Cognition of Music

HUL281 Mind, Machines and Languages

Term Paper

Ravee Malla

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Group 4

Indian Institute of Technology, Delhi

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Abstract

Music, like Language is arguably one of the most prized gifts that human civilisations across ages and regions have cherished and wondered. Over the past century, with the advent of modern non-invasive brain imaging techniques, cognition of the Mind/Brain has become a very diverse and open problem appearing in many fields. Human cognition has been put to test in various circumstances in hope of understanding the brain further and getting an insight into the deeper questions of consciousness, intelligence, etc. In the present paper, I present my views on "**Cognition of Music"** by the Human Mind/Brain*. I have tried to look at music and the brain in isolation at first, and studied the possible changes both physical and psychological that take place in the mind/brain in the event of their interaction. I wish to throw light on which elements of a song* does the brain perceive most easily and what effect(s) does it trigger in the brain. Due to limited means of experimentation available, I have only gone so far as to mention the experimental set-up that may be used to perform the experiments I have proposed. As far as possible, I have tried to devise as many thought experiments as possible. I have also looked at the association of music with memory and language. I have briefly studied the Binding Problem in context of perception and cognition of music as well.

Keywords: music, cognition, music memory, language, perception of elements of music

*by a song, I refer primarily to the non-lyrical content of it, i.e. the semantics derived from the music and the instruments.
*I use mind and brain interchangeably.

Introduction

Music is universal. Everybody "understands" music. Music has no language and knows no boundaries. All this might sound cliché, but when one introspects as to just how truly music is all around him/her, he/she realizes this consuming truth. I had my tryst with music about 8 or 9 years ago, when I started playing the guitar. But, as time passed and my cognitive apparatus took over, I realized that I was "seeing" music. Music that I heard had become independent of instrumentation and lyrics. It became a universal idea that needed no language (the instrument) to be expressed. Musical ideas were pouring in my mind day and night, and I needed an outlet to store them forever. Luckily at the time, I found a music designing software on which I performed my experiments on music. I started first by remixing songs, and then making some of my own. With every song, I discovered newer facets and secrets of music, and how my brain might be interpreting them. Every song had a different emotion, a different impact on my mind.

I needed a means to formally study the relation between music and the mind. It was when I came across Cognitive Psychology and its sub-fields that I felt certain that this was the perfect way to characterise music as I understood it.

So here I am today, talking of **"Cognition of Music".** In the presented paper, I talk of music and cognition in isolation and conjunction, the impact they have on each other and how music is meaningless without cognition. First I will talk of music, and its elements that the human mind detects most easily. I will also talk a little about the human auditory system, taking care to take the physical and psychological aspects hand in hand as much as possible. After dealing with the different elements of music, and how the brain could possibly perceive each, I will look at how the Binding Problem helps in integrating these elements together to form the final "musical" input. I will finally look at how music affects memory and language acquisition. For these I have devised thought experiments, which may be implemented in the lab.

I have divided my approach to understanding cognition of music, moving from the physical into the psychological. I will first look at human auditory system, without which music holds no meaning. It is only due the complex meaning that the mind attaches with the music, we can enjoy it and feel it.

Auditory Perception

The human ear, in the most general of terms, is a physical transducer/transformer which can not only convert pressure energy to electric impulses, but also amplify it to suitable values. It is an intricate arrangement of 3 layers, inner, outer and middle ear. While the outer and middle ears function primarily to efficiently transmit sound upto the Ossicular chain, the inner ear is laid with thin neurons which vibrate along with the input frequency of the sound wave. The outer and middle ear regions are much more physical in operation, and channel the sound into the inner ear. The inner ear is where the mechanical vibrations are converted into electrical impulses which are then sent to the brain. I attempt to describe the working of the inner ear in detail.

