This is Your Brain on Music
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Introduction. I Love Music and I Love Science-Why Would I Want to Mix the Two?

The more you learn the more interesting music becomes.

1. What Is Music? From Pitch to Timbre

- **Pitch** is a purely psychological construct, related both to the actual frequency of a particular tone and to its relative position in the musical scale. It provides the answer to the question "What note is that?"
- **Rhythm** refers to the durations of a series of notes, and to the way that they group together into units.
- **Tempo** refers to the overall speed or pace of the piece.
- **Contour** describes the overall shape of a melody, taking into account only the pattern of "up" and "down"
- **Timbre** (rhymes with amber) distinguishes one instrument from another when both are playing the same written note. It is, a kind of tonal colour that is produced in part by overtones from the instrument's vibrations. The timber of a single instrument changes as it moves across its range.
- **Loudness** is a purely psychological construct that relates to how much energy an instrument creates.
- **Reverberation** refers to the perception of how distant the source is from us in combination with how large a room or hall the music is in.

When these basic elements combine and form **relationships** with one another in a meaningful way, they give rise to higher-order concepts such as meter, key, melody, and harmony.

- **Meter** is created by our brains by extracting information from rhythm and loudness cues, and refers to the way in which tones are grouped with one another across time.
- **Key** has to do with a hierarchy of importance that exists between tones in a musical piece. Key is a psychological function of our experiences with a musical style, idioms and schemas.
- **Melody** is the main theme of a musical piece, the part you sing along with, the succession of tones that are most salient in your mind.
- **Harmony** has to do with relationships between the pitches of different tones, and with tonal contexts that these pitches set up that ultimately lead to expectations for what will come next in a musical piece - expectations that a skilful composer can either meet or violate for artistic and expressive purposes.

Pitch is one of the primary means by which musical emotion is conveyed. The auditory cortex has a tonotopic map. A **scale** is selected based on cultural tradition and is a subset of an infinite number of pitches. Note names repeat because of a perceptual phenomenon that corresponds to the doubling or halving of frequencies, forming an **octave**. An **interval** is the distance between two tones. The Western octave is divided into 12 tones of a chromatic scale. A major scale, used in composition, has a specific interval pattern of steps – whole, whole, half, whole, whole, whole, half. A minor scale has - whole, half, whole, whole, half, whole, whole. Both **major and minor scales** hold a momentum to return to the tonal centre or key but have a different sound and emotional trajectory. Different scales have strong associations to different styles. In any scale, a hierarchy of importance exists among scale tones; some are more stable, structurally significant, or final sounding than others, causing us to feel varying amounts of tension and resolution. A **chord** is a group of three or more notes played a the same time.

Physical objects vibrate at a fundamental frequency and at (nearly) integer multiples of the fundamental, each with a characteristic energy, collectively known as an overtone series. Brains respond to such sounds with synchronous neural firing and restore a missing fundamental. “... pitch is a fundamental cue to an objects identity ….” [1] pg.44. Humans have acute timbre discrimination. Pipe organs and electronic synthesisers allow the performer to construct similes of instrumental sounds by creating overtone series. However, convincing recreations also requires attention to attack (initial transient) and flux (change during a note).

2. Foot Tapping. Discerning Rhythm, Loudness, and Harmony

A majority of non-musicians are able to sing a song within 4% of the original tempo – which is also the detectable perception of a variation on the original. The neural basis is probably the cerebellum and basal ganglia.

Syncopation creates surprise and excitement in music by playing a note a bit earlier than the strict beat would call for. Another mechanism to create excitement is to delay a word to the following downbeat.

Very tiny changes in loudness have a profound effect on the emotional communication of music –

even stressing a singe note in a chord.

Pleasing sounding chords and intervals are refereed to as consonant and other dis-consonant Simple integer frequency ratios are the most consonant.

People can easily recognise a musical “gestalt” despite wholesale changes in pitch (while retaining relative pitches in the melody) and tempo and timbre. Grouping in vision allows us to perceive a forest as a whole (rather than individual leaves) and in sound we can discern a single voice in a group of talking people or we can group a whole ensemble in an orchestra. Our auditors system exploits the harmonic series in grouping sounds together. We hear a trumpet rather than the individual overtones. Simultaneous onsets (temporal positioning) are also critical to discern instruments with similar overtone series. Other factors include spatial location, timbre, amplitude, and pitch. For the most part these are independently processed at a fairly low level, but they can come under some attentional control and be improved with experience.

