The Brain on Music

Nandini Chatterjee Singh and Hymavathy Balasubramanian

Permeating across societies and cultures, music is a companion to millions across the globe. Despite being an abstract art form, music affects all of us deeply, encouraging us in periods of difficulty, comforting us in moments of sadness and celebrating with us in times of joy. In recent years, neuroscientists have recognized that listening to and producing music involves a tantalizing mix of practically every human cognitive function. Thus, music has emerged as an invaluable tool to study varying aspects of the human brain such as auditory and motor perception and learning, attention, memory, and emotion. In this paper, we will discuss the different attributes of music and the neural structures associated with them. We will also highlight some recent work in our laboratory at the National Brain Research Centre in India on emotions associated with Hindustani *rāga* music.

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Keywords
Music, brain, neuroscience, amusia, fMRI, *rāga*, emotion.

Perception of Music and Amusia

In a paper written in 1951, philosopher Susanne Langer noted, "The most highly developed type of purely connotational semantic is music," [1] thereby suggesting that meaning or communication through music came to us long before meaning given by words. This led to the proposition that along the evolutionary road, the articulation of emotions possibly began through other sensory modalities and included music and gestures. In the past two decades, a number of studies have been undertaken to understand the perception of music by the brain. Thus, research has revealed that music provides a tool to study not only emotion processing but also many other processes like sound processing, motor-skill learning, attention, memory storage and retrieval and sensory-motor integration.

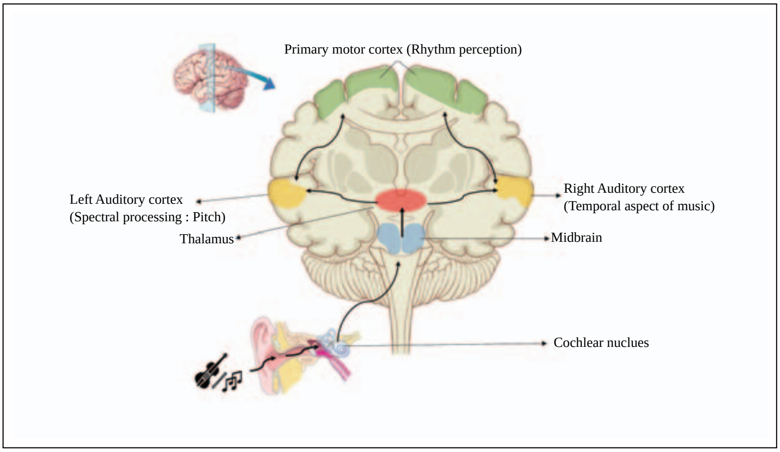

Figure 1. The pathway from the ear to the cortex during music perception depicted on the coronal section of the brain. Sound signals are converted to neural impulses at the cochlear level and move up to the primary auditory cortex for music information decoding. From the auditory cortex, we see strong connections with associated regions of motor, premotor regions. (Coronal section image credits: Patrick J Lynch, Medical Illustrator; C Carl Jaffe, MD, Cardiologist)

The initial perception of music, similar to other sound stimuli, starts in the cochlea, in the inner ear, where acoustic information is translated into neural activity. This neural activity is then translated into distinct music features (attributes) such as pitch, timbre, roughness, and intensity in the midbrain. Moving up to the thalamus, the relay center for sensory stimuli, this information is then directed to the auditory cortex of the brain.

Following this, music processes are divided, with the left auditory cortex dominating spectral processes like pitch and the right auditory cortex governing temporal aspects like beat, rhythm and tempo. The temporal aspects of music have been shown to involve a strong interaction between the auditory and motor cortices. Additionally the processing of temporal information in music is very similar across perception and production. This means that the brain responds very similarly when the rhythm is being perceived (auditory) and when it is being produced (motor). Thus, an interesting feature of music processing is its intercortical nature since most processes involve a strong interaction between two or more cortices. *Figure* 1 shows the different structures and pathways in the brain known to be involved in music processing.

How has music processing in the brain been studied? The earliest report of the neural correlates of music came from deficits in music processing. In 1878, Grant-Allen reported the case of a 30-year-old educated man without any brain lesions suffering from a severe musical handicap. The man was unable to discriminate the pitch of two successive tones, failed to recognize familiar melodies and could not carry a tune. This condition went on to be termed as 'amusia'. Amusia is impaired perception, understanding, or production of music not attributable to disease of the peripheral (external to the brain, in this case the ear) auditory system or motor system. Individuals with amusia are unable to recognize wrong notes or even familiar melodies.

