PERSPECTIVES: BIOLOGY AND MUSIC

The Music of Nature and the Nature of Music

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Our world is filled with innumerable natural sounds, and from the earliest times humans have been intrigued and inspired by this "soundscape." People who live close to nature perceive a wider range of sounds than those of us living in industrialized societies, who rely heavily on advances in sound technology. The sounds of whales in the ocean, for example, were first recorded in the 1940s, yet the Tlingit, Inuit, and other seafaring tribes have been hearing them through the hulls of their boats for millennia. Similarly, the ultralow frequency communications of elephants have only just been recorded even though the Hutu and Tutsi tribes of central East Africa have incorporated these sounds into their songs and stories for centuries.

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It is said that every known human culture has music. Music has been defined as patterns of sound varying in pitch and time produced for emotional, social, cultural, and cognitive purposes (*1*). Is music-making in humans defined by our genes? Do other species show musical language and expression? If they do, what kinds of behavior invoke music-making in these animals? Is there evidence in the animal kingdom for the ability to create and recreate a musical language with established musical sounds? How are musical sounds used to communicate within and between species? Do musical sounds in nature reveal a profound bond between all living things?

The Music of Nature

Whales. The undersea songs of humpback whales are similar in structure to bird and human songs and prove that these marine mammals are inveterate composers (see top figure, next page). If songs can be defined as "any rhythmic repeated utterance, whether by a bird, a frog, an insect, a whale or a human being" (*2*), then humpback whale songs are constructed according to laws that are strikingly similar to those adopted by human composers.

- Singing humpbacks use rhythms similar to those in our own music, yet they could just as easily formulate free-form, arrhythmic sounds.
- They use phrases of a similar length to ours—a few seconds—and create themes out of several phrases before singing the next theme. Their songs could easily "grow" organically without the need for repetition but, like human composers, these marine mammals prefer to reiterate their material.
- Whale songs fall between the length of a modern ballad and that of a movement of a symphony. Perhaps they have chosen the same length of performance as we have because, with their large cerebral cortex, they have a similar attention span to humans.
- Even though they are capable of singing over a range of at least seven octaves, humpbacks use musical intervals between their notes that are similar to or the same as the intervals in our scales.
- Whales mix percussive or noisy elements in their songs with relatively pure tones, and do so in a ratio similar to that used by humans in Western symphonic music.
- In some whale songs, the overall song structure is similar to human compositions: a statement of theme, a section in which it is elaborated, and then a return to a slightly modified version of the original theme (that is, the ABA form).
- The tone and timbre of many whale notes are similar to human musical sounds. With an infinitude of possible sounds to choose from, whales could easily prefer to make sounds that we would deem unpleasant (roars, stutters, grunts).
- Most surprisingly, humpback songs contain repeating refrains that form rhymes. This suggests that whales use rhyme in the same way that we do: as a mnemonic device to help them remember complex material (*2*).

The fact that whale and human music have so much in common even though our evolutionary paths have not intersected for 60 million years, suggests that music may predate humans—that rather than being the inventors of music, we are latecomers to the musical scene.

Birds. Advances in audio technology allowed the late Luis Baptista to draw fascinating parallels between bird song and human music (*3*). For instance, when birds compose songs they often use the same rhythmic variations, pitch relationships, permutations, and combinations of notes as human composers. Thus, some bird songs resemble musical compositions; for example, the canyon wren's trill cascades down the musical scale like the opening of Chopin's "Revolutionary" Etude (see main figure, next page).

An examination of bird song reveals every elementary rhythmic effect found in human music (*4*). There are interval inversions, simple harmonic relations, and retention of melody with change of key. Many birds regularly transpose motifs to different keys (*5*). Some birds pitch their songs to the same scale as Western music, one possible reason for human attraction to these sounds. For example, notes in the song of the wood thrush (*Catharus mustelina*) are pitched such that they follow our musical scale very accurately (*6*). The interval between the first and second parts of the song of a ruby-crowned kinglet (*Regulus calendula*) is often a full octave. The canyon wren sings in the chromatic scale (which divides the octave into 12 semitones) (*7*) and the hermit thrush (*Catharus guttatus*) in the pentatonic scale (which consists of five different tones within the octave) (*8*).

The simple melodic canon, a frequent device in human composition based on imitation, is reminiscent of the matched countersinging of many bird species. The Socorro mockingbird (*Mimodes graysoni*) of Mexico sings a long series of short themes and its immediate neighbor will then respond to each theme with the identical theme (*9*). The Californian marsh wren (*Cistothorus palustris*) may sing as many as 120 different themes in a fixed sequence. Each theme is matched by its neighbor in a leader-follower sequence (in music this is known as the call-response pattern) (*10*).

