Reflections on music, affect, and sociality

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Abstract

Music is an important facet of and practice in human cultures, significantly related to its capacity to induce a range of intense and complex emotions. Studying the psychological and neurophysiological responses to music allows us to examine and uncover the neural mechanisms underlying the emotional impact of music. We provide an overview of different aspects of current research on how music listening produces emotions and the corresponding feelings, and consider the underlying neurophysiological mechanisms. We conclude with evidence to suggest that musical training may influence the ability to recognize the emotions of others.

Keywords

Music, Affect, Pleasure, Functional magnetic resonance imaging, Diffusion tensor imaging

1 INTRODUCTION

Music is certainly but so far inexplicably tied to pleasure. While enjoyment associated with the procurement of food, sex, social interactions, and monetary goods can be explained because they directly promote homeostasis, music appears to be intrinsically rewarding without serving a clear physiological purpose. Music does not directly nourish our bodies. It is not a tangible commodity. Throughout history, there have never been threats of music shortage, nor cases of persons becoming addicted or overdosing on music. And yet, the enjoyment of music making and music listening has remained an integral aspect of human cultures across time and place.

Because of its special status, music has become a tool in the study of human emotions and feelings. Indeed, many scholars contend that the rewarding aspects of music derive from its emotive power. Music can make us smile and move us to tears, excite us and calm us, and connect us to our feelings and to the feelings of others. This ability is all the more baffling when one considers that music is in essence abstract, an art form without an objective, agreed upon meaning.

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In this chapter, we discuss findings from psychological and neuroimaging studies that attempt to describe the neurobiological mechanisms that may support music's extraordinary hold over us. We begin with a review of the literature on the neural responses associated with music-evoked emotions, highlighting some of our own work in which we used advanced analytical techniques of neuroimaging data to elucidate the nature of affective experiences caused by music listening. We then explore cases in which music induces intense emotional responses, pleasurable or not, underlining how such extremes further our understanding of neural structures involved in musical experiences. We conclude with a discussion of musical training, addressing how the development of musical skills through the process of learning to play an instrument may influence the ability to process emotions as well as the ability to understand, connect with, and bond with others.

2 NEUROBIOLOGY OF MUSIC-EVOKED EMOTIONS

2.1 EMOTIONS AND FEELINGS

To begin the discussion of how music is able to co-opt human affective processes, it is useful to summarize what is known about affect in more general terms. Emotions are often conceptualized as physiological action programs triggered by changes in the internal or external environment, and executed by a partnership of brain and body. The changes that result from the action programs may serve to draw attention to a particular aspect of the environment that is relevant for survival or to motivate a behavior that promotes or executes homeostatic regulation (Phillips et al., 2003). Emotions are therefore adaptive and evolutionary and are significant because they aim at optimal life regulation (Damasio, 1999). It is generally accepted that several "basic" emotions, those that are universal and utilitarian, are seen across many species. These basic emotions include happiness, sadness, disgust, fear, surprise, and anger (Ekman, 1992). Each category is associated with qualitatively distinct bodily state changes which serve unique functions in terms of regulating homeostasis (James, 1890).

In addition to emotions, many species also have emotional feelings, phenomena that specifically refer to the mental experience of the bodily state changes associated with the emotion (Damasio and Carvalho, 2013). Feelings serve to mark a particular situation or circumstance in a way that signifies whether it should, in future occasions, be pursued or avoided (Berridge and Kringelbach, 2008). Situations marked by pleasant feelings, often labeled as having a "positive valence," are to be approached in the future. Situations marked by unpleasant feelings, having a "negative valence," are to be avoided. We can experience a range of feelings, which lie somewhere on a valence spectrum, from negative to positive. Emotions and feelings can also be categorized along a spectrum corresponding to how activating or energizing they are (Russell, 1980). Often termed *arousal*, this component is what separates the positively valenced emotion of joy from another positively valenced emotion such as peacefulness, for example.

Capitalizing on the spatial resolution that functional magnetic resonance imaging (fMRI) provides, neuroscientists have been using an array of affective stimuli, including pictures, faces, smells, sounds, films, music, and autobiographical memories, to induce discrete emotional states, while measuring neural activity. The available results suggest that emotional experiences of varying degrees of valence and arousal involve the cooperative functioning of a distributed network of brain regions associated with basic psychological processes such as reward processing, salience detection, learning, and memory (Lindquist et al., 2012). There is no one-to-one match between the function of a singular brain region and a particular emotional state. Instead, emotional experience engages brain networks such as the limbic system—including the amygdala, ventral striatum (including the nucleus accumbens), anterior cingulate cortex (ACC), thalamus, hypothalamus, and hippocampus—as well as the related paralimbic system—including the insula, orbitofrontal cortex (OFC), and medial prefrontal cortex (MPFC; Kober et al., 2008).

