Investigating Emotion with Music

Neuroscientific Approaches

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ABSTRACT: This article briefly reviews the few functional imaging studies conducted so far on the investigation of emotion with music. Basically, these studies showed involvement of limbic and paralimbic cerebral structures (such as amygdala, hippocampus, parahippocampal gyrus, temporal poles, insula, ventral striatum, orbitofronal, as well as cingulate cortex) during the processing of music with emotional valence (such as pleasant or unpleasant). The second part of this article highlights the role of unexpected musical events for the elicitation of emotional responses. Recent studies suggest that music-syntactically irregular chords elicit changes in electrodermal activity, and that such chords activate orbital frontolateral cortex, as well as the amygdala (that is, brain structures that have been implicated in emotion processing). The third part of this article mentions findings on the temporal dynamics of emotion (that is, changes in the physiological correlates of emotion processing over time). This issue has so far been mainly neglected in the functional imaging (and psychophysiological) literature.

KEYWORDS: music; emotion; fMRI; PET

NEUROSCIENCE STUDIES ON MUSIC AND EMOTION

So far, the majority of neuroscience studies on human emotion has used static visual images as experimental stimuli. However, during the past years, the neurosciences have discovered that music is also a valuable tool to investigate emotion. Important advantages of music are (1) that music is capable of inducing emotions with a fairly strong intensity, (2) that such emotions can usually be induced quite consistently across subjects,[1,2] and (3) that music can induce not only unpleasant, but also pleasant emotions (which are rather difficult to induce by static images). Neuroscience studies on the investigation of emotion with music basically indicate that networks of limbic and paralimbic structures (such as amygdala, hippocampus, parahippocampal gyrus, insula, temporal poles, ventral striatum, orbitofrontal cortex, and cingulate cortex) are involved in the emotional processing of music. These structures have previously been implicated in emotion, but the functional significance of each of these structures is still not well understood.

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Ann. N.Y. Acad. Sci. 1060: 1–7 (2005). © 2005 New York Academy of Sciences.
doi: 10.1196/annals.1360.034

Using PET, Blood *et al*.[3] investigated the emotional dimension of pleasantness/unpleasantness with sequences of harmonized melodies. The stimuli varied in their degree of (permanent) dissonance and were accordingly perceived as less or more unpleasant (stimuli with highest permanent dissonance were rated as the most unpleasant). Stimuli were presented under computerized control without musical expression. This paradigm was not intended to induce the full range of (pleasant) musical mood, yet it allowed us to examine emotional processing with music while simultaneously excluding effects of musical preference on the perception of the emotional valence of the stimuli. Variations in pleasantness/unpleasantness affected activity in a number of paralimbic structures: increasing unpleasantness of the stimuli correlated with activations of the (right) parahippocampal gyrus, while decreasing unpleasantness of the stimuli correlated with activations of frontopolar, orbitofrontal, and subcallosal cingulate cortex.

A PET study by Brown *et al*.[4] investigated activations elicited by unfamiliar (pleasant) music (instrumental songs in the rembetika style; only two songs were used, which were, unfortunately, composed by only one Greek composer). Contrasted to a rest condition, pleasant music activated limbic and paralimbic structures, including subcallosal cingulate cortex, anterior insula, the posterior part of the hippocampus, and part of the ventral striatum (possibly nucleus accumbens). Similarly, another PET experiment by Blood and Zatorre[5] measured changes in regional cerebral blood flow (rCBF) during "chills" when participants were presented with a piece of their own favorite music (using normal CD recordings; as a control condition, participants listened to the favorite piece of another subject). Increasing chills intensity correlated with increases in rCBF in brain regions thought to be involved in reward and emotion, including the insula, orbitofrontal cortex, the ventral medial prefrontal cortex, and the ventral striatum. Decreases in rCBF (with increasing chills intensity) were observed in the amygdala and the hippocampus.

