Music and Its Effect on Us

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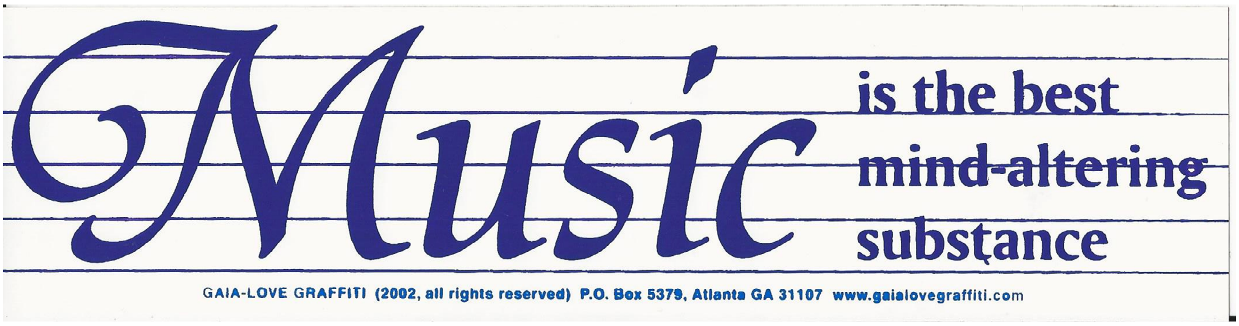
PLAY: The Swan by Camille Saint-Seans

While I am not a talented musician, as an engineer I became interested in the science of music. Tonight I want to talk about:

1. The science of good and bad sound
2. How music affects our brains, and
3. Music and learning

I saw this bumper sticker the other day.



Music is very important to us, and that is because it affects our minds. Music stirs our emotions. It evokes feelings of tension and release, anticipation and fulfillment, inspiration and hope, sadness and happiness, aggression or surrender. Music touches our emotions, high and low.

This is especially true of music combined with words, like opera or song, or combined with action, like movies or TV. But is also true of music alone, from popular to classical. Remember your reaction to our national anthem or "God Bless America" or, if your taste is more classical, the opening *Ba, ba, ba, bah* of Beethoven's Fifth or the choruses of Handel's Messiah.

No civilization has been discovered that did not have its music.

Americans spend more on music than we do on prescription drugs.

I want to start with a little history of music. We probably have to concede that vocal music is the oldest human music, but it leaves no artifacts to help us date it. The earliest instrumental music was almost certainly drumming. Rhythm makes us dance or move, even if it is just to tap a toe. Tempo can excite with a fast pace or lull with a slow pace. Rhythm underlies all music.

Next came melody. The earliest known tonal instruments are bone flutes found in various European caves. These Paleolithic flutes date about 42,000 to 43,000 years old. One comes from a cave in NW Slovenia. Another comes from the cave in SW Germany where the Venus of Hohle Fels was discovered. Flutes of reeds and other vegetable materials no doubt predated the bone flutes but left no artifacts.