2.2 BRAIN REGIONS INVOLVED IN EMOTIONAL RESPONSES TO MUSIC

How does music convey emotions and how does the human brain process them? It has been shown that basic emotions, e.g., happiness, sadness, fear, and anger, can be detected aurally through the acoustical aspects and structure of music (Balkwill and Thompson, 1999; Fritz et al., 2009). Music, additionally, has the ability to *induce* those emotions and respective feelings in the listener, as well as a wide range of more complex feelings that are rarely experienced outside of an aesthetic context, such as transcendence, wonder, and nostalgia (Zentner et al., 2008). There is evidence that the same psychophysiological (Lundqvist et al., 2008) and cognitive changes (Vuoskoski and Eerola, 2012) associated with basic, everyday emotions have also been found in association with music-evoked emotions, such as changes in facial muscular activity, changes to internal body temperature, responses in the sympathetic nervous system, and biases in perception and judgment.

Similarly, results from both functional neuroimaging and lesion studies suggest that the same brain networks collectively involved in processing everyday basic emotions are also involved in processing emotions conveyed through music (Habibi and Damasio, 2014). Music selected to evoke a wide array of emotions (happiness, sadness, joy, fear, or pleasantness/unpleasantness) engages regions in the paralimbic and limbic systems, such as the ventral striatum, insula, ACC, parahippocampal gyrus, hippocampus, amygdala, and OFC (Brattico et al., 2011; Koelsch, 2014; Mitterschiffthaler et al., 2007).

The exact role that each of these regions plays in processing emotions in music is not entirely clear, but in conjunction with findings from neuroimaging studies on emotional responses to more basic stimuli, it is possible to advance some hypotheses. The amygdala, hippocampus, and parahippocampal gyrus, three closely related brain regions located in the medial temporal lobe, may be collectively involved in inducing early emotional reactions to sounds, specifically those related to fear and surprise (Frühholz et al., 2014). The amygdala is believed to trigger positive and negative reactions to potentially salient stimuli and to induce the appropriate approach or avoidance behaviors (Lindquist et al., 2012). The hippocampus is primarily known for its role in learning and memory and therefore is an ideal structure to be involved in connecting past experiences and previous associations with the musical stimuli with current behavioral responses to music (Juslin, 2013). The parahippocampal gyrus may be particularly associated with processing music with negative valence, given that patients with damage in either the left or right region exhibited reduced responses to dissonant music (Gosselin et al., 2006).

The insula and ACC, two brain regions that are functionally and structurally connected (Medford and Critchley, 2010), appear to be involved in numerous cognitive processes. Regarding affect, these regions are likely responsible for mapping the body-state changes that constitute emotional responses (Craig, 2009) and are the basis for the respective feelings (Damasio et al., 2000). Both the insula and ACC were found to be activated in functional neuroimaging studies in which participants listened to pleasant musical stimuli, rather than to neutral musical stimuli (Blood and Zatorre, 2001; Brown et al., 2004; Trost et al., 2012).

The ventral striatum (nucleus accumbens) and the OFC are part of the reward circuitry of the brain (Leknes and Tracey, 2008). Both regions have been found to be activated in conjunction with feelings of liking (Brattico et al., 2013) and are also activated in response to intensely pleasurable musical stimuli. The OFC has been shown to be involved in numerous decision-making tasks and, therefore, seems to be a good candidate for initiating the process of making aesthetic judgments about beauty (Brown et al., 2011). The nucleus accumbens is believed to be the central site involved in both the anticipation and consummation of a reward (Berridge and Kringelbach, 2008). Its activation is also correlated with peak pleasurable experiences with music (Salimpoor et al., 2013).

What we provided so far is a brief overview of brain regions associated with emotional experiences caused by music. We believe these regions form a complex network that is involved in numerous aspects of the emotional experiences to music, and they certainly are not to be seen as "centers" for that experience.

2.3 ADVANTAGES OF NEWER ANALYTICAL TECHNIQUES

Machine learning algorithms, used primarily in the field of computer science, have more recently been applied to the analysis of neuroimaging data. The goal with such methods is to identify patterns within the recorded fMRI signal and relate these patterns to the cognitive states being experienced by the participant. Termed multivoxel pattern analysis (MVPA; Norman et al., 2006), this method evaluates the fMRI signal recorded from multiple voxels at once, which can provide a more nuanced picture of how information is spatially encoded/distributed across the brain. By classifying cognitive states based on the spatially distributed patterns of neural signal associated with them, this type of analysis does not identify brain regions that are "activated" by a stimulus, but, rather, brain regions that carry key information regarding some identifying property of that stimulus (Mitchell et al., 2004).