Reminiscent of the study from Blood *et al*.,[3] a recent fMRI study from Koelsch *et al*.[6] also used pleasant and unpleasant musical stimuli. In contrast to the study from Blood *et al*.,[3] the pleasant musical excerpts were not computerized sounds, but natural musical stimuli (joyful instrumental dance tunes, recorded from normal CDs). Unpleasant stimuli were electronically manipulated, permanently dissonant counterparts of the original musical excerpts. The stimuli of that study were, thus, not only intended to induce unpleasantness, but also pleasantness in response to the joyful, naturalistic music. The use of identical stimuli across subjects enabled the investigation of emotion independent of personal preferences of listeners.

Unpleasant music elicited increases in blood oxygen level–dependent (BOLD) signals in the amygdala, the hippocampus, the parahippocampal gyrus, and the temporal poles (strong decreases in BOLD signal were observed in these structures in response to the pleasant music). During the presentation of the pleasant music, increases in BOLD signal were observed in the ventral striatum and the insula (and in cortical structures not belonging to limbic- or paralimbic circuits; this activity will not be reported further here).

Involvement of the amygdala in the emotional processing of music has also been reported by a recent lesion study from Gosselin *et al*.,[7] in which patients with medial temporal lobe resections (including the amygdala) showed impaired recognition of fearful music. Involvement of the ventral striatum (nucleus accumbens) in response to normal music (contrasted to scrambled music) is also reported by a study from Levitin and Menon.[8]

The mentioned studies show that listening to music can elicit activity changes in limbic and paralimbic structures that have previously been implicated in emotion (amygdala, hippocampus, parahippocampal gyrus, insula, temporal poles, cingulate cortex, orbitofrontal cortex, and ventral striatum), and that, thus, functional brain imaging using musical stimuli can potentially contribute to the investigation of emotion.

MUSICAL EXPECTATIONS AND EMOTIONAL RESPONSES

The studies reported in the previous section used experimental paradigms with "pleasant," "unpleasant," "scary," "happy," or "peaceful" tunes. This section deals with the possible role of music-structural aspects for the processing of emotion. Meyer[9] proposed a theory of musical emotions on the basis of fulfilled or suspended musical expectations. He proposed that the confirmation and violation of musical expectations produces emotions in the listener. According to this proposal, Sloboda[10] found that specific musical structures lead to specific psychophysiological reactions, and he showed that new or unexpected harmonies can evoke shivers.

FIGURE 1 shows two chord sequences, ending on a structurally regular, and thus expected, chord (left) and ending on a structurally irregular chord, which is, thus, perceived as unexpected (right). These chord sequences have so far been used in a number of studies (for an overview, see Koelsch and Friederici),[11] which originally aimed at investigating the processing of musical structure (not processing of emotion). Interestingly, recent functional imaging experiments using such chord sequences[12] have shown activations of orbital frontolateral cortex (OFLC) in response to unexpected chords. The OFLC (lateral orbital gyrus of BA11, as well as medial inferior frontal gyrus, BA47 and 10; for an overview, see Ref. 13) is a paralimbic structure that plays an important role in the processing of emotion: The OFLC has been implicated in the evaluation of the emotional significance of a sensory stimulus[13] and is considered as a gateway for preprocessed sensory information into the (medial) orbitofrontal paralimbic division.[13]

The unexpected chords (which sound odd to listeners familiar with major–minor tonal regularities) violate the sensory expectancies of listeners.[14] As mentioned above, the violation of musical expectancies has been regarded as an important aspect of generating emotions when listening to music.[1,9] Moreover, the perception of irregular chord functions has been shown to lead to an increase of perceived tension,[15] and the perception of tension has been linked to emotional experience dur-

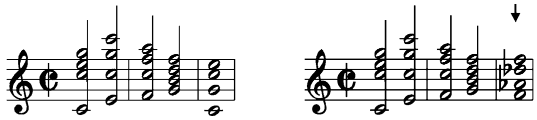

FIGURE 1. Chord sequences ending on a structurally regular chord (*left*) and ending on a structurally irregular chord (*right*) The irregular chord is indicated by the *arrow.*

ing music listening.[1] Thus, the activation of the OFLC points to the possibility that unexpected chords generate emotional responses.

