NEUROSCIENCE

The Beasts That Keep the Beat

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New insights from neuroscience — aided by a small zoo's worth of dancing animals — are revealing the biological origins of rhythm.

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Olena Shmahalo/Quanta Magazine

There are moments when we witness an animal do something so far outside its presumed repertoire of behavior — something so uncannily human — that we can never look at that animal, or ourselves, the same way again. For Irena Schulz, one of those moments happened on an otherwise ordinary day in August, 2007. Schulz lived in Schererville, Ind., where she managed a sanctuary for abandoned parrots. A man named Dane Spudic came by with a young male Eleonora cockatoo called Snowball — a striking creature with milk-white plumage and a sweep of lemon feathers on his nape that fanned into a mohawk when he was excited. Spudic explained that his family could no longer give the attention and care he needed.

Oh, and by the way, he added, this bird is an incredible dancer. You should see what he can do. Spudic left behind a burned CD of Snowball's favorite music.

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Schulz was someone who already had a deep appreciation for the intelligence and myriad talents of birds. She had even seen some parrots sway and bob to music. But Spudic's claims seemed a bit hyperbolic. "We were humoring him, saying, 'Sure, sure,'" Schulz recalls. Later that evening, she and her husband popped Spudic's CD into the computer in their living room. "Everybody (Backstreet's Back)" by The Backstreet Boys started playing. Immediately, Snowball, who was perched on Schulz's arm, began kicking up his feet and bouncing his head with great zeal — and precision. His movements were synced with the beat. "I couldn't believe my eyes," Schulz said. "This bird was like a choreographed phenomenon. He wasn't just picking up his leg and gingerly putting it down. He was literally foot stomping. I thought, 'My god — the bird is enjoying this.'"

In time, the whole world would delight in Snowball's exuberant jig. Schulz posted a video of the dancing parrot on the shelter's blog, which someone else — possibly someone in Russia — copied to YouTube. It went viral, earning more than 200,000 views in one week. (Today, the video, which is now hosted on Snowball's official YouTube channel, has more than five million views). Snowball appeared on *The Late Show with David Letterman, Good Morning America* and numerous other talk shows, and starred in commercials for Taco Bell, Geico and Loka bottled water.

BirdLoversOnly

Video: Snowball the cockatoo dances to “Everybody (Backstreet’s Back).”

Snowball’s public debut also caught the attention of two scientists at the Neurosciences Institute in La Jolla, Calif. John Iversen and Aniruddh Patel were interested in the evolutionary origins and neuroscience of rhythm and music. At the time, there was no documented evidence that nonhuman animals could dance — or, in more scientific terms, that they could “entrain” their movements to an external beat. “We saw this video, and it really knocked us out — it was the first time we had ever seen this,” Iversen said. “As scientists, you love these kinds of moments.”

Iversen and Patel tested Snowball in controlled experiments, altering the tempos of his favorite songs and observing how he responded without any training or encouragement. Snowball danced in bouts, rather than continuously, but frame-by-frame video analysis confirmed that he adapted his movements to match the altered beats. Soon after, other studies by separate research teams showed that numerous species of parrots could entrain to a beat, as could elephants. Monkeys, on the other hand, did not display much rhythmic talent in the lab.

The findings seemed to fit a hypothesis Patel had recently conceived: Musical rhythm, he argued, is a byproduct of “vocal learning” — the ability to reproduce sounds one has never heard before. Humans, parrots and elephants are all vocal learners. Elephants have been documented imitating the sounds of trucks and other animals, and parrots are literally synonymous with mimicry. Monkeys, on the other hand, are stuck with an inborn set of hoots and screams. Patel’s notion was that the evolution of vocal learning in select species strengthened the links between brain regions in charge of hearing and movement, which made musical rhythm possible. In the years following its introduction, the vocal learning hypothesis seemed to fit all the relevant data.

