2016
220th Annual Oration

ORATOR: **Joel Popkin, MD, FACP**
Clinical professor of medicine at UMass Medical School
and the director of Special Services at St. Vincent Hospital.

ORATION: Symphony of the Brain

A Summary of the WDMS Annual Oration, February 10, 2016

Some years ago, my wife Zenie and I attended a concert by the Shanghai Symphony, which played a glorious Beethoven's 7th Symphony. We talked about her being able to speak with the orchestra members in her native language and my being able to speak them in mine. They would understand both of us perfectly, although her symbols would be more accurate in language and my symbols more accurate in emotion. Magically, it would have been a great conversation for all of us.

How – and maybe more importantly why – did the truly international language of music – this lingua franca – develop? After all, music is one language the world over, whereas, according to the BBC, it's estimated that there are up to 7,000 different spoken languages in the world.

Why Did Music Evolve?

First of all, music has been around an awfully long time.

Apollo was god of the sun, healing and music. But music was around a lot longer than the Greeks, or the ancient Egyptians, or even the Chinese, whose flutes from more than 7,000 years ago seem contemporary compared to a Neanderthal bone flute from 43,000 years ago, which fits the holes of a modern flute. (Fig. 1) And who knows when reed flutes and animal skin drums preceded the Neanderthal flute?

Theories abound as to why music has evolved and been an integral part of every culture, bar none.

Josef Rauschecker, director of the Laboratory of Integrative Neuroscience and Cognition at Georgetown University, says this: "The idea that the brain gives specialized treatment to music recognition, that it regards music as fundamental a category as speech, is very exciting to me. … There are theories that music is older than speech or language. Some even argue that speech evolved from music. … Music works as a group cohesive. Music-making with other people in your tribe is a very ancient, human thing to do."[1] This makes sense, since hunter-gatherers' communities may have well been inspired by communal music and dancing.

The socialization and creation of communities were enormous evolutionary advantages. Most other animals (except birds, which are musical) don't live in big communities. It took music to do that – what turns out to be a very human trait.[2]

Which evolved first – music or language? Literacy was not "invented" until about 5,000 years ago, so it's much younger than music and must be taught. Music is universal, however. Babies develop music and dancing *spontaneously.* And they babble. No other animal does. And they do it even if congenitally deaf.[2]

Then, there's this whole human thing regarding the ability to enjoy music and take part in the emotion, the memories it elicits, the socialization it enhances. We are exposed not only to our thoughts and emotions but share those of others. And that was all said – and more – in nine words by Leonard Bernstein: "Music can name the unnamable and communicate the unknowable."

How Does Music Get to the Brain, and How is It Processed?

The auditory pathway begins with a vibrating ear drum, which delivers the vibrations to the snail-shaped, fluid-filled cochlea. Here, hair-like receptors that capture various frequencies turn music into electrical impulses, which then link via the auditory nerve to begin a remarkable journey deep into the brain via the auditory brain stem.

At the first relay station, the cochlear nuclei receive *tonotropic* (think, keyboard) projections and send fibers to the olives, which localize sound by calculating the difference in time of arrival of the sound as well as intensity – especially critical information in the days of hunter-gatherers. Farther up the pathway, changes in volume and background noise let them know about any saber-toothed tigers lurking nearby. It's this early in the pathways that motor centers are activated, well before awareness in the conscious brain.[3]

Higher up in the primitive brain stem (the mid-brain), harmony actually gets analyzed; discordant sounds activate this area. Very precise sets of sound data then move on to the auditory cortex, where, as Dr. Psyche Loui describes, "music makes the leap into the soul." Musicality is now extending to regions far beyond the auditory cortex, connecting sound processing to other things the brain does: moving, planning, remembering, imagining, feeling, co-activating all these other systems. [2,3] (Fig. 2)

Until now, the precise representation of music in the auditory cortex was poorly understood: Is processing of music, speech and other sounds based on shared or distinct neuronal paths? But in December 2015, an extraordinary group from MIT may well have transformed our understanding of music processing using a new calculation of voxel morphometry (think of voxels as three-dimensional pixels). We now know that the auditory cortex doesn't share pathways with linguistics but has its own dedicated, hard-wired music pathway.[4] (The implications of this technique for delineating and understanding other brain structures are staggering.)

