that the similarities are more significant, are more--than the differences. There certainly are differences in frequency range, obviously. You mentioned dogs. They have better hearing for higher frequencies than people do. Birds, which is my sort of research subject right now, have good focused hearing in the same frequency range that people do, but much--mu--much more of a narrow band, a limited frequency range. And a very different process in birds, for example, is that they're able to regrow the sensory cells in the inner ear when they're damaged, and then that doesn't happen in mammals or humans.

GOODWIN: What does that mean, where they can regrow these things?

Dr. RYALS: In a human, if you happen to have been in a very, very loud environment or had a firecracker go off by your ear, you can destroy some of the sensory cells that transmit the sound to the brain, and those cells go away and a scar is formed. In a bird, there are cells within the ear, stem cells if you will, that are then able to divide and become new hair cells, so that that hearing is regained.

GOODWIN: Now does this relate to human hearing loss, and are you working on that?

Dr. RYALS: Our Holy Grail, if you will, would be to be able to do that in a human, certainly. So far we've not been able to do that in a mammal, much less a human, but we are learning more and more about cell cycle and what s--triggers a cell to be able to divide and regrow and then differentiate into a sensory cell.

GOODWIN: Dr. Ryals, do you have any thoughts about the differences among species and how that--you--how d--some species evolved hearing one way and others did it another way? You--you mentioned birds and mammals.

Dr. RYALS: It's very clear that the--for species who vocalize, hearing has evolved specifically around their vocalization, which makes a lot of sense. If you're a tree frog and you want to mate, you want your mate to hear your vocalization best.

GOODWIN: Most people don't pay much attention to their hearing, until they begin to lose it, and--and some don't even pay attention then. But what are the major causes of hearing loss?

Dr. RYALS: Most hearing loss occurs in the cochlea at the level of the sensory cells, and it is environmental or health--internally health related. There are studies that have shown that heart disease or smoking or other environmental or things that you do to yourself, to your body, can harm your ears. Genetics--there are hereditary patterns for hearing loss, of course. Noise is a big factor and--as are some drugs which are toxic to the ears. They're generally called imunnoglycoside antibiotics, and as long as you monitor the level of the antibiotics, which hospitals do very well now, you can keep the ototoxicity down.

GOODWIN: Just give us a brief summary of where we're going with cochlear implants and--and how they work, Dr. Ryals.

Dr. RYALS: One of the terrific things that's happened in the last five or 10 years is that we can now diagnose hearing loss very early, within the first 24 hours of birth, and for those with profound hearing loss, cochlear implants can provide a signal to the brain, which can give the person, the child, an opportunity to--to hear a good speech signal and to develop speech and language at a much better rate than hearing aids, in the past, were ever able to do.

GOODWIN: There's also been progress in hearing aids, then--the new digital ones that can amplify certain frequencies more than others and...

Dr. RYALS: Absolutely.

GOODWIN: ...the ones that go right in the canal, so people that might not like the appearance of it don't have to worry so much about that. Those are pretty good advances, aren't they?

Dr. RYALS: Certainly. And--and the digital hearing aids are trying to take advantage of some of the issues that Dr. Bregman mentioned about picking up these different signals and bringing them into a digital processor to mimic the normal system, to bring that to an impaired ear.

GOODWIN: Do you think we'll get to a place where we can say we can cure hearing loss?

Dr. RYALS: I hope that that will be the case. I think that where we'd like to go, instead of having to regenerate or--like birds do and grow new sensory cells within the ears, to prevent hearing loss in the first place, understand why hearing goes away, why cells are damaged and how we can stop that damage from occurring. And there's a lot of progress in that area.

GOODWIN: I've been speaking with two leading researchers in hearing: Dr. Brenda Ryals, a professor at James Madison University, and Dr. Albert Bregman, professor of psychology at McGill University in Montreal, Canada.

I'd like to thank both of you for--for joining me on THE INFINITE MIND.

Dr. BREGMAN: Our pleasure...

Dr. RYALS: It's been--it's a pleasure.

Dr. BREGMAN: ...I'm sure.

GOODWIN: We've just heard how birds, unlike humans, can regenerate the hair cells in their ears. Even if they're deafened, they regain the ability to hear. Many researchers hope this knowledge will lead us to a method for curing or preventing human hearing loss. Next, THE

INFINITE MIND's Marit Haahr reports on exciting work in this area by Dr. Sarah Woolley at the University of California at Berkeley. Her work may help us understand more than just hearing loss. She's also uncovering clues to how birds and perhaps humans learn and remember the things they hear.