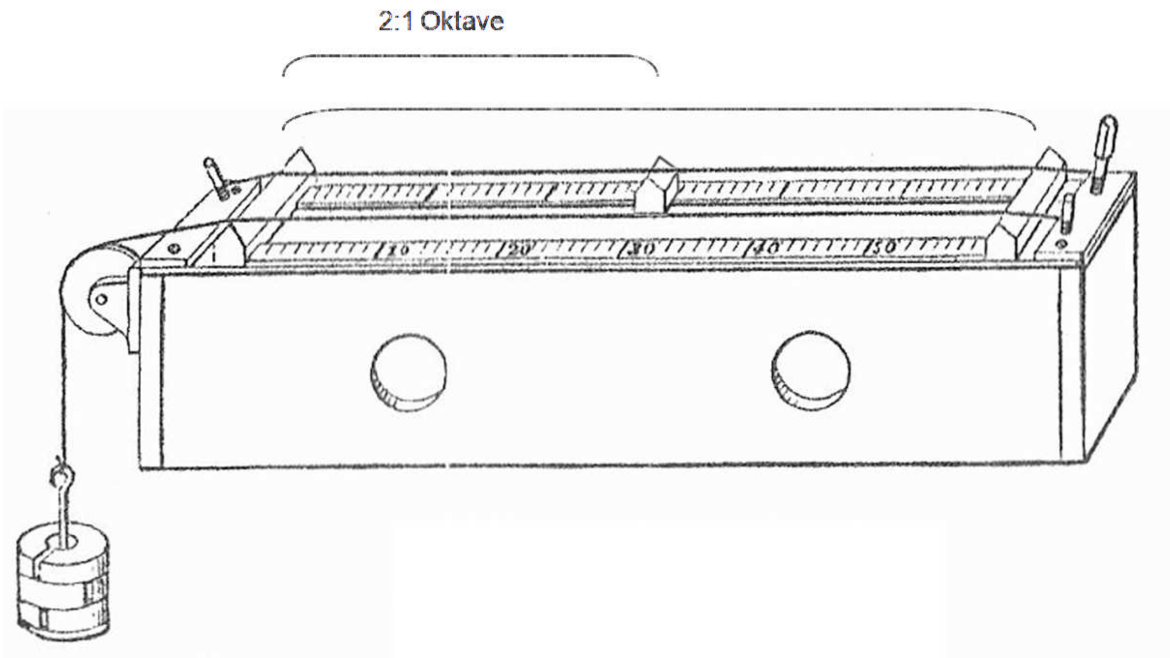
1 Divje Babe flute

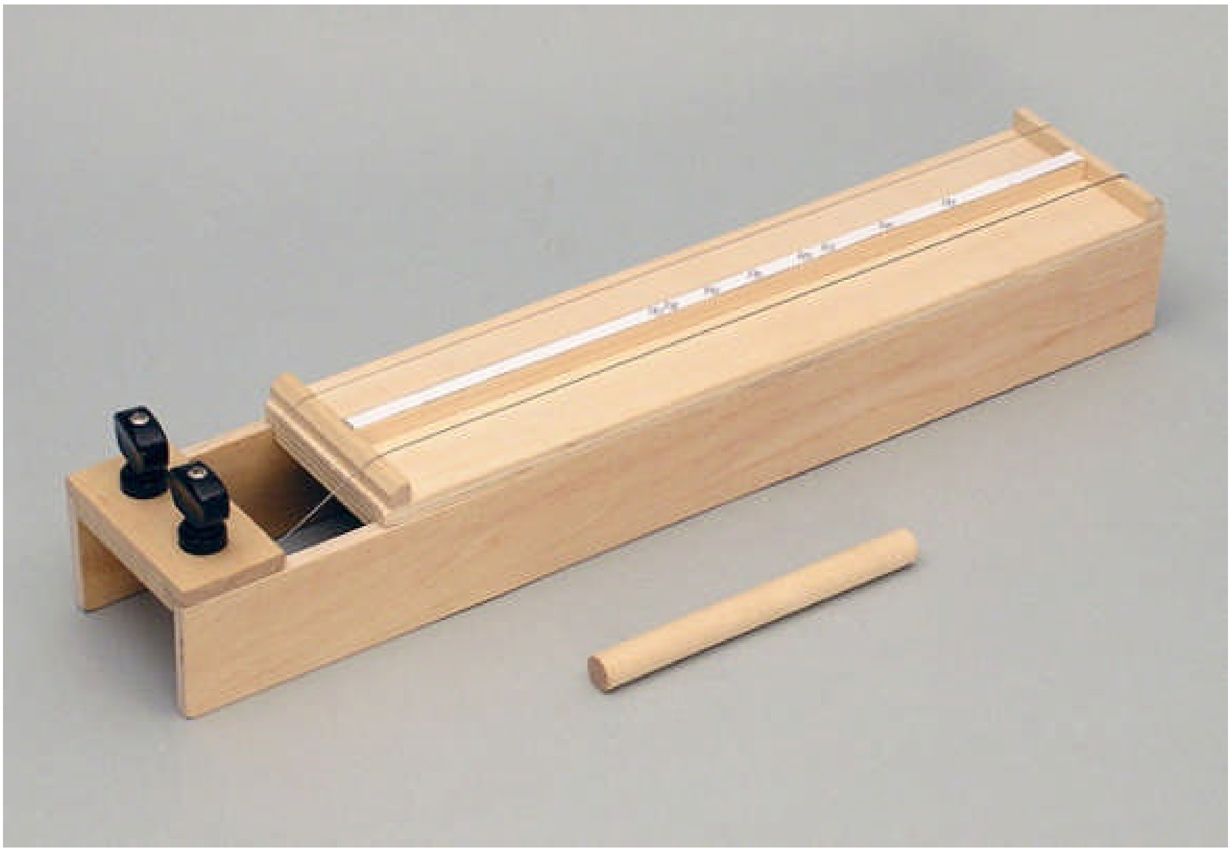
2 Hohle Fels Flute

Melody carries the emotion. The smaller phrases of music, such as theme, variations, and repetition, combine into larger structures—sonatas, symphonies, operas, etc. Dramatic arch, tension and release, anticipation and fulfillment, tells the full story.

