The Differences Between Musicians' and Non-musicians' Brains

By Molly Gebrian

As musicians, we subject our brains to a regime of training that is virtually unparalleled in its intensity and duration, not to mention the level of exquisite perfection we are expected to attain. Most of us started our instruments when we were very young, have practiced daily for hours ever since, and will continue to do so for many more decades. There is no other field that demands this sort of commitment or the high level of performance from our ears, hands, and mouths that we easily take for granted. This is bound to leave an impact on the functioning of our brains. In fact, neuroscientists see musicians as a ready-made experimental group to study what happens to the brain when it undergoes this kind of rigorous training. How the brain learns is one of the mysteries of neuroscience and scientists have turned to studying *us* to help answer some of their questions. What they've found is fascinating, but musicians rarely find out about it because neuroscience studies are really hard to read. In this paper, I hope to describe (in an intelligible way) the findings of neuroscientists working in this field to help musicians better understand themselves and their audiences, both musicians and non-musicians' alike. I will divide this discussion into two parts: functional differences (differences in the way musicians' brains respond to music) and structural differences (actual differences in the brain itself, not just how it responds). Finally, I will look at the phenomenon of perfect pitch and what has been discovered about how it works.[*] Hopefully, you will come away with a new appreciation of your brain and how you have sculpted it, figuratively and literally, in all your years of practice and study to be a musician.

Functional Differences

Everyone has heard about left-brained versus right-brained people. Left-brained people are supposed to be analytical and logical, while right-brained people are supposedly creative, abstract, and holistic in their approach. While this is an oversimplification of both people and brains, it is nonetheless fundamentally accurate as a gross comparison. When neuroscientists first started looking at musicians' brains, it was noted that non-musicians' processed melodies better in the right hemisphere, while musicians showed left hemisphere superiority.[**] When Thomas Bever and Robert Chiarello found this difference (Bever and Chiarello, 1974), they explained it as evidence that a musician's training enabled him to listen to a melody more analytically. Musicians, it seems, are able to perceive and mentally manipulate the component parts of the music they hear, while non-musicians can only treat a melody as a whole entity. This left hemisphere dominance, not just for melody perception but also rhythm and harmony, has since become widely accepted in the neuroscience community. Interestingly, the left

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[*] This paper is not intended to show how music education benefits other brain functions; that is an insult to the study of music because it assumes that music is only worth studying as a way to boost other mental faculties.

[**] Neuroscientists all use different definitions of what constitutes a musician. Most often, the musicians in these studies are working professionals or conservatory students. Almost all of the musicians studied were in their late 20s to early 40s, had started their instrument before age 7, and practiced 4 hours a day on average.

hemisphere is also the dominant hemisphere for language, a connection that will be looked at more later.

In addition to this shift in which side processes music, the area of the brain that processes sound in general (called the auditory cortex) also reacts differently to musical input. Whenever any kind of sensory input comes into the brain, be it the opening of the *Rite of Spring* or someone stepping on your toe, the brain responds to it so you know to sit still and listen or to pull your foot away. This response is in the form of an electrical and magnetic change which neuroscientists can measure using something called EEG (electroencephalography) and/or MEG (magnetoencephalography). When musicians are played something as simple as a single note, the response of their auditory cortex is about twice as large as a non-musicians' (Schneider, et al., 2002). In addition, the strength of this response is highly correlated with the age that the musician began their instrument. This response of the auditory cortex happens so quickly that it is not under conscious control, meaning that musical training fundamentally changes how our brains respond to what we hear. In fact, Patrick Wong and his colleagues at Northwestern recently found that musicians have enhanced processing of pitch patterns in language (because most of us don't talk in a flat voice like a robot, but have ups and downs in pitch while we speak) in the *brainstem*, which is evolutionarily the oldest part of the brain and is concerned with the fundamentals of existence (Wong, et al., 2007). When you usually think of musical training, it makes sense that it would affect the so-called "higher" functions of the brain, those associated with intellect and analytical processes, but that it can affect the brainstem too is incredible.