MARIT HAAHR reporting:

Believe it or not, when it comes to the sense of hearing, we're more like birds than you might think. There are very few animals that need to hear vocal sounds before they can utter them, at least properly: There are humans, which is why people who are born deaf don't naturally acquire speech; there are porpoises and whales, possibly bats; and birds, though only three types, hummingbirds, parrots and songbirds.

(Audio of birds)

Dr. SARAH WOOLLEY (University of California, Berkeley): Their songs are also very acoustically complex, similar to speech.

HAAHR: That's Dr. Sarah Woolley, a postdoctoral fellow in behavioral neurobiology at the University of California at Berkeley. She conducts her work on a type of songbird, the Bengalese finch.

Dr. WOOLLEY: We study them because some years ago we discovered that these birds require hearing in order to sing normally. So they--once they learn to sing, they can't just sing without any sensory feedback after that. They actually must hear themselves in order to sing normally.

HAAHR: Again, much like humans. We don't speak well when we can't hear ourselves. So what does the mature finch song sound like? For one thing, it has phrases, just like human speech. Dr. Woolley.

Dr. WOOLLEY: Finches sing in what we call song bouts, and that is several repetitions of a song motif, and a motif is a stereotyped sequence of song syllables. He sings over and over again like (imitates bird sound), and then he stops, and that whole sequence of repeated elements is what we call a song bout.

HAAHR: Here's the recording she made of an actual finch.

(Audio of finch recording)

HAAHR: So if the finch needs to hear itself to sing properly, what happens when a bird loses its hearing?

Dr. WOOLLEY: The song degrades beginning in a few days after hair cell loss or surgical deafening, and it continues to degrade until the bird no longer produces much vocalization at all. It adopts the posture of a singing bird, and almost no sound comes out of the bird.

HAAHR: In the example you're about to hear, the bird's hearing won't come back. Its cochlea, the part of the inner ear responsible for

hearing, has been surgically removed. Twelve weeks later, this is what the finch sounds like.

(Audio of finch recording)

HAAHR: Need to hear that again? This is the song in a hearing bird.

(Audio of finch recording)

HAAHR: And this is the song in the deaf bird.

(Audio of finch recording)

HAAHR: So what's happening here?

Dr. WOOLLEY: When he can't hear himself sing, he mixes up his syllables, so that he no longer has a repetition or any organization to the song. And then the syllables themselves, the acoustic composition of the syllables themselves, also degrades more slowly.

HAAHR: Now here's an example of a bird whose hair cells were killed. The bird's hair cells function just like ours do; they convert sound into signals that are interpreted by the brain. This is the bird's song when its hair cells were functioning normally.

(Audio of bird recording)

HAAHR: This is the song immediately after the same bird lost its hearing. Since not much time has passed, the song doesn't sound quite as degraded as in the deaf bird we heard from earlier.

(Audio of bird recording)

HAAHR: Now this is the song after the bird's hair cells regenerated.

(Audio of bird recording)

HAAHR: Not perfect yet, but the bird is clearly relearning its original song. Let's hear that again. Before hearing loss.

(Audio of bird recording)

HAAHR: After hearing loss.

(Audio of bird recording)

HAAHR: After hearing restored.

(Audio of bird recording)

HAAHR: So what does all this mean?

Dr. WOOLLEY: Once we discovered that birds needed to hear themselves sing in order to sing normally, we didn't know whether they maintained a stable song behavior over time, just normally, by just singing the

same song over and over again, or whether they actually stored a memory of song in those special areas of the brain that are devoted to song production and song learning and then used their own vocalizations, the feeds--the auditory feedback of their own vocalizations to match with that internal model or the memory of song. So those are two very different mechanisms that the brain is using to maintain stable vocal behavior over time. And so now that we know that they have a memory, we can look for the neural representation of that memory in those special areas of the brain.

HAAHR: So we might learn something about how songs, and perhaps speech, are stored and remembered. Dr. Woolley found out something else very interesting. She says it's her most amazing finding, and it happened completely by accident. It's been known for a while that once a baby finch learns its song, it's a fixed, stable thing. It never changes, no matter how many other songs the bird hears. But after losing their hearing, and then later regenerating hair cells, some of her finches started picking up new notes from other birds in their cages. Their fully adult brains actually became more plastic, more able to learn, than they had been. Here's an example. This is the finch's original song.

