Ann. N.Y. Acad. Sci. ISSN 0077-8923

ANNALS OF THE NEW YORK ACADEMY OF SCIENCES
Issue: *The Emerging Science of Consciousness: Mind, Brain, and the Human Experience*

Music and the mind: the magical power of sound

Steve Paulson,[1] Jamshed Bharucha,[2] Vijay Iyer,[3] Charles Limb,[4] and Concetta Tomaino[5]

[1]Wisconsin Public Radio, Madison, Wisconsin. [2]Cooper Union for the Advancement of Science and Art, New York, New York. [3]New York City, New York. [4]Johns Hopkins University School of Medicine and Peabody Conservatory of Music, Johns Hopkins University, Baltimore, Maryland. [5]Institute for Music and Neurologic Function, Bronx, New York

Address for correspondence: annals@nyas.org

Music has been a wonderful tool to investigate the interconnection between brain science, psychology, and human experience. Moderated by Steve Paulson, executive producer and host of *To the Best of Our Knowledge*, cognitive neuroscientist and musician Jamshed Bharucha, music therapy pioneer Concetta Tomaino, jazz pianist Vijay Iyer, and physician musician Charles Limb discuss the neurological basis of creativity and aesthetic judgment and the capacity of music to elicit specific emotions and to heal the body. The following is an edited transcript of the discussion that occurred December 12, 2012, 7:00–8:15 PM, at the New York Academy of Sciences in New York City.

Keywords: music; consciousness; experience; mind; aesthetics

Steve Paulson: Thank you. We have a great evening ahead of us exploring the connection between music and the mind and many fascinating questions such as, What's going on in the brain when we make music and when we listen to music, and what's happening in the rest of our bodies? Why is music so enjoyable, so powerful? And for people with certain cognitive impairments, why can music open up their lives in ways that words cannot? What happens in the brain when musicians improvise, and does this speak to the larger question of the nature of creativity itself? We will talk about all of this and much more.

We have a terrific panel and a very special treat for you, so let me introduce our speakers.

Jamshed Bharucha is president of the Cooper Union for the Advancement of Science and Art; he is a cognitive scientist who's published widely on the cognitive and neural roots of music; he's also a national leader in issues dealing with the challenges facing higher education; and he is a classically trained violinist. Charles Limb is a neuroscientist and surgeon at the Johns Hopkins School of Medicine; he is also a faculty member of the Peabody Conservatory of Music; his current research areas focus on the neural basis of musical improvisation and creativity, as well as the study of music perception in deaf people with cochlear implants. Concetta Tomaino is the executive director and co-founder of the Institute for Music and Neurologic Function and senior vice president for music therapy at CenterLight Health System; she's lectured on music therapy around the world; her research colleagues have included Oliver Sacks, who dedicated his book, *Musicophelia,* to her; she also plays the trumpet. And Vijay Iyer is a jazz composer and pianist who has been described by *Pitchfork* as one of the best in the world at what he does; his recent honors include the "quintuple crown" in the *DownBeat* international critics poll, including best jazz artist and best jazz album; he also earned an interdisciplinary Ph.D. in music perception and cognition from UC-Berkeley, with a particular interest in embodied cognition.

Now you've probably figured out what our surprise is for the evening because we have a piano here. Vijay has very graciously agreed to perform two short pieces during our program and in fact we're going to start with one of them. So, Vijay, take it away.

doi: 10.1111/nyas.12183

Vijay Iyer: [*Sitting at a grand piano left of the stage*] Thank you. Hello everyone, I'm really happy to be here. I'm very interested in improvisation and rhythm, and I wanted to do something that involves both.

This is actually not a composition of mine; it's by John Coltrane. If you've heard of him, then you know this song. If you haven't, that's okay; but know that it's a preexisting work that gives rise to improvisative possibilities.

[*Plays piano*]

[*Audience applause*]

Iyer: Thank you.

Paulson: That was fantastic.

As Vijay is reclaiming his seat, Charles let me throw it to you. What's going on in the brain while musicians play? What do you think was going on in Vijay's brain while he played that piece?

Charles Limb: First, let me say that I'd much rather listen to him play than hear myself talk . . .

We were talking about this earlier, before we came out here this evening. Vijay mentioned that he felt like he was an amateur pianist who just fell into a music career. But listening to him play makes me realize why I didn't fall into a music career.

There is, I think, a level of concentration and abandon that occurs during expression of many different capacities and behaviors. Musical creativity, which we just experienced as Vijay played, is unique in many ways, but it probably also shares many commonalities with other forms of improvisation.

In my lab we are trying to understand the biological basis for creativity and for improvisation. From the outset let me say that this is somewhat treacherous scientific ground because I don't want people to think we are under any illusions that what happened just now can be fully captured in a scientific experiment. One has to be very careful when even proposing the idea that somehow such experiences can be subject to experimentation, or that they even should be. And so I don't make any of these assumptions, yet I'm still trying to understand it.

The reason why I'm trying to understand creativity and improvisation is, I suppose, because I'm a physician and I see patients' brains and ears all the time, and so I can't help but realize that there's a biology to everything people do musically, that there's a physicality—an actual neurobiology—that is leading to all of these great musical creations. While it's comfortable as a music listener, admirer, and artist to want to say, "well, let's not delve deeper; let's not try to subject this amazing thing to the constraints of science," there's something missing, I think, if one doesn't try to search for an understanding. And so I feel a degree of obligation to keep on trying to understand this process.

Paulson: Well, let me throw it to Jamshed for a moment. What do we know about what parts of the brain are activated when a musician performs?

Jamshed Bharucha: If I were to put you in an MRI machine and play music, we would see a splash of activity in many parts of the brain: the auditory cortex, the cerebellum because there's timing, the motor cortex, the prefrontal cortex—we would see a lot of activity in many areas. To follow up on what Charles said, I think you're asking a question that we can only scratch the surface of in terms of specifically what goes on in the brain.

Paulson: Is that just because the technology is limited right now, and that we may develop technology in the future that will enable us to pinpoint it more?

