Bird-Brained

A sparrow's song may seem a simple melody, but it's actually the product of some pretty sophisticated brainwork. In fact, studying how birds sing may give us new insights about our own ability to speak, move, and think.

By Ashley Yeager

From a low branch of a towering oak in Duke Forest, a cardinal belts out his signature *cheer, cheer, cheer, tweeee*. There's a *twe-twe-cha, cha-cha-cha, twee-chaaa* from a well-camouflaged song sparrow and the *tu-a-wee-wu-we* of a brown-breasted bluebird. The forest is alive with springtime conversation, and although it's early morning, it feels a bit like a Saturday night at a bar. All the guys are puffing out their chests and rolling out their best pick-up lines.

"Hey, baby, come check me out."

For all its cacophony of chirps and trills, the dawn performance is really like one big chorus of "Hey, baby, come check me out," according to Susan Peters, a behavioral biologist at Duke who studies animal communication. After studying songbirds for thirty years, Peters can hear the birds' biographies in their melodies. A clear, consistent song is a male songbird's way of saying he was fed well as a nestling and is now a strong, intelligent adult with superior genetic traits—in other words, a perfect mate.

But there will soon be another bird with a story Peters finds even more interesting. As spring turns to summer in the woods and more male songbirds are born, somewhere in those branches a fledgling sparrow or finch will sit perfectly still in his nest. His black eyes blinking, he'll silently wait. And then, with his beak virtually closed, he'll whisper a note or two that he's heard from the birds around him. At first, the sounds will not be quite in tune with the rest of the chorus and instead come out as raspy chirrups and cheeps. But with practice, the juvenile bird will catch on.

"It's very sweet to watch a young male bird making its first attempts at song," Peters says. A musician herself who plays the piano and other instruments, she can relate to the trial-and-error frustration of learning how to perform a new melody.

But as a scientist, she sees the bird's song—and the weeks-long process the birds must go through to master it—as a tool for understanding how complex behaviors like singing evolve.

And it's not just birds she's interested in. Peters is one of a growing number of scientists, including several at Duke, who think studying birds can help them understand how the human brain directs complicated tasks such as speech or movement, which may not be nearly as different from a finch learning to warble as once believed.

As scientists have learned more about the regions of a bird's brain involved in singing, they have made surprising connections to the mechanisms humans use to speak and move. There is now promise that birds might offer a model for figuring out human neurological diseases like Huntington's and Parkinson's.

The idea that there are parallels between birdsong and human speech began to emerge in the 1960s. Among the first scientists to make the connection was Peter Marler, a behavioral biologist who studied birdsongs first at the University of California at Berkeley and then at Rockefeller University in New York. By observing and recording sparrows as they learned to sing, Marler showed that songbirds picked up the unique melodies of their species at a critical stage early in life and that, like humans, they depended on hearing themselves sing to get better. Those features of bird communication, Marler wrote in a 1970 article for *American Scientist*, "may in turn serve to remind us that human language is a biological phenomenon with an evolutionary history."

Les Todd

Robo-calls: Designed by Duke students, the robotic sparrow encroaches on another bird's turf—and often pays the price.

Angry Birds

Birds, like humans, don't like others treading on their turf. At first sight of an intruder, most birds will squawk and flap their wings, a warning that, if unheeded, is usually followed by attack. But fighting can be costly, even deadly. What happens in those tense moments before a bird decides enough is enough?

To find out, Rindy Anderson, a postdoctoral researcher in biologist Steve Nowicki's lab, is using a robotic sparrow to play the role of the interloper. Designed by Duke engineering undergraduates and a local taxidermist, Robo-Sparrow sits on the boundary of a male swamp sparrow's turf and flicks its wings while a sparrow song plays through a nearby speaker. To a sparrow, this is a defiant act of aggression that demands a response.

From observing sparrows in the field, Anderson has found the interactions often start with songs. A defensive bird will repeat an interloper's song, as if to say, "I heard you, and I am paying attention to what you are doing." This is what scientists call song matching, and it can go back and forth until one bird finally flings down the gauntlet.