The inner ear houses the sensory organ of hearing (cochlea) as well as the vestibular system. The latter part assists in maintaining balance. The cochlea is a snail-shaped organ which can stretch up to 32 mm approximately. It is filled with a sea water-like fluid. The inner surface of the cochlea is lined with over 17 000 hair-like nerve cells which perform one of the most critical roles in the process of hearing. There are two types of hair cells, namely inner and outer hair cells. There is a single row of inner hair cells, and typically there are three rows of outer hair cells. These nerve cells differ in length by minuscule amounts and they also show different resiliency to the fluid which passes over them. As a compressional wave moves from the interface between the hammer of the middle ear and the oval window of the inner ear through the cochlea, the small hair-like nerve cells are set in motion. Each hair cell has a natural sensitivity to a particular frequency of vibration. When the frequency of the compressional wave matches the natural frequency of a nerve cell, that nerve cell resonates with a larger amplitude of vibration. The increased vibrational amplitude induces the cell to release an electrical impulse which passes along the auditory nerve towards the brain where it is decoded and interpreted. Only about 5% of neurons connect to the outer hair cells, this means that each neuron receives input from numerous outer hair cells. Their activity is summated by the neurons to improve sensitivity. The other 95% of neurons connect to the inner hair cells providing better discrimination.
The inner ear is a link between the physical and the psychological. It is studied to understand how our brain processes sounds. This can be used to improve algorithms and hardware of machines used today.

Levels of auditory perception

In cognition of music, or any other item in general, there always persists a notion of levels of cognition. At the lower end, the cognition is independent of the perceiver, and as one goes up, it becomes relative. Many researchers have identified levels of cognition of music to determine what music means to an average individual and how different it is for different people.
The elements of music that appear in the lower levels are occurrence of masking, perception of pitch and loudness. For all these elements, we can model a physical system which mimics how a human brain may be perceiving and cognizing them. I will talk more about these when I talk of elements of music in general.

Besides these, the levels higher up can be broadly classified as:

- **Musical information**: melody, rhythm, metrum, harmony, modality;
- **Environmental information**: spatial location, room characteristics, background sounds identification;
- **Cognitive information**: instrument identification, recognition of a melody, a composer or a musical style;
- **Emotional information**: identification of emotional intentions of a composer or a musician.

The sensation, perception and cognition triad can be used to explain these levels of auditory perception. Sensation is the same for all individual. As we move towards cognition and perception, our ideas become relative. After sensing the primary elements of music i.e. the tonality, pitch, locality, etc we move onto to describe perception of music.

Music Perception

Perception is by definition the act of perceiving, cognizance by the senses or intellect, apprehension by a bodily organ or by mind of what is presented to them. Thus it is a conscious mental awareness and interpretation of a sensory stimulus.
Music perception is an interdisciplinary area which combines a number of disciplines, such as physics, psychoacoustics, mathematics and musicology. Each of them plays an equally significant role in the understanding of musical phenomena. The target of physics is to understand the mechanism of sound creation in musical instruments. Psychoacoustics focus on the other side of sound nature – effects of music upon humans which in turn approaches the area of cognitive psychology, dealing with the highest level of organization of the heard sound and the area of the sound scene analysis. Both the musical theory and the musical psychology have had a significant impact on this area. They focus on high-level modelling of musical structures, dealing with such structures as key, metrum, or harmony.
The 2 levels can be compared to the deep and surface structures that one studies in linguistics.

Pitch perception is the primary component of music perception, and happens independently. The brain has a well defined neural network to decode pitch and loudness of music (Allott 2004). These serve to give the primary impressions of what the mind hears. Other physiological components of music are as follows:

- **Synaesthesia**

It is hypothesized that synaesthesia is possible due to some extra connections in the brain which occur between areas concerned with auditory and visual perceptions. It is referred to as "seeing" sounds, "hearing" colours resulting from mutual relations and connections of different senses. The most common musical synaesthetic experience is seeing colours or patterns when music is heard or composed.

- **Temporal (rhythmic) effects**

It is assumed that the perception of musical rhythm is crucial to understanding the auditory perception abilities of the right cerebral hemisphere. Apart from the rhythm of breathing, the other dominant rhythmic sound in our lives is the heartbeat (McLaughlin 1970).