Bharucha: I'm sure at some time in the future we will learn a lot more. But let me just say something about the question that's begged when we ask what happens in the brain with creativity, which is, Why do we

have creativity in the first place? To address this question one would likely take a theoretical stance without necessarily knowing what's going on in the brain. Human beings are capable of creativity in a number of domains, music being one. There are creative chess moves; there is creativity in language; and so on. Commonalities exist across these domains. For example, each has a *structure* and a *framework*, and then there are an infinite number of possibilities within a given framework. And so at one level creativity can be viewed as a *generative system*—originally from the linguist Noam Chomsky, who coined the term to explain linguistic capacity. And although I'm not saying creativity is necessarily like language, it is generative in that it's productive. For example, Vijay can take a Coltrane basic structure and his own creative procedures—many automatic within him—to create a potentially infinite number of improvisations of new creative sequences that in some sense are subsumed by that basic structure.

And so why would human beings have such a capacity as creativity? There's no agreement on a single answer to this question. But my view is that creative domains enable human beings to connect; to form groups that synchronize each other emotionally; to synchronize their brains and create a sense of group identity, but only if they become familiar with the structures that enable them to understand, if you like, all of the improvisations based on the structures underlying the creative domains. Every culture has various creative domain structures, and the people embedded in a given culture can understand what their improvisation is all about. People outside a culture—outside the Coltrane culture, for example—may not necessarily get it. And so creativity gives the human species the ability to create group cohesion in an infinite number of possibilities.

Paulson: I want to come back to the question of, Why music? Why did it evolve?

But first, Vijay what were you thinking about when you were playing?

Iyer: It's kind of a truism in the way this kind of music is taught, which isn't how I learned it, but the way it's often taught: you are told you must *not* be thinking when you play. And I think that's an impoverished view of what thought is because thought is something that's distributed through all of our actions. I view cognition as an embodied process, as you mentioned in my Ph.D. thesis . . .

Paulson: . . . when you say "embodied" you mean that cognition is not something that happens just in the brain but that the mind interacts with the fingers; the body reacts to the audience . . .

Iyer: . . . right. So there are aspects of bodily expertise, in terms of responding and making choices and actions in real time, and then there's also the situated aspect of it, which is that my expertise is useless sitting over here, whereas it matters that I'm sitting there at that instrument, not just anywhere. Structural aspects of the environment matter and they are productive.

In terms of what I am thinking as I play, I deliberately chose a piece that had a preexisting structure that is meant to be improvised through. The piece is called "Giant Steps" and Coltrane wrote it for himself as a kind of etude; it involves a sort of unlikely set of harmonic progressions—harmonic leaps or steps—and he wanted to see if he could create lines that made sense across those weird harmonic leaps. He also wanted to achieve this playing at quite a high velocity—if you're familiar with the original you'll know what I mean. So there's a degree of athletic rigor that's involved, and just achieving that—merely achieving that alone—says something important. In fact there's a famous CD of outtakes of Coltrane when he first created this song; he tried recording it many, many times, about 100 or so times, and there's a bunch of outtakes where you hear him trying, but being dissatisfied, and then trying again. In addition to this there's just a few seconds of banter at the beginning where he's talking to his band mates and he says, "you know, I don't think I'm going to improve this; I'm just trying to make the harmonic changes; I'm not telling no story." And then one of his band mates said, "well, really, if you make these changes, that'll tell them a story." I thought that was really interesting; that there's actually something to be said for putting oneself through a set of rigors or trials and emerging, somehow, on the other side, having grown and developed a new kind of expertise.

Paulson: Well, I guess what I'm so fascinated by is the question of how much you're thinking this out as you're playing. Or, are your fingers leading? Where do you think it comes from?

Iyer: Well, there are a lot of micro decisions being made every step of the way. There are certain—how should I put it—potentialities. The tendency for people who try to play this Coltrane song is to outline the chords and play a lot of arpeggios and things that are intended to indicate, "look, I'm playing the changes . . . "

But I want to work more with what's at hand, what's actually *right here* where my hand is; that is a solution, one of many possible solutions. And if you start looking within a small compass of the range of the hand you find very different pathways to the same materials. So I'm often making choices that have to do more with creating very small melodies—melodic fragments with a small compass—that have an almost folk-like character because they have simple intervals in them. So I guess I'm trying to think in those terms, about just stringing together little fragments of melody.

I set this Coltrane song in a different rhythmic cycle than the original, so I'm also thinking about the rhythm. When I say "thinking about" I mean *making myself do the rhythmic work*, because rhythm is not just something one gets right, it's something that is meant to be communicated, or else it's not really working. It's meant to be something that's shared.

Paulson: Well, I want to follow up on this idea of how music can "take over" our bodies in some way. And Connie, I want to bring you into this because you're a music therapist. You have worked with people whose lives have been transformed by music.

Concetta Tomaino: Sure.

Paulson: How do you explain that? Tell us about some of the kinds of people you've worked with.

Tomaino: Well, it's interesting because we're talking about *thinking about doing*—how much we think when we do music. The patients I work with usually can't think about how to do something because of a brain injury; they can't think about how to walk if they have Parkinson's disease, or they can't think about how to initiate a movement or how to speak because speech has been damaged through a stroke. But yet there's something about the temporal structure of the music—the emotional content of the music—that arouses areas of the brain that are still functioning and allows a lost ability to become present as they participate in the music. For example, the patients in "Awakenings," who Oliver Sacks wrote about, were the patients we worked with before L-DOPA was available who through music and rhythm could walk again.

Paulson: So some of these are people who literally cannot speak but that music somehow opens up.

Tomaino: This speaks to the structures that are shared in music perception and ability and other types of brain function that take over from motor function and speech.

Paulson: And aren't there stories about people who can actually sing musical lyrics even though they can't carry on a conversation?

