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Music and the Brain

Course Guidebook

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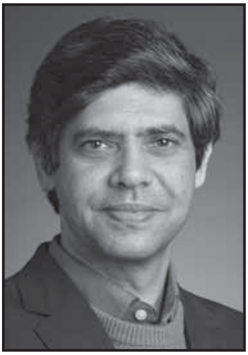

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Professor Aniruddh D. Patel is a Professor of Psychology at Tufts University. After attending the University of Virginia as a Jefferson Scholar, he received his Ph.D. in Organismic and Evolutionary Biology from Harvard University, where he studied with Edward O. Wilson and Evan Balaban. His research focuses on the cognitive neuroscience of music.

Prior to arriving at Tufts, Professor Patel was the Esther J. Burnham Senior Fellow at The Neurosciences Institute, a scientific research organization founded by the late Nobel laureate Gerald M. Edelman. Professor Patel's major contributions have included research on music-language relations, the processing of musical rhythm, cross-species comparisons, and relations between musical training and neural plasticity.

Professor Patel is the author of *Music, Language, and the Brain*, which won a Deems Taylor Award from the American Society of Composers, Authors and Publishers in 2008. In 2009, he received the Music Has Power Award from the Institute for Music and Neurologic Function in New York City.

Between 2009 and 2011, Professor Patel served as President of the Society for Music Perception and Cognition. He is active in education and outreach, having given more than 70 scientific lectures and colloquia and more than 20 educational and popular talks. Professor Patel's research has been reported in such publications as *The New York Times*, *New Scientist*, and *Discover* magazine and on National Public Radio. He has appeared in science documentaries, including *The Music Instinct*, which aired on PBS. ■

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Music and the Brain

Scope:

This course will introduce you to the new field of music and the brain. Interest in music and the mind is more than 20 centuries old, but most of what we know about music and the brain today was discovered in just the last 20 years.

In the first lecture of this course, you will learn about how cultural and neuroscientific approaches to music can coexist and about how music perception engages brain regions far outside of the auditory cortex. The next two lectures focus on evolutionary studies of music. You will learn about different theories of the adaptive role that musical behavior played in human evolution (including Charles Darwin's theory) as well as theories that argue that music is a purely cultural invention, which arose without any impetus from biology. Theoretical debates about music and adaptation continue today, but in recent years, a new approach has emerged. This approach uses empirical research, including behavioral experiments with humans and other species, to test ideas about the evolutionary history of music.

In the next two lectures, you will learn about the relationship between music and emotion. You will learn about the different ways in which music can express emotion, including by using acoustic cues shared with emotional speech. You also will learn about several different ways in which music can evoke emotion in listeners' brains and how these relate to music's ability to communicate cross-culturally.

The following lecture examines two fundamental building blocks of music—pitch and timbre—and explains how the perception of even single musical sounds (or very short musical excerpts) involves complex mental processing. Next, you will learn how combinations of pitches give rise to the perception of consonance and dissonance and how musical scales and keys are organized, physically and psychologically. You will discover how implicit learning gives rise to powerful expectations that shape your perception of music and your emotional responses to music.

The next two lectures focus on musical rhythm. You will learn that there is much more to musical rhythm than the beat. You also will learn that beat processing is surprisingly complex from the standpoint of brain science. In the following lecture, you will learn how the brains of musicians differ from those of nonmusicians and about the role of experience (versus innate factors) in shaping these differences. In the next lecture, you will learn about cognitive benefits associated with musical training and how researchers tease apart whether these are caused by musical training or merely correlated with musical ability. The next two lectures shift to explore how music cognition develops in normal individuals and how it goes awry in individuals with neurological music perception disorders.

In the following two lectures, you will learn about the relationship between music and neural rehabilitation. These lectures focus on people with a variety of medical conditions, from newborns in neonatal intensive care units to older adults with strokes or Parkinson's disease who suffer from problems with language or movement. You will learn how both listening to music and making music can have measurable biological impacts on medical patients.

In the penultimate lecture, you will learn how human song compares to the songs of other animals, including birds and whales. The last lecture will return to evolutionary questions from the standpoint of cognitive neuroscience and will explore the biological significance of music.

At the end of this course, you will be able to appreciate how much science has learned about music and the brain in the past 20 years, and you will have a solid foundation for understanding the future discoveries that lie ahead in this young field of research. ■

Music: Culture, Biology, or Both?

Lecture 1

Music always has been, and always will be, part of the human condition. The ability to process and enjoy it seems effortless, instinctive, and even primal. But brain science suggests that this is all an illusion. Behind the curtain of conscious awareness, musical experience depends on a sophisticated mental machinery with many parts, some of which are relatively new in terms of brain evolution. This lecture will focus on one component of that machinery: our capacity for relative pitch perception. It's just one in a larger set of mechanisms that underlie human musicality.

Music versus Musicality

- Studying music from the standpoint of neuroscience runs up against a serious challenge: Music is a human universal, but it's also tremendously diverse in its structure and meaning across cultures and time.

- These facts about the cultural and historical diversity of music mean that music is a moving target, and this presents a challenge for the study of music and the brain. Neuroscience doesn't typically deal with behaviors that vary so dramatically across cultures and time. Brain science usually focuses on phenomena that are culturally and historically stable.

- Fortunately, there is a way that brain science can acknowledge the great diversity of music and still move forward in a way that leads to interesting discoveries about music and the mind. This way involves making a key conceptual distinction: the distinction between music and musicality.

- Music, like other arts, is a social and cultural construct that strongly reflects the historical context in which it's created. Musicality is the set of mental processes that underlie musical behavior and perception, and these are much more stable across place and time.

- One of the things humans do when we perceive music is recognize the similarity of melodies when they are transposed—that is, shifted up or down in pitch. We recognize this similarity without any conscious effort, just as you would recognize a familiar tune, such as the "Happy Birthday" song, if it was played on a piccolo or a double bass, even if you had never heard it played that high or low before.

- Recognition of transposed melodies is a component of musicality, one of the mental processes involved in music perception. We have no reason to believe that this ability varies radically across cultures or historical eras. Many types of music, across culture and time, rely on transposition in creating musical patterns.

- The ability to recognize transposed melodies develops spontaneously in humans: It doesn't require any special training in music. A study by Judy Plantinga and Laurel Trainor showed that even six-month-old infants have this ability.

- For infants, just as for adults, an important part of the identity of a melody is not the absolute pitch of the notes, but the relative pitch pattern that the notes create—that is, the pattern of upward and downward pitch movements across the note sequence. This pattern stays the same when a melody is transposed.

- Research on this ability has revealed surprising and interesting things about this aspect of human musicality. Research has shown that songbirds, such as starlings and mockingbirds, do not recognize transposed melodies, even though humans easily do. This research shows that relative pitch perception doesn't just automatically emerge in a brain that processes complex sound; a certain kind of auditory system is needed.

- Could it be that it requires a primate auditory system? A primate's brain is much larger than a bird's brain, so you might expect that it could do more complex processing. Also, the auditory system of monkeys is thought to be very similar to that of humans in terms of its basic neuroanatomy and neurophysiology.

- Research on relative pitch perception in monkeys, which has had contradictory results, is too young to draw any firm conclusions. At this point, however, it's distinctly possible that our spontaneous tendency to use relative pitch in melody perception is uniquely human.

Relative Pitch and Sex Differences

- Comparative psychology reminds us that what's familiar to us in terms of music perception might actually be quite strange from the perspective of other species. This effortless ability we have to recognize transposed melodies might be quite odd when viewed in an evolutionary perspective. Why would our brain have been modified over evolutionary time to make relative pitch so natural to us?

- It might stem from an unusual feature of our bodies: the sex difference between men and women in the pitch of the voice. In humans, male voice pitch lowers dramatically during puberty. Stimulated by testosterone, male vocal folds become longer and thicker so that they tend to vibrate more slowly, producing lower pitches. This is reflected by the growth in the male Adam's apple during puberty, which is the cartilage that covers the larynx, or voice box.

- The Adam's apple sticks out more in men than in women because the vocal folds have grown larger. The resulting difference in average voice pitch is remarkable. Due to changes during puberty, adult male voices end up being about 50 percent lower than females—way out of proportion with our body size difference, which is only about 8 percent.

- This sex difference in vocal anatomy is universal in humans and very unusual among primates, and it might have set the stage for our facility with relative pitch perception. The big difference in voice pitch between men and women means that when we communicate with each other, any pitch patterns we make with our voice are going to be far apart in absolute frequency.

- In order to recognize the similarity of an opposite-gendered person's pitch pattern to yours when he or she asks a question or makes a statement, you need to process the pattern in terms of relative pitch, not absolute pitch.

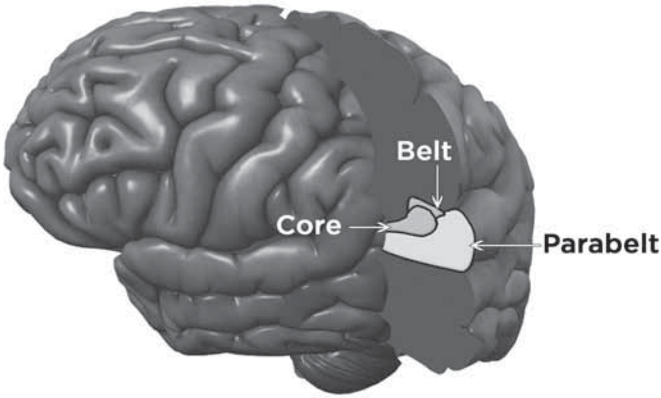
- Thus, one scenario for the evolution of relative pitch perception is that it emerged due to the need to recognize pitch patterns coming from individuals whose average voice pitch is very different from ours. This could explain why birds and monkeys might not have this ability: Many do use pitch patterns to communicate, but they don't have big differences between individuals in average voice pitch.

The Neural Bases of Relative Pitch Perception

- In addition to the insights about relative pitch that we've gained from comparative psychology, cognitive neuroscience has taught us surprising things about the brain circuits that process relative pitch.

- The auditory system is very complex. There are multiple neural processing centers between the ears and the cerebral cortex. These brainstem and midbrain centers are very similar in anatomy and function between humans and other mammals. They are involved in basic functions, such as sound localization and integrating auditory and visual signals. So, if we're looking for specializations of brain structure (or processing) in humans, these areas are probably not good candidates.

- When neuroscientists study the auditory cortex, which resides in the temporal lobes on the left and right side of the brain, they find multiple regions, which have been named the core, belt, and parabelt. In general, the farther one gets from the core region, the more complex the processing is that takes place.



- For example, a neuron in the core region might respond when a particular frequency is heard, while a neuron in the belt or parabelt regions might only respond if a particular frequency is followed by another particular frequency.

- Neurons in these higher-order regions are more interested in combinations of features than in single features. Neuroscientists know this because they are able to measure the responses of single neurons in the brains of animals. This is generally not possible with humans.

- Following this logic, one might expect neurons in the belt or parabelt regions to be involved in relative pitch perception, because relative pitch perception is not just about which frequencies are heard, but about relations between frequencies: whether pitch goes up or down and by how much.

- Research conducted by Robert Zatorre and colleagues at the Montreal Neurological Institute in 2000 showed that relative pitch involves a brain specialization in the right auditory cortex of humans. This finding lined up with other studies that Zatorre and colleagues had done, suggesting that in humans, the right side of the brain is particularly important for musical pitch processing.

Brain Regions and Relative Pitch Processing

- The study of people whose brains have been impacted by disease or damage is a classic method in neuropsychology that far predates modern brain imaging. Such studies can tell us if a brain region is critical to a particular mental ability by asking if patients with damage to that region still have that ability.

- In the last few decades, this traditional method has been complemented by new methods of noninvasive brain imaging that allow us to look at brain structure and function in healthy, normal individuals. For example, functional magnetic resonance imaging (fMRI) uses magnetic fields to measure increases and decreases in blood flow in different regions of the brain. When blood flow to a particular region increases, we infer that there is more neural activity in that region, because neurons in that region are consuming metabolic resources that the blood is delivering.

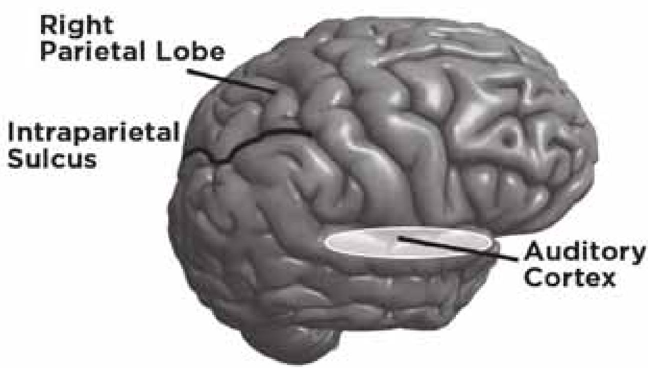
- In 2010, Zatorre and colleagues used fMRI to study relative pitch perception. In this study—part of which involved listeners using relative pitch to recognize the similarity between transposed melodies—the researchers discovered that one of the key regions activated by the relative pitch task was far outside of the auditory cortex. It was a region in the right parietal lobe, known as the intraparietal sulcus.

- Why would this region be involved in recognizing the similarity between transposed melodies? This is a brain region that is known to be involved in visuospatial processing and in visually guided spatial tasks, such as reaching and grasping.

- One thing that made this evidence so compelling is that not only did this region "light up" when people were doing the relative pitch task, but the degree to which it "lit up" in an individual correlated with how well he or she did on the task. This strongly implies that activity in this brain region is related to the ability to do the task.

- But it's not the only region that's involved. Relative pitch perception of melodic phrases likely involves a network involving the right auditory cortex, the right parietal cortex, and perhaps other regions. This illustrates an important point about the brain basis of cognition: Any reasonably complex cognitive task engages a network of brain regions, not just a single brain area.

- But why would a visuospatial brain processing area be involved in relative pitch processing? In monkeys and humans, this area is involved in integrating information from different senses and in visually guided grasping.



- Interestingly, another visual task that activates this region, the intraparietal sulcus of the parietal lobe, is mental rotation: looking at two three-dimensonal objects and determining if one is a rotated version of the other. Like relative pitch perception, this involves interpreting a sensory pattern in terms of the relations between elements. In vision, this could be important for programming how you would reach out and grasp an object.

- Thus, this brain area might support the ability to recognize patterns that are transformed but that still retain their relational properties. In humans, it seems that pitch processing has become connected to this ability, likely via strong neuroanatomical connections between auditory regions and this region.

- This illustrates something very important about musicality: It involves brain networks that extend well outside of auditory regions. This has deep implications for how music interacts with other aspects of cognition.

- From the brain's perspective, music perception is not just about the auditory system—it's about connecting sound processing to other things that brains do, such as moving, planning, remembering, imagining, and feeling.

Suggested Reading

Fitch, "Four Principles of Bio-Musicology."

Foster and Zatorre, "A Role for the Intraparietal Sulcus in Transforming Musical Pitch Information."

Questions to Consider

1. What is the difference between music and musicality?

2. What is one example of how music perception relies on brain regions outside of the auditory cortex?

Seeking an Evolutionary Theory of Music

Lecture 2

This lecture will provide you with an overview of the ongoing debate between people who view musical behavior as having adaptive, biological origins and those who view it as an entirely cultural invention. In addition, you will be introduced to a third perspective that might be able to reconcile these opposite positions. The three different kinds of theories about music's relationship to biological evolution that you will learn about are adaptationist theories, invention theories, and gene-culture coevolution theories.

Adaptationist Theories

- There are several theories that support the theory of musical behavior being adaptive in origin. The first and most famous adaptationist theory of music's origin comes from Charles Darwin.

- Darwin's theory comes from synthesizing an observation about the effect of music on humans with an observation about the use of music-like sounds by animals. Concerning the effects of music, he noted that in humans, music arouses great emotions, especially emotions of tenderness, love, triumph, and ardor for war, as well as rich mixtures of these.

- But Darwin wanted to know why there were these responses, so he connected his observations of music's emotional effects on us to his observations about how music-like sounds are used by animals, especially birds.

- Birds are nature's most musical creatures. In birds, singing is an acoustic display used to attract a mate or to defend a territory. Song in birds is thought to have arisen via a process that Darwin called "sexual selection": the selection of traits that promote the ability to compete for mates.

- Male birds use songs as displays to attract females or defend territories, even though singing takes up time that could be used for finding food and reveals a bird's position to predators. Darwin connected his observations about the emotional impact of music on humans with his ideas about singing as a product of sexual selection.

Male birds use songs as displays to attract females or defend territories.

- Darwin asserted that music evokes such strong and complex emotions in us because it once served a function in human life similar to its function for birds—namely, a function in finding a mate. Music activates ancient, primal emotions in us because of its ancient, primal role in the emotionally charged business of attracting and defending a mate. Darwin felt that music had this role in human life before we had articulate language.

- Darwin's idea that a song came before speech in human evolution has been elaborated on by cognitive archaeologist Steven Mithen and by cognitive biologist Tecumseh Fitch, both of whom see merit in Darwin's idea of a "musical protolanguage," a songlike communication system that is simpler than music as we know it today but that came before the evolution of full-blown speech. These researchers are less committed to Darwin's idea that the primary function of this language was in mate attraction.

- Another prominent idea about adaptive origins for music concerns mother-infant communication. The ideas about mother-infant communication are rooted in some of the unusual features of human infants compared to the infants of other primates.

- Because of our bipedal locomotion, which is unique among primates, the human female pelvis has a narrow birth canal, meaning that human infants have to come out of the womb relatively early in their biological development. As a result, human babies have an unusually long period of total dependence on their mother and other caregivers. Mothers and infants need to communicate long before babies can speak, even though babies don't understand words.

- Also, human mothers, unlike all other primate mothers, don't have fur that a baby can cling onto. So if a mother needs both hands for something, she may need to put the baby down and then needs a way to stay connected to the baby, to soothe it without physically touching it. One important channel that human mothers use to communicate and stay connected to their infants is sound, which is again unlike other primates.

- Researchers like Ellen Dissanayake and Dean Falk have argued that mother-infant vocal interactions early in human evolution, possibly even before language evolved, could have laid the foundation for the emergence of musical behavior. Thus, another possible adaptive function for a "musical protolanguage" lies in human mother-infant communication.

- The final adaptationist idea about music shifts the focus from two-way communication, such as between potential mates or between a mother-infant pair, to communication between members of a group. Across cultures, music is often a group activity, not just an exchange between potential mates or between a mother and her child. It's very common for groups of people to come together to make or listen to music at the same time. And when people do this, there is a tendency to share a similar emotional state, to sense a real connection to the people around you and to the identity or message that the music projects.

- In our own culture, think of church hymns, gospel music, national anthems, or concerts where people gather to make or hear music they love. Music often binds people together into larger social units.

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Across cultures, music is often a group activity that encourages a shared emotional state.

- According to the social bonding theory of music's origins, which has been proposed by several researchers—including physicist Juan Roederer, neurobiologist Walter Freeman, psychologist Steven Brown, and evolutionary biologist Robin Dunbar—a key function of music in early human groups was to strengthen bonds between group members via shared emotional experience.

- The idea is that these bonds led to more cooperative, or prosocial, behavior between group members outside of musical contexts, which then enhanced the ability of the group to function as a successful social unit.

- There is always conflict within human groups, and this conflict can reduce a group's ability to deal with challenges from the environment or from other groups. If groups in which members cooperate outcompete groups where individuals behave more selfishly, then there is a selective pressure favoring behaviors that promote in-group cooperation.

- Edward O. Wilson explores this idea of multilevel selection theory, in which natural selection can operate simultaneously at the individual and group levels. The social bonding theory of music's origin is focused on the group level. Note that this theory isn't wedded to the idea that music came before language, although theorists who favor the musical protolanguage idea point out that this bonding function could have happened before language evolved.

- In recent years, the social bonding theory has been rising in popularity, replacing the sexual selection theory as the most prominent adaptationist theory of music's origins. One thing that makes the theory so interesting is that it fits with some of the widespread features of human music.

- For example, music typically also has a lot of repetition built into its structure. This is very different from language, where we're told not to repeat ourselves. In music, repetition is celebrated. That repetition, which would be pointless, or even irritating, in language is great in music: It invites the listener to not just listen passively but to join in, sing along, and share in the feelings and message of the song.

Invention Theories

- There is a very different view of music's origins that regards music as a purely cultural invention, like reading or writing. One prominent thinker who held this view is the great psychologist William James, the father of American psychology. In sharp contrast to Darwin, he clearly says that music has no biological function and that its origin is a byproduct of having a complex hearing system.

- In light of what we know today, James's idea doesn't hold up. If it were true, then birds and other animals that have complex auditory systems should perceive music the same way we do, but that's not the case.

- But even if James was wrong about human musicality as a byproduct of complex auditory processing, he made a broader point that we still need to think about. Perhaps musicality arose not because it had some survival value but as an unintended byproduct of other mental abilities.

- The psychologist who has developed this idea the furthest is Steven Pinker. While he offers examples of many human mental faculties that have been direct targets of natural selection, he sees music as a counterexample, a prominent aspect of mental life that has not been shaped by biological evolution.

- Pinker sees music as an invention that became universal in human culture because of the strong links between music and pleasure. In this view, music is a technology, something humans invented, like literacy. Music is much more universal and ancient than literacy, and unlike literacy, basic musical abilities develop without any special instruction. So, how can something that's ancient, universal, and spontaneously developing be a human invention?

- Pinker has an answer to this challenge. He suggests that music taps into other brain functions that are ancient, universal, and spontaneously developing. In fact, he suggests that music is an invention that taps into five distinct types of mental functions, each of which did have an adaptive role in human evolution, but a role that had nothing to do with music.

- The key idea is that because these nonmusical mental functions are adaptive, the brain gives us pleasure when we activate them. By coactivating multiple adaptive brain functions, music triggers a concentrated dose of pleasure, without itself being adaptive.

- The five nonmusical brain functions are language, auditory scene analysis (the ability to mentally separate the different sounds that reach the ear), the processing of emotional vocalizations, habitat selection, and motor control.

- The idea is that when you hear music, even though you consciously know it's music, your brain analyzes it using sound-processing mechanisms that evolved for other reasons, such as language or emotional vocalization processing. The pleasure we feel arises because those mechanisms all have adaptive functions, but those functions did not originate because of music. We just feel the pleasure and attribute it to music.

Gene-Culture Coevolution Theories

- The debate between music having an adaptive origin versus being a purely cultural invention, or exaptation, is probably going to be with us for a long time to come. But a third perspective—gene-culture coevolution—might provide a way to integrate these views.

- This perspective is based on the idea of a feedback loop between human cultural inventions and biological evolution. The idea is that a cultural invention can gradually change the biology of a species in lasting ways. This is about genetic changes, changes that can be inherited biologically from one generation to the next.

- Music might have originated as an invention among human ancestors based on mental capacities that evolved for other reasons. In this non-adaptationist view of music's origins, the invention of music can be compared to the ability to control fire—a product of human ingenuity, not of biological evolution.

- The control of fire started as invention but quickly became universal because it provided things that humans everywhere value deeply: It allowed us to cook, fend off predators, and stay warm. Music might have quickly become universal because, like fire, it provides things that humans universally value, although these things were mental rather than physical: its emotional power, its usefulness in rituals, and its usefulness in helping us remember long sequences of information.

- All cultures recognize the emotional power of music and use music in rituals, large and small. As for memory, before writing, music was the primary way to remember long culturally important stories.

- How might the invention of musical behavior have led to permanent changes in the biology of humans? One place to look might be brain specializations for synchronized, simultaneous rhythmic action. This is a very distinctive feature of music, compared to other behaviors, such as language. In language, people exchange information by taking turns: One person speaks, and then another person speaks. In music, people often do things in synchrony: They sing, play, or dance at the same time. If this coordination did promote social bonding in early human groups, then perhaps our brains have become specialized for tightly synchronized rhythmic actions with others.

Suggested Reading

Patel, "Music, Biological Evolution, and the Brain."

Tomlinson, *A Million Years of Music.*

Questions to Consider

1. What was Darwin's theory of the evolutionary origins of human music?

2. What is gene-culture coevolution, and how might it apply to music?

Testing Theories of Music's Origins

Lecture 3

In this lecture, you will be introduced to studies of music perception in nonhuman primates. You also will be exposed to research on human behavior, inspired by an adaptationist theory about the origins of music—the social bonding theory. As you will learn, research on nonhuman primates and humans inspired by evolutionary questions—such as how ancient the brain mechanisms that underlie our capacity for music are—has led to some surprising and interesting results.

The Evolution of Human Musicality

- Genetic research strongly supports the idea that all living primates are descended from a common ancestor that lived about 90 million years ago. Humans are especially close genetically to chimpanzees; we share more than 98 percent of our genes and had a common ancestor about 6 million years ago.

- Ancient aspects of brain structure and function are shared by humans and other primates. If musicality is based on ancient brain mechanisms, then those same mechanisms should be present in other living primates, because of our shared ancestry with them.

- In 1838, Darwin first used this logic to test music perception in another primate—a young orangutan named Jenny in the London Zoo. Jenny listened with great attention to a harmonica and even put it in her own mouth to try. This fit with Darwin's idea that our love of music, along with many of our other traits, had ancient roots that we shared with other apes. His research also showed that the love of music was present early in human life, consistent with the idea of musicality having ancient roots.