Not all bird sounds emanate from the vocal tract—some are produced with "instruments" such as special feather structures, others by the bird pounding on an object with a "preferred" resonance. Perhaps the most remarkable example of a bird using an instrument to produce sound is that of the palm cockatoo (*Probosciger aterrimus*) of Northern Australia and New Guinea (*11*). Each male breaks a twig from a tree, then shapes it into a drumstick. The bird selects a hollow log with a preferred resonance and then, holding the stick with its foot, drums on the log as part of its courtship ritual.

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"Humphrey's Blues." A breaching humpback whale.

Humans. Human music-making may vary dramatically between cultures, but the fact that it is found in all cultures suggests that there is a deep human need to create, perform, and listen to music.

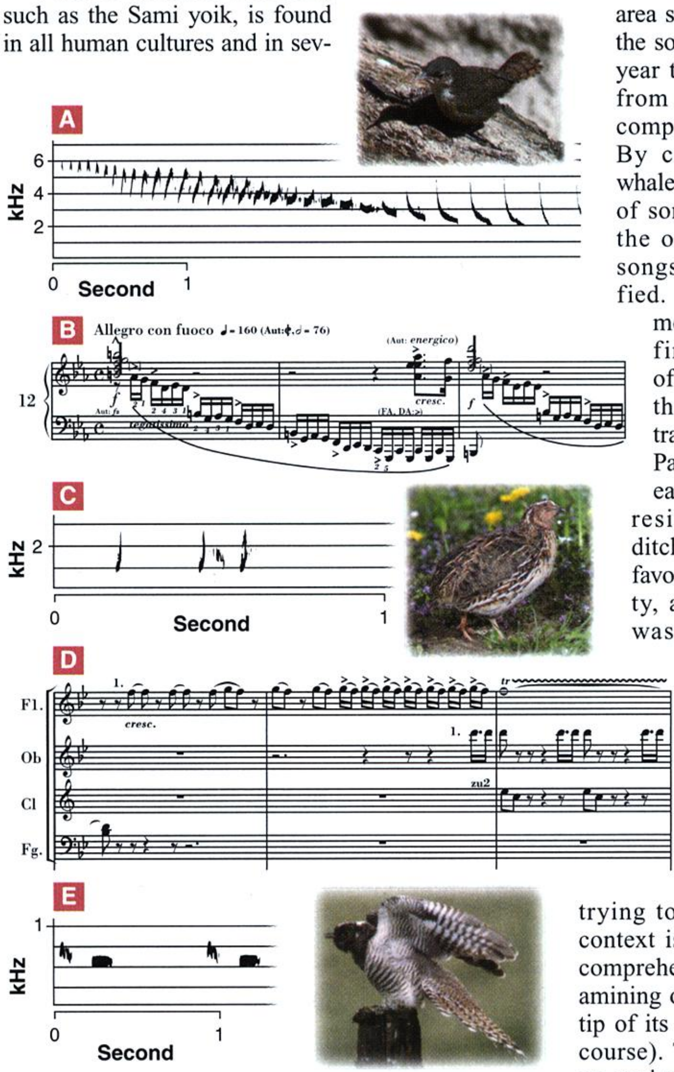
It appears that our Cro-Magnon and Neanderthal ancestors were as fond of music as we are. The discovery of prehistoric flutes made of animal bone in France and Slovenia, ranging in age from 4000 to 53,000 years old, demonstrates that ancient civilizations devoted considerable time and skill to constructing complicated musical instruments (see the figure, next page). Reconstructions of these prehistoric flutes suggest that they resemble today's recorders (*12*). It is possible that these ancient instruments even had a sound-producing plug (a fipple), making them easier to play but more difficult to make. Remarkably, many different types of scales can be played on reconstructed prehistoric flutes, and the sounds are pure and haunting. Given the sophistication of these 50,000-year-old instruments, it is quite possible that humans have been making music for several hundred thousand years.

The oral tradition of the Sami—the indigenous people of the northern Scandinavian Peninsula and the Kola Peninsula of present-day Russia—is contained in exclusively vocal songs called yoiks (*13*). Yoiks—consisting of short repeated cycles of nonsense syllables without linguistic meaning—describe everyday life and always carry personal meaning for the yoiker. Although not described in words, the topic of a yoik may be a person, livelihood, an animal, a place, or an aspect of nature. It is believed that musical knowledge is acquired in part by the internalizing of frequently repeated patterns in a particular musical style, thereby enabling listeners to abstract recurring commonalities from the music that they hear (*13*). The ability to memorize and recognize musical patterns thereby creates learned oral traditions that are passed on to subsequent generations.