Tomaino: Sure. People who have a stroke in Broca's area and have nonfluent aphasia many times can sing a song perfectly well because of dominance on the right side of the brain—sort of the Broca's homologue of that ability. From neurologists I've spoken to this was once used as a kind of parlor trick: they'd have somebody with aphasia sing a song. The challenge was that it was assumed if a person could sing, he/she would never recover speech—that the brain was damaged and there was no chance of plasticity and recovery.

But we now know that patients who use music and speech within the structure of music and song regain some of these elements of speech. This really speaks to the fact that there must be shared processes that inform the brain through music.

Paulson: Well, let's bring the neuroscientist back in. What's the relationship between music and speech, music and language?

Bharucha: Actually there are quite a few links. For example, there's work by Lerdahl and Jackendoff, one of the seminal works on the relationship between music and language, who argue that there's a fundamental relationship between the *syllabic structure* of speech—the way our syllables are sequenced according to their relative stress—and music. If I say "we're in New York," we tend to say "New York" where "York" is strong and "New" is weak; so pairs of syllables in what's called a *syllable in a stress timed language* have this kind of hierarchal structure, where one can take a syllable that's stronger and one that's weaker and show them as a sort of a branch of a tree, pairing up, and then larger units. And you'd find exactly the same kind of structure in Western music, Indian music, folk music—you can find it in most forms of music. And so there are some very, very fundamental aspects of brain organization that are not necessarily auditory; they are more abstract than sound.

Paulson: Well, isn't there a big debate—I don't know if "debate" is the right word—a big question among those who study human evolution about which came first: music or language?

Bharucha: Well, linguists think language came first, but we musicians say music . . .

Paulson: Charles, what's your guess?

Limb: Language and music share many parallels, but they also have many differences; they're both complex auditory systems that are meant to convey meaning. There's a neurobiological aspect and there's a teleological aspect. The teleological aspect is that language has a very pragmatic function, which is to convey meaning with semantic precision. A sentence has a particular definition that everyone has agreed upon a priori so that when I say a specific string of words you know what I meant, what I intended. Music doesn't have any of that semantic precision; in fact one could argue that music has no real meaning at all—which is, I think, a pretty fascinating possibility given that we love it.

Iyer: But there are possible counter examples to music having no meaning . . .

Tomaino: Right. I was going to say depending on where one studies . . .

[*Audience and panelist laughter*]

Bharucha: It doesn't *necessarily* have meaning . . .

Paulson: Does anyone want to jump in and quibble with this, that music has no meaning?

Iyer: Well, I think it can serve a communicative purpose. But I think what you [*Bharucha*] said earlier about it's being a synchronizing force in a collective experience says a lot. Because I think what rhythm does is it allows us to synchronize our actions; a rhythmic expertise allows us to do this. For example, hitting a drum at the same time in the same rhythm repeatedly; when two people do this it's twice as loud as when one person does it, which means it covers twice the area and reaches four times as many people. Thus, this synchronizing ability allows an instant gain in communicative power.

In my own experience playing for audiences, synchronization is the primary force that I feel is at work—the sense that we're all in a room experiencing this together. And I think we tend to forget that because

nowadays we stockpile music by the terabyte and keep it in our shirt pocket, and we forget that until about 100 years ago music was something we did in the same space together.

Paulson: So what about from the listener's perspective? We've been talking mostly about people who perform music. But as listeners why are we so often compelled to tap our foot or bob our head when listening to music? What is it that takes over in our bodies that is part of the musical experience?

Bharucha: Well, music is embodied; I think Vijay is correct. As I said, if I put you in an MRI machine where music is playing and you're told to lie completely still, we would actually see your motor cortex active even though you're not moving. So our brains show activity in areas of the cortex that drive movement even when we actively try to inhibit the music's tendency to make us move automatically.

I play Western classical music. It's the only form of music I know where we're taught to sit *absolutely still* in an audience, which is very hard because the brain is telling us to move! Most cultures have structured ways of moving with music, and music is related to dance, and that's related to the synchronization ability. In both ancient and contemporary societies dancing is another form of synchronizing people to create a sense of group.

Paulson: So dance and music, from an evolutionary perspective, probably came up together?

Iyre: They do coexist in every culture on earth, that much we know, and I don't know how much more data we need than that.

I think also we have to remember what music *is*. We often, especially in the field of improvisation, have a tendency to speak of it as if it's something we *come to* rather than something that *comes from* us. Music is first and foremost the sounds of us *doing* stuff with our bodies; and so when you hear music, you're hearing other bodies moving, and that's the baseline level of music perception—somebody is doing something. Again, it's easy to forget that because we have electronic music and iPods and so on. But music is somehow an auditory trace of human *activity*. And so I think a rhythmic response to music listening like bodily motion or dance—perhaps a refined form of a more basic impulse—is a sympathetic recognition of the activity and movement that makes music happen.

Mark Changizi has a book called *Harnessed*, which came out this year, in which he talks about how music is the sound of other humans doing things and how our perceptual systems are attuned to code for these things—to hear and pick out of the environment the sound of a body moving with the particular rhythms that it has. Changizi makes the case that we're evolutionary attuned to hear each other in our midst, and that music is made of the rhythms of bodies in motion.

Paulson: So *why* is music pleasurable? Why does music have the power that it so often has? We know this from our personal experiences, but do we know what's happening in the brain to explain it?

Tomaino: Well, Robert Zatorre and Anne Blood[a] did a study a while back that looked at this; it was interesting because they looked at music that gave people chills. They found that the specific type of music was important to a given individual person, that each person had their own particular music that gave them the chills. To show this Zatorre and Blood used the "other person's music" as a control, so a piece of music that would make you excited or feel really good wouldn't make me feel good.

It's interesting because over a lifetime, of course, we start creating these responses to music that then become wired.

Paulson: But you're suggesting that we have specific music memories and that perhaps these are a different kind of memory than other memories we have.

[a]http://www.pnas.org/content/98/20/11818.short

Tomaino: Right. When people have chills in response to certain music, certain neurochemicals get released; when we hear a piece of music that makes us feel good, there are actual chemical changes in our brains in that moment; otherwise we wouldn't have those feelings. So, we develop music tastes and responses, I believe, through experience over time. Music doesn't necessarily turn everybody on the same way.