- **Motor effects**

Music has a direct relation to the nervous organization of postures and movements. Composition, performance and listening imply wide involvement of the cerebral motor cortex, subcortical motor and sensory nuclei and the limbic system (Critchley et al 1997).

- **Other body-based responses**

Perceptual and emotional musical experiences lead to changes in blood pressure, pulse rate, respiration, and other autonomic functions. These autonomic changes represent the vegetative reflections of psychological processes. During the act of conducting, the highest pulse frequencies are not reached at moments of greatest physical effort but at passages producing the greatest emotional response, passages which the famous conductor von Karajan singled out as being the ones he found most profoundly touching.

- **Neural patterning**

There are strong analogies or structural similarities between music and the fundamental activities of the nervous system. The characteristics of nerve impulses - timing, intensity, synchronicity, frequency-contrasts, patterning generally - can be set in parallel with many aspects of musical construction.

Elements of Musical Sounds

- **Pitch:** As mentioned before, pitch refers to the linear arrangement of sounds in terms of their frequency. Moving from lower to higher frequency regions, sound becomes shriller. The brain is more sensitive to changes in higher frequency domain.
- **Dynamics:** Degrees of loudness or softness of the music constitute its dynamic quality. Loudness is associated with the amplitude of vibration of sound waves.
- **Tone Colour:** It is the nature or quality of the sound which is characteristic of the producer of it. The instrument or device used to create the sound inherently imparts it a distinct signature and the mind decodes this sound. Taking the example of an ILI triad, we can say that if a trumpet is an item, its signature sound is the label that the mind gives it. Hence, not only is the trumpet stored as a visual image of a trumpet, but also as a form of the signature sound it produces.
- **Duration:** The length of time interval the sound is played.

Elements of Music

- **Melody:** After hearing a piece of music, we usually remember its melody the most. Melody is a series of single tones which add up to a recognizable whole. A melody begins, moves, and ends; it has direction, shape, and continuity. The up-and-down movement of its pitches conveys tension and release, expectation and arrival. This is the melodic curve, or line.
- **Harmony:** A harmony refers to the way chords are played together in a song. Essentially, a chord is a combination of 3 or more tones played together. More tones played together give a richer feel to the sound, and add greater emotional content to it. In contrast with melody, it is secondary and works only to support the main melody of the song.
- **Key:** The key of the song refers to the central tone and the central scale that is employed all through the song. It helps to maintain a constancy of intention and regularity of thought. A song involving a change in key sends out a message of change, in the nature and meaning of the song.

Rhythm Perception

Rhythm is perhaps the most striking element of music. It spills over onto other forms of expression involving music such as dancing. It plays a major role in defining the purpose of the music. Faster songs, happier songs have more energetic beats; beats that make the listener move his body with the pace of the song. Slower songs, on the other hand, have more subtle, sober beats, which soak up all the energy from the listener.

Rhythm, along with melody, constitutes a large part of what we perceive in music. Byrd and Crawford (2001), popular musicologists claim that the most informative are melody and rhythm, assigning about 50% of informativeness to a melody, 40% to rhythm and remaining 10% to the rest of such elements as harmony, dynamics, agogics, articulation, etc. Therefore, rhythm is a fundamental part of any kind of music.

The appearance of rhythm seems to be the first step in the evolution of a musical culture. In the days of ancient Greece and Rome, rhythm – tempo, measures and note duration – were defined by the kind of rhythmical recitation. Rhythmic, dynamic and harmonic notations differed greatly from modern musical notation. During the Renaissance, the tempo fixed at the beginning of a musical score was constant for the whole piece and denoted on the basis of '*taktus*' (*Latin*), the basic time signature, also referred to as '*integer valor notarum*' (*Latin*). Starting from that time, awareness of rhythm "grew up". In the Baroque period of music, rhythmic features started to be important, and the Classical period began with a new interest in rhythm. The modern period is marked by the strengthening of rhythmic features, exemplified in the compositions of Bartok and Stravinsky (The New Grove 1980).

