By Eckart O. Altenmüller

Music in Your Head

Listening to music involves not only hearing but also visual, tactile and emotional experiences. Each of us processes music in different regions of the brain

GREG MILLER


TWINKLE, TWINKLE LITTLE
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It is evening, after a long day at work. I play my favorite CD: Johannes Brahms's second piano concerto. The solemn horn solo in the first two measures flows into the soft crescendo of a piano chord. A wave of memories floods my mind: pictures of the forest around Rottweil, Germany; lines from poems; that day late one summer when I was 16 years old and first discovered the concerto. The conclusion of a particular movement takes my breath away. The pianist gradually increases the tempo and volume and completely expends his energy. I feel a tingling down my spine.

We have all probably at one time or another experienced this sort of thrill from music. When music causes one of these "skin orgasms," the self-reward mechanisms of the limbic system—the brain's emotional core—are active, as is the case when experiencing sexual arousal, eating or taking cocaine. It is conceivable that such self-reward helped to lead ancient peoples to make music. Humans were already constructing the first music-making tools more than 35,000 years ago: percussive instruments, bone flutes and jaw harps. Since then, music, like language, has been part of every culture across the globe.

Some researchers believe that music also conveys a practical evolutionary advantage: it aids in the organization of community life and in the forging of connections among members of one group when disagreements occur with another. Consider forms such as lullabies, work songs for spinning or harvest time, and war marches. In recent decades, youths listen to and play certain types of music as a means of identification and to set themselves apart from other groups.

Still, many questions remain. What happens in the brain when we listen to music? Are there special neural circuits devoted to creating or processing it? Why is an appreciation for music nearly universal? The study of music as a major brain function is relatively new, but researchers are already working on the answers.

FAST FACTS

The Perception of Music

1» Music is a powerful form of expression that can bring us to tears—or to our feet. Like language, music has been a part of every human culture across the globe. Exactly why is a matter of debate.

2» Scientists are piecing together what happens in the brain when someone listens to music. The brain's response involves a number of regions outside the auditory cortex, including areas normally involved in other kinds of thinking.

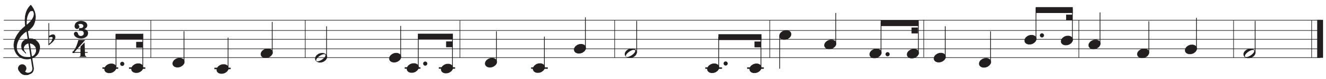
3» The ear has the fewest sensory cells of any sensory organ—3,500 hair cells occupy the ear versus, for example, 100 million photoreceptors in the eye. Yet hearing is remarkably adaptable; even a little practice at the piano can alter mental patterns considerably.

Presstimo Nervoso: The Path to the Brain

It is helpful to review how sound reaches the brain. After sound is registered in the ear, the auditory nerve transmits the data to the brain stem. There the information passes through at least four switching stations, which filter the signals, recognize patterns and help to calculate the differences in the sound's duration between the ears to determine the location from which the noise originates. For example, in the first switching area, called the cochlear nucleus, the nerve cells in the ventral, or more forward, section react mainly to individual sounds and generally pass on incoming signals unchanged; the dorsal, or rear, section processes acoustic patterns, such as the beginning and ending points of a stimulus or changes in frequency.

After the switching stations, the thalamus—a structure in the brain that is often referred to as the gateway to the cerebral cortex—either directs information on to the cortex or suppresses it. This gating effect enables us to control our attention selectively so that we can, for instance, pick out one particular instrument from among all the sounds being produced by an orchestra. The auditory nerve pathway terminates at the primary auditory cortex, or Heschl's gyrus, on the top of the temporal lobe. The auditory cortex is split on both sides of the brain.

At this point, the picture grows more complicated, for several reasons. Observations of patients with brain injuries—a common way to gain insights about which areas of the brain are responsible for specific tasks—made over the past decades have been frustratingly varied and occasionally contradictory. Even modern imaging techniques for measuring mental activity in healthy individuals have produced only incomplete explanations of the anatomical and neurophysiological bases for the perception of music. Part of the difficulty stems from the complexity of music itself [*see box on opposite page*]. In addition, the various aspects of music are handled in different, sometimes overlapping regions [*see box on page 28*]. Last, differences among individuals have clouded interpretations of findings.