In experiments with Robo-Sparrow, Anderson has noted that just before attacking, sparrows quickly flick one or both wings several times. The wave is a deliberate signal intended to frighten the trespasser away—sort of the bird equivalent of humans flipping the bird. If that's not enough, the defensive bird will try a soft song, as if to say, "C'mon, man, don't make me do this."

Of course the birds aren't actually thinking those things. It's more likely their brains work like computers, responding in specific ways to specific stimuli. But with the help of Robo-Sparrow, researchers are figuring out the complex vocabulary of these conversations.

In the mid-1970s, Marler hired Susan Peters to his lab at Rockefeller's Field Research Center in Millbrook, New York. Together, they began to explore how baby sparrows learned the chirps and trills that characterize their species' song. Through careful experiments, they eventually traced, note by note, the birds' musical progression from those early weak warbles, called subsong, to their first clear imitations of melodies, and finally to mastery and repetition of their species' song. As Marler had anticipated, the birds' pattern of development was much like the progression a human infant follows from babble to individual words to sentences.

Marler and Peters pursued the birds' song progression for nearly a decade, by which time a new biologist named Steve Nowicki had joined the lab. Peters and Nowicki began collaborating on birdsong studies and then married in 1986. The couple moved to Duke in 1989, and Nowicki is now a professor of biology, psychology, and neuroscience, as well as dean of undergraduate education. They also brought with them a collection of swamp and song sparrows they had captured in New York.

Today, Peters houses dozens of new sparrows in the Biological Sciences Building. The room where the birds live is painted white, with a long row of wire cages along one wall. Each cage holds a single sparrow, along with a perch, a bath, and a trough of seeds. The room is sealed so Peters can control light and temperature, precisely simulating the seasonal changes in daylight and climate. On a day this past winter, the space is strangely silent, except for a few chirps and squawks and the hum of a heater. There are no songs.

Songbirds typically don't sing in the winter, Peters explains as she reaches into a cage and tries to trap a swamp sparrow, an adult male, in her hand. The bird dances just out of reach. She focuses on the bird for a moment and then gingerly corners it, closing her palm around his brown-feathered body. The bird cocks his head from side to side, surveying his situation. His black eyes blink quickly, but he remains calm. Like all males, his chest is plain gray, and he has a cap of streaked head feathers that turn brownish red in spring—or, in this case, when Peters lengthens the days and warms the air in the room to simulate the season. The longer days, she says, initiate changes in the birds' brains, which spur them to sing.

During her career Peters has logged thousands of hours listening to sparrows and other songbirds compose their melodies. These days most of the analysis is done with the aid of software programs that translate recorded birdsongs into sound spectrographs, which create a visual readout of the birds' songs. Individual notes appear as tiny lines on a horizontal scale, with the length and height of the lines representing the duration and pitch of the note. It's clear from looking at a few of these graphic representations that there's a lot going on in a bird's song that human ears often don't appreciate. Even the shortest bit of sparrow song reveals multiple notes and precisely timed pauses.

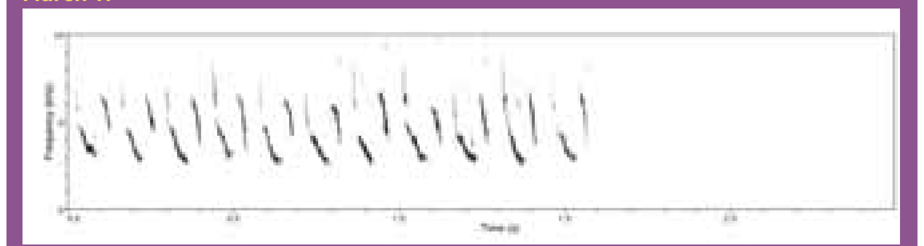
But to a bird, those subtleties make all

Catching a Tune

For a young swamp sparrow, mastering his species' song (shown in the sound spectrograph at the bottom) takes practice. The top three graphs show the same sparrow attempting the song—and getting better with age.