The specific sequence of sound stimuli and pauses can be perceived as certain rhythm. The rhythm can be perceived if the presentations of sound stimuli are distributed in time interval of critical duration. Too short as well as too long duration of stimuli presentation precludes perceiving the rhythm.

While talking of rhythm, there is an inherent notion of the temporal line that comes into picture. All the events, i.e. different notes being played together are first marked down on this temporal line, and then bound together and played sequentially. Since music also has a repetitive quality, this temporal line need only store the time values when a new note is played, and not the note itself. Hence, this time line is used only to make an internal structure of the sound in the mental space.

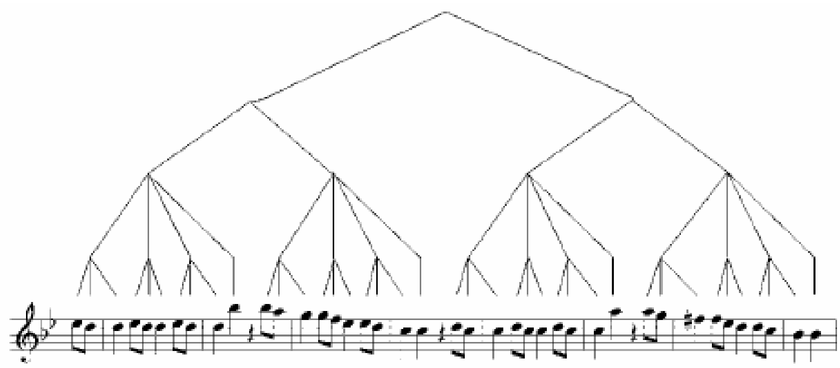
Perception of Time in the Mental Space (Jingu's model)

I wish to deviate a little from my topic here, and talk of this "temporal line" mentioned in the previous section. Many areas of cognitive psychology touch upon the need of such a timeline, as time is indispensable in almost all areas of logical thinking.

Jingu (Nagai 1996) proposed an inner procedural model of time perception. It is quite natural to assume the existence of an equivalent for a quartz oscillator of clocks in a human brain. This device serves as an internal clock. The internal clock and its pulse counter are considered to be used directly to evaluate temporal information and generate subjective time. The pacemaker in Jingu's model is based on the reverberating circuit in a brain. The pacemaker of this rhythm perception model is a black-box, but the same cycle of pulses as Jingu's model (4ms) is postulated as a standard.
The counter is a device to count pulses generated by the pacemaker. This counter, dependent on the mode, counts from 4ms to 12ms pulses. The chrono-store in the rhythm perception model is an equivalent of echoic-memory in auditory perception. It is a temporary storage space for pulses from its pacemaker. The information stored is forwarded to the short-term memory (Nagai 1996).
An interesting concept was proposed by Nagai. He observed that in the field of psychophysics, time shown by a physical clock is a physical continuum, while time felt by human beings is a psychological continuum. Both times change continuously in quantity, but the latter time needs consciousness, and is called **subjective time**.

Formal Ways of Analysing Music

Formal analysis of music within the frame of Cognitive Psychology has been attempted by many researchers. Many of the theories look upon music just as language. The basic idea behind this is that the brain cognizes every object as a binary tree. Leach and Fitch (1995) propose a theory based on the assumption that music is an association of music phrase repetitions. In the figure below, a music piece is analysed. It can be thought as groups of 3, but every 11th note in the work forms a new sub-category and thus falls in another sub-tree.



Leach and Fitch (1995): Theory of Music Analysis

The starting point for the analysis is the construction of a model that reflects the listener's perception of music. Such a model of structural hearing was first introduced by Lerdhal and Jackendoff, reexamined by Narmour, and again as complex structures consisting of various dimensions. Structural hearing, according to Lerdhal and Jackendoff, is a concept that allows one to understand music as complex structures consisting of various dimensions.