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The disorder has further been categorized into two types – congenital and acquired amusia. 'Congenital' amusia, also known as tone-deafness, is a musical disorder that is inherited whereas 'acquired' amusia occurs as a consequence of brain damage. People suffering from congenital amusia lack basic musical abilities that include melodic discrimination and recognition. This disorder cannot be explained by prior brain lesion, hearing loss, cognitive deficits, socio-affective disturbance, or lack of environmental stimulation. Individuals suffering from congenital amusia often only have impaired musical abilities but are able to process speech, common environmental sounds and human voices similar to typical individuals. This suggested that music is 'biological' i.e., it is innately present in humans. Although there are no cures for congenital amusia, some treatments have been found to be effective in improving the musical abilities of those suffering from congenital amusia. In one such study, singing intervention was shown to improve the perception of music in amusic individuals, and it is hoped that more methods will be discovered that may help people overcome congenital amusia.

Acquired amusia is a cognitive disorder of perception and/or processing of music and is found in patients with brain damage. Acquired amusia has been observed in two distinct forms, namely 'anhedonia' and 'auditory agnosia', based on the different deficits in music processing. Anhedonia is a disorder that leads to inability of experiencing pleasure while listening to music. Thus,

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individuals with this disorder have difficulty experiencing or recognizing emotion in music. On the other hand, individuals with associative agnosia generally fail to recognize the source of the sound. Despite being taught, they might fail to identify the instrument producing the sound or may have trouble naming the tune played.

[1] A brain area that is part of the limbic system.

Brain damage resulting in acquired amusia may arise from strokes, diseases, tumors etc. Consequently, there are a large number of cases of acquired amusia, all implicating different brain regions. Here, it is important to note that a considerable understanding of how the brain processes music has emerged because of loss of function. For example, a rare subject with complete bilateral damage in the amygdala[1] was found to be significantly impaired only in musical emotion processing. This finding indicates that the role of amygdala in music processing is crucial for recognizing emotion in music. Further research on the amygdala then went on to establish its role in emotion processing in general. Similarly, in another study, musical emotion was affected in 26 patients with fronto-temporal lobar degeneration. As the name indicates, fronto-temporal lobar degeneration is associated with a progressive decay in the nerves of the frontal and temporal regions of the brain. This illustrated that recognition of emotion in music is not restricted to a single region namely the amygdala but is distributed over a network of regions that also include the fronto-temporal lobes. Over the years, research has shown that musical emotion is processed by a large distributed network of regions that includes insula , orbitofrontal cortex, anterior cingulate and medial prefrontal cortex, anterior temporal, posterior temporal and parietal cortices, amygdala, and the subcortical mesolimbic system (see *Figure* 2 for regions involved in emotion network). Therefore, it is fair to say that music processing is distributed all over the brain.

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Music and Emotion

Despite the knowledge that the primary function of music is to communicate emotion, scientific studies investigating the impact

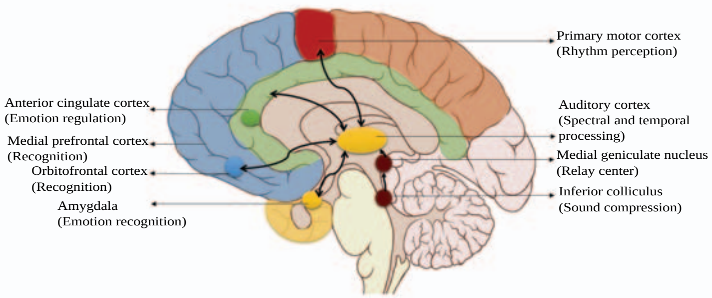

Figure 2. Sagittal section of the brain depicting the lobes and regions involved during music processing. The following lobes are depicted in different colors: frontal lobe (blue), temporal lobe (yellow), parietal lobe (orange), and limbic lobe (green). Sound processed at the cochlear level reaches the thalamic level (medial geniculate nucleus), which projects it to the primary auditory cortex. From the auditory cortex, we see interactions with the primary motor cortex for rhythm perception, the orbitofrontal cortex for recognition, amygdala, cingulate, and limbic system for emotion recognition. (Sagittal section image credits: Patrick J Lynch, Medical Illustrator; C Carl Jaffe, MD, Cardiologist.)

