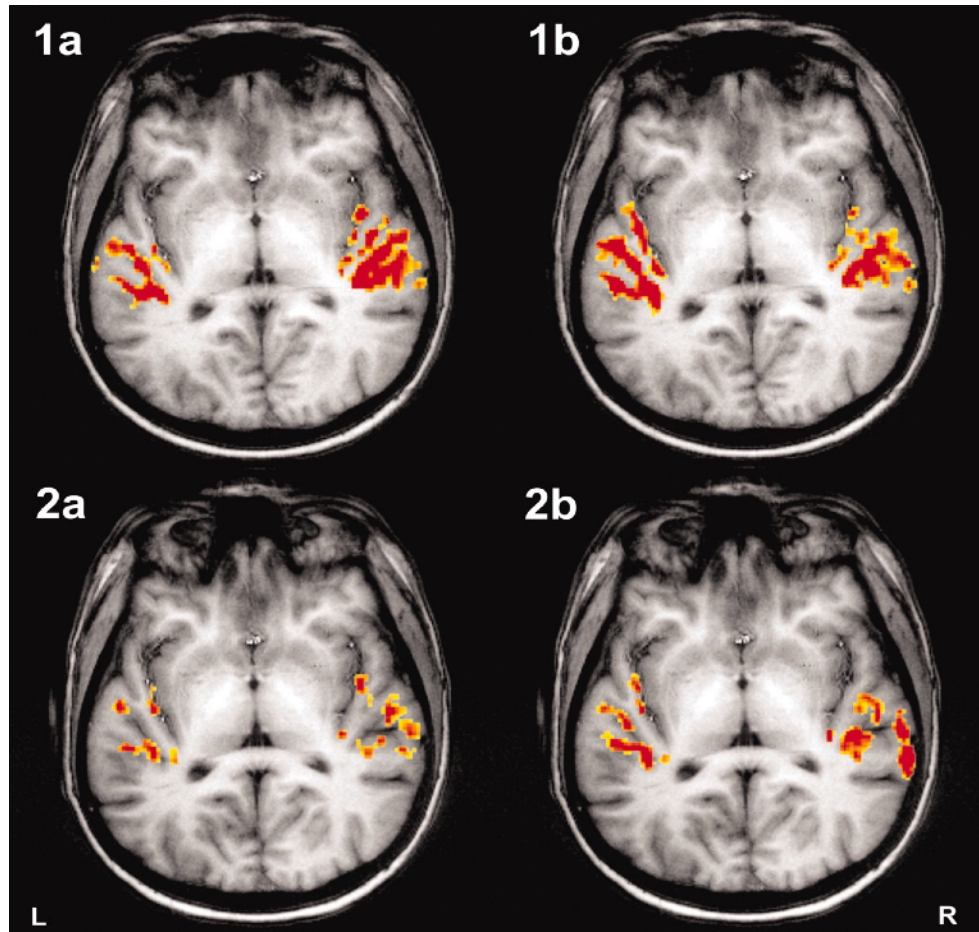


Musicianship and the Brain

And their effect on perception, audition, and musical memory



—Auditory cortex activation (Behne 2005).

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Introduction

This paper addresses connections between the critical features of music and current brain research. The most important and basic components of music that are relevant to brain physiology and neurology are pitch and rhythm. A person's ability to perceive and organize pitch and rhythm will influence all their higher order musical skills, like audiation. Audiation, the ability to "visualize sound," is a skill essential to musicianship and deeply connected with short term, or working, memory. The facts behind these perceptions are investigated here in the hopes to inspire future research on the topic.

On Music (Briefly)

There is no all-encompassing definition of music. Most agree music is sound¹; however, beyond this definitions differ greatly, particularly on what distinguishes music from noise. Delineations diverge regarding the structural qualities as well as the aesthetic qualities of the sound. For the purposes of this discussion I've chosen to consider Edgard Varèse's definition of music as "organized sound," as the purpose of this research is to explore physiological structures not affective and emotional consequences of music.

To consider "organized sound" and relate it to specific neurological structures, one must break it into essential components that can be classified. Daniel J. Levitin does this exceptionally in his book "This Is Your Brain On Music" (2006) with his "basic elements of any sound." They are loudness, pitch, contour, duration (or rhythm), tempo, timbre, spatial location, and reverberation. These components of sound create music when one's brain organizes them into "higher level concepts," which Levitin identifies as meter, harmony, and melody.

¹ Some also include sounds not perceivable by human ears in their definition of music. For a discussion of "music" on an astronomical scale, see Levin's (2011) TED Talk: "The Sound the Universe Makes" (especially 8:46 to 12:19).

