Psychology of Aesthetics, Creativity, and the Arts
2013, Vol. 7, No. 1, 48–61

1931-3896/13/$12.00 DOI: 10.1037/a0031624

The Neuroaesthetics of Music

Elvira Brattico
University of Helsinki and University of Jyväskylä

Marcus Pearce
Queen Mary, University of London and Goldsmiths, University of London

The increasingly intensive study of music by neuroscientists over the past two decades has established the neurosciences of music as a subdiscipline of cognitive neuroscience, responsible for investigating the neural basis for music perception, cognition, and emotion. In this endeavor, music perception and cognition have often been compared with language processing and understanding, while music-induced emotions are compared with emotions induced by visual stimuli. Here, we review research that is beginning to define a new field of study called neuroaesthetics of music. According to this fresh perspective, music is viewed primarily as an expressive art rather than as a cognitive domain. The goal of this emerging field is to understand the neural mechanisms and structures involved in the perceptual, affective and cognitive processes that generate the three principal aesthetic responses: emotions, judgments, and preference. Although much is known about the frontotemporal brain mechanisms underlying perceptual and cognitive musical processes, and about the limbic and paralimbic networks responsible for musical affect, there is a great deal of work to be done in understanding the neural chronometry and structures determining aesthetic responses to music. Research has only recently begun to delineate the modulatory effects of the listener, listening situation, and the properties of the music itself on a musical aesthetic experience. This article offers a review and synthesis of our current understanding of the perceptual, cognitive, and affective processes involved in an aesthetic musical experience and introduces a novel framework to coordinate future endeavors in an emerging field.

Keywords: music, auditory cortex, cognitive neuroscience, pitch, rhythm

Overture: From Neuroscience to Neuroaesthetics of Music

People value music primarily for aesthetic reasons: for the emotions it generates, for triggering memories, and for its beauty (Juslin & Laukka, 2004; Laukka, 2007; McDonald & Stewart, 2008). Just as in other aesthetic domains such as visual art, architecture, or dance (see also Leder, Belke, Oeberst, & Augustin, 2004), listening to and performing music generates, in concert with a favorable environment and listening situation, aesthetic experiences that include specific emotions and evaluative judgments of beauty, aesthetic quality, and liking. The question of how music generates an aesthetic experience has been addressed with scientific methods since the dawn of experimental psychology. A new era of empirical work on musical perception began with Helmholtz (1863/1985) who, inspired by Hanslick (1854/1954), associated the aesthetic qualities of musical notes and scales with their psychoacoustic properties (especially frequency ratios between partials of complex tones). Wundt, a founder of experimental psychology and one-time assistant of Helmholtz in Heidelberg, developed a more psychological approach to the study of aesthetics, introspecting, for example, about how his own sensations of pleasure, tension, and excitement varied with the tempo of a metronome (see Miller & Bukhout, 1973). Elsewhere, Wundt demonstrated that physiological arousal is related to stimulus complexity and argued that aesthetic pleasure is maximal at intermediate degrees of complexity (Wundt, 1874). In his *new experimental aesthetics,* Berlyne (1971) developed this idea into an inverted U-shaped function linking the "arousal potential" of a stimulus with its "hedonic value," such that intermediate degrees of arousal correspond to maximum pleasure and attempted to identify how stimulus properties (such as complexity, familiarity, novelty, uncertainty) influence aspects of the aesthetic experience such as arousal, pleasure, and interestingness.

Elvira Brattico, Cognitive Brain Research Unit, Institute of Behavioral Sciences, University of Helsinki, Helsinki, Finland and Center of Excellence for Interdisciplinary Music Research, University of Jyväskylä, Jyväskylä, Finland; Marcus Pearce, Centre for Cognition, Computation and Culture, Goldsmiths, Queen Mary, University of London, London and Goldsmiths, University of London, United Kingdom and School of Electronic Engineering and Computer Science, Queen Mary, University of London.

The authors contributed equally to this article. We thank the Academy of Finland (project No. 133673) and the University of Helsinki (3-year grant, project No. 490083), as well as the United Kingdom Engineering and Physical Sciences Research Council (EPSRC project number EP/H01294X/1) for financial support.

Correspondence concerning this article should be addressed to Elvira Brattico, Cognitive Brain Research Unit, Institute of Behavioral Sciences, P.O. Box 9, 00014 University of Helsinki, Finland. E-mail: elvira.brattico@helsinki.fi, or Marcus Pearce, School of Electronic Engineering and Computer Science, Queen Mary, University of London, London E1 4NS, United Kingdom. E-mail: marcus.pearce@eecs.qmul.ac.uk.

Although the neurosciences of music can be now considered an autonomous subdiscipline of cognitive neuroscience (Levitin & Tirovolas, 2009; Peretz & Zatorre, 2003), the neuroaesthetics of music remains relatively undeveloped. For example, many experiments have been conducted on the neural effects of musical expertise on perceptual and cognitive skills (e.g., Brattico et al., 2009; Kraus & Chandrasekaran, 2010; Pallesen et al., 2010; Schulze, Zysset, Mueller, Friederici, & Koelsch, 2011; Tervaniemi, Rytkönen, Schröger, Ilmoniemi, & Näätänen, 2001), but only two such studies have focused on aesthetic or affective judgments (Müller, Höfel, Brattico, & Jacobsen, 2010; Brattico et al., in preparation). By contrast, neuroscientific and psychological research on the visual perception of artistic stimuli seems to have given equal weight to cognitive processing (e.g., Wiesmann & Ishai, 2011, for expertise effects in perception of Cubist paintings) and aesthetic and affective experience (e.g., Kirk, Skov, Christensen, & Nygaard, 2009, for expertise effects on aesthetic preference for architecture). We suggest two reasons for this asymmetry: first, most musical experiences occur in nonaesthetic situations, leading to a focus on basic goal-oriented emotions (Jacobsen, 2009; Sloboda, 2010); second, interest in the relationship with language processing in the neurosciences of music has led to a cognitive rather than aesthetic approach to musical experience (i.e., a focus on the cognitive representation and processing of musical structure rather than the affective and aesthetic experiences that often result from this processing). Even in the psychology of music, "Psychologists have tended to avoid studying aesthetic response to music . . . [and] rather focused on more mundane aspects such as preference" (Juslin, Liljeström, Västfjäll, & Lundqvist, 2010, p. 635). Here we view preference as an important, possibly even necessary though not sufficient, component of the aesthetic experience of music.

Research has found that beauty is an important part of most people's understanding of musical aesthetics, for music experts and nonexperts (Istok et al., 2009), and for 6- to 9-year-old children (Nieminen et al., 2011) replicating results for visual art (Jacobsen, 2004). Drawing on proposals by Brattico, Bogert, and Jacobsen (in press); Juslin et al. (2010); Sloboda (2010); Hargreaves and North (2010); and Leder et al. (2004), we define an aesthetic experience of music as one in which the individual immerses herself in the music, dedicating her attention to perceptual, cognitive, and affective interpretation based on the formal properties of the perceptual experience. We identify here three main outcomes: first, emotion recognition (e.g., "this song is sad") and induction (e.g., "I feel nostalgic"); second, aesthetic judgment (e.g., "this song is beautiful"); and third, liking (e.g., "I like this song") and preference (e.g., "I love rock & roll"). As noted by Juslin et al. (2010), not all of these outcomes may be present but typically they combine to form a genuine aesthetic situation: The presence of a music-induced emotion is not *sufficient* for an aesthetic experience (p. 636). We examine the kinds of emotion induced by music before reviewing research on the different psychological and neural mechanisms involved in the generation of emotion by music. In doing so, we emphasize the need to take account not only of the properties of the music, but also the listener and listening situation on the aesthetic experience (Hargreaves & North, 2010).