- Research on music perception in other animals has recently begun to pick up steam. Scientists have just begun to appreciate that cross-species research is a powerful way to study the evolution of human musicality. It's also a powerful way to compare human and animal cognition more generally.

- Music perception involves complex mental processing that doesn't rely on words. Because other animals don't use words, research on music perception provides a great way to study how our mental processes compare to theirs when language is taken out of the equation.

Music Preferences in Other Primates

- Darwin's informal experiment with Jenny was about musical preference. Humans get pleasure out of music. Jenny's interest in music suggested to Darwin that she might like it too, which would suggest that music taps into something in ancient primate brains. But informal experiments have their drawbacks. Perhaps Jenny was just interested in the novelty of Darwin's harmonica and its sound. Controlled experiments are needed to test whether other primates really do like music.

- In 2007, Josh McDermott and Marc Hauser did a well-controlled study of music perception in primates. They tested two species of monkeys that normally live in the jungles of South America—cotton-top tamarins and common marmosets—and built a device to test musical preferences in animals.

- The device is made of two long boxes that join together to make the arms of a "V" shape. A monkey is released into the base of this "V maze," where the two arms come together. Each arm of the maze has a small food treat.

- At the end of each arm of the maze is an audio speaker. When the monkey enters one of the arms, sound from that arm's speaker begins to play, and it stays on as long as the monkey stays in that arm. When the monkey moves to the other arm, the first sound stops, and sound from the other speaker begins to play.

- The researchers used the maze to test whether monkeys liked music. One speaker in the maze produced music that sounded pleasant to Western listeners: a lullaby played on a flute. The other speaker produced silence. The study asked whether monkeys would prefer music or silence, given the choice.

- The researchers used the same conceptual design to test humans, and while the people preferred music to silence, the monkeys preferred silence to music: They actively spent more time on the side of the maze that turned the music off. McDermott and Hauser tried a few other kinds of music—a sung version of a lullaby and a string quartet by Mozart—but the results were the same for both humans and monkeys.

- These results suggest that the love of music is not something ancient that we share with all other primates. But in 2014, a group of researchers at Emory University, led by Frans de Waal, published a study on musical preferences in chimpanzees, which humans are much more closely related to than monkeys.

- De Waal's group studied chimps in their normal, large living enclosure. To test their musical preferences, the researchers put a speaker at one end of the enclosure and played either music or silence through the speaker. They tried different types of music, and unlike the monkey study, they chose non-Western music. They pointed out that if monkeys don't like Western music, that doesn't mean that they don't like music in general.

- They tried three kinds of music: West African Akan music, North Indian raga music, and Japanese *taiko* music. For each kind of music, they measured how much time the chimps spent in four different zones, ranging from near the speaker to far from the speaker. The researchers measured where the chimps sat when the different kinds of music played and compared these positions to where they sat when the speaker produced silence.

- The researchers found that when African or Indian music was played, the chimps moved toward the speakers, compared to where they sat during silence. This is the opposite result from the monkey study, where the monkeys preferred silence to music. The chimps did not move toward the speaker when it played Japanese *taiko* music, so they weren't just interested in any sound that the speakers produced.

Music and Emotion

- Without doing experiments that manipulate the sound of the music, we don't really know what aspect of the sound is driving the animal's preferences. The next logical step for studies of music processing by other primates is to manipulate the structure of the music we play them, to try and understand what it is about musical sounds that leads them to either like or dislike music.

- This line of work is related to a particular theory about music's origin that predates Darwin's ideas about music having emerged as a courtship signal, like birdsong. This theory comes from Darwin's contemporary Herbert Spencer, whose theory was about the psychological roots of musical behavior.

- Spencer thought that music got much of its emotional power from the way musical sounds resembled the sound of human emotional vocalizations. He thought that as a voice became more and more impassioned, it became more and more music-like in its characteristics. Spencer thought that music first arose as a stylization of emotional speech—that language came before music. This was the opposite of Darwin's idea.

- Today, there is a lot of interest in the idea that music's ability to express emotion comes partly from the way it reflects the acoustic qualities of emotional vocalizations. Unlike Spencer, modern researchers who believe in this idea don't necessarily think that

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Using the voice to express emotion is something that many animals do, not just humans.

language came before music. After all, an animal can make emotional sounds without knowing how to speak, in the form of growling, or whining, or yapping.

- The idea that music has its origin in the sounds of emotional vocalizations led to a primate study that was published in 2010. It's an usual study that came out of a collaboration between an expert on primate behavior, Charles Snowdon, and a cellist and composer, David Teie. They reasoned that if music grew out of emotional vocalizations, then other animals should respond to music that reflects their own emotional vocalizations, not necessarily human emotional vocalizations.

- They found that monkeys—specifically, cotton-top tamarins—did respond to music composed on the basis of monkey emotional vocalizations. This was a species that chose silence over human music in the earlier study. They saw this result as supporting the idea that the early roots of music lay in an ancient emotion-signaling system that used the voice.

- Using the voice to express emotion is something that many animals do, not just humans, so this would be a case of music building on ancient brain circuitry. Their idea was that tapping into this circuitry with music requires making music based on the particular emotional sounds a species makes.

- Can music based on an animal's emotional sounds actually have stronger emotional effects on an animal than just playing the emotional sounds themselves? Classic research in animal behavior has shown that artificial stimuli can be stronger than natural stimuli in the reactions they elicit. Could music for animals take the acoustic features of animal emotional sounds and make them even more salient, leading to stronger emotional responses than to the species' own emotional sounds?

Studies of Synchrony and Cooperation in Humans

- There has been growing interest in recent years in testing the social bonding theory of music's origins by studying the impact of group music making on the social behavior of people. The social bonding theory focuses on how making music with others could have been a mechanism for helping bond together the members of early human groups.

- One thing that distinguishes humans from other long-lived, group-living mammals like chimpanzees, elephants, and lions is how cooperative, or pro-social, we are toward other group members that aren't closely related to us.

- How did humans become able to bond socially with relatively unrelated group members? One idea is that we developed behavioral mechanisms to bond us together.

- The social bonding theory argues that musical behavior was one of the mechanisms for making group members feel more psychologically connected to each other. This would then translate into more cooperative and prosocial behavior between group members outside of musical contexts. If groups with better cooperation outcompeted other groups, then behaviors that promoted in-group cooperation could be selected for.

- How would this work? One idea is that when humans make or listen to music in groups, they often synchronize their movements to a common beat: This allows them to coordinate a complex pattern of simultaneous actions.

- In neuroscience, there is some evidence that the brain circuits responsible for controlling one's own actions are also involved in perceiving the actions of others. Thus, if you perform movements that are simultaneous with someone else, this could lead to a certain amount of blurring between self and other from the brain's perspective. On some level, your brain begins to think of you and the others as part of a larger self, and this might promote a sense of emotional and psychological connection.

- In a 2014 paper, the evolutionary biologist Robin Dunbar and colleagues have suggested that this "self-other blurring" could work in tandem with neurochemical effects of repeated rhythmic movement. This type of movement can lead to the release of endorphins in the brain. Endorphins can lead to elevated emotional states and also are part of the brain's opioid system, which is involved in social bonding in humans and other animals.

- How can you test if moving to a common beat with someone really promotes a sense of social connectedness outside of musical contexts? In 2010, a study by conducted Sebastian Kirschner and Michael Tomasello was published that tested this idea. They focused on four-year-old children and tested them in pairs.

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Researchers have found that participating in a musical activity seems to promote cooperation between children.

- In the pairs where children did a musical activity before a task, one child was much more likely to help the other child with a task than in pairs where the children did a fun but nonmusical activity. The synchronized singing and drumming that took place before the task was thought to have promoted prosocial behavior, consistent with evolutionary theories about music and social bonding. The researchers also found that the musical activity seemed to promote cooperation between children.

- This pioneering study is now one of several studies that have found links between joint synchronization to a beat and subsequent helpfulness or cooperation between group members. The fact that effects are seen with different methods and different ages suggests that there really is something to this link between simultaneous, synchronized rhythmic movement and prosocial behavior.

- This supports the social bonding theory of music's origins, although we need research on the brain mechanisms behind these effects, because we don't know whether they're really due to self-other blurring and endorphins release.

Suggested Reading

Kirschner and Tomasello, "Joint Music Making Promotes Prosocial Behavior in 4-Year-Old Children."

Snowdon and Teie, "Affective Responses in Tamarins Elicited by Species-Specific Music."

Questions to Consider

1. How can composing music based on animal calls help test evolutionary theories of music?

2. How might moving in synchrony with another person impact how psychologically connected you feel to that person?

Music, Language, and Emotional Expression

Lecture 4

The focus of this lecture is on the emotions that are expressed by music—those emotional qualities that listeners perceive in a musical piece, whether or not they have an emotional response. How does music express different emotions? For example, what makes a piece of music sound sad? Or joyful? Or angry? By focusing on how music expresses emotion, we can explore the idea that music and language processing have significant overlap in the mind.

The Study of How Music Expresses Emotion

- The study of how music expresses emotion brings up two themes. The first is the concept of multiple simultaneous mechanisms. Much of the psychological richness of music comes from the fact that it simultaneously activates multiple distinct processing mechanisms, some of which rely on brain regions well outside of traditional auditory processing areas.

- The second theme is the connections between music processing and language processing—the relations between the processing of purely instrumental music (music without words) and the processing of ordinary, day-to-day spoken language. There must be some sharing of brain processes by music and spoken language: They both use the auditory channel for communication. The question is how much overlap there is in the mental foundations of these two abilities.

- If there are important shared cognitive mechanisms, then these mechanisms are likely to be fundamental to how humans communicate with each other, and we have two pathways for exploring them: a path through music and a path through language. In addition, if music and language have significant cognitive overlap, this means that we might be able to use music training to impact language processing.

The Expression of Emotion in Prosody and Music

- Like music, speech is another sound pattern than can be used to express emotions. When we speak, we don't just convey words and phrases; we convey attitudes and emotions by the way we say those words and phrases. The pace and loudness of our voice, the way pitch moves up and down, the rhythm of our syllables, and the way we articulate our speech sounds all work together to express an emotional tone.

- These elements of language are called speech prosody. As listeners, we're sensitive to the emotions expressed by speech prosody: We know when someone sounds happy or angry from the way that he or she talks, not just from the words he or she says. If we can see the person, we also get cues to emotion from his or her facial expressions and gestures, but we can perceive emotions from just speech prosody, such as when we are talking on a phone. And we can perceive emotions in nonspeech vocal sounds, such as laughter or crying.

We can perceive emotions just from the way a person talks; we don't necessarily need to see the person.

- The kinds of emotions that are most clearly expressed by speech prosody are what psychologists call primary emotions or basic emotions. These are thought to be ancient and universal human emotions, such as happiness, sadness, anger, and fear, which have a strong biological basis and have analogs in the emotions of other animals.

- These basic emotions can be contrasted with secondary, or more complex, emotions that depend more on culture and learning, such as jealousy or guilt. It's more difficult to express these secondary emotions by the way you say something—conveying them depends more on the actual words you say or actions you make.

- We believe that the basic emotions have a long evolutionary history. Darwin argued that we share basic emotions with other species, and subsequent biologists have supported this idea with research that looks at similarities in the neuroanatomy and neurochemistry of basic emotions in different mammalian species.

- So, when we express basic emotions in speech, we're likely tapping into ancient emotional circuitry with our evolutionarily modern language system. One line of evidence that supports this idea is that the way basic emotions are expressed through speech is much more consistent across languages than many other aspects of language.

- In the language sciences, there has been a lot of interest in how different emotions are expressed through speech. Researchers have done detailed sound analysis of voices expressing different basic emotions, such as happiness or sadness, and have found some consistent acoustic cues that distinguish these different emotions.

- Happy-sounding speech tends to be relatively fast, with medium to high loudness; has a high average pitch and a wide pitch range, a brighter sound quality, and crisp articulation; and emphasizes upward pitch movements. Sad-sounding speech is slow, quieter, and lower in average pitch with a narrow pitch range, a darker sound quality, and duller articulation, and it emphasizes downward pitch movements.

- In 2003, Patrik Juslin and Petri Laukka published a landmark study that provided strong support for this idea. They reviewed many acoustic studies of emotion expression in speech and music and found a remarkable degree of correspondence in the acoustic cues to basic emotions in the two domains. For example, the same cues that are characteristic of happy- and sad-sounding speech are also seen in music that listeners judge as sounding happy or sad.

- Music can express different shades of a basic emotion, such as sadness, just as a painter can use different shades of a basic color, such as blue. Music also can express different intensities of basic emotions, such as joy, just as a painter can choose the intensity of a particular hue. And music can blend cues to different basic emotions, which allows for more complex emotional expressions than just the basic emotions. By varying the shading, intensity, and blending of basic emotions, music can express emotions that are rich and nuanced and not simply captured by basic labels like “happiness” or “sadness.”

By varying the shading, intensity, and blending of basic emotions, music can express emotions that are rich and nuanced and not simply captured by basic labels like “happiness” or “sadness.”

- Music goes beyond speech prosody in its ability to convey emotions with sound. Unlike speech prosody, music can simultaneously express a blend of different basic emotions, producing something closer to the complex inner feelings that we have but that we can't express with speech prosody alone.

- Juslin and Laukka suggested that one distinct way that music uses those cues is that it makes them stronger than emotional cues that occur in ordinary speech. For example, happy speech has limits on its tempo and volume and pitch range because of physical limits on the human voice. Musical instruments can go beyond these limits; they can take some of the same cues that make a voice sound joyful and make them stronger.

- Juslin and Laukka suggested that this made instrumental music a kind of superexpressive voice from the standpoint of brain processing—that is, even though a listener consciously knows that a piece of instrumental music is not a human voice, at some level of brain processing, the sound is being analyzed as a voice, but a voice with powers of emotional expression that far outstrip anything a human voice could do.

- This idea could help explain why we're so attracted to the sounds of musical instruments: This attraction could be based on inborn attraction to the sound of human voices and our natural tendency to be sensitive to the emotional qualities of those voices.

The Connection between Vocal and Musical Affect Expression

- An interesting line of research that is consistent with the idea that we perceive emotions in music and in voices using similar brain mechanisms comes from cross-cultural studies of the perception of emotion in music.

- Musical traditions vary enormously around the world, and if the way emotion was expressed also varied enormously, then you would expect that people from one culture would not be able to accurately perceive emotions in the music of another culture.

- In 1999, Laure Lee Balkwill and William Forde Thompson published a study that showed that people can guess the basic emotion conveyed by culturally unfamiliar music, although they are not as good as cultural insiders. Cues that can be related to speech prosody seem to play a role, which makes sense, because voices convey basic emotions in similar ways across cultures.

- The most direct evidence for overlap in the brain pathways that perceive emotion in music and in voices comes from brain imaging. An fMRI study published by Jorge Armony and colleagues found that when people listen to either music or voices that express the emotion of fear, a similar cluster of brain regions is activated, which includes the left amygdala, a deep-brain structure that's known to be involved in processing threat-related stimuli.

- Individuals showed a correlation in how strongly their amygdalas responded to expressions of fear in music and in the voice. Most likely, none of these listeners would consciously confuse the sound of the music with the sound of a human voice, but parts of their brain are subconsciously "confusing" the two sounds when it comes to analyzing their emotional qualities.

- Furthermore, researchers found that children who had studied piano for a year were as good at perceiving emotions in spoken voices as children who had studied drama for a year (and both were better than children who had no special training). Music training enhanced an aspect of language processing that hadn't been directly trained.

Other Ways Music Can Express Emotion

- In 1980, Stephen Davies and Peter Kivy suggested that music's emotional expressiveness is based on a perceived resemblance between how music moves and nonverbal human expressive behavior. This theory, which is called the contour theory of musical expressiveness, emphasizes how we tend to perceive emotion in things that resemble nonverbal human expressive behavior, even if those things are inanimate.

Humans' interest in the emotions of others leads us to anthropomorphize inanimate objects, such as the "weeping willow."

- Stephen Davies suggests that it's our strong human interest in the emotions of others that leads us to read expressiveness in inanimate objects that just happen to resemble the way human bodies express emotions, such as "weeping willow" trees.

- Two ways that music expresses emotions—with acoustic cues that resemble speech prosody and through resemblances to human nonverbal expressive behavior—are the most likely to cut across cultural boundaries, because the way voices and bodies express emotion has a deep biological basis that cuts across cultures. But there are culture-specific aspects to how music expresses emotion that aren't obvious to cultural outsiders.

- Music can express emotion through the ebb and flow of tension in music. All around the world, music is structured in ways such that at certain points listeners perceive a sense of tension, a sense that the music must continue before coming to a resting point.

- The ebb and flow of tension is central to music all around the world. We can think of it as a kind of emotional expression that's very dynamic: It unfolds in time, giving music a kind of emotional narrative that can reflect the way our own emotions unfold over the course of a day, although music can make this happen over just a few minutes.

- Different musical traditions create tension in different ways. In Western European music, harmony plays a big role, but not all musical traditions have harmonic structure. Other traditions might use greater or fewer degrees of acoustic consonance or dissonance, or melodic complexity, or other features to create tension and resolution. This means that a cultural outsider is much less likely to pick up on these cues to emotion, because they are more culture-specific.

- Finally, there are conventional associations between aspects of musical structure and expressions of emotion. For example, the philosopher Peter Kivy has suggested that in Western music we have come to perceive minor keys as expressing darker moods, such as sadness or seriousness, purely by conventional associations, not because those keys intrinsically reflect dark moods.

- Conventional associations can be psychologically powerful and shared by many listeners. Pioneering work on how music expresses emotion in the 1930s by the psychologist Kate Hevner included experiments in which the same piece was played in a major or minor key, while everything else about the piece was kept constant.

- When people rated the emotions expressed by the different versions, there was a lot of consistency in rating the minor-key version as more somber, without any feeling of conscious effort. This could lead to the sense that this is an unlearned, instinctive response, but that's an illusion. Several studies have shown that children seem to learn that the minor key expresses sadness.

Suggested Reading

Balkwill and Thompson, "A Cross-Cultural Investigation of the Perception of Emotion in Music."

Juslin and Laukka, "Communication of Emotions in Vocal Expression and Music Performance."

Questions to Consider

1. What is the conceptual difference between music's ability to express emotion versus induce emotion?

2. What are some similarities in the way that emotion is expressed in music and speech?

Brain Sources of Music's Emotional Power

Lecture 5

One of the primary reasons humans are drawn to music is its effect on the emotions. You already have learned how music expresses different basic emotions, such as joy or sadness. This lecture will focus on the other side of the coin: emotional responses to music. Our emotional responses to music can be very rich and varied, and people often differ in the emotional response they have to the same piece of music, making research in this area difficult.

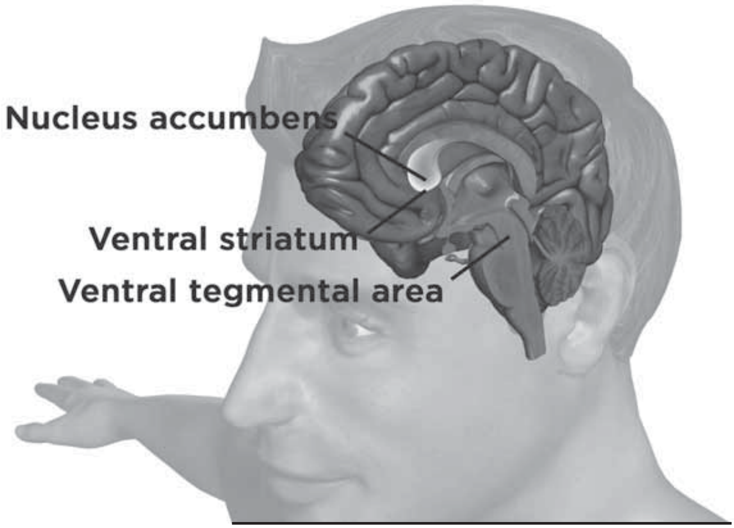
Physiological/Emotional Responses to Music

- Emotion is becoming a hot topic in music cognition research. Brain imaging studies have played an important role in this sea of change, because they have found clever ways to deal with individual variability in emotional response.

- A landmark paper that found a particularly clever way to deal with this variability was published in 2001 by Anne Blood and Robert Zatorre. They focused on one particular response to music: the experience of chills (or goose bumps, or shivers down the spine) that many people get when listening to music and that is usually felt as a moment of intense pleasure.

- In 1991, psychologist John Sloboda found that chills were the most frequently reported physical response to music. He noted that individual listeners could often identify specific pieces, and specific moments within those pieces, that gave them the chills. People varied in which type of music gave them chills, but the experience of chills seemed widespread and reproducible enough for Blood and Zatorre to study its brain correlates.

- Blood and Zatorre found that several brain areas showed activity that correlated with the chills response. These included the ventral striatum, which contains the nucleus accumbens, and other areas known to be involved in the brain's reward system. In a later PET study that focused on the role of dopamine in musical pleasure, Zatorre and colleagues confirmed that the nucleus accumbens was active during the experience of musical chills, along with other deep-brain reward areas, such as the ventral tegmental area, which contains dopamine-producing neurons.



- These ancient brain reward areas are part of a system that evolved to reinforce biologically important behaviors like eating and reproducing. Parts of this system are targets for addictive drugs like cocaine, yet brain imaging shows that this system can be activated by a purely abstract stimulus: instrumental music. Curiously, music doesn't have obvious survival value for us today, and it's not a chemical substance.

- In their 2001 paper, Blood and Zatorre suggested that evolution had somehow forged a link between newer brain circuits doing advanced cognitive processing of sound patterns and ancient, survival-related brain systems, such as the dopamine reward system.

- In 2013, Valorie Salimpoor and colleagues found support for this idea in a brain imaging study. Instead of focusing on chills, which are fairly rare events, they studied what happens when subjects get pleasure from music more generally. They found that musical pleasure seems to emerge from linking ancient reward circuits for survival behaviors to modern sound pattern-processing brain circuits, even when those circuits process sound patterns with no obvious survival value.

The Chills Response and Fear

- Cognitive musicologist David Huron has suggested a brain-based theory of the chills response. His theory involves a brain structure that is known to be involved in fear responses: the amygdala. This is a deep, ancient brain structure that has several subregions; it's a complex structure that's involved in interpreting the emotional content of signals.

- It's not just a fear center in the brain, but its role in fear is what interested Huron, who believes that music turned an ancient fear response into a source of pleasure. According to Huron, the pleasure we feel at musical chills is due to a fast-track fear response involving the amygdala, quickly followed by slow-track inhibition of the amygdala.

- This theory builds on the dual-track theory of fear processing and the amygdala, which comes from the work of neuroscientist Joseph Ledoux and is based on animal research. Huron has applied this theory to the study of emotional responses to music to come up with his own theory of musical chills: the contrastive affect theory.

- One supporting piece of evidence for Huron's theory comes from brain science. In the brain imaging study of chills, the researchers found that chills were associated not just with increased activity in some brain regions, but also with decreased activity in others.

- One of the areas showing decreased activity was the amygdala. This is consistent with the idea that chills involve inhibition of the amygdala. Unfortunately, PET brain imaging doesn't have the

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In a brain imaging study, chills were the most frequently reported physical response to music; individual listeners could often identify specific pieces, and specific moments within those pieces, that gave them the chills.

time resolution to determine if there was a fast activation before a more long-lasting inhibition, as Huron's theory predicts. Hopefully, future research will allow scientists to test this prediction.

- For now, we can appreciate the counterintuitive nature of Huron's suggestion: An intensely pleasurable response to music might have its evolutionary roots in fear-based mechanisms in the brain. If this proves true, it will be a great example of how our modern cognitive processing mechanisms tap into evolutionarily ancient brain circuits and use them to give emotional power to art.

- Huron's theory is also a good example of the notion that processing music involves multiple simultaneous mechanisms. If Huron is right, then it means that even something as specific as the musical chills response isn't just the result of a single brain mechanism being activated. The response arises from the simultaneous, or near-simultaneous, activation of at least two distinct brain mechanisms: a fast and slow pathway between sound input to the brain and the amygdala.

Instinctive Brain Mechanisms of Music

- A more general theory of how music evokes emotion, which takes the multiple simultaneous mechanisms idea even further, comes from a 2008 paper by Patrik Juslin and Daniel Västfjäll, with a later update by Juslin in 2013.

- According to this theory, there are at least eight distinct psychological mechanisms by which music can arouse emotion in listeners. One thing that makes this theory so interesting is that some mechanisms reflect more instinctive emotional responses to music, while others depend on individual experience and learning. In other words, the theory gives us a way to understand how nature and nurture can both contribute to the human emotional response to music.

- Starting with the mechanisms that are more instinctive and moving toward ones that depend more on personal experience, the first mechanism is called brain stem reflexes. It refers to quick, automatic responses to salient sensory qualities of sound. These reflexes are evolutionarily ancient and alert us to potentially important or dangerous events that need immediate attention. These reflexes can help explain why fast-tempo music with lots of acoustic roughness and sudden percussive events is emotionally arousing, whether we like it or not.

- The second mechanism is rhythmic entrainment and refers to the way a musical rhythm can entrain a bodily rhythm, such as when we tap our foot or dance to the beat of music. Humans find that moving rhythmically to music with a beat is pleasurable; we see this in young children and in adults across cultures. Rhythmic entrainment is a widespread, and probably very ancient, response to music with a beat.