MVPA has been used to classify emotional states induced by music based on patterns of fMRI data. Kragel and LaBar (2015) found that distinct patterns of activity within several cortical and subcortical brain regions could predict one of seven discrete emotional states induced by music. These included the precuneus, cingulate, insula, thalamus, amygdala, and prefrontal cortex. Another study using music with either positive or negative valence corroborated those findings, reporting that patterns of activity within the precuneus, cingulate, thalamus, and prefrontal cortex could successfully predict the valence of the musical piece that was presented (Kim et al., 2017).

Recently, in our own work (Sachs, Habibi, Damasio, & Kaplan, 2018), we showed that emotional categories of musical sounds expressing happiness, sadness, and fear, produced by a violin and clarinet, could be reliably distinguished in fMRI data, based on the patterns of the neural signal detected in bilateral auditory cortices, insulae, parietal opercula, post- and precentral gyri, inferior frontal gyri, and right medial prefrontal cortex. Neural patterns within the primary and secondary auditory cortices, insulae, and parietal opercula could also reliably distinguish the same three emotions when training the classifier on data using a different set of nonmusical, nonverbal vocalizations, e.g., the sound of a person crying, screaming, or laughing (see Belin et al., 2008), suggesting that these patterns of activity are not unique to the processing of emotions conveyed through musical instruments. In combination, the MVPA results appear to support the conclusions drawn from fMRI studies with univariate data, namely that feelings induced by music evoke responses similar to those associated with feelings induced by other stimuli (Koelsch, 2014).

In addition to MVPA, other model-free methods have recently been employed with neuroimaging to assess brain responses to more naturalistic, ecologically valid stimuli. One such approach involves recording neural signal continuously (using either EEG or fMRI) during the presentation of a full-length piece of music. This type of approach does not rely on a predefined model to evaluate the changes in neural signal. Instead, it involves calculating correlations between the neural signal in different brain regions or between the neural signal in the same brain region across different participants. Changes in these correlations over time can then be related to specific changes in the music. In this way, the fluctuating patterns of brain synchrony can be linked to an emotional experience, shared among different subjects, in response to the music presented. Studies using such an technique have shown that continuous ratings of valence and arousal while listening to a music piece were associated with synchronized activity in the amygdala, insula, ACC, and caudate nucleus across participants (Trost et al., 2014). Furthermore, within-network analyses showed that synchrony of activity within regions of the limbic system was correlated with changes in valence ratings during a listening period (Singer et al., 2016). While these methods have only been used with musical stimuli recently and sparsely, the early findings provide further support for the hypothesis that music-evoked feelings involve the continuous interaction of multiple brain regions over time, highlighting the importance of capturing the temporal parameters of emotional responses to music.

2.4 MECHANISMS OF MUSIC-EVOKED EMOTIONS

Based on self-reports, psychophysiological evidence, and neuroimaging results, we have established that music can induce a range of emotional states. But what are the actual mechanisms which allow music to do so? Some theorize that it is the detection of certain acoustical features in music, which have come to be associated with specific emotions, that actually trigger an affective response, e.g., faster tempos, major tonalities, increased volume, higher fundamental frequencies, and faster tonal attacks tend to characterize happy music (Juslin and Laukka, 2003). But it is difficult to accept that acoustic properties of music alone could account for the range and intensity of possible feelings. Often, the emotions evoked by music are neither discrete nor immutable; rather, they are multifaceted and mercurial, continually influenced by one's auditory abilities, previous experiences, personality, and current mood.

In an effort to systematize the breadth of complex factors at play, Juslin (2013) proposed a list of eight mechanisms by which music is able to induce an emotion, each characterized by a unique set of brain regions and networks. These mechanisms can work independently or in tandem, which may result in multiple distinct feelings in response to the same piece of music. One way that emotions can be induced by music, according to the model, is through the process of evaluative conditioning, i.e., the pairing of a stimulus with an affective marker. This can occur when the sounds of a given piece of music trigger a memory that, through previous experience, was associated with a certain emotion. For example, a piece of music played repeatedly at a joyous occasion can eventually trigger joy, even when removed from that event. Or, as described earlier, it could also be that the sounds in and of themselves are associated with positive or negative feelings because, over time, and through the process of learning, these sounds have acquired the affective significance of the objects or events that typically produced them (Damasio, 2018). The sound of the blaring trumpet, for example, may induce unpleasant feelings because these acoustic properties commonly accompany fearful or distressing events. This process of pairing sounds with affective labels likely involves the amygdala. On the other hand, an emotion to the same piece of music could be induced through a separate mechanism, such as that of assessing the aesthetic qualities of the piece, in which case it is likely that other brain regions in the prefrontal cortex might be involved. This is not the place to review in detail all eight mechanisms proposed by Juslin; but we would like to acknowledge that, while further research is needed to corroborate the hypotheses presented in Juslin's model, the framework provides a systematized way to understand and evaluate the vast array of emotional experiences and neural activity that we see associated with listening to music.