(Dissecting "Happy Birthday")

Imagine we're at a birthday party. With champagne glasses in hand, we strike up what may be the most familiar number of all time: "Happy Birthday to You." We may be thinking we're warbling an uncomplicated tune, but a closer look at this seemingly simple eight-measure song demonstrates how complex and multilayered music actually is.

Music has four types of structures: melodic, temporal, vertical harmonic and dynamic, and each of these categories contains several subcomponents. We can start by listening to the melody as a whole—that is, we can perceive it globally or holistically. We can also break down the melody into separate length-based constituents, starting with the shortest. Taking this local, or analytical, means of perception to the extreme, we may experience the music as its individual tones. If we then put these tones together as a progression, we can consider every so-called interval between each pair.

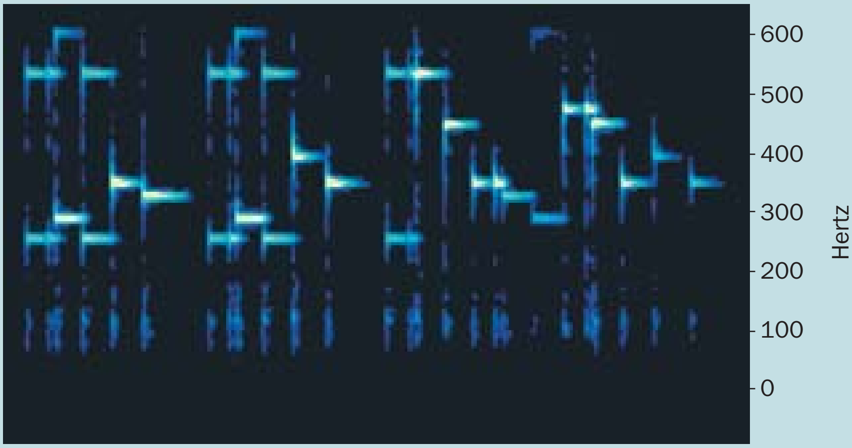
We can also work within the context of larger temporal-perception units and concentrate on the melody's contours. First, the melody rises somewhat, then falls and rises again in increasingly large steps up to the third "happy birthday to you." At this timescale, the subdivision into antecedent and consequent phrases within a musical period becomes interesting. These phrases adhere to rules of symmetry and harmony and produce a rising tension and then a release. In "Happy Birthday," the antecedent ends shortly before the last, tension-filled jump upward, leading to a softening consequent, from which the melodic line falls away.

In addition to melodies, music has temporal structures, such as rhythm and meter. A rhythm results from the temporal progression of at least three consecutive events. At the beginning of "Happy Birthday," we hear an energetic or punctuated rhythm. This gives the song its festive character, which is underscored by the solid, even progression of quarter notes. The meter is the regular beat, in this case three-four time, which forms the supporting basis for the melody. "Happy Birthday" is not so much a clumsy march but embodies more of the swaying, dancelike character of a minuet or even a waltz. To perceive rhythm and meter, our brains store acoustic events in a temporal context and then recognize how they are arranged.

But there is more to "Happy Birthday" than the horizontal structure made up of melodies, contours, rhythms and meter. Music also has a vertical structure: the timbre and harmony of the individual and multiple tones. The brain perceives all the different elements in milliseconds. The timbre of the birthday party guests' voices as they sing, for example, results from sounds and transient phenomena created by phonation (the production of speech sounds) and by the combination of the singers' harmonics. If we hear the song sung by several voices or with accompaniment, we perceive the harmonies by recognizing the proportion between the number of vibrations in a given time. Simple vibrational proportions generally sound more pleasant to us than the more complex ones. These sensations are subjective: they differ from person to person and from culture to culture and can even change over time.

Finally, when listening to "Happy Birthday," we hear its dynamic structure. The vertical dynamic constitutes volume proportions within a single tone. It arranges the individual voices by their stressing or backing off from the foreground or background of the tone area. The horizontal dynamic describes the volume progression within a group of consecutive tones. This dynamic has a strong effect on the listener's emotions.