Iversen and Patel’s study of Snowball turned out to be just the prelude to a new concerto of research on musicality in the animal kingdom. In recent years, scientists have tested various species and found evidence that nonvocal learners such as sea lions and bonobos have rhythm too. In parallel, pioneering studies have begun to elucidate how the brain tracks a beat, work that may help corroborate that rhythm is not restricted to the planet’s most loquacious creatures. The new findings suggest that rhythm has a more ancient and universal evolutionary origin than was originally thought. “I don’t think the vocal learning hypothesis has much to teach us anymore,” said Peter Cook, a comparative psychologist at Emory University. “Beat keeping might be rooted in a really old, widely conserved mechanism, which is basically how brains communicate. What is more interesting is why some animals don’t do it.”

A World of Wild Rhythms

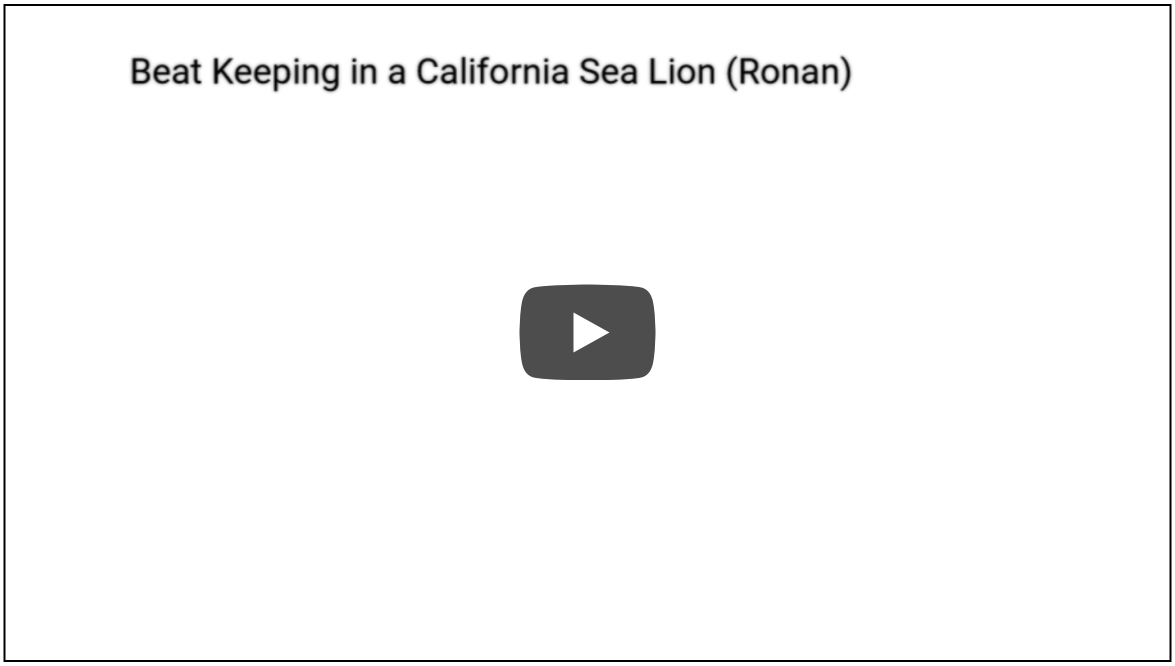
Patel and Iversen published their first study on Snowball in 2008. (Irena Schulz was a co-author on the paper.) The following year, Adena Schachner, at the time a researcher at Harvard University, and her colleagues demonstrated that an African grey parrot named Alex — the Koko of the bird world, famous for his large vocabulary — could also move to a beat, as could Asian elephants and 13 other parrot species identified through an exhaustive search on YouTube. Further evidence came from Columbia University neuroscientist and musician David Sulzer, also known as Dave Soldier, who had been recording albums with an orchestra of Asian elephants in Thailand, for whom he had constructed supersized drums, gongs and chimes. Meanwhile, Yoshimasa Seki of the Brain Science Institute in Japan and his team successfully trained budgerigars (parakeets) to peck an LED in time to a wide range of tempos. In related experiments by other researchers, rhesus monkeys largely failed to learn rhythmic tapping tasks: They took more than a year to grasp the concept and even then were inconsistent and tended to lag behind the rhythm.