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Humans find that moving rhythmically to music with a beat is pleasurable; we see this in young children and in adults across cultures.

- The third mechanism is emotional contagion. When we perceive an emotion expressed by music, we might have physiological responses that mirror aspects of that emotion, and then we start to feel the same emotion.

- Some of the cues to emotional expression in music reflect cues to emotion in the voice. If you put this idea together with the idea of emotional contagion, you can begin to understand why there could be some cross-cultural similarity in emotional responses to music.

- For example, lullabies from around the world have many of the characteristics you hear in calm and soothing voices: slow tempo, rhythmic repetition, and falling pitch contours. Babies from one culture will happily fall asleep to lullabies from another culture.

- One way to test whether these mechanisms really are instinctive is to see if people from very different musical cultures have similar emotional reactions to the same music. A study published in 2015 by Stephen McAdams and colleagues showed that the impact of music on emotional arousal does show cross-cultural similarity, even though the impact of music on emotional valence (positive or negative) does not. This supports the idea that emotional responses to music do rely to some degree on instinctive responses to sound patterns.

Experiential/Learned Mechanisms of Music

- As opposed to instinct, other mechanisms of music and emotion depend more on experience and learning. The first concerns a kind of learning you share with other members of your culture: musical expectancy. Music evokes emotion when the unfolding musical structure strongly confirms or denies an expectation the listener had about how the music would continue. Responses to musically unexpected events are often shared by members of the same musical culture, because they grew up listening to broadly similar music and thus acquired similar implicit knowledge.

- A mechanism that is more individual is evaluative conditioning, which means that a piece of music can induce emotions simply because of the context in which it has been heard in the past. If the context was positive, such as music that you used to enjoy with friends or family, you might have a positive emotional response, although it's not triggered by the specifics of the musical characteristics.

- Another individual mechanism is episodic memory—the memory of particular events in your life that get associated with particular musical pieces. For example, a song might trigger memories of when you were falling in love, because you heard that song repeatedly during that important time.

- Another individual mechanism underlying emotional response to music is visual imagery. For many people, music can activate mental images that aren't memories associated with the music but images conjured up in the mind by the music. These can be landscapes, or social or historical images, and they can have emotional connotations that get attached to the music.

- The final individual mechanism has to do with an aesthetic response to music. Sometimes music arouses emotion because we recognize the tremendous skill or expression that went into a performance. We also can be awed by the grandeur or elegance of the musical structure a composer has created. Recognizing a great performance or reacting to the large-scale structure of a piece is strongly culture and individual-specific: It depends on having learned what many other performances and pieces of music in your culture sound like.

Suggested Reading

Juslin, "From Everyday Emotions to Aesthetic Emotions."

Koelsch, "Brain Correlates of Music-Evoked Emotions."

Questions to Consider

1. What is one of the ancient brain structures involved in musical pleasure?

2. How might musical chills be related to biologically ancient fear responses?

Musical Building Blocks: Pitch and Timbre

Lecture 6

The perception of pitch and the perception of timbre are two processes that are fundamental to musicality. Pitch is the perceptual property of sound that allows us to order sounds from low to high. Timbre is the perceptual property that allows us to distinguish two sounds when they have the same pitch and duration—it's the character of a sound. Pitch and timbre are two of the main building blocks of musical structure, and in this lecture, you will discover some of the mental processes that are involved in their perception.

Pitch Perception: Pure Tones and Harmonics

- Pitch has an important relationship to sound frequency. This relationship can be illustrated with the simplest of all sounds: a pure tone, which is a tone with just one frequency. Pure tones aren't that interesting musically; they sound very thin to us. But they're important in the study of pitch, because in pure tones, the pitch equals the frequency. This means that we can measure the pitch of a more complex sound, such as a clarinet tone, by matching its perceived pitch to a pure tone.

- Almost all the sounds that we and other animals encounter naturally are more complex than pure tones. From an acoustic standpoint, that means they contain many frequencies at the same time.

- Many sounds that we're attracted to musically, such as clarinet or guitar tones, have many frequencies at once, but the frequencies are organized in a very particular way: There is a lowest, or fundamental, frequency and higher frequencies that are integer multiples of this fundamental frequency.

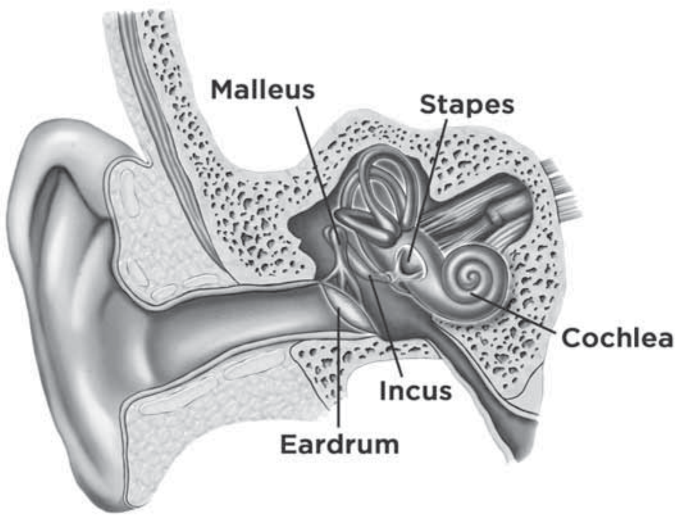
- Complex harmonic tones contain more than one frequency, and the frequencies are all related to a basic, or fundamental, frequency in a particular way: They are integer multiples of that fundamental.

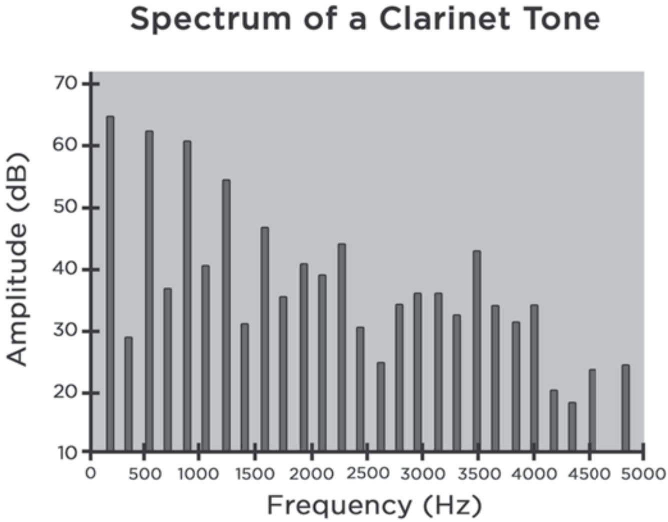
- Most of the melodic musical instruments we're familiar with—such as cellos, guitars, pianos, saxophones, and so on—produce complex harmonic tones. One reason we find musical instruments with complex harmonic tones so attractive is that they are reminiscent of human vowel sounds. Our brains have great interest in such sounds, because they're fundamental to speech.

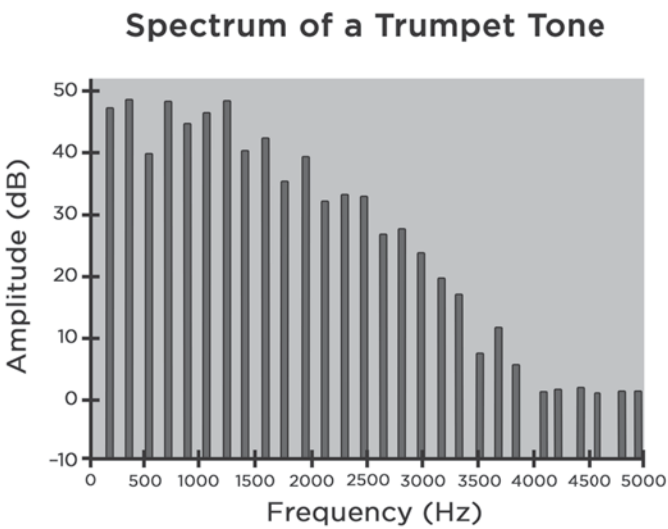
- In brain imaging research that directly compared the processing of musical sounds based on complex harmonic tones, such as clarinet and flute sounds, to human syllables and vowels, Amber Leaver and Josef Rauschecker found a good deal of overlap in regions responding to musical and vocal sounds in auditory regions of the temporal lobe.

Brain Structures and the Mental Construction of Pitch

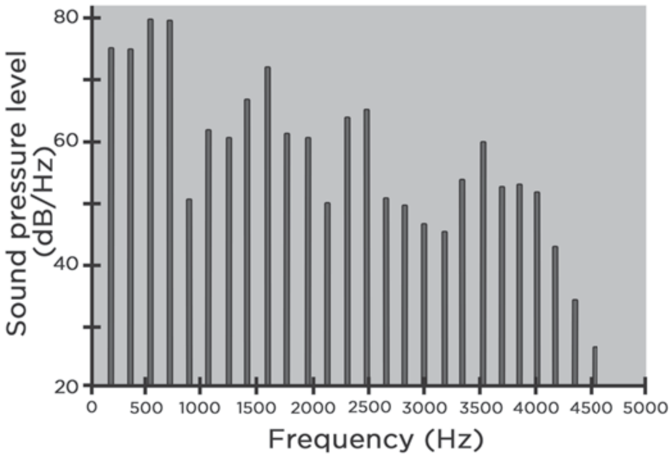
- Sounds are first received as vibrations of the eardrum, and these vibrations mix all the frequencies together. The sensory organ that converts these vibrations into nerve impulses, the cochlea, has ways of separating the different frequency components of a sound. This means that the brain can use the pattern of different frequencies and their energies to construct the sense of pitch.



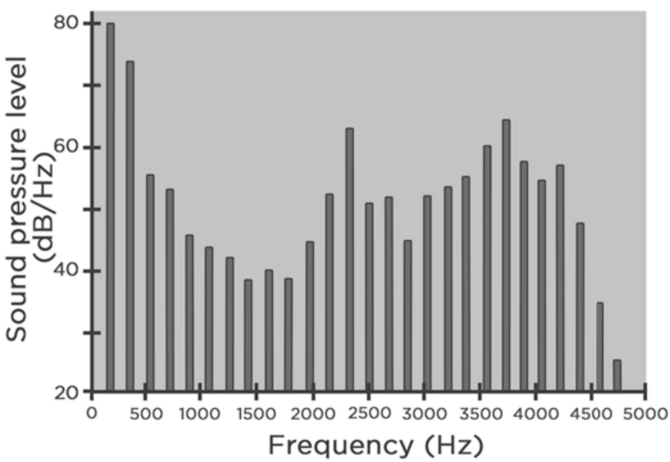

Spectrum of a Clarinet Tone
Amplitude (dB)
70
60
50
40
30
20
10
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Frequency (Hz)


Spectrum of a Trumpet Tone
Amplitude (dB)
50
40
30
20
10
0
–10
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Frequency (Hz)

Spectrum of the Vowel “ae” (as in “bat”)



Spectrum of the Vowel “e” (as in “beet”)



- In a complex harmonic tone, the fundamental frequency corresponds to the pitch. If pitch perception in complex harmonic tones were just a matter of the brain detecting the lowest frequency in a spectrum, then pitch perception would be simple. But a classic phenomenon in auditory perception teaches us that things aren't that simple.

- If we remove the fundamental frequency of a clarinet tone, or a trumpet tone, or a vowel, then the brain constructs the pitch from the information in the remaining frequencies. This is called perception of the missing fundamental, and it's just one of many ways that we know that pitch is a construct of the brain, not a physical fact about sound.

- Research with other animals, such as monkeys and songbirds, suggests that they also perceive the pitch of the missing fundamental, so this constructive nature of pitch perception is likely to be very ancient in evolution.

- The missing fundamental leads into a broader topic in the study of music and the brain—namely, differences between the two cerebral hemispheres. Research with patients with damage to the auditory cortex, as well as brain imaging research with healthy people, suggests that the right auditory cortex is particularly important for missing fundamental perception. The right auditory cortex also is important for the ability to judge the direction of pitch change between two tones: up or down, which is important for melody perception.

- In 2002, Robert Zatorre and his colleagues reviewed these and many other studies that pointed to a right hemisphere bias in musical pitch processing. They suggested a reason why this might be the case: that anatomical differences in the left and right auditory cortex gave them complementary skill sets.

- The right side was better at tasks that required very precise analysis of the frequency structure of sounds, and the left was better at tasks that required very precise analysis of timing information in sounds. They suggested that this was a fundamental trade-off in brain processing: Precision in frequency analysis came at the cost of reduced temporal precision, and vice versa.

- If you want to go fast, you can't be that precise. Zatorre and colleagues said that analyzing speech sounds puts a premium on analyzing fast changes. A spoken sentence can have 20 or more phonemes, or distinctive speech sounds, each second. To process those fast changes, the brain has to track patterns with very good time resolution.

- A melody will typically be much slower in terms of notes per second. On the other hand, melodies tend to use much more precise pitch patterns than speech: A small pitch change can make a big perceptual difference in music but can go almost unnoticed in speech.

- Zatorre and his colleagues suggested that because speech sounds put a premium on precise temporal analysis, and musical pitch puts a premium on precise frequency analysis, the same brain region couldn't analyze both with high precision at once. So, it specialized the left and right auditory cortex for one or the other.

- The researchers emphasized that this was a matter of relative specialization, not an absolute categorical difference. But this difference is enough to lead to many aspects of speech processing having a leftward bias in the brain and many aspects of musical pitch processing having a rightward bias.

- So, there is some truth to the idea that music is more of a right-brain phenomenon and that language is more of a left-brain phenomenon. But this is a bias—a matter of relative weighting—not an all-or-none distinction. Language and music both involve processing on both sides of the brain and are intertwined in ways that are just beginning to be understood.

Other Perceptual Dimensions of Pitch

- Pitch has multiple perceptual dimensions. Pitch height refers to the high-low dimension. In music, pitch also has another very important dimension, called octave equivalence. An octave is a doubling in frequency. Pitches separated by an octave sound very similar to humans, and we tend to give them the same name. Octave equivalence provides the framework for the structure of musical scales.

- This way of perceiving pitch is not just something that happens automatically when you have a complex auditory system. Recent research with songbirds, which use complex auditory processing in their own communication system, suggests that they don't perceive octave equivalence. So, this aspect of musicality must be younger than basic pitch perception, such as perceiving the missing fundamental, which birds can do.

- One study suggests that monkeys might perceive it, but in research on perception, it's usually best to wait for replication before drawing any strong conclusions. Currently, it's possible that octave equivalence, this seemingly basic aspect of musicality, does not come naturally to any other species besides us.

- A psychological property of pitch that is widely shared by us and other animals, because it has an ancient evolutionary history, is the relationship between pitch and the behaviors of aggression and appeasement. In many animals, low sounds indicate aggression or dominance, and higher-pitch sounds indicate appeasement or deference. For example, a dog's low growl is an aggressive signal, while it's high whine is a sign of begging for attention.

- These ideas were first explored by psychologist Eugene Morton in the 1970s and elaborated by linguist John Ohala in the 1980s. Think about how humans use their voices when trying to sound dominant and confident versus deferent or uncertain.

- These psychological qualities of low versus high pitches might stem from a connection between body size and pitch: Larger animals, like lions, tend to make lower sounds than smaller animals, like housecats, because they have bigger vocal folds. When animals want to appear aggressive or dominant, they usually want to seem bigger, and making lower sounds can convey an impression of a large size—and vice versa.

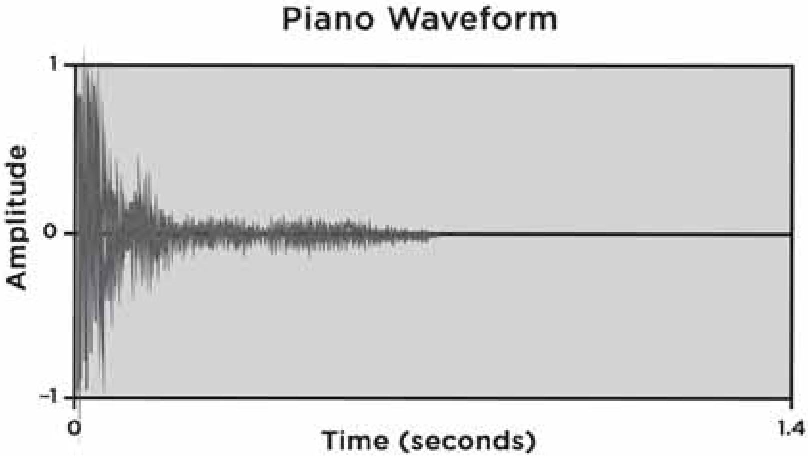
- These ancient associations of high and low pitch find their way into music. If you want to write a musical theme that sounds menacing, you're probably not going to score it for piccolo. And if you want to write music for a scene of a child playing joyfully, you're not going to rely heavily on trombones. These decisions seem intuitive to us, but they're more than just convention—they probably reflect associations built up over millions of years of evolution.

- The spatial metaphor of high and low that we use to describe pitch is not universal. Cross-cultural research has shown that cultures vary in the way that they describe pitch differences. The research suggests that the variation we see in metaphors for pitch differences around the world is not just arbitrary, random variation but is tapping into some deep multimodal associations that people have with pitch.

Timbre and Its Psychological Properties

- One reason why timbre is such a powerful perceptual attribute in musical sound is because of the crucial role it has played in mammalian hearing for hundreds of millions of years, long before humans were on the scene. Our early mammalian ancestors were nocturnal creatures that must have relied heavily on hearing for navigating their world and identifying things in it.

- One of the evolutionary innovations of mammals was having three middle ear bones—the malleus, incus, and stapes—instead of just one, like reptiles have. This probably gave early mammals enhanced abilities to discriminate and identify sounds very rapidly. This would have been important for survival.



Pressure waveform created by piano tone

- As nocturnal creatures, they needed good "night hearing": the ability to identify objects by hearing alone. Was that the sound of a delicious insect they could eat, or a small dinosaur predator, or a member of their own species? These judgments depended on quick and accurate processing of timbre. We have inherited this remarkable power to rapidly identify sound sources based on their timbre, and we put this ability to use in music.

- One reason why musical timbre has such a powerful relationship to musical memory is because of the role timbre played in mammalian evolutionary history. For our early mammalian ancestors, quickly identifying a wide range of sound sources, and remembering what they represented, was key for survival.

- Our early mammalian ancestors didn't need to just identify sounds in the night—such as a predator or a potential mate—they needed to act appropriately in response to them, and one of the main motivators of action is emotion.

Suggested Reading

McAdams, "Musical Timbre Perception."

Oxenham, "The Perception of Musical Tones."

Questions to Consider

1. What is a complex harmonic tone, and how is it related to human vocalization?

2. From an evolutionary perspective, why might timbre have such powerful links to memory and emotion?

Consonance, Dissonance, and Musical Scales

Lecture 7

When two pitches are played at the same time, the resulting combination can sound very rough and dissonant or very smooth and consonant. These differences aren't just perceptual; they also have psychological qualities. Acoustic consonance and dissonance both play a big role in music. They help structure the ebb and flow of tension and resolution, and they help give music an expressive, living quality. In this lecture, you will consider why pitch combinations differ in how consonant or dissonant they sound, and you will learn about the structure of musical scales, which are collections of pitches used to make music.

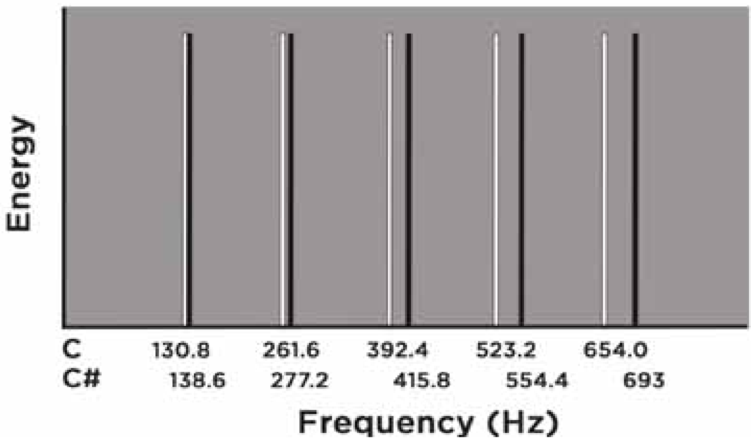
Musical Scales and Pitch Intervals

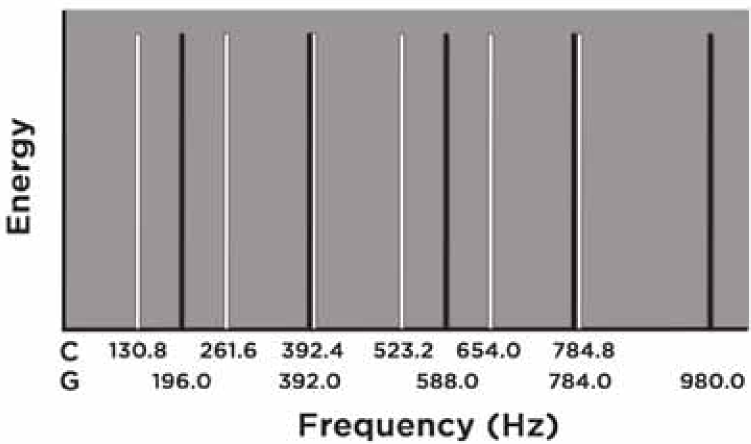
- Two pitches separated by an octave, or a doubling in frequency, sound very similar to us. They have the same note name—for example, C—in Western music. They blend perfectly. All cultures recognize the similarity of pitches separated by an octave; it's a basic component of human musicality. When men and women sing the "same note," they're often singing pitches that are an octave apart.

- In Western music, each octave contains 12 pitches, which are given letter names. If we start on C, we have C#, D, D#, E, F, F#, G, G#, A, A#, B, and then return to C. This is called the chromatic scale. These 12 notes are the basic pitch material for making intervals and for constructing the scales of Western music, such as the C major scale.

- The interval between any two neighboring pitches on the chromatic scale (such as C and C# or E and F) is called a semitone: It's about a six percent difference in pitch. Every pitch interval in Western music can be measured in semitones.

- For example, an interval made from the pitches C and C# is an interval of one semitone, which is called a minor second in music theory: It's a very dissonant interval. An interval made from the pitches C and G is an interval of seven semitones, which is called a perfect fifth in music theory: It's a very consonant interval.





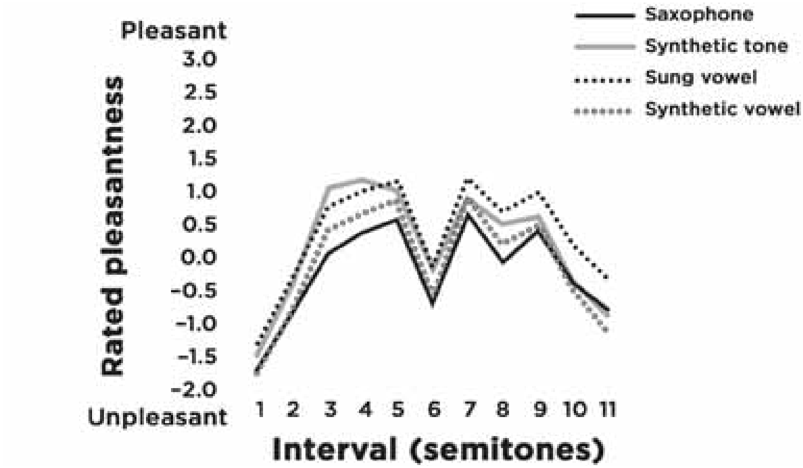
- A key fact about intervals is that they are transposable, or moveable up or down in pitch. You can make a minor second from a C and C#, but you also can make it by playing any two adjacent notes in the chromatic scale, because those notes are always one semitone apart. Similarly, you can make a perfect fifth by taking any pitch and playing it with the pitch that's seven semitones above it, such as an F combined with a C or a D# combined with an A#.

- Pitch intervals are interesting because they have perceptual properties that aren't present when their individual pitches are played alone. Any single musical pitch, such as the piano note C or C#, doesn't sound rough or smooth by itself. But when you take two pitches and make a minor second or perfect fifth, you get a new perceptual property: dissonance or consonance.

- It's been known for thousands of years that different combinations of pitches vary in how consonant they sound, but the reason for this has long been debated. The ancient Greek Pythagoras had a numerical theory of consonance and dissonance, based on his measurements of the lengths of the strings that produced the pitches of a musical interval. These measurements fueled his belief in the powerful role that certain ratios and proportions played in nature.

- As people learned more about how hearing works, biological theories of consonance and dissonance began to emerge. These theories try to explain people's perception of consonance and dissonance across a wide range of different pitch intervals, not just the minor second and perfect fifth.

- A study by Josh McDermott and colleagues in 2010 measured the average rating of the "pleasantness," or consonance, of all pitch intervals between 1 semitone and 11 semitones, when each interval was heard in isolation, outside of any musical context. There were four sets of ratings, because the ratings were made with four different kinds of sounds: saxophone sounds, synthetic tones, sung vowels, and synthetic vowels.