Neuroscientists have also looked at differences in the motor areas of the brain between musicians and non-musicians. Usually these studies involve teaching everyone a finger tapping task and seeing how quickly and accurately they can do it. As you would expect, the musicians always do better. The surprising thing is that the musicians' brains show *less* activation in these tasks, not more. Many different areas of the brain are busy when non-musicians do these tasks, but not all these brain regions have to get involved when musicians do them. This result is taken to mean that even complex finger taping tasks are so easy and have become so automatic for musicians that they don't really have to think about them. For musicians, complex finger movements have become as second nature as writing, another complex fine-motor task. There is a very interesting study by Lotze and his colleagues in Germany that compares professional and amateur violinists while they finger the third Mozart violin concerto (Lotze, et al, 2003). They also found much wider activation in the amateurs (meaning more brain areas were busy). Interestingly, an area of the brain associated with motor control, the basal ganglia (this is the area that goes haywire in those with Parkinson's disease), is only active in the *amateurs*. It has been hypothesized, based on other studies, that once a motor response has become automatic, the basal ganglia are not needed anymore. This is very strange if you think about it: playing a Mozart violin concerto becomes so automatic that an area of the brain deeply important for motor control isn't even necessary!

Another intriguing finding of this study, that has been reported in other experiments as well, is that musicians' motor and auditory cortices are interconnected. For most people, what they hear doesn't cause them to have automatic associations with movement, and moving certainly doesn't cause them to hear things in their heads. But if a musician listens to a recording of a piece they know and play well, not only does their auditory cortex light up on a brain scan (called an fMRI), but the portion of their motor cortex devoted to their fingers does too. Furthermore, neuroscientists have shown that the motor cortex isn't just lighting up as a whole unit – the areas that control the individual fingers light up in the order and timing necessary to execute the correct fingering (Bangert and Altenmüller, 2003). (When these kinds of studies are done, measures are taken to make sure the musicians aren't actually moving their fingers.) The opposite happens too: in Lotze's study, when the professional violinists fingered the Mozart on their chests, their auditory cortex lit up as it would if they were actually playing (and hearing) the piece. Interestingly, this wasn't the case in the amateurs - only their motor cortices lit up.

All of the studies discussed so far show that musicians' auditory and motor processing of music as a whole, as well as their motor output, is fundamentally different than in non-musicians. But when you break music down into its component parts, you continue to find differences in the way a musician's brain responds. The next batch of studies I will describe look at how musicians process pitch, melody, harmony, timbre, and phrase structure. In order to understand them, you have to know about a brain response called mismatch negativity (MMN). This is often used in language studies and is a way to look at how well the brain has internalized different "rules." So, in the case of language, if you present a sentence one word at a time (either aurally or in print) that reads, "The man went to the store to buy a walrus," your brain would elicit an MMN at the word walrus because that's clearly not the right word. You don't know what he's going to the store for, but it's not a walrus. The MMN is simply an electrical brain response to something that's out of place. Neuroscientists studying music perception use this technique as well to see how well musical rules have been internalized.

First we'll look at studies on pitch perception and melody. In a study by Mireille Besson and Frédérique Faïta, musicians and non-musicians were played familiar melodies in which the last note was either correct or incorrect (Besson and Faïta, 1995). There were two varieties of incorrect notes, those which were diatonic and those which weren't. The musicians' brains had a much larger response to the incorrect pitches than the non-musicians', especially when the wrong note was diatonic. This was also found in children who had studied music for an average of four years (Magne, Schön, and Besson, 2006). In the children, those who had studied music showed brain responses that weren't even present in the brains of those who hadn't had music lessons. That means that the child musicians were processing information that the non-musician children didn't even *perceive*. In another experiment, Tervaniemi and her colleagues played a four-note scale (E-F-G-A) over and over to musicians and non-musicians while they read a book to make sure they weren't paying attention to the aural stimulation (Tervaniemi et al, 1997). Every once in awhile, the scale turned into broken thirds instead (E-G-F-A). Although the brains of both groups elicited an MMN to the broken thirds, the response of the musicians' brains was much larger, even though they weren't even paying attention.