(Audio of bird recording)

HAAHR: This is its cage-mate's song. Listen for the high-pitched frequencies.

(Audio of bird recording)

HAAHR: Now here's the original bird again, some weeks later. If you listen closely, you may be able to hear how it's picked up those high-pitched sounds.

(Audio of bird recording)

HAAHR: Need to hear that again? Here's the original...

(Audio of bird recording)

HAAHR: ...and here's the new version, with the high-pitched notes. They come in toward the end.

(Audio of bird recording)

HAAHR: So we've heard a lot about bird brains. What might this mean for humans?

Dr. WOOLLEY: If you force the brain's circuits into a plastic condition--this is theoretically--then it may then be able to accept new material, and that could be a mechanism that occurs in humans.

HAAHR: In other words, because hearing is so crucial to learning, at least for these finches, Dr. Woolley and other scientists hope to gain insight into more than just hearing loss. They're hoping they'll uncover some of the deep secrets of human learning and memory. For

THE INFINITE MIND, I'm Marit Haahr.

GOODWIN: To find out more about the sense of hearing, order CDs and transcripts of THE INFINITE MIND programs or hear recent shows in Real Audio, visit our award-winning Web site at theinfinitemind.com. If you have a question or comment about this show or a suggestion for an upcoming show, call us toll-free at 1 (888) 350-MIND. That's 1 (888) 350-6463. Or send us e-mail at lcm@lcmedia.com.

I'm Dr. Fred Goodwin and this is THE INFINITE MIND. Coming up in our second half, problems in the ear that cause people to hear ringing and problems in the brain that cause people to hear voices. Plus, commentator John Hockenberry.

HOCKENBERRY: Of all the senses, I think it's clear that hearing has the most imagination.

GOODWIN: All this coming up. Stay tuned.

I'm Dr. Fred Goodwin and we're talking about hearing today on THE INFINITE MIND, produced by Lichtenstein Creative Media in association with WNYC New York.

We all hear a ringing in our ears from time to time. Now imagine that ringing never went away. That's what it's like for millions of Americans who suffer from tinnitus. Tinnitus can be caused by a variety of factors, but one of the biggest culprits is loud music and noise.

Joining me now is Ms. Kathy Peck, a former bass player and singer for the San Francisco rock band The Contractions. In 1988 after developing tinnitus and hearing loss, she launched a grassroots organization called HEAR, H-E-A-R, Hearing Education and Awareness for Rockers. She's enlisted the help of a wide range of artists, including Herbie Hancock, Joe Satriani and Metallica's Lars Ulrich.

Also with me is audiologist Dr. Natan Bauman, the founder and director of The Hearing, Balance and Speech Center in Connecticut.

Dr. Bauman, Ms. Peck, I'd like to welcome both of you to THE INFINITE MIND.

Dr. NATAN BAUMAN (The Hearing, Balance and Speech Center): Why, thank you very much.

Ms. PECK: Thank you for having us.

GOODWIN: Ms. Peck, let me begin with you. When did you first start experiencing tinnitus?

Ms. PECK: I was playing with my all-girl band, The Contractions, and we were opening up for Duran Duran at the Oakland Coliseum. After we played that show, my ears rang for three days straight. And then later, I also had a substantial hearing loss, and it was very devastating. It, basically, ended my career.

GOODWIN: Did it seem to you that this was a--a kind of a sudden thing that just hit you because of a particularly loud concert?

Ms. PECK: Well, it was exacerbated by the concert and the screaming little girls, but now that I look back, it was something that was cumulative. It's insidious. Hearing loss is insidious. It just creeps up on you. The music industry and folks weren't really aware how music can also damage your hearing, and we weren't cautioned to wear hearing protection.

GOODWIN: You brought along, I think, a--one of your public service announcements that the--your organization, HEAR, has made. One of them is made by the group The Mermen, which actually gives a sense of what tinnitus is like. Can you tell us a little bit about it and then we can play it?

Ms. PECK: Well, The Mermen are very loud, and it's the surf music--Surf Punk music. It's really wonderful. And then you hear the--start hearing the sound, and it takes over.

(Excerpt from public service announcement)

Ms. PECK: And at the very end, it's--there's a message, and it's, `Tinnitus sucks.' Excuse me. But, you know, we're--we're reaching kids with this message, and they understand. It's very powerful.