March 4

March 11



May 20

Mastered Song

Susan Peters

the difference. Swamp sparrows, for example, sing two-second trills comprising identical syllables, each with between two and five notes. In 1989, Peter Marler and colleagues showed that male sparrows perceive even slight alterations in the length and arrangement of the notes. When the birds hear songs that sound different than what they have learned, they get defensive, identify regions of a songbird brain associated with learning and producing songs. Jarvis and his collaborators made a significant connection between human speech and birdsong in 2004 when they identified a gene called *FOXP2*—one of the key genes in human speech—in songbirds, parrots, and hummingbirds. In humans, mutations to the *FOXP2* gene result in se- the song-producing regions, where it had a role in making body movements, such as when a bird hops or flaps its wings. The fact that the gene handles both duties suggests that the areas of a songbird's brain involved in singing evolved from areas controlling movement.

For Jarvis, a professionally trained dancer, the connection of song and motion

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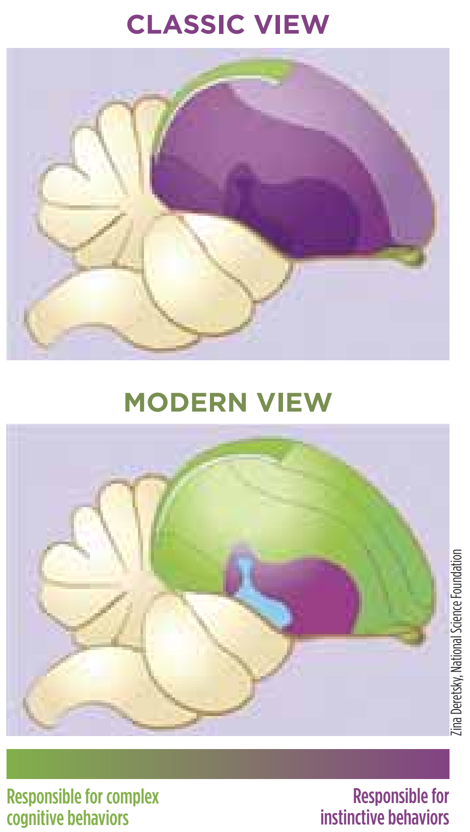
as if an intruder has invaded their space. To look tough, the sparrows puff out their chest feathers and flap their wings (see story, page 36).

In the first few weeks of life, young birds are listening and making a "mental image" of the sounds they hear, Peters says. At the same time, they are developing seven regions in their brains that they use to sing. Connections in and among those regions will allow a bird to master coordinating his beak movements and vocal tracts to make specific sounds. But this takes practice and maturation. On her computer, Peters pulls up two spectrographs from the same sparrow, one when he was nine months old and one from a month later. The improvement is obvious, with the notes and tune becoming more coherent and consistent as the bird matures.

The similarity to a human infant's language development—from listening to babble to words and phrases—isn't completely unexpected. Because the basic organization of the vertebrate brain has been well-conserved by evolution, the brains of birds and humans are in some ways quite similar. What is surprising is how far the similarities run. Scientists have found that some birds can solve problems by insight and learn by example, just as human children do. Birds can learn to use tools and even do basic math. Such recent discoveries have guided neurobiologists to probe deeper, exploring the pathways birds and humans use to process information.

One such scientist is Erich Jarvis, an associate professor of neurobiology at Duke. Jarvis is another product of the Peter Marler family tree, having studied under Marler's former graduate student Fernando Nottebohm, who was among the first to



Deep thinkers: Researchers now believe birds have a much greater capacity for complex thought.

vere impairments in the ability to learn to speak, and Jarvis expected it would play a similar role in a songbird's ability to sing. And it does—in zebra finches, the gene turns on during the critical period for song learning, and when it is blocked, birds cannot accurately imitate their tutors.

Jarvis also has studied a gene called *egr1*, which too is active in all seven regions of the brain associated with singing. But he was surprised to discover that the gene is turned on also in seven areas adjacent to

offers exciting possibilities. He imagines that the same pattern may exist in humans, which could be why, for example, we naturally move and gesture with our hands when we talk.