All of these studies, however, use familiar melodies or pitch patterns (like scales). You could argue that musicians just have better musical memories, not that they are better at processing melodies. A study by Fujioka, et al., on the other hand, used melodies composed for the experiment and found the same thing (Fujioka, et al., 2004). In this study, musicians and non-musicians were presented with short, five-note melodies composed for the experiment. Like the Tervaniemi study, they were distracted so they wouldn't be paying attention to the stimuli. Every so often, the last note of the melody changed, either in contour (down instead of up) or in interval. The musicians had really big MMNs, even though the "correct" melodies were new to them. The responses of the non-musicians were very vague and didn't constitute a clear MMN. The experimenters also ran another experiment with the same people in which they played the same stimuli, but asked them to pay attention this time. They presented two melodies, either exactly the same, or one with a changed last note (either by interval or contour) and asked the subjects to say whether they were the same or different. The musicians got over 95% correct regardless of whether the non-matching ones differed in interval or contour. The non-musicians, on the other hand, only got 63% correct when the interval was changed and 86% correct when the contour was changed. So whether or not they were paying attention to what they were hearing, the musicians could detect changes far better than the non-musicians. This shows that the auditory processing of musicians is much more finely tuned at a fundamental, unconscious (or pre-attentive, as scientists call it) level than non-musicians.

Perhaps the most interesting study on melodic processing in musicians is one by Tervaniemi and her colleagues from 2001. In this study, they also played melodic fragments to musicians and non-musicians who were not paying attention, with infrequent "incorrect" melodies, although this time, the "wrong" note was in the middle. Nobody elicited MMNs. Next, they had them pay attention and to press a button when they heard the incorrect melody. By analyzing the results, they were able to divide the subjects into accurate and inaccurate responders. Then they played the melodies to them again, but had them ignore them (by watching a silent movie). This time, the accurate responders showed an MMN, while the inaccurate responders did not. The most interesting part of this study is who the accurate and inaccurate responders were. All the accurate responders were musicians, most of them jazz and pop musicians. All of the non-musicians were inaccurate responders, but so were most of the *classically-trained* musicians. This result is fascinating because jazz and pop musicians learn music almost entirely by ear, while classically trained musicians do not. It would be interesting to see if Suzuki trained musicians responded more accurately since their early training is done entirely by ear.

The same superiority is found in musicians for processing harmonies (Koelsch, Schroger, and Tervaniemi, 1999). In this study, musicians and non-musicians were played major chords that were either in tune or very slightly out of tune while they read a book. The musicians showed an MMN to the out of tune chords, but the non-musicians did not. When asked afterwards if they remembered hearing anything out of tune, even those musicians who said they didn't had elicited MMNs. When they were asked to pay attention, the musicians detected 83% of the out of tune chords, while the non-musicians only detected 13% (with six of them detecting less than 1%!). This is amazing: musicians can automatically detect very slightly out of tune chords even when they're not paying attention that non-musicians can't hear even if they are paying attention.

