"What can modern neuroscience tell us about our predisposition to receive emotion through music?"

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Part I: Introduction

Music is an enigma. A seemingly meaningless assembly of tones over time, it captivates emotions and the human imagination. For centuries, philosophers have mused about humanity's love for music, but a concrete, scientific answer has evaded them. The key seems to lie in the last major mystery of biology: the human brain. In the past several years, modern neuroscience has allowed us to get a better look at the human brain than ever before. Technological developments, like fMRI scans and PET scans, have allowed us to understand more about how the brain functions and what happens when we listen to music, specifically the emotions that music conjures. These types of technologies are shedding new light on a fundamental part of human existence. What can we learn about music from new neurological developments? Modern neurological data suggests that music communicates true, biological emotions in the brain, providing potential applications in areas such as psychotherapy and education.

Part II: Historical Context

Dating all the way back to ancient Neanderthal bone flutes (McDermott), humans have found musical tones aesthetic, artistic, and fascinating. When Pythagoras was creating his musical instruments, he based his scale around the intervals of an octave (1:2 frequency ratio) and a perfect fifth (2:3 frequency ratio). He created the scale in this manner simply by what sounded concordant and consonant, the biological reasons unbeknownst to him (Pythagorean Scale). The Ancient Greeks, feeling the underlying emotion in their music, believed that music was a work of the Gods, and began documenting a human fascination with music that continues today.

Until recently, the mystery of human adoration of music has been mainly limited to philosophical and historical evidence because the science did not exist to understand the human brain. Charles Darwin said that music “must be ranked amongst the most mysterious (abilities) with which (man) is endowed" (Perlovsky, p. 3). Friedrich Nietzsche famously said that "without music, life would be an error". From Aristotle to Kant, philosophers throughout the ages have grappled with humanity's ability to play and listen to music. Though these theories and musings were certainly valuable, philosophy as a whole could not come to an answer as to why we are so attracted to music.

More recently, scientists have used newer technologies like functional Magnetic Resonance Imaging (fMRI) scanners, Positron Emission Topography (PET) scanners, and Electroencephalography (EEG) to explore the brain's reaction to music. fMRI scanners use strong magnets to detect small changes in oxygen in the brain. The subject is put in a large, cylindrical tube, where a powerful electromagnet influences atomic nuclei in the brain, creating a signal strong enough to measure. Because blood carries oxygen to more active areas of the brain, fMRI scanners are able to track blood flow and provide a good estimate of brain activation.

PET scans are similar in function: the scanner measures blood flow using a harmless radioactive substance, called a tracer, which is injected into the subject's blood. EEG is a more direct way to measure the brain. It measures electronic signals stemming from neurons in the brain by measuring voltage. While EEG is useful for measuring activity of neurons, it lacks the spatial resolution of PET scans and fMRI scans. For this reason, it is used less than PET or fMRI technologies. These types of technology have allowed researchers to find out more about the inner workings of the brain, and how the brain reacts emotionally to music.

Part III: Summary of Past Research

What happens anatomically when we communicate through music? When we hear music, sound waves make our eardrums vibrate at the same frequency as the sounds (Perlovsky, p. 5) A musical tone contains overtones, which vibrate more quietly at higher frequencies. When another tone is played at the same time, its overtones are also subtly perceived by the ear. When the two tones share several overtones, like in a perfect fifth, the sound is judged as concordant and pleasant by the brain. On the other hand, if the overtones are slightly off, like in a minor ninth, the brain judges the two notes as discordant and fearful. This biological capability to discriminate consonance and dissonance may have led to the music we have today.

There are several theories about why humanity developed its unique attraction to music. These theories examine several types of evidence, including knowledge of human history, experiments done on human infants to measure music perception, and lesion studies.

