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Music and the Brain

Course Guidebook

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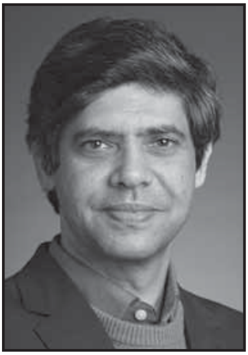

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Professor Aniruddh D. Patel is a Professor of Psychology at Tufts University. After attending the University of Virginia as a Jefferson Scholar, he received his Ph.D. in Organismic and Evolutionary Biology from Harvard University, where he studied 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. ■

Table of Contents

INTRODUCTION

LECTURE GUIDES

Table of Contents

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.

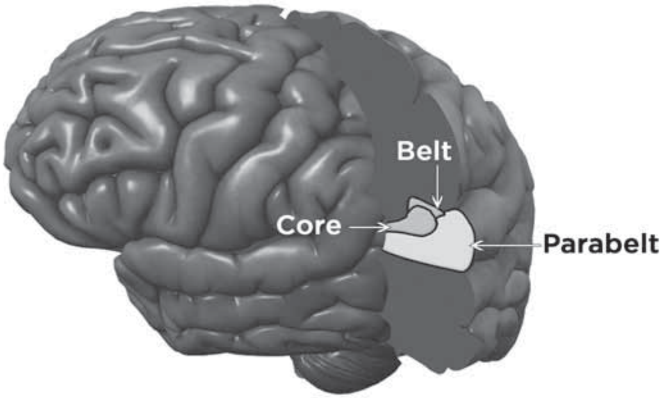
- Thus, one scenario for the evolution of relative pitch perception is that it emerged due to the need to recognize pitch patterns coming from individuals whose average voice pitch is very different from ours. This could explain why birds and monkeys might not have this ability: Many do use pitch patterns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

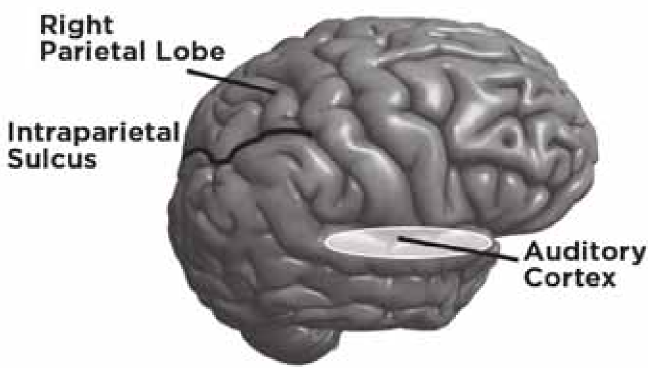
- In 2010, Zatorre and colleagues used fMRI to study relative pitch perception. In this study—part of which involved listeners using relative pitch to recognize the similarity between transposed melodies—the researchers discovered that one of the key regions activated by the relative pitch task was far 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?

- 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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