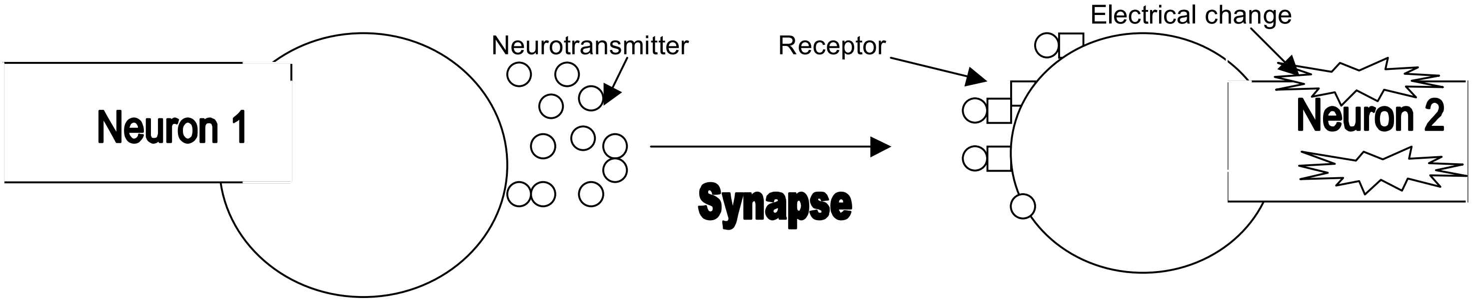
In all of these studies on musicians' brains, two alternative explanations for the results exist: either the musical training we undergo changes our brains, or our brains are different to begin with and the people who end up as musicians were predisposed to it because of their superior auditory abilities. Most people would agree intuitively that it is the former, but science always has to consider the alternative. In the first studies I discussed, about superior auditory processing in general, it was always found that musicians' brains had a larger response to piano or violin tones or to tones with many overtones, than to pure tones (which are just the fundamental with no overtones, a sound only a synthesizer and some organ pipes produce). This implies that something about musical training and listening to musical instruments causes this increased response. The study that makes this idea even stronger is one that looked at violinists and trumpeters (Pantev, et al., 2001). They found that the violinists' responses were the strongest to violin tones and the trumpeters' responses were the strongest to trumpet tones. It would be quite ridiculous to say that trumpeters become trumpeters because their brains respond preferentially to trumpet tones over the notes of any other instrument. This study adds decisive support to the idea that it is our *training* that changes our brain responses, not some predisposition in how our brains function.

The final category of studies in this section concerns the processing of musical phrases. Studies have shown that musicians are better and more precise at integrating sounds together into a phrase when there is a long rest in the phrase, even when they're not paying attention (Rüsseler, et al., 2001); and are better at grouping notes together by a variety of parameters (sameness of pitch, contour, meter, duration) than non-musicians who seem to have a more limited means of grouping pitches (van Zuijen, et al., 2004 and 2005). The most interesting study, which ties into the idea of left hemisphere specialization in musicians, was done in 2006 by Neuhaus, Knosche, and Friederici. They played binary phrases (mostly parallel periods) to musicians and non-musicians and manipulated the cadence in the middle to prolong or eliminate rests. The main finding of their study was that musicians process musical phrases much like language is processed. Non-musicians, on the other hand, relied strongly on violations of what they expected in terms of sound continuity to group the notes into phrases. While they listened, they were asked to do a task unrelated to musical phrasing to ensure that their brain responses were passive rather than active. That musicians process music like language is fascinating in itself, but also in light of the finding that musicians are left hemisphere dominant for musical perception. It implies that the more trained in music you become, the more you are able to analyze musical input and think about it analytically rather than abstractly and to manipulate its parts in your mind, just like words.

Structural Differences

Perhaps it is not surprising that musical training causes differences in how the brain responds to music. It is fascinating, but maybe not all that unexpected. What is more amazing to consider is that musicians have *structurally* different brains than non-musicians. Our brains look different, even to the untrained eye, if you know where to look. Probably the oldest and best-know structural difference concerns the fingers of string players. If you could open someone's head and stimulate the motor or sensory cortex of a person's brain (the area that controls movement or the area that receives touch input from the body), you would find a "map" of the body on the cortex, with different areas in charge of different body parts. The area devoted to the fingers on a string player's left hand (but not the thumb and not the right hand) is significantly enlarged due to how much they use those fingers and the fine motor abilities and sensory discrimination they need to play their instruments (Elbert, et al., 1995). And it's not just a little bit bigger, it's millimeters bigger, which is enormous in brain terms. The same thing is seen in the auditory cortex of all musicians. Not only does it respond more robustly to musical input, it is also structurally bigger. Furthermore, the size of the auditory cortex is correlated with the age that the musicians began their instruments, with those who started younger having bigger auditory cortices.