On Pitch and Steady Pulse (Rhythm)

Levitin (2006) defines pitch as “the mental representation an organism has of the fundamental frequency of a sound.” Humans can identify pitches because the cochlea (a part of the inner ear) is lined with hair cells that respond to particular sound frequencies. Because these cells are spread out topographically across the cochlea, they form what is called a tonotopic map. When sound activates these hair cells they send signals into the auditory cortex of the brain. The auditory cortex also has a tonotopic map, spread out across the cortical surface, in order of pitch. The implication of this structure is that the brain actually directly and literally responds to the absolute pitch frequencies a person hears, a response thought to be entirely unique to pitch stimulus. To illustrate this important distinction consider the following example from Levitin (2006):

“If I put electrodes in your visual cortex (the part of the brain at the back of the head, concerned with seeing,) and I then showed you a red tomato, there is no group of neurons that will cause my electrodes to turn red. But if I put electrodes in your auditory cortex and play a pure tone in your ears at 440 Hz, there are neurons in your auditory cortex that will fire at precisely that frequency, causing that electrode to emit electrical energy activity at 440 Hz – for pitch, what goes into the ear comes out of the brain!”

The physiological reasons behind human perception of audible pulse (as distinguished from heart rate) are less clear than that of pitch. This is because our sense of pulse and rhythm is more entangled with as of yet uninvestigated neuroscience than the physical structures of our hearing are, and therefore is currently less understood than our pitch perception. As Levitin (2006) writes, our rhythmic perception is so accurate because it is “probably in the cerebellum,” because our essential timekeeping structures are thought to reside there. The unsurety comes in part because the structures of the brain responsible for timekeeping are difficult to investigate. They form a part of a complex network, and studies of people performing tasks over time have

revealed connections to the basal ganglia and cerebral cortex in addition to the cerebellum (Sanders 2015).

Similar to neurons in the auditory cortex firing at pitch frequency, rhythm can also have an influence on human physiology. One such example is how scientists have found music making and heart rate to be intertwined. Vickhoff et al. (2013), in a study of choirs and their individual singers, found that “Unison singing of regular song structures makes the hearts of the singers accelerate and decelerate simultaneously.” This is because heart rate variability is affected by respiration (a relationship known as respiratory sinus arrhythmia). The senatorial node (the primary pacemaker of the heart) is affected by the autonomic nervous system (ANS) (the part of the peripheral nervous system that controls organ functions) as is respiration. The sympathetic nervous system (part of the ANS) and the vagal nerve transmit signals from the brainstem to the senatorial node of the heart, regulating heart rate (Vickhoff 2013). The interconnected nature of rhythmic singing and breathing with heart rate and the neural activity which controls it speaks to the intrinsic connection between our neurophysiology and music, and have implications for the value of music to overall health.

Large and Snyder (2009) discuss that although there are a myriad of approaches to explain rhythm, one of the best “relies upon neural oscillations that resonate with rhythmic stimuli.” This means that it is possible that neurons in the brain are literally firing at the same tempo as music we make or listen to. Therefore, meter, an interpretive organization of pulse, would be a higher level grouping of these rhythmic neural pulses, comparable to the physical relationship between overtones and fundamental pitch.

“The theory holds that listeners experience dynamic temporal patterns (i.e., pulse and meter), and that they hear musical events in relation to these patterns because they are

intrinsic to the physics of the neural systems involved in perceiving, attending, and responding to auditory stimuli.” – Large and Snyder (2009)

But what is the actual difference between pitch and pulse? From a physics standpoint, pitch and pulse are fundamentally the same. They are both auditory stimuli happening at even time intervals. The difference is merely a perceptual boundary humans draw in their minds based on the speed². When people listen to a pulse of sound played at a steadily accelerating tempo, there will come a point where the pulse crosses a perceptual threshold and begins sounding like a pitch, increasing in frequency as the tempo continually accelerates. To listen to an audio example of this phenomenon, as well as an additional discussion on the relationship between composite rhythms and pitch intervals, see Tepfer, 2012.

Now consider the facts of how humans perceive pitch in the context of the relationship between pitch and pulse. The difference between pitch and rhythmic pulse is speed as it applies to our physical ability to perceive sound. When the auditory pulses are fast enough to activate a particular subset of hair cells that correspond to a certain frequency, and therefore a particular location on the tonotopic maps of the cochlea and auditory cortex, the person perceives the sound as pitch. When the auditory pulses are too slow to activate a particular frequency grouping of hair cells, the person perceives the sound as a pulse. Pulse is then conceptually organized into meter and then rhythm based on patterns and emphasis. Therefore, when we listen to a melody we are simultaneously listening to the patterns of sound pulses over time on many processing levels, regardless of musical training. At one frequency range we perceive rhythm, at the next faster frequency range we perceive pitch³.