The relevance of a scientific approach to the aesthetics of music is debated. While some philosophers of aesthetics have embraced psychological and neuroscientific research (e.g., Carroll, Moore, & Seeley, 2011; Meyer, 1956; Robinson, 2005), others argue that neuroscience has nothing to tell us about aesthetic questions (e.g., Tallis, 2008). Equally, although some scientists argue that "aesthetic philosophy is receding to a sideline 'advisory' role, while cognitive science takes an unaccustomed leadership position" (Huron, 2010, p. 151), here we try to build an interdisciplinary framework for delineating a neuroaesthetics of music that explicitly includes philosophical, psychological, neuroscientific, and evolutionary approaches.

Emotions in Musical Experience

Increasing neuroscientific interest in affective processes has spread to the neurosciences of music. However, research to date has been limited primarily to the most common emotions encountered also in everyday life, such as happiness or sadness, and their role in mood regulation. Indeed, musical emotions are either interpreted with reference to the categorical framework of "basic" emotions, supposedly universal affective states, panculturally recognized and necessary for species survival (Ekman, 1999; Peretz, 2010), or to general dimensional models of emotion (e.g., Russell, 1980; Schimmack & Grob, 2000), in which emotions are locations within a continuous 2-D or 3-D affective space. It has been suggested, however, that music generates emotions of a special kind, qualitatively different from goal-oriented, common (or utilitarian) emotions (Scherer & Zentner, 2008), although there is little neuroscientific research to date on such aesthetic emotions.

Basic Emotions

Much research on music and emotion has been inspired by work on the categorical perception of facial emotion (Ekman, 1999). This framework identifies basic (or primary) emotions such as happiness, sadness, anger, fear, and disgust, which, it is argued, are panculturally recognized and are associated with innate motor and physiological responses. Music may express and induce these basic emotions in individuals of all ages, including infants, and across many cultures (Peretz, 2010), although within a safe aesthetic environment, the negative emotions lose some of their aversive character (Juslin & Västfjäll, 2008).

The amygdala plays a central role in the processing of salient negative emotions, fear in particular, induced by aversive stimuli. The amygdala also seems to be a crucial brain structure for perception and recognition of fear in music, because patients with medial temporal resection encompassing the amygdala, and one patient with bilateral amygdala damage, confused scary music with peaceful music while showing intact perceptual skills (Gosselin et al., 2007; 2005). The amygdala is activated by sad and dissonant music (contrasted with emotionally neutral and consonant music, respectively; Koelsch, Fritz, von Cramon, Muller, & Friederici, 2006; Mitterschiffthaler, Fu, Dalton, Andrew, & Williams, 2007; Trost, Ethofer, Zentner, & Vuilleumier, 2012) and even by single unpredictable chords (Koelsch, Fritz, & Schlaug, 2008), indicating that further research is needed to isolate the role of the amygdala in musical listening (Koelsch, 2010).

Sad emotions associated with slow minor classical piano pieces activated the left medial frontal gyrus (BA 10) and the adjacent superior frontal gyrus (BA 9) when compared with happy major and fast pieces (Khalfa, Schon, Anton, & Liegeois-Chauvel, 2005). These regions were also activated during aesthetic judgment of pictures (Jacobsen, Schubotz, Hofel, & Cramon, 2006) and rhythms (Kornysheva, von Cramon, Jacobsen, & Schubotz, 2010), suggesting that their activation might reflect subjective preference for minor pieces rather than sadness per se. In a functional MRI (fMRI) study of emotional responses to classical music, Mitterschiffthaler et al. (2007) found no regions activated by sad compared with happy music, but did find activation in the hippocampus/amygdala for sad compared with neutral music. Again, this study did not control for the effects of preference.

Turning now to positive emotions such as happiness, Mitterschiffthaler et al. (2007) found that happy classical music induced activation of the ventral striatum compared with neutral music. Compared with sad music, happy music activated left superior temporal gyrus (BA 22), a region of the nonprimary auditory cortex, devoted to integrating sounds over longer time spans as opposed to the primary auditory cortex, and hence processing more abstract aspects of sounds. In a recent study, Brattico et al. (2011) confirmed these findings in music from several genres (pop, jazz, classical) and also found activation of the limbic insula, adjacent to the superior temporal gyrus. A contrast between sad music and happy music indicated recruitment of the caudate nucleus, responsible for the preparation of the chill response according to Salimpoor, Benovoy, Larcher, Dagher, and Zatorre (2011), and of the left thalamus, associated in many previous studies with processing of sad facial expressions (Fusar-Poli et al., 2009). In sum, musical emotions activate some brain structures previously associated with emotions induced by visual stimuli: this partial overlap in neural processing may facilitate crossmodal transfer of emotions, such as the modulation of neural processing of neutral faces during listening to happy music (Logeswaran & Bhattacharya, 2009).

Dimensional Models of Emotion

Dimensional models attempt to identify a series of dimensions capable of representing all possible emotional states. In theory, the dimensional structure should be rich enough to represent the basic emotions as points in the space. The most widely known dimensional model of emotion is the circumplex model (e.g., Russell, 1980, 2003), which distinguishes valence (pleasure-displeasure) and arousal (activating-relaxing) as two orthogonal dimensions of an emotional experience. This model has been applied to music in many behavioral and neuroscientific studies (e.g., Krumhansl, 1997; North & Hargreaves, 1997; Schmidt & Trainor, 2001; Vieillard at al., 2008). A variant on this approach (Schimmack & Grob, 2000) includes the three dimensions of valence (pleasant-unpleasant), arousal (awake-tired), and tension (tense-relaxed). In applying this model to music, Ilie and Thompson (2006) found that loudness and tempo increased judgments of arousal and tension while loudness and pitch height increased pleasantness. In a study of excerpts of film music, Eerola and Vuoskoski (2011) found that participants were able to correctly discriminate examples differing in the three dimensions, and noted that removing tension did not impair the fit of the model. Eerola and Vuoskoski also found that the categorical model of basic emotions (Krumhansl, 1997) is inferior to the dimensional model (including energy, tension/arousal and valence as dimensions) in characterizing emotionally ambiguous examples.

In an fMRI study of emotional responses to excerpts of classical music, Trost et al. (2012) report differences in arousal and valence were reflected by changes of activation in the reward and limbic system (including the striatum, ventral tegmental area, and orbitofrontal cortex for valence and the ventromedial prefrontal cortex and the subgenual cingulate for arousal), with additional effects in brain areas related to memory, motor control, and self-reflective processes for musical arousal (Trost et al., 2012). There is further evidence for the role of physiological arousal in the aesthetic experience as proposed by Berlyne (1971). Increases in electrodermal activity, generated by the sympathetic autonomic nervous system, are greater while listening to energetic than relaxing music (Khalfa, Peretz, Blondin, & Robert, 2002) and by unexpected compared with expected chords (Steinbeis, Koelsch, & Sloboda, 2006). According to Hargreaves and North (2010), the arousal level of the autonomic nervous system predicts liking for music and leads to finer grained emotional responses related to the listener's engagement with the music (e.g., feeling excited, bored or unsettled). However, these predictions await experimental neuroscientific research.

