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The Neuroscience of Emotion Elicitation by Music

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ABSTRACT

At the intersection of music and neuroscience, the auditory system plays a critical role in human responses. Initial reception of music stimuli is followed by auditory processing, allowing people to perceive, interpret, analyze, and understand these sounds. This article will review the main stages in this sensory reception and processing of music in the nervous system and how they result in emotional responses. To aid in understanding the processing of music, the article briefly addresses- the origins of music and its role in human history. Of particular interest are the aesthetic emotions – the feelings that arise as one evaluates the beauty, novelty, expressiveness, etc. of the music as one listens. We also consider whether the processing of these emotions in the brain leads to the experience of pleasure and reward in a fashion similar to that of basic survival-related behaviors such as eating and drinking. Finally, we consider brain disorders affecting the perception, evaluation and emotional response to music.

Musical Stimuli and Origins of Human Response to Them

Sound stimulation is an aspect of everyday life experience. Hearing and processing information – whether it be in conversation, abrupt noises, or music -- allows humans to formulate a response and reaction to these stimuli. The main focus of this paper is musical stimuli and their effects on auditory and emotional processing in the brain. However, it may be helpful to begin by placing this review in the larger context of attempts to define the basis of music and to understand its evolution in human history.

During human evolution music became a crucial part of communication and expression. So what exactly is music? Although an adequate definition has eluded scholars, music might be defined in terms of the universal human tendency that allows an individual to take pleasure in the structure of sounds they call music, even though others may dismiss them as noise (Burke, 2015). Moreover, recent neuroimaging and psychological findings suggest that music plays a role in forming trust, social bonds, and cultural affiliations (Harvey, 2018). It is widely believed that the universality of music and music-related behaviors has evolved alongside language and articulate speech, which are important in helping to promote emotional synergy, social bonding, and coordination early in human evolution (Harvey, 2018). Scientists have placed emphasis on analyzing variation in the perception of music and on the neurological structures that provide the basis for human responses to music.

The wide variety of music across different cultures has been found to elicit extremely diverse emotional responses. A recent large-scale investigation has identified 13 dimensions of emotion that are elicited by music (Cowen et al., 2020). Thus, the neuroscience of music must account for a vast range of human emotional responses.

Processing in the Ear and Pathways to the Brain

Musical stimuli travel from the ear to the brain through the auditory system. The ear is composed of three sections: outer, middle, and inner. The sound waves in the air first reach the outer ear. The bones of the middle ear, separated from the outer ear by the eardrum, vibrate from the sound waves and pass the sound to the inner ear. In the inner ear 20,000 to 30,000 microscopic hair cells differentiate the music by its components (McCollum, 2019). For example, frequency is represented along the basilar membrane of the inner ear. The microscopic hairs near the wide end of the inner ear detect higher frequencies; lower frequencies are detected as one moves toward the center of the cochlea (National Institute on Deafness and Other Communication Disorders, 2018).

The hair cells transmit signals to neurons of the spiral ganglion, of which axons then ascend in the VIIIth cranial nerve to the cochlear nuclei in the medulla. Further steps in the pathway carry signals through the medulla to the inferior colliculus of the midbrain, then to the medial geniculate nucleus of the thalamus, and then to the primary auditory cortex within the superior temporal gyrus (Gray, 2020). Some of these pathways project from the cochlea only to the opposite (contralateral) primary auditory cortex, while others project to the cortex in both hemispheres.