² Speed here means the time interval between points of auditory stimulus.

³ Additionally, when we subdivide the frequency range of pitches we perceive overtones (the perceived pitches that result from regular multiples of pitch frequencies).

The discussion of these perceptual groupings applies to how people construct meter and hypermeter⁴. Radocy and Boyle (1997) surveyed studies on pitch and rhythm perception and found people gravitate toward tempos in the range of 60 to 120 beats per minute. This means when listening to a piece of music, people will half or double their reproduction of the tempo so it falls within that range⁵. This observed behavior shows the commonalities we have in how we perceive the meter and hypermeter of a piece of music, and where we draw the perceptual boundary between the two.

Before the following discussion on audiation and memory, an important distinction must be made between the learned skills of musicianship and the normally innate skills of musicality. Performance skills, music literacy, and analysis usually require moderate to intensive study of music, but the foundations of musicality (tunefulness, perception of steady pulse, musical comparison, and evaluation, for example) are seemingly inherent in most people from birth. It is upon these foundations that those who choose to study music build their understandings.

Therefore, no matter who they are or what their education was, the reader of this paper is most likely at least somewhat inherently musical. Even without training the vast majority of people can distinguish between pitches, differentiate between melodies, and perceive dissonance. However, about 4% of people do not develop a normal pitch processing system (Hyde & Peretz 2004). This group of people have congenital amusia, defined as “a developmental disorder that arises from failures to encode pitch with sufficient resolution to allow acquisition of core knowledge regarding the pitch structure of music” (Hyde & Peretz 2004) and therefore cannot discern pitches less than two semitones apart (the average human sensitivity is at least four times

⁴ The organization of meter into larger scale forms.

⁵ It is also why, quite intentionally, so much pop music is written in that tempo range.

more defined). This deficit in perception causes great difficulty in identification and comparison of music⁶. However, Hyde and Peretz (2004) found that these people who were unable to discern differences in pitches with normal resolution were able to discern differences in rhythm with normal resolution (“with 75% correct detection for an asynchrony of about 40 ms”). The physiological causes of congenital amusia are not well understood, but this research is a strong indication that pitch and steady pulse perception are discrete neurological processes.

On Audiation & Memory

Because pitch and pulse (and therefore rhythm) are likely processed differently in the brain, it follows that our minds and memories most likely interact with them in different ways. This crucial difference likely has an influence on the functions of audition and musical memory. Essentially, to audiate is to imagine sound. The word audiation was coined by Edwin Gordon as an auditory alternative to imagination, which focuses on visual images. To teach aural skills is to teach audiation. It is the ultimate goal of any musician to be able to audiate (or imagine sound) before creating sound because it is the key to many higher level musicianship skills.

Audiation can be broadly categorized in two ways: recollection of sound and synthesis of original sound. This is similar to how a person can use his or her imagination to either remember something from his or her past or to synthesize something completely original. This research is concerned with the functions of the former over the latter because of its connections with working memory. Because of its connections with working memory, synthesis of original music often is in fact an obstacle for certain musical skills, like dictation. It tends to cause

⁶ However, people with congenital amusia often do not have issues understanding spoken language because the pitch fluctuations in spoken language are usually much larger. For example, the rise in pitch that signals a question is typically over seven semitones in English and French (Fitzsimons, Sheahan, & Staunton, 2001).

consonant mistakes in the finished product (wrong notes that are members of the same harmony, or subdivisions of given rhythms, for example).

Although philosophical and psychological study of brain function is not new, most physiological research concerning the brain is. Most of what scientists know about the brain is the result of the veritable explosion of brain research following the introduction of Functional Magnetic Resonance Imaging (fMRI) in the 1990s. For the first time, scientists could have a look at blood flow patterns in the active living brain and start drawing directly observable conclusions about function. Prior to this, all scientists knew about brain localization was learned from studying the behaviors of people with brain injuries. Ultimately, while our knowledge of the brain is becoming more detailed, much more research is needed, particularly in relation to music cognition.

Broadly, current scientific understanding of memory divides the phenomenon into two groups, short term and long term memory (each with various subcategories). Short term memory (also known as working memory) is engaged with that which is recalled soon after exposure. Long term memory is engaged when something is recalled after some time has lapsed. This research is involved with the greatly debated functions and limitations of working memory.

George Miller's article "The magical number seven plus or minus two: some limits on our capacity for processing information" is widely considered to be the seminal article that sparked interest in working memory research. In his 1956 article published in *The Psychological Review*, Miller discussed a particular limitation on the number of items a person could store in their working memory (which he referred to as "channel capacity") based on current research. According to the research of the time, universally that number was about seven, with some people remembering as few as five and some as many as nine items.