Bharucha: Yet pleasure is a very limited criterion if you think about it. Sometimes we listen to very sad music; sometimes to music that's very angry. So I think the notion that we listen to music just for pleasure or as something pleasing is very limited. Yes, we do that a lot. But we listen to music for other reasons. Consider if somebody in your family is sad; family or friends may have the tendency to think, "oh, let's play something happy and we'll cheer him/her up!" Well, the person is likely going to respond by saying, "stop it! I don't want to listen to that; I want to listen to something sad." So I think that we resonate to sad music if we're sad and to happy music if we're happy.

Again, the notion of resonance or synchronization is much more important than simply making one happy or lifting up one's spirits.

Tomaino: I agree. In the field of music therapy there's a concept called the *iso principle*, which applies to when one matches music with how a patient feels at that moment to allow them to release either emotionally or physically something that's been blocked otherwise. The only way music can really be effective is to be able to touch a patient where they're feeling or how they're feeling in that moment.

Paulson: Well, it sounds like you're also saying that perhaps we haven't really developed a vocabulary to talk about emotion in music. The experience that we have is so much bigger and more complicated than the language that we have for it.

Charles, what's your sense?

Limb: It's important to point out that there's a certain primitive neurobiology at play when listening to music. A lot of the reward or aversion systems we have are basic biology—fear, hunger, thirst. All are senses for really primitive survival instincts; these senses can also be stimulated by music. This is a pretty interesting idea, especially when considering that music is very old; it has existed in every historical epoch that's ever been studied. Humans were making primitive musical instruments 50,000 years ago out of bones of animals, which is a very peculiar behavior when one is also trying simply to survive!

And so there is I think a very close linkage between music and emotion. This, to me, is really the wonder of music: that this abstract acoustic vibration in the air leads to a deep emotional response. That's a remarkable process. The feelings evoked by music can be overwhelming, so to try to study it scientifically is very daunting.

I would like to touch back on the language and music comments that were made. The brain has very clear anatomic structures and we have loose models, for the most part, of what these structures do. But, as we continue to study how music impacts the brain, we're realizing that our model is too simplistic. It's not that there's simply a "music part" of the brain. Instead, there are parts of the brain that process complex sound, parts of the brain that process syntactic components of language and music, parts of the brain that process meaning, parts of the brain that process emotion, etc., and they're all coordinated by the executive frontal lobe. For example, music and language share some of the same neural architecture; the same neurons are involved in language operations and in musical operations. But historically, language studies came first. And so our first understanding of Broca's area, for example, was that it is central for a language capacity: a stroke that led to a language deficit led to it being ascribed a language function. We know now that when two musicians play music back and forth trading fours in a jazz gig, they're using Broca's area of the brain, yet no words are spoken.

Tomaino: That's right.

Paulson: I have to ask you about something that follows up on an interview I did with Oliver Sacks. He told me something that I found astonishing, which is that if one looks at the brain image of a professional musician, one can usually identify that it's a musician's brain, whereas this isn't possible with a mathematician or a visual artist. This seems to imply that the musician who has been playing his/her whole life has a rewired brain. Is that true, do you think?

Limb: I'm not sure which data he's talking about. There are structural and functional anatomy distinctions that we have to think about differently. The brains of musicians clearly function differently than the brains of nonmusicians. If we were to scan Vijay's brain while he's listening to something and scan somebody who's never played jazz piano, the brain activation patterns would be totally different. Yet the basic core anatomy—the contour of the brain, the shape of the sulci and gyri—is relatively consistent between people, though there are exceptions. In people who have perfect pitch, for example, the primary auditory cortex seems to be actually compact in size, at least in the right hemisphere. This is an example of a structural change induced by music or perhaps the structural change leads to one going into music—perhaps this is a chicken or the egg kind of question

So there are anatomical or morphological differences between musicians and nonmusicians, but I think by and large the real differences are functional more than they are morphological.

Paulson: Well, I have to ask about the so-called Mozart effect. The idea that we should all play music to our kids, maybe even when they're still in the womb, because they're going to become smarter. Is there any science behind this?

Tomaino: [*To Limb*] You know Fran Rauscher's work . . . .

Well, it's interesting. That was a really good marketing campaign for a research article that was really about attention and, I think, stimulation. Because of that one study, there was this generalization that listening to Mozart would make you smarter. I think some of the subsequent studies that came out were more about stimulating or priming the brain for attention, for example, that listening to certain types of music primes a person to be more attentive to task when something's happening. So, maybe the role that music plays is to get us *ready* to learn; to arouse the right part of the brain.

Iyer: I think in the original study, it wasn't about *types* of music; it was really only the two Mozart concertos. And the control experiment was silence or something.

Bharucha: It was a deeply flawed experiment . . . [*audience laughter*].

Tomaino: But good marketing . . .

Bharucha: Yes, the marketing—it was extraordinary. It was one of these things that went straight from the lab to the front page of the newspapers, bypassing science editors and reviewers. And it's not specific to Mozart at all. Some years back I was editing a journal called *Music Perception* at a time when there was a lot of hype about the Mozart effect, and somebody sent in a paper saying the same thing for Schubert.

So, maybe we should call it the Schubert-Mozart effect . . . [*audience laughter*].

Iyer: Nobody tried Ellington or Hendrix?

Bharucha: I think they have tried everything by now . . . First there was a purported Mozart effect and then other music was found to do the same thing. But then somebody tried just listening to stories and they found a similar phenomenon. But of course these accounts are only of the people who found something; there are a lot of people who have tried to replicate these studies and haven't found anything at all.

Actually, I do think there is something going on here; if you look at the meta-analysis—an analysis of the hundreds of studies that have been done, not all of them replicate, but there are enough replications that something is going on—it looks like what's occurring is what Concetta mentioned, something to do with attention or, as some have suggested, to mood manipulation. As Vijay said, if you were randomly picked for the Mozart condition, you listened to Mozart for 10 minutes; whereas if were in the control group sitting in silence in a tiny little cubicle at some psychology department somewhere for 10 minutes and then you had to take an IQ test, you may not be in a very good mood . . . [*audience laughter*].