Rhythm

Rhythm is terribly complex. Clapping to the beat requires *anticipating* the beat, not clapping once it's happened. Animals don't have rhythm. They can be taught to "dance," but it's not spontaneous, nor do non-human animals adjust to a change in tempo – except for a remarkable cockatoo named Snowball. (Fig. 3) Dr. Aniruddh Patel, a brilliant neurocognitive scientist at Tufts, studied thousands of claimed talents, but his close examination of the tapes consistently revealed inability to respond to variations, coaching by the owner or music layovers to match the animals' performance. But then he met up with Snowball, who spontaneously taps to rhythms, and, amazingly, with faster rhythms than he can manage, he taps every other beat! It turns out that parrots are one of the few vocal learners, other than humans, and this is probably the key to Snowball's and several other parrots' impressive performances. But even these champion musicians in the animal kingdom can't recognize transposed music or relative pitch, which simply might be exclusively human characteristics.[2]

Music-Evoked Emotional Responses

A large part of "Why music?" is the emotional response, rewards and pleasures. Happy or sad music, consonant (pleasant) or dissonant (harsher) music, and joy- or fear-evoking music all activate diverse areas of the brain in response to the differing music. Thus, music can arouse activity in the very core brain regions that underlie all emotion.[5]

Three of the major emotion centers of the brain are the amygdala, the nucleus accumbens and the hippocampus.

<u>Amygdala:</u> The superficial amygdala is sensitive to faces, sounds and music, suggesting that this crossover conveys signals of basic socio-affective information.[5] (Back to the hunter-gatherers.) But not only pleasurable or unpleasant music activates the superficial amygdala. Even unexpected or less pleasant single chords can do so. This is relevant because affective disorders such as depression or pathologic anxiety have been associated (among other causes) with amygdala dysfunction, so that modulation by music perception has implications for therapeutic approaches for the treatment.[6]

<u>Nucleus Accumbens:</u> Several studies have shown activation by pleasant music, leading to chills and so called "musical frissons" – experiences of shivers or goosebumps. The area is also sensitive to primary rewards (food, drink and sex) and secondary rewards (money and power).[5]

So can measurement of activity of the nucleus accumbens tell us how much a subject is enjoying a particular piece of music? And can it therefore even predict how much money the listener would be willing to spend on his or her preferred selection? Amazingly, the answer to both questions is yes.[7] So for those who worry that Google seems to know our every movement, ponder more about the power of functional MRIs!

<u>Hippocampus:</u> The hedonistic rewards that activate the nucleus accumbens do not fire up the hippocampus, even though music-evoked emotions do. By regulating the hypothalamus-pituitary-adrenal axis, the hippocampal formation reduces emotional stress via lower cortisol levels. Hippocampal activity stimulated by musical activity additionally supports social engagement and the communal sense of "we."[5] And it has been well shown that overall health is much better with socialization.[8]

Emotional Results and Rewards

Dr. Psyche Loui, a dazzling cognitive neuroscientist and mentor to me, has related this experience: "I was in a friend's dorm room in my third year as an undergraduate. … Rachmaninov's Piano Concerto No. 2 came up on the radio, and I was instantly captivated. … There are these slight melodic and harmonic twists in the second half that always get me! The aesthetic experience can be so intense that you can't do anything else."[9] The physical feelings – chills, tingles or "frissons" – can be felt so powerfully, these sensations are sometimes described as "skin orgasms."[9]

These feelings may become yet more powerful, even after knowing a song well. While the sense of surprise may have dissipated, a Pavlovian type of conditioning may lead to frissons. And singing and dancing can make people more cooperative, and chill-inducing songs effectively encourage altruism.[10]

Brain Chatter

So how do these disparate areas of the brain talk with one another?