GOODWIN: Dr. Bauman, what kind of reactions do people have when they experience tinnitus?

Dr. BAUMAN: The tinnitus can be associated and often is associated with a lot of different misconceptions on the part of the patient. And that could lead to very significant problems with tinnitus overwhelming the patient's, actually, way of thinking, where the patient continues to think and monitor the tinnitus, thinking, `Well, you know, am I--am I going crazy? Is there something growing--growing in my brain? Am I losing my hearing?'

GOODWIN: Now you said a misperception--there's a misperception that tinnitus and hearing loss are related, but is it possibly they're related in the sense that some of the same factors can cause both?

Dr. BAUMAN: That is true. You know, most of the time, tinnitus related to the fact that there's some structural changes in what is called outer hair cells in the inner ear. And that is often associated also with hearing loss. However, it is not true that all people who have hearing loss suffer from tinnitus. And it's also not true that people who have tinnitus need to have hearing loss.

Ms. PECK: I--it's a warning sign, and it's something to pay attention to. It used to be that musicians and people would say, `Oh, that's a great concert. I came home and my ears just rang and rang and rang,' and that would be to gauge what a great show it was. Well, you know, you're going to start losing that ability to hear, you know, and it--it's--can be very devastating.

GOODWIN: Dr. Bauman, what are the other things that--besides, like, damage to the hair cells, what else do we think might be causal here and what are the various theories about it?

Dr. BAUMAN: Well, one of the very simple, really, sometimes problems related to tinnitus could be as simple as wax in the ears. Other causes can be causes related to the function of the middle ear. Often, deprivation of hearing can cause the brain to think that there is a change, a peripheral change in hearing, in a way that would try to compensate for that. And compensating for that often can be responsible for tinnitus.

There is another very significant element in this whole picture of tinnitus that plays a very important role, which is the limbic system. The limbic system is a part of our brain that monitors all the activity and then decides whether the activity should be filtered out, whether the activity should go to the brain or whether the activity should be dealt in an automatic fashion.

GOODWIN: I imagine that insight has some meaning for treatment, which I want to come back to in a minute. But first, I want to ask Ms. Peck, what are the things that you do basically? What do you advise people, both musicians and concert-goers or just listeners, in general?

Ms. PECK: Ask them to turn it down at first and then that they should bring hearing protection. In fact, we worked with the--in San Francisco, we worked on an earplug ordinance for the clubs, and it's probably one of the first ones in the nation. And the clubs were really pro--you know, for it. These hearing disorders really affect people in the music business very dramatically because it's tied in to their career and also their self-image. So--and depression also sometimes walks hand in hand with it. And it's really important that we let people know that they don't have to give up their music, but they might have to alter what they do.

GOODWIN: Your earplug ordinance, it just says that earplugs have to be available?

Ms. PECK: Yes, they do. They have to be available.

GOODWIN: Does the ordinance say that they have to provide them free for the audience?

Ms. PECK: We tried to work on a free thing. I think a lot of the clubs do and will, but it says, `to make available.'

GOODWIN: Dr. Bauman, you've focused a lot of your work on treatment, and I understand you practice a particular type of treatment called tinnitus retraining therapy, or TRT. But TRT does not make the noise go away; what it does is work on how people pay attention to it. Explain that in terms of the limbic system.

Dr. BAUMAN: People who have tinnitus and they don't have a hearing

loss, they wear devices that generate a certain noise. When we put another sound into the ear, a--with tinnitus, then the perception of the tinnitus is diminished. At the same time, what we want to do is we want to basically disconnect the limbic system of monitoring the tinnitus.

GOODWIN: And what is the overall success rate of it?

Dr. BAUMAN: The success rate across the country is somewhere within 80 percent to 85 percent.

GOODWIN: OK. I'd like to conclude by asking each of you where you think the hope lies for the future in terms of prevention and treatment of tinnitus. Dr. Bauman?

Dr. BAUMAN: Tinnitus is something that can be treated, and it's important for people to know because, often, people are told that, you know, `You have to live with this,' which is not really true anymore.

GOODWIN: OK. Ms. Peck.

Ms. PECK: Prevention is key. When people are out at dance clubs, they should stay at least 10 feet away from the--the speakers. It's--it's--that's really important. Don't shout in somebody's ear at the dance floor. That can actually damage the hearing. And they should always carry some hearing protection with them.