But to have melody, we need our sound organized into tone and harmony, and this is where the physics comes in. Because it involves math and is probably boring to most of you, I will get it out of the way first.

Scientific study of tone and harmony began with Pythagoras and his contemporaries about 2500 years ago. They used an instrument called a monochord to relate the pitch of a plucked string to its length and tension.





Key to music’s effect is consonance and dissonance between two tones, the good and bad of music. The Pythagoreans explored the consonance and dissonance by dividing the string into two portions with a moveable bridge. They adjusted the bridge until the tone from each section blended into a pleasant harmony. They found that the most pleasing combinations occurred when the strings lengths were simple ratios to each other. In addition to unison (1:1) and the octave (2:1), the ratios of 4:3 and 3:2 produced the most pleasing combinations. Today these intervals, the Fourth and Fifth, are still called the perfect intervals as the Pythagoreans called them. In fact, they believed that all of the major musical intervals could be expressed as simple rations of the first four integers.

This conviction to simple proportions pervaded other fields, especially art and astronomy. Ptolemy wrote on both music and astronomy. Plato gave the name “harmony of the spheres” to the unheard music of the revolving planets, an idea that influenced Kepler in his description of planetary motion and has persisted in literature through Shakespeare and Milton.

The reasons for the consonance of simple rations became better understood when we learned about harmonics, also known as overtones. Every item that vibrates does so at not only its base frequency, but at 2x, 3x, 4x, etc. the base frequency. If we play a tone of 100 Hz, it will contain components of 200, 300, 400, 500, 600 Hz etc. Using our ratio of 3:2 or a fifth, the tone 150 Hz will contain harmonics at 300, 450, 600Hz etc. So you see, they reinforce each other at 300, 600 Hz, etc.

Much of the pioneering work in this field was done by Hermann Helmholtz, who was inspired by the mathematical work of Georg Ohm, for whom the famous electrical law is named. Helmholtz painstakingly developed “harmonic profiles” of different sounds by using resonators sensitive to particular tones.

Let’s go back to Pythagoras and build a scale between our first note and its octave. We have a base or tonic and its octave, plus two notes in the middle. To put it in musical terms, if we are building a C Major scale (the white notes on the piano) we have determined the relative pitch of C, F, G, and C’.

The next most pleasing rations are 5:4 (third) and 5:3 (sixth). Our scale now has 5 of its seven notes.

C	D	E	F	G	A	B	C
1/1		5/4	4/3	3/2	5/3		2/1
first	second	third	fourth	fifth	sixth	seventh	octave

Going up a fifth from E (5/4 x 3/2 = 15/8) or a third from G (3/2 x 5/4) gives us a B at 15/8. Not exactly the simple ratios of 1, 2, 3 or 4 that Pythagoras hoped for, but it is in harmony with two other notes.

C	D	E	F	G	A	B	C
1/1		5/4	4/3	3/2	5/3	15/8	2/1
first	second	third	fourth	fifth	sixth	seventh	octave

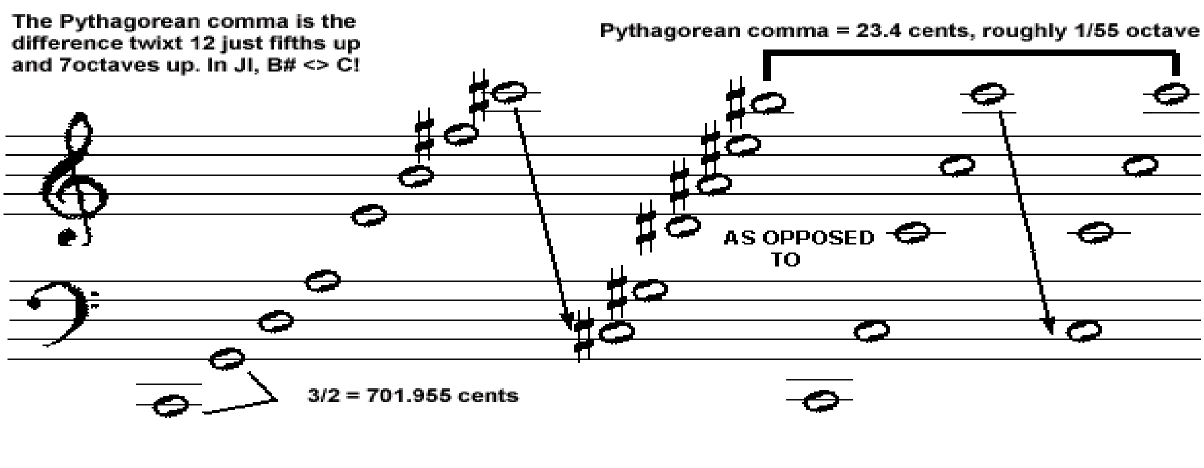
Now let us fit in a D. Going down a fourth from G gives us 9/8 (3/2 ÷ 4/3 = 9/8). But going down a fifth from A gives us 10/9 (5/3 ÷ 3/2 = 10/9). Already we have identified a dilemma on one note. What if we take the ratio of 9/8 for our D and go up a fifth to calculate the A (9/8 x 3/2 = 27/16)? Again this does not agree with our previous value of 5/3. Each time we try a different approach we find another conflict. Here is a one octave C scale with some of the possible conflicts shown.