One key characteristic of how we hear music is that we can switch among types of perception, only a few of which are described here. We can also quickly become engrossed in the music, thereby again changing the way we are listening. Somehow "Happy Birthday" doesn't sound quite the same anymore. —*E.O.A.*



Complex patterns make up music. In the "Happy Birthday to You" melody, a spectrograph's horizontal lines represent the individual tones' frequency spectra (*left to right*). The dynamic structure is represented by color: louder tones are lighter. Octave intervals appear on the left side (*red lines*); at the bottom is the standard pitch A440.

BEIDE ABB.: HANS-CHRISTIAN JABUSCH

Where Does the Brain “Hear”?

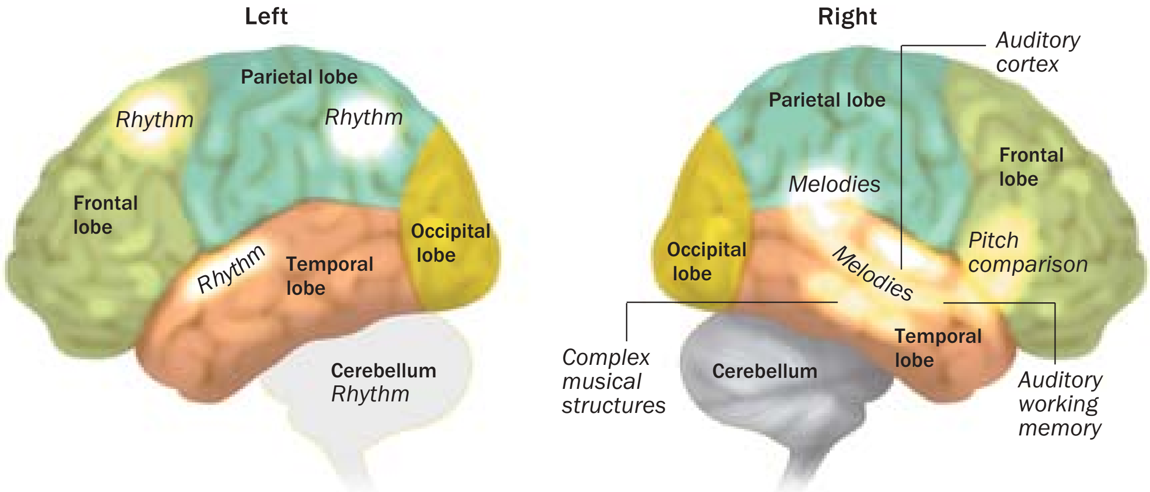
Left Hemisphere: Rhythm

Music is processed in various areas of the brain, which change depending on the focus of the listener and his or her experience. When the brain of an amateur musician processes simple rhythmic relations in a melody, such as the variance in length between certain tones, he utilizes the premotor, or movement-preparation, regions as well as sections of the parietal lobe in the left hemisphere. If the temporal relations among the tones are more complex, premotor and frontal lobe regions in the *right* hemisphere become active. In both cases, the cerebellum (which is commonly supposed to be involved in movement control) also participates. In contrast, musicians who are discerning between rhythms or meter predominantly employ parts of the frontal and temporal lobes in the right hemisphere. Rhythmic relations display a similar picture: people who are not musically trained process in the left side, whereas experienced musicians generally do so in the right.

Right Hemisphere: Pitch and Melody

When a musical layperson compares different pitches, the right posterior frontal lobe and right upper temporal lobe convolution are active. The tones are stored for future use and comparison in the auditory working memory located in the temporal region. The middle and lower areas of the temporal lobe are also active when processing more complex musical structures or structures being stored in memory for a longer period. In contrast, professional musicians show increased activity in the *left* hemisphere when they are differentiating among pitches or perceiving chords.

When the listener is focusing on whole melodies rather than individual tones or chords, entirely different sections of the brain become active: in addition to the primary and secondary auditory cortices, the auditory associative regions in the upper temporal lobe are at work. In this case, the activity is once again concentrated in the right hemisphere.