GOODWIN: I've been speaking with Dr. Natan Bauman, director of The Hearing, Balance and Speech Center in Connecticut, and Ms. Kathy Peck, the founder of HEAR, H-E-A-R, Hearing Education and Awareness for Rockers. You can learn more about her organization on hearnet.com. I'd like to thank both of you for being with me on THE INFINITE MIND.

Dr. BAUMAN: Well, thank you very much for having me.

Ms. PECK: Thank you so much.

GOODWIN: I'm Dr. Fred Goodwin, and you're listening to THE INFINITE MIND.

We've been speaking about tinnitus, the perceived ringing or buzzing noise that's usually caused by damage to the ear. Now imagine your ears are fine, but you're hearing more than just ringing. People with psychotic disorders, such as schizophrenia, often experience auditory hallucinations, hearing voices that originate in their own brains, but sound as real and distinct as if somebody were speaking to them. In a moment, we'll speak with a neuropsychiatrist about what's going on in the brain to create these voices. But first, we'll hear Edith Shuttleworth, a woman with schizophrenia, describe her auditory hallucinations. She was originally recorded for our 2001 show, Schizophrenia: Second Chances.

Ms. EDITH SHUTTLEWORTH: I started hearing voices when I was nine years old. That's a little early for most people to hear voices, but

I did. And it's mostly negative stuff that I--my voices. It's very--it's very negative. There's nothing positive like giving me numbers to win the lotto or stuff like that. It's mostly jealousy, in case I have an outfit that I like or something like that. All of a sudden, they'll say something and I'll--I'll spill something on myself and destroy it and I have to throw it away or give it away.

I'm on a new medication now called Zyprexa, but it hasn't completely got rid of the voices. But the Zyprexa, even though you still have the symptoms, it's like you have more control. You can hear the voices and you can tell them, `Shut up,' or `Leave me alone. Don't bother me,' and continue doing what you're doing and stuff like that. You know, you just--you have tolerance.

Sometime, the voices now is cooperative; sometime, they're not. Like, I'll be on the subway downstairs, and they'll says, `Do you want to jump?' You know, or `Do you want to jump under the car?' or something like that. And I will just ignore them and says, `No,' you know. Like, before, if they had said something to me, I would have said, `Yes,' and do it. But now with the medication, I can say, `No,' and stand still without shaking or worrying about it, you know?

GOODWIN: That was Edith Shuttleworth describing her auditory hallucinations. But what's going on in the brain to create these voices? Dr. David Silbersweig is a director of the neuropsychiatry program at Cornell University.

Dr. Silbersweig, welcome to THE INFINITE MIND.

Dr. DAVID SILBERSWEIG (Director, Neuropsychiatry Program, Cornell University): Thank you, Dr. Goodwin. It's a pleasure to be here.

GOODWIN: Give us a sense of what patients with hallucinations actually say to you when they come and see you in your office.

Dr. SILBERSWEIG: Patients tend to complain that there are voices talking to them. It can be a single person, it can be a number of people. It can be someone who's familiar to them. And certainly, over time, the voices become familiar to them because they hear them chronically. They describe that it could be very specific in terms of what they hear, the same way that you're hearing me right now, or that it can be more vague and that they get the sense of what the person is trying to say. The localization of the sound can be either directly in front of them, to the side or somewhere more ethereal. Nevertheless, they perceive it as being real, and when they're psychotic, they not only hear the voice, but they believe the veracity of the voice and they may even have emotional connections to the material that they're hearing. Sometimes it can be run-of-the-mill, sort of running commentary upon what they're doing, and as the patient goes through his or her daily life, there's a voice commenting upon it. At other times, their--the voices are hurling insults and commenting in a negative fashion upon what the person's doing.

GOODWIN: You've been doing some fascinating studies on where these voices might be generated, where they're coming from in the brain. So

tell our listeners about what you're finding.

Dr. SILBERSWEIG: We use PET scanning, or positron-emission tomography, and also functional magnetic resonance imaging. And these are relatively new techniques that allow one to image brain function and not just brain structure, to see where in the brain there is activity that's occurring when a person has a certain perception, thought, emotion or behavior.

GOODWIN: Tell us what you found with these techniques.