When I was in medical school, in what now seems like the Dark Ages, knowledge about nerve pathways was based on myelin staining of brain tissue. This involved the pesky problem of requiring whole brains for pathology sectioning, for which volunteers were lacking. And, of course, it was not possible to follow up serially.

Back then, neuroplasticity was an unknown concept. The teaching was that the neurons we were born with went on to decline inexorably. For those who were more fortunate, decline was a slower process. But the advent of CT and MRI imaging of brain structure has shown that such is not the case. Moreover, functional MRI and other techniques represent even more staggering technological leaps by delineating *where* things happen in the brain and *how* these areas communicate with each other.

Progress continues, and at the Massachusetts General Hospital and other institutions, neurocognitive workers have pushed brain imaging toward the realm of science fiction, using purpose-built scanners – the most powerful in the world. The magnets consume 22MW of electricity – enough to power a nuclear submarine – to create a process called diffusion tensor imaging, or *tractography*, which allows us to visualize actual nerve tracts and demonstrate that communication can be enhanced in response to certain stimuli, one of the most important of which is music.[11] (Fig. 4)

For this discussion, we will touch upon only one representative, but vital tract, the arcuate fasciculus. (Fig. 5) This is the superhighway of language and music, and the newly modeled grid is part of recent data that suggest a novel view of the brain's organization. The arcuate fasciculus connects the two major language centers in the brain – Broca's and Wernicke's areas.[11]

How Does the Processing Affect Us?

Musical activity shapes the organization of the developing brain and also produces long-lasting changes. It sends visual, auditory and motor information to a specialized brain network consisting of fronto-temporo-parietal regions, which overlap with a "hearing-doing" or "seeing-doing" action-observation network. This is commonly known as the mirror neuron system – a critical component in learning and recovery from injury.[12]

Fetuses pick up sounds and move in response at about 37 weeks. They move more to familiar tunes, and the newborns who heard the tunes respond with higher heart rate, movement and alertness than those not exposed.[2]

And the reason they respond to familiar tunes is this: Using functional MRIs, newborns *1-3 days old* listening to tonal consonant music showed distinct right auditory cortex activation, whereas dissonant alterations of the music significantly reduced those activations, meaning that newborn brains have built-in specialization in processing music.[13] At age 6 months, starting music classes not only improves tonal pitch structure, etc., but also leads to a more positive *social trajectory*.[14]

As children get older, the pro-socialization advantages continue. Four-year-olds playing games linked with music-making show significantly increased spontaneous helpfulness and cooperation compared to those playing the same games without a music context.[15]

Children from underserved backgrounds stand at high risk for academic and social problems. With two years of musical training, they show a marked improvement in differentiation of syllables. So here we see a translation of the crossover of music and language that we see in brain imaging.[16]

Many gray matter structures are more prominent in musicians, as seen and measured by MRI. These structural differences appear to be more pronounced in those musicians who began training early in life, but functional improvements in older students beginning music studies are also impressive. Changes of white matter – the nerve tracts that we're now seeing with tractography – have now also come to light. Let's now return to the arcuate fasciculus.

In Fig. 6A and 6C, we see similar baseline arcuate fasciculi of two 8-year-olds. One then went on to study a string instrument while the other did not study music. Two years later, the size difference of their right arcuate fasciculi was striking, with the musician, and now others like her, demonstrating comparatively dramatic growth. (Fig. 6B and 6D) Other studies have shown that in adults, the amount of practice time correlates directly with arcuate fasciculus size.[12]

Work from a decade ago using PET scanning demonstrated the overlap of brain structures in music and language, in this case, comparing generation of melodies and sentences.[17] (Within the confines of this discussion; we won't even get to mention other central neurocognitive studies, such as EEG, MEG and SPECT scanning.) With this known overlap of music and language, we shouldn't be surprised that in development, children who have problems with music have problems with *prosody* – the patterns of stress and intonation in language. Prosodic cues are a fundamentally important aspect of communication.[18]

Can Musical Training Slow Cognitive Decline in the Elderly?