In view of the ongoing debate about the extent to which dimensional models of emotion can encompass categorical emotions (Eerola & Vuoskoski, 2011; Gosselin et al., 2007; Khalfa et al., 2008; Vieillard et al., 2008), the challenge for proponents of these models is to identify the smallest number of dimensions capable of representing all distinguishable emotional states. It is not clear, for example, that the circumplex model is capable of sufficiently distinguishing closely related emotions such as anger and fear. In an aesthetic context, one difficulty with existing dimensional models is that they equate valence with pleasure, which would seem to preclude the possibility of finding a frightening or sad (negative valenced) experience of music enjoyable. Schubert (1996) proposes that we enjoy negative emotions in music by inhibiting displeasure thanks to the "safe" aesthetic context that nullifies the possible dangerous consequences associated with real everyday negative emotions (see also Huron, 2006). Therefore, we suggest using valence to indicate positive and negative affective character and including pleasure or enjoyment as an extra dimension (see also the discussion of aesthetic emotions below). We also propose a finer distinction between different types of pleasure: immediate *sensory pleasure* and a more reflective process of *enjoyment* although empirical research has yet to tease apart these two different kinds of pleasure.

As a final comment, we note that dimensional models are fundamentally unable to accommodate the possibility of mixed emotions combining the extremes of a single dimension, such as feeling happy and sad at the same time (Hunter, Schellenberg, & Schimmack, 2008).

Aesthetic Emotions

Scherer and Zentner (2008) distinguish between *aesthetic* and *utilitarian* emotions: aesthetic emotions differ from their utilitarian counterparts by occurring in situations that do not trigger self-interest or goal-directed action. They argue that music-induced emotion reflects a multiplicative function of structural features of the music, listener features, performer features and contextual features leading to distinct kinds of emotion such as wonder, transcendence, entrainment, tension and awe. In a series of related studies with over a thousand subjects from adolescents to elderly individuals, Zentner, Grandjean, and Scherer (2008) identified nine factors underlying the adjectives used retrospectively to describe felt and expressed musical emotions: wonder, transcendence, tenderness, nostalgia, peacefulness, power, joy, tension, sadness (embodied in the Geneva Emotional Music Scale; GEMS). These factors include specifically aesthetic emotions (e.g., tension, transcendence) but also emotions (e.g., sadness and joy), which also arise in nonaesthetic contexts.

Three aesthetic emotions that have attracted the most detailed research are awe, nostalgia, and enjoyment. Aesthetic awe has been identified as a crucial characteristic distinguishing a peak aesthetic experience of music from everyday casual listening (Gabrielsson, 2010). Awe is a rare aesthetic emotion triggered by very beautiful music, outstandingly performed in an optimal acoustic environment, such as a medieval cathedral (Konecni, 2005). Another important aesthetic emotion is nostalgia induced while listening to a piece of music. Using a novel paradigm for eliciting autobiographical memories of songs, Janata (2009) presented subjects with a pop/rock repertoire dating back several years. Correlations between individual ratings of autobiographical relevance and changes in brain metabolism showed that dorsal regions of the medial prefrontal cortex are crucial for experiencing nostalgia induced by music.

In music neuroscience, the aesthetic emotion of enjoyment has been investigated by focusing on the chill reaction. Possibly the most thoroughly studied aesthetic experience of music, chills correspond to physiological changes such as goose bumps and shivers down the spine, also referred to as frisson or thrills. Although not everyone experiences chills during musical listening or playing, those who experience them do so relatively frequently and reliably (Panksepp, 1995; Sloboda, 1992). In addition to being easy to record behaviorally, chills have the additional advantage of producing characteristic physiological markers including changes in heart rate, breath depth, and skin conductance (e.g., Blood & Zatorre, 2001). People who score highly on openness tend to experience chills to music (McCrae, 2007; Nusbaum & Silvia, 2011), and this effect appears to be mediated by the degree to which people listen to and value music in their everyday lives (Nusbaum & Silvia, 2011). However, age, gender, and music education appear to have no influence on the experience of chills (Grewe, Kopiez, & Altenmueller, 2009). Turning to the experience itself: chills are associated with increased subjective emotion and physiological arousal (Grewe et al., 2009) and are usually experienced as highly pleasurable (Goldstein, 1980; Panksepp, 1995; Sloboda, 1992).

In a pioneering study, Blood and Zatorre (2001) attempted to determine the neural correlates of the chill experience by asking musically trained subjects to bring their chill-evoking music to the lab and using the pieces of other subjects as the control stimulus. When correlating the metabolic brain responses measured by positron emission tomography (PET) with ratings of emotional intensity, it was found that the strongest chill responses activated the bilateral insula, the left ventral striatum (including the nucleus accumbens), the right orbitofrontal cortex (BA 14), the medial anterior cingulate and supplementary motor area (BA 6), the right thalamus and the left midbrain whereas they down-regulated the right amygdala, the left anterior hippocampus/amygdala formation, and the bilateral medial prefrontal cortex (BA 10/32). Indeed, highly pleasant, familiar music enhances connectivity between the ventral tegmental area and the nucleus accumbens, and between this latter area and the hypothalamus, pointing toward pleasure-related responses in the autonomic nervous system (Blum et al., 2010; Menon & Levitin, 2005; Salimpoor et al., 2011; Sutoo & Akiyama, 2004). Salimpoor et al. (2011) have recently shown that chills are associated with dopamine release in the ventral striatum and with activation of the nucleus accumbens while the caudate nucleus is activated during anticipation of a passage of music inducing chills.

Further evidence for the link between dopamine release and intense musical pleasure comes from the reduction of the chill reaction in music by naloxone, an opioid antagonist, whose transmission in the nucleus accumbens is associated with dopamine release in the ventral tegmental area (Goldstein, 1980). In addition, exposure to Mozart's music in rats improves dopaminergic transmission in the neostriatum, as indicated by decreased systolic blood pressure (Sutoo & Akiyama, 2004). The ventral striatum of the basal ganglia, including the nucleus accumbens, which controls dopamine release in the ventral tegmental area, is associated with reward, pleasure and motivation derived from primary activities necessary for survival (e.g., eating, sex), and plays a central role in the transition to habitual drug use (Haber, 2009). The fact that such ancient survival-related circuitry is modulated so efficiently by an abstract stimulus such as music argues for the adaptive evolutionary status of music making (Brattico, Brattico, & Jacobsen, 2009–2010; Cross, 2003; Huron, 2003; Justus & Hutsler, 2005). It has been claimed that music has beneficial functions in cohesion, mother–infant interaction and mate choice (Wallin, Meyer, & Brown, 2000) but one cannot reject the alternative hypotheses that music appreciation is a spandrel exapted from a collection of abilities originally adapted for other reasons or else that it originated through mechanisms of biological evolution, such as genetic drift, gene flow, or nonrandom mating, not entailing any adaptive function (Brattico et al., 2009–2010).

Despite the physiological and evolutionary salience of a central aesthetic emotion such as musical pleasure, Juslin and colleagues (2010) argue against the existence of aesthetic emotions claiming: first, that defining them as emotions associated with art is not informative; and second, that defining them as lacking goals and action-oriented coupling does not make them unique to music. Similarly, Koelsch (2010; see also Koelsch, Offermanns, & Franzke, 2010) describes music-induced emotions as "real" emotions because they activate the same brain structures that are involved in everyday affective states and rejects their association with aesthetic experiences "lacking motivational components and goal relevance" (p. 131). According to Juslin and Västfjäll (2008), music may evoke emotions more frequently than other kinds of events, but the emotions themselves are indistinguishable from everyday emotions.

To address these questions, recent empirical research has compared the GEMS model with the dimensional model. In a study of emotional responses to film music, Vuoskoski and Eerola (2011) found that a dimensional model (Schimmack & Grob, 2000) showed better consistency among participants and was better able to discriminate the musical excerpts than the GEMS model. Therefore, the GEMS model, which was constructed using classical instrumental music, may not reflect the aesthetic experiences of listeners to other musical styles. In a recent fMRI study of individuals listening to classical music, Trost et al. (2012) found evidence for grouping the 9 GEMS factors into higher-order affective dimensions distinguished by arousal and valence, with some evidence for a finer categorization (e.g., vitality, unease, sublimity).