Leonid Perlovsky theorizes that music and language evolved simultaneously in humanity. Perlovsky proposes that language made us able to cognitively disconnect our thoughts from our actions, thus enabling us to think and say things not directly related to survival: "For example, when sitting around the table and discussing snakes, humans do not jump on the table uncontrollably in fear, every time “snakes” are mentioned" (Perlovsky p. 13). We can harbor the thought and concept of a snake without the survival instinct originally associated with this danger. For this reason, the emotional impact of verbal communication is less in us than in animals, and the "human psyche is not as harmonious as psyche of animals" (Perlovsky, p. 16) As language evolved, words no longer affected the whole human psyche. Perlovsky hypothesizes that music fills this disconnect between cognition and survival instinct, allowing humans to communicate emotions with each other while the innate emotionality of verbal communication left humanity.

There are several other theories about why music evolved in humans, including the ideas that "music promoted social cohesion in group activities such as war or religion, that music was an evolutionary antecedent to language, or that its evolution was driven by the pacifying effect it has on infants" (McDermott 2008, p. 287). However, as McDermott states, it is difficult to find evidence for this in the fossil record. He also says that "There is no guarantee that a full account of music’s origins will ever emerge; in fact, that seems quite unlikely at present" (McDermott, 2008, p. 288). His tentative hypothesis, though, is that music developed as a side effect of other, more evolutionarily helpful traits, agreeing with Perlovsky that a primary function of music was to communicate emotions.

These theories were mainly based off of studies examining infant comprehension of music (Perlovsky, McDermott 2005). Comparative studies on human infants and animals found that, even when musical exposure was at a minimum, humans far outperformed animals on tasks that involved recognizing melodic contour and transposition (McDermott 2005, p. 40-41). Even when significantly trained, animals are unable to recognize transposed melodies, which infants do with ease (McDermott 2005, p. 41). According to McDermott, these infant studies suggest that our ability for music is innate and unique to humans.

Other studies examine the cultural effects on music knowledge and listening (Balkwill). With the exception of one 1980 study, all studies have found that humans are able to perceive emotions across cultures. For example, when presented with Hindu music designed to evoke emotions of joy, sadness, anger, and peace, American listeners were consistently able to distinguish the emotion (Balkwill, p. 43). Another study compared music memory of adults and 5th graders (Morrison). When presented with Turkish music, 5th graders were slightly better at memorization than adults, while the adults performed significantly better than the 5th graders when memorizing familiar Western music. The 5th graders also performed much better with Western music than they did with Turkish music, suggesting "that culture-specific schemata for musical structure are formed relatively early" (Morrison, p. 126).

In another study, college music students were given several different songs in different keys and asked to rank the emotions in the songs (Broze). This study found a significant difference in both loneliness and pride, two social emotions present in songs. Songs with more voices were seen as less lonely and more prideful than the other songs. In general, polyphonic melodies were seen as more emotionally positive (Broze, p. 143)

Several more recent studies have looked inside the brain to see what emotional centers are in use when the brain is listening to music. Several have found, similar to previous infant studies, that "newborn infants show limbic responses to music and 5‑month-old infants enjoy moving in synchrony with music" (Koelsch, p. 170). Lesion and imaging studies have found that different musical emotions take place in different parts of the brain; for example, the amygdala has been shown to be responsible for the 'fear' emotion in music, while disgust was prevalent in the insula and basal ganglia (Rauscher, p. 150).

In a 2007 article, Gunter Kreutz and Martin Lotze used a combination of lesion studies and neuroscience to examine emotion in the brain. One case they examine is of patient IR, a woman with serious damage to the auditory cortex who "shows normal speech, intelligence and memory capacities, while being unable to recognize familiar tunes or learn novel melodies" (Rauscher, p.153). However, she is still able to classify songs as 'happy' or 'sad', so even though she cannot understand songs musically, she is emotionally affected by music. With imaging studies, Kreutz and Lotze found that deeper areas of the brain, like the amygdala, insula, hippocampus, nucleus accumbens, and entire limbic system were activated when listening to their favorite songs (Rauscher, p. 154). These findings are related to Perlovsky's idea that emotional and cognitive processing of music occur in different areas of the brain.