Dr. SILBERSWEIG: What we found is that, in association with hearing voices, there's activity in the auditory language area of the cortex that normally is responsive when a person hears voices from the outside world. And that's striking because in the scanner, no one is speaking to the patient and it's silent during the scanning. And so their brain, in fact, is reporting or is processing the information as if it's occurring from the outside world, whereas, in fact, it's not occurring from the outside world. In addition to these surface areas of the brain that are involved in the sensory processing, we see other areas deep within the brain that are phylogenetically older and that are involved with processes such as emotion, memory and attention. And these areas of the brain, we are finding, are active as well during hallucinations. And it's the interaction between these deep areas and the surface areas, we think, that are relevant for the generation of hallucinations.

GOODWIN: Some people make an analogy between hallucinations or at least psychotic process, in general, somewhat like dreaming. We all think we hear something in a dream, but during the waking day, that part of the brain is kind of filtered out or--or blocked off in some way.

Dr. SILBERSWEIG: There are other instances in healthy, normal people where people do have perceptions in the absence of external stimuli. And those include dreamings when we're asleep and also auditory imagery or mental imagery, the ability to evoke an image in your mind, either a visual image or an auditory image, a sound image, so that you can imagine what somebody's voice sounds like or you can hear in your own mind them speaking to you or sometimes yourself speaking to yourself.

And we've performed with colleagues experiments to try to get at this issue, to study the neural substrates of auditory mental imagery in healthy people and to see how those differ in patients with schizophrenia, and particularly those who are prone to hallucinate. And what we've found is that during mental imagery tasks--that there are similar levels of activity in auditory sensory areas of the brain, but an area in the frontal lobe involved in the generation, in the voluntary generation and control of this sort of brain or mental activity, has a deficit in the patients with schizophrenia. And this may help to explain the involuntary nature of hallucinations that, among other things, the areas of the brain that are involved in controlling our mental processes voluntarily, normally, are disrupted in schizophrenia.

GOODWIN: What we sometimes call the executive functions.

Dr. SILBERSWEIG: The executive functions. And there's another related concept that's been talked about in the field and that we and others have investigated, which is the issue of inner speech and the frontal lobe. We all speak to ourselves or think in language to various extents. And normally that's under control and normally that's very low-level and it's part of normal processing. One theory has it that in schizophrenia, and in particular patients with hallucinations, what starts to happen is that inner speech goes awry or that inner speech is happening and that the output of that in the brain is somehow being perceived as coming from somewhere or someone else.

GOODWIN: It may just be their attempt to make sense of something that's coming from a part of their brain and they want to say it must be someone else talking to me.

Dr. SILBERSWEIG: Exactly. In fact, the more we learn about the neural substrative hallucinations--there are many things such as this, for example--the more we realize that the patients are merely reporting what is happening to them, that their brains are experiencing and--and telling them that these things are happening, and they are merely responding to that, and are not, quote, "crazy," unquote, in the sense that, you know, they have a disorder that happens to affect their brain in the same way that somebody else can have a disorder affecting the kidney or the lungs.

GOODWIN: I've been speaking with Dr. David Silbersweig, director of neural psychiatry programs at Cornell University.

David, thank you so much for appearing with me on THE INFINITE MIND.

Dr. SILBERSWEIG: You're quite welcome.

GOODWIN: Finally, commentator John Hockenberry, who thinks that hearing, of all the senses, unlocks the richest experience in the brain.

HOCKENBERRY: Of all the senses, I think it's clear that hearing has the most imagination, by far. Perhaps it's partly an identity crisis brought on by those ugly flaps of skin on the sides of the head. The eyes admire themselves in the mirror first of all, then it's the nose that gets second billing, skin and hands are right in there, the tongue has its own tantalizing opportunities to show off, but the ears are observed mostly to make sure that they are hidden, or at best, they become fleshy places for poking holes and hanging some shiny baubles, baubles for megalomaniac eyes to admire. But hearing, the sense of hearing, has no need for vanity.

(Soundbite of music)

HOCKENBERRY: Hearing, by itself, can powerfully evoke all of the other senses. There! Can you see it? The green hills, misty and

foggy in the distance, and then, then, a horse, along the road, coming closer. You can smell the cool air of the morning. The earthy horse smell is right there, too. Birds soar through the sky. It's so beautiful, and it feels like I'm right there in the middle of it.