Another area of the brain that is bigger in musicians is the corpus callosum. This is a structure that connects the two sides of the brain. If you were looking at the brain from the top, it would be running right down the middle. To understand this next point, you need a crash course in Neuroscience 101. Our brains are composed of hundreds of thousands of neurons that communicate with each other to makes us do (or not do) something. The way neurons talk to each other is largely through synapses, which are tiny gaps between individual neurons. Basically, when one neuron wants to send a message to another one, it releases neurotransmitter (a chemical signal) into the synapse. Receptors on the other neuron pick up this chemical signal, which causes an electrical change in that neuron so it can pass on the message (or stop the message dead in its tracks).



The part of the sending neuron that the neurotransmitter comes out of is called the axon terminal. This can be really far away from the neuronal body if need be. The long thing that connects the neuronal body to the axon terminal is called an axon. A whole bunch of axons running somewhere together like a bunch of electrical cables is called a fiber bundle. Fiber bundles connect different parts of the brain and look white when you cut a brain open. This so-called "white matter" is what the corpus callosum is made up: it's a bunch of axons connecting the two halves of the brain so they can talk to each other. In musicians, the anterior or front part of the corpus callosum is bigger than in non-musicians (Schlaug, et al., 1995). This is the part that is thought to connect the two motor cortices. Bigger corpus callosums in general are though to reflect more symmetrical brain organization, meaning that the two hemispheres work together more. Interestingly, bigger corpus callosums were only found in male musicians, not female musicians, possibly because females are thought to have more symmetrical brain organization in general.

Echoing this finding is one concerning the size of the cerebellum. The cerebellum is a structure at the back and bottom of the brain that looks a little like a cauliflower. It is very important for motor learning, among other things. The cerebellum is also significantly larger in male musicians than non-musicians, but no difference was found between female musicians and non-musicians (Hutchinson, et al., 2003). For the male musicians, the size of their cerebellum correlated with how much they practiced. Females are thought to have larger cerebellums relative to overall brain size in general, which may have masked the effect of large cerebellums in female musicians. Even though males on average have larger brains than females, the cerebellar size of the females was close to that of the non-musician males. In general, females have somewhat better fine motor skills than males and this increase in cerebellar size in musician males may reflect an increase in fine motor dexterity.

The different areas of the brain are a little like your muscles: the more you use them, the bigger they get (with some exceptions). It's no surprise that the areas most important to musicians are the areas of their brains where you see the biggest structural differences. And these aren't just little differences in size. When you look at a picture of a musicians' corpus callosum or cerebellum next to a non-musicians' you can tell immediately which is which. The final part of this paper will discuss additional functional and structural differences between musicians with perfect pitch and all the rest of us, musicians and non-musicians alike.

Perfect Pitch

Perfect pitch in an amazing ability and is unlike anything else in the world. It is extremely rare in the general population (it is estimated to be 1 in 1500 to 1 in 10,000), but every musician knows at least one person with perfect pitch. As a perceptual ability it is absolutely unique. For those of us without perfect pitch, the experience of having it is commonly explained using a color analogy. When you see the color red, you don't have to see it next to blue and compare the two to determine that it's red, you know just by seeing it. It is the same with perfect pitch: you know when you hear a C# that it is a C# without having to compare it to any other note. But that analogy isn't completely accurate. For the most part, people with perfect pitch have absolute memories for the pitches in the scale (sometimes people's perfect pitch can get out of whack with lack of sleep, medication, age, hormonal changes, etc.). If you ask a person with perfect pitch what note is coming from the refrigerator, for instance, they'll likely say something like "a flat G#" or "a sharp Eb" which means they can make graded distinctions between notes that are perfectly in tune and those that are out of tune. For a musician, with or without perfect pitch, this is, of course, unremarkable. But if you think of it in terms of the color analogy, it is quite astounding. We all can tell the difference between red and green and blue, but, as Robert Zatorre points out, we cannot hold absolute representations of a specific color in our heads like people with perfect pitch do for pitches. That is why when we go to buy paint for our living room, we bring along a swatch of the carpet to make sure it matches. We all have "relative color" not "perfect color." The same goes for smells, tastes, and textures, and all other sounds. We need something to compare it to. For this reason, perfect pitch is a remarkable ability, but also very mysterious. How does it work in the brain and why do some people have it and others don't?