3 INTENSE MUSICAL PLEASURE AND ITS ABSENCE

One aspect of music listening that warrants its own discussion is its strong connection to feelings of pleasure. Engaging with music is often reported as a highly enjoyable activity in many people's lives and there is empirical evidence to suggest that such engagement can trigger the same biological and psychological responses associated with other highly rewarding, and yet transparently valuable stimuli, such as food, sex, and money (Salimpoor et al., 2013). Psychophysiological, highly pleasurable experiences with music were associated with increases in heart rate and electrodermal activity (Salimpoor et al., 2009). Regions in the brain involved in hedonic responses and reward, such as the ventral striatum, insula, ACC, and OFC, are activated when listening to pleasant or self-selected pleasurable music (Brown et al., 2004; Koelsch, 2014; Menon and Levitin, 2005; Trost et al., 2012). Activity in the ventral striatum in particular was shown to be positively correlated with subjective ratings of how much a person liked a piece of music (Salimpoor et al., 2013) and activity in the insula and amygdala was shown to be correlated with physiological measures of arousal during music listening (Blood and Zatorre, 2001).

How do feelings of pleasure relate to the previously discussed emotional responses to music? Neuroimaging and behavioral evidence suggest that feelings of pleasure and conscious enjoyment of a piece of music emerge later in time, after the initial emotional response. In a recent report, Brattico et al. (2013) drew on the findings from previous fMRI and EEG studies to attempt to outline the temporal order of the neural events involved in pleasurable responses to music. These authors hypothesized that after the initial processing of the acoustical properties of the sounds in the brainstem, and subsequently the auditory cortex, the recognition of the valence and arousal level of the music is processed in association with activation of the amygdala, hippocampus, and parahippocampal gyrus. Subsequently, feelings associated with valence and arousal emerge in association with activity in the insula and ACC. The aesthetic judgment of beauty occurs in association with activity in the OFC (Brown et al., 2011), which may or may not result in feelings of pleasure and enjoyment. If the product of all of these complex processes does result in a pleasurable response, Brattico and colleagues assume that the ventral striatum and nucleus accumbens are most likely involved in such experiences (Brattico et al., 2013).

3.1 EXPERIENCE OF CHILLS AND OTHER “STRONG EXPERIENCES OF MUSIC”

While many people find music pleasurable, there are certain sensations associated with music listening that go beyond the everyday emotional experience in terms of intensity and are rarely felt outside of an aesthetic domain. These “strong experiences of music,” sometimes referred to as “aesthetic emotions,” include sensations such as awe, feeling of a lump in the throat, feeling moved, and experiencing chills (Lamont, 2011). Chills are one of the most widely documented strong emotional experiences to music. While the nature of the sensation can vary markedly across individuals, chills are most frequently reported as “shivers down the spine,” or scalp, or back of the neck are often accompanied by “goose bumps” and “hair standing on end”, and tend to be associated with moments of peak pleasure and enjoyment (Nusbaum et al., 2014). A variety of different terms have been used throughout the literature to describe this phenomenon when it occurs in response to the arts, including “aesthetic chills,” “thrills,” and “frisson” (Nusbaum and Silvia, 2011). Why we would experience sensations typically associated with coldness or fear in response to music, a stimulus that poses no clear threat to our well-being, remains largely unclear. However, recent explorations, in particular several neuroimaging studies, have begun to provide some answers as to how such a link may have emerged.

Research on the frequency and likelihood of experiencing aesthetic chills has garnered several possible explanations for their existence. Early findings that music expressing sadness is more likely to induce chills in women lead researchers to postulate that the sensation was the product of the music’s resemblance to separation calls, sounds emitted from offspring that inform their parents of their whereabouts (Panksepp, 1995). Such sounds are designed to induce deep, biological responses that encourage social bonding behaviors and thus motivate a parent to find and protect her progeny (Panksepp and Bernatzky, 2002). This explanation, however, does not account for chills that occur in response to other modalities, such as to nonmusical works of art, and subsequent studies have failed to replicate these gender differences (Silvia and Nusbaum, 2011).