“There seems to be some limitation built into us either by learning or by the design of our nervous systems, a limit that keeps our channel capacities in this general range.” – Miller 1956

Miller was particular in his specification that this applied exclusively to one-dimensional stimuli. That is, input information with only one discernible characteristic (a collection of colors, of pitches, of rhythms, etc.). When the stimuli was multi-dimensional (more identifying characteristics per unit of information) working memory capacity increased greatly. This observation encouraged a body of research extending all the way to the neurological research of today⁷ involving the nature of the limits on working memory.

Chunking also plays a significant role in retention and reproduction of musical examples. Generally speaking, chunking⁸ is the natural function of human minds to group relevant pieces of information together, the intention being to fit more information into the approximately seven working memory slots people have. This is how people can keep track of and engage in conversations, for example. A typical conversation will contain more than seven words or sentences but it is in the chunking of ideas that people can engage in advanced dialogue. Just as chunking happens with spoken language it happens with music. A person who knows more musical patterns will identify those patterns immediately⁹ and store the entire pattern in memory as opposed to its individual components. This is the process that enables skills such as sight reading or listening to a piece of music and tracking the occurrence of multiple motives throughout.

⁷ "Despite decades of research, the source(s) of the severe capacity limits of WM [working memory] storage are still under intense debate." (Fougnie et al. 2015)

⁸ A term Miller coined in his 1956 article.

⁹ Here we see the influence of the time it takes someone to identify something on overall understanding. Those who identify patterns more quickly are able to chunk information more effectively.

“As musical understanding increases, so does musical memory. Listeners who can hear and immediately understand such features as scalar passages, triads, repetitions, sequences, modulations, and rhythmic patterns have a leg up on those listeners still listening without immediate comprehension. Such immediate comprehension affords listeners the opportunity to encode music in meaningful chunks, thereby dramatically reducing the number of memorable “bits” [of information] in a passage.” – Karpinski 2000

Some studies argue that limitations on working memory are domain specific (such as Baddeley & Loggie 1999), meaning that working memory limits are specific to the type of information being recalled. Consider the following simplistic example: if a person could store seven items in her working memory then she would be able to store and recall seven colors as well as seven tones simultaneously. Other studies argue the limits are not domain specific (such as Cowan 2006), meaning there is a hard limit on the number of items a person can store in their working memory regardless of content. For the person in the previous example, she would be able to recall seven items of color or tone total. The question proves difficult to answer because causes of working memory interference are hard to isolate and study experimentally.

“Thus, the debate centers on the degree to which limits arise from interference in content-specific stores or from a capacity-limited process that operates over items regardless of content.” – Fournie et al. 2015

In modern neurological studies, working memory is examined using fMRI but can be measured in a number of ways. Older studies used short term memory tasks like digit span and word span in which the subject was asked to look at lists, remember them, and reproduce them with complete focus on the task. However, the most valid and reliable way of measuring working memory capacity (according to Chein, et al. 2011; Bayliss et al. 2005; Conway et al. 2005; Engle et al. 1999; & Miyake, 2001) is to use Complex Working Memory Span Tasks, in which subjects remember a short list, recall it, and engage in a secondary processing task while doing so. This is because it's a more realistic measure of working memory in an everyday

situation. Remembering items while concurrently processing an additional task is how Miller and Baddeley originally defined working memory in their seminal work. It also better controls for individual differences in fluid intelligence among subjects and more predictive of other cognitive abilities (Chein et al. 2011).

The structures currently believed to be involved in working memory are the primarily the prefrontal cortex and likely the anterior cingulate cortex and the posterior parietal cortex. The currently small body of neuroimaging studies that make use of Complex Working Memory Span Tasks is quite diverse in investigative methods and thus difficult to draw consistent conclusions from. Some make use of reading span activities while others use listening or operation spans. fMRI contrasts also differ greatly across studies. Despite these complications, engagement of the prefrontal cortex has been “universally” found and “some” have found anterior cingulate cortex and posterior parietal cortex involvement (Chien et al 2011). The integration of these structures with the musical structures of the auditory cortex must be studied in the future.

The learned skills of musicianship are built upon a foundation of musicality that is enabled by a complex network of physiological and neurophysiological structures. Pitch and rhythm perception, essential to the consumption and production of music, are possible because of the structures of the human auditory cortex and inner ear. Additionally, although our physiology clearly influences our music, our music also influences our physiology in subtle ways. Audiation is a higher level skill, essential to musicianship, and inexorably tied to working memory behaviors and physiology. Even with a great existing body of research, working memory is still in the process of becoming understood today. This research is an exciting start to a far deeper exploration of the connections between our neurophysiology and our musicality.

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