- A similar pattern emerged in each case. The very small and very large intervals—1, 2, 10, and 11 semitones—received low ratings, meaning that they are perceived as more dissonant. The middle intervals, except for the interval of 6 semitones, received much higher ratings, meaning that they're heard as more consonant.

- In the middle of the series of intervals, just before the perfect fifth, is a dissonant interval of 6 semitones known as the tritone. This interval might be described as unstable, suspicious, or incomplete. In the early 1700s, this interval was sometimes called the "Devil in music."

The Neurological Basis for Perceiving Consonance and Dissonance

- What is happening in the brain that leads people to hear certain intervals as more consonant and others as more dissonant? There is a long history of debate about this. The 19th-century German scientist Hermann von Helmholtz suggested that we can understand this pattern if we look at the acoustic structure of the two sounds that go into making the interval.

- Musical tones are often complex harmonic tones. A complex harmonic tone has a set of frequencies consisting of a fundamental and several upper harmonics, which are integer multiples of the fundamental. If two complex harmonic tones are played at the same time, then the brain receives both sets of frequencies at once, creating a composite sound with all the frequencies from both tones.

- Helmholtz said that if there are frequencies in this composite that are very close to each other, then they create a phenomenon called beating, a kind of warbling quality. The rate of beating depends on the frequency distance between the two tones. Helmholtz argued that the more pairs of nearby frequencies a composite sound had, the greater the overall roughness of the sound, due to beating between nearby frequencies.

- Until recently, this was the most favored theory of why we perceive different degrees of consonance and dissonance in different pitch intervals. But in 2010, McDermott and colleagues supported a different theory. The results of their research suggest a deep connection between the perception of consonance and dissonance and the acoustic structure of the human voice.

- When judging the consonance or dissonance of a pitch interval, people seem to be implicitly comparing the composite frequency structure of the sound to the frequency structure of a complex harmonic tone.

- The most common complex harmonic tone in our environment is the human voice. Whenever we hear a vowel, we're hearing a complex harmonic tone: a fundamental frequency and a series of harmonics that are integer multiples of that fundamental.

- Our brains are deeply attuned to the sounds of human voices. This makes sense because the voice is such an important carrier of information for our species: It conveys words and the emotions with which we say those words.

- There is some overlap in brain regions that respond to the sounds of musical instruments and the sounds of human voices. It may be that our perception of acoustic consonance and dissonance in musical pitch intervals reflects how well or poorly the resulting sound matches the acoustic structure of a human voice.

- This research is based on the fact that Western listeners show general agreement on how they perceive the acoustic consonance and dissonance of pitch intervals. But is this perception universal? Does the minor second sound dissonant, and the perfect fifth sound consonant, to someone who grew up in a very different musical culture?

- This is an important question if we're interested in the biology of music. To answer this question definitively, we would need to test people's perception of pitch intervals in a wide range of different cultures, and this hasn't been done yet.

- Such work might show that there is a universal element in how people perceive acoustic consonance and dissonance, but to get at that element, we would need to make a conceptual distinction between perception and preference. In other words, people from different cultures probably would agree that a minor second sounds more dissonant than a perfect fifth, because of the shared biology of hearing. They would have similar perceptions.

Perception versus Preference

- However, people might differ strongly in how much they like acoustic dissonance, reflecting the culture they were brought up in—they might have different preferences. In other words, while the perception of acoustic consonance and dissonance is probably an inborn aspect of human musicality, preference for consonance or dissonance is probably strongly shaped by culture.

- One line of evidence that is consistent with this idea comes from research with other primates. If a preference for consonant sounds is deeply ingrained in the biology of hearing, then other primates should show this preference, too, because basic auditory neuroanatomy and physiology is quite similar in humans and other primates.

- McDermott and Hauser found that cotton-top monkeys didn't show a preference for consonant over dissonant intervals. This finding was important because earlier work by other researchers had shown that monkeys can discriminate between consonant and dissonant intervals. This experiment showed that even though monkeys can perceive the difference, they don't seem to care about it. This finding was later replicated with another monkey species that is a little closer to humans genetically, the Campbell's monkey from West Africa.

- If humans do have an ancient and inborn preference for consonant sounds, we might expect to see these preferences expressed in infants. In 1996, two independent studies were published that suggested that four- to six-month-old infants preferred consonant sounds to dissonant musical intervals.

- However, a study in 2013 by Judy Plantinga and Sandra Trehub didn't replicate this result. The researchers who did this study pointed out that their infants came from more ethnically and culturally diverse households than the infants in the 1996 study. That means that they likely heard a greater diversity of music (and other sounds) than the infants in the earlier study. This could have shaped their auditory preferences. This suggests that even if infants are born with a predisposition for acoustic consonance, it's easily changed by experience.

Cross-Cultural Musical Scales

- Musical scales aren't just constructs from music theory. Through our exposure to music, scales become mental constructs that influence how we perceive music. Scales can evoke cultural associations for us. In the United States, a blues scale is part of what gives the blues its characteristic sound. In Western tonal music, the most common scale is the diatonic major scale, which has seven distinct pitches.

- All human cultures have music based on some sort of scale. Does musical scale structure have any cross-cultural consistency? If so, this could give us some clues about the mental foundations of music perception.

- One striking thing about musical scales from around the world is that most have five to seven notes per octave. Given that we can distinguish more than 100 pitches within an octave, the tendency to use just five to seven doesn't reflect sensory limits on auditory perception. It reflects cognitive limits on how many different pitches and intervals we can keep track of as we process a melody.

- In Western music psychology, there has been a long history of searching for universals in scale structure, based on the laws of acoustics and the biology of hearing. All musical scales use the octave, and most use the perfect fifth, which suggests that there is

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All human cultures have music based on some sort of scale, and most scales from around the world have five to seven notes per octave.

something about the biology of human hearing that leads us to these intervals. Beyond that, though, the intervals used in musical scales show a lot of cultural variation.

- But even though scale structure varies a lot across cultures, we shouldn't lose sight of the fact that all human cultures use musical scales. People everywhere create melodies using a small set of pitches and pitch intervals made by dividing up the octave into discrete steps.

- As music psychologist Andrzej Rakowski has pointed out, there is an analogy to how all human languages make sentences from a small set of distinct speech sounds or phonemes. Just as different cultures make melodies from different sets of pitch intervals, different languages make sentences from different sets of phonemes. This tendency to make an infinite variety of sound sequences, from a limited set of basic sound categories, is a human universal, seen in both language and music.

Suggested Reading

McDermott, Lehr, and Oxenham, "Individual Differences Reveal the Basis of Consonance."

Patel, *Music, Language, and the Brain*, Chap. 2.

Questions to Consider

1. What is harmonicity, and how is it related to sensory consonance and dissonance?

2. What auditory illusion helps demonstrate that a musical scale serves as a mental framework for perceiving pitches?

Arousing Expectations: Melody and Harmony

Lecture 8

This lecture continues the exploration of how pitch is organized in music, focusing on melody and harmony. Melody refers to how a single stream of pitches is organized over time; harmony refers to how multiple pitches are combined simultaneously or near-simultaneously and how these combinations are sequenced over time. Addressing melody and harmony will help illustrate the fundamental role of expectation in music perception and also will allow us to look deeper into the relationship between music and language as cognitive systems.

Musical Expectations

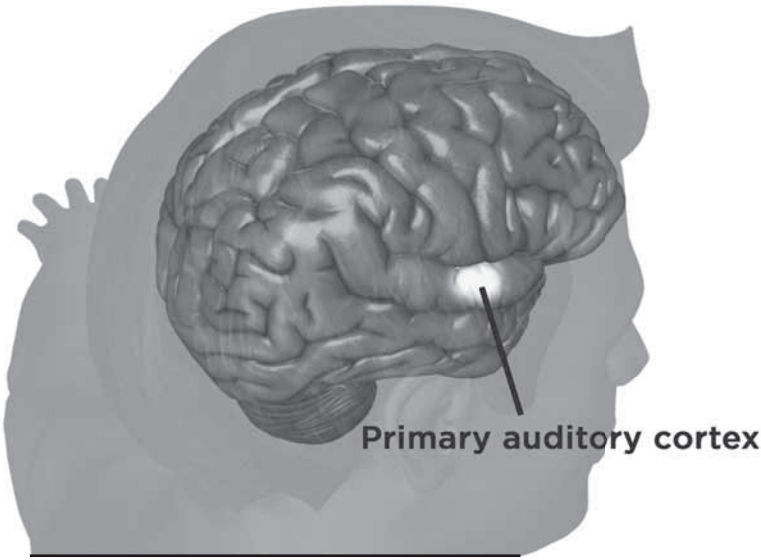
- The ability of musical sequences to arouse strong expectations is a fundamental part of music cognition. This is because there is a strong link between music's ability to arouse expectation and its ability to evoke emotion.

- In music, expectations arise because melodies and harmonies are made by combining pitches in principled ways. As listeners, we implicitly learn these principles, and this implicit knowledge guides our musical expectations, without any conscious effort on our part.

- In language, sentences are made by combining words in principled ways, and this guides our linguistic expectations. That is, as we process the words of a sentence, we often subconsciously use the structural principles of our language to predict what's coming next. The particular structural principles differ from language to language, but all languages have a set of principles for building sentences.

- Similarly, all widespread musical traditions have principles by which pitches are combined to make melodies, although the principles might differ from culture to culture.

- Our perception of the abstract qualities of musical tones—such as tension, resolution, and contextual dissonance—reflects sophisticated neural processing that depends on more than just the primary auditory cortex of the brain. In fact, brain imaging research suggests that processing these aspects of music might involve mechanisms that are also involved in processing linguistic grammar.



- The idea that there might be deep connections between the way the mind processes musical and linguistic structure predates modern brain studies. In the 1970s, the composer and conductor Leonard Bernstein speculated about connections between music and linguistic grammar in the mind. His ideas were greeted with a lot of skepticism by researchers at the time.

Connections between Processing of Music and Language

- Musical scales are sets of pitches and pitch intervals created by dividing up the octave in a particular way. For example, the major scale is made by dividing the octave according to a particular pattern of pitch intervals, starting from the lowest pitch of the scale.

- The key of C major uses the C major scale, but a key is much more than just a set of pitches from a scale. It also involves using the scale pitches in a particular way. For example, the starting note of the scale serves as the structurally most central note when making melodies. It's played often, especially at structurally important points in melodies, such as the ends of phrases. This note is called the tonic in music theory, and it comes to serve as a kind of cognitive reference point, so that other pitches are heard in relation to it.

- For example, the seventh tone of the scale, which is a B in the key of C major, is structurally much less central in melodies and often leads back to the tonic. In fact, this note is called the leading tone in music theory because it so often leads to the tonic note.

- In the major scale, the leading tone and the tonic are neighbors, such as B and C in the C major scale. They are physically quite close as pitches, yet they are psychologically quite distant. One is very stable; one is very unstable.

- In 1982, Krumhansl and Kessler published a landmark study in which listeners heard a short musical context and then heard a single pitch, or probe tone. The listeners were asked to rate how well the probe tone fit with the preceding context. If the pitch was the tonic, it got a very high rating. If it was the leading tone, it got a much lower rating.

- Different pitches of the major scale have different degrees of structural centrality to the key, and this degree is not just a simple function of physical frequency distance from the tonic. In a musical key, the psychological distance between tones is not the same as physical distance. This contrast between physical and psychological distance is part of what makes a musical key so psychologically powerful.

- The term “tonality” (or “tonal melodies,” or “tonal music”) can be used to refer to Western music that is organized in terms of a musical key. Tonality contributes to making melody processing a little bit like sentence processing. When people process a tonal melody, they make mental connections between notes that aren’t right next to each other. When we process sentences, we make mental connections between words that aren’t right next to each other.

- Variation in the structural centrality of pitches in a key is part of what allow us to process melodies hierarchically—that is, not just in terms of relations between immediately adjacent pitches. Hierarchical processing is also a fundamental to language: It allows us to mentally connect words that aren’t right next to each other in a sentence.

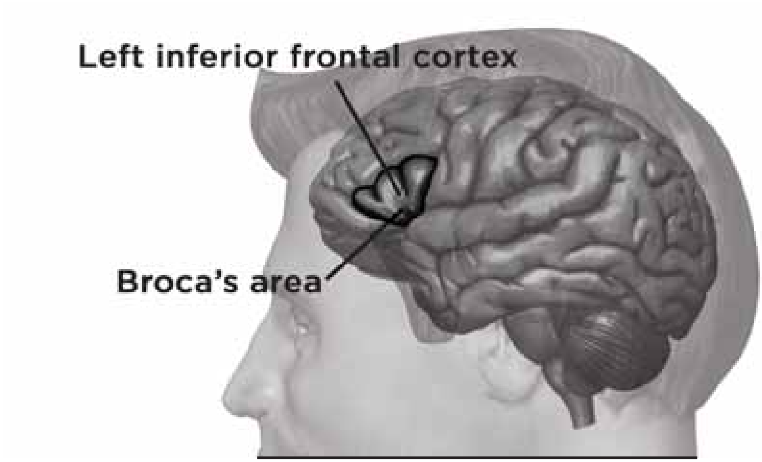
- In the 1983 landmark book *A Generative Theory of Tonal Music*, music theorist Fred Lerdahl and linguist Ray Jackendoff used some of the tools of linguistic theory to analyze the hierarchical structure of tonal melodies and harmonies. They recognized that their analysis suggested a certain parallel with language processing, but they warned that the details of tonal and linguistic hierarchies were actually very different.

- In fact, in the years following their book, evidence began to accumulate that processing of tonality had nothing in common with processing of language grammar. This came from patients with brain damage that impaired their perception of tonality but left their language processing completely intact.

Using Brain Imaging to Study Music and the Brain

- Around the turn of the millennium, brain imaging methods, such as EEG and fMRI, began to be used to compare the processing of tonality to the processing of linguistic grammar. Research published in 1998 provided the first evidence that in healthy, normal people, there appeared to be overlap in the brain mechanisms involved in processing tonality and linguistic structure.

- Soon thereafter, studies by Stefan Koelsch, Barbara Tillmann, and colleagues showed that processing musical tonality appeared to engage Broca's area, a region of the left inferior frontal cortex known to be involved in processing linguistic grammatical structure.



- These brain imaging studies used chord sequences instead of melodies. Chords are made by combining scale tones in particular ways. In a musical key, each tone of the scale can serve as the basis for a chord, which is a collection of simultaneous or near-simultaneous pitches. For example, in the key of C major, the C major chord is C, E, and G, and the G major chord is G, B, and D.

- Just as with the individual tones of the scale, different chords vary in how structurally central they are to the key. Chords built on the first, fourth, and fifth scale tones are the most structurally central chords and are called the tonic chord, the subdominant chord, and the dominant chord, respectively.

- Brain imaging studies of musical tonality examined what happened in the brain when a listener heard an unexpected chord. This could be a chord from a different key, in which case it sounded contextually dissonant (unexpected given our implicit knowledge about how pitch patterns tend to be organized in Western music), or a chord from the same key that was unexpected at a particular point in the music.

- The finding that processing these chords engaged language areas in the front of the brain created a paradox in the neuroscience of music. There was evidence from brain-damaged patients that one could lose sensitivity to tonality without having any language problems. In other words, evidence from brain imaging suggested overlap in the processing of tonality and language, and evidence from brain damage suggested no overlap.

- One hypothesis is that language and music involve domain-specific knowledge but share mechanisms that act on that knowledge as part of sequence processing. In other words, language and music have unique knowledge bases, but when you process language or music, mentally connecting the different elements in a sequence might engage shared cognitive mechanisms.

- This hypothesis generated specific predictions, which have been tested, and so far, the hypothesis is still viable and is still a topic of research and debate. If it holds up, it would have both theoretical and practical implications for the study of grammatical processing in the brain.

Musical Structure, Expectations, and Emotional Power

- In music theory, a progression from a dominant or dominant seventh chord to a tonic chord is a fundamental structure, called an authentic cadence. It helps establish the musical key and acts as a kind of musical punctuation mark, or point of rest.

- In 1956, music theorist Leonard Meyer published a book called *Emotion and Meaning in Music*, in which he argued that there was a close relationship between expectations aroused by music and our emotional response to music. He especially focused on cases where expectations were aroused but then not fulfilled and said that these moments triggered subtle emotional responses in us.

- Meyer was decades ahead of his time. In modern cognitive neuroscience, there is a lot of interest in the brain mechanisms of expectation or prediction and in the brain processes that ensue when our predictions are not fulfilled.

- It's thought that prediction is a fundamental function of the brain. We're constantly awash in a sea of sensory input, and the more we can accurately predict what's going to happen next, the faster we can respond to events and process them efficiently. The brain rewards itself for making accurate predictions and triggers specific internal processes when predictions are wrong, processes that can help trigger learning. Modern philosophers of mind and modern neuroscientists have emphasized the fundamental role that prediction plays in human cognition.

- In tonal music, one way of setting up an expectation and then thwarting it is with a harmonic progression that seems like it's going to end on an authentic cadence but actually ends another way. For example, after a tonic–subdominant–dominant-seventh progression, instead of delivering a tonic, a composer might deliver a chord build on the sixth note of the scale, which would be the note A in C major. This is called a deceptive cadence, because an authentic cadence was expected, but something different was delivered.

- Research that measures subtle physiological signals of emotional arousal, such as measures of skin conductance, has shown that people do react emotionally to unexpected chords. Brain imaging by Stefan Koelsch and colleagues has revealed that regions of the limbic system, including the amygdala, respond to unexpected chords.

- One very interesting thing about the deceptive cadence is that it can produce an emotional effect even in a piece you know well.

But when you know a piece of music, how can a chord progression deliver anything unexpected?

- In 1994, music psychologist Jamshed Bharucha made an important conceptual distinction between two types of expectations in music. One type is called schematic and reflects your implicit knowledge of how Western music is generally patterned. This type of knowledge leads you to expect that after a dominant seventh chord, you'll get a tonic chord. Another type of knowledge called veridical knowledge reflects your memory for a specific piece of music.

- Bharucha's point was that schematic knowledge operates automatically. Even if your veridical knowledge knows about an upcoming deceptive cadence, it can't suppress a surprise reaction triggered by your schematic knowledge.

- The link between expectation and emotion in music has been a major idea in music cognition and has been updated and put into a modern cognitive science framework by David Huron, who has argued that musical expectations and our responses to them don't just reflect a single brain process but the interplay of several processes.

Suggested Reading

Huron, *Sweet Anticipation*.

Patel, "Language, Music, Syntax, and the Brain."

Questions to Consider

1. What is the difference between contextual dissonance and sensory dissonance?

2. How does the deceptive cadence illustrate the link between music, expectation, and emotion?

The Complexities of Musical Rhythm

Lecture 9

In addition to pitch, melody, and harmony, another major aspect of music is rhythm. There is something primal about musical rhythm—something that taps into ancient aspects of how our brains and bodies work. Biology is full of rhythms. For example, every mammal, reptile, and bird has a heart that beats rhythmically. With our bodies so full of rhythms, it might seem that rhythmic processing should be the most basic and primal aspect of music. But in this lecture, you will learn how mentally complex even basic musical rhythmic processing can be.

Periodic versus Nonperiodic Rhythms

- There are two types of rhythmic patterns: periodic and nonperiodic rhythms. Periodic rhythms are patterns that repeat regularly in time, such as the heartbeat. Periodic rhythms play a very important role in music. Much of the world's music has a musical beat, which is a perceived periodic pulse that listeners use to guide their movements and performers use to coordinate their actions.

- The beat is a very interesting aspect of music cognition. It's a prototypical example of a periodic rhythm. But sequences of events can have structure in time without having any periodicity. All periodic patterns are rhythmic, but not all rhythmic patterns are periodic.

Nonperiodic Rhythms and Expressive Performance

- If you look at a musical score of a piece of piano music, such as a piece by Chopin, you'll see visual symbols that represent which pitches should be played at which time. The melodic, rhythmic, and harmonic structures of the music are all there on the page, but a compelling performance involves much more than just accurately playing the notes from the score.

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A compelling performance involves much more than just accurately playing the notes from the score.

- The differences between a performance that is technically accurate but lacking in rhythmic expression and a rhythmically expressive performance of the same passage concern the patterns of timing and intensity of individual notes.

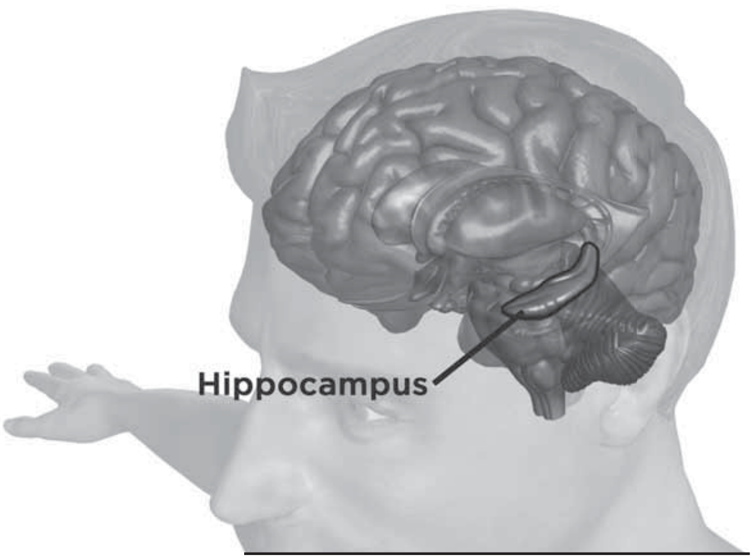
- The timing aspect of expressive performances has been studied empirically. Pioneering work by such scientists as Manfred Clynes and Bruno Repp showed that there are interesting and systematic patterns in the expressive timing that musicians add to music.

- In 2011, Daniel Levitin and colleagues published an interesting study about the relationship between expressive timing in Chopin's music and people's perception of how strongly the music expresses emotion.

- The researchers asked a professional pianist to perform several Chopin nocturnes with "normal expressivity," the way he would at a concert. Then, they used sound-editing software to create different versions of the performance, with less and less expressive variation in timing and intensity.

- They presented listeners with these versions and asked them to rate how emotional the performance was for each. They told the listeners to focus on how strongly the piece expressed emotion, not on what particular emotion was expressed. They found a systematic relationship between the amount of expressive variation in timing and intensity and people's ratings of how strongly the music expressed emotion. In another experiment, they showed that it was primarily the expressive variations in timing, not intensity, that were driving people's ratings.

- Another study of this type looked at how expressive timing and dynamics influence brain responses to music. Edward Large and colleagues did an fMRI study of listeners hearing mechanical versus expressive versions of a Chopin étude and compared brain responses to the two versions. The expressive versions led to significantly stronger activation in multiple areas of the brain. Some of these areas were in the limbic system, including the amygdala and hippocampus, which suggests that the expressive performances evoked stronger emotion and were more memorable.



- Other areas that were more active are known to be involved in cognitive processing. These included a region in the inferior frontal lobe of the brain, near Broca's area, involved in processing musical structure. These effects of expression on the emotional and structural processing of music were coming from the way a performer shaped subtle, nonperiodic aspects of a piece's musical rhythm.

Nonperiodic Rhythm and Phrasing

- Another important aspect of musical rhythm that doesn't concern periodicity or beat is grouping or phrasing, the perceptual segmentation of events into coherent chunks. When we hear a coherent melody, we typically hear it as broken into groups of notes, or phrases. This is crucial for our ability to encode and remember it. Sometimes those groups are physically separated by short silences, but sometimes the boundaries we perceive are entirely in our minds.

- We have the tendency to hear a boundary after a note that is longer than preceding notes. This is known from speech, too, where a syllable just before a perceived phrase boundary tends to be longer than that same syllable if it were inside the phrase. This mental boundary placement based on duration is an important aspect of rhythm perception, which is not about the beat.

- It used to be thought that the tendency to hear a boundary after a longer event in a sequence was a law of auditory perception that applied to music and language. This idea came from research extending back more than 100 years on how people hear grouping in simple tone sequences where the duration of tones is the only thing that varies.

- But some researchers, including linguist Roman Jakobson, found that basic rhythmic grouping perception (in nonlinguistic sounds) could be shaped by the rhythms of one's native language.

Nonperiodic Rhythm and Musical Reflections of Linguistic Rhythms

- A final example of nonperiodic rhythm in music shows how thinking of rhythm more broadly than just periodicity can help drive scientific research forward. In this case, the research was inspired by an old and provocative idea in musicology—the idea that purely instrumental music reflects the prosody of a composer's native language.

- Prosody refers to the rhythm and melody of speech. Different languages don't just differ in their words and grammar; they also have different patterns of rhythm and pitch in their sentences. Part of what makes an accent is the prosody of speech: the rhythm of the syllables and the way voice pitch moves up and down during spoken phrases.

- For decades, musicologists have suggested that purely instrumental music can reflect the rhythm and melody of a composer's native tongue. For example, in *The Tradition of Western Music*, Gerald Abraham quotes the harpsichordist and music scholar Ralph Kirkpatrick as saying "both Couperin and Rameau, like Fauré and Debussy, are thoroughly conditioned by the nuances and inflections of spoken French. On no Western music has the influence of language been stronger."

- This is a provocative idea, because instrumental music and spoken language sound so different. No one would ever confuse the sound of a Debussy piano piece with the sound of spoken French. Yet Kirkpatrick sensed a connection: Something about Debussy's music reminded him of the sound of the French language.