Musical Commonalities

The ability to memorize and recognize musical patterns is also central to whale and bird music-making. These learning patterns may be vertical traditions (when a behavior is passed from parent to offspring), oblique traditions (when adults who are not blood-related pass the culture to younger generations), or horizontal traditions (when peers learn from each other).

Vertical musical tradition, such as the Sami yoik, is found in all human cultures and in several finch species, including the zebra finch (*Taeniopygia castanostis*) and the Northern bullfinch (*Pyrrhula pyrrhula*). Oblique musical tradition is the central component of every music lesson and is probably the most widespread mode of learning songs among birds (*14*). Horizontal musical tradition is found on every children's playground, in hand-raised juvenile chaffinches (*Fringilla coelebs*), white-crowned sparrows (*Zonotrichia leucophrys*), and in Anna's hummingbirds (*Calypte anna*), which when raised together develop very similar songs (*14*). Horizontal transfer of songs is also found among humpbacks—every whale in the same breeding area sings the same song and the song slowly evolves from year to year (*2*), but whales from different oceans sing completely different songs. By comparing any given whale song with a collection of song tapes, the year and the ocean from which the songs came can be identified. A recent report documented the extraordinary finding that the arrival of a few humpbacks from the Indian Ocean (Australia's west coast) to the Pacific Ocean (Australia's east coast) resulted in the resident Pacific whales ditching their own song in favor of the newcomer's ditty, a transformation that was complete within 3 years (*15*).



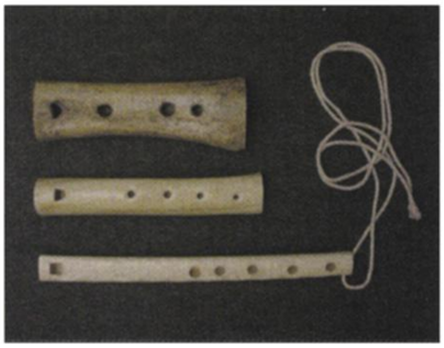
Composers of the avian world. A spectrogram of a canyon wren's song **(A)**, in which the syllables cascade down the musical scale, compared with **(B)** a portion of the score of Chopin's "Revolutionary" Etude. **(C)** A spectrogram of the three-note "dactylic" call of the quail. **(D)** A section of Beethoven's Sixth Symphony illustrating the similarity of the songs of the quail and cuckoo to the refrains of the oboe and clarinet, respectively. **(E)** A spectrogram of the two-note call of the cuckoo, the first note pitched a major third higher than the second.

Universal Music

Ambient sound is a central component of natural habitats. Abstracting the voice of a single creature from a habitat and trying to understand it out of context is a little like trying to comprehend an elephant by examining only a single hair at the tip of its tail (before cloning, of course). The ambient sound of an environment mimics a modern-day orchestra: the voice of each creature has its own frequency, amplitude, timbre, and duration, and occupies a unique niche among the other musicians (*16*). This "animal orchestra" or biophony represents a unique sound grouping for any given biome and sends a clear acoustical message.

CREDITS: WHALE: IAIN KERR AND ROGER PAYNE/OCEAN ALLIANCE; SOURCE FOR MIDDLE FIGURE: LUIS BAPTISTA AND ROBIN KEISTER; CANYON WREN: NOAH SATAT/ANIMALS ANIMALS; QUAIL: ROBERT MAIER/ANIMALS ANIMALS; AND CUCKOO: PETER BAUMANN/ANIMALS ANIMALS

Musical sounds form an exciting, natural conduit between members of our own species, between our species and others, and between the arts and sciences. By looking at musical commonalities, our understanding of music is enlarging, and by viewing musical sounds as an intuitive, nonverbal form of communication, we can better understand our own development in a biodiverse world.



No bones about Neanderthal music. Reconstructions of **(top)** a 53,000-year-old Neanderthal flute made of bear bone found in Slovenia (possibly recorder type), **(middle)** a 30,000-year-old French deer bone flute (most likely recorder type), and **(bottom)** a 4000-year-old French vulture bone flute (definitely recorder type).

CREDIT: JELLE ATEMA

It has been postulated that there is an unproven (and probably unprovable) concept called mathematical Platonism, which supposes that there is a universal mathematics awaiting discovery. Is there a universal music awaiting discovery, or is all music just a construct of whatever mind is making it—human, bird, whale? The similarities among human music, bird song, and whale song tempt one to speculate that the Platonic alternative may exist—that there is a universal music awaiting discovery.

It is not known when the ancient art of making music first began. But, if it is as ancient as some believe, this could explain why we find so much meaning and emotion in music even though we cannot explain why it makes us feel the way it does. Such an impenetrable vagueness about this most basic of human creations seems to signal that the roots of music lie closer to our ancient lizard brain than to our more recent reasoning cortex, that music has a more ancient origin even than human language.