Research on the aesthetic emotions, therefore, presents a somewhat mixed picture. Following Sloboda (2010), we suggest that musical experiences in everyday contexts can induce basic emotions, such as sadness, happiness, and fear (which sometimes reach intensities comparable to those triggered by life events), while musical experiences in aesthetic situations as defined above can generate special kinds of emotion that are distinct from the other aesthetic outcomes (judgment and preference) but interact with them to produce an aesthetic experience. Key challenges for research in neuroaesthetics are to recreate the right experimental conditions for inducing a genuine aesthetic experience and to understand which minimal set of dimensions are required to represent adequately both utilitarian and aesthetic emotional responses to music.

How Does Music Generate Emotions?

The relationship between music and emotion is "the much-vexed question that has been at the centerpiece of musical aesthetics since . . . the late 18th century" (Kivy, 2006, p. 288). The rise of instrumental music and subsequently program music in 18th- and 19th-century Europe generated a debate between *referentialists,* such as Hegel and Wagner, and *formalists*, such as Hanslick and Stravinsky. The debate centered on the question of whether music possesses referential content such that musical structures designate nonmusical entities such as physical objects, individuals, or feelings. This prompted Hanslick (1954) to argue that the aesthetic function of music is not to induce emotion: music cannot represent definite feelings (which have objects) because it cannot represent the thoughts that support these feelings; it can represent dynamic changes in intensity of such feelings but not as properties of specific emotions since other phenomena also share such dynamic changes. Hanslick argues instead that the aesthetic effects of music are specifically musical:

> The most significant factor in the mental process which accompanies the comprehending of a musical work and makes it enjoyable . . . is the mental satisfaction which the listener finds in continuously following and anticipating the composer's designs, here to be confirmed in his expectations, there to be agreeably led astray. It goes without saying that this mental streaming . . . occurs unconsciously and with the speed of lightning. Only such music as brings about and rewards this mental pursuing . . . will provide fully artistic satisfaction. (Hanslick, 1954, p. 64)

Meyer (1956) argued that this debate had been founded on a spurious association of referentialism with expressionism: the fact that referentialists tend to be expressionists does not render expressionism incompatible with formalism. Meyer sought to develop a formalist account of emotional expression in music founded on the psychological process of expectation which creates patterns of tension and resolution, which, in turn, generate affective states such that violations of expectation are negatively valenced, indicating predictive failure (Meyer, 1956, p. 27).

In their review, Juslin and Västfjäll (2008) emphasize the importance of distinguishing *emotion perception*, where a listener perceives or recognizes emotions expressed in the music, and *emotion induction*, where music evokes an emotion in the listener. They go on to identify six psychological processes supporting the induction of emotions by music. First, *brain-stem reflexes* (originating from areas such as the inferior colliculus) mediate the induction of arousal by sudden, loud, dissonant or rapidly pulsing sounds. Second, in *evaluative conditioning*, music can induce emotion through association, as a conditioned stimulus, with an aversive or rewarding stimulus. Third, musical structures may induce emotion through *emotional contagion*, by mimicking other means of emotional expression such as language, posture and gait. Fourth, music may invoke emotions through the use of structures with close external referents in the sensorium thereby evoking *visual imagery* (e.g., a storm). Fifth, music may evoke emotion through the intermediary of an *episodic memory* associated with the music ("Darling, they're playing our tune"). Finally, the *generation and violation of expectations* can induce experiences of tension, release, surprise, and uncertainty.

Here we focus on the psychological mechanisms most specific to *musical* aesthetic experience, and also most studied by neuroscientists: brainstem mechanisms (such as those producing the dissonance sensation), emotional contagion or imitation, and expectation.

Sensory Dissonance

Of the brainstem mechanisms discussed by Juslin and Västfjäll (2008), most attention has been paid to sensory consonance and dissonance, which have long been used by composers and musicians in Western and non-Western cultures to manipulate aesthetic responses to music. Two sounds played simultaneously are dissonant, experienced as beating amplitude modulation or roughness, when their physical distance is smaller than two-thirds of the critical bandwidth stimulating neighboring hair cells in the basilar membrane and causing neurons in the cochlear nucleus and brainstem to fire without properly resolving the two sounds (Kameoka & Kuriyagawa, 1969; Peretz, 2010; Plomp & Levelt, 1965). On reaching the primary auditory cortex, the signal causes neurons to resonate at the beat frequency (Fishman et al., 2001), generating more neuronal activity than consonant sounds (Brattico, Näätänen, Verma, Välimäki & Tervaniemi, 2000; Brattico et al., 2009; Schön, Regnault, Ystad, & Besson, 2005). These sensory responses to dissonant sounds are coupled with an affective experience of irritation, whose neural basis seems to rely on the parahippocampal gyrus, a brain region responsible for withdrawal behavior, and the amygdala, associated with salience and negative affect (Blood et al., 1999; Gosselin et al., 2006; Koelsch et al., 2006). It is interesting to note that a clear-cut lateralization of the parahippocampal gyrus during listening to affective classical music was observed by Trost et al. (2012): the left parahippocampal gyrus was recruited by highly arousing music whereas the right parahippocampal gyrus was activated by tender and nostalgic music with low arousal. In turn, the soothing sensation of consonance is usually described as an absence of dissonance, but some identify it as an active process involving reward centers in the brainstem and ventral striatum (Blood et al., 1999; Braun, 1999; Koelsch et al., 2006; Tramo, Cariani, Delgutte, & Braida, 2003). A motor circuit, including the rolandic operculum, probably related to the automatic impulse to imagine singing during pleasant music, is also activated while nonmusicians listen to consonant music (Koelsch et al., 2006).

Musical Reference and Imitation

> Hence . . . it becomes possible for motion in music to imitate the peculiar characteristics of motive forces in space . . . And on this, as I believe, essentially depends the power of music to picture emotion. (Helmholtz, 1985, p. 370)

By virtue of imitation (*emotional contagion* and *visual imagery* in Juslin & Västfjäll, 2008), musical structures can denote or refer to external entities of two kinds: first, physical objects and events; second, subjective states such as emotions via their behavioral effects. The former include overt references to birdsong, thunderstorms, and the like, although this form of referential semantics is severely limited in scope to phenomena clearly identified by some auditory pattern (there is no musical structure which could unambiguously denote a castle, for example). For similar reasons, it is difficult for a musical structure to unambiguously denote an emotional state (although see the section on expectations below). However, by virtue of its temporal and spatial structure (pitch is often expressed and understood in spatial terms), a piece of music can exhibit characteristics that refer, more or less unambiguously, to behavioral expressions of emotion. Perhaps the best-known advocate of this approach is Kivy (1989), who argues that instrumental music can be *expressive of* specific emotions by imitating aspects of emotional speech, gesture, facial expression, gait, and so on. Thus, a slow, ponderous piece of music can be expressive of sadness, while a fast piece with high, ascending melodic contours can be expressive of lighter emotions. Other authors such as Davies (1994) and Langer (1953), also propose imitation theories of musical expression.

Clarke (2005) discusses apparent motion resulting from changes in musical structure from the perspective of Gibsonian affordances (Gibson, 1979), and several neuroimaging studies have reported activation of brain structures controlling movements or imagining actions while listening to music, especially when it is pleasurable (Alluri et al., 2012; Koelsch et al., 2006; Pereira et al., 2011). Strikingly, Koelsch, Kasper, Sammler, Schulze, Gunter, and Friederici (2004) report a semantic priming task with target words presented visually after spoken sentences or a musical excerpt, which showed comparable late negative electrophysiological responses (N400) to target words following semantically unrelated linguistic or musical contexts, demonstrating that music may imitate some qualities of objects (e.g., ascending pitch scales for staircases), contain gestural cues (e.g., a cry) or describe a concept (such as hero for a symphony by Beethoven). These findings have been replicated for single chords varying in pleasantness (Steinbeis & Koelsch, 2008) and for single sounds varying in timbre (Grieser-Painter & Koelsch, 2010).