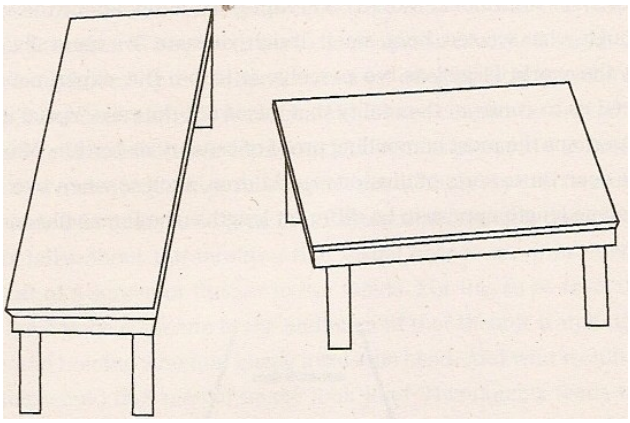
3. Behind the Curtain. Music and the Mind Machine.

Musical activity involves nearly every neural subsystem.

Michael Posner considers cognitive neuroscience as a way to provide constraints for theories in cognitive psychology.

A good experiment is theoretically motivated, and makes clear predictions as to which one of two or more competing hypothesis will be supported. A good experiment is also generalisable to other conditions. It is important to work with real-world music rather than simplified, abstracted sounds.

Our perceptions are very selected and distorted versions of the information our sense organs receive.



The brains ability to separate out and identify things in the real world based on the the undifferentiated, ambiguous and incomplete information the sense organs receive is remarkable. The eardrum is akin to ping-pong balls hitting an opaque screen and the brain manages to discern how many people are throwing the ping pong balls and from where! There is a low-level bottom-up process of feature extraction combined with a top-down process of anticipation based on context and memory.
Brains have an innate capacity to understand any of the worlds languages (Chomsky) or music (Levatin) and this is capacity is plastic in youth becoming increasingly less so in mid-childhood years.

4. Anticipation. What We Expect from Liszt (and Ludacris)

A cadence is a chord sequence that sets up a clear expectation and then closes, typically with a satisfying resolution. The deceptive cadence repeats the chord sequence many times and then inserts an unexpected chord, in the same key, but that doesn't completely resolve.

“The setting up and manipulating of expectations is the heart of music, and it is accomplished in countless ways.” [1] pg.112 Examples are provided with chords, melodies, timbre, and rhythm.

A schema is a group of elements that are common to multiple situations and create a framework within which to place them. Musical schema's include implicit knowledge of scales, meter and other characteristics of musical styles.

Dopamine is release by the nucleus accumbens and is involved in mood regulation and the coordination of movement. It is famous for being part of the brains pleasure and reward system (drugs, gamblers, chocolate) and music. Some aspects of language and music processing are lateralized. Music training appears to have the effect of shifting some music

processing from the right (imaginistic) hemisphere to the left (logical) hemisphere.

Using EEG … “The structural processing - musical syntax - has been localized to the frontal lobes of both hemispheres in areas adjacent to and overlapping with those regions that process speech syntax, such as Broca's area, and shows up regardless of whether listeners have musical training. The regions involved in musical semantics-associating a tonal sequence with meaning-appear to be in the back portions of the temporal lobe on both sides, near Wernicke's area. The brain's music system appears to operate with functional independence from the language system” based on post injury disruption. [1] pg.27

“ Consider that a very early age, babies are thought to be synaesthetic, to be unable to differentiate the input from the different senses, and to experience life and the world as a sort of psychedelic union of everything …. The process of maturation creates distinctions in the neural pathways as connections are cut or pruned.” [1] pg.128

“Listening to music and attending to its syntactic features-its structure-activated a particular region of the frontal cortex on the left side called pars orbitalis - a subsection of the region
known as Brodmann Area 47. The region we found in our study had some overlap with previous studies of structure in language, but it also had some unique activations. In addition to this left hemisphere activation, we also found activation in an analogous area of the right hemisphere. This told us that attending to structure in music requires both halves of the brain, while attending to structure in' language only requires the left half.