By 2012, the vocal learning hypothesis seemed to be transitioning from a tentative notion to a promising explanation of rhythm's biological origins. Because people, parrots and elephants had all evolved to be vocal copycats, they had an innate talent for recognizing and replicating auditory rhythms; in contrast, acoustically inflexible primates did not. But then a single maverick mammal — one not known for musical prowess — leapt from sea to stage, stole the spotlight and urged the scientific community to reconsider.

A few years after word of Snowball got around, Cook, then a graduate student at the University of California, Santa Cruz, was contemplating a suitable research project for himself and Andrew Rouse, a UCSC undergrad. Cook was studying cognitive psychology, in particular the behavior of pinnipeds — walruses, seals and sea lions — and he knew that Rouse had a passion for music. Perhaps, Cook thought, they could combine their interests and really put the vocal learning hypothesis to the test.

Though not quite as vocally proficient as parrots, walruses and seals can mimic novel sounds. In the 1970s and '80s, one especially remarkable Atlantic harbor seal named Hoover learned to imitate human speech, greeting New England Aquarium visitors with phrases such as, "Hello there," "How are ya?" and "Get outta here," all reproduced with a thick Kennedy-esque accent. Sea lions, however — separated from their pinniped cousins by more than 20 million years of divergent evolution — are not nearly as vocally flexible. "They can bark and grunt on command, at a fast or slow rate," Cook said. "But they don't seem to be able to alter frequency or produce novel calls."

So Cook, Rouse and their colleagues decided to try to teach a sea lion named Ronan to dance. At first, Cook trained Ronan to bob her head to simple metronome-like pulses of 80 and 120 beats per minute (bpm). But that did not prove Ronan had a general ability to identify a rhythm and move in sync; she might have learned to simply move at two specific speeds in response to two distinct sounds, the same way a dog might trot at one whistle and sprint at another. In a second experiment, Cook presented Ronan with beats she had never encountered before: 96, 88, 108, 132 and 72 bpm. This time she had to bob her head in time with the beats without any training or practice rounds. She performed superbly, sometimes slightly ahead of slower beats, or a smidge behind the faster ones.



PinnipedLab

Video: Ronan the sea lion dances to “Boogie Wonderland.”

The real test, however, was whether Ronan could dance to genuine music — to pop and rock songs with all their phrases and flourishes overlaid on the underlying beat. Could she, like Snowball, extract the rhythm from The Back Street Boys’ “Everybody,” or “Boogie Wonderland” by Earth Wind and Fire? She could. Even playing “Boogie Wonderland” at varying tempos did not throw her off — she adjusted her bobs accordingly. “She was incredibly precise. Right out of the gate, she nailed it,” Cook said. “We showed that there is no way she could have hit all of those beats by chance.”

Cook and his colleagues published their results in the *Journal of Comparative Psychology* in 2013. Several more-recent studies have indicated that other animals classified as nonvocal learners — in particular the great apes — also have a sense of rhythm.

Unlike parrots, elephants and Hoover the harbor seal, the great apes are not adept at mimicking sounds or even the basics of human speech. Nonetheless there have long been inklings that apes might know how to follow a beat: Wild chimpanzees and bonobos drum their hands and feet on their bodies, or on resonant objects like logs and tree roots, when playing or reinforcing their dominance. In 2012 Yuko Hattori of Kyoto University published the first evidence from a controlled experiment showing that chimpanzees will spontaneously tap to a beat. And last year Patricia Gray, a concert pianist and director of the biomusic (music created by nonhuman animals) program at the University of North Carolina, Greensboro, revealed that she had discovered Snowball’s equal among a group of bonobos.

One day in 2010, while waiting for an experiment to be set up at a great ape research center in Des Moines, Iowa, Gray began idly tapping her hand on the side of a glass enclosure. From the other side of the glass, a bonobo named Kanzi started to tap as well, matching Gray's tempo. "Well, this is interesting," she thought. "I wonder how long we can keep it up?" They kept going — and going. Even when it was time for Kanzi's snack, he rolled onto his back, ate his helping of green onions with his hands and continued tapping with his dexterous feet.