References and Notes

1. The BioMusic Program is a program of National Musical Arts (NMA), the resident ensemble of the National Academy of Sciences. The program emerged from NMA's involvement in the National Forum on BioDiversity conference co-hosted by the National Academy of Sciences and the Smithsonian Institution in 1986. It now serves as a think tank for a diverse group of scientists and musicians. The BioMusic Program is a unique conduit between art and science, as it seeks to examine music in all species and to explore and understand its powerful role in all living things. This Perspective summarizes presentations at the BioMusic Symposium held as part of the American Association for the Advancement of Science Annual Meeting (17 to 22 February 2000, Washington, DC). We dedicate this Perspective to our colleague Dr. Luis Baptista (deceased July 2000).
2. R. Payne, *Whale Songs: Musicality or Mantra?* BioMusic Symposium, AAAS Annual Meeting, 2000.
3. L. F. Baptista, R. Keister, *Why Bird Song Is Sometimes Like Music*, BioMusic Symposium, AAAS Annual Meeting, 2000.
4. C. Hartshorne, *Born to Sing* (Indiana Univ. Press, Bloomington, IN, 1973).
5. E. A. Armstrong, *A Study of Bird Song* (Oxford Univ. Press, London, 1963).
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11. G. A. Wood, *Corolla* **8**, 94 (1984).
12. J. Atema, *Old Bone Flutes: Tracing the Origins of Human Music*, BioMusic Symposium, AAAS Annual Meeting, 2000.
13. C. L. Krumhansl *et al.*, *Music Percept.* **17**, 151 (1999); C. L. Krumhansl *et al.*, *Cognition* **75**, 13 (2000).
14. L. F. Baptista, S. L. L. Gaunt, in *Social Influences on Vocal Development*, M. Hausberger, C. Snowdon, Eds. (Cambridge Univ. Press, Cambridge, 1997), pp. 23–40; L. F. Baptista *et al.*, *Neth. J. Zool.* **43**, 17 (1993).
15. M. J. Noad *et al.*, *Nature* **408**, 537 (2000).
16. B. Krause, *The Niche Hypothesis: How Animals Taught Us to Dance and Sing*, BioMusic Symposium, AAAS Annual Meeting, 2000.

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Music of the Hemispheres

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All of us are born with the capacity to apprehend emotion and meaning in music, regardless of whether we understand music theory or read musical notation. Without conscious effort, the human brain is able to translate spectral and temporal patterns of acoustic energy into music's basic perceptual elements: melody, harmony, and rhythm (see the figure, next page). Music, like language, is an acoustically based form of communication with a set of rules for combining a limited number of sounds in an infinite number of ways (*1*). Universal among human cultures, music binds us in a collective identity as members of nations, religions, and other groups.

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It is astonishing how early in life musical competence can be demonstrated (*2*). By 4 months of age, babies prefer consonant musical intervals (major and minor thirds) to dissonant musical intervals (minor seconds) (*3*). Even if an infant's preference for consonant intervals has been influenced by 6 to 7 months of exposure to music in the womb, it is likely that the human brain enters the world primed to extract the spectral and temporal regularities that characterize popular music. Developmental psychologists are joining forces with ethnomusicologists to investigate whether babies weaned on non-Western music also "prefer" consonant intervals like major thirds.

Rats and starlings can distinguish chords deemed consonant and dissonant by Western standards (*3, 4*). Many of the auditory pathways that we use to perceive music evolved in animals for communication, sound source identification, and auditory object segregation. The prevalence of octaves and fifths in music from many different cultures may be a consequence of the way that our ears and brains are built.

"The Star-Spangled Banner" (the American national anthem) illustrates the close relation between the musical chord known as the major triad, a cornerstone of Western harmony, and the harmonic series, "the built-in preordained universal" and "common origin" of all music according to the composer Leonard Bernstein (*5*). We find that the first three notes of any major triad (root position) correspond to the fourth, fifth, and sixth harmonics of any harmonic series (*6*). Residing in the cochlea of our inner ear is the basilar membrane. This membrane behaves like guitar strings of varying thickness, enabling groups of sensory receptors (hair cells) along its length to become activated in response to sounds of specific frequencies (see the figure, page 56). The pattern of hair cell excitation is as orderly as the arrangement of keys on a piano, with equal steps along the chromatic scale mapped out as equal distances along the basilar membrane (*7*). However, different groups of sensory hair cells and their associated neurons are activated by different major triads, even by different inversions of the same triad. So, how is the characteristic harmonic structure of the major triad represented in the brain? In the auditory nerve, which transmits information in the form of action potentials from the inner ear to the brainstem, the neural excitation map may encode the octave the triad is played in; the timing of neural activity may indicate the pitch of each note and the consonance of the combination of

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