Carlos Botero, a former postdoctoral fellow at Duke and birdsong expert at the National Evolutionary Synthesis Center, believes Jarvis' connection of movement, song, and speech is revolutionary, describing the theory as "kick-ass." But not everyone is sold. Other neurobiologists call Jarvis' model speculative and say it lacks enough evidence to be widely accepted.

The criticisms, Jarvis argues, stem from scientists' preconceived ideas. "The notion with song learning and spoken language is that the two are something ephemeral. They're believed to be special and therefore different from anything else. So the minute you call them a motor behavior like learning to walk, or fly, that's sacrilege."

Jarvis recently has identified other genes that have mutated over thousands of years to allow song-learning birds to control vocalization. He suggests that those same genes may contribute to our own ability to coordinate our mouth, larynx, and lung muscles to speak. "My prediction has been that if the behaviors are similar and the brain pathways are similar, then the underlying genes may be similar, and we are beginning to find that this is the case," he says.

Based on the commonalities of these genes, Jarvis believes he can take them from the brains of a learning species, such as zebra finches, and insert them into the brains of animals like pigeons or mice that do not have the ability to make intricate songs. In the lab, he will try to get those genes working so that they stimulate new connections in the non-song-producing animal's brain. Essentially, he will try to develop a song-producing system in a species that doesn't have one. And even if the experiment produces only a feeble note, it will provide compelling evidence for a link between song and muscle movement.

A striking example of why that connection could be important comes from a lab just down the hall from Jarvis' office in the Bryan Research Building. There, neuroscientist Richard Mooney is exploring whether understanding birdsongs—and the brain circuitry behind them—can give scientists new insights about human neurological disorders like Huntington's and Parkinson's diseases.

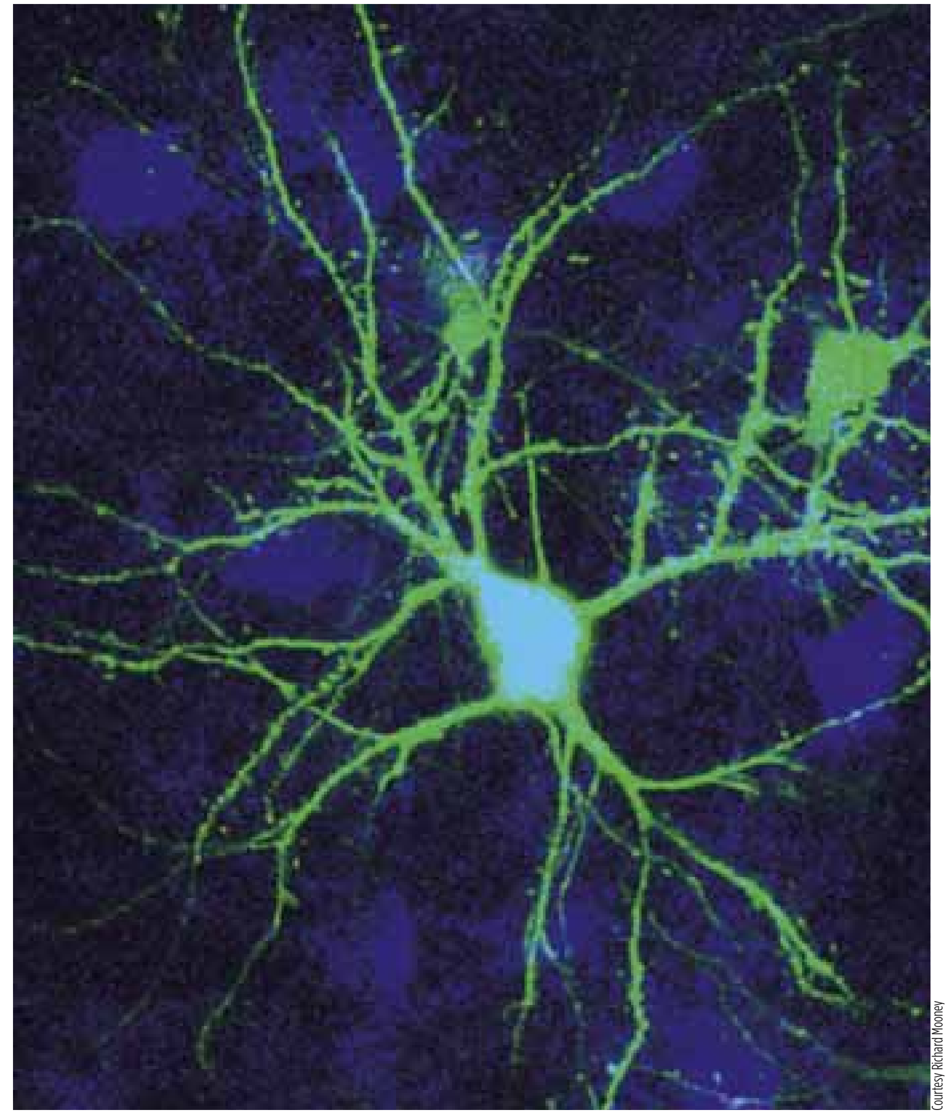
Mooney, the George Barth Geller Professor of neurobiology, has studied the brains of songbirds for almost thirty years to try to understand the neurological roots of learning. In 2009, he helped Susan Peters and Steve Nowicki establish how swamp sparrows tell the difference between correct and altered versions of their songs by placing electrodes into a song-producing region of the birds' brains known as the high vocal center, or HVC. The team then recorded the birds' brain activity and behavior as the sparrows listened to altered versions of their trills. The research showed that certain cells in the HVC were highly attuned to slight differences in the length of song notes, firing only when the notes fell within a narrow range of familiarity. This same pattern of recognition, called categorical perception, helps humans recognize subtle sounds in language, such as the difference between "ba" and "pa." The Duke research was the first to explain the brain activity that underlies that categorical perception in birds.