C	D	E	F	G	A	B	C
1/1	9/8 or 10/9	5/4	4/3	3/2	5/3 or 27/16	15/8 or 243/128	2/1
first	second	third	fourth	fifth	sixth	seventh	octave

And we have not even considered the sharps and flats needed to make a complete 12 tone chromatic scale.

The long story made short is that the ratios of small whole numbers do not add up to a simple scale system. Not that this stopped people from trying and hundreds of scale versions have been developed over the centuries.

Another example: we can continue our expansion with the 3:2 ratio (fifth) by simple multiplication, creating what is called the circle of fifths. It takes 12 repetitions to get around the circle, creating each of the 12 tones of the full chromatic scale. The final note created, B#, should be equal to a C, but it is higher by a ratio of 531441/524288, or 1.01364. The difference is known as the Pythagorean comma"—it is the dislocation between the system of octaves and the system based on fifths.



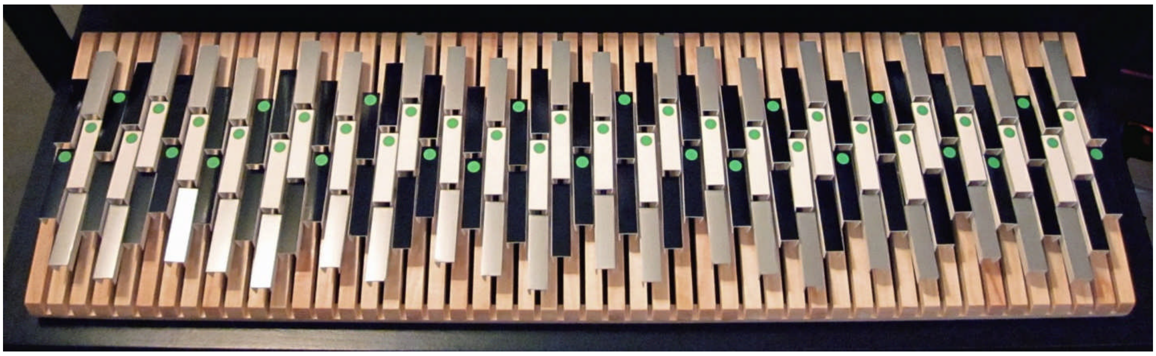
We can find other examples of the misfit between these fractional approaches by building scales with thirds or fourths. I picked the octave vs fifth as an easy way to illustrate that music does not yield to a simple mathematical solution. In fact, this became a major philosophical battleground for nearly 2000 years. The subtitle of one on my references is “How Music Became A Battleground For The Great Minds Of Western Civilization”. Among the notables who weighed in were Isaac Newton, Johannes Kepler, Jean-Jacques Rousseau, Galileo Galilei, Rene Descartes and Voltaire.

The philosopher Schopenhauer said, "...thus, a perfectly pure harmonious system of tones is impossible not only physically, but even arithmetically. The numbers themselves, by which the tones can be expressed, have insolvable irrationalities.”

In early Greek music there was still no concept of harmony. Early music avoided the harmony problem by limiting music to one melody line, called monophony. Later an embellished version of the same line was added, creating heterophony. The first polyphony was parallel organum with two to four identical melody lines a fifth or an octave apart. Gradually, the melody lines diverged and developments, like counterpoint and the fugue, developed. These more advanced forms of music were often banned by the early Catholic Church, which preferred monophonic music. They felt embellishment and even harmony obscured the words of the Mass. The best example is plainchant, also known as Gregorian Chant.

As music became more complex the need for better-tuned thirds and increased and temperament was born. Temperaments involve variations of spreading the Pythagorean comma around. In the Renaissance, a popular tuning was quarter mean-tone temperament in which 8 thirds are in tune and the remaining 4 are out of tune. This was practical because Renaissance music was composed in only a few keys that avoided the dissonant or “wolf” thirds. Other irregular temperaments evolved and carried the names of the master tuners who invented and used them—Werckmeister, Kirnberger, Neidhardt, Vallotti and others. An irregular temperament of this type was probably what Bach intended for his Well-Tempered Clavier.