Perception of Musical Sound in the Brain

The auditory system can obtain much information about the world simply through sound waves that reach the two ears. That information goes far beyond simply representing frequencies in the sound wave to being able to perceive meaningful elements of music such as melodies, harmonies, rhythmic patterns, etc. – what hearing science researchers call auditory objects (Nelken et al., 2014). Perception of these auditory objects reflects a use of auditory information such as onset time or the sound's frequency spectrum to identify the pattern, separate it from other sensory events, and recognize it in spite of variations (Ogg & Slevc, 2019). For instance, this perception process can be applied to a melody that is sung by one voice or another or played by different instruments (Griffiths & Warren, 2004). This perceptual process for music, as well as for human speech or communication signals of animals, is based upon perception of pitches and the harmonic structure of the sound (i.e., its frequency components that are all integer multiples of the same frequency, called the fundamental frequency). Neurons in the auditory pathways tend to be activated most strongly by particular sound frequencies. For example, a frequency of 440 Hz (A above middle C) will activate a particular set of neurons, and other neurons will respond to other frequencies. As the activation spreads to areas adjacent to the primary auditory cortex, many neurons are found to respond strongly to more than one frequency, and these frequencies for an individual neuron tend to be integer multiples of a particular frequency. Thus, neurons in the pathway beyond the primary auditory cortex appear to respond to the harmonic structure of the sound, enabling the extraction of the auditory objects of music (Nelken et al., 2014). Further processing of these auditory objects occurs along a pathway, called the ventral stream, projecting forward in the temporal lobe from the auditory cortex and into a ventral portion of the frontal lobe, the inferior frontal cortex. Information about the spatial location or movement of these auditory objects is processed somewhat independently in the dorsal stream, projecting from the auditory cortex into the parietal lobe and then into a dorsal portion of the frontal lobe known as the premotor cortex (Bizley & Cohen, 2013).

Perception and Experience of Emotion in the Brain

The process of perceiving and recognizing musical objects, such as melodies, does not occur in a moment but rather emerges over time as the music unfolds. As individuals listen to this music, the processing in the ventral stream, described above, results in recognition of patterns of sound. As these patterns are recognized, expectations about what will happen next in the music are created, and these expectations lead to anticipation and to emotional responses, depending upon whether the expectations are confirmed or disconfirmed (Salimpoor & Zatorre, 2013). For instance, a recent study has shown that changes in the relative activation of the right and left frontal lobes (an index of degree of positive affective response) occurred when expectations regarding motif or instrument were likely violated (Arjmand et al., 2017).

Along with these expectations, certain acoustic features of the music may play an important role in the resulting perception and feeling of emotion. Processing of these features occurs in the brain areas described above. Measurement of psychological responses to music indicates that certain features give rise to particular emotional perceptions and feelings. For example, fast tempo leads to emotional arousal, dissonance to unpleasantness, brightness of timbre to happiness, etc. The ventral striatum, anterior cingulate cortex, and amygdala are among the areas that have been found to be activated in this emotion processing (Trost et al., 2015). These generalizations have emerged mostly from studies in which emotion ratings were made for entire pieces of music. Since the features just described will often change considerably within a particular musical work, it is also important to know what changes in the brain may provide the basis for response to these shifting features of music. In recent work magnetic resonance imaging during music was used to identify moments in the music for which activation of brain areas was similar for different listeners (Trost et al., 2015). One specific finding was that energy-related musical features produced changes in activation of the amygdala. There was also simultaneous activation of the left nucleus accumbens at various points in the music. These two areas are of particular interest because of the large body of evidence linking the amygdala to emotion processing and linking the nucleus accumbens to the experience of reward.

There has been considerable research on the question of whether emotion is only perceived in music or also felt by the listeners. Numerous studies have indicated that listeners do indeed feel these emotions themselves in at least some circumstances (Kallinen & Ravaja, 2006). This issue is rendered more complex by the evidence that the emotions associated with music include the nuances of feeling that are intertwined with the evaluation of music. A recent review (Menninghaus et al., 2019) distinguishes among emotions represented in music (or other art), emotions that are elicited by music, and emotions that arise specifically as one evaluates music. It is this third category that has been called “aesthetic emotions.” Examples of the judgments involved include the beauty of the music, its novelty, the expressiveness of the performance, etc. A word such as “beauty” suggests a property of the music itself. However, in keeping with the findings that the emotions of music are not only perceived but also felt, aesthetic judgments are believed to elicit actual feelings in those making the judgment. Thus, for example, they not only judge the music to be beautiful but also experience a feeling of beauty. The question of how such aesthetic emotions may arise through the processing of music in the brain is addressed below.