The specific brains mechanisms underlying perfect pitch are still somewhat unclear. There are, however, easily identifiable function and structural changes in the brains of those with perfect pitch. When people with perfect pitch hear different notes, a portion of their brain lights up, the posterior dorsolateral frontal cortex, which is involved in conditional associative learning. Conditional associative learning is learning to pair two arbitrary things together, like a pitch and a letter of the alphabet. When people with *relative* pitch listen to the same tones, the posterior DLF cortex doesn't light up because they don't have the same automatic association with tones and note names as people with perfect pitch do. But, when people with relative pitch are played a pair of notes and asked whether the interval is major or minor, their posterior DLF area *does* light up because now they are doing an association task: interval sound with a name (major or minor). Those with relative pitch also show activation of the right inferior frontal region with is used to update working (short-term) memory, an area that is silent in those with perfect pitch when they do the interval naming task. Presumably, the representation of pitches in those with perfect pitch is so ingrained and fundamental, that they don't have to hold the first pitch in memory in order to compare it to the second pitch to determine the interval like those of us with relative pitch do.

Structurally, there is one area of the brain that is strikingly different in the brains of those with perfect pitch: the left planum temporale (PT). This area is bigger on the left in just about everybody because it is really important for language functions and language is predominantly a left brain activity. Most studies on those with perfect pitch show a much larger than normal PT in perfect pitch musicians compared to non-musicians and musicians with relative pitch. At least one study, however, has shown that perfect pitch musicians have a much *smaller right* PT, still resulting in leftward asymmetry, but the left PT is not actually bigger (Keenan et al, 2001). Clearly, more research should be done to straighten this out. What the PT actually does in regard to perfect pitch is another story. Nobody really knows. Usually, when you have a group of people with a special ability and an area of their brains that is different too, that area is active when they are engaged in their special ability. Not so with perfect pitch. Early response of the auditory cortex, of which the PT forms the posterior (or back-most part), is shifted posteriorly by 1 cm (*huge* in brain terms) in those with perfect pitch, but it isn't activated *differently* than in people without perfect pitch (Hirata, Kuriki, and Pantev, 1999; Zatorre, et al., 1998). However, the PT has axons that go directly to the posterior DLF cortex, the association area that *is* activated differently in those with perfect pitch. Exactly what is happening when these two areas talk to each other and how it manifests itself as perfect pitch still remains to be discovered.

Next, we turn to the old nature/nurture discussion: can you learn perfect pitch or are you born with it? As with nearly everything else, it's a little bit of both. It should be said first off, however, that any program claiming to teach you perfect pitch once you have reached adulthood is completely bogus. You might acquire something that resembles perfect pitch superficially, but you'll never have true perfect pitch. This is because, like language (and vision, and many other things), there is a critical period: if you don't acquire it by a certain age, you never will. With perfect pitch, this window closes around 9-12 years of age. There also seems to be a genetic component to perfect pitch. It often develops without any explicit training, other than an exposure to notes and note names that any child taking music lessons will learn. Robert Zatorre, eminent music psychologist and neuroscientist, also points out the high rate of perfect pitch in families and among siblings. The sibling recurrence rate of perfect pitch (meaning the percentage of sibling that both have perfect pitch) is 8-15%, which doesn't sound like a lot, but in genetics it is. Much more complex traits that are known to have a genetic component, like schizophrenia, have a sibling recurrence rate of about 9%, just to put it in perspective (Zatorre, 2003). Also, the incidence of perfect pitch in Asian children is much higher than in Caucasian children, even when the effects of musical exposure and the influence of speaking a tonal language (like Chinese) are factored out. As with most things, to develop perfect pitch, the evidence looks as though you must have a genetic predisposition towards it and then be exposed to notes and their names before a certain age.