In short, yes. Practicing musicians have greater gray matter volume in the left inferior frontal gyrus compared to that of matched non-musicians. Age-related reductions in total brain volumes in matched non-musicians were not seen as frequently in musicians. This may translate into the observations that piano lessons seem to help age-related cognitive decline in musically naïve adults from 60-85[19] and that older professional musicians do better on a number of cognitive tests than matched non-musician controls.[20]

And who's to argue with Einstein, who predicted gravitational waves 100 years before their discovery? During his struggles with the extraordinarily complex mathematics that led to his general theory of relativity, Einstein often turned for inspiration to the simple beauty of Mozart's music. "Whenever he felt that he had come to the end of the road or into a difficult situation in his work, he would take refuge in music," recalled his older son, Hans Albert. "That would usually resolve all his difficulties." Einstein himself and his wife confirmed the same.

How Do We Use Music in Health and Disease?

Let's again start with the little ones, and in this case, among the most challenging and heartbreaking of problems: autism.

Auditory-Motor Mapping Training: AMMT is a process in which singing of words along with motor activities seems to employ the pathways that overlap language function. Children with autism process music the same way we do, *including* emotion. What we have to learn how to do (and just maybe we are getting there) is to transfer the music emotion to non-musical emotional responses.[21,22]

Recent data have added support to this concept by showing that connectivity in these children is preserved with song but not spoken words. What may actually be the problem is *hyper*connectivity for music at the expense of language, an area where Dr. Loui and others have contributed much important work. Song may be able to overcome the structural deficit for speech in autism.[23] And a recent paper suggests just that. In a pilot study, it was found that increased socio-communicative responsiveness in autistic children was brought about by sung vs. spoken directives.[24]

Alzheimer's Disease: We have long known that some patients have striking memory of music from earlier days and they retain words better if they learn them to music.[5] This is not really surprising, since many studies of Alzheimer's Disease have shown that the music areas of the brain are generally better preserved than the rest of the brain.[25] We don't yet know why.

Can we prevent Alzheimer's? An intriguing twin study has shown that the co-twin who played an instrument in older adulthood was 64 percent less likely to develop dementia or cognitive impairment.[26] While music is unlikely going to improve cognition in established Alzheimer's, it has been shown that music therapy decreases anxiety and depression, although it takes more than three months to do so, and it must be with music the patient likes.[27]

Strokes

Melodic Intonation Therapy: For strokes involving speech, MIT is a promising therapy. Patients can relearn to speak through a kind of singing speech – without overt singing – presumably by utilizing language-capable areas of the right brain. Congresswoman Gabrielle Giffords, following a horrific gunshot to her head, credits MIT for return of her speech.[28]

Actual increases in gray matter volume in frontal areas of the brain are seen in patients by simply listening to music after strokes, with the areas of increase correlated with enhanced recovery of verbal memory, attention, language skills and improvement of mood.[29]

Rhythmic Auditory Stimulation: RAS is a technique that provides impressive results for gait disturbances secondary to strokes, as well as Parkinson's. Videos from Spaulding Rehabilitation Hospital show us post-stroke patients who underwent weeks of intense physical therapy, but still required a walker and assistants. After just one hour of RAS, they were walking unassisted! Parkinson's patients, struggling mightily to do a simple step exercise, can do the task essentially normally during accompanying rhythmic music!