Paulson: I want to come back to the question of creativity, which we started with. Charles, you've done some remarkable studies by putting jazz musicians inside fMRI machines. How does someone play in one of those machines?

Limb: It's slightly awkward. For those of you that have been in a regular MRI, a functional MRI is not really different ergonomically; it's a really tight space—it kind of feels like being in a coffin. You lie down on your back and have two mirrors that enable you to see your hands. There is a piano keyboard sitting on your lap; your legs are propped up. And then you have electrostatic headphones that allow you to hear the output from the piano. The piano sends a digital signal to a computer, outside of the machine, that then sends a note that corresponds to the note that you played on the piano back to your headphones. So it's not an acoustic instrument.

The process actually works pretty well; I've been in one for hours myself, trying to get the thing to work. It's doable.

Paulson: So, one of the things you've been studying is what happens in the brain when jazz musicians improvise. I know you've studied when they do it solo and also when they've been playing with other musicians. What have you found?

Limb: I'm looking at several different spontaneous improvisation conditions, including visual artists drawing and rappers rapping, to understand what happens in moments of spontaneous improvisation. Suffice it to say, it's complicated. The one defining trait that is always present, in some form or another, is a degree of prefrontal inhibition. We see this over and over again; large or important portions of the prefrontal cortex that are, relatively speaking, turning off during improvisation behavior.

I think this speaks to Vijay's comment earlier about a way of conceiving thought during improvisation. What Vijay said, and what our work shows, is that the brain doesn't shut off, rather certain cognitive processes that are normally at the forefront are put into the background.

Paulson: What is someone who is improvising trying to shut down?

Limb: Conscious self-monitoring and effortful processing—paying enormous attention to the detail of what one is doing, and concern about making sure one's response is correct or appropriate.

Paulson: So the musician has to shut down that critical inner voice that might prevent him/her from doing something new.

Limb: That is a kind of qualitative musical explanation of it, yes. That in order to generate a new idea or to play something with abandon, one has to have a certain lack of concern about being right, or correct, or even whether it sounds good. I think what makes a great jazz musician great is that they can do that.

Paulson: So, Vijay, does that resonate with you?

Iyer: Well, I don't know what makes anyone great . . . [*To Limb*] I've been following your work for a long time and it's very exciting. Yet you use very specific and focused examples of improvisation, and your control

situations are playing memorized music, which to me is an extremely different and unlikely situation. The way I think of improvisation is that it's almost everything that we do anyway. To me, your control is more the experiment and improvisation is the *background noise* of everything we do. Improvisation is how we learn to do everything; it's how we learn how to talk, how we learn to walk, to eat—to do everything. We tend to think of improvisation, especially in the West, as some sort of extreme occasion. But really it's sort of a banal thing that we always do, including right now.

Paulson: You're shattering my illusions of what creativity is all about here . . . [*Iyer laughing*]. I want to push on this for a moment because one of the questions here is about people who are truly creative, and let's just focus on music for a moment. What's going on with them? What makes them different? Can we talk at all about creative genius in terms of what's happening in the brain?

Limb: I think it's really important to point out that improvisation as a process takes place at low mundane levels and at high profound levels.

Tomaino: That's the difference.

Limb: These levels may be related, but they also may be different, especially considering that the people who can improvise at profound levels have a skill set that most people don't have and they have trained for years to be able to improvise. Among other things this means that their brains are different and that their entire functional apparatus is different.

And so while I agree completely that improvisation matters for communication, more generally, I don't see how human society would have survived without it. I think we would have died off if we weren't creative; we wouldn't have been able to solve any problems—we would still be stuck trying to figure out how to get something to roll. We need creativity to be innovative, to solve problems, to see things laterally that we didn't see before. It's this way of putting combinations of things together and coming up with something new that is a very fundamental facet of human society.

Paulson: But that doesn't necessarily explain *artistic* creativity.

Limb: Correct. But I think that maybe artistic creativity is a way to tap into the window of this process that happens when we talk about geniuses. If we want to understand genius, we need to start looking at some geniuses. And that's why I've studied expert musicians. I'm stacking the deck; I'm only looking at experts to see what they do, and they very naturally go into this state of mind when they are doing their musical activities. [*Directed more to Iyer now*] Now that's not to say that a child doodling on piece of paper isn't being creative, but I suspect it's a different form of creativity, at least in terms of the rapidity with which they can enter a certain mind state. And I think there's also a reason why amateur pianists or jazz musicians struggle with improvisation—partly it's the way we're educated, partly the musical systems we grow up in., but I think that there are many musicians in the classical domain that can't improvise at all.

Iyer: Yeah, I'm one of them in the sense that my first instrument was the violin and I'd had 15 years of violin lessons. In the meantime, I started doodling on the piano, on my sister's piano—she was taking piano lessons. And so I actually learned to play the piano by improvising, whereas my violin training was basically teaching me how *not* to improvise [*laughs*], how *never* to improvise—it was stamping any improvising tendency out of you. That's part of what it means to acquire that skill or that expertise. There are choices one can make at the interpretative level that are very real time and can feel very "in the moment" and there are perhaps some aspects of what we're calling improvisation. But in terms of *generating* material on the violin, I'm kind of paralyzed.

Bharucha: We talk about genius, and yet I think that the concept of genius is overly mythologized and that most people in cognitive science and neuroscience would agree. We have this tendency to express awe, "he/she's a genius functioning at some different kind plane!"