The activation of the OFLC in response to unexpected chords has been replicated in a recent fMRI study from Barbara Tillmann and colleagues (personal communication with BT), in which less related harmonies (subdominant chords presented at the end of eight-chord sequences) elicited an activation of the OFLC (contrasted to regular tonic chords). Similar activations have also been reported by Levitin and Menon[16] in response to normal music contrasted to scrambled music, and it is likely that this activation is due to differences in the emotional valence of natural music on the one side, and of scrambled music on the other.

With a lower statistical threshold, the data obtained in the study from Koelsch *et al.*[12] also showed bilateral activations of the amygdala in response to the unexpected chords, underlining the assumption that unexpected, or irregular chords, can elicit emotional responses.

A recent study from Steinbeis *et al.*[17] further tested the hypothesis that unexpected chords generate emotional responses. In that study, physiological measures, including EEG, electrodermal activity (EDA), and heart rate, were recorded while subjects listened to three versions of Bach chorales (see Steinbeis *et al.*, this volume): one version was the original version composed by Bach with a harmonic sequence that ended on an irregular chord function (submediant, top of FIG. 2). The same chord was rendered expected (tonic chord, middle score of FIG. 2), and very unexpected (Neapolitan sixth chord, bottom of FIG. 2). The EDA to these three different chord types showed clear differences between the expected and the (very) unexpected chords (FIG. 2b). Because the EDA reflects activity of the sympathetic nervous system, and because this system is intimately linked to emotional experiences, these data clearly corroborate the assumption that unexpected harmonies elicit emotional responses in normal listeners.

The reported findings show that unexpected musical events do not only elicit responses related to the processing of the structure of the music (or other stimulus features that may systematically be perceived as more or less expected), but also to emotional responses. It is, thus, important to be aware of this. Research using stimuli that are systematically more or less expected should ideally assess the emotional valence (and emotional arousal) of the experimental stimuli (even if an experiment is not originally designed to investigate emotion), so that these variables can potentially be used to explain variance in the data.

TIME COURSE OF EMOTION

The intensity of emotions usually changes over time (even if the emotion itself might be the same). Intuitively, it seems plausible that aversive sounds elicit fast emotional responses (although longer durations of such sounds might even increase the degree of unpleasantness), and that especially tender emotions might take a while to unfold. To date, only little is known about the time course of emotional processing and the underlying neural mechanisms.

One of the very few psychophysiological studies that has investigated the time course of emotion was conducted by Krumhansl.[1] In this study, several physiological measures (including cardiac, vascular, electrodermal, and respiratory functions) were recorded while listeners heard musical excerpts chosen to represent one of three emotions (sadness, fear, and happiness). Significant correlations were found between most of the recorded physiological responses and time (measured in one-second intervals from the beginning of the presentation of each musical excerpt). The strongest physiological effects for each emotion type generally tended to increase over time, suggesting that the intensity of an emotional experience is likely to increase over time during the perception of a musical excerpt.