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Despite the gaps, scientists are piecing together a general understanding of where the brain “hears” music. We know, for example, that both sides, or hemispheres, of the brain are involved, though asymmetrically. For a long time, it was common to believe in a distinct division between the left brain’s processing of language (the side that also handles reasoning tasks) and the right brain’s processing of music (the half that contains emotional and spatial information). Many medical textbooks included this simplified theory until the 1980s. In recent years, however, researchers have established that injuries to either side can impair musical abilities. This happens not only in the case of damage to the auditory areas in the temporal lobe but also when associated regions of the frontal lobe and the parietal regions are affected. (If the Heschl’s gyrus is destroyed on both sides, incidentally, total deafness does not occur. Instead the ability to distinguish between various sounds is severely impaired. A patient with this condition would not be able to understand language or perceive music at all.)

Early stages of music perception, such as pitch (a note’s frequency) and volume, occur in the primary and secondary auditory cortices in both hemispheres. The secondary auditory areas, which lie in a half-circle formation around the primary auditory cortex, process more complex music patterns of harmony, melody and rhythm (the duration of a series of notes). Adjoining tertiary auditory areas are thought to integrate these patterns into an overall perception of music. Farther forward, behind and to the sides lie the so-called auditory association regions. (Wernicke's region, in the left hemisphere, which plays a major role in the perception of language, is located here.)

My studies of stroke patients with Maria Schuppert, also at the Institute for Music Physiology and Performing Arts Medicine, and with other colleagues also support the theory that the perception of music is organized hierarchically. The left brain appears to process such basic elements as intervals (the spaces between individual tones) and rhythms (the duration of a series of notes). The right brain, in comparison, recognizes holistic traits such as meter (beat) and melodic contour (the pattern of rising and falling in a piece). If the left side is damaged, patients generally become incapable of perceiving rhythms. If, however, the right side is injured, the patient no longer recognizes contours, melodies, meter or rhythm.

Andante Adaptabile: The Role of Learning

Past experiences and training have a significant effect on where and how the brain processes music. Laypeople and professional musicians show several significant differences.

For instance, scientists have investigated the perfect, or absolute, pitch that some people possess. Individuals with this ability can name a musical note when it is played alone, without the need for another note for comparison. Musicians with perfect pitch have a larger anterior, upper temporal lobe convolution in the left hemisphere. It seems that for perfect pitch and for the enlargement of that brain region to occur, musical training must begin early, before the age of seven.

Intensive musical training for years also leads to heightened activity in the corresponding brain regions, as reported in 2001 by Christo Pantev, then at the University of Münster in Germany. The "musical" brain structures of professional trumpet players react in such an intensified manner only to the sound of a trumpet but not, for example, to that of a violin, and vice versa.

Directional hearing abilities also sharpen with exercise. Conductors, who must be continuously aware of the musical balance of the entire orchestra, can pay close attention to members who sit near the edges of the group. They are also superior to, say, pianists when it comes to locating the sources of sounds.

But only a few hours of training can demonstrate how plastic the perception of music can be. Pantev, now at the Rotman Research Institute at the University of Toronto, and his colleagues played music, which had a certain range of frequency filtered out, for test subjects. After just three hours, the subjects' primary and secondary auditory cortices were notably less active in response to this frequency band.

Experienced listeners also register musical structures such as intervals and rhythms more accurately. Scientists at our institute conducted numerous studies of the changes that occur in the brain when a subject undergoes musical instruction or "listening cultivation" exercises. Gundhild Liebert conducted these tests in our EEG (electroencephalogram) laboratory with the help of Wilfried Gruhn, professor emeritus at the Freiburg Music School in Germany. Thirty-two music students had to identify 140 major, minor, diminished and augmented chords played at random. Each chord was sounded for two seconds, followed by two seconds of silence for "internal listening." After a half-hour session, a subset of the subjects received a standardized listening-cultivation lesson on cassette tape, which was meant to help them recognize the differences between diminished and augmented chords. The rest read short stories during this time. All the subjects then listened to the same chords they had heard previously, but in a different order.

When subjects heard the chords for the first time, the frontal and temporal regions were active in both brain hemispheres. Immediately thereafter, however, activity generally decreased in the participants who had not undergone the listening-cultivation session. The trained group, though, recognized the chords more readily and also displayed more activity in the central brain regions that connect sensory perception with motion perception,

(Past experiences and training have a significant effect on where and how the brain processes music.)