Pleasure and Liking in the Brain

The study of emotions has often focused on negative emotional states such as fear, anger, disgust, sadness, etc. While music may sometimes elicit such emotions, the study of aesthetic emotions has revealed a strong bias toward positive emotions (Menninghaus et al., 2019). Some of these positive emotions may even include or be mixed with negative emotions. In particular, many studies have shown that sad music can be experienced as pleasurable (Sachs et al., 2015). Thus, music and other stimuli that evoke similar aesthetic judgments are sought out for their own sake even though their specific survival value is not apparent, i.e., they appear to be rewarding in and of themselves.

These observations raise the question of whether these aesthetic rewards are processed in the brain in a similar fashion as are basic rewards – stimuli that do have obvious survival value (Salimpoor & Zatorre, 2013). Eating, drinking, and sexual stimulation are among these basic rewarding activities, and the mechanisms mediating these rewards in the brain are relatively well known. A fundamental component of these mechanisms is a pathway arising in a part of the midbrain known as the ventral tegmental area (VTA), projecting forward to the nucleus accumbens (NAcc) of the ventral striatum and releasing the neurotransmitter dopamine at that site. Release of dopamine in this area is thought to play a critical role in mediating the rewards of these survival-related activities (Salimpoor & Zatoree, 2013. A natural question is whether this process also underlies the rewards of music.

Pathways from the VTA also project to the prefrontal cortex (anterior portion of the frontal lobe) and to the amygdala and hippocampus. In general, there are multiple pathways carrying signals in both directions among the structures just mentioned. The amygdala is of special interest because of its well documented role in mediating emotion. The hippocampus is also worthy of special mention since it plays a major role in the storage and retrieval of memories, which may provide the basis for the effects of prior musical experiences on emotional responses. The reward-related pathways are embedded in a complex network of interconnected structures. In an effort to demonstrate whether this network might be activated by rewarding music, some researchers have turned to the study of “chill” responses to music that experiment participants chose for the intense emotion they experienced from it. Brain imaging indeed showed dopamine release much like that for basic rewards (Salimpoor & Zatorre., 2013). These findings were further supported by recent work showing that enhancing dopamine release by orally administering a dopamine precursor produced enhanced reward (seeking of the music), while a drug that blocks dopamine action decreased reward (Ferreri et al., 2018). A related finding was that these manipulations had a similar effect on the pleasure experienced by participants, implicating dopamine in the pleasurable feeling as well. However, other studies suggest that opioid substances in the brain may also play an important role in the feelings of pleasure (Mallik et al, 2017).

The aesthetic judgments involved in eliciting aesthetic emotions are likely mediated in the prefrontal cortex (Salimpoor & Zatorre, 2013). Thus, the interconnections between this area and reward areas just reviewed probably play a critical role in the reward and pleasure of aesthetic emotional experience. Just to complete the connections among brain areas discussed earlier, one should note that there are extensive connections between the auditory processing areas in the temporal lobe and the prefrontal cortex (Plakke & Romanski, 2014).

Disorders Influencing Musical Emotion Processing

The neural systems mediating music perception and elicitation of emotion are also subject to certain disorders. The study of disorders of musical ability is somewhat more recent than the study of speech disorders although musical impairments after brain injury are not uncommon, notably in stroke patients in which the middle cerebral artery is affected (Sihvonen et al., 2017). These impairments, referred to as acquired amusia, may have a variety of features, including diminished ability to perceive pitch or rhythm. A number of brain regions, mostly in the right hemisphere, have been found to contribute to the impairments (Sihvonen et al., 2017). A similar disorder may be present from birth – congenital amusia. A study of more than 15,000 participants found congenital amusia in about 1.5 % – some with a disorder of pitch perception and others with a time-based deficit (e.g., impaired rhythm perception; Peretz & Vuvan, 2017). Forty-six percent of these participants with amusia reported that their first-degree relatives also had this impairment, suggesting a genetic basis for the disorder. Congenital amusia appears to have little overlap with other neurological disorders, such as those affecting attention or emotion. Thus, participants with a pitch-based amusia were found to judge the emotions in music to be less intense, but they categorized the emotions expressed in the music in largely the same manner as did control participants (Fernandez et al., 2021).