Huron (2006) proposed that chills are the body’s programmatic response to stimuli that are surprising and therefore considered to be potentially threatening at first, but that are later reappraised as nonthreatening. In this account, the pleasurable feelings that accompany chills would derive from this mismatch between the initial negative physiological response and its subsequent cognitive appraisal as something positive (Huron, 2006). Chills may also be the physiological by-product of feelings of awe (Silvia et al., 2015), an intense emotional mixture of joy and fear that arises when one experiences something unfathomably vast, novel, and/or beautiful (Konečni, 2005). Music is a frequently reported inducer of feelings of awe, suggesting that chills to music may in fact represent a deeply rooted emotional reaction designed to help process startlingly novel information of any kind (Silvia et al., 2015).

Intriguingly, not everyone experiences chills in response to music and the actual rates of frequency vary wildly from study to study. In one particular sample, 90% of participants reported experiencing chills in response to music (Sloboda, 1991), whereas in a study in which participants listened and responded to musical stimuli in a laboratory setting, less than 25% felt chills (Grewe et al., 2005). A more recent study had participants reported on their activities, environment, and feelings in real time at various moments throughout the day and found that participants experienced chills 14% of the time while listening to music (Nusbaum et al., 2014).

The frequency and likelihood of experiencing chills to music, as well as several other intense aesthetic experiences, have been shown to be associated with one of the Big Five personality traits called openness to experience, a trait marked by intellectual curiosity, and a tendency to examine one’s own feelings (McCrae, 2007). Knowledge about, or engagement with, the arts and music is also found to be associated with the experience of chills by the same authors. In a follow-up assessment, the authors suggested that one's musical experience and the frequency of engagement with music (e.g., listening to music, going to concerts, seeking out new bands) seemed to mediate the interaction between personality and chills (Nusbaum and Silvia, 2011). No specific acoustical, harmonic, or lyrical features have been found to be a direct trigger of chills; however, there are certain music structures and themes that are commonly associated with the experience. People often report feeling chills during passages that contain an entrance of a new voice or instrument, rapid or large changes in tempo or dynamics, or unexpected harmonic shifts (Grewe et al., 2007; Guhn et al., 2007). Individuals were also more likely to experience chills to pieces that were more familiar; even so, the frequency of chills did not increase with an increase in familiarity (Grewe et al., 2007). Taken together, these findings suggest that the induction of chills in response to music is likely caused by an interaction between a subject's personality and the previous musical experience, mood at the time of the experience, level of attention, and the structural features of the music in question (Grewe et al., 2007).

Because chills can be highly variable and hard to define, recent attempts have been made to identify more objective, neurophysiological markers that accompany this experience. Increases in psychophysiological measures, including electrodermal activity, heart, and respiration rates, have been observed during self-reported experiences of chills in response to music stimuli (Grewe et al., 2009; Sachs et al., 2016; Salimpoor et al., 2009). These increases generally indicate intensified feelings of arousal (Fowles, 1980). Importantly, similar increases were not observed in those subjects who did not report experiencing chills or pleasurable responses while listening to the same pieces of music, suggesting that the autonomic nervous system response could not be solely accounted for by changes in acoustical elements of the music, such as increases in volume or tempo (Salimpoor et al., 2009).

Neuroimaging techniques have also been used to further our understanding of chills induced by music. Several fMRI studies have shown increases in brain activity in the ventral striatum, insula, ACC, thalamus, right OFC, and dorsomedial prefrontal cortex when participants experienced chills; decreases in neural signal during the same episodes were observed in the amygdala and hippocampus (Blood and Zatorre, 2001). Within the ventral striatum in particular, dopamine appears to be released during both the anticipation and culmination of a peak pleasurable response to self-selected pieces of music (Salimpoor et al., 2011). Other neuroimaging studies exploring brain responses to highly pleasurable music, but not the experience of chills per se, have found similar patterns of brain activity, primarily in reward and emotion processing regions, including the ventral striatum, ACC, anterior insula, and hippocampus (Brown et al., 2004; Koelsch et al., 2006; Menon and Levitin, 2005).

Individual variation in the experience of chills may additionally be a function of structural differences in the human brain. Our own work with diffusion tensor imaging, a neuroimaging tool that allows the visualization and quantification of white matter connections between various regions of the brain, has shown that those who frequently and reliably experience chills while listening to music have greater white matter volume in the tracks connecting the auditory cortex, insula, and prefrontal cortex as compared to people who rarely, if ever, experience them (Sachs et al., 2016). This suggests that the capacity for music to trigger intense emotional responses may be related to this more robust structural connection between auditory and emotion processing areas of the brain.