The following year, Gray embarked on an experiment to formally answer a simple question: Can bonobos drum to a beat? She and Edward Large, a neuroscientist at the University of Connecticut specializing in music perception, studied a group of bonobos at Jacksonville Zoo and Gardens in Florida — in particular a 29-year-old female name Kuni. Unlike Kanzi, none of these apes had any prior exposure to musical instruments. But Gray and Large did not want to give the primates any old instrument. Bonobos, it should be noted, are much stronger than humans and could easily break a typical drum. The scientists commissioned the drum maker Remo to design a sturdy tube drum that was an appropriate height for a bonobo and could withstand 500 pounds of pressure. For good measure, they bolted it to a concrete floor in the bonobos' living quarters.

At first the apes approached the drum with trepidation, but once the researchers and zoo staff started demonstrating, the bonobos were rapt. By the fall of 2011, several high-ranking females, including Kuni, were voluntarily drumming along with staff members, which encouraged others to join in too. The real experiments began in December 2011 and continued through the spring. On one side of a steel mesh door, an experimenter listened to a metronome through headphones and drummed along. On the other side, Kuni — the most proficient player — could choose to beat on her drum. Kuni's performance was comparable to Snowball's: Both matched the abilities of a human child, accurately tracking a beat in bouts rather than continuously. "We wanted the bonobos to choose to participate," Gray said. "They can be as moody as humans. The data we collected clearly demonstrated that Kuni could entrain to a beat, even if she was only interested for a short time. Every time we have new species such as a sea lion or bonobo demonstrating this timing ability, it pokes a hole into what we thought was going to be clear-cut delineation of who has rhythm and who does not."

The Brain's Beats

Despite these new findings, Patel and Iversen are not quite ready to let go of the vocal learning hypothesis. "I think it still explains most of the data," said Iversen, who is now at the Swartz Center for Computational Neuroscience at the University of California, San Diego. They want to see more experiments with other species, in particular dogs and horses, both of which are decidedly not vocal learners. "Some researchers have raised the question: Why don't dogs dance? After all, dogs have been exposed to our music and dancing for tens of thousand of years," Iversen said. "It could be intrinsic neural limitations. Maybe you need the right brain circuits."

Bonobos are the latest example of non-vocal learners that are also able to keep a beat.

If, however, future experiments parallel the latest studies and confirm that an innate sense of rhythm does not depend on neural circuits unique to vocal learners, then how does the brain follow a beat? And what explains the evolutionary origins of this ability? An alternative explanation is coming into focus.

Scientists have known for decades that the brains of all creatures are highly rhythmic biological machines. Both individual neurons and groups of brain cells display repetitive fluctuations in their electrical and chemical activity. But when scientists speak of neural oscillations, they are usually referring to cyclic changes in the strength of the electric fields generated by thousands or millions of interconnected brain cells. Devices such as an electroencephalogram (EEG) — a net of electrodes placed on the scalp — can detect these fluctuations and graph them as sinuous lines similar to those drawn by a seismograph.

Although researchers know that these rhythms vary widely depending on someone's behavior and that certain rhythms correlate with specific physiological states — wake versus sleep, for instance — their exact purpose remains unclear. Some have argued that they are inevitable and largely ineffectual byproducts of the brain's wiring. Others think that such vacillations might encode and transmit information. Since at least the 1970s, researchers have proposed that neural oscillations might be especially important for recognizing patterns and rhythms in the environment — that the brain's own rhythms might actually sync up with those in the world around us. Until recently, however, there was no experimental evidence to support that idea.

In 2005, Large and Joel Snyder, now at the University of Nevada, Las Vegas, published an EEG study showing that when people listen to tones played at regular intervals, certain neural circuits begin to oscillate in time with the tones. It was the first study of its kind. "Oddly, no one had looked before," Large said. "There had been behavioral evidence accumulating for 40 years, in experiments with people tapping along to beats. But we wanted to go in and see if the brain's own oscillations sync with what we hear." Since then, dozens of similar experiments have demonstrated that neural oscillations in both human and other animal brains — including those of monkeys and zebrafish — consistently synchronize with auditory rhythms, including those that come from a simple metronome, classical music or human speech.