of music on emotion are relatively recent. In order to understand and systematically assess the emotional response of participants to music, psychological studies used emotion rating. In order to quantify the extent of emotion experienced, emotion studies used self-reports, where participants are required to rate the emotion experienced from a given set of emotion cues while listening to that music sample. To understand or experience this, visit `http://emotion-in-music.nbrc.ac.in/p1/`. In order to establish the neurobiological evidence for emotions experienced by the brain while listening to music, research studies have used techniques like functional Magnetic Resonance Imaging (fMRI), which measures brain activity by detecting changes associated with blood flow. It is based on the understanding that when an area of the brain is in use, blood flow to that region also increases. In fMRI studies, brain activity is measured while individuals listen to music in the MRI scanner, and make responses on how much they liked or disliked the music. Such studies fall under the realm of psychophysiology as they link psychological processes like emotion perception with physiological brain responses.

In addition to the emotional impact of music on the brain, these studies have established that listening to music can be linked to changes in the hormonal system of the body mediated by the brain. Music has been shown to have a positive effect on the mood of an individual and listening to music has been linked to

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the release of the pleasure hormone 'dopamine'. Furthermore, performing musical activities has been suggested to strengthen social bonds such as coordination, cooperation, communication, social cognition, contact, copathy, and social cohesion in a group.

Since music is a spectrally rich, time varying auditory stimulus, a large body of research has focused on establishing the association between the musical structure and emotions perceived by listeners. Research from the field of music psychology has indicated that emotions are elicited as a consequence of the musical structure. Musical structure is characterized by acoustic features that can be broadly classified into 'tonal' (intensity, pitch height, timbre, dissonance, harmony) and 'rhythmic' (rhythmic complexity, tempo) cues, which blend together to create a seamless perception of pitch in the musical composition. Some of the earliest research conducted in the field of music psychology manipulated these cues of musical structure to identify the change in participants' response along the 'happy-sad' continuum axis. These research studies used musical pieces that systematically varied in several cues and the results of these studies indicated that mode, tempo, and rhythm are the three cues that are the strongest determinants of the perceived emotion in listeners. The expression of happiness is associated with faster tempo, a high-pitch range, and a major rather than minor interval (see *Box* 1 for definition), and these cues are reversed in musical expressions of sadness.

A Case for Hindustani Music

Most of our current understanding of musical emotions and its association with musical structure has come from studies conducted using western music. Although past studies using western music have established the association of musical mode (minor/major) with mood (negative/positive), and tempo with intensity of the emotion response, most findings lack generalizability across multicultural representations of music. Consequently, while music and emotion studies have standardized the use of Western classical music as a source of stimuli, only a few studies have incorporated genres of music native to other cultures. This not only precludes any interpretations of universality in musical emotions from their findings, it also overlooks an entire canon of musical stimuli, which might be uniquely suited to disentangling different acoustic effects on musical emotion. Classical music from the subcontinent of India, exists in two forms – Carnatic and Hindustani. Hindustani music, popularly known as North Indian Classical Music (NICM), born out of cultural synthesis of Vedic chant tradition and traditional Persian music, has been historically associated with emotional (*rasa*) communication. Thus, by its innate design of tonal structure, Indian Classical Music lends itself rather appropriately to investigate some existing questions and raise new ones for cross-cultural studies of musical emotion.

Rāga– Rasa Theory in the Context of Music Emotion Research

As stated earlier, Indian classical music is principally based on melody and rhythm, rather than harmony, counterpoint, chords, modulation (see *Box* 1 for definitions) and the other basics of Western classical music. *Rāga*s form the central notion in both Hindustani and Carnatic music. The word '*rāga*' originates in Sanskrit and is described as 'the act of coloring or dyeing' (the mind and mood/emotions in this context) and refers metaphorically to 'any feeling or passion especially love, affection, sympathy, desire, interest, motivation, joy, or delight'. The notion of a *rasa* (mood) is thus inherent in both Hindustani and Carnatic music. A *rāga* uses a set of five or more notes from the fixed scale of seven notes to construct a melody. However, it is not enough to define a *rāga* in terms of mode or scale alone, as a number of *rāga*s have the same notes, yet each maintains its own musical identity. For instance, both *rāga*s '*Miyan ki Malhar*' and '*Bahar*' contain the same notes (*Sa*, *Re*, *ga*, *Ma*, *Pa*, *Dha*, *ni*, *Ni*) and yet sound quite different because of the way the notes in the scale are approached and combined.