Most astonishing was that the left-hemisphere regions that we found were active in tracking musical structure were the very same ones that are active when deaf people are communicating by sign language. This suggested that what we had identified in the brain wasn't a region that simply processed whether a chord sequence was sensible, or whether a spoken sentence was sensible. We were now looking at a region that responded to sight-to the visual organization of words conveyed through American Sign Language. We found evidence for the existence of a brain region that processes structure in general, when that structure is conveyed over time. Although the inputs to this region must have come from different neural populations, and the outputs of it had to go through distinctive networks, there it was-a region that kept popping up in any task that involved organizing information over time.

The picture about neural organization for music was becoming clearer. All sound begins at the eardrum. Right away, sounds get segregated by pitch. Not much later, speech and music probably diverge into separate processing circuits. The speech circuits decompose the signal in order to identify individual phonemes-the consonants and vowels that make up our alphabet and our phonetic system. The music circuits start to decompose the signal and separately analyse pitch, timbre, contour, and rhythm. The output of the neurons performing these tasks connects to regions in the frontal lobe that put all of it together and try to figure out if there is any structure or order to the temporal patterning of it all. The frontal lobes access our hippocampus and regions in the interior of the temporal lobe and ask if there is anything in our memory banks that can help to understand this signal. Have I heard this particular pattern before?” [1] pg.130

5. You Know My Name, Look Up the Number. How We Categorize Music.

How are music memories different and why are they evocative? How does expectation in music generate emotion?

The human ability to recognise a piece of music despite changes in volume, tempo, key etc is remarkable. There is evidence for both the constructionist view (based on relationships) and the record-keeping (based on invariant elements) theories of memory. Aristotle argued that categories result from a list of defining features (a matter of logic) but then Wittgenstein asked “what is a game?” and offered 'family resemblance' as an alternative. Rosch showed that categories have fuzzy boundaries and challenged the validity of studying isolated non-real-world scenarios You cannot study a river by staring at a bucket of water! Rosch to conclude that:

- categories are formed around prototypes;
- these prototypes can have a biological or physiological foundation;
- category membership can be thought of as a question of degree, with some tokens being "better" exemplars than others;
- new items are judged in relation to the prototypes, forming gradients of category membership; and
- there don't need to be any attributes which all category members have in common, and boundaries don't have to be definite.

There are three reality-appearance problems:

- a single object may manifest itself in multiple viewpoints,

- several objects may have nearly identical viewpoints
- objects, although different in presentation, are of the seem natural kind (category).

Music recognition is quite robust in the face of transformations and distortions of its basic features.

Only a few people have absolute pitch – the ability to name a pitch precisely. Most people identify sounds by their timbre rather than pitch. However, people can recognise a specific known pitch. Also, even non-musicians can sing a familiar song at very close to the correct pitch and usually the correct tempo. The EEG traces for listening to and imagining a tune are almost identical. “Remembering may simply be the process of recruiting that same group of neurons we used during perception to help us form a mental image during recollection.” [1] pg.155 Musicians and people with obsessive-compulsive disorder are more likely to be troubled by ear-worms – usually a portion of a song less than the capacity of auditory short-term (echoic) memory (15-30sec). Some songs, artists and music styles have an overall sound or sonic colour – similarly a place like the blue mountains has a certain “look”. These are strong evidence for memory of absolute features of music.

However, we can also scan a song in our mind to find a word in the lyrics. The process typically involves scanning faster than the original (but maintaining pitch) from a particular entry point, in phrases. There is a hierarchical encoding. Musical scores are learnt with a hierarchical phrase structure making it difficult to begin playing from notes in the middle of a phrase and rendering some notes more important than others..
Prototype theory begins to break down when the category is very broad – such as the category “tool” where a prototype is difficult to identify. Exemplar theory is the intellectual descendent of the Gestalt residue-theory. Exemplar theory holds that every experience is encoded as a trace, including both details and context. Something is judged as a member of a category when it resembles that category more than alternatives. A prototype is the central tendency of the category. The convergence of exemplar theory and memory theory has resulted in multiple trace memory models. This involves high fidelity traces, but with interference and degradation on recall. This has been tested with PDP models.

Unique cues are the most effective mechanism to activate old memories. Memory involves repetition and music is based on repetition. Memory systems are closely related to emotional systems (amygdala is adjacent to the hippocampus).

6. After Dessert, Crick Was Still Four Seats Away from Me. Music, Emotion, and the Reptilian Brain.

Groove is built by establishing a rhythm and then introducing often subtle alterations and surprises on the base with accents, pitch, contour, timing, additions etc, but not so much as to loose orientation. The basic structure needs to be understood so that the liberties can be appreciated.