- Kirkpatrick was not alone. In 1953, linguist Robert Hall Jr. published an essay suggesting that the symphonic music of Sir Edward Elgar, a Victorian composer who lived around the same time as Debussy, reflected the prosody of British English.

- One thing that made the ideas of scholars like Kirkpatrick and Hall so provocative is that they weren't presented with any evidence. They were intuitions, informed by a deep knowledge of music and language. But these ideas might be testable.

- For example, focusing on rhythm, one could look for rhythmic differences between languages, such as English and French, and see if those differences are reflected in rhythms of instrumental music, such as the music of Elgar and Debussy. The challenge was figuring out what to measure.

- Linguists agreed that English and French had very different speech rhythms. According to an influential theory developed in the mid-1900s by Kenneth Pike and David Abercrombie, English was a stress-timed language, meaning that stressed syllables were spaced evenly in time.

- Abercrombie argued that French came from an entirely different category: the syllable-timed languages. These were languages in which each syllable marked off a roughly equal time interval. Many Romance languages were said to be syllable-timed languages, such as Spanish and Italian, but also languages from other parts of the world, including some African and Indian languages.

- Stress timing and syllable timing were ideas about linguistic rhythm that were based on periodicity. But years of empirical research have failed to support the existence of stable periodicities in ordinary speech.

Comparing English and French Music

- Finding measurable differences between the rhythms of English and French had to wait until about the year 2000, when linguists began measuring nonperiodic aspects of rhythm. And it was precisely these aspects that turned out to be the key for showing that instrumental music really did reflect speech rhythm.

- One nonperiodic rhythmic difference between English and French that was first pointed out by the linguist Rebecca Dauer has to do with the way the two languages differ in a phenomenon called vowel reduction.

- In English, unstressed syllables, such as the second syllable in the word "CE-le-brate" sometimes contain a reduced vowel—a very short vowel with a neutral kind of sound like "uh" or "ih." In the case of "celebrate," we don't say "CE-leh-brate"; we say "CE-le-brate." The vowel in "le" is reduced.

- Because reduced vowels tend to be very short (sometimes less than $1/20^{th}$ of a second long), they are often next to syllables with much longer vowels. For example, the vowel in a stressed syllable might be more than twice as long as the reduced vowel in the syllable right next to it. This creates a lot of duration contrast between neighboring vowels in sentences of English.

- Dauer pointed out that many languages that had traditionally been classified as stress-timed had strong vowel reduction, and many languages that had traditionally been classified as syllable-timed had weak vowel reduction. This means that in languages like French, you don't see vowels getting squashed down into short little "uh" and "ih" sounds nearly as often as you do in English. As a result, neighboring vowels in French sentences are likely to have less duration contrast, on average, than they do in English.

- Around 2000, linguist Francis Nolan and colleagues published a paper with an equation that could be used to measure the average degree of duration contrast between adjacent vowels in sentences: the normalized pairwise variability index (nPVI). Soon thereafter, using the nPVI, other researchers showed that English sentences had a higher average degree of duration contrast between adjacent vowels than did French sentences.

- Later, the nPVI equation was applied to instrumental music, measuring note durations instead of vowel durations. This research found that, on average, the themes of English composers had greater durational contrast between adjacent notes than the themes of French composers. This was the first empirical evidence that speech rhythm was reflected in purely instrumental music. The key to this discovery was measuring a nonperiodic aspect of rhythm: the average amount of duration contrast between successive events in a sequence.

- This research raised many questions, some of which have been pursued by other researchers. For example, we now know that this relationship between rhythm in speech and instrumental music isn't just restricted to English and French classical music from around 1900. In 2011, Rebecca McGowan and Andrea Levitt used the nPVI to show that the rhythms of folk fiddling in Ireland, Kentucky, and Scotland reflect the speech rhythms of English dialects in those places.

- Also, research published in 2006 showed that English and French classical music doesn't just reflect the rhythm of speech, but it also reflects the melody of speech: the pattern of speech intonation in British English and French.

Suggested Reading

Honing, "Structure and Interpretation of Rhythm in Music."

Patel and Daniele, "An Empirical Comparison of Rhythm in Language and Music."

Questions to Consider

1. What is the difference between periodic and nonperiodic rhythms?

2. How do nonperiodic rhythmic patterns contribute to making performances sound expressive?

Perceiving and Moving to a Rhythmic Beat

Lecture 10

This lecture will focus on an aspect of musical rhythm that seems simple: the beat. But the processing of beat is mentally complex and is based on sophisticated brain processing. A beat is a perceived periodic pulse that listeners use to guide their movements and performers use to coordinate their actions. In this lecture, you will learn about research with humans that show how mentally complex musical beat processing is and research with other species that suggests that the way we process musical beat might be unique among primates.

The Basics of Beat Perception

- A beat is part of a lot of the world's music. Ethnomusicologists tell us that every culture has some form of music with a beat. This suggests that beat perception is a fundamental aspect of music cognition. Not all music has a regular beat, but a great deal of music does have a beat, including most Western popular music.

- Beat perception seems simple. The beat is usually an effortless percept; it doesn't seem to require any mental energy to perceive. Young children usually develop the ability to move and clap to a beat without any special training. When you connect these observations with the fact that all cultures have some form of music with a beat, it leads to the idea that beat processing is a very ancient and primal aspect of music.

- We feel a beat most strongly when the rate of beats is between about 50 and 150 beats per minute. In that range, there seems to be a preference for a tempo of about 100 beats per minute. This range is not radically different from the range of the human heartbeat, so it is intuitive to think that the musical beat has its origins in basic physiological rhythms like the heartbeat.

- Another basic aspect of beat perception is that it involves periodicity: a pattern that repeats regularly in time. In most Western music, the beat itself is periodic. There are other musical traditions where the periodic pattern is at the level of groups of beats, because the time intervals between individual beats are not all the same.

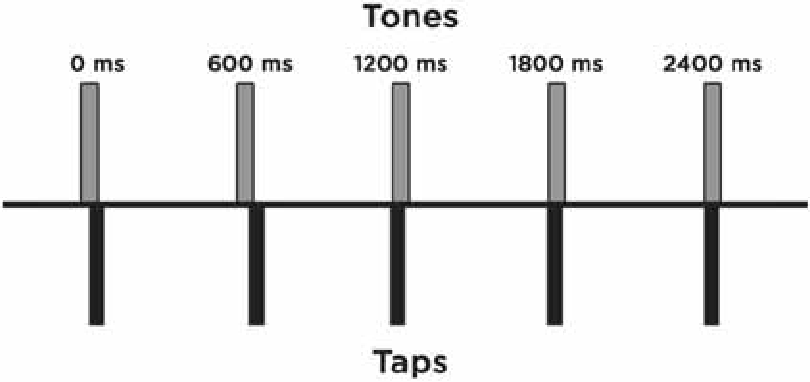
Six Key Features of Beat Perception

- When you consider musical traditions that are rhythmically rich, it might seem as though a simple periodic beat, like we're used to in most Western popular music, is not that complicated. But even "simple" beat perception is mentally complex.

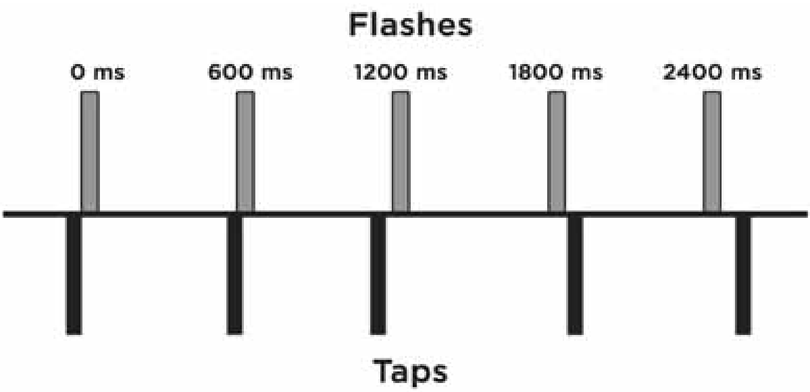
- There are six key features of human beat perception. Human beat perception is predictive, highly tempo flexible, modality biased, constructive, hierarchical, and strongly engages the brain's motor system.

- First, beat perception is predictive. Beat perception isn't just about perceiving the timing of events; it's also about predicting the timing of events, with a high degree of precision. One way we know this is by examining how people move to a beat. A simple way to study this in the lab is to ask people to tap along with a metronome, which is the simplest form of a beat. Most people spontaneously tap very close in time to each metronome event. In fact, they anticipate the onset of each tone, not react to it.

- In humans, this ability to accurately predict the timing of beats is highly tempo flexible. The kind of accurate synchronization we just saw can occur over a broad tempo range. For example, if the rate of the metronome is decreased by 30 percent, people could still predict and synchronize accurately. This broad tempo flexibility is a hallmark of human beat perception. This suggests that our mechanisms of beat processing are more complex than those seen in other animals.

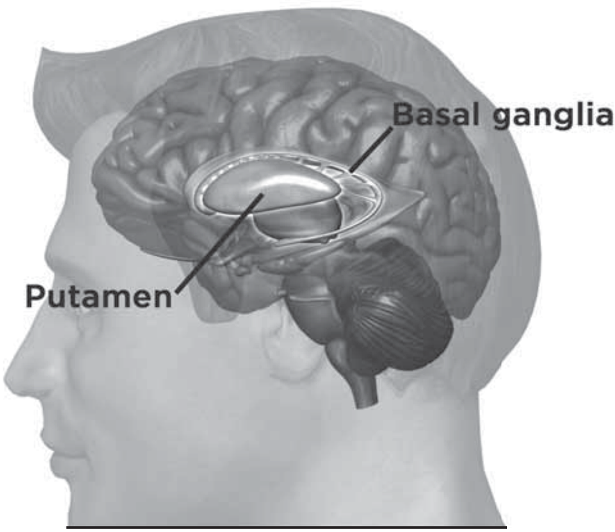


- Another thing that distinguishes our beat processing is modality bias. We seem to get a much stronger sense of a beat out of rhythms that we hear than rhythms that we see. This has been shown in the lab for more than a century: People can synchronize to a visual metronome, but they don't seem to predict the timing of beats nearly as accurately as they do if the metronome is auditory. Research has shown that experience alone can't explain the auditory advantage for beat perception; it seems to reflect something about the basic wiring of the human brain.



- Furthermore, beat perception is constructive in nature, meaning that the beat is a mental periodicity, constructed in the brain in response to a rhythmic pattern. The easiest way to demonstrate this is with syncopated patterns. In syncopated patterns, not all accents are on beats, and not all beats are marked by accents. With syncopation, one can even have a beat where there is no sound at all. Feeling a beat at a point with no sound, a point of silence, is strong evidence that the beat is a mental construct. The only events that occur at silent points are mental events.

- The fifth key feature of beat perception, which also shows the mental complexity of beat, is that it is hierarchical. We often talk about "the beat," but beats in a sequence can differ in their perceived strength. Some beats can be perceived as stronger than others, and this contributes to the perception of musical meter, or the higher-level organization of beats in time.



- The final key feature of musical beat perception is something that neuroscience discovered relatively recently: that beat perception strongly engages motor regions of the brain. This happens in the absence of any overt movement or any intention to move. In a study published by Jessica Grahn and James Rowe in 2009, the putamen in the basal ganglia (a critical part of the brain's motor system), the auditory cortex, and the motor planning regions of the cortex seemed to form a network of regions involved in beat perception.

Beat Perception in Nonhuman Primates

- One intuitive idea is that beat perception taps into very ancient aspects of animal biology. The body is full of rhythms, including the heartbeat and rhythmic oscillations of electrical potentials in the brain. If the perception of musical rhythm is common to all animals, then other primates should perceive a musical beat in a way that is similar to the way we do.

- Research on beat perception in other primates is just beginning, but what evidence we have so far suggests that other primates might not perceive a beat in the same way that humans do. The evidence comes from a line of research started in 2009 by Hugo Merchant and colleagues, working with rhesus monkeys. They were the first researchers to train an animal to tap along with a metronome. They were interested in the neural mechanisms of timing in sequences with multiple periodic time intervals.

- They knew that previous research had showed that other animals, such as rabbits and rats, were good at learning the timing of a single interval. In the 2009 study, they showed that rhesus monkeys also were good at timing single intervals.

- When humans tap with a metronome, our taps are very closely aligned in time with the metronome tones, which shows that we accurately predict the timing of those tones. With the monkeys, it seemed that they were not predicting the beat in the same way we do.

- Merchant and his colleagues got this same result when they tried metronomes at different ranges. They also got this same result when the metronome used a visual flash instead of an auditory tone. Humans tap more accurately to an auditory metronome than to a flashing visual metronome, and monkeys didn't show this pattern, either: Their tapping accuracy was the same with both types of metronomes.

- These differences between monkeys and humans on such a simple sensorimotor task has come as a surprise to neuroscientists. In fact, some researchers who study perception and motor control in monkeys are convinced that if you train monkeys in the right way, they will tap to a metronome just like humans do. But until someone shows that to be true, we have to consider the possibility that beat-based processing doesn't come naturally to nonhuman primates.

- This difference in beat-based processing might not just be about the ability to synchronize movements to a beat; it might also be about the ability to perceive a beat at all. In a subsequent 2012 study that Merchant and colleagues did with music psychologist Henkjan Honing, they used EEG to look for a brain signature of beat perception when monkeys heard rhythms without moving.

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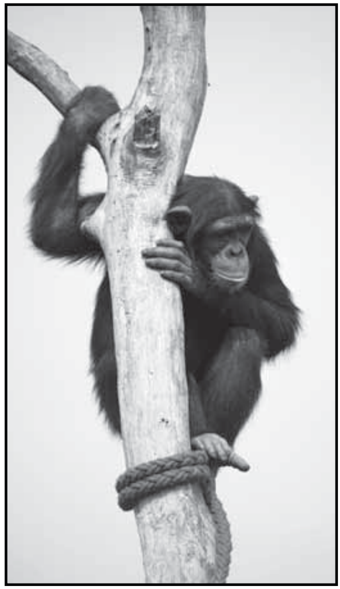
When humans tap with a metronome, our taps are very closely aligned in time with the metronome tones.

- Honing and his colleagues had used this technique before to show brain signatures of beat perception in humans. But when they tried it with the monkeys, they didn't see that signature of beat perception.

- This is a very young line of research, and it's possible that future studies will show that monkeys are very similar to humans in their ability to perceive a beat and move to a beat. But if the differences found by Merchant, Honing, and their colleagues hold up, their findings will be some of the most important in the history of research on beat-based processing. Such findings strongly contradict the intuition that beat processing reflects primal aspects of brain function widely shared by many animals.



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It seems logical that if any other primate is capable of perceiving and synchronizing to a beat the way we do, it would be a chimpanzee or bonobo.

- In future research on beat processing in other primates, it would be especially interesting to look at chimpanzees and bonobos, because they are much more closely related to humans than monkeys are.

- Chimpanzees are especially interesting because drumming is part of their natural behavior. In the wild, chimps drum on trees with their hands and feet. Biologist Tecumseh Fitch has pointed out that drumming in primates seems to be restricted to humans and the African great apes. So, it seems logical that if any other primate is capable of perceiving and synchronizing to a beat the way we do, it would be a chimpanzee or bonobo.

- A lab in Japan has begun to investigate whether a chimpanzee can synchronize its movements to an auditory beat. In 2013, Tetsuro Matsuzawa found that one out of three chimps showed some synchronization with a metronome, but there wasn't evidence of tempo flexibility, which is a hallmark of human beat-based processing. We need more research to see whether chimps really do process beat the way we do.

The Vocal Learning Hypothesis

- The idea that only certain types of brains are capable of perceiving a beat and synchronizing to it the way humans do—predictively and with a lot of tempo flexibility—was proposed in a theoretical paper in 2006. These were brains that connected complex auditory processing and complex motor processing.

- Humans connect complex auditory and motor processing because of something we do called complex vocal learning, which is the ability to reproduce complex sounds that we hear—we all do this as part of learning to speak our native language.

- Complex vocal learning is unique to humans among primates. All other primates are born with an instinctive set of calls that they can modify in rather modest ways based on their auditory experience. The hypothesis is that the evolution of vocal learning created the strong auditory-motor pathways needed for beat perception and synchronization.

- The hypothesis made a strong, provocative prediction: that animals that weren't vocal learners couldn't synchronize their movements to a steady auditory beat predictively and with a high degree of tempo-flexibility.

- Most animals are not vocal learners. For example, dogs and cats are not vocal learners. This vocal learning hypothesis predicts that they could never learn to move in synchrony to a beat in a predictive and flexible way, no matter how hard you try to train them. They just don't have the right kind of brain structure.

- Research in this area has shown that parrots seem to have the capacity for predictive and flexible beat perception and synchronization. As far as we know, they don't do this behavior in the wild. This suggests that the capacity for predictive and flexible beat processing might have originated as a by-product of brain circuitry they have for other reasons, such as for complex vocal learning.

- The vocal learning hypothesis continues to be tested in modern research. In 2013, Peter Cook led a study showing that a sea lion could synchronize its movement to a musical beat in a predictive and tempo-flexible way. Sea lions are not known to be vocal learners, but they are related to seals and walruses, which are vocal learners. We don't know yet whether sea lions have the brain mechanisms for vocal learning; it's a topic of current research.

Suggested Reading

London, *Hearing in Time*.

Patel, "The Evolutionary Biology of Musical Rhythm."

Questions to Consider

1. What is a musical tradition where beats are not evenly spaced in time?

2. How does tapping to a beat by monkeys differ from human tapping to a beat?

Nature, Nurture, and Musical Brains

Lecture 11

In this lecture, you will learn about some of the specific differences that have been found between the brains of musicians and nonmusicians. For the purposes of this lecture, the term "musicians" doesn't just apply to professionals, or people who earn a living by making music; it can mean anyone who regularly engages in making music. Alternatively, the term "nonmusicians" includes people who love music (and maybe had music lessons early in life) but who don't make music regularly and people who have never studied or made music regularly.

The Brains of Musicians versus Nonmusicians

- In current research on music and the brain, some researchers favor the view that many of the differences between the brains of musicians and nonmusicians are due to nature (inborn predispositions). Other researchers favor the view that many of the differences are due to nurture (the effect of experience). Others favor an interactional view (nature plus nurture). This is a young field, and we need more data to resolve these debates.

- There are ways of doing experiments to determine if musical experience can play a significant role in changing brain microstructure and processing. This is worth knowing because of its implications for how musical training might impact other brain functions.

- Magnetoencephalography (MEG) measures the magnetic fields produced by electrical activity in groups of neurons. This method can't measure brain activity at the level of single neurons, but it can detect activity produced by large groups of neurons in the same region, if those neurons have synchronized patterns of activity.

- MEG was involved in one of the first studies to examine brain differences between musicians and nonmusicians, published in 1995 by Thomas Elbert, Christo Pantev, and colleagues. In this study, researchers lightly stimulated the little finger or the thumb of violin players or nonmusicians on their left or right hands, while measuring the size of the neural response in sensorimotor regions of the brain.

- When the right hand was stimulated, they saw no difference between musicians and nonmusicians. But when the left hand was stimulated, musicians showed a stronger response. The left hand is the hand that does the fingering on a violin.

- This work came in the wake of earlier work with animals suggesting that if a particular digit of the hand was used extensively, more neurons in a given brain area became involved in representing that digit's activity. This was one line of evidence for a phenomenon that has become a major theme in brain science—namely, experience-dependent neural plasticity, which is the capacity of the brain to modify its structure and function as a result of experience.

- Today, neural plasticity is a major research topic in brain science, with profound implications for our understanding of the brain and for practical issues ranging from education to neural rehabilitation. We have long known that the brain generates behavior, but neural plasticity means that behavior can modify the brain.

- In the study of the violinists, the greater response of musicians when their left hand digits were stimulated suggested a role for neural plasticity. After all, if musicians just had bigger brain representations for their fingers than nonmusicians, one would expect stronger brain responses to stimulation of either the left or right hand.

- Another clue that plasticity might be involved was that the difference in response between musicians and nonmusicians was larger for the little finger than for the thumb, which was consistent with the more important and active role of the little finger in playing the violin.

- Furthermore, for the little finger, the size of the response was largest in violinists who started their training at a younger age and thus had more practice, again pointing to a role for experience, rather than just genes, in shaping this brain difference.

- Another study, published in 1995, was the first to use MRI to show structural differences between the brains of musicians and nonmusicians. This study, by Gottfried Schlaug and colleagues, focused on the corpus callosum, which connects the two sides of the human brain and is critical for communication between the two hemispheres.

- Schlaug and colleagues compared the size of the corpus callosum in professional classical musicians and nonmusicians who were matched for age, sex, and handedness. The musicians played keyboards or strings, or both. They found that the anterior half of the corpus callosum was significantly larger in the musicians. This difference made some intuitive sense, because keyboard and string players have to coordinate complex movements in the two hands. Thus, the greater size of the anterior half of the corpus callosum could reflect greater inter-hemispheric communication between the motor areas of the two hemispheres.

- Furthermore, the researchers found that the difference in corpus callosum size was greater in musicians who had started their training before the age of seven. This raised the possibility that musical experience had a particularly strong impact on brain development during an early period in life.

Connections between Brain Hemispheres

- In research in animal neuroscience, it’s well known that there are times during maturation when experience can have a particularly long-lasting effect on the brain and on behavior. These times are called sensitive periods. In humans, sensitive periods are thought to be important in the development of language, including our ability to discriminate and produce the speech sounds of our native language.

- In a 2013 study, Virginia Penhune and colleagues provided evidence for the idea that the development of musicians' brains could be subject to sensitive periods. They once again looked at the corpus callosum of musicians using MRI, but they used a newer method to look in more detail at the structure of the neural fibers in the corpus callosum. This technique is called diffusion tensor imaging (DTI).

- Penhune and colleagues used DTI to measure the corpus callosum in highly trained musicians and compared them to people with minimal musical training. The researchers were interested in the idea of a sensitive period, so they recruited two groups of musicians: those who had started training before age seven and those who had started after age seven. These early-trained and late-trained groups were matched for number or years of training and for the amount that they practiced.

- The researchers found differences between musicians and nonmusicians in the degree of connectivity between the two hemispheres, in the middle part of the corpus callosum. Supporting the findings of Schlaug and colleagues, these differences were due to the early-trained musicians—those that started before age seven. The connectivity in the late-trained group didn't differ from that seen in nonmusicians.

- Thus, even though the late-trained group had learned complex bimanual movements as part of music training—and had played as long, and practiced as much, as the early-trained group—this didn't result in differences in corpus callosum structure. In other words, it was the timing of the onset of training, not just the amount of practice, that drove the structural changes seen in the brain.

- A study published in 2009 by Krista Hyde, Gottfried Schlaug, and colleagues looked at the impact of musical training on brain structure in children. They focused on six-year-old children and measured the structure of their brains using MRI before and after

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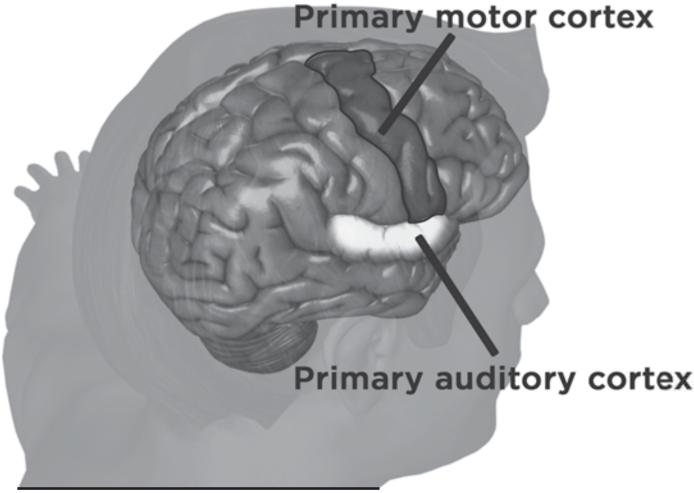
Research has shown that the timing of the onset of musical training, not just the amount of practice, is what drives the structural changes to the corpus callosum that are seen in the brains of musicians.

15 months of weekly keyboard music lessons. The other group they studied consisted of six-year-old children who were matched to the musician group for socioeconomic status but who didn't have weekly private music lessons.

- The researchers found that at the beginning of the study, there were no significant differences in the sizes and shapes of brain regions in the two groups of children. But after 15 months, there were measurable differences in a number of brain regions. One of those regions was located in the middle part of the corpus callosum.

- Other brain areas showed differences, too. These included regions in the primary motor and primary auditory cortex. This makes sense, because keyboard training is demanding both in terms of motor skills and auditory skills.