Association of Music with Memory

Magical music never leaves the memory (Sir Thomas Beecham 1962).

Experiments prove that music is tightly bound with memory, and a part of the memory is dedicated to music, the so called **music memory**. Music memory is best studied as a comparison between people with normal memory and those with memory disorders like Alzheimer’s disease (AD). This study can give an insight as to whether the music memory component works independently, or is it just a manifestation of the regular memory of the brain.

<u>Forms of Music Memory:</u>

Classically, memory has been categorised as Short-term and Long-term memory. However, experiments suggest that music memory is invoked only when a musical piece needs to be committed for a longer duration. Short term commitment is done by the working buffer memory itself.
Long-term musical memory comprises two different forms, explicit and implicit. Explicit or ‘declarative’ memory involves ‘remembering that’, and enables conscious recollection of events and facts. In the non-musical domain, explicit memory has been defined as having two divisions, episodic and semantic memory.
In the musical domain, semantic or conceptual musical memory can be defined as memory for factual musical knowledge or memory for associative or emotional concepts that is not linked to the retrieval of a specific personal experience or autobiographical event. Implicit or ‘non declarative’ memory involves ‘knowing how’ and is mediated by non-conscious processes, including priming, procedural memory or motor skill learning, which is critical for playing a musical instrument.

<u>Neuroimaging Results of Music Memory</u>

Along with Lesion studies, non-invasive brain imaging has been used to study the influence of music on the brain. This has highlighted how different regions of the brain get activated by different forms of music, and also by different elements of music. A few results have presented briefly.

Zatorre et al. (1996) observed significant activations bilaterally in the inferior frontal poles associated with musical imagery of familiar songs with lyrics, and a subsequent musical imagery study using familiar melodies without lyrics demonstrated activation in the right inferior frontal region and middle frontal lobes which was predominately right sided. This activation was interpreted as reflecting retrieval of familiar songs from semantic musical memory. An alternative explanation acknowledged by the authors was that the right frontal activation might reflect episodic retrieval of the point at which they were trained to stop imagining the melody.

Watanabe et al. (2007) found that successful retrieval of unfamiliar musical phrases (defined as the number of hits minus correct rejections) was associated with significant activations in the left inferior frontal gyrus, and to temporal lobe regions including the right hippocampus. In addition, a negative correlation was observed between the haemodynamic response and the ‘corrected recognition rate’ (defined as hits minus false alarms) in the left inferior frontal gyrus. This pattern of frontal activation was attributed to retrieval effort.

Plailly et al. (2007) found that unfamiliar music elicited activation of the right superior frontal gyrus and superior middle gyrus, in addition to the left central and superior precentral sulci and left parietal operculum.

Music and Memory

Can music aid the memory mechanisms? Do musicians have sharper and more refined memory? Is music memory unaffected by such a lethal memory disorder disease such as AD? These are open questions, and research is going on in these areas. Currently, neuropsychologists agree that implicit music memory is largely unaffected by AD. This means that a musician will not forget how to play an instrument, neither the core fundamentals of music. Hence, the neural networks preserving this form of memory can potentially be reused for non-musical memory.

Thought Experiments to test Music Memory

Many thought experiments can be devised so as to test the impact of music memory on regular memory. A common memory game, where the subject has to recall images and labels he/she was made to memorize earlier can be modified to include the element of music. Not only is he/she shown an image, but is also made to hear a particular song. The recalling ability of the same subject can now be compared to when he/she was not given any music aid. In most cases, this ability improves. This gives an insight into newer and more effective learning techniques.
Non invasive imaging techniques may also be employed to pinpoint the regions of the brain that get activated while playing or listening to music. On comparing the brain images of an accomplished pianist and an average person taken while they were playing the same musical piece, it was found that the average person had to focus harder and was under stress. In contrast, the pianist was adept at the complex finger movements, and his image showed him involving fewer regions of the brain. This implies that the implicit memory doesn't take up much of the blood flow or energy.