Another study found that listening to music is associated with a distinct dopamine release in the ventral and dorsal striata in the limbic system (Salimpoor, p. 257). Using PET scans, they found that the reward associated with music uses very primitive parts of the brain associated with survival instincts: "This phylogenetically ancient circuitry has evolved to reinforce basic biological behaviors with high adaptive value" (Salimpoor, p. 260) Because music does not serve a clear adaptive function, Salimpoor suggests that it is "perceived as being rewarding by the listener, rather than exerting a direct biological or chemical influence" (Salimpoor, p. 261). The study also found that the dopamine release happens both at the climax of a song and in anticipation of the climax. The ancient reward systems in place while listening to music are biological motivators related to survival instinct (Salimpoor, p. 260), perhaps revealing some of the mechanisms behind the human drive to create and listen to music.

Like Salimpoor, Stefan Koelsch found neurological evidence that music can affect the regions that underlie emotions (Koelsch, p. 171). He found that the amygdala and other areas associated with emotion were more highly connected (to each other) during joyful music than during fearful music. Koelsch also found activation in the hippocampus, a part of the brain associated with memory and social activities. In contrast to Salimpoor, though, Koelsch states that "music can trigger changes in the major reaction components of emotion, indicating that music can evoke real emotions (not merely subjective feelings)" (Koelsch, p. 178). He also cites a study providing evidence that music produces activity in the endocrine system, which, among other things, functions to control mood and release hormones. By using more modern methods, Koelsch was able to examine music and emotions with more precision than McDermott and Perlovsky, who relied on infant and lesion studies.

Few studies have examined the effects that playing music has on the brain. A reason for this is the innate difficulty of examining the brain of musicians while they play music. However, one such study found a way around this, using a non-magnetic keyboard specifically designed for an fMRI scanner to study the brains of jazz musicians while improvising (Limb, p. 7). The experiment used a control jazz melody as well as jazz improvisation. Different sections of the brain were activated and deactivated during improvisation and the rehearsed piece. Many parts of the prefrontal cortex, used for higher functions like planning, were deactivated, along with, surprisingly, parts of the limbic system. Limb explains: "The deactivation of the amygdala and hippocampus we observed may be attributable to the positive emotional valence associated with improvisation" (Limb, p. 5). The parts of the brain activated included areas associated with motor control, probably to carry out all of the complicated finger movements involved with improvising. More research into playing music is required and could reveal new insights into the brain's processing of music and emotion.

A 2014 documentary examined the emotional effects of playing music for elderly people. One dementia patient, named Henry, completely isolated himself from the world. Yet when his favorite music was played for him, he came alive and began talking and singing (*Alive Inside*, 10:36). Another woman named Denise was able to get up and start dancing after she listened to music. She had been using a walker for the past two years (*Alive Inside*, 23:20). The documentarians found that patients were able to emotionally connect to music and become more active, more responsive as a result. This may provide evidence to suggest the practical applications of music in areas of therapy, as well as highlighting the need for new research into music and the brain.

Part IV: Findings and Analysis

While most of the studies done on music and emotions were conducted by approximating brain activity, I find modern neuroscience-based evidence to be the most compelling toward a better understanding of the way that music affects our emotions. Several studies (Perlovsky, McDermott) give an overview of knowledge on music and emotions, incorporating the best lesion studies and infant studies done at the time. However, these papers fail to include modern technological developments in brain science, such as fMRI and PET data, mainly due to the newness of these developments. In this section, I will examine these ideas on music and emotion through the lens of modern neurological studies.

Both Perlovsky and McDermott speak of multiple theories of how music evolved in humans. In particular, a theory proposed in Perlovsky is worth some analysis. His most compelling argument is that, as language developed in the brain, we were able to cognitively disconnect language from emotion. After all, the original use of verbal communication, as in animal cries, was to relay emotions, such as danger. As language became detached from emotion, music filled the void to enable humans to continue to communicate using emotion. I find this to be an interesting and believable argument, but Perlovsky does not base this on enough evidence to be scientifically responsible in my view. However, the cognitive disconnect between language and music processing and the underlying emotions is a fascinating idea to dissect and can give us insights into our predisposition to communicate and listen to music.