A formalist such as Hanslick would question the specificity with which these imitative characteristics of music can reliably and exclusively express particular well-defined emotional states and Kivy himself no longer defends this particular theory of how music acquires its expressive properties (Kivy, 2002). Acknowledging that not all examples of musical expression can be explained by imitation, Kivy (1989) proposes a second mechanism based on convention. Thus, in Western tonal music the association of the minor mode with negative valence, and the activation in brain structures classically associated with negative visual emotions such as the amygdala, thalamus and brain stem (Brattico et al., 2011; Green et al., 2008; Pallesen et al., 2005), may derive from the conventional association of this mode with, for example, sad lyrics, slow tempi, and so on.

Expectation

Hanslick (1954), Helmholtz (1985), and Meyer (1956) have argued that musical enjoyment is linked with patterns of tension and resolution resulting from the confirmation and violation of perceptual expectations of which we are usually unconscious. These expectations might concern, for example, the pitch of the next note in a melody, the next chord in a pattern of harmonic movement, or the timing of the next note in a solo percussion performance. In each case, the preceding context of the music sets up expectations (or predictions) in the mind of the listener for what is to happen next.

Recent research suggests that expectations in music are acquired through a process of statistical learning in which listeners construct implicit probabilistic models of the next element in a musical sequence given the preceding context both at psychological (Huron, 2006; Meyer, 1957; Oram & Cuddy, 1995; Pearce & Wiggins, 2006; Tillmann, Bharucha, & Bigand, 2000) and neural levels (Loui, Wu, Wessel, & Knight, 2009; Kim, Kim, & Chung, 2011; Pearce, Ruiz, Kapasi, Wiggins, & Bhattacharya, 2010). Electrophysiological research has identified characteristic neural responses to violations of harmonic expectation, including an early right anterior negativity (ERAN) peaking at around 180-ms post-stimulus (Koelsch, Kilches, Steinbeis, & Schelinski, 2008; Steinbeis et al., 2006). The amplitude of this component is related to the long-term transition probability of the chord (Kim et al., 2011; Loui et al., 2009). In an electroencephalography (EEG) study of listeners to hymn melodies, Pearce et al. (2010) examined oscillatory and phase responses to high and low probability notes predicted by a complex variable-order probabilistic model of pitch expectation. Violations of expectation increased phase synchrony across a wide network of sensor locations and generated characteristic patterns of beta-band activation in the superior parietal lobule, previously associated with tasks involving auditory-motor interaction, suggesting that violations of expectation may stimulate networks linking perception with action.

Huron (2006) proposes a framework for linking expectations based on statistical learning to aesthetic responses. He distinguishes three responses to an event: first, a *prediction response* evaluating whether the event conforms to prior expectations; second, a *reaction response*, a fast, automatic, subcortical affective reaction; and third, an *appraisal response*, a more leisurely, cortically mediated process of consideration and assessment. Positive emotions resulting (via the prediction response) from anticipatory success are misattributed to the stimulus itself, leading to a preference for predictable events while the stress resulting from surprising events, as an indicator of maladaptive anticipatory failure, activates fast fight, flight, or freeze responses and provides negative feedback for the learning processes that generated the prediction. How is it then that surprise can be enjoyable even though it is associated with negative emotion resulting from the failure to correctly anticipate the future event? According to Huron (2006), an event that is unexpected but ultimately innocuous induces a negative prediction response that increases, via a process of *contrastive valence,* the relatively positive limbic effect of the subsequent reaction or appraisal responses.

There is some empirical evidence to support the theory that the confirmation/violation of expectations is capable of leading to aesthetic experiences. In behavioral studies, probabilistic measures of stimulus predictability produce inverted U-shaped profiles of subjective pleasantness and beauty in simple tone sequences (Vitz, 1966; Crozier, 1974) and predict the historical popularity of musical works (Simonton, 1980, 1987). Turning to the bodily effects of expectations, empirical research has shown that unexpected chords produce greater physiological arousal as indexed by skin conductance, than expected chords (Koelsch, Kilches, et al., 2008; Steinbeis et al., 2006).

Violations of expectation may also be related to the chill response, discussed above, because it tends to be associated with unexpected harmonies, sudden dynamic or textural changes, or other new elements introduced in the music (Grewe, Nagel, Kopiez, & Altenmuller, 2007; Sloboda, 1991). Familiarity is also a significant influence on chills (Grewe et al., 2009) such that people are less likely to experience chills to unfamiliar music (see below for more on the effects of familiarity on aesthetic experience). This raises a criticism that is often leveled at Meyer's theory: if emotion and meaning are conveyed by expectation, how is it possible for one to enjoy a familiar (i.e., expected) piece of music (Budd, 1985)? From a psychological perspective, there appears to be a difference between *veridical* expectations based on explicit knowledge of a work, and *schematic* expectations based on years of implicit learning through exposure (Bharucha, 1987). It appears to be impossible for us to "switch off" our schematic expectations even when we know consciously what is about to happen (just as we are unable to consciously influence our perception of certain visual illusions even when we know them to be illusions).

Huron (2006) suggests that contrastive valence may also be capable of generating pleasurable experiences of awe and laughter as well as chills although these claims await detailed neuroscientific study.

Aesthetic Judgments

It is possible to have an aesthetic experience without making an aesthetic decision or judgment about the stimulus causing that experience. When we do make an aesthetic judgment (consciously or unconsciously), such as when we decide that an object is beautiful, research in visual neuroaesthetics suggests that areas in the prefrontal regions of the brain, and specifically the dorsolateral prefrontal and orbitofrontal cortex, are activated (Nadal, Munar, Capo, Rossello, & Cela-Conde, 2008). Ventromedial prefrontal cortex is thought to be crucial for judgmental processes based on affective valence of stimuli such as in aesthetic context (Damasio, 1996; Kringelbach, 2005). Activation in orbitofrontal cortex has been found in tasks involving judging the beauty of paintings (Kawabata & Zeki, 2004), black-white abstract shapes (Jacobsen et al., 2006), and faces (Aharon et al., 2001).

Several neuroimaging studies of musical listening confirm the role of the orbitofrontal cortex in positive affective experiences associated with aesthetic judgments of preference or beauty for music (Alluri et al., 2012; Blood & Zatorre, 2001; Blood et al., 1999; Brattico et al., 2011; Pereira et al., 2011). For example, judging the beauty of a rhythmic sequence activated the ventromedial prefrontal cortex when contrasted with judging the tempo of the sequence (Kornysheva et al., 2010). In a recent fMRI study (Ishizu & Zeki, 2011), a finer localization of the area involved in beauty judgments of both musical pieces and paintings was obtained: activation in a very small region of the medial OFC, the A1 field, correlated with the intensity of beauty experienced. Expertise also modulates beauty judgments of music: Müller et al. (2010) found enhanced emotion-related neural processing for beauty judgments compared with cognitive judgments in nonmusicians but not in musicians, suggesting the latter make less use of emotion and rely on other strategies in making aesthetic judgments.

The dorsomedial midbrain nuclei, belonging to the dopaminergic reward circuit of the brain, are also activated by consonant chords judged as beautiful, irrespective of their major or minor keys, when contrasted with dissonant chords judged as ugly (Suzuki et al., 2008). In addition, Kornysheva et al. (2010) report the activation of ventral premotor cortex and cerebellum to rhythmic patterns judged as beautiful contrasted with those judged as nonbeautiful. The involvement of these motor regions in beauty judgments of music may reflect the powerful ability of beautiful music to entrain behavioral responses such as song and dance (see Calvo-Merino and Christensen, this issue, pp. 76–88).