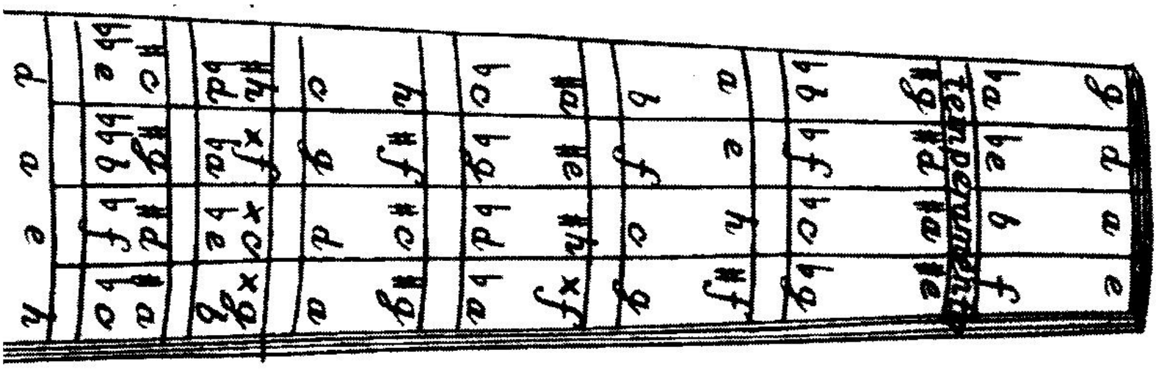
Many other tuning systems were tried. Keyboards were made using 19, 31, 43, 50, 53, and even 55 notes per octave.

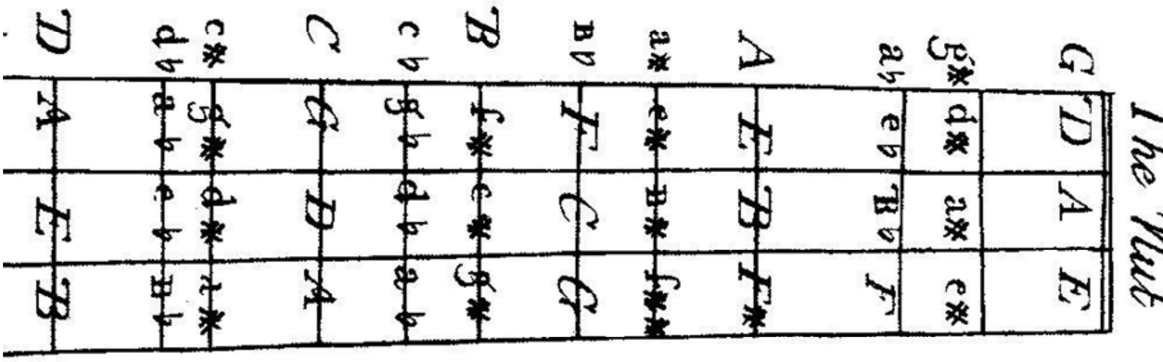


Modern keyboard with 31 notes per octave

Orthotonophonium with 60 notes per octave circa 1914.

Just intonation is a system that requires all consonant intervals to be harmonically pure. This means that some notes have to change in tone depending on the context, for example, a G# in the key of A will be slightly different than an Ab in the key of Eb. This is not possible with keyboard instruments or stringed instruments that utilize frets; it is possible only with the voice and instruments whose tone can be changed at will.





One result of a just-tuned group of voices or instruments is that the overtones can be heard just as if someone was singing or playing them. The Mamas and the Papas called this fifth voice “Harvey.”

The important thing about all of the above temperaments and Just Intonation is that each key sounded differently. When a composer wrote in E he expected it to have a different character than a piece in Bb. In 1796 Francesco Galeazzi wrote, “Bb Major is tender, soft, sweet, effeminate, fit to express transports of love, charm and grace. E Major is very piercing, shrill, youthful, narrow and somewhat harsh.”

The temperament we use today—equal temperament (ET)—was known as early as the 1700s but was resisted for a long time by musicians because of out-of-tune thirds.

It finally became the standard for keyboard instruments around 1917. ET is based on the absolute same spacing between the twelve semitones on the octave by a ratio of the twelfth root of 2, or 1.05946. Critics contend that all the intervals are now out of tune. In 1759 Robert Smith wrote, “But the harmony in this system of 12 Hemitones is extremely coarse and disagreeable.”