A rather different disorder of music processing is specific musical anhedonia, an inability to experience reward or pleasure from music, despite having intact auditory processing capacities (Martinez-Molina et al., 2016). Note that people with musical anhedonia still perceive music in the same way as those without; the difference lies in not experiencing musical reward or pleasure. Neuroimaging studies show that musical pleasure is induced by interaction between the auditory processing areas of the superior temporal gyrus (STG) and the nucleus accumbens (NAcc), a part of the reward pathway described earlier (Salimpoor et al., 2013), suggesting that music anhedonics may have reduced functional connections between these two areas. To test this hypothesis, an experiment was conducted involving three groups: anhedonics (ANH), hedonics (HDN), and hyperhedonics (HHDN – people with unusually strong emotional responses to music), recording skin conductance response (SCR, a measure of emotional arousal) and scanning activity of various brain areas using functional magnetic resonance imaging. These measurements were taken while participants listened to and rated multiple excerpts, producing varied degrees of rated pleasure. As expected the ANH group rated the music as less pleasurable and less emotionally arousing. Furthermore, results showed that both the SCR magnitude and the functional connectivity between the right STG and the NAcc were greatly reduced in the ANH group, while activity in the STG itself remained unchanged. In addition, responses to the rewards of a gambling task did not differ between groups, indicating that the deficit was specific to musical rewards. These findings support the hypothesis that music's reward value is determined by the functional connectivity between the STG and the NAcc and that deficits in this connectivity may be the source of the impaired emotional response in specific musical anhedonia.

While amusia and musical anhedonia are disorders that impair responses to music, autism can actually improve one's rewards from music. For individuals who have been diagnosed with autism spectrum disorder (ASD), studies have shown that music can be seen as a strength for those with ASD by comparison to their impairments in social communication and interaction (Quintin, 2019). The strengths linked with music include enhanced musical pitch perception and memory, allowing music-evoked emotions to be identified. For example, in one study (Heaton et al., 1998), children with ASD were taught to associate musical notes or speech syllables with a picture of an animal. A week later the children with ASD displayed greater accuracy than did matched controls in their memory for pitches and similar accuracy in their memory for syllables. Children and adolescents with ASD have also been found to be similar to matched controls in their ability to categorize emotions represented in music (Heaton et al. 1999; Quintin et al., 2011). Moreover, adults with ASD show similar activation of neural circuitry that is associated with reward and emotive processing (Gebauer et al., 2014). Although those with ASD are able to associate emotions with music, their responses may still differ from those of controls. For instance, in one study (Allen et al., 2013) adults with ASD used fewer words than a control group did when asked to describe the emotions they felt when listening to music. The findings on ASD, taken together, suggest the possibility that music therapy could be useful in fostering the development of social skills in children with ASD, a possibility for which there is ample evidence (LaGasse, 2017).

Summary and Conclusions

The human response to music begins in the auditory system and spreads to other areas of the brain as sound perception leads to interpretation, evaluation, and emotional response. Musical stimuli are first processed in the ear, transduced into neural signals, and conducted to the brain, reaching the primary auditory cortex in the temporal lobe. Pitch processing occurs in temporal lobe regions adjacent to the primary auditory cortex. Furthermore, interaction of these temporal lobe areas with the amygdala underlies the emotional effects of music, and interaction with midbrain and basal forebrain circuits leads to the rewarding experiences of music. In fact, a person can associate pieces of music with conflicting emotions. The variations in emotions that result from music processing are due to a multitude of factors, including culture and self-expression. Disorders of music processing can impair accurate processing of pitch (amusia) or elicitation of emotion by music (musical anhedonia); however, enhanced processing of music and enhanced emotional response may occur in people with autism spectrum disorder. Thus, initial music processing in auditory pathways leads to extensive engagement of other brain regions, supporting the varied cognitive and emotional responses to music but subject to a number of disorders as well.

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