Neural processing of rhythm and meter extraction are separate, as is melody. The cerebellum is involved in tracking beat but it is also involved in emotion with heavy connections to the amygdala.

Francis Crick (and Watson) discovered the structure of DNA (Nobel prize) and argued that consciousness arises as a sum total of our thoughts beliefs, desires and feelings in “The Astonishing Hypothesis”. Levitin and Crick (see “A Mad Pursuit”) both began science late in life and see it as an advantage.

Emotions are poorly defined. In evolutionary history, emotions are closely associated with motivation to act, as they promote immediate (rather than analytical) response. Lesions in the cerebellum can cause dramatic changes in arousal. There are direct connections from the inner ear to the cerebellum that coordinate orientation in auditory space (including location sensitive neurons). “Our perception system is exquisitely tuned to detect changes in the environment ….. The auditory startle is the fastest and arguably most important of our startle responses.” [1] pg.185. The cerebellum acts as something of a timekeeper in the auditory habituation circuit which is critical for filtering out unimportant repetition in the environment and also to notice change in that repetition.

Crick proposed that the binding problem (associating colour, form, sound, etc) was a result of synchronous firing of neurons throughout the cortex and that consciousness arises from synchronising at 40Hz. Crick strongly promotes a deep knowledge of brain structure and function in order to constrain hypothesis. “Look at the connections”.

The ventral striatum includes the nucleus accumbens, which is the centre of the reward system (pleasure and addiction).

“Listening to music caused a cascade of brain regions to become activated in a particular order: first, auditory cortex for initial processing of the components of the sound. Then the frontal regions, such as BA44 and BA47, that we had previously identified as being involved in processing musical structure and expectations. Finally, a network of regions-the mesolimbic system-involved in arousal,

pleasure, and the transmission of opioids and the production of dopamine, culminating in activation in the nucleus accumbens. And the cerebellum and basal ganglia were active throughout, presumably supporting the processing of rhythm and meter. The rewarding and reinforcing aspects of listening to music seem, then, to be mediated by increasing dopamine levels in the nucleus accumbens, and by the cerebellum's contribution to regulating emotion through its connections to the frontal lobe and the limbic system. Current neuropsychological theories associate positive mood and affect with increased dopamine levels, one of the reasons that many of the newer antidepressants act on the dopaminergic system. Music is clearly a means for improving people's moods." [1] pg.191

"Our response to groove is largely pre- or unconscious because it goes thru the cerebellum rather than the frontal lobes." [1] pg.192

7. What Makes a Musician? Expertise Dissected.

It is a pity that the musicianship has become polarised to novice and expert. Davidson and Sloboda defined talent as something (1) that originates in genetic structures; (2) that is identifiable at an early stage by trained people who can recognize it even before exceptional levels of performance have been acquired; (3) that can be used to predict who is likely to excel; and (4) that only a minority can be identified as having. However, it is very difficult to separate genetic from environmental cause and effect.

"The emerging picture …. is that ten thousand hours of practice is required to achieve the level of mastery associated with being a world-class expert – in anything" [1] pg.197.

Memory strength is a function of repetition and also of the amount one cares about the experience. The release of Dopamine, associated with emotional regulation, alertness and mood aids in the encoding of a memory trace.

Even studies of identical twins are frustrated by the fact that the physical appearance of people will influence how they are treated in society. Also, certain physical endowments, like large hands, assist in playing the likes of guitar and piano.

Skills such as determination, self-confidence and patience are involved in becoming an expert at anything. "... on average, successful people have had many more failures then unsuccessful people." [1] pg.207.

Great music is more than technique. Emotional performance is critical, but not taught. Non-musician listeners are exquisitely sensitive to the physical gestures that musicians make. Performing music is a whole mind/body experience expressing/feeling the mood for/in which the music was written. Many hugely successful musicians lack formal musical training. Joni Mitchell lacked formal musical training and as a result threw together chords that were ambiguous and have two or more different roots; thus creating a distinct style.

People with incredible memory for music are highly reliant on their knowledge of structure. Short term memory id generally limited to about 9 pieces of information. Musicians using chunking to encode entire chords (rather than the tones within the chord), sequences of chords (ie aeolian cadence) rather than isolated chords, stylistic norms (i.e. grunge, or disco) rather than the component timbre, harmonic and rhythmic elements.