3.2 MUSIC ANHEDONIA

What do we make of individuals who do not experience chills? Individual variation in ability to experience strong emotional responses to music is such that there are people who report being unable to derive any pleasure from music, despite normal responses to other rewarding stimuli, such as those associated with money, sex, and drugs (Mas-Herrero et al., 2014). Even more surprising is that these individuals show normal perceptual abilities when it comes to both processing structural features of music and identifying the intended emotion that music conveys (Zatorre, 2015). This incapacity to derive pleasure specifically from music has been called "musical anhedonia" and recent investigations found that roughly 5% of a large sample of individuals demonstrated such a condition (Mas-Herrero et al., 2014).

In addition to these behavioral differences, while listening to pieces of music rated as highly pleasing by an independent group of participants, people with musical anhedonia displayed attenuated psychophysiological responses (in both heart rate and electrodermal activity) compared to a group of participants who experienced typical emotional responses to music (Mas-Herrero et al., 2014). Importantly, no differences in psychophysiological responses were found between musical anhedonics and controls when the experiment involved monetary rewards, confirming that the lack of pleasure experienced in the subjects with music anhedonia was specific to musical stimuli. Recently, this experiment was replicated with fMRI. Both the music-listening task and the monetary reward task activated the nucleus accumbens; however, the music anhedonia group showed significantly less activation in the nucleus accumbens during music listening compared to the control group, a difference that was not seen during the monetary reward task (Martínez-Molina et al., 2016). Furthermore, during the music-listening task, the patterns of activity in the ventral striatum and auditory cortex were less correlated in the music anhedonia group, suggesting that the origin of this special form of anhedonia could result from abnormal communication between the reward and auditory processing regions of the brain (Martínez-Molina et al., 2016).

In another study [in which one of us (Sachs) was involved], this hypothesis was tested by obtaining structural brain images of an individual with musical anhedonia using diffusion imaging and probabilistic tractography. When compared to a group of adult participants, who demonstrated normal sensitivity to musical rewards (though were not matched in terms of age or gender), the music anhedonic participant showed less volume in the white matter track connecting the left auditory cortex and the left nucleus accumbens as well as that connecting the left anterior insula to left nucleus accumbens. Furthermore, in the comparison group, sensitivity to musical rewards was directly related to volume in these white matter pathways. Specifically, people who were more likely to experience pleasurable and rewarding responses to music had larger tracks connecting the left auditory cortex and left anterior insula (Loui et al., 2017). The results from this study and the functional imaging results referred to above suggest that the lack of reward from music may be linked to aberrant connections *between* regions of the brain involved in processing sounds and regions of the brain involved in processing pleasure, rather than malfunctioning *within* one or several brain regions.

4 THE CASE OF SAD MUSIC

The relationship between emotions and pleasure, affect and reward, is clearly entwined, though the exact relation can become rather complex and muddled when it comes to music. For example, there are certain situations in which an intended emotion can be recognized within a music piece without the listener feeling the said emotion (Gabrielsson, 2001). Even more intriguing, the valence of the felt emotion might be different from, or even the opposite of, the emotion that is identified as the intended one. Such a mismatch is commonly observed in the case of sad music, when people often report experiencing positive feelings, such as tenderness and enjoyment, in response to what they would classify as sad music (Sachs et al., 2015). This attraction to sad music has been labeled the "tragedy paradox" and is particularly intriguing from a psychological standpoint because sadness is generally conceptualized as a negatively valenced emotion, an unpleasant feeling that is to be avoided. The fact that so many people report enjoying music meant to convey sadness to such an extent that they explicitly seek it out is therefore strange and worthy of empirical investigation.

To better understand this paradox, several researchers have attempted to both qualify and quantify the exact nature of the emotional experience typically reported in response to sad music. Some have suggested that because music does not pose a tangible threat, any corresponding sensations are devoid of real-life consequences and therefore must be "vicarious" by nature, the implication being that the emotion of sadness can be recognized in the music, but it need not be experienced as unpleasant or pleasant (Kawakami et al., 2013). Instead, people can actually feel pleasure as a result of the beauty of the music or the music-listening experience itself, regardless of the emotional intent of the piece (Kawakami et al., 2013; Schubert, 1996).

On the other hand, there is psychological and neurophysiological evidence suggesting that full-fledged, "genuine" feelings of sadness in response to music that conveys sadness, feelings as intense and visceral as sadness felt in response to a real or perceived loss, can be felt in response to music that conveys sadness. Psychophysiological differences were found in participants when listening to sad music vs happy music, including decreased skin conductance, higher finger temperature, and decreased activity in the muscles of the face (Lundqvist et al., 2008). Listening to sad music also had subsequent effects on performance during a word recall task and a picture judgment task, and these effects were similar to those caused by sadness induced through autobiographical recall (Vuoskoski and Eerola, 2012), suggesting that affective responses to sad music can alter perception and judgment in a similar way as sadness induced in other situations. In neuroimaging studies, sad music activated some of the same regions associated with sad affective states triggered by other means, and these included the hippocampus, amygdala, caudate nucleus, and the thalamus (Brattico et al., 2011; Mitterschiffthaler et al., 2003; Vytal and Hamann, 2010).