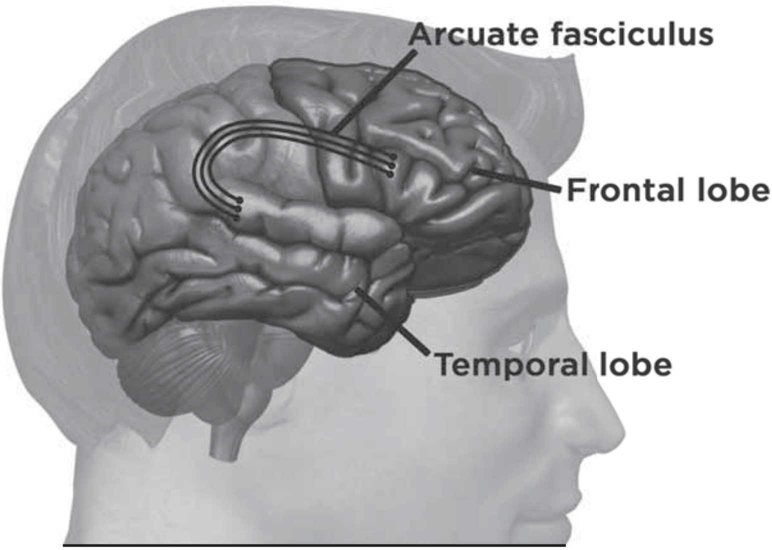
- In this study, the amount of change seen in the corpus callosum, and in the motor and auditory areas, correlated with performance on simple motor and auditory perceptual tasks that the children did in the lab. This suggests that these brain differences had functional correlates relevant to music.

- There were also differences in regions of the brain that weren't directly involved in motor and auditory processing. Some of these regions were in left frontal areas of the brain, in areas known to be involved in cognitive processing. This shows that music is not just a right-brain phenomenon and raises interesting questions about the cognitive impact of musical training.

Connections within Brain Hemispheres

- The past few years have seen a surge of interest in human neuroscience in the pattern of long-distance connections between different brain areas. Most people share the same overall pattern of long-distance connectivity, but the strength of connections (number, size, and structural organization of axons) between regions can vary between individuals, and these differences can have consequences for cognition and behavior.

- There are numerous long-distance fiber tracts within each hemisphere of the brain, and they are very important to higher cognitive functions. In 2011, a study by Gus Halwani, Gottfried Schlaug, and colleagues looked at one particular long-distance fiber tract in the brains of musicians and nonmusicians: the arcuate fasciculus, which connects regions in the temporal lobes with regions in the frontal lobes.



- Both hemispheres have an arcuate fasciculus, but in humans, it's better developed on the left. The left arcuate is important for language processing. This is the fiber tract that helps connect two left-hemisphere regions involved in language processing.

- The arcuate on both sides of the brain is also important for auditory-motor integration more generally. Thus, it's plausible that this fiber bundle might differ in strength in musicians and nonmusicians. Musical training involves learning to precisely coordinate sound and movement. When you play an instrument or sing, small differences in how you move your muscles can cause slight changes in the sound you make, and these differences matter to listeners.

- Halwani and colleagues used DTI to compare the volume of the arcuate fasciculus in highly trained singers, highly trained instrumentalists, and nonmusicians. They found that this fiber tract was larger in the musicians than in the nonmusicians, on both the right and left sides of the brain. Between the two groups of musicians, the singers had an even larger arcuate volume in the left hemisphere. Once again, we see that music is not just a right-brain phenomenon.

- Another study also examined connections between brain regions within each cerebral hemisphere but focused on a remarkable musical ability known as absolute pitch (AP). Musicians with AP can name the pitch class (a note's letter name) of a musical tone without any reference. All the notes named C on a piano, for example, are the same pitch class.

- AP does appear to have an association with early musical training. It's very rare to find AP in musicians who did not start their training as young children. But early training is no guarantee of AP. AP might reflect the interplay of biological predispositions with early musical experience.

- For years, people have wondered what it is about the brains of AP musicians that underlies this special ability. In 2010, Psyche Loui and colleagues published a study that compared the brains of AP musicians and non-AP musicians, focusing on connectivity patterns within each hemisphere.

- The two groups of musicians were matched in terms of age, sex, IQ, native language, age of onset of musical training, and amount of musical training. Using DTI, the researchers found that the AP musicians had significantly stronger connectivity between two regions of the temporal lobe. This was found on both sides of the brain, but the connections on the left side seemed particularly important for AP. On the left side, but not the right side, the size of the connection correlated with how well the musicians did on tests of AP.

- The authors argued that the strong connections they found represent a link between brain areas involved in pitch perception and brain areas involved in categorizing sounds. Research by other scientists has shown that temporal lobe regions play an important role in sound categorization in speech: our ability to take a continuously varying speech signal and map it onto perceptually discrete categories, such as the vowels and consonants of our language. So, again, music and language seem to have a deep relationship in the brain.

Suggested Reading

Hyde, Lerch, Norton, Forgeard, Winner, Evans, and Schlaug, "Musical Training Shapes Structural Brain Development."

Steele, Bailey, Zatorre, and Penhune, "Early Musical Training and White-Matter Plasticity in the Corpus Callosum."

Questions to Consider

1. What is a metaphor that can help us think about the interaction of nature and nurture in brain development?

2. What is one brain structure that has been found to differ between musicians and nonmusicians?

Cognitive Benefits of Musical Training

Lecture 12

Today, a hot topic in the study of music cognition is the impact of musical training on other cognitive functions. For example, researchers want to know if learning to play a musical instrument can influence the way a child's brain processes language, or math, or visuospatial patterns. This topic is exciting because it has both theoretical and practical significance. In this lecture, you will learn about some of the research on the relationship of music training to other cognitive skills.

The Effect of Musical Training on Brain Processes

- In 2009, Sylvain Moreno and colleagues published a study on the impact of musical training on language skills for eight-year-old children. The researchers randomly assigned children to a music-training group and to an active control group that consisted of painting training. The groups were matched for socioeconomic status, and at the outset of the study, the children in the two groups didn't differ significantly in IQ.

- Each group met twice weekly with a professional teacher. The music group focused on things like rhythm, melody, and harmony. The painting group focused on things like color, perspective, and texture. After six months of training, the children were brought back for another round of cognitive testing and also for brain measurements. The brain measurements used a technique called event-related potentials (ERPs).

- The researchers found that after training, both the music and painting groups scored higher on a standardized IQ test. This made sense, because the children were older and had been in school for six months during the study. The interesting finding was that the music group improved more than the painting group on a different test that focused on reading abilities, even though neither group had done reading training.

- Also, behavioral and ERP brain measurements showed that children in the music group were more sensitive to small changes in the pitch pattern of sentences, even though neither group had been trained on this.

- The researchers concluded that music had provided auditory training that had influenced not only music processing but also language processing. In particular, musical training had influenced reading skills and the processing of spoken pitch patterns—both of which are important life skills.

- Because the researchers saw these differences in language processing despite no significant differences in IQ scores after the two kinds of training, they favored the view that there were some specific links between music processing and language processing in the brain.

- Another study, conducted by Glenn Schellenberg, also showed an impact of musical training on nonmusical cognitive skills, but it argued against specific links between music and any particular other cognitive domain, such as language or math.

- In 2004, Schellenberg published the first study to use random assignment to examine the impact of musical training versus other types of training on IQ in a relatively large group of children. In his study, six-year-old children were randomly assigned to music training (which could be keyboard or voice), drama training, or no training. The training groups studied weekly with professional teachers for about one school year.

- Before and after training, IQ was measured using standardized tests. IQ went up significantly in all the groups—again, which was expected. The interesting finding was that the amount of IQ increase was significantly larger in the music groups than the other groups.

- When Schellenberg looked at different components of the IQ tests that he had used, such as the mathematical components and the verbal components, he didn't see any particular areas where the gains were stronger than other areas. It seemed like a general boost across a range of cognitive skills. He believed that this argued against a specific link between music cognition and any particular other aspect of cognition, such as math or language.

Musical Training and Speech Processing in the Brain

- Music and speech both use highly structured sound sequences, and there is a growing body of research examining how music and speech processing are related in the brain. An interesting technique for measuring brain responses to speech sounds in musicians and nonmusicians focuses on the sensory processing of sound before neural signals reach the cerebral cortex.

- The auditory system has a complex network of subcortical processing regions between the ear and the cortex. After sound is first transduced into neural impulses by the cochlea, it is processed in multiple regions of the brainstem and midbrain. This means that the sound-related neural signals that reach the primary auditory cortex have already been subject to a lot of processing.

- It used to be thought that subcortical auditory processing was hardwired and not subject to the same kinds of experience-dependent neural plasticity observed in the cortex, but there is now evidence that the early sensory processing of sound can be modified by experience.

- One way that this might occur is via neural connections that project from the cortex down to these subcortical auditory regions. That's the opposite direction than we usually think of brain signals traveling in the auditory system. In some parts of the subcortical system, these descending projections from cortex may actually outnumber the projections going up to the cortex.

- In a 2008 study, Nina Kraus and colleagues provided compelling evidence for experience-dependent plasticity in subcortical auditory processing. In this study, the researchers made up nonsense words and gave these words meanings that depended on the pitch contour of the word. Listeners had to learn this vocabulary, as if they were learning the words of a foreign language.

- This kind of language, where the pitch pattern of a word can completely change its meaning, is called a tone language. The participants in this study were native English speakers who didn't know any tone languages. Even so, the participants learned this novel vocabulary of nonsense words, which showed that they were capable of learning words where the meaning depended on the pitch pattern.

- Before and after this training, Kraus and colleagues measured subcortical auditory responses to speech using ERPs. They focused on subcortical responses to a Mandarin Chinese syllable spoken with the three different pitch contours they had used in their study.

- It's important to note that this syllable had not been part of the study. Thus, the researchers were focusing on pre-attentive sensory processing of sound and measuring how accurately subcortical brain activity reflected the detailed pitch contours of a spoken syllable. In particular, they wanted to know how the training would influence general subcortical processing of linguistic pitch contours, not just processing of syllables that had been explicitly trained.

- After training, the subcortical responses reflected linguistic pitch contours more accurately than before training. Early, "primitive" parts of the auditory system had changed their responses to speech sounds due to the training—only eight half-hour sessions spread over two weeks—the participants had done.

- These results demonstrated rapid neural plasticity in a part of the brain where responses were once thought to be hardwired and not very modifiable by experience. They showed that learning a new vocabulary where pitch patterns change the meaning of words could alter early auditory responses to linguistic pitch contours more generally.

- Learning new vocabulary definitely involves the cortex, so we're seeing an influence of cognitive processing on sensory processing. This fits with the idea of auditory processing as a two-way street in the brain, an idea that has been supported by research in animal neuroscience.

- In 2007, Patrick Wong, Nina Kraus, and colleagues published a study that compared subcortical brain responses in musicians and nonmusicians to a Mandarin syllable with different pitch contours. The musicians weren't professional musicians; they were people with at least six years of musical training who had started their training at age 12 or before. All the participants were native English speakers. None of them knew Mandarin. Once again, they didn't pay attention to the syllable during the experiment.

- The researchers wanted to know if musical training would lead to enhanced sensory processing of syllable pitch patterns. Pitch patterns are important in both music and speech. In music, pitch patterns are the basis of melody; in speech, they can signal focus on particular words or the emotions or attitude of a speaker.

- The results of the study were clear: The subcortical auditory responses of musicians did more accurately reflect the pitch contours of the spoken syllables. Kraus and colleagues have now done numerous studies showing that subcortical auditory responses to speech are enhanced in musicians.

- Musicians' brains seem to encode speech sounds with greater acoustic detail. These enhancements don't just concern pitch patterns. They also have been found for other aspects of phonetic structure, such as the detailed patterns of frequency and timing that help a listener distinguish between different consonants.

- These studies by Kraus and colleagues have not focused on professional musicians. They have focused on people who have been engaging with music regularly for a number of years, including children, young adults, and older adults.

- In a 2014 paper, Kraus and colleagues showed these enhancements in a longitudinal study of eight-year-old children who were randomly assigned to music training (with a focus on instrumental music) or no music training. After two years in the music-training program, the children's subcortical responses to speech sounds were significantly enhanced.

- We need more longitudinal studies of this type. At the moment, longitudinal studies are much less common than cross-sectional studies, which compare musically trained people to musically untrained people at a single point in time. This makes cross-sectional studies much easier to conduct, but if you find differences between musicians and nonmusicians, you don't really know what caused these differences. Are they inborn differences? Are they the result of musical training? Do they reflect an interaction between biological predispositions and musical training?

- However, in the cross-sectional studies that Kraus and colleagues have conducted, there is one thing that suggests that musical training plays a role in causing enhancements in speech processing: The researchers often find a relationship between the degree of enhancement in a musician's brain response to speech and the number of years of musical training that person has. If the enhancements were entirely due to inborn differences, you wouldn't expect this pattern.

The OPERA Hypothesis

- The OPERA (overlap, precision, emotion, repetition, and attention) hypothesis is a theoretical framework that explains why musical training can enhance speech processing. The basic idea is that music training can enhance speech processing when several specific conditions are met.

- First, there has to be overlap in the brain circuits that process a certain aspect of music and speech. For example, there is evidence that processing the ups and downs of pitch contours in music and language draws on overlapping brain mechanisms in the right cerebral hemisphere.

- Second, music has to place higher demands on these shared brain circuits than language does. For example, music processing involves more precise processing of pitch patterns than language. If music shares brain networks with language, and demands more of those networks, then this sets the stage for music to enhance speech processing. Any improvements in the function of those networks will impact both music and speech, because they both rely on those networks.

- The remaining three conditions of OPERA—emotion, repetition, and attention—refer to factors that are known to drive neural plasticity in brain networks. Research in animal neuroscience has shown that experience-dependent plasticity due to auditory training is the strongest when the training is associated with strong emotion, extensive repetition, and focused attention. Music has all of these factors.

- The original OPERA hypothesis was focused on explaining musician benefits in the sensory processing of speech sounds. In 2014, the OPERA hypothesis was expanded to consider musician benefits in the cognitive processing of speech sounds.

- The OPERA hypothesis now states that if music and language share sensory or cognitive brain mechanisms, and music places higher demands on these mechanisms, then music training can enhance those mechanisms through experience-dependent neural plasticity, if the training involves emotion, repetition, and attention.

- In the OPERA framework, music's strong relationship to emotion is seen as an enabler of neural plasticity. It's the combination of this emotional power with the high sensory and cognitive demands of music that gives music the ability to affect language processing.

Suggested Reading

Moreno, Marques, Santos, Santos, Castro, and Besson, “Musical Training Influences Linguistic Abilities in 8-Year-Old Children.”

Schellenberg and Weiss, “Music and Cognitive Abilities.”

Questions to Consider

1. Why is random assignment important in longitudinal studies of the impact of musical training on cognition?

2. What is the difference between a cross-sectional study and a longitudinal study, and how do they differ in the kind of inferences one can make about music’s relation to other cognitive abilities?

The Development of Human Music Cognition

Lecture 13

In this lecture, you will learn about research on the development of music cognition in infants and children. This is a very important topic for the study of music and the brain, because tracing how music cognition develops can tell us about the different components of musicality. Not all components of musicality mature at the same rate. Some components develop more quickly than others, and this gives us a way to parse the musical mind into different components. Also, developmental studies can teach us about the interaction between inborn predispositions and experience in shaping the musical mind.

The Development of Sensitivity to Pitch

- In 1992, Laurel Trainor and Sandra Trehub conducted a study designed to test whether infants were sensitive to musical key. Even if you've never studied music theory, you implicitly know something about musical key. One way we know this is by people's sensitivity to out-of-key notes—notes that are well tuned but stand out because they're not part of the key of the melody.

- In their study, Trainor and Trehub tested eight-month-old infants for their sensitivity to musical key. A simple 10-note melody in the key of C major was repeated in the background. The melody was transposed to different keys from one repetition to the next, in order to focus the infants' attention on the pattern of relative pitch between notes, rather than on the absolute pitch of the notes. Infants did grow bored with this repeating melody—that is, they habituated to the repeating stimulus.

- In one condition, the sixth note of the melody was changed to another in-key note. The sixth note was four semitones higher than the same note in the original melody. In another condition, the background melody changed so that the sixth note became an out-of-key note. The changed note was just one semitone higher than the same note in the original melody. It was a smaller physical change than the in-key change, but for adults, it's a large perceptual change, because of our implicit knowledge of musical key.

- The study found that infants detected the in-key and out-of key changes equally well. When adults were tested using these same melodies, they detected the out-of-key change much better than the in-key change. This suggests that eight-month-old infants have not yet developed implicit knowledge about musical key. This makes sense, because key is a fairly abstract aspect of music.

- Later research showed that by four or five years of age, children in Western culture do more easily detect out-of-key changes to melodies than in-key changes. By then, they have implicitly learned some of the principles of their culture's music, just by being exposed to the music. This process is called musical enculturation.

- These results teach us that infants don't perceive music the same way we do. We know that infants can enjoy music, so it's natural to assume that they hear music the same way adults do. But that's not the case. Their cognitive processes of music perception are not the same as ours. Many aspects of ordinary music cognition take time to develop.

- If we find that an aspect of music cognition, such as sensitivity to musical key, takes time to develop, one question that immediately comes to mind is whether experience can influence the time course of development. There are certain aspects of human biology that have a preprogrammed timing—for example, a boy's voice getting lower when he goes through puberty due to hormones.

- In 2012, Laurel Trainor and her colleagues David Gerry and Andrea Unrau published a paper showing that experience can have a powerful role in the development of music cognition. They looked at six-month-old infants who took weekly hour-long music classes with a parent. Infants were randomly assigned to one of two groups: the active group, in which teachers encourage infants to play percussion instruments and sing and to actively engage with the music; and the passive group, in which infants listened to a selection of classical music CDs while teachers encouraged them to play with nonmusical toys or to do visual art.

- After six months, Trainor and colleagues tested different aspects of cognitive and social development in the two groups, including sensitivity to musical key. The results suggest that with six months of active engagement with music, one-year-old infants can begin to show sensitivity to musical key. Experience can strongly influence the time course of cognitive development in music. Before this study, it was generally believed that sensitivity to key didn't start to emerge till about four years of age, based on passive exposure to music.

- In a 2015 paper, Trainor and her colleagues reported brain measurements of the infants that had been in the two groups in their earlier study. They wanted to know if there was evidence of faster brain development in the active group, in terms of responses to musical tones. They used EEG to measure brain responses to one tone, the note C, when it was played repeatedly.

- At six months, there were no differences between the groups in their brain responses to this tone. But at 12 months, the brain signals from the infants who had been in the active group were significantly larger. Basic tone processing in their brains was more advanced than in the passive music group.

Musical Learning Before Birth

- The human fetus starts to hear in the third trimester of pregnancy, around 27 weeks. This means that hearing has a head start over vision in terms of development, because structured visual stimulation doesn't start until after birth.

- Multiple studies have shown that newborns recognize sounds they have heard in utero, such as their mother's voice. They don't understand the meaning of the words they hear in utero, but they have picked up things about the sound pattern of words.

- In the 1980s, research showed that newborns prefer hearing a story that their mother has read repeatedly during the last six weeks of pregnancy than a novel story read by their mother. This means that they can pick up on specific sound patterns they've heard repeatedly while in utero. So, if the mother sings a song over and over during pregnancy, a newborn would probably recognize it. But this is still the mother's voice, which might get special treatment in a baby's brain, because it's heard so often.

- In 1992, researcher Sheila Woodward was able to insert a hydrophone (an underwater microphone) into the uterus of a pregnant woman and make a recording. She recorded herself singing nearby the pregnant woman. The big surprise of this research was how audible the singing was. But do they learn?

- The answer isn't obvious. The middle ear of a fetus is full of fluid, and this probably damps the vibrations of the middle ear bones. This means that what music sounds like to us in recordings made inside the uterus might not be what music sounds like to a fetus. We have to be careful about assuming that babies hear the world the way we do.

- One way to test if fetuses can learn about music (that isn't produced by the mother) is to expose them to recorded music during gestation and then test them as newborns to see if they recognize this music. This was done in a 1991 study by Peter Hepper, who had one group of mothers listen to a particular tune once or twice a day throughout their pregnancy and had another group of mothers not listen to the tune. At birth, Hepper tested newborns in the two groups.

- The group that had heard the tune prenatally reacted to the tune, through changes in heart rate, movement, and alertness. The other group didn't show these reactions. In follow-up studies, Hepper showed that newborns who heard a tune in utero didn't react to a different tune or to the original tune played backward. This means that the music exposure didn't just increase their responsiveness to music generally but actually resulted in their learning about a particular tune.

- Hepper also found that fetuses showed signs of recognizing a familiar tune before birth. At around 37 weeks, fetuses moved more in response to the familiar tune than to other tunes.

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Fetuses can pick up on specific sound patterns they hear repeatedly; at around 37 weeks, fetuses moved more in response to familiar tunes than to other tunes.

The Development of Sensitivity to Rhythm

- The tendency to move in synchrony with a musical beat is a very widespread aspect of musical behavior. It is seen in every culture and is fundamental to dance all over the world. Even though this ability seems simple to us, it reflects complex brain processing and might not be possible for many animals, including most other primates.

- In Western culture, the ability to move in synchrony to a beat doesn't appear reliably in children until about five years old. These types of movements include clapping, bobbing, or dancing in a way such that rhythmic movements line up with a beat, the way they do in adults. But until recently, no one had measured the movements of babies to see if they were already doing a simple version of this.

- In 2010, Marcel Zentner and Tuomas Eerola published a paper in which they measured babies' movements to music. They found that infants did move rhythmically much more to music than to speech. However, the movements were not synchronized to the beat. It might be that the babies perceived the beat but just couldn't coordinate their movements with it. Motor control takes time to develop in babies. Maybe that's why it isn't until age four or five that children seem like they can move in synchrony with a beat.

- One interesting 2009 study by Sebastian Kirschner and Michael Tomasello showed that in social situations, children might be able to synchronize at a younger age. If a child drums with a human social partner, and not just with recorded drumming, he or she can synchronize around two and a half years old. Social context can modulate the musical abilities of children.

- This line of research brings up an important point about the difference between innate predispositions and the age of emergence of a behavior in development. The fact that people in every culture move to the beat of music, and that this ability doesn't come easily to other animals, suggests that something about human brains predisposes us to engage in this behavior. But having a biological predisposition for a behavior doesn't mean that the behavior is fully developed at birth.

- Developmental research can teach about how experience interacts with innate predispositions to shape adult cognition. Often, this experience serves to fine-tune our cognitive processing for the sound patterns in our culture.

Infant Response to Music

- We all intuitively know that music can capture infants' attention and influence their emotions. Infants might smile or move rhythmically to music that they like, or frown or cry to music that they don't like. Also, many cultures use lullabies and play songs to soothe or arouse infants.

- We also know that infants are very interested in speech and can be soothed or aroused by it. Adults often use a special form of speech when talking to infants, which researchers have named "motherese" or "parentese." This infant-directed speech has exaggerated pitch contours and more regular rhythm compared to adult-directed speech and often involves exaggerated facial expressions, too.

- In research on language development, there are studies showing that infants prefer to listen to speech than to acoustically similar nonspeech sounds. This is often taken as evidence that infants have an inborn predisposition to attend to speech. This makes sense, because speech is the primary communication channel for our species.

- In a recent study, Marieve Corbeil, Sandra Trehub, and Isabelle Peretz did an experiment that compared infants' (six to nine months old) interest in music and speech. They found that when the infants heard singing, they took almost nine minutes on average to become fussy. If they listened to infant- or adult-directed speech, they began to fuss after about four or five minutes. In other words, singing seems a lot more interesting to infants than speech.

- A study by Niusha Ghazban and Sandra Trehub also compared infant responses to singing and speech, but this time, it looked at emotional reactions. Singing was more effective than speech in calming the infants, even though in the speech condition, researchers noticed that the mothers engaged in more playful touching than the mothers in the singing condition did. In this study, music seemed to touch the emotions of infants more powerfully than physical touch.

Suggested Reading

Hannon and Trehub, "Metrical Categories in Infancy and Adulthood."

Trainor and Hannon, "Musical Development."

Questions to Consider

1. What is one study that shows that babies perceive music differently from adults?

2. What is the evidence that humans can learn to recognize melodies while still in utero?

Disorders of Music Cognition

Lecture 14

This lecture is about disorders of music cognition. Research on these disorders has taught us that there are many different ways in which music cognition can break down. This makes sense, if we think of musicality as having multiple distinct components. By studying the different ways in which music cognition can go wrong, we can gain insights into how these components are organized in a normal brain. In this lecture, you will learn about a few music cognition disorders that have taught us interesting things about the musical mind.

Musical Anhedonia

- Musical anhedonia was first scientifically described in a 2014 paper by Ernest Mas-Herrero and colleagues. They studied individuals who reported getting no pleasure from music. When they tested their basic pitch, melody, and rhythm perception, these individuals seemed fine. They could also recognize basic emotions expressed by music, such as happiness, sadness, or peacefulness. Also, these individuals weren't depressed; they had a normal enjoyment of biologically important things like food and romance.

- To determine if these people really didn't get pleasure out of music, the researchers asked these musical anhedonics to listen to music that had been judged as very pleasurable by other members of their culture. As they listened, they were supposed to rate the pleasure they felt by pressing buttons numbered one to four, where one was neutral and four was intense pleasure. These people did press different buttons, but there was something strange about their data.

- During this experiment, the researchers also collected skin conductance and heart rate responses, which reflect the activity of the autonomic nervous system, which operates largely outside of voluntary control.

- When the researchers did the pleasure rating experiment with normal listeners, they found that the higher the numerical rating, the higher their skin conductance and heart rate. With the anhedonic listeners, there was no relationship between rated pleasure and physiology. No matter how they rated the music, skin conductance and heart rate stayed at the same low level.