Music can facilitate Neuroplasticity

Neuroplasticity is undoubtedly the most important and powerful tool that can be used to understand and treat neural disorders. If carefully understood, it can become the most important discoveries of the 21st century. Music which was previously thought to have its own set of neural networks in the brain, has recently been shown to facilitate plasticity in a set of lab rats.
About sixty rats were divided in four groups, two of which had *callosotomy* performed on them: a small section of the brain was removed just after they were born, an area that is considered important for e.g. spatial memory. The research elaborates on earlier studies that showed music to have an effect on hippocampal neurogenesis, as well as facilitated spatial memory (e.g., Kim et al., 2006).

The authors concluded that an enriched sound environment -exposing rats to piano music- helped the recovery from neural damage. Rats with a damaged brain showed signs of recovery after about fifty days of listening to Mozart piano sonates for about 12 hours a day. Compared to rats that also had brain damage, but that did not listen to music, they performed significantly better in a spatial memory task (finding their way in a maze) and in their emotional reactivity (using a marble burying task).

Music and Language

I have a strong inclination towards the fact that music and language utilize the same neural networks all through the brain, invoking and communicating with the same regions for equivalent requests. Music perception shares its characteristics with language processing because both are independent of perceptual modes such as vision and speech.

However, having said this, I also maintain that there are some innate, fundamental differences between them. Most notably among them is that where language is assumed to be universal (Chomsky), music is in fact truly universal. Many psychologists believe in the presence of a Language

Acquisition Module, which generates and comprehends the deep structure of a sentence independent of the language used. However, this is a mere hypothesis.
Each language has its own set of rules, which makes it unique and very much unlike the others. However, music, across ages and regions, differs only in the semantic content, i.e. the instrumentation and the surface elements of it (e.g. pitch, loudness, etc). The basic ideas are innate to the sounds and need to prior training to be comprehended, much unlike language, where the listener needs to be trained in the language. Hence, the phrase “Music knows no boundaries”.

We could devise thought experiments to determine the exact extent of the interdependence between music and language. This could involve analysing patients with language acquisition and production disorders for their musical abilities and vice versa.

A Binding approach to Music Cognition

The Binding problem is a general class of problems dealing with the logical addition and association of various stimuli perceived by the brain of a single event.
In case of music, just like language, many elements are present in parallel. Different areas of the brain sense and perceive these elements, and they are bound together before they are cognised. I suspect that the binding mechanisms are much like those of language. I can assume this because language and music are both primarily audio signatures spoken in space and time. Just as music has pitch, loudness, tempo, rhythm, harmony, tonality, etc. language has acoustics of characters, syllables, words, sentences. Both of these meet at the top, wherein the semantics and the emotion are decoded.
From here, the 2 branch apart as music has somewhat vague decoding rules and language has a fixed set of rules, based on prior knowledge of the language in use.
Even music memory that was discussed before comes into play and is bound with the binary tree that was generated using Leach-Fitch theory.

Why are some forms of music more appealing than others?

Everyone has their own choices when it comes to music. How is this choice made? Is it genetic or environmental or growth related? All these questions are explained by idealizing the reward system of the brain. A reward is psychological activity which when offered causes a behaviour to increase its intensity. Secondary reward includes music. The form of music which one likes the most, releases the maximum rewarding neurotransmitters like Dopamine. This is also dependent on the nature of memories that are invoked on hearing this music. All put together, it plays an important role on how we perceive music.

Conclusion

I have spent the last 8-9 years of my life with music. Throughout these years, my favourite band, my favourite music, my favourite instrument changed with time as my cognitive apparatus evolved, moulded and changed forms. With time, I got more and more confident of the universality of music. I have constantly tried to listen to newer forms of music, to decipher common elements of music and use this knowledge to design my own tunes. I intend to not only understand cognition of music, but make music a means to understand how brain cognises the environment in general.

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Note: I apologize for any wrong spellings or sentence constructs that may have crept in while preparing this document as well as for any incorrect or absent citing of references.