One piece of evidence supporting Perlovsky's claim is that deeper levels of the brain are responsible for producing emotions in music (Salimpoor, Koelsch). These studies found that the limbic system, a system largely associated with emotion and motivation, is responsible for the emotion we feel in music. Several structures are involved in our emotional connection to music, like the amygdala sensing fear (Koelsch,

p. 172) and a unique release of dopamine in the striatal system (Salimpoor, p. 257). While these areas do not have much to do with processing language or music (Limb, p. 5), they play a large role in our emotional involvement in music. If music is cognized in one part of the brain and emotions are processed in a deeper area, it could mean that our love for music is much deeper than we thought. This hormone release in the limbic system supports the idea that hearing music creates a dopamine-based reward using the deeper part of our brain, which could be the basis of our unique affinity toward communicating emotion through music.

However, an interesting argument is also present between Salimpoor and Koelsch. While Salimpoor states that emotions in music are simply a result of perception by the listener and not 'real' emotions, Koelsch clearly states that music can create true biological emotions, the same type of emotions that act as feedback to help ensure survival. Clearly, either Koelsch and Salimpoor is incorrect, and knowing the answer to this question is significant in terms of practical applications, in psychotherapy for instance, where changes in the brain could be harnessed to improve lives.

Salimpoor's study was a specific look at the dopamine release in the limbic system. He bases his claims off of the idea that, "similar to other aesthetic stimuli... the rewarding qualities of music listening are not obviously directly adaptive" (Salimpoor, p. 260). While this makes sense when regarding music as similar to other aesthetic art forms, if music is regarded as stemming from animal cries or something similarly biological (Perlovsky, McDermott), there is no reason to regard it in the same emotional context as other aesthetic art forms.

Koelsch, on the other hand, reviewed many articles on different emotional centers in the brain, including Salimpoor's. He begins his conclusion: "As has been shown consistently across studies, music can evoke changes in activity in the core structures underlying emotion" (Koelsch, p. 178). I find his conclusion more believable than Salimpoor's because he provides a much more thorough analysis of more systems involved, all of which support the conclusion that we have biological, concrete emotions toward music. Also, the phenomenon of musically-induced 'chills', which "involve a clear and discrete pattern of autonomic nervous system (ANS) arousal" (Salimpoor, p. 257), seems to support that the biological reaction to music is not just perception. This finding, in importance, goes well beyond Perlovsky's argument about why music was formed because it provides us with a method to artificially and non-intrusively induce real, biological emotions in humans.

Because the evidence suggests that music can induce true emotions in humans, it is certainly an area that warrants further study using new developments in neuroscience. One aspect that has not been studied deeply, other than Limb's research, is how playing music affects the brain. Music began as a social event where everybody played as well as listened, so it would make sense for there to be interesting and potentially different emotional responses between playing and listening to music.

This type of research has potential applications in the field of psychotherapy, particularly. There are currently 5 million people with dementia in the United States, with 10 million people employed to take care of them (Alive Inside, 12:00). Giving the patients music has already been proven to provide them with emotional support and needs to be used more widely. If we are able to control a patient's emotional reaction by having them play or listen to music, many forms of psychotherapy could benefit immensely. As our knowledge of the brain increases, along with our technological capability to understand how it works, further studies will need to be conducted to flesh out the extent of the human brain's reaction to music and harness its emotional potential.

Part V: Conclusion

What is it about a sequence of frequencies and rhythms that has such emotional power over us? I believe that modern neuroscience can help us answer this fundamental question of humanity. One of the most important discoveries made so far is that musical emotions are created in the deeper part of the brain, while the cognition of these emotions takes place in higher levels. Modern neuroscience gives us a much more specific and concrete idea of where musical emotions take place in the brain, rather than the guesswork required of infant and lesion studies.

From neurological research done so far, it seems that music originated alongside language as a way to convey emotions and to trigger actions, like animal calls. Eventually, as Perlovsky hypothesizes, this probably led to music becoming a mechanism to make humans more sociable, providing them with a way to cohesively form groups. As language has evolved, it has disconnected itself from our biological emotions, allowing us to crucially form thoughts separate from actions. Music, on the other hand, has remained connected to our biological emotions, making it a literal language of emotions.