Preference

Another important outcome of the musical aesthetic experience is preference, which differs from enjoyment or subjective pleasure (with which it is often identified) in that it includes making a decision about the stimulus as a whole. Such a decision typically occurs after listening to an entire piece of music and may endure long after the listening episode. This decision may be based on the intensity of enjoyment, on an aesthetic judgment related to beauty or other formal properties of the stimulus (but it can also be divergent and independent from such judgment), and on other intrapersonal factors related to the listening history of an individual or her current mood or personality. Schubert (2007) demonstrated that induction of any emotion (negative or positive) by music predicts preference: the more we are moved by music, the more we like it. Another predictor of preference is the gap between the emotion expressed by the music (external locus) and emotion felt by the listener (internal locus): when we listen to a sad piece of music we may recognize the sad expression but not feel sad ourselves (a large gap) but preference tends to be higher when the gap between emotional loci is minimal (Schubert, 2007). Finally, Vuoskoski and Eerola (2011) observed that individuals characterized by high trait empathy tend to show higher preference and feel sadder than less highly empathetic individuals when listening to sad music.

There is evidence that musical preference activates lateralized brain networks. A pioneering electroencephalography study by Altenmüller, Schurmann, Lim, and Parlitz (2002) identified left-lateralized frontotemporal responses when listeners preferred classical, pop or jazz excerpts lasting 15 s, and right-lateralized anterior responses when they disliked them (neutral music generated bilateral brain responses). In a subsequent EEG and fMRI study (Flores-Gutierrez et al., 2007), preferred 30-s excerpts by Bach and Mahler similarly activated left-hemispheric regions, including Heschl's gyrus, middle temporal gyrus and cuneus, whereas disliked excerpts by a contemporary composer generated brain responses in the bilateral inferior frontal gyrus and insula. An electrophysiological study with isochronous chord cadences (Brattico, Jacobsen, De Baene, Glerean, & Tervaniemi, 2010) revealed a distinction between neural mechanisms for liking judgments and judgments of correctness, reflected by a late positive potential, peaking at around 1100 ms after the decisive sound. A subsequent EEG study (Istók et al., 2012) applied to real commercial pop/rock music showed that the late positive potential was also elicited by preferred music but only when subjects were doing a genre-classification task and not during the liking task, probably because the affective brain response in the liking task was not time-locked to the stimulus.

Although these studies have made important initial advances, further neuroscientific research is urgently required on the neural basis of musical preferences and the factors that determine them (Schubert, 2010).

Modulatory Influences on Aesthetic Experience

We have argued that an aesthetic experience of music involves an emotional experience, a judgment of beauty (or other formal qualities) and a verdict of liking or preference. To these, we add familiarity with the stimulus and attention as psychological mechanisms modulating the affective and cognitive responses to music in an aesthetic situation.

Familiarity

It has been proposed that the hedonic influence of subjective predictability (or complexity) can account for both the *mere exposure effect* (Zajonc, 1968), where enjoyment and related liking judgments increase with increasing exposure, and the *boredom effec*t (Cantor, 1968), where enjoyment and liking decrease with increasing exposure. With greater exposure, increasing familiarity ought to reduce perceived predictability with concomitant U-shaped effects on hedonic value (Crozier, 1974; Vitz, 1966). Heyduk (1975), for example, obtained subjective ratings of complexity and liking for four piano compositions finding an inverted-U function relating the two. In a subsequent experiment in which one of the pieces was repeated 16 times, decreases in liking with repeated presentation were more common among those individuals for whom the complexity of the composition exceeded their preferred level (as ascertained in the first study), while increases or inverted-U functions of liking were more likely in those for whom the stimulus complexity was lower than their preferred level. North and Hargreaves (1997), however, report a positive linear relationship between liking and familiarity for pop music excerpts. In explaining this result, they suggest that inverted U-shaped functions should not be found when individuals have control over their exposure to a stimulus, when only the positive monotonic portion of the inverted U-shaped function should be observed.

A recent fMRI study demonstrated the close connection between familiarity and hedonic musical experiences; Pereira et al. (2011) report activation of limbic and paralimbic areas including the nucleus accumbens to familiar music (contrasted with unfamiliar music), but only minimal activation when contrasting liked musical pieces with disliked ones, regardless of familiarity. These findings suggest that familiarity is one of the strongest influences on emotional and hedonic responses in the brain. Familiarity with music affects neural responses even at the level of the brainstem and auditory cortex. For instance, individuals with formal musical education show more accurate neural processing of chords that are atypical in Western tonal music, whereas discrimination in the auditory cortex of prototypical minor chords is comparable between musicians and nonmusicians (Brattico et al., 2009). Reber, Wurtz, and Zimmermann (2004) argued that the valence of aesthetic response is determined by the ease and speed with which a stimulus can be processed: the more fluent the processing, the more pleasant the experience. Given this, we might predict that if musical training improves auditory processing ability, musicians would show a preference for more complex musical styles (e.g., atonal music; cf. Brattico et al., 2009). Professional classical musicians also possess reinforced expectations for sounds following Western tonal rules, showing larger inferior frontal brain response (the ERAN discussed above) to unexpected chords in a sequence, compared with nonmusicians (Koelsch, Schmidt, & Kansok, 2002; although for discrepant findings with folk musicians, see Brattico et al., under revision). Children 5 and 6 years of age show similar reactions to unexpected chords, indicating that a few years of passive exposure to Western tonal music are sufficient to form a neural representation of harmonic syntax, although not as clearly or accurately as in older adults or in musicians (Koelsch, Fritz, Schulze, Alsop, & Schlaug, 2005). It remains to be seen whether these effects of stylistic familiarity, and ease of processing, impact on the aesthetic experience of music.

Functional neuroimaging studies have further investigated the neural structures involved in long-term memory for a particular piece. In a PET study, Satoh, Takeda, Nagata, Shimosegawa, and Kuzuhara (2006) found that familiarity judgments of piano melodies generated activation in the anterior portion of bilateral temporal lobes, posterior portion of superior temporal gyri, anterior and posterior portion of the medial frontal lobes, the bilateral cingulate gyri, the left inferior frontal gyrus, and the left superior temporal gyrus. In an fMRI study, Peretz et al. (2009) found that familiar melodies activated the bilateral superior temporal sulcus more than identical reversed melodies. Plailly, Tillmann, and Royet (2007) compared responses with familiar classical music excerpts and odors, finding activation for familiar over unfamiliar music in several left-hemisphere regions, including superior and medial frontal gyri, precentral gyrus, and superior temporal sulcus, posterior cingulate gyrus, and supramarginal gyrus. Multimodal areas activated by both familiar music and odors included superior and inferior frontal gyri, angular gyrus, precuneus and parahippocampal gyrus, suggesting that these areas are involved in neural circuits underlying the experience of familiarity during an aesthetic or hedonic experience regardless of sensory modality.