The appeal of ET is that it allows music in any key to be played on keyboard instruments without retuning, but when we move a piece from Bb to E we simply transpose it to a new pitch without changing the characteristics. About the only key characteristics that have been preserved are Major and minor.

The physicist Art Benade liked to do an experiment similar to Pythagoras’ but with modern electronic oscillators. When he used whole ratios everyone agreed the interval was in tune. Otherwise, “when the equal temperament or Pythagorean thirds [were sounded] by means of two electronic tone generators, the usual question [was] ‘What makes anyone think that those are acceptable tunings?’”

Our attitudes have changed today, and we have become accustomed to ET. And even though it does not produce perfect harmony, ET does produce music acceptable to most of us.

For a thorough discussion of temperament I refer you to <u>How Equal Temperament Ruined Harmony (and Why You Should Care)</u> by Ross Duffin. Duffin is an advocate of Just Intonation and director of the Cleveland based vocal group Quire.

But in all tuning systems there are dissonant as well as consonant intervals. Today we consider the Unison, Octave, Fourth and Fifth to be consonant, the second and seventh to be dissonant, while the third and sixth are called imperfect consonances.

MUSIC AND THE BRAIN

Writings on music and the brain were non-existent before the 1980s. The first reports were anecdotal. Dr. Oliver Saks relates many cases when upset patients were calmed by music, patients who could not speak could sing, and ideas that they could not understand in words were understood when sung. I recommend reading any book by Sacks, especially <u>Musicophilia</u>. One quote from Sacks:

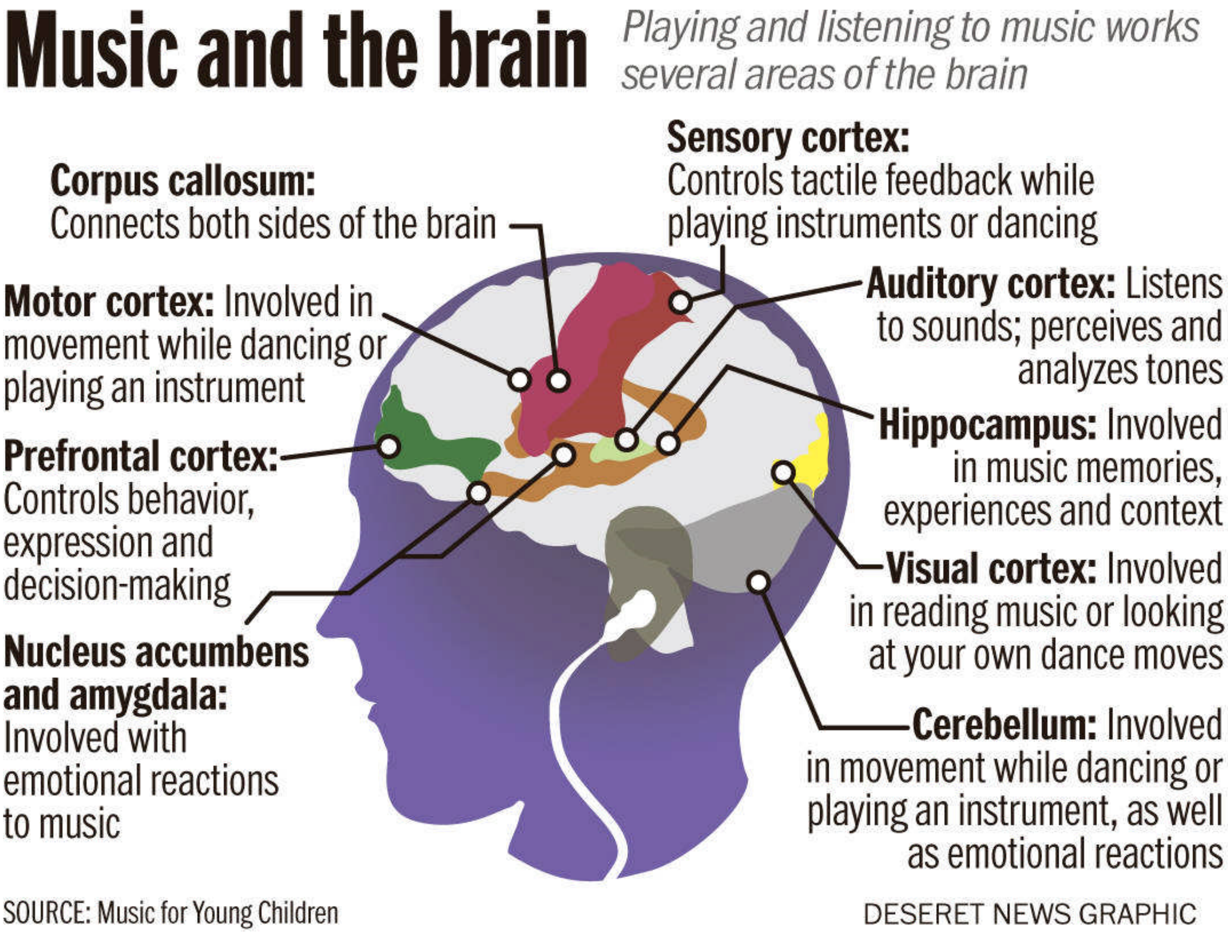
"One does not need to have any formal knowledge of music — nor, indeed, to be particularly 'musical' — to enjoy music and to respond to it at the deepest levels. Music is part of being human, and there is no human culture in which it is not highly developed and esteemed."