In light of this (and seemingly in contrast), there is very interesting research that seems to show that all infants are born with a rudimentary perfect pitch system that disappears in most of us as we grow up. In the domain of language, it has been known for some time that all infants are born with the ability to distinguish all speech sounds, even those that are meaningless in the language they will eventually speak. As they are exposed to language more and more, they become less sensitive to the sound distinctions that have no meaning in their language. This is why, for instance, Japanese adults have a hard time hearing and speaking the difference between /l/ and /r/: in Japanese, this is not a meaningful sound distinction. It would be maladaptive for people to remain sensitive to all possible sound distinctions in language; if we did, we couldn't understand people who spoke the same language in a slightly different accent, for instance (although, granted, it's hard for Americans to understand an Irish brogue half the time!). In music, a similar mechanism seems to be at work. Perfect pitch is actually maladaptive – it is much more useful to be able to recognize that "Happy Birthday" is the same song whether it is in G major or C# major just as it's more useful to recognize that "car" and "cah" are the same word, even though the second one, in Boston, is missing the last letter.

In the study that was done to show that infants have some perfect pitch ability, Jenny Saffran and Gregory Griepentrog designed a pitch task that could only be done correctly using perfect pitch (Saffran and Griepentrog, 2001). Infants did very well in this task, while adults did terribly. When given another task that could only be done correctly using relative pitch, the infants did terribly, while the adults did very well. This implies that infants are relying on absolute pitch cues when listening, an ability that deteriorates in favor of relative pitch later in life. A brief word of explanation regarding how infants could do a pitch task: in all perceptual experiments involving infants, experimenters rely on the fact that infants get bored with things that are repetitive and are fascinated by things that are new and novel. Usually, infants are presented with something (in this case, notes) until they get bored with it. Then something novel is presented to them. If they look at it (in this case, the stereo speaker), and continue to look at it, it means they recognize it's different from what they were hearing (or seeing) before. If not, it means they don't regard it as any different from what has been going on previously. It is impossible to tell, of course, if this method actually represents what is going on in the infant's brain, but it is the standard method of infant research and nothing has surfaced to indicate it is an inaccurate measure of infant perception.

Perfect pitch, then, seems to be as complicated an ability as it is unique. From the study just described, it looks as though all of us are born with perfect pitch to some degree. Why some people grow out of it and others don't is a mysterious combination of genetics and musical training. Those people who retain perfect pitch have different brains than all the rest of us: their planum temporales are bigger on the left and their brains respond differently in an association area of the frontal cortex when they hear notes. Because this is such an unusual ability, neuroscientists will continue be fascinated with it and hopefully provide us with more answers in the future.

Conclusions

Being a musician has a profound impact on our brains. We process pitch, rhythm, harmony, melody, and structure differently from those who do not undergo our rigorous training. In many cases, we are able to unconsciously hear things that everyone else can't hear, even if they're paying attention to it. When we play our instruments, much of it has become so automatic that entire brain regions don't have to get involved. Other brain regions are significantly enlarged as a result of our years of practicing and listening. We have also caused two of our brain regions, the motor cortex and the auditory cortex, to become linked. For those musicians with perfect pitch, their brains respond to music differently still, in ways that are still being unraveled by neuroscience. The brain is amazing in what it can do, but hopefully this paper has given you a sense of awe at the power and effect of our musical training. For most of us, music has been so much a part of our lives for so long, we take for granted what we can hear and do on our instruments. But because of our hard work, we have fundamentally changed our brains in a way that makes us quite distinct from the rest of the world. If someone were to do the type of experiments on you that are described in this paper, they would know you were a musician without you telling them, just from the responses of your brain. That's something that goes beyond "mind reading" – the activity of our musical brains is a window into how we have chosen to live our lives. We have left indelible marks on our brains and changed our perception and functioning, probably forever, by our study and love of music.

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