(The Author)

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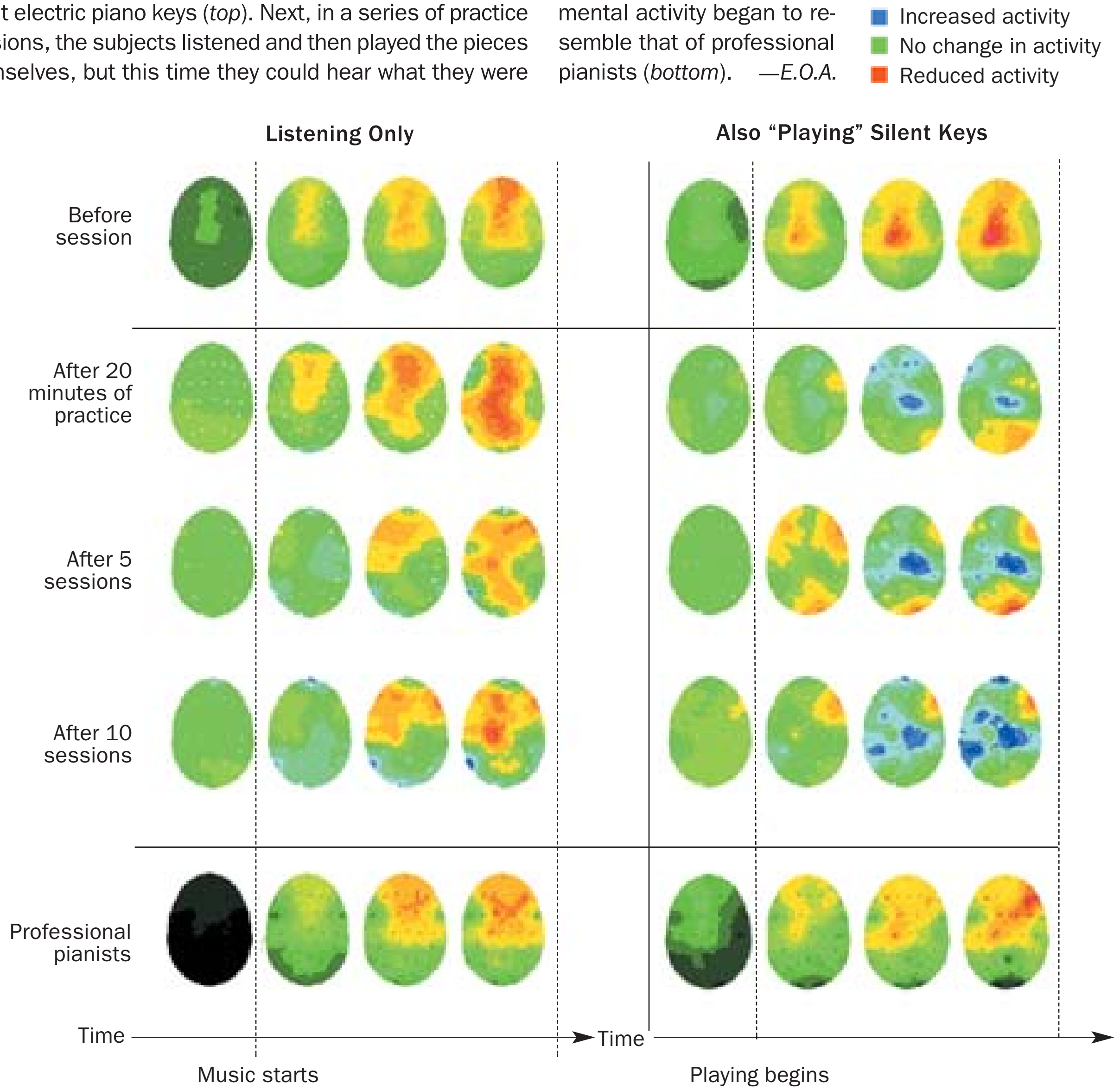
Helping Hands for Hearing

A connection between areas of the brain involved in listening and motor activities becomes clear in electroencephalogram (EEG) images of the top of the head (nose pointing upward). Amateur musicians first either simply listened to a simple piano melody or listened as they "played" silent electric piano keys (*top*). Next, in a series of practice sessions, the subjects listened and then played the pieces themselves, but this time they could hear what they were playing. After just 20 minutes, activities in the auditory and tactile regions began to change: when participants were simply listening to tunes, their sensory motor regions became active (*middle rows*). By the end of the experiment, the subjects' patterns of mental activity began to resemble that of professional pianists (*bottom*). —*E.O.A.*



especially during the internal listening phase. How could these be connected?