MUSIC AND LEARNING

The next generation of research involved looking at EEGS of people who were playing or listening to music, and, as far as I have seen, this research was fairly unproductive.

There were also many studies that showed that listening to music increases intelligence—the so-called "Mozart Effect." This seems to be true of spatial, verbal, and mathematical intelligence, but the effect seems to be short-lived. There is considerably more evidence that *playing* music increases intelligence and that it does so on a more permanent basis. At first, this research was anecdotal, but recent science is showing us concrete evidence of how and why.

Things started to change when neuro-scientists began to use PET and fMRI to show brain images during musical activity. Key discoveries were that consonant and dissonant sounds activated different areas of the brain, explaining our different response to them. Listening to music stimulates more areas of the brain than reading, doing math, viewing art, or watching sports. Even better, playing music stimulates even more areas of the brain and causes them to grow. One scientist called playing music a full-body workout for the brain.



In particular, playing music causes an increase in size of the Corpus Collosum, the bridge between the right and left hemispheres of the brain. Since music involves both hemispheres, more rapid communication between them enhances our skill. And this improved bridge also improves other skills that involve both hemispheres, including social skills, decision-making, and memory.

I should add at this point that Oliver Sacks has been an active supporter and participant in this latest research. In the bibliography there are links to two interviews with Sacks. In one his brain is scanned as he listens to music. Dr. Sacks says, “There is now an enormous and rapidly growing body of work on the neural underpinnings of musical perception and imagery...these new insights of neuroscience are exciting beyond measure.”

At a cellular level, we also understand what is going on better than we did previously. Practice of any skill, but particularly playing music, increases the number of neural or networks pathways, and repeated practice causes these pathways to become insulated with the compound myelin: that is the white substance mixed up with the grey matter in our brains. Myelination allows the neural network to fire faster. MRI scans show that musicians have more myelin in their brains than non-musicians.

You may have heard of the “ten thousand hour theory,” which says that it takes 10,000 hours of practice to become an expert in any field. That’s a lot of time and will probably keep most of us from becoming experts in some new field. But music playing brings so many benefits that it is worth a shot.

The adage “practice makes perfect” has been turned on its head to “perfect practice makes perfect.” If you really want to improve a skill there are certain key ways to go about it.

1. Chunk your activity into manageable parts, maybe just one measure of music at a time.
2. Start slowly so you can do it without mistakes.
3. Repeat. Repetition is a key element to retention
4. Keep it challenging. Play faster, or add another measure.
5. Practice frequently.
6. Get feedback to make sure you are practicing correctly.