Attention

Attention is central to a musical aesthetic experience because the listener must concentrate on the music in order to appreciate the emotions and memories induced by it, judge whether it is beautiful or well performed, and decide on its aesthetic value. Several neuroimaging studies of musical listening have reported the involvement of the superior parietal lobule, the precuneus, and other parietal structures related to the ventral network for stimulusdriven attention (e.g., Fan, McCandliss, Fossella, Flombaum, & Posner, 2005), and to the default-mode network, constantly monitoring and integrating the external environment (Raichle & Snyder, 2007). In addition, while neural processes related to the extraction of sound features, their integration into auditory objects (e.g., the pitch categories of the chromatic scale) and their maintenance in sensory memory are fast and automatic (Brattico, Tervaniemi, Naatanen, & Peretz, 2006), analyzing the conformity of a chord sequence to the rules of Western tonal harmony, an important part of aesthetic appreciation, requires the allocation of attentional resources (Loui, Grent-'t-Jong, Torpey, & Woldorff, 2005; Maidhof & Koelsch, 2011). Neuroimaging studies confirming the role of attention in a musical aesthetic experience remain to be conducted, but research in the visual domain on the importance of contemplation (Höfel et al., 2007) suggests a similar role for attentive processing in the auditory modality.

Reprise: Establishing a Neuroaesthetics of Music

We have proposed a framework for developing a neuroaesthetics of music in which music is viewed as an expressive art rather than as a cognitive domain sharing properties with language, as is often the case in the neurosciences of music. This interdisciplinary approach emphasizes the interplay between perceptual, affective and cognitive processes that generate aesthetic responses, including emotions, judgments and preference. Our approach is broadly compatible with the model of Leder et al., (2004) proposed for understanding aesthetic experiences of visual art and further developed for musical aesthetic experience by Brattico et al. (submitted). Regarding perceptual analysis, we have reviewed research on several properties of music, which are thought to be involved in aesthetic experience of music (including the effects of sensory dissonance, imitation and expectation) and how these generate emotional states. The induction of emotion by music can lead to states of variable enjoyment but these are not sufficient for an aesthetic experience per se, which typically also requires an appreciation of the properties of the music that determine the experience, an aesthetic judgment of how beautiful it is and a decision about how much we like it. The state of the listener and the listening context combine with the music to determine these judgments. Regarding implicit memory integration of these features, we have reviewed research suggesting that processing of these features is modulated by attention, familiarity and expertise. The field remains in its infancy, taking its first steps toward legitimate scientific status. As a way of assessing its current state, we recall the five tests of a healthy research paradigm suggested by Sloboda (1986, p. 199).

First, an established paradigm must have "an agreed set of central problems." Sloboda (1986) himself identifies two central questions in music psychology: What is the nature of musical knowledge or representation? And how does music have emotional and aesthetic effects? Assuming a neuroscientifc approach to music, we can view the second of these questions as the proper topic for the neuroaesthetics of music, the first being appropriate for the cognitive neuroscience of music. For more detailed questions, we propose that the set of problems distinguishing the neuroaesthetics of music from other areas of study can come from the field of neuroaesthetics, established in the late 90s by Zeki (1999) and whose research agenda is steadily maturing (e.g., Chatterjee, 2011; Livingstone & Hubel, 2002; Nadal & Pearce, 2011). The central questions of neuroaesthetics are to understand how and why (in an evolutionary sense) the human brain enables the capacity for appreciating and creating artifacts that are experienced as aesthetic. A neuroaesthetics of music would address a strong bias in the current literature on neuroaesthetics toward visual art to the virtual exclusion of other sensory modalities. In defining and delimiting the central questions of a neuroaesthetics of music, it will be profitable to examine the philosophical literature of musical aesthetics (e.g., Carroll et al., 2011; Robinson, 2005) and research in empirical aesthetics (e.g., Berlyne, 1971; Wundt, 1874).

The second condition for a healthy paradigm is, according to Sloboda, "agreed methods for working on these problems," which, in the case of neuroaesthetics of music, are largely borrowed from neighboring disciplines, and particularly cognitive neuroscience and experimental psychology. One factor that distinguishes the field, however, is a concerted effort to focus on real-world musical examples in real-world settings so as to reliably induce aesthetic experiences. In a methodological attempt to simulate an ecologically valid situation, for example, Alluri et al. (2012) implemented a nonconventional analysis of the continuous fMRI signal correlated with the acoustic features extracted from an 8-min piece of music (*Adios Nonino* by A. Piazzolla). In this way, they were able to identify large-scale brain networks involved in processing of timbral, tonal, and rhythmic features during online musical listening.

The third condition proposed by Sloboda is "agreed theoretical frameworks in which to discuss [the research problems]". We acknowledge that this is work in progress but we have aimed here and elsewhere (Brattico et al., submitted) to propose a theoretical framework for establishing a context within which future empirical results and theoretical observations within the neuroaesthetics of music may be assessed.

The fourth condition for a healthy research paradigm requires "techniques and theories which are specific to the paradigm." We have argued above that although it inherits from music psychology, the neuroaesthetics of music is distinguished from the cognitive neurosciences of music by a focus on emotion and aesthetics rather than cognitive representation and processing. Furthermore, although it inherits from neuroaesthetics, the neuroaesthetics of music is distinguished from the neuroaesthetics of art by its subject which is a complex multidimensional, auditory signal extended in time and processed in distinct neural pathways from visual stimuli. These distinctions call, to take one example, for a specific focus in a neuroaesthetic of music on the role of time: a piece of music cannot be viewed as a static entity but rather one that unfolds in time, generating and manipulating expectations and interpretations in order to induce an aesthetic experience.

Finally, Sloboda calls for "research which is appropriate to the whole range of phenomena in the domain being studied." As a field in its infancy, it is clear that the neuroaesthetics of music can only develop with further empirical research, which will, in turn, further clarify its status as an independent field of research and its relationships with neighboring disciplines. As a stimulus to this process of maturation, we suggest that one of the most pressing issues is to identify those topics and questions from the traditional and empirical aesthetics of music (taking a broad view of these disciplines), which can benefit from a neuroscientific approach, as well as to formulate new questions and hypotheses that could not have been developed within existing traditional frameworks. With this in mind, we propose the following central questions for the field. Which neural regions and mechanisms are involved in the experience of aesthetic emotions to music? To what extent are they distinct from the neural mechanisms of basic emotions? What is the neural basis of imitative processes in music perception? Is there a cross-modal component to these processes and how is this reflected in neural processing? Is attentive contemplation during listening necessary to induce an aesthetic emotion? Can an understanding of underlying neural processes help to clarify how unexpected musical events can produce the pleasurable experiences of chills, awe and laughter? What are the relationships, at the cognitive and neural levels, between judgments of liking, beauty, preference and sensory pleasure: are they synonymous, functionally related, or completely independent? At what stage of infancy do aesthetic emotions, preference, and aesthetic judgments appear in the maturing brain and what are their developmental trajectories? Is motor-cortex recruitment a precondition for a hedonic experience of music? Can the effects of the listening context and aesthetic attitude be identified at the level of neural processing?

We know from psychological research (e.g., Hargreaves & North, 2010) that aesthetic experience depends on the listener (e.g., expertise, internal state, mood, personality, attitude) and listening situation (e.g., social context, concurrent tasks) as well as the music (e.g., sensory dissonance, timbre, congruency with formal rules) but much work remains to be done on the underlying neuroscience of how these influences combine to generate an aesthetic experience. Perhaps most crucially, we feel it is fundamentally important for researchers in neuroaesthetics to try to replicate all facets of the aesthetic experience so as to encourage a genuine aesthetic judgment based both on a fully immersed emotional experience and a focused analysis of the formal properties of a musical work. In doing so, the neuroaesthetics of music can develop an understanding that will have significant practical implications. Music is widely used to induce emotions and regulate mood (Thayer, Newman, & McClain, 1994; Särkämö et al., 2008), and music therapy is increasingly being investigated for treatment of affective and psychiatric disorders (Erkkila et al., 2008; Erkkila et al., 2011): a deeper knowledge of the neural mechanisms involved in the aesthetic experience of music will help put these clinical developments on a sound scientific footing.