Menuetto Corepresentativo: The Ear and Hand Cooperate

The researchers learned the answer when they asked the subjects whether they had employed any specific listening strategy. Several students stated that after the training, they had pictured the chords as they would be fingered on a piano keyboard. Almost all the participants had practiced their listening skills at home on a piano. It is possible that the lessons could have brought the mental representation of the keyboard fingering—the information about how to play certain chords as stored in the cortex—to the forefront.

To find out how much time the brain needs to create such connections, my colleague Marc Ban-

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gert, also at the institute, measured the brain activity of amateur musicians in two different situations: they either simply listened to short piano melodies or they listened while also "playing" on electric piano keys, which produced no sound. He found two completely different activity patterns. Then he ran a practice phase. Participants listened to simple piano melodies and then played the pieces themselves. This time the subjects were able to hear what they were playing. Whenever a subject mastered a particular melody, he would be given a more difficult one, until he was no longer able to show improvement. Generally, the subjects became proficient at 20 to 30 melodies during the 11 training sessions.

The result: after the first 20 minutes of piano practice, activity patterns in both the auditory and the tactile regions of the brain began to change slightly. Three weeks later the changes were clearly present. (We measured one subject again a year later and found that the changes remained intact, although she had not practiced the piano at all since the training.) When listening to tunes, the participants' sensory motor regions became active, even when they did not move their hands in the slightest. If the subjects then began to finger the silent keys, other regions in the frontal and temporal lobes became involved. By the time the experiment ended, participants showed neural activity patterns similar to those of professional pianists.

Thus, our studies underscore a very important fact: humans perceive music as more than just sound. During a concert, we watch the musicians play, using visual perception; louder passages create vibrations, which we perceive as tactile stimulus. If a person is playing a piece on an instrument, the music is perceived as a series of fingerings and therefore is also a sensory motor activity. If one studies notes on a page, the music is registered by symbolic means, requiring the processing of abstract information. In each of these modes, we can represent music in our brains and store it in our memory systems. When we play musical instruments, our brains must be continuously processing auditory information together with sensory motor data. Bearing this out, in imaging studies the same music is represented in multiple ways in the brain of a professional musician: as a sound, as movement (for example, on a piano keyboard), as a symbol (notes on a score) and so on. Not so in the brain of an unpracticed listener.

Test subject wears a "bathing cap" with 32 electrodes in an experiment using an electroencephalogram, or EEG, to determine which areas of the brain become active in response to music.

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Last, music can elicit strong emotions, which researchers have recently begun to investigate with imaging techniques. The limbic system, which lies below the cerebral cortex and is responsible for emotions, is intensely involved: music perceived as pleasant stimulates parts of the frontal lobe and also a region called the gyrus cinguli, located farther toward the center of the brain. Music perceived as dissonant and unpleasant, however, elicits activity in the right gyrus parahippocampalis, close to the underside of the brain. Feelings about the music itself can also influence the brain's processing. Our work group found that when teenage test subjects liked a song, parts of the frontal and temporal lobes on the left side were predominantly active. If they found the music less enjoyable, the corresponding sections of the right brain were more active.

(Thus, our studies underscore an important fact: humans perceive music as more than just sound.)

What, then, can we conclude about how our brains process music? If music is experienced variously by each person, in different regions of the brain, it is difficult to find rules that apply universally. Therefore, in the strictest sense, the world today holds about six billion unique "music centers"—one for every human brain. The brain structures that process tunes in each of those music centers adapt quickly to new circumstances. We are only now beginning to recognize and investigate this neuronal dynamic.

(Further Reading)

- **How Many Music Centers Are in the Brain?** Eckart O. Altenmüller. *Annals of the New York Academy of Sciences,* Vol. 930; 2001.
- **The Cognitive Neuroscience of Music.** Edited by Isabelle Peretz and Robert Zatorre. Oxford University Press, 2003.