Now, Mooney is focusing on another song-producing region, located in a part of the brain known as the basal ganglia. In both birds and humans, the basal ganglia sit behind the eyes, deep within the tissues of the head. Neuroscientists think the brain cells in this area control voluntary movement of limbs and eyes, cognitive thinking, and possibly emotions. Yet, even subtle damage to cells there can severely impair movement, as in the case of Parkinson's and Huntington's diseases.

Scientists are trying to gain a better understanding of how these diseases cause their effects, but researchers are limited by their ability to replicate the disorders in the lab. There are mouse models, in which the animals exhibit the same physical symptoms as patients with Parkinson's or Huntington's, including lack of coordination and unsteady balance while moving around. "You can tell that the behavior is abnormal, just like you can tell a person with a given neurological disorder is behaving abnormally," says Mooney. "But it's harder to know what's wrong with the brain, and even more difficult to identify how damage to specific brain circuits produces certain motor abnormalities."

cells involved with learning songs, they should be able to trace learning problems to changes in specific brain cells. That, in turn, could suggest how the gene, when activated in our own basal ganglia, affects humans with the neurological disease.

Mooney cautions that what happens in a bird's brain is not exactly parallel to what happens in the brain of a human. But he



Song on the brain: Using a protein to make nerve cells glow bright green under a laser-powered microscope, scientists are able to observe how the structure of nerve cells in a living songbird's brain change as the bird learns to sing.

Mooney thinks songbirds might offer a better model. In his next research project, he plans to insert a gene thought to cause Huntington's disease in the brains of zebra finches, activating it in a part of the basal ganglia known to be important in song learning. His research group will then observe how the gene affects the juvenile birds' ability to learn a new song or repeat ones they have already learned. Because the team already knows the specific brain

is confident that the rich understanding scientists have gained in recent years about birds and their songs will ultimately benefit the understanding of our own minds, a revelation that adds a sweet harmony to all those tweets, chirps, and pick-up lines we hear each day at dawn. ■

Yeager is a science writer for the Duke Office of News and Communications. This is her first story for Duke Magazine.