- The researchers suspected that the anhedonics just pressed different buttons because they figured that's what the experimenters wanted them to do. They weren't really feeling any pleasure in music.

- Perhaps these are people who don't get pleasure out of things that are abstract—things that are not connected to ancient biological functions. This could explain why they still enjoy eating and reproducing, but not music.

- To test this, the researchers had the anhedonics do a monetary task where they could win or lose money. In this task, the anhedonics performed very similarly to non-anhedonic people, including having skin conductance responses, which were high when there was a lot of money on the line. For these musical anhedonics, money (an abstract cultural construct) was still very rewarding.

Congenital Amusia

- Congenital amusia is sometimes referred to as musical tone deafness, but researchers prefer the term "congenital amusia" because "tone deafness" is used informally to mean different things by different people.

- True congenital amusics have serious problems with music perception. They might not be able to tell if two short melodies are the same or different. They can't tell when their own singing is way out of tune. They often can't recognize what should be very familiar tunes in their home culture, unless the tunes have words.

True congenital amusics can't tell when their own singing is way out of tune.

- Reports of true musical tone deafness date back to the 1800s, but the modern cognitive study of congenital amusia began with the work of Isabelle Peretz in the early 2000s. In the 1990s, Peretz had done many pioneering studies of patients with acquired amusia—people who had experienced dramatic changes in their music perception following brain damage.

- By studying cases of acquired amusia using methods from cognitive science, Peretz and other researchers helped analyze the different mental subcomponents of music cognition. They showed that when music cognition broke down after brain damage, it didn't just break down as a whole. Different patients could have different problems, depending on the site of their brain damage.

- In the 2000s, Peretz and colleagues published the first modern studies of congenital amusia, or amusia for short. These were people who had severe music perception problems in the absence of any obvious neurological damage or intellectual impairments. Problems with pitch and melody are quite consistent in amusia. Problems with rhythm are much more variable.

- Amusics don't seem to apply the mental framework of musical key that most Western adults use when they listen to music. Amusics don't usually say that music sounds like the banging of pots and pans, but their problems perceiving musical key or tonality make it difficult for them to enjoy melodies and to sing them accurately. When they do sing, they usually can't tell when they are producing out-of-key notes.

- Research by Dennis Drayna, Isabelle Peretz and others has shown that amusia has a strong genetic component—it runs in families. Amusia gives us a rare chance to study how genetic differences between individuals can end up severely affecting one mental faculty while leaving other faculties largely intact.

Music and Language Processing in Amusics

- Another reason amusia is so interesting is that it gives researchers a chance to study the relationship between music processing and language processing. One of the most striking things about amusia is how differently amusics seem to process music compared to other people, while their language processing seems largely intact. However, when you test amusics in the lab, they do have some subtle deficits in language processing.

- In 2002, Julie Ayotte, Peretz, and colleagues published the first modern group study of amusia. One of the tests they used was a test of sensitivity to sensory dissonance in music. In this test, listeners heard a series of musical excerpts, in two different versions. In one version, there was a melody and an accompaniment that had a lot of sensory consonance. In the other version, the music was modified by shifting all the notes in the melody up or down by one semitone.

- When non-amusic listeners were asked to rate these types of passages on a scale of pleasant to unpleasant, they rated the consonant versions as quite pleasant and the dissonant versions as quite unpleasant. In contrast, the amusics rated both versions as mildly pleasant.

- In more recent work, Peretz and colleagues have shown that this indifference is not just a lack of preference; it's a problem in hearing a difference between sensory consonance and sensory dissonance at all.

- This is strikingly different from how non-amusic people hear the musical world. Recently, Peretz has collaborated with experts in the mechanisms of auditory pitch perception, such as Andrew Oxenham. In 2015, they published a paper that used experiments with amusics to test different theories of how the normal auditory system constructs the percept of pitch. This is a good example of how research on music cognition disorders is contributing to auditory cognitive science more generally.

- Another way in which amusia has contributed to cognitive science is through the investigation of language processing in amusic people. The way amusic people process speech can tell us about the mental architecture of cognition.

- In a study published in 2010, the ability of congenital amusics to distinguish between sentences on the basis of their pitch patterns was examined, with a focus on the ability to discriminate statements from questions. The sentences differed in the direction of the pitch movement on the final word: It went down for a statement and up for a question. The size of these pitch movements was fairly subtle for speech but still in the natural range.

- Amusics had difficulty discriminating statements from questions on the basis of these different pitch contours. This showed that their problems weren't specific to musical melody, but also influenced speech melody perception. They also had problems just listening to one sentence at a time and deciding if it was a statement or a question, something that non-amusics in the study found quite easy.

- In a 2008 study of statement/question discrimination, only about 30 percent of the amusics had problems. The difference between the two studies was in the size of the pitch movements that distinguished statements and questions. In the earlier study, the upward and downward pitch movements at the ends of sentences had been much larger.

- Comparing these two studies can help us understand why amusics don't often show problems in ordinary speech perception. Their problems with speech melody aren't all or none; they depend on the size of linguistic pitch movements. When these are big pitch movements, which often happens in real speech, they can hear contrasts between spoken pitch patterns. When pitch movements are small, which is less common in speech, then they have trouble.

The Brain Structure of People with Amusia

- A 2007 brain imaging of amusia by Krista Hyde, Timothy Griffiths, Peretz, and colleagues used MRI to measure the thickness of the cerebral cortex in amusics and non-amusics. The researchers found a few specific regions where the cortex was thicker in amusics, which can be an indication of abnormal development. These cortical regions had been shown to be important for melody perception in normal individuals, so it seems likely that abnormal brain structure in these regions might be part of what causes amusia.

- In 2013, Barbara Tillmann and colleagues published a paper that showed that amusic brains don't just have disruptions to specific brain areas; they have disrupted communication between certain brain areas. Amusia might thus give us a way to study how normal music perception depends on the dynamic interactions of different brain regions.

- Recent years have seen other interesting discoveries about amusia based on methods from brain science. Techniques that measure brainwaves, such as MEG and EEG, have been especially informative. Studies of amusia using these methods have shown that even when amusics can't consciously detect out-of-key notes, certain parts of their brain do respond to these notes.

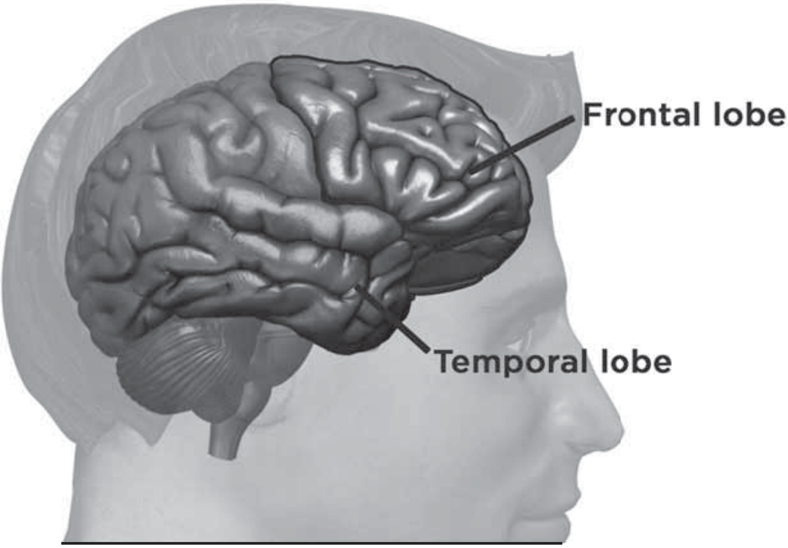
- For example, in 2015, Benjamin Zendel, Peretz, and colleagues published a paper using EEG to examine brain wave responses to out-of-key notes in melodies. Amusics usually can't consciously process musical key relationships, but in this study, their brains showed a response that's typically associated with the processing of musical key. This shows that amusia does not involve an absence of implicit knowledge about musical key; some implicit knowledge appears to be present in their brains. The problem involves conscious access to that knowledge during music perception.

- Amusics' lack of sensitivity to musical key relationships might be because they can't bring their implicit knowledge into consciousness when they focus on music. This might be due to impaired connectivity between different brain regions, especially auditory regions and regions that process musical structure.

Frontotemporal Dementia

- Frontotemporal dementia involves atrophy in the frontal and temporal lobes and is often associated with serious changes in social cognition. These patients often have trouble interpreting the behavior of others in terms of underlying mental states—what's known as theory of mind.

- In a 2013 paper, Jason Warren and colleagues asked patients with frontotemporal dementia to listen to musical excerpts and classify them in one of two ways. In one condition, they tried to match them with labels that had to do with mental states. In the other condition, they tried to match them with labels that had to do with objects or events that the music seemed to represent. The patients had significant problems in the task that involved matching music to mental states.



- This finding meshed well with a 2009 fMRI study by Nikolaus Steinbeis and Stefan Koelsch. In this study, healthy people listened to a piece of contemporary music by Arnold Schoenberg. These listeners didn't know Schoenberg's music. The researchers told some of the listeners that the music had been composed by a computer and others that it had been composed by a human.

- The group that had been told the piece was composed by a human showed activity in multiple brain regions associated with theory of mind. To them, the music was a gateway into the thoughts of another person. For the group that was told the music had been composed by a computer, the music didn't lead to this kind of processing. The brain regions activated in the first group included regions that are known to be involved in theory of mind.

Suggested Reading

Peretz, "The Biological Foundations of Music."

Sacks, *Musicophilia*.

Questions to Consider

1. What are some of the symptoms of congenital amusia?

2. What are some of the subtle nonmusical perceptual deficits that have been found in congenital amusia?

Neurological Effects of Hearing Music

Lecture 15

The idea that music can help people with medical conditions has an ancient history. Today, there is an entire discipline devoted to using music to help people with different physical or mental issues they are facing. This is music therapy. In this lecture, you will learn about some of the research on the biological impact of music on people with a few different medical conditions. The focus will be on how music can influence our brains and bodies in measurable ways from a cognitive neuroscience perspective.

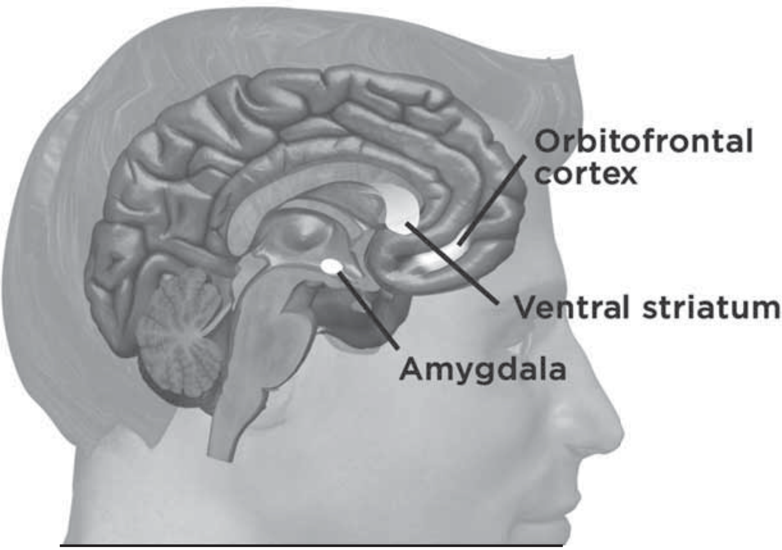
Music and Physiological Processes

- There is growing interest in the idea that music might provide a useful nonpharmacological way to influence people's physiological state as they undergo surgical procedures or recover from surgery. In 2011, Stefan Koelsch and colleagues published a study that measured the effect of music on patients undergoing hip surgery. This study was notable for being a randomized, placebo-controlled study, designed the way you would design the study of a medication on a physiological process.

- The researchers studied older patients having total hip joint replacement, under spinal anesthesia (light sedation). They found that the patients who listened to instrumental music (such as jazz) versus relaxation sounds (such as ocean sounds) during surgery had lower levels of the stress hormone cortisol in their blood during surgery: about 20 percent lower than the group that didn't listen to music.

- In addition, patients listening to music also consumed about 15 percent less anesthesia during surgery. The amount of anesthesia was adjusted so that the patients reached a certain level of sedation as measured by objective brain measurements. With music, patients required substantially less anesthesia to reach this level.

- In trying to understand the mechanisms behind these effects, the researchers suggested that there could be at least three different ways music affected the patients. First, the dopamine reward system could have been activated by the music. Second, there could have been a downregulation, or decrease, in activity of the central nucleus of the amygdala, a brain structure involved in processing fear and threat-related stimuli. Third, the music could have used their cognitive and attentional resources and, thus, distracted them from the surgical procedure.

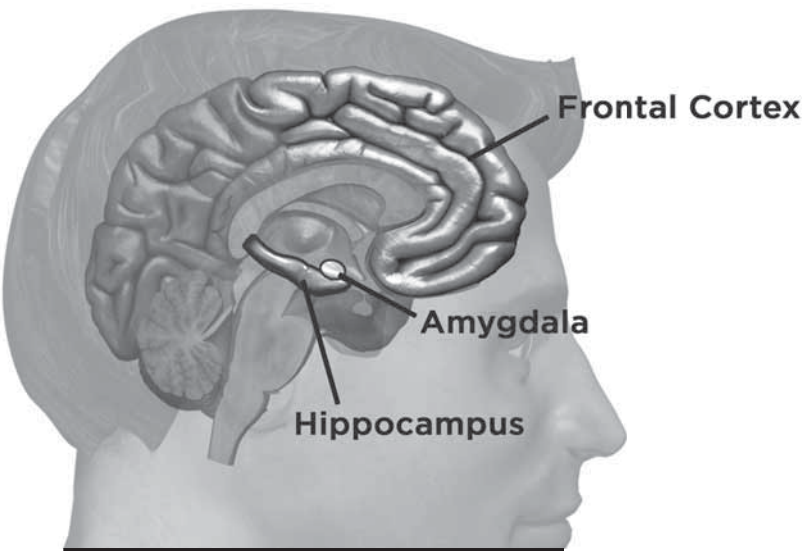


- These all make sense. When people experience pleasure in music, there is activity in the nucleus accumbens and other rewards areas of the brain that use the neurotransmitter dopamine. Prior research has shown that music can modulate activity in the amygdala. And music engages multiple brain regions involved in complex cognitive processing.

- In this study, all of these mechanisms could have been involved; they're not mutually exclusive. This study offers a nice model for how to study the biological effects of music in the short term, while the music is on.

- Listening to music can lower stress hormone levels—specifically, the stress hormone cortisol, which is produced by the adrenal glands as part of an evolutionarily ancient stress response that uses the brain's hypothalamic-pituitary-adrenal system (HPA axis).

- Stress hormones are very adaptive when the HPA axis is activated occasionally. Stress hormones help the body mobilize energy for muscular action by increasing circulating glucose and by reducing the energy channeled into long-term projects like digestion, growth, and immunological function. This is adaptive in the context of mammalian evolution, where an animal has to rapidly fight or flee to survive a sudden threat and can afford to divert energy from long-term projects for the purpose of immediate survival.



- However, if the stress response is repeatedly activated, this can be bad for the brain. Animal research shows that frequent activation of the stress response leads to persistently elevated levels of stress hormones, such as cortisol. This is bad for the brain because cortisol can cross the blood-brain barrier and lead to changes in brain structures that have cortisol receptors, including regions in the hippocampus, the frontal cortex, and the amygdala.

- Persistently elevated cortisol in the brain can lead to atrophy of dendrites and loss of synapses in the hippocampus and prefrontal cortex. It can also lead to increases in the number of dendrites and synapses in the amygdala. In humans, these changes could impair mental processes involving these brain structures, such as memory, attention, and emotional regulation.

Infants in the NICU

- Premature birth is on the rise in the United States, and it has important neurodevelopmental consequences. For example, children who are born prematurely are more likely to exhibit cognitive deficits, including language delays and ADHD as well as emotional regulation issues. Some of these problems might be due to the biological factors that led to premature birth, but it's also worth considering whether neonatal experience contributes to the severity of these problems.

- The environment of most preterm infants is the neonatal intensive care unit (NICU), where they stay from days to months before discharge. The NICU saves the lives of many infants, but it also places them in an environment very different from that of the uterus.

- These differences include frequent sleep interruptions, loud and unpredictable noises (such as alarms), and invasive procedures (such as injections and blood sampling). This is a very different experience than the normal newborn experience, where people normally go out of their way to make infants comfortable and make sure that they aren't disturbed.

- The early experiences of NICU infants might be relevant to their neurodevelopmental outcomes. These experiences seem likely to repeatedly trigger the stress response. It was once thought that the HPA axis of newborns was not very responsive, but current research shows that it does respond to stressful events.

- Frequent activation of the stress response in the NICU could have long-term consequences for the brain. This is because the responses are happening at a time of rapid brain development. Most of the brain's neurons and major structures are present by mid-gestation, but a great deal of brain development occurs during the late prenatal and early postnatal periods. Having elevated stress hormone levels at this point in life is probably not good for the developing brain, especially for structures that have stress hormone receptors.

Pioneering work by music therapists has shown that music in the NICU can have effects on behavioral measures of distress in NICU infants.

- If music can lower stress hormones levels for infants in the NICU, this could have lasting neurodevelopmental benefits. Fortunately, there is an entire branch of music therapy devoted to NICU infants. Pioneering work by music therapists has shown that music in the NICU can have effects on behavioral measures of distress in NICU infants.

- NICU infants who get music therapy will sometimes grow faster than other babies. This means that they are discharged earlier, which is good for them and their parents. What causes them to grow faster? Lower levels of stress hormones like cortisol mean less energy devoted to short-term fight-or-flight responses and more energy devoted to long-term projects, such as growth and digestion.

Stroke Victims

- In 2008, Teppo Särkämö and his colleagues in Finland published a landmark study that looked at the effect of music on the recovery of brain function following strokes, which are brain events in which poor blood flow to the brain causes cell death. This can result in serious, and sometimes permanent, motor and cognitive problems.

- They studied 60 patients with strokes in their left or right hemisphere. All of them had standard post-stroke therapy. Every patient was also randomly assigned to one of three groups: A music group listened to one hour of self-selected music per day, a story group listened to one hour of self-selected stories per day, and a control group had no additional treatment.

- The experiment lasted for two months, beginning soon after stroke onset. Soon after their strokes, all of the patients were tested on several standard cognitive tasks and mood measurements. These tests were repeated again at three and six months post-stroke.

- Soon after their strokes, patients in the three groups showed no significant differences in any cognitive or mood measures. But at three and six months, significant differences did emerge between the groups. On the cognitive tests, verbal memory and focused attention were better in the music group than in the other two groups—either the story group or the control group. On the mood measures, the music group showed significantly less depression than the group with no treatment.

- Särkämö and colleagues suggested that the music acted as a kind of environmental enrichment. There is work in animal neuroscience showing that animals that live in enriched environments, with toys to play with or structures to explore, show richer patterns of connections in their brain microstructure than animals that live in impoverished environments, such as simple, empty cages. The researchers suggested that music could be a form of cognitive enrichment for humans after stroke, because music engages so much complex mental processing.

- After stroke, stress hormone levels can become very high, which would make sense given what patients have been through. If those stress hormones enter the brain, they could affect brain structures with stress hormone receptors. Perhaps the music that the patients in the music group listened to lowered their stress hormones to a level where they didn't do as much damage to some of the brain structures involved in these functions.

- In 2014, Särkämö and colleagues published another paper about the patients in this study. This newer study used MRI to examine structural changes in the brains of the patients in the different groups. The researchers had obtained structural brain scans of the patients soon after their strokes and then again at six months, after they had been regularly listening to music, listening to stories, or neither.

- The brain study used a method called voxel-based morphometry (VBM) to examine changes in gray matter and white matter between the first and second MRI scans. Increases in gray matter as measured by VBM is thought to reflect things like the sprouting of axons, the branching of dendrites, the formation of new synapses, and an increase in small blood vessels in a brain region. These are changes to the microarchitecture of the brain. Brain microarchitecture is shapeable by experience-dependent neural plasticity.

- There were significant differences between the three groups in the pattern of gray matter increase between the two MRI scans. In multiple regions of the brain, the music group showed significantly larger increases in gray matter than the other groups. The researchers also found relationships between the amount of gray matter change in specific regions and the amount of recovery in particular cognitive and emotional measures.

Implications for Future Research

- How would the impact of regular music listening after stroke interact with biological therapies, such as inserting growth factors in the brain or using electrical stimulation to promote neural plasticity? Could there be synergies, so that the combined effect of music and one of these treatments is greater than the sum of doing one or the other?

- Another question that deserves study is how listening to recorded music compares to interacting with a live music therapist, in terms of biological impact. Social interactions can play a big role in music cognition. Humans often react much more strongly to live musical interactions than to recorded music. Using a design like the one in Särkämö's study, one could add live music therapy as another condition and study its impact on brain reorganization after stroke.

- Alzheimer's disease is a neurodegenerative disease that leads to dementia, with severe problems in memory, judgment, mood, and language use. Because it causes cognitive and emotional decline but leaves physical abilities largely intact, Alzheimer's places a huge burden on caregivers and on society. As the world population ages, the number of Alzheimer's cases is expected to reach 43 million by 2020.

- Some randomized controlled studies show that the structured use of music can have lasting benefits for Alzheimer's patients, including a significant reduction in anxiety scores during the treatment period from pre-treatment levels. In one study, the reduction was still present at the two-month follow-up, and patients reported that the music had triggered salient autobiographical memories. This reconnection with their past might be one factor behind their reduced anxiety levels.

Suggested Reading

Särkämö, et al, "Music Listening Enhances Cognitive Recovery and Mood after Middle Cerebral Artery Stroke."

Vanstone and Cuddy, "Musical Memory in Alzheimer's Disease."

Questions to Consider

1. How has regular listening to music been shown to help stroke patients?

2. What impact can music listening have on patients with Alzheimer's disease?

Neurological Effects of Making Music

Lecture 16

Can engaging in simple musical activities help patients with neurological disorders? As you have learned in this course, music has strong connections to multiple brain systems, including systems involved in language, motor control, and social cognition. In this lecture, you will learn about a few different lines of research that suggest that simple musical training can enhance communication and movement in patients with a variety of neurological disorders, including aphasia, Parkinson's disease, and stroke.

Melodic Intonation Therapy and Aphasia

- Aphasia is a language disorder caused by damage to the brain. Strokes that lead to lasting aphasia are devastating to human communication. Large strokes in the left frontotemporal regions of the brain can lead to persistent non-fluent aphasia, in which individuals struggle to produce words long after their stroke, even though their language comprehension might be quite good.

- Standard speech therapy is helpful for many patients, but people vary widely in how much they benefit from this therapy. Many are left far from full recovery. There is growing interest in exploring how recovery can be enhanced, by combining speech therapy with other interventions. These include treatments that facilitate neural plasticity in non-damaged left-hemisphere brain regions.

- Melodic intonation therapy (MIT)—which was invented in the early 1970s by Martin Albert, Robert Sparks, and Nancy Helm—is a music-based therapy that's also attracting some attention. It was inspired by an old and striking clinical observation: Non-fluent aphasics can have great difficulty getting just a few words out but can sometimes sing familiar songs with great fluency. Albert and colleagues hypothesized that this was due to intact right-hemisphere circuits for song and sought to use these circuits to aid speech recovery.

- MIT trains the production of short phrases (such as “I love you”) using songlike pitch and rhythm patterns. There are only two pitches: Each syllable is “intoned” with a fixed high or low pitch and is produced with a slow and steady rhythm—for example, one syllable per second. The therapist models a phrase, and the patient sings it back while also tapping the phrase’s rhythm with the left hand, with one tap per syllable. Phrase length is gradually increased over the course of the therapy. The goal of the therapy is to have the patient be able to produce self-initiated, untrained speech.

- Gottfried Schlaug and colleagues are comparing MIT to a control therapy called speech repetition therapy, which is matched to MIT in all respects except that phrases are spoken (not sung) and tapping isn’t used. In 2008, they published a paper that examined two severely non-fluent people with Broca’s aphasia who had large left-hemisphere lesions.

- When these two individuals started the experiment, they were both already more than one year post-stroke and had already undergone traditional speech therapy. One patient was given 40 sessions of MIT, and the other was given 40 sessions of speech repetition therapy.

- Both patients improved with therapy. This shows that improvement is possible, even when non-fluent aphasics are a year post-stroke and conventional wisdom says that by this point, people have recovered the most function they will ever recover. Between the two patients, the MIT patient showed larger improvement in the number of coherent phrases produced per minute and in the number of syllables per phrase.

- In a second paper in 2009, Schlaug and colleagues examined six non-fluent patients with aphasia who participated in MIT, all of whom were more than one year post-stroke. All six patients showed significant language improvements following MIT.

Melodic Intonation Therapy and the Brain

- It's generally thought that there are two routes to language recovery after a left-hemisphere stroke. The first is for remaining brain areas in the left hemisphere to take over some of the functions of the damaged tissue. This is thought to happen when lesions on the left side are relatively small. But when lesions are large, it's thought that regions in the right hemisphere, opposite the damaged regions on the left side, can sometimes compensate for the damaged regions.