But I think the scientific view is that genius is not a qualitative difference but a quantitative difference of extreme, and that there are some necessary conditions for having genius, which Charles alluded to. There are no examples of that level of performance, whether it's creative performance or just simply executing on an instrument, that aren't predicated on years and years of intense training. So there used to be this notion that, somehow, one is just born with talent—that Mozart just wrote his symphonies, viola! He didn't. Whether you're talking about the Bobby Fischers or the Mozarts, or whoever, there are no examples that haven't involved very, very intense years of training, which is what makes some of these processes, as Vijay says, automatic; one doesn't have to start thinking about them. The brain has the capacity to transfer conscious or controlled processes into automatic processes through a lot of practice/training.

Paulson: There is a movement in some circles in neuroscience who try to come up with what's been called *neuroaesthetics*, and there are some very well-known neuroscientists, like V.S. Ramachandran and Eric Kandel, who have signed on to the idea that there are aesthetic categories structurally embedded in our brains, and that if we can understand them we can come up with a science of aesthetics.

So my question is, Can aesthetics, can beauty, really be explained by science?

[*Panelist laughter and pausing*]

Limb: Maybe it's how you've framed the question that's difficult. I don't know that explain is what we do for beauty. Rather, I think we appreciate and recognize it and then we figure out why we recognize beauty, why we care about beauty. That, to me, is what understanding beauty means. We needn't try to demystify it or make it less spectacular than it is.

At the same time, I think it's clear that when we see something beautiful and it affects us it is our brains that are responsible for its effect on us. There is neuronal activity that leads to the perception of beauty. There's a neurologic function that includes sensory processing, analyzing output, and an emotional response, and if we didn't have brains we wouldn't feel that something we perceive is beautiful.

So I think that while we want to be very respectful when approaching things like art, we should also be realistic and not shy away from attempting to understand them better. The way I feel about these kinds of projects is that we may never get to the end, but we can keep asking.

Paulson: We could go on and on about this, but I want to bring in the audience here. But before that Vijay will play, I hope, one more piece for us. And then we will go to the audience.

Iyer: This is something I created in memory of my grandparents. It's called "Remembrance."

[*Iyer plays*]

Paulson: Thank you so much, Vijay . . .

Okay, let's now take questions from the audience.

Audience member 1: I missed the panel discussion on memory[b] and the issue I want to ask about brings together very vividly music and memory. I'm not a performer of music; I stopped playing the piano at the age of 12, but I listen to lots and memorize an awful lot. As a scientist, I have attempted to measure the amount of terabytes that are stored in my brain and it's amazing; this is only an approximation, but 387 terabytes. I have memorized 3481 pieces of music, including 359 operas from beginning to end. And I was interested in finding out how all this could fit [in my brain]. And I'll tell you, there is more than just a collection of simple notes. Vijay, the first piece you played invaded part of my brain and now Coltrane

[b]Paulson, S., A. Aciman, J. LeDoux, D. Schacter, and A. Winter. 2013. The mystery of memory: in search of the past. *Ann. N.Y. Acad. Sci.* **1303**: 4–24.

occupies a little more than it did before. I asked a specialist at Intel what amount of silicon could store all of this data because it's not only notes, it's emotions linked with the notes. And he said, there's no way this can fit in this little space here. And so I don't know how we do it.

Paulson: Okay. Who wants to take this on? How do we remember all this?

Bharucha: Well, clearly it does fit in our brains, but we are still a long way off from understanding how all of the information is encoded. There are theories and models of how networks of neurons interconnect by changing the strength of the synapse that connect them. And if we think about the number of neurons there are and the number of synaptic connections, we get into some very, very, very large numbers. And there's actually a mathematical theorem that shows that orthogonal patterns can be encoded in the same neural network without interference. And so it's not as if you need a separate chip or a separate memory register for each new memory; there are very clever ways that evolution has found to use the ensemble of neurons interconnected in certain ways to store multiple memories that are triggered by appropriate contexts. And so within the same circuit, a certain cue will result in one state, which is the recovery of a memory, and another cue will result in another state, which is the recovery of another memory. And so when we start thinking about it that way, we get tremendously large combinatorics that all fit into our skull.

Having said that, it wouldn't surprise me that in 50 years or 100 years people will discover some other neuroscientific phenomena that also are involved in memory that we don't know about today.

Paulson: Well, let me follow up with Vijay. Do you find that you can keep memorizing new pieces? Or to make space for those new pieces, do you have to forget other things?

Iyer: I would say I felt differently before I became a parent . . . There was a time when I thought memory was infinite and now I'm quite aware that it isn't [*laughing*].

Much of what happens certainly in improvisational music is that you have generative processes, so it can take very little structural information to enable a whole night of music. It's sort of like data output from a MIDI keyboard, the kind of machine they play in the fMRI that sends out something like 8 bits of data, which are a very low-resolution control data. So I see the compositional form, especially with an improvisation, as sort of like control data that is very low resolution but which enables a lot of things to happen.

And the other thing I would say is that in the particular case of the piece I just played, I really do think about my grandparents—before I play anything I try to reach a state of remembering them—because I'm interested to see if this become a compositional element—*me making myself think about somebody*—and what that brings out, what it elicits. And maybe each instantiation of the piece—each time I play it—will be different somehow because of that.

Paulson: More questions from the audience.

Audience member 2: I don't know if I got an incorrect impression, but you sort of spoke about improvisation as limiting one's critical faculty, that is, the desire to say your playing is wrong gets reduced and things that are in the front of your mind get pushed to the back. But there's a definite musical structure that even if, when you improvise, you have to maintain. So Vijay was playing in a minor key, in a specific minor key, and when he improvised he had to stay either within the key or he had to shift to an appropriate key. So there's a great deal of critical work going on as one improvises. So if you're improvising on, say, "Mary Had a Little Lamb" or "Happy Birthday," the tune has to still be there, otherwise it's just random noise. So improvisation is certainly not uncritical; it's very critical and very structured, even if you call it improvisation. You have to migrate from one key to the appropriate key and stay within a key; fingers can't be just random. I wonder if you all could comment on that.

Paulson: Charles?