Initially, Large and other researchers focused such studies on oscillations in the auditory cortex — a small, centrally located brain region that organizes and interprets neural signals related to sound. In the last eight years, however, studies using magnetoencephalography (MEG) and fMRI — a measurement that tracks blood flow in the brain — have revealed that neural circuits specialized for movement are also used to perceive auditory rhythms. "What was surprising is that motor areas are active even when people are sitting still and just listening," Large said. "The emerging picture is that the auditory and motor regions sync with each other at the same time as they synchronize to external rhythms, which might help us store and remember the patterns so we can generate them later."

Patel and Iversen view these findings as further support for the vocal learning hypothesis. The fact that neural oscillations match patterns in speech and music is not sufficient to explain how we or other animals track a beat, they argue. Rather, musical rhythm emerges only in species that have robust bridges between brain areas specialized for hearing and movement, which allows them to synchronize oscillations in those regions all the more precisely. According to their model, when we sit perfectly still and listen to music, brain regions responsible for planning our movements predict when the next beat will drop. It's as though these regions were anticipating an upcoming footfall while running or the subsequent swing of an arm. The brain's auditory regions then use the motor regions' predictions to sync with the beat as well. Put another way, the brain can only make sense of music by relating it to rhythmic bodily movements, even if we aren't moving at all.

Large thinks this is a misinterpretation. "I don't think any especially complex circuitry is needed for a sense of rhythm," he said. "If a brain has connections between the auditory and motor regions, then we should be able to see them synchronize."

Cook agrees. The first thing to realize, he said, is that what we think of as musical rhythm — singing, dancing or otherwise following an auditory beat — is just one form of rhythm among living things. Consider the synchronous flash of the lustful firefly; or the lockstep of cheetah and gazelle; the ease with which millions of bats move together like living smoke in the night sky; the highly coordinated hunts of wolves and orcas; and the intricate mating dances of tropical birds. Clearly rhythm is fundamental to life — a fact reflected in the numerous links between sensory organs and muscles as well as between sensory and motor regions in all animal brains. Indeed, the fundamental purpose of neurons and brains is to form those connections: to guide behavior using information gathered from the outside world. "You can take this really far back in the evolution of brains," Cook said. "Brains are basically networks of circuits, and the way they work together is by synchronizing their firing patterns. Rhythm is baked in."

If rhythm itself is so commonplace among living things, then why is musical rhythm so rare? Perhaps it's not. What the latest evidence suggests is that the latent ability to follow a beat is much more widespread than previously realized — but, in many species, it probably needs some coaxing to reveal itself. Humans, parrots and elephants are all highly intelligent social species that depend on vocal communication to reproduce and survive. It makes sense that species like these will be especially responsive to auditory rhythms. But their precocious skills necessarily build upon far more common abilities and neural wiring found in a wide range of animals. When these less ostentatious creatures are given appropriate opportunities and encouragement, their latent musical abilities divulge themselves. "The tricky part is motivation," Cook said. "At first Ronan [the sea lion] didn't give a crap about the beat. But once we gave her the right training and impetus, she was like, 'Oh, yeah, of course I can do that.'"

Up until now, the idea has been that biological differences explain humans' unique musical gifts. Perhaps, though, that discrepancy stems more from culture than biology. Some human infants instinctively bob up and down and shake their limbs when they see people singing and dancing, which implies an innate sense of rhythm. Yet studies show that children do not learn to synchronize their movements to a beat until preschool-age at the earliest, and even then they are not very consistent. And if a child were never exposed to dancing or music, would she develop any musical rhythm at all?

Maybe we're more like Snowball and Ronan than we'd like to admit: We all have an inborn capacity for rhythm that requires the right environment to reveal itself. Perhaps it's not that we're biologically so different or superior, but rather that we're so much better at creating that suitable environment. Some scholars believe that our hominin ancestors were dancing and singing long before they evolved language, investing considerable resources in ritual performances and the construction of drums and flutes. Today, music continues to suffuse every phase of our lives, from lullaby to elegy. We may not be the only species with rhythm, but we are the only ones with a universal culture of music and dance. We have become the ultimate keepers of the beat.

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