In the case of attraction to sad music, these genuine feelings of sadness are likely experienced in tandem with other, more positive emotions. As pointed out in Juslin's model described earlier, more than one mechanisms of music-evoked emotions can be engaged during music listening and at times, these different mechanisms can culminate in two different emotional experiences (Juslin, 2013). In this account, when listening to enjoyable, sad music, a person may feel sadness through one mechanism, by the process of recognizing and internalizing the negative emotion being conveyed, for instance, while also feel positive emotions through a separate mechanism, by the process of assessing the aesthetic qualities of the music, for example (Juslin, 2013).

Whether people who enjoy listening to sad music actual feel sad or, rather, only recognize sadness, but feel some other, more positive emotion most likely depends on a combination of factors. Previous experiences and associations with the music may play a role. It has been suggested that sad music may become linked to certain psychological benefits that are less commonly associated with music and that convey more positive valence. When participants were asked about their motivations for engaging with self-identified sad music over happy music, they reported that sad music allowed them to understand, savor, and ultimately resolve their own intense feelings without any real-life implications (Taruffi and Koelsch, 2014). Sad music may also be enjoyed because it has the ability to trigger specific memories, to connect people with others, to distract them from current problems or situations, and to regulate or enhance mood, or purely because it has become associated with something that is beautiful and aesthetically pleasing (Eerola and Peltola, 2016).

Whether a person can experience these psychological benefits from sad music may depend on personality. Empathy, for instance, has been shown to be correlated with the liking of sad music (Kawakami and Katahira, 2015). It has been proposed that people with higher empathic abilities may be more likely to gain the psychological benefits from listening to sad music because they can more easily resonate with and vicariously feel the intense emotions being conveyed (Sachs et al., 2015). Openness to experience was also correlated with liking of sad music (Ladinig and Schellenberg, 2012; Vuoskoski et al., 2011), a relation that was also found with experiencing chills, suggesting that both experiences may be related, in that they are likely to occur with music that is moving and in people that like to be moved. Stemming from the findings that rumination is also found to be positively correlated with enjoyment of sad music, other researchers have concluded that some individuals have a maladaptive attraction to sad music, and enjoy it *because* of the negative feelings associated with it (Garrido and Schubert, 2011). Musical expertise might additionally play a role, as some studies have found that individuals with more music training tend to report feeling joy and pleasure in response to sad music (Eerola and Peltola, 2016).

The social context surrounding the music-listening experience is also important. People report choosing to listen to sad music more often when they are alone, when they are in contact with nature, when they are in distress or feeling lonely, or when they are in reflective or introspective moods (Taruffi and Koelsch, 2014). Positive feelings toward sad-sounding music were also shown to increase when played after a sad-mood induction paradigm (Hunter et al., 2011). However, there is also evidence that some people select sad music when they are not feeling sad. In one study, people who exhibited a subtype of empathy called perspective taking, referring to the tendency to cognitively adopt the viewpoint of an observed other, were more likely to listen to sad music when in a positive mood; on the other hand, people who exhibited another subtype of empathy called fantasy proneness, referring to the tendency to become transported into the feelings of characters when engaging with works of fiction (Davis, 1983), were more likely to listen to sad music when they were in a negative mood (Taruffi and Koelsch, 2014).

Preliminary survey data collected in our laboratory may help explain how the different subtypes of empathy can impact emotional responses to sad music. We collected responses in a survey in which people answered questions regarding various reasons why they might engage with sad music. We found that people who scored high on the perspective taking reported enjoying sad music because it was associated with certain cognitive benefits, such as allowing them to better understand their situation and emotional state. In this survey, we also assessed the situations in which people were likely to engage with sad music and found that people who scored higher on the fantasy component of empathy chose to listen to sad music when in a negative mood, such as after a breakup or when feeling lonely, because, paradoxically, they were more likely to feel positive, rather than negative, emotions in response to the music.

5 MUSIC TRAINING AND EMOTION PROCESSING

So far, we have discussed varied ways in which music is systematically tied to emotions and feelings. But can this connection be tightened or altered with music training? Learning to play a musical instrument has been associated with improvement in auditory skills (Kraus and Chandrasekaran, 2010; Schellenberg and Moreno, 2010; Schön et al., 2004), yet, it is unclear whether music training is associated with better social or emotional abilities. With this in mind, we have been investigating the impact of music training on child development, specifically whether music instruction in childhood is predictive of improvements in recognizing and understanding the emotions of others and whether this improvement can be detected at the neural level.