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A *rāga* composition is typically presented as a specific sequence

Box 1. Definitions

Tonal (tonic) Intervals: A tonal interval is determined by two tones, one of which is conventionally the 'tonic'. The tonic is the root note around which a musical piece is organized, providing a reference for each tone that is sounded during the performance. In Hindustani classical music, it is always *Sa*.

Major and Minor Intervals: Based on the 12 tone equal temperament scale used in Western classical music, the major intervals are the natural notes namely, second, third, sixth, and seventh interval. A minor interval is one semitone less than each of the major intervals of the scale (flat positions). In terms of Hindustani music, the major intervals are the *shuddh swaras* while the minor intervals are the *komal swaras*.

Melody: A melody is a linear succession of musical tones that the listener perceives as a single entity. In Hindustani music, *rāga* uses a set of five or six notes to construct the melody.

Rhythm: Rhythm is described as the systematic patterning of sound in terms of timing and grouping leading to multiple levels of periodicity.

Harmony: In Western classical music, harmony is the simultaneous occurrence of multiple frequencies and pitches (tones, notes or chords).

Counterpoint: Counterpoint is the art of combining different melodic lines in a musical composition and is a characteristic element of Western classical musical practice.

Chords: Harmony with three or more notes are called chords and they provide the harmonic structure or background mood of a piece of music. Intervals are the building blocks of chords.

Modulation: Modulation, is the change from one key to another; also, the process by which this change is brought about.

of events, namely the *alaap* followed by the *gat*. *Alaap* is the note-by-note delineation of a *rāga* bound by a slow tempo, but not bound by any rhythmic cycle. *Gat* is the composition rendered at a faster tempo with accompaniment of a percussion instrument that provides a rhythmic cycle. The rhythmic cycle is measured in terms of time units or beats. Recently Mathur *et al.*, [2] empirically showed the association between emotions and *rāga*. Three minute instrumental renditions of 12 ragas were played by a professional musician on a sarod[2] and digitally recorded in both

[2]A stringed instrument.

alaap and *gat*. An online survey was created (`http://emotion-in-music.nbrc.ac.in/p1/`) where participants listened to these *rāga* samples (randomized in order for each participant) and rated each sample with the emotion labels on a Likert scale[3] from 0 – 4 (0 – "not at all felt" to 4 – "felt the most"). The emotion labels used in the study were; happy, romantic, devotional, calm/soothed, angry, longing/yearning, tensed/restless, and sad. Data collected from 122 participants provided the experimental verification of the hypothesis that distinct emotional responses are associated with the *alaap* and *gat* of a *rāga*.

[3]The Likert Scale is a five (or seven) point scale which is used to allow the individual to express how much they agree or disagree with a particular statement.

Specifically, this study showed that *rāga*s evoke a wide variety of emotional responses that range from 'happy' and 'calm' to 'tensed' and 'sad'. It also demonstrated that rhythmic regularity was distinctly related to the arousal of emotion. For instance, the emotional response to *rāga*s (like '*Desh*' and '*Tilak Kamod*') shifted from 'calm/soothing' in the slower arrhythmic *alaap* to 'happy' in the faster rhythmic *gat*. A major finding of the study by Mathur *et al.*, was that major and minor intervals are also indicators of positive and negative emotions respectively.

The *alaap* and *gat* use the same set of notes as defined in the *rāga* and are thus controlled in their use of tonal intervals and vary only in their rhythmic structure, with the *gat* having an explicit rhythm. This provided a unique opportunity to study the effect of rhythm on emotions in music. Research in our laboratory at the National Brain Research Centre is exploring the role of different musical structures in predicting the emotions in music.

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In recent years, with the advancement in the field of perception of music in the brain, its application as an intervention in addressing mood disorders and emotion processing, especially in disorders like autism spectrum disorder has become widely popular. While brain imaging has provided support for this, it is crucial that any new claim made in this area be approached with caution, be well investigated and supported by robust research evidence before it is implemented. We hope this brief review will provide a glimpse into the fascinating world of music and the brain and will motivate research towards understanding perceptual aspects of music through approaches using psychology, neurobiology, and neuroimaging techniques to tap into the intricacies involved in its processing and production.

Acknowledgments

The authors would like to acknowledge Vitul Agarwal, Avantika Mathur, and Sakshee Singh for useful contributions to the manuscript.

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