Limb: Yes, I'm happy to comment. I think, first of all, that what you're pointing out is correct. I think it's part of the danger in trying to summarize a very complicated story in two or three sentences. When we talk about something like the prefrontal cortex, such an immense area of the brain, it is important to remember that it does many, many things and is not simply the jazz area of the brain. It's involved in different processes ranging from things like working memory and conscious monitoring to full step-wise planning. If we had to list the number of functions of the prefrontal cortex we'd never finish.

I think a current problem that some neuroscientists face, especially in functional imaging, is that they need to explain their findings. For example, we observe something fairly simple, less blood flow to a specific part of the brain, yet there's this whole context where we have to say, "okay, what does this mean?" It is this interpretative aspect of neuroscience that is problematic. Much of the time we don't really know what these findings mean, and too much emphasis is placed on them. In published studies, interpretations are found in the "Discussion" sections of papers and they need to be taken with a grain of salt because they are simply that, *discussions*.

So going back to the studies I described earlier, I described that during a solo an expert jazz musician is relatively disinhibiting certain areas of the brain so that he/she might promote activity in certain other synaptic networks. This is a fairly modest claim. I wouldn't want you to have the impression that what I'm saying is, "a musician turns this part off and turns that part on; he/she has no memory and forgets that he/she is playing an instrument." There is a lot of information that becomes hard wired for an expert musician—e.g., music theory, knowledge of the instrument—which may be partly why an expert can improvise better than an amateur. Things like theory, playing the actual notes on the keyboard, hearing not just the conception of the idea but the execution of the idea, become much harder when you're an amateur. And so I don't want you to take a too binary view of what I said when I discussed the prefrontal cortex; it's really very complicated.

There's also medial prefrontal cortex activity that goes up during certain solo jazz improvisations, which makes sense when we think about that area of this default network of the brain being evoked by musical memories. So it's an autobiographical self-reflective part of the brain that turns on during improvisations, which might be part of why musicians have their own musical sound or voice while improvising.

Paulson: Let's go to the next question.

Audience member 3: I love music. But when I try to clap along with people or to sing with them in a complicated tune where there's more than one group, like in a chorus, I'm not able to do that very well. What does that say about me, that I'm not able to follow along with different rhythms as well, but I still love music?

Tomaino: It's interesting because there's the whole area of auditory perception and rhythmic perception. I'm curious to hear from the scientists what that means because there's a test for people who have amusia, the inability to hear or process certain aspects of sound, and it could be that your perception of rhythm is somehow skewed.

Paulson: But on the other hand, what he's saying is that . . .

Tomaino: . . . he enjoys music.

Paulson: He enjoys music, even though . . .

Tomaino: . . . despite the fact that he can't produce it.

Paulson: Yes.

Tomaino: [*To audience member 3*] So you can't physically clap to music but you can obviously hear the rhythm of the music; otherwise you wouldn't be able to appreciate it. So it talks about the separation of that function, too, from mode to execution.

Limb: But let's be fair; we don't know how good his perception is either, right?

Tomaino: Well, but he enjoys it.

Limb: But one can be legally blind and still enjoy looking at a painting.

Tomaino: That's right.

Limb: A blind person is not seeing a painting the way somebody with perfect vision is but yet can enjoy it nonetheless; the same thing can happen in music. Take cochlear implant patients; I have many that love music. Maybe they love it because they were deaf their whole life and can finally hear. When I actually test them, though, they can't tell an octave apart.

Iyer: Just to add . . . , rhythm is something one can train oneself into and acculturate oneself to. Different cultures have different levels of rhythmic expertise—rhythmic expertise that might work in James Brown's band, might not work when you're playing Dvorak's second symphony, for example.

Paulson: Let's go way in the back.

Audience member 4: In terms of creativity, how does the brain process dissonant music as opposed to consonant music? And how does dissonant music impact the motor cortex if there's no tempo or beat to follow? Is the motor cortex still active?

Paulson: Dissonant music. Do we know what's happening?

Tomaino: There are some studies about how babies respond to consonant and dissonant music; how much time they attend to a consonant interval compared to a dissonant interval; how they get distracted by the dissonant, or turn away from it. So perhaps there is hardwiring of a sort that has something to do with consonance versus dissonance perception. But exposure to it over time can create an incredible like for dissonant music, again through training and exposure.

Bharucha: Consonance and dissonance is one of those topics that I think we will continue to understand more and more without ever understanding it completely. It's the kind of topic where you think it's simple and you grab onto it, but there's a lot more.

There are purely acoustic determinants of consonance and dissonance that have to do with the harmonic nature of periodically vibrating objects, but then there are clearly cultural aspects of consonance and dissonance. There's no question about it.

In some studies we've demonstrated that the brain, as a result of being in a culture, learns certain patterns so that when it hears mere fragments of a musical pattern it will actually lead to *expectation* of the missing pieces. In a sense, that's what a culture is, it allows the brain to become so used to particular structures that it need only fragments to derive expectations or anticipations, or even cause one to think he/she actually heard something but didn't.

Unfamiliarity with a culture causes its music to sound dissonant; whereas familiarity with a culture makes its music sound consonant. So there are cultural as well purely acoustic determinants.

Paulson: Let's come to the front row right here.

Audience member 5: I guess my question concerns evolution. I'm an ornithologist and I did field work in the Amazon with an indigenous society in which music accompanied every aspect of their life. Of course we're not the only species that sings; whales sing and birds sing. And in the Amazon there are many, many birds, and much of the music of the indigenous people often imitated the sound of birds. The Indians would go into the forest with these very primitive flutes and communicate—they would imitate the bird and they would communicate with the supernatural—in order to be able to hunt successfully and so on and so forth.

One of you was mentioning how we have language and music; well, in the Indian society, language and music were interwoven for different occasions and different encounters; one had ceremonial oratory or dialogues with different cadences and different intensities, and so on and so forth. So it was really just a total musical fabric throughout all of their life.

I just wondered, have we degenerated from that?

Paulson: Does anyone want to take a crack at that? Are we less musical in modern civilization than a culture like that?

Iyer: I'm curious, did they have a word for music? I mean, in their language, do they, is there—

Audience member 5: Well, they have terms for all the different types of hymns and dance songs and forms of oratory . . . , yes, they do. But in general, I can't think of one general term.