"It seems unlikely from what we now know that musical expertise is wholly different from expertise in other domains. Although music certainly uses brain structures and neural circuits that other activities don't, the process of becoming a musical expert-whether a composer or performer-requires many of the same personality traits as becoming an expert in other domains, especially diligence, patience, motivation, and plain old-fashioned stick-to-it-iveness. " [1] pg.220

8. My Favourite Things. Why Do We Like the Music We Like?

Children recognise and prefer the music they were exposed to in the womb. Young children are prime candidates for suggestion. It has not been demonstrated that listening to music enhances cognition in the now, but over the longer term, music listening enhances or changes certain circuits including the density of dendritic connections in the primary auditory cortex. Also, Schlaug showed that the front portion of the corpus callosum is significantly larger in musicians than non-musicians, especially for those receiving early training. Schlaug also showed that musicians have larger cerebellums and increased concentration of grey matter. Music also has therapeutic value.

Infants prefer consonance over dissonance, can recognise tempo changes, and can attend to absolute-pitch cues but the most salient musical feature is contour. Mothers in particular use exaggerated intonation when talking to children.

Simple music interest begins at 2 years, but real interest in music comes at about age 10-12 and that at age 14 is particularly salient due to the emotionally charge in teenage years. Musical preference is also a form of social bonding and externalizing that bond. Also, neural maturation, pruning and myelination is approaching adult levels of complexity and plasticity is reducing by age 20.

Familiarity with a musical style (schema) defines an area of music which is neither too simple (trivial) or complex (unpredictable). Structural processing is one source of difficulty in appreciating new music. Dimensions other than complexity also contribute to its palatability such as dynamic range, emotional range (Mahlers 5th), pitch preference (thumping hip hop vs violins), rhythm (Latin), and timbre (a particular artist). New experiences tend to be acceptable if they are incremental extensions of the familiar. Safety is also important to feel comfortable to abandon one's self to the emotional trajectory, and at times, political ideas, of the the music.

9. The Music Instinct. Evolution's #1 Hit

Steven Pinker argued that language is an evolutionary adaptation and that music is spandrel (by-product). “Music is auditory cheesecake.” Pinker. “an evolutionary parasite” Sperber.

However, Darwin argues that music has a role in charming the opposite sex and preceded language. Proficiency in music and dance communicates physical and mental health and stamina, and ample wealth. Musical interest peaks in adolescence concurrent with mate finding. Women prefer creativity for long term relationships and athleticism for short term encounters – distinguishing between best fathers (in the biological sense) and best dads (in the child-rearing sense).

If music were non-adaptive then it would tend to have a short evolutionary history – but musical instruments are among the oldest human artefact found – a flute of at least 50,000 years. A flute is unlikely to be the first instrument. Furthermore, there is a genetic lag of 50,000 years between the mutation and wide distribution in the human gene pool. Music has been inseparable from dance in all but the most recent history.

More recent arguments for music's adaptation value.

Social bonding and cohesion is relevant to groups but also people with Williams syndrome are intellectually impaired but with highly developed music and social skills. People with autism spectrum disorders lack empathy and the ability to appreciate the aesthetic qualities of art and music.

Music may have promoted cognitive development and acted as a primer for language evolution and development. High intelligence children have a greater tendency to over extend the rule set and make errors such as “goed” instead of went. Also, both language and music are generative and not just repeated. Mother child interactions universally involve music and rhythm.

While being careful not to anthropomorphise, many other species use vocalizations for a variety of functions, and often related to courtship.

“Music's evolutionary origin is established because it is present across all humans (meeting the biologists' criterion of being widespread in a species); it has been around a long time (refuting the notion that it is merely audio cheesecake); it involves specialized brain structures, including dedicated memory systems that can remain functional when other memory systems fail (when a physical brain system develops across all humans, we assume that it has an evolutionary basis); and it is analogous to music making in other species. Rhythmic sequences optimally excite recurrent neural networks in mammalian brains, including feedback loops among the motor cortex, the cerebellum, and the frontal regions. Tonal systems, pitch transitions, and chords scaffold on certain properties of the auditory system that were themselves products of the physical world, of the inherent nature of vibrating objects. Our auditory system develops' ways that play on the relation between scales and the overtone series. Musical novelty attracts attention and overcomes boredom, increasing memorability.” [1] pg.265.

References.

[1] **Levitin**,D. (2006), This Is Your Brain On Music. Penguin