Neurological evidence suggests that music is able to create true emotions in the brain, not just ones of perception. This means that music can change the brain and, with an ever-increasing volume of studies confirming the brain's immense plasticity, music's effects on emotion needs to be researched further. If therapy can harness the power that music has over our emotions, it could provide countless people with a more effective way to endure mental conditions and achieve emotional stability. Also, as a doctor in *Alive Inside* stated, "We haven't done anything, medically speaking, to touch the heart and soul of the patient" (Alive Inside, 17:41). As we learn about the biological changes music creates in the brain, doctors could begin prescribing music as a treatment, perhaps far more effective than medications like antidepressants and antipsychotics.

Future research might provide even more interesting applications. Manipulating emotions using music could help children with autism or ADD. Controlling emotions of young children in general, even those without mental difficulties, can prove to be very strenuous, and music could be a solution. We could potentially use these same technologies in education, to make curriculum more emotionally engaging to students. Even more excitingly, knowledge of music and emotion could permeate everyday life, giving us the tools we need to survive a tough breakup, study for a college class, or concentrate more effectively on work. While more research needs to be done, if we can use music to change the brain, the practical applications are staggering.

Playing music, and not just listening, provides another avenue of research. How does playing music influence us emotionally, and can it create even greater responses than listening to music? If so, could we use this in psychotherapy and education, to produce the emotional responses we want in patients and students? This is a question that needs answering, and we will soon have the tools to answer it.

Think about this the next time you listen to music: while the higher parts of your brain are processing the music, the older, more instinctual part of your brain reacts to it emotionally. If we learn more about what drives our neurological predisposition to communicate emotion through music, we can potentially use it to non-intrusively manage human emotions and better the human experience for countless individuals.

Bibliography

Alive Inside: A Story of Music and the Brain. Dir. Michael Rossato-Bennett. Perf. Dan Cohen and Oliver Sacks. Projector Media, 2014. Web. 13 Jan. 2015.

Balkwill, Laura-Lee, and William Forde Thompson. "A Cross-Cultural Investigation of the Perception of Emotion in Music: Psychophysical and Cultural Cues." *Music Perception: An Interdisciplinary Journal* 17.1 (1999): 43-64. Web.

Broze, Yuri. "Polyphonic Voice Multiplicity, Numerosity, and Musical Emotion Perception." *Music Perception: An Interdisciplinary Journal* 32.2 (2014): 143-59. *JSTOR*. Web. 08 Jan. 2015.

Koelsch, Stefan. "Brain Correlates of Music-evoked Emotions." *Nature* (2014): 170-80. Web. 7 Jan. 2015.

Limb, Charles J., and Allen R. Braun. "Neural Substrates of Spontaneous Musical Performance: An FMRI Study of Jazz Improvisation." Ed. Ernest Greene. *PLoS ONE* 3.2 (2008): E1679. Web.

McDermott, Josh. "The Evolution of Music." *Nature* 453.7193 (2008): 287-88. Web. 8 Jan. 2015.

McDermott, Josh, and Marc Hauser. "The Origins Of Music: Innateness, Uniqueness, And Evolution." *Music Perception* 23.1 (2005): 29-59. Web.

Morrison, S. J., S. M. Demorest, and L. A. Stambaugh. "Enculturation Effects in Music Cognition: The Role of Age and Music Complexity." *Journal of Research in Music Education* 56.2 (2008): 118-29. Web.

Perlovsky, Leonid. "Musical Emotions: Functions, Origins, Evolution." *Physics of Life Reviews* 7.1 (2010): 2-27. Web.

"Pythagorean Scale." *Pythagorean Scale*. N.p., n.d. Web. 05 Jan. 2015.

Rauscher, Francis, and Wilfried Gruhn. "Neuroscience of Emotion and Music." *Neurosciences in Music Pedagogy*. New York: Nova Biomedical, 2008. N. pag Print.

Salimpoor, Valorie N., Mitchel Benovoy, Kevin Larcher, Alain Dagher, and Robert J. Zatorre. "Anatomically Distinct Dopamine Release during Anticipation and Experience of Peak Emotion to Music." *Nature Neuroscience* 14.2 (2011): 257-62. Web.