For this study, young musicians were recruited from music schools and studios in the greater Los Angeles area. Participants were between the ages of 8 and 13 and had been playing a string instrument continuously for at least 2 years. These children completed two emotion perception tasks while inside an MRI scanner: one musical (auditory) and one nonmusical (visual). Using both a musical and nonmusical task of emotion perception would allow us to inquire if music training influences the processing of emotions when presented in the auditory domain, and if such influence extends to a nonauditory domain with nonmusical stimulus.

For the auditory (musical) task, we developed a set of auditory stimuli by recording an adult violinist performing two musical pieces (Jules Massenet's *Meditation from Thaïs* and Sergei Rachmaninoff's *Rhapsody on a Theme of Paganini, Variation 18*) in four different emotional styles: happy, sad, peaceful, and angry. During the task, children listened to the recordings and were instructed to respond to the question "How do you think the musician is feeling during the performance" using an MRI-compatible button box with four answer choices. Given that the same musical piece appeared in every video clip, this task required that the children pay close attention to the subtle differences of timing and expression in the performance in order to determine which emotion was being conveyed.

For the visual (nonmusical) task, the children were presented with a series of full color emotional faces, taken from the NimStim dataset (Tottenham et al., 2009), corresponding to one of three basic emotions: sadness, fear, or anger. The faces were subsequently morphed, to varying degrees, with neutral, expressionless faces to create images that ranged in intensity of expression. In one condition, children had to judge the intensity of the emotional expression, independently of the type of emotion being expressed. Like the auditory (musical) emotion perception task, accurate performance on this condition requires attention to specific details of the stimulus. As a control condition, children were asked to identify which emotion was being conveyed. Responses were again recorded via the MRI-compatible button box with four possible choices. We analyzed correlations between years of music training and (1) the behavioral responses to the two tasks as well as (2) the degree of neural activation.

Behaviorally, we found that during the auditory task, years of musical training were positively correlated, after controlling for age, with correct identification of the emotion that the musician was attempting to convey. For the visual task, no correlation was found between years of music training and correct identification of the intensity of the emotion being conveyed by the face nor between music training and correct identification of the emotion.

For the fMRI analysis of the auditory task, we contrasted the positively valenced audio stimuli (happy and peaceful) with the negatively valenced audio stimuli (sad and angry) in order to quantify brain activity related to perceiving differences in the emotional style of the performances. We then correlated these signal differences with years of musical training and found significant positive relationships: children with more musical training showed increased activity for this contrast in the right superior parietal lobule, postcentral gyrus, and middle and superior frontal gyri. These regions are proposed to be part of the action–observation network, i.e., a collection of brain areas involved in both performing an action and observing that same action in others (Caspers et al., 2010; Grezes and Decety, 2001; Meyer et al., 2011) and, relatedly, are activated during various tasks that involve socioemotional experiences (McLellan et al., 2012; Schulte-Rüther et al., 2007). Our neuroimaging finding might therefore indicate that children with more music training may be better at mentally simulating the actions involved in expressing emotions through music, which may help to correctly identifying the intended emotion.

In the visual (nonmusical) task, the judgment of emotional intensity is a more sensitive measure of emotional perception than simply labeling an emotion and, predictably, produced greater brain activation. However, neural activations from this contrast did not correlate with years of music training. Thus, in the visual task neither behavior nor brain activation was related to musical training.

These findings suggest that learning to play a musical instrument can enhance the ability to perceive emotions conveyed by musical stimuli. This improvement in the behavior may be related to maturation of brain functions, as our study shows that music training was associated with heightened activity in the neural systems that underlie emotion perception. However, given that the number of years of music training is highly correlated with age, it is not clear, in the absence of a control group of same-age children without music training, if the effect we detected might or might not be related to age. Furthermore, our results did not provide evidence that the emotion perception benefits of musical training transfer to the visual, nonmusical domain. Nevertheless, we should note that there is evidence that adult musicians demonstrate an enhanced perception of emotion in nonmusical auditory stimuli, such as speech, suggesting that music training can provide perceptual benefits to nonmusical stimuli presented to the auditory system (Lima and Castro, 2011; Strait et al., 2009). It remains to be determined if the possible influence of musical training on the emotion processes in a nonauditory domain would be evident with a different task or in a larger sample.

6 CONCLUDING REMARKS

We have provided an overview of current research on the ways in which music and human affective experiences are connected and on the brain mechanisms that support this connection. Future neuroimaging and psychological explorations are likely to provide a clearer picture of how music and reward processes interact and continue to reveal the ways in which music plays a role in so many aspects of human cultures.

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