Activity changes of physiological correlates of emotion were also observed in the previously mentioned fMRI study from Koelsch *et al*.[6] In that study, the (pleasant and unpleasant) excerpts had a duration of about 1 min, and data were not only modeled for the entire excerpts, but also separately for the first 30 s, and for the remaining 30 s to investigate if there are differences in brain activity over time. As described above, activity changes during the entire pieces were observed in response to the (un)pleasant music in a number of limbic and paralimbic structures (amygdala, hippocampus, parahippocampal gyrus, temporal poles, insula, and ventral striatum). When looking at activation differences between the first 30 s and the remaining 30 s, activations of all of these structures, except the hippocampus, were stronger during the second block of the musical excerpts, presumably because the intensity of listeners' emotional experiences increased during the perception of both the pleasant and the unpleasant musical excerpts. This finding corroborates the notion that emotion processing has a temporal dynamic,[1] especially when listening to music (that unfolds over time; see also the study from Ref. 5, in which musical stimuli selected to evoke chills had a duration of 90 s). It remains to be specified why no clear differences between both blocks were observed in the hippocampus. One possibility is that the signal-to-noise ratio was not high enough to yield a substantial difference, and future studies should investigate if this finding can be replicated.

As mentioned before, it is intersting to note that increases of BOLD signals were observed in the amygdala (as well as in the hippocampus, the parahippocampal gyurs, and the temporal poles) in response to the unpleasant music, but clear decreases of BOLD signals were additionally observed in response to the pleasant music. Note that signal changes observed with fMRI (and often also with PET) do not necessarily have to be due to excitatory (post)synaptic processes, as they can as well be due to inhibitory synaptic processes. It is, for example, possible that the BOLD responses observed in the contrast *unpleasant* > *pleasant* (in the study from Koelsch *et al*.[6]) originate from inhibitory, rather than from excitatory synaptic activity,[18] and that, thus, the unpleasant stimuli inhibited emotional activity in limbic regions (compared to activity as present during a positive emotional state), rather than activating excitatory processes in those regions.

With respect to this, it is interesting to note that the hippocampus is presumably one of the most sensitive cerebral structures, because it appears to be the only brain structure that can be damaged by traumatic stressors (such as extreme violence; see, e.g., Ref. 19). Thus, inhibition of neural pathways projecting to the hippocampus during the perception of unpleasant stimuli could represent a neural mechanism that serves the prevention from potential damage of hippocampal neurons. In other words, in a number of studies on the investigation of emotion it is well possible that activity changes observed in the amygdala were not due to the generation of fear (or other unpleasant emotions), but rather due to inhibitory processes that reflect a mechanism activated to prevent the hippocampus from traumatization during the exposure to potentially harmful stimuli. In the mentioned experiment from Koelsch *et al.*[6] it is, thus, possible that the signal increase ("activation") of the amygdala (and the hippocampus) during the unpleasant music actually reflects inhibitory processes. This issue remains to be specified.

With respect to the amygdala, it is also worth mentioning that the amygdala is not a single nucleus but composed of several distinct groups of cells, usually referred to as the lateral, basal, and accessory basal nuclei (which are often collectively termed the *basolateral amygdala*), as well as of several surrounding structures, including the central, medial, and cortical nuclei. These surrounding structures, together with the basolateral amygdala, are often referred to as the *amygdala*, although including the basolateral nucleus with surrounding nuclei into a single entity does not make anatomical sense.[20] Because the spatial resolution of PET and 3-T fMRI is not high enough to differentiate signal changes originating from different nuclei of the amygdala, it can often be problematic to compare, and relate, signal changes within the amygdala between different studies.

In summary, the results of the studies presented in this section suggest that processing of emotion may have a temporal dynamic. Thus, temporal dynamics of emotion (and the underlying neural correlates) could be taken into account for an appropriate description of emotional processes. Therefore, the length of musical stimuli for experiments investigating emotion should be sufficient. However, the details about the time course of emotion (for example, details about how pleasant emotions unfold over time) remain to be specified. One way to do this is to conduct more fine-grained investigations of the activity of the structures involved in emotional processing over time. Information about activity changes over time of the structures implicated in emotion (e.g., information about how activity in one structure affects activity in another) could provide insight into the functional significance of these structures. Note that, so far, most neuroscience studies on emotion have used static visual images when investigating emotion; thus, with respect to the time course of emotion, music is particularly appropriate to investigate this issue.

[Competing interests: The author declares that he has no competing financial interests.]

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