Iyer: I have started to wonder if our tendency to treat music as a separate *thing* from other forms of behavior has reduced our understanding of it. There are a lot of protomusical behaviors we have in everyday life—I'll bring up parenthood again and my daughter; I'll easily sort of sing a sentence to her instead of saying it or just speak in a more rhythmic way—such behaviors in everyday life are musical but not what we would consider to be music. There are also plenty of forms of music that some people wouldn't call music. So I think the word *music* ends up creating separation between what may at one point have been very connected forms of behavior.

Bharucha: I think that's right and that it's a result of the development of so-called "high culture" in which certain art forms become extremely elaborated and require high levels of expertise and training, and then we put people on a stage and we say, "*that's* the musician and *that's* music." And then the culture loses what you say, which is that in traditional cultures music is part of the fabric of everything people do. There aren't musicians and nonmusicians. Everybody's sings, everybody's dances, and while some might be better than others, no one has become specialized.

So we have lost something; there's no question about it.

Audience member 5: My only other comment would be that when I see orchestras at Lincoln Center—I was trained in dance as a kid—I notice all the musicians almost "dance" around their instrument in order to coordinate the music. I see the contact with their heads; they coordinate in that way.

Bharucha: They're synchronizing . . . .

Audience member 5: Yes. And it's really a dance.

Paulson: Another question please.

Audience member 6: I would like to ask whether you can tell us something about the musical functions of brain areas have not been mentioned here. Half of the cells of brain are glial cells; according to Douglas Fields, who has studied them more than most neuroscientists, who seem to ignore them, white matter or myelin, which is made up of glial cells, that surrounds professional pianists' axons is much more extensive

and thicker than it is for average people. What could possibly be the musical functions of glia? And the same question about most of the neurons, which are usually not mentioned because they are, I guess, so small; but, for example, three-quarters of neurons are in the cerebellum. Does the cerebellum have any musical functions that you know of?

Limb: Those are great questions. I have to say that the techniques that we use are really very crude. As I've mentioned, functional MRI is a vascular method; it's a hemodynamic method. It's not an electrical method, so we are not actually studying neurons with fMRI. We're studying blood flow. Among other things this means that we don't really know which neurons we're studying; we could be studying glia but just don't know it. Even so, fMRI is the best method we have for certain experiments and we know that it tells us information that we couldn't get before; yet, we can't take it to the next logical step.

Now, this is where I think experiments in humans are also limited because you just can't do single unit physiological recordings of neurons in an awake human, safely—we certainly can't get volunteers for it. So I think that we have to be quite realistic about what we're going to *know* when a human listens to music using techniques such as fMRI. And so I think the question you're asking is a good one but we're probably, I think, many years away from actually answering your question.

As far as the cerebellum, it's highly musical: if you hear this [*snaps fingers*] without moving, you will have cerebellar activity. And if I make the snapping slightly less regular, the activity is going to go up. If I make it even less regular, it's going to go up again. This implies that the cerebellum is efficiently hard wired to train to regular intervals, and when patterns deviate from that we start calculating that automatically, even though we're not moving. And so I think the cerebellum plays a huge role, probably an underappreciated role, in music perception because we tend to think of it as a motor coordination structure. But the cerebellum is probably very important in a lot of sensory processing that precedes motor outputs.

Paulson: We have time for one final question.

Audience member 7: I wanted to hear more both about embodiment and about emotion. I have a colleague at the University of Wisconsin who proposes that music evolved from the emotional communication in animals and has conducted interesting experiments consistent with that idea. So, the notion that music is generated by the need to communicate emotion would suggest that the body's peripheral and central systems are doing a particular thing when music is generated and when music is perceived, if you're going to actually communicate the emotion.

So does anybody have something to say about the preparation to create music through the induction of emotion and the role that the central and peripheral systems play in receiving the emotion from that perspective?

Bharucha: Well, I have something to say about emotion, anybody else go first here.

Tomaino: I can only speak to the resiliency of music and emotion in patients who have lost the ability to understand what they're going through. One of the reasons why we think that music affects, for example, people with Alzheimer's disease is that the emotional connections to music are so strong and so basic that it's able to be stimulated even when they can't consciously process what they're listening to. But that's from a clinical point of view; I'll let the scientists talk.

Limb: I'm not going to give a very scientific answer here. That's quite a last question to try to answer [*audience laughter*].

I have to say that I'm very skeptical, or cautious, about possible parallels between animal life and human life, particularly when talking about emotion. As a human I'm biologically biased to think in human terms and I can only apply these constructs in a pseudo-anthropomorphic way to try to understand what an animal's feeling. As far as we know, no animals have been able to report what they're feeling. I am very cautious about claims, for example, that a bird song is somehow linked to a bird's feeling about something.

That's not to say that the bird song doesn't serve a very primal biological function that birds require. I think about this in much the same way that I think about a flower being pretty: it doesn't care that it's pretty, we care. A bird might not care that its song is beautiful; it cares that the song it sings is correct. I don't know how we can prove these things. Yet, if you look at the brain of an animal and you look at the brain of a human there are a lot of similarities; in fact, probably a lot more similarities than differences.

Bharucha: I think emotion is one aspect of musical communication; I don't think it's the only one. I think there was a time when people would say music is the language of the emotions. I do not think that's true. We all know music can express emotions extremely powerfully; but music communicates movement as well, not necessarily just emotion. Music enables people to synchronize their movements and to create a very powerful sense of being a group—essentially a group consciousness. Is that an emotion? I don't think so.

But I think it goes further. Knowledge or experience in a particular music culture or subculture, and simply paying attention to certain kinds of complex patterns that might be recognized, synchronizes people in some way. They aren't necessarily feeling an emotion and they aren't necessarily dancing together, yet they are, in some sense, sharing the experience. So I think there are many ways in which music can actually communicate by virtue of synchronizing brains.

Paulson: We are out of time. Thank you so much, everyone.