- An approach that uses electrical stimulation focuses on promoting plasticity in undamaged left-hemisphere brain areas. Long before the modern research on this electrical approach, MIT was designed with the idea of retraining right-hemisphere circuits to compensate for damaged left-hemisphere brain regions. This idea was ahead of its time.

- Modern fMRI research with normal, healthy individuals has shown that the production of song does have a greater right-hemisphere bias compared to the production of speech, but it also recruits many cortical regions shared with speech production. Hence, from the perspective of modern research on neural plasticity, the idea that MIT might recruit "song" networks in the brain, and retrain them for speech production, seems like a plausible hypothesis.

- As part of their ongoing research on MIT, Schlaug and colleagues have investigated this hypothesis with functional and structural neuroimaging. The data from their research indicated that a major right-hemisphere fiber tract of the brain was being structurally modified in MIT patients. A music-based therapy seemed to be changing the structure of the brain.

- In a 2014 paper, Catherine Wan, Schlaug, and colleagues examined structural changes in the brains of non-fluent aphasic patients who did MIT. After 15 weeks of therapy, the patients showed significant gains in communication, in terms of how much speech they could produce in a given amount of time. They also showed increased local white matter structure in several regions of the brain.

Music and Parkinson's Disease

- Parkinson's disease is a degenerative disorder with prominent motor symptoms, including shaking, rigidity, slowness of movement, and difficulty with walking and gait. Parkinson's patients often have a kind of shuffling stride. The problem is not muscle weakness but a problem in complex motor control. Later stages include psychological and emotional problems.

- Parkinson's mostly affects older adults. Even though its first detailed medical description was in 1817, by James Parkinson, as of now there is no cure. Early in the disease, drugs that target dopamine receptors are used, such as L-dopa, but these drugs gradually become ineffective and can cause side effects.

- The pharmacological treatments for Parkinson's often have limited impact on gait problems, so physical rehab programs are often used for therapy. Recently, there has been growing interest in the use of music and rhythm in gait therapy. Over the years, there have been striking clinical observations about how people with Parkinson's can move more fluidly when they move to music.

- Michael Thaut did early pioneering research on this phenomenon and showed that music with a beat can help patients with motor disorders initiate and coordinate walking movements. Thaut has published basic research on how healthy people synchronize their movements to a rhythmic beat and applied research on the impact of music with a beat on the gait of neurological patients, including patients with Parkinson's or stroke.

- Thaut and his colleagues have designed a music-based gait therapy called rhythmic auditory stimulation. They've compared it to conventional physical therapy in several randomized studies. In rhythmic auditory stimulation therapy, patients practice walking to music with a steady beat, such as folk and jazz music. The beat is enhanced by overlaying a metronome click track on the musical beats. The beat tempo is initially matched to the patient's own natural gait and then is gradually increased in small increments over the course of training.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There have been striking clinical observations about how people with Parkinson's can move more fluidly when they move to music.

- In a 1997 study that focused on stroke patients, patients were randomly assigned to rhythmic auditory stimulation therapy or conventional physical therapy as a treatment for abnormal gait. Both groups participated in six weeks of gait therapy. Pre- and post-therapy gait measurements were conducted on a flat walkway (without music) using a computerized foot sensor system.

- The researchers found that gait velocity and stride length improved in both groups, but the rhythmic auditory stimulation group showed significantly greater improvement in both measures. They showed about twice the improvement of the traditional physical therapy group. This advantage was replicated in a 2007 randomized study of stroke patients, with larger sample sizes.

- In 1996 and 1997, Thaut and colleagues published some of the earliest research comparing rhythmic auditory stimulation to conventional physical therapy in Parkinson's patients. These studies focused on patients with moderate gait deficits. Like the stroke studies, these studies showed that the rhythm-based therapy led to greater improvements in gait.

Music-Supported Therapy

- There are patients with strokes that affect their arm and hand on one side, leaving it weak and uncoordinated. This is called a one-sided upper limb paresis, or partial paralysis. In these patients, their stroke has not affected their communication—they're not aphasic.

- Eckart Altenmüller, Thomas Münte, Sabine Schneider, and colleagues have developed a novel music-based therapy for patients with upper limb paresis called music-supported therapy and started publishing papers about it in 2007.

- The idea of the therapy is to use simple forms of music making to promote neural plasticity in the undamaged brain tissue around the lesion, to help it take over some of the functions of the damaged areas.

- In music-supported therapy, a patient is trained to produce patterns on two different instruments: An electronic drum set is used to train gross motor movements, and an electronic piano keyboard is used to train fine motor movements.

- The experimenter first plays a pattern on one of the devices, and then the patient repeats it. The first patterns are very simple, with just a single note. They gradually become more complex, working up to sequences of several notes and then to the beginnings of children's songs.

- In 2010, Altenmüller and colleagues published a study that directly compared music-supported therapy to a few traditional therapies and found that music-supported therapy led to the largest gains in terms of standard behavioral measures of motor function.

Music-Supported Therapy and the Brain

- In 2011, Nuria Rojo, Altenmüller, and colleagues published a case study using music-supported therapy that combined behavioral and brain measurements to see what changed in the brain as a person went through this therapy.

- The patient was a woman who had a left subcortical stroke about two years before the therapy. She had a moderate paresis of the right arm and hand. She had no prior musical training. The patient was able to do the music-supported therapy; she had 20 sessions over the course of a month.

- Before and after therapy, she did a number of standardized tests of motor control, which had nothing to do with music. After therapy, she showed improvement in the ability to grasp, grip, and pinch with her affected hand. She also was able to tap faster with that hand and to tap more smoothly with the fingers of that hand. The therapy had improved general aspects of her arm and hand motor control.

- In addition, the researchers found that the neural pathway between the brain and the hand on the damaged side of the brain was working better, suggesting that some neural reorganization had taken place in the hand area of the motor cortex. Perhaps more neurons in that region had become involved in representing structured finger movements, because of the motor demands of the music-based therapy.

- Furthermore, the researchers used fMRI to measure motor function and auditory perception in this patient, before and after training. Before training, they found that moving the affected hand was associated with an odd pattern of brain activation that suggested a failure of normal cross-hemisphere inhibition. But after the therapy, fMRI showed that cross-hemisphere inhibition seemed to be working better again.

- Before and after training, they had the patients listen to tone sequences. Before training, these were the sequences they would go on to learn. After training, these were the sequences they had learned. They were the same sequences, but they had a different relationship to the motor system before and after training. In the before-training fMRI study, listening to these sequences just activated auditory regions of the brain. But after training, hearing the same sequences activated both the auditory and motor regions of the brain.

- In 2007, Amir Lahav and colleagues had gotten this same result with a group of healthy young adults, using fMRI. Learning to play a sequence of notes changes the way your brain reacts to those notes when you just hear them played. Parts of your motor system become activated. Altenmüller and colleagues believe that this auditory-motor coupling is part of what drives neural plasticity in music-supported therapy.

Suggested Reading

Amengual, et al, "Sensorimotor Plasticity after Music-Supported Therapy in Chronic Stroke Patients Revealed by Transcranial Magnetic Stimulation."

Schlaug, "Musicians and Music Making as a Model for the Study of Brain Plasticity."

Questions to Consider

1. What is melodic intonation therapy, and how might it help stroke patients with language problems?

2. What is music-supported therapy, and how might it help stroke patients with motor problems?

Are We the Only Musical Species?

Lecture 17

Humans might be the only animals that speak, but we are not the only animals that sing. As you will learn in this lecture, birds are not the only singers in nature, apart from humans. In addition, you will learn about the similarities and differences between our singing and the singing of other species (besides the fact that we usually use words when we sing and other animals don't), with a focus on the sound structure of song. Putting our singing in a comparative perspective with sounds made by other species can help us appreciate what's distinct about human musicality.

Animal Songs: From Fruit Flies to Whales

- You might think that fruit flies primarily communicate with vision or odor; after all, they are attracted to the smell of fruit. But research has shown that male fruit flies use songs to attract females. They don't produce vocal sounds. They make their songs by extending a wing and beating it to create a series of sound pulses.

- Different species have different patterns of pulses. When you record these pulses and listen to them carefully, they sound like more than just the buzzing sound we're familiar with when we hear houseflies inside a room.

- There is something very important that distinguishes fruit fly song from human song, and it's not just the degree of acoustic complexity—it's how the song is acquired. Fruit fly songs are instinctive. In fact, the timing patterns in fruit fly songs are under genetic control, and some of the genes are even known. This is very different from human song, because the structure of the songs we produce as children and adults depends to large degree on the cultural and historical context in which we grew up, not on the genes we inherited from our parents.

- We might be able to dismiss fruit fly song as having little in common with human song, but once you get into vertebrates, such as humans, you might think that animal songs and our songs would start to have a lot more in common.

- There are many vertebrates that sing, especially birds. But from a biological perspective, some bird songs are more like fruit fly songs than human songs. That's because they, too, are instinctive. Instinctive doesn't have to mean structurally simple. The song of the common loon—which is a beautiful, haunting song that is often used in films to evoke feelings of wilderness—is much more complex than a fruit fly song but is also instinctive.

- It turns out that the only other primates besides us that sing complex songs also have instinctive songs. Gibbons, which are lesser apes that live in tropical and subtropical rainforests in parts of Asia, sing complex songs, often at a particular time of day. These songs are used to mark territories and help reinforce pair bonds. Like the loon song, the gibbon song is acoustically complex.

- Unlike gibbons, humans learn their songs. Learning one's songs through experience is a hallmark of human music, and it sets us apart from many singing animals. Our songs are the product of complex vocal learning—learning to produce complex sounds based on auditory experience.

- Complex vocal learning sets us apart from many other singing animals, but not from all singing animals. Among birds, there are three groups that have independently evolved the capacity for complex vocal learning: songbirds, hummingbirds, and parrots.

- Among the mammals, we are the only primate with complex vocal learning, but not the only mammals with this trait. Dolphins are vocal learners. Bottlenose dolphins communicate using little pitch glides called signature whistles. They can imitate each other, or artificial whistle patterns produced by a human. Harbor seals are vocal learners, too.

- Other mammalian vocal learners include certain whales, such as the humpback whale. The beluga whale, a white whale found in arctic waters, has sometimes been called the "canary of the sea" because of the complex tonal sounds it makes. Its remarkable vocal flexibility was discovered in the 1980s by the marine mammal researcher Sam Ridgway.

Beluga whales—the "canary of the sea"—are capable of complex vocal learning.

- In 2012, Ridgway and colleagues published a scientific paper that proved that beluga whales were capable of complex vocal learning. They are able to copy speech. In fact, the vocal flexibility of beluga whales might be underrated; they might be able to copy speech with even better fidelity than they already can if they could hear clear speech underwater.

- Humpback whales are vocal learners that are famous for their songs. In their songs, we begin to see some structural patterns that are reminiscent of how humans organize songs. Male humpbacks sing in warm waters during the mating season. Early research on the structure of these songs by Roger and Katy Payne revealed that one could identify notes, phrases, and themes in these songs.

- Humpback song might be the closest that another mammal comes to human song. In humpback song, we see familiar characteristics: a complex structure with multiple levels of organization (notes, phrases, and themes) that can change over time and be passed between members of a community.

- Humpback whale song is unlike human song because whales have a special adaptation for singing underwater. In land animals that sing—such as gibbons, birds, and humans—the primary sound source is our mouths. We sing as we exhale air into the environment. Whales don't do this. Underwater films of whales singing show that there are often no bubbles escaping their bodies.

- When a whale sings, the blowhole is closed, like its mouth. The humpback songs that we hear are probably radiated from the whale's throat as it moves air over its vocal folds and into other parts of its vocal tract, where it can be stored and recycled.

Birdsong

- The best biological analog to human song comes not from other mammals, but from birds. In particular, it comes from vocal learning birds, which learn their songs, just as we do. There are three groups of vocal learning birds. Among the many living groups of birds, they're not particularly closely related, so they seem to have evolved their complex vocal learning capacities independently.

- Songbirds, hummingbirds, and parrots are all vocal learning birds. Of these, parrots are perhaps the most famous vocal learners. Some species have incredible vocal powers. They can imitate human speech or singing with amazing fidelity.

- From the standpoint of the comparative biology of music, parrots are fascinating creatures to study. They are the only animals that rival us in terms of vocal flexibility. Some parrot species can also synchronize their movements to the beat of music in a flexible way, like we do. This suggests that there might be some important underlying similarities in the neurobiology of their auditory-motor circuitry and our own.

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Parrots are the only animals that rival humans in terms of vocal flexibility.

- Within the field of avian neurobiology, there has been much more work on the neurobiology of songbirds than of parrots. Songbirds are much easier to study in the lab than parrots, and there are now many studies of the neurobiology of birdsong.

- Songbirds have a specialized set of brain regions and connections that seem to be absent in birds that don't learn their songs, such as chickens and pigeons. These regions and connections have been studied in great detail, and in the future, it might be possible to make direct comparisons between the neurobiology of birdsong and human song.

- These comparisons are challenging because of differences in brain organization in birds and humans, but comparative neuroanatomists are making progress in comparing bird and mammal brains.

The Acoustic Structure of Avian Song and Human Song

- There is a long history of interest in the idea that birdsong and human song might have some deep similarities in how they are organized. If you listen closely to many birdsongs, you sometimes hear things that are reminiscent of human musical structures.

- This was a favorite idea of the late birdsong biologist Luis Baptista. In recent years, musician and philosopher David Rothenberg has explored the idea of parallels between birdsong and human music in detail. While interest in similarities between birdsong and human song is quite old, empirical research comparing the structure of birdsong and human song is still relatively rare.

- One persistent question that has intrigued researchers is whether there is any evidence that birds gravitate toward certain pitch intervals between the notes of their song. In 2014, Emily Dolittle, Tecumseh Fitch, and colleagues published a paper that examined this issue using the song of the hermit thrush, which is a North American thrush with a beautiful, evocative song.

- The researchers analyzed a large sample of songs from 14 different hermit thrushes and focused on notes that sounded like they had stable pitches when the songs were heard slowed down. In this group of songs with stable pitches, they found that in most of them, the frequencies of the notes seemed to fall into a harmonic series, as if they were all upper harmonics of a fundamental frequency. It was as if the frequencies were outlining part of a complex harmonic tone.

- Not all songs had this property, but it was common enough that it seemed like the birds might be gravitating toward it. This supported the idea that complex harmonic tones might play a special role in influencing the creation of musical patterns, an idea proposed by biologist Dale Purves, among others.

- There are other ways to compare birdsong and human music besides looking at frequency relationships between tones. In a study published in 2011, researchers looked at the shapes of pitch contours in human songs and birdsongs. They wanted to know if the simple fact that humans sing while exhaling could lead to certain widespread features in human song contours.

- They found that the statistical properties of birdsong pitch contours at the level of single notes reflected the statistical properties of human pitch contours at the level of song phrases. Both seem to result from a basic biomechanical commonality in how birds and humans sing.

- There is much more work that can be done in comparing the acoustic structure of birdsong and human song, using empirical methods. This kind of research can help address the larger question of how the music of our species is related to the music of other species that evolved alongside us.

Suggested Reading

Rothenberg, *Why Birds Sing*.

Tierney, Russo, and Patel, "The Motor Origins of Human and Avian Song Structure."

Questions to Consider

1. What is complex vocal learning, and how common is it among animals?

2. How is whale song both similar to and different from human song?

Music: A Neuroscientific Perspective

Lecture 18

This lecture will consider the biological significance of music through the lens of cognitive neuroscience. At this point, we need to keep an open mind about whether or not musicality is something we've been shaped for by evolution, and we need to get beyond framing the debate about our musical capacities as the product of biological evolution or of human invention. This lecture will shift from considering music and biology on evolutionary timescales to considering it on the timescale of individual lifetimes, informed by the perspective of cognitive neuroscience.

The Evolutionary Status of Music

- Charles Darwin believed that human music—with its universality, power, and antiquity in human life—must have had a biological function for our ancestors. His argument was that music's biological significance was in its survival value as a courtship signal that helped our ancestors find mates.

- Darwin began a debate that is still going on today. Even for those who don't subscribe to Darwin's particular theory of the evolutionary function of music, the larger issue of whether our brains have been specifically shaped by evolution to support musical behavior is still an active topic of debate.

- In an evolutionary sense, we have the capacity for all kinds of behaviors that our brains aren't specialized for. Every normal human being has the capacity to learn to ride a bicycle, or to learn to read and write. But we can be quite sure that evolution didn't specialize our brains for these behaviors; they are too recently invented to have been the targets of evolutionary forces.

- On the other hand, every normal human also has the capacity to learn language, and many cognitive neuroscientists believe that our brains have been specifically shaped by evolution to support linguistic processing. Facts about how language develops in human children and evidence for some of the genetic and biological foundations of language abilities are what convince cognitive neuroscientists that we have been biologically specialized for language.

- There are five key aspects of language that provide evidence that we've been biologically specialized for language: babbling, complex vocal learning, the rapidity with which we learn the sound structure of language, critical periods for language acquisition, and the discovery of a universal language-relevant gene whose sequence is different in humans than in other animals. In each case, the same evidence can be used to argue that we have been biologically shaped for music.

- The first aspect of language that points to biological specialization is babbling. Around the age of seven months, human babies begin to produce nonsense syllables in repetitive sequences. No other primate does this. Babbling helps babies learn the relationship between their vocal tract movements and the sounds that they make.

- Apart from the fact that we are the only primates that babble, there is one other thing that suggests that babbling is a biological specialization for language: Its emergence is spontaneous. It's not just an imitation of adult speech. We know this because even deaf babies produce vocal babbling, even though they don't hear their parents.

- Babbling is often taken as evidence of a specialization for language, but because humans normally sing using words, it could just as easily be seen as a specialization for musical behavior.

- A second aspect of language that points to biological specialization is complex vocal learning, or learning to produce vocal signals based on auditory experience and sensory feedback. Every child learns to produce a complex set of sounds as part of learning to speak. They're not born knowing the vowels and consonants of their language. Babies also learn the characteristic prosody of their language—its melodies and rhythms.

- All of this seems ordinary to us. But a comparative perspective shows that complex vocal learning is an uncommon trait in animals. It has only evolved in a few groups of animals. Among primates, humans are unique in having complex vocal learning.

- Vocal learning appears to be part of an ensemble of traits that we have acquired through evolution, to help us learn our complex acoustic communication system. Many see it as evidence for specialization for language, but just as with babbling, vocal learning could just as easily be a specialization for musical behavior, because it's a core part of musicality.

- A third aspect of language that points to biological specialization is how quickly we learn the sound structures of our language. Babies usually don't begin to speak in coherent words and phrases until after the first year of life. But before that, they are doing a great deal of rapid and complex perceptual learning of the sounds of their native language.

- In terms of production, by three to four years of age, children aren't just speaking—they are also singing. In addition to enjoying producing music, infants from a very young age enjoy listening to music. Research has shown that song is much more powerful at sustaining interest in infants than both infant- and adult-directed speech. In addition, research has shown that song is more powerful in physiologically soothing distressed infants than speech.

- A fourth aspect of language that points to biological specialization is the fact that we have critical periods for language acquisition. A critical period, or sensitive period, is a time window when developmental processes are especially sensitive to environmental input. Input (or lack of it) during this time can have a profound effect on the ultimate level of adult ability in specific skills.

- Vocal development in songbirds is a well-studied case in biology. The best evidence for a critical period for language in humans comes from research on sign language. Rachel Mayberry and colleagues have shown that when sign language input is delayed in deaf individuals with no other language, there is a significant impact on adult communication skills.

- Evidence from structural brain imaging by Virginia Penhune and colleagues has provided evidence that early musical training impacts brain structure in a way that is different from later musical training, even when the amount of training is matched. So, there might be evidence for sensitive periods in music acquisition. This is a young research area, and we'll probably be learning a lot more about it in the coming years.

- A fifth aspect of language that points to biological specialization is the discovery of a universal language-relevant gene in humans. In research on the biology of language, there has been a lot of excitement about the discovery of a single-gene mutation in humans that has a strong influence on speech and language. This gene is called FOXP2. When one copy of this gene is damaged, individuals show a range of problems with speech and language, including deficits in oral movements, difficulty in manipulating phonemes, and problems with grammar and lexical judgments.

- FOXP2 is not unique to humans. It occurs in many other species, including chimpanzees, birds, and crocodiles. However, the exact DNA sequence of human FOXP2 differs from other species and shows almost no variation within our species. Quantitative analysis of this variability suggests that this gene has been a target of selection in human evolution and was fixed (i.e., became universal) in its current form within the past 200,000 years.

- Research by Katie Alcock and colleagues has shown that FOXP2 isn't just a language gene; it's a gene that seems to influence fine sequencing and timing in ways that impact speech and musical abilities. FOXP2 might be involved in building circuits that do complex sequencing operations for speech, language, and musical rhythm. We need a lot more research on how FOXP2 might be related to both linguistic and musical abilities.

Gene-Culture Coevolution

- If we want to argue that we're biologically specialized for language, we should consider the aspects of language that make us believe that and ask whether we could make similar arguments for music. Currently, we can make similar arguments for many of these aspects. This means that we should keep an open mind about whether we have been biologically specialized for music or not.

- Also, we need to change the way we talk about the options for the evolutionary status of music. For a long time, there has been a debate between people who see musical behavior as having emerged because it had some survival value for our ancestors and people who see it as a purely cultural product. It's framed as a choice between two totally different options.

- We need to start talking seriously about a third option, based on the idea of gene-culture coevolution—the idea that human inventions can end up impacting our biology in lasting ways. In other words, a cultural invention leads to a biological change that is inherited from generation to generation: a genetic change.

- In discussions about music and evolution, more and more thinkers are beginning to think about gene-culture coevolution. This could be a very productive line of theorizing, if it can lead us to ideas for specific things to look for or test in terms of behavior or brain function. This way of thinking about music and evolution is still in its infancy, but it might become a major theme of future research and writing about music and biological evolution.

The Biological Significance of Music to Individuals

- It can be argued that we are unique among all living creatures in our ability to invent things that transform our own existence. For example, written language makes it possible to share complex thoughts across space and time and to accumulate knowledge in a way that transcends the limits of any single human mind. In addition, the inventions of aircraft and the Internet are examples of technologies invented by humans that have become intimately integrated into the fabric of our lives, transforming the lives of individuals and groups.

- As the philosopher Andy Clark has argued, this never-ending cycle of invention, integration, and transformation is uniquely human and has ancient roots. We can think about music in this framework, as something that we invented that transforms human life. Just as with other transformative technologies, once invented and experienced, it becomes virtually impossible to give it up.

- This notion of music as a transformative technology helps to explain why music is universal in human culture. Music is universal because what it does for humans is universally valued. It transforms our lives in ways we value deeply—for example, in terms of emotional and aesthetic experience and the way we form social bonds. Current archaeological evidence suggests music has had this transformative power for a very long time.

- Because of music's ability to significantly impact brain structure and function within human lifetimes, it can be argued that music is a transformative technology of the mind. It's a trait that can shape the biological systems from which it arose, within individual lifetimes. It's a human invention that can substantially influence the microarchitecture and function of the human brain, and it probably was doing this long before any other technology that we know about.

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Music transforms our lives in ways we value deeply—for example, in terms of emotional and aesthetic experience and the way we form social bonds.

- Music might have started as a human invention. Even if there has been no gene-culture coevolution—no biological specialization for music—music still has profound biological significance for our lives because of what it can do to individual brains within individual lifetimes.

- Even if it wasn't a direct product of natural selection, musicality and its different components still have biological roots, and we can study the evolutionary history of those roots using the methods of cognitive neuroscience and of comparative psychology, which compare our mental abilities to other animals.

- There is growing interest in using music as a way to probe how our cognition is related to, or is different than, the cognition of other species. Music gives us a way to study complex cognitive processes that don't depend on words, and it thus levels the playing field for comparing our abilities to other species, because they don't use words. This is an area where there probably will be a lot of growth in the coming years.

Suggested Reading

Herholz and Zatorre, "Musical Training as a Framework for Brain Plasticity."

Patel, *Music, Language, and the Brain*, Chap. 7.

Questions to Consider

1. What is one line of evidence that could suggest biological specialization for language or music in our species?

2. What is the FOXP2 gene, and why is it relevant to the evolution of language and music?

About the Composer: Jason Carl Rosenberg

Jason Carl Rosenberg is an acclaimed composer and researcher who received his Ph.D. in Music from the University of California, San Diego. Originally from the United States but having worked in Europe and Asia for several years, Dr. Rosenberg is active in several contemporary music scenes and is seeking to link these communities through collaboration and innovative projects and programming. He was employed as an Assistant Professor of Humanities (Music) and the Director of Student Music at Yale-NUS College in Singapore but has relocated to San Francisco to continue working as a composer, theorist, conductor, and researcher.

Dr. Rosenberg's music regularly interacts with historical models, especially from the Renaissance and Baroque periods, and his pieces frequently employ dynamic systems that permit individual agency, creating an interplay between collaboration and independence. He has been a selected composer at several festivals, including the Royaumont and Acanthes festivals, and has received the Salvatore Martirano Award and the Foro de Música Nueva Composition Prize.

Dr. Rosenberg's research interests broadly cover four areas and their intersections: form and perception, syntactic processing, theory of meter, and contemporary vocal practices. He has collaborated with cognitive neuroscientists at multiple universities on research projects that explore whether language and music rely on shared cognitive mechanisms.

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