I end our adventure with the symphony of the brain with the hope that someday we will discover yet a new neurological pathway: one that maps out *resilience*. How were Beethoven, Mozart and other geniuses who suffered so mightily throughout their lives able to create music of such beauty that has yet to be surpassed? If only we knew how to channel the maniacs of our world to *sublimate* their frustrations from destruction to creativity. Who knows? Maybe more study and understanding of music will get us there. …

Figures:

Fig.1.Neanderthal Flute

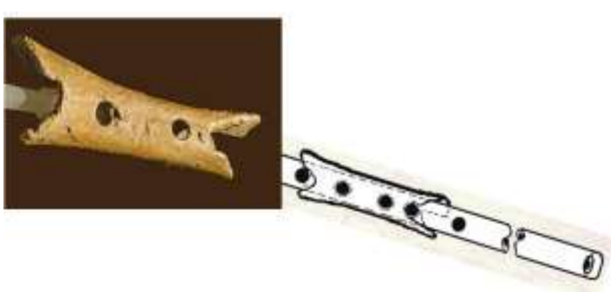


Fig. 2. Auditory Cortex

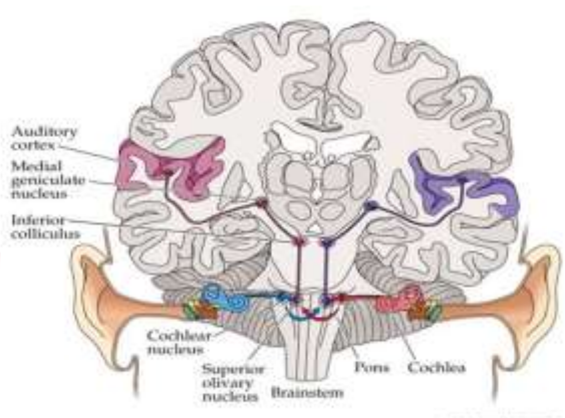
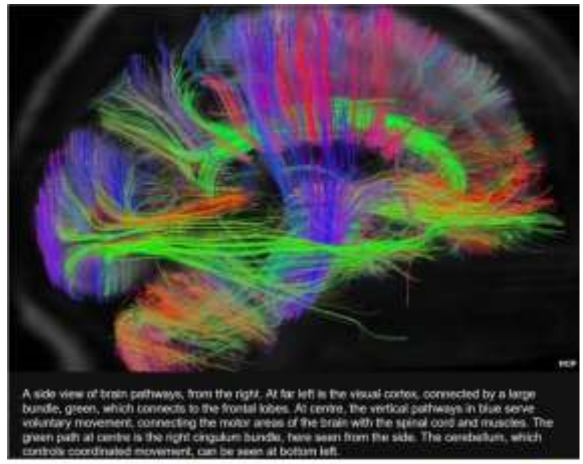


Fig. 3. Dr. Aniruddh Patel and Snowball



http://www.bbc.com/news/science-environment-21487016

Fig. 4. Tractography (see text)

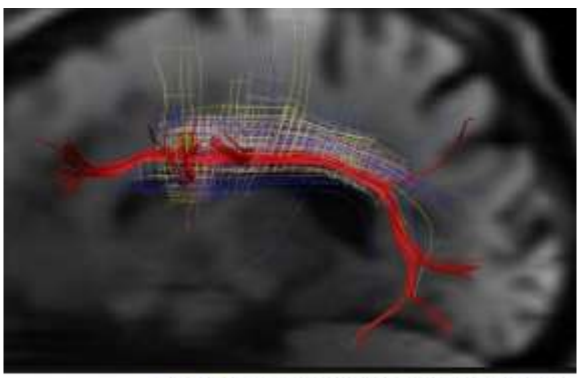


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Fig. 5. Arcuate Fasciculus (see text)

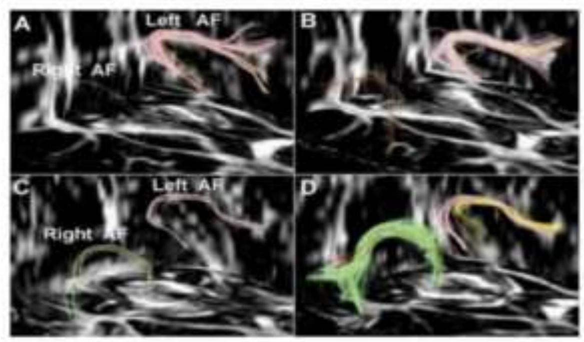

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Fig. 6. Arcuate Growth (see text)

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