(Soundbite of music)

HOCKENBERRY: Beethoven put all of that together in the first movement of his "Sixth Symphony." But it's not only Beethoven who can get the ears to imagine or even recreate the experience of another sense. With a song about smell--Smells like teen spirit, anyone?--Nirvana created a movement.

(Soundbite of music)

HOCKENBERRY: I can feel the skin on my knee in my ripped jeans. Only sound can do this. Sound is reality and imagination. And imagination goes with the soundtrack. The mind is skeptical of visual information. Close your eyes and you're still there, but cover your ears, and I don't care what you're looking at, it recedes into the background. Big screen, little screen, it's not real without good speakers and a subwoofer. The visual arts don't try to depict sound, because who would want to? Perhaps a painting tries to visually record what a piece of music or a natural sound already suggests. You don't use your sense of smell to evoke standing atop a tall building. And if you taste something wonderful with your eyes closed, you don't need to see it unless somebody wrote your name on the birthday cake, but that's vanity again.

Sound can make the whole world. Sound is different. Sound is everything. Hearing constitutes an intimate connection to the brain and it's an old connection. Song is among the oldest arts because of the ancient connection between the voice and our inner emotional world. Hearing is so intimate a connection to the brain that it doesn't even require ears.

(Soundbite of music)

HOCKENBERRY: Beethoven, again. You know, he wrote his "Ninth Symphony" when he was completely deaf. The sounds came from the silence in his brain. They were coded into black markings on manuscript paper, detailed instructions for instruments and voices to be read off the page by the eyes, the vain and self-important eyes, reduced here to mere data collectors, the eyes watching the conductor keep time, the eyes completely enslaved now to the ears, and a symphony is born. The mapping of thought into visual symbols read back as sound, which evokes the whole world. Whoo, what a symphony.

This is both the mechanism and miracle of music. For good reason, music and sound are the oldest windows on the brain, older than writing, from a time when the blind were thought to be wiser, gifted ones. Without eyes, Tiresias could see the future. This mechanism of mapping thought onto the senses is, of course, how all of our digital technology works. A programmer encodes some aspect of experience which is read out as sensory data, visual data or sound on a DVD.

They're still working on smell and taste, but they're getting there. Yet the easiest and most powerful channel still is sound. It needs little enhancement. The ears want to be fooled. They need no IMAX theater.

(Soundbite of music)

HOCKENBERRY: Simply listen and a vista opens on a whole world. And when you close your eyes, you can see it.

For THE INFINITE MIND, I'm John Hockenberry.

(Soundbite of music)

GOODWIN: To find out more about the sense of hearing, order CDs and transcripts of THE INFINITE MIND programs, or hear recent shows in Real Audio, visit our award-winning Web site at theinfinitemind.com. If you have a question or comment about this show or a suggestion for an upcoming show, call us toll-free at 1 (888) 350-MIND. That's 1 (888) 350-6463. Or send us e-mail at lcm@lcmedia.com.

I'm Dr. Fred Goodwin. Each week we explore the new frontiers of THE INFINITE MIND, right here on this public radio station. Thank you for joining me in this journey.

KAELIN: You can visit our award-winning Web site at www.theinfinitemind.com. For a copy of this program on CD or for a printed transcript, please call Burrelle's Transcripts at 1 (800) 777-TEXT. If you have a comment about THE INFINITE MIND, please call us toll-free at 1 (888) 350-MIND. That's 1 (888) 350-6463.

The executive producer of THE INFINITE MIND is Bill Lichtenstein; series producer, June Peoples. This program is produced by Marit Haahr; technical direction by Gregory Seaton; associate producer, Devorah Klahr; original music by Art Labriola. Our engineers at WAMU in Washington are John Holt, Tobey Schreiner and Jonathan Charry. Bookkeeper, Anna Evanova. Mr. Lichtenstein's assistant is Ruth Nolan. Dr. Goodwin's assistant is Joanne Davis. Office support, Aryeh First; intern, Rafael Perez; announcer, Katina Kaelin.

Major underwriting for THE INFINITE MIND comes from the John D. and Catherine T. MacArthur Foundation, the National Science Foundation, the National Institute of Mental Health, and the Non-Profit Finance Fund. Additional funding for this program comes from the George B. Storer Foundation, Bob Ellis and in the form of an unrestricted educational grant from Eli Lilly and Co.

Special thanks to listeners like you for additional support.

The ideas and editorial content of THE INFINITE MIND represent those of the producers and guests, not our underwriters.