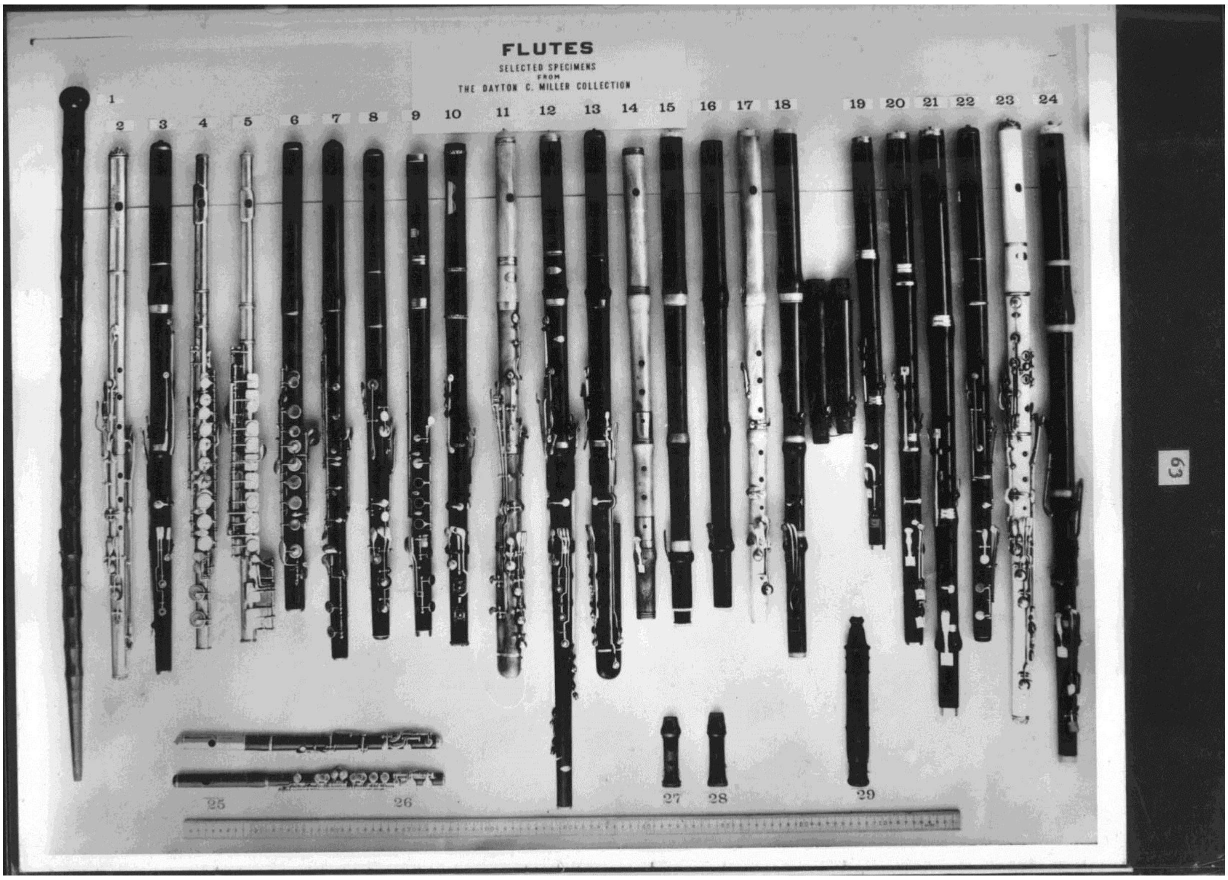
I hope this has interested some of you to start or return to playing music. While the young mind is a little myelin factory, our older minds remain plastic and capable of forming new neural pathways at any age. To peak your interest, I want to point you to some inspiring books on adult learners:

<u>Noah Adams’ Piano Lessons</u> chronicles the year when, at age 52, Adams purchased a piano and learned to play. Adams is the host NPRs All Things Considered.

Ari Goldman’s <u>The Late Starters Orchestra</u> is about his return to playing the cello after a 25-year absence and joining the LSO.

<u>In Guitar Zero,</u> Gary Marcus writes about taking up guitar at age 40. Marcus discusses the science of learning, the importance of proper practice, and finding the right teacher.

Summary



As I explored these aspects of music, two themes kept popping up: flutes and CWRU. As a flute player, I learned of the Dayton C. Miller collection of flutes housed at the Library of Congress. Dayton Miller was an enthusiastic amateur flute player and amassed a collection of over 1500 flutes, plus hundreds of other items related to the flute. He translated the book The Flute and Flute Playing by Theobald Boehm, the inventor of the modern flute fingering system. Miller was also a physics professor interested in musical acoustics and published a book on the subject. By coincidence, Miller was head of the Physics Department at the Case Institute of Technology until his death in 1941.

Miller was succeeded at Case by another flute player and musical acoustician, Arthur Benade. Benade published several books on the subject, including Fundamentals of Musical Acoustics, a book I keep referring back to. Benade lived until 1987, but I did not have the pleasure of meeting him.

When my wife retired and returned to studying music, I became curious about tuning and picked up the book How Equal Temperament Ruined Harmony, little knowing its author, Ross Duffin, was a professor at Case, now renamed CWRU.

The final coincidence was when I began exploring the history of music and discovered that the oldest known instruments were flutes.

Thank you for your attention.

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TV and Internet

PBS Nova Musical Minds with Oliver Sacks
Jon Stewart interviews Oliver Sacks
Steven Errede, Consonance and Dissonance: UICU Physics 406
http://national.deseretnews.com/article/2281/Tuning-up-childhood-The-power-of-playing-music-in-the-lives-of-kids.html

Recommended reading in **Bold**