References

Aharon, I., Etcoff, N., Ariely, D., Chabris, C. F., O'Connor, E., & Breiter, H. C. (2001). Beautiful faces have variable reward value: FMRI and behavioral evidence. *Neuron, 32,* 537–551. doi:10.1016/S0896-6273(01)00491-3

Alluri, V., Toiviainen, P., Jääskeläinen, I. P., Glerean, E., Sams, M., & Brattico, E. (2012). Large-scale brain networks emerge from dynamic processing of musical timbre, key and rhythm. *NeuroImage, 59,* 3677–3689. doi:10.1016/j.neuroimage.2011.11.019

Altenmüller, E., Schurmann, K., Lim, V. K., & Parlitz, D. (2002). Hits to the left, flops to the right: Different emotions during listening to music are reflected in cortical lateralisation patterns. *Neuropsychologia, 40,* 2242–2256. doi:10.1016/S0028-3932(02)00107-0

Berlyne, D. E. (1971). *Aesthetics and psychobiology.* New York, NY: Appleton-Century-Crofts.

Bharucha, J. J. (1987). Music cognition and perceptual facilitation: A connectionist framework. *Music Perception, 5,* 1–30. doi:10.2307/40285384

Blood, A. J., & Zatorre, R. J. (2001). Intensely pleasurable responses to music correlate with activity in brain regions implicated in reward and emotion. *Proceedings of the National Academy of Sciences, 98,* 11818–11823. doi:10.1073/pnas.191355898

Blood, A. J., Zatorre, R. J., Bermudez, P., & Evans, A. C. (1999). Emotional responses to pleasant and unpleasant music correlate with activity in paralimbic brain regions. *Nature Neuroscience, 2,* 382–387. doi:10.1038/7299

Blum, K., Chen, T. J., Chen, A. L., Madigan, M., Downs, B. W., Waite, R. L., . . . Gold, M. S. (2010). Do dopaminergic gene polymorphisms affect mesolimbic reward activation of music listening response? Therapeutic impact on Reward Deficiency Syndrome (RDS). *Medical Hypotheses, 74,* 513–520. doi:10.1016/j.mehy.2009.10.008

Brattico, E. (2010). It's sad but I like it: An fMRI study on the aesthetic dissociation between preference and basic emotions in music. *Abstracts of HBM10, 16th Annual Meeting of the Organization for Human Brain Mapping, Barcelona, June 6–10, 2010.*

Brattico, E., Alluri, V., Bogert, B., Jacobsen, T., Vartiainen, N., Nieminen, S., . . . Tervaniemi, M. (2011). A functional MRI study of happy and sad emotions in music with and without lyrics. *Frontiers in Psychology, 2,* 308. doi: 10.3389/fpsyg.2011.00308

Brattico, E., Brattico, P., & Jacobsen, T. (2009–2010). The origins of the aesthetic enjoyment of music - A review of the literature. *Musicae Scientiae, Special issue* 2009–2010, 15–31. doi:10.1177/1029864909013002031

Brattico, E., Bogert, B., & Jacobsen, T. (in press). Towards a neural chronometry for the aesthetic experience of music. *Frontiers in Psychology.*

Brattico, E., Jacobsen, T., De Baene, W., Glerean, E., & Tervaniemi, M. (2010). Cognitive vs. affective listening modes and judgments of music: An ERP study. *Biological Psychology, 85,* 393–409. doi:10.1016/j.biopsycho.2010.08.014

Brattico, E., Näätänen, R., Verma, T., Välimäki, V., & Tervaniemi, M. (2000, August). *Processing of musical intervals in the central auditory system: An event-related potential (ERP) study on sensory consonance.* Paper presented at the Sixth International Conference on Music Perception and Cognition, Keele, United Kingdom.

Brattico, E., Pallesen, K. J., Varyagina, O., Bailey, C., Anourova, I., Jarvenpaa, M., . . . Tervaniemi, M. (2009). Neural discrimination of nonprototypical chords in music experts and laymen: An MEG study. *Journal of Cognitive Neuroscience, 21,* 2230–2244. doi:10.1162/jocn.2008.21144

Brattico, E., Tervaniemi, M., Naatanen, R., & Peretz, I. (2006). Musical scale properties are automatically processed in the human auditory cortex. *Brain Research, 1117,* 162–174. doi:10.1016/j.brainres.2006.08.023

Braun, M. (1999). Auditory midbrain laminar structure appears adapted to f0 extraction: Further evidence and implications of the double critical bandwidth. *Hearing Research, 129,* 71–82. doi:10.1016/S0378-5955(98)00223-8

Budd, M. (1985). *Music and the emotions: The philosophical theories.* London, United Kingdom: Routledge and Kegan Paul.

Cantor, G. N. (1968). Children's "like-dislike" ratings of familiarized and unfamiliarized visual stimuli. *Journal of Experimental Child Psychology, 6,* 651–657. doi:10.1016/0022-0965(68)90109-4

Carroll, N., Moore, M., & Seeley, W. P. (2011). The philosophy of art and aesthetics, psychology, and neuroscience: Studies in literature, music, and visual arts. In A. P. Shimamura & S. E. Palmer (Eds.), *Aesthetic science: Connecting minds, brains, and experience* (pp. 31–62). New York, NY: Oxford University Press. doi:10.1093/acprof:oso/9780199732142.003.0019

Chatterjee, A. (2011). Neuroaesthetics: A coming of age story. *Journal of Cognitive Neuroscience, 23,* 53–62. doi:10.1162/jocn.2010.21457

Christensen, J. F., & Calvo-Merino, B. (2013). Dance as a subject for empirical aesthetics. *Psychology of Aesthetics, Creativity, and the Arts, 7,* 76–88. doi:10.1037/a0031827

Clarke, E. (2005). *Ways of listening: An ecological approach to the perception of musical meaning*. New York, NY: Oxford University Press.

Cross, I. (2003). Music, cognition, culture, and evolution. In I. Peretz & R. J. Zatorre (Eds.), *The cognitive neuroscience of music* (pp. 42–56). Oxford, United Kingdom: Oxford University Press. doi:10.1093/acprof:oso/9780198525202.003.0004

Crozier, J. B. (1974). Verbal and exploratory responses to sound sequences varying in uncertainty level. In D. E. Berlyne (Ed.), *Studies in the new experimental aesthetics: Steps toward an objective psychology of aesthetic appreciation* (pp. 27–90). Washington, DC: Hemisphere.

Damasio, A. R. (1996). The somatic marker hypothesis and the possible functions of the prefrontal cortex. *Philosophical Transactions of the Royal Society of London*. Series B: Biological Sciences, *351*(1346), 1413–1420. doi:10.1098/rstb.1996.0125

Davies, S. (1994). *Musical meaning and expression*. Ithaca, NY: Cornell University Press.

Eerola, T., & Vuoskoski, J. K. (2011). A comparison of the discrete and dimensional models of emotion in music. *Psychology of Music, 39,* 18–49. doi:10.1177/0305735610362821

Ekman, P. (1999). Basic emotions. In T. Dalgleish & M. Power (Eds.), *Handbook of cognition and emotion* (pp. 45–60). Sussex, United Kingdom: John Wiley & Sons, Ltd.

Erkkila, J., Gold, C., Fachner, J., Ala-Ruona, E., Punkanen, M., & Vanhala, M. (2008). The effect of improvisational music therapy on the treatment of depression: Protocol for a randomised controlled trial. *BMC Psychiatry, 8,* 50. doi: 10.1186/1471-244X-8-50

Erkkila, J., Punkanen, M., Fachner, J., Ala-Ruona, E., Pontio, I., Tervaniemi, M., . . . Gold, C. (2011). Individual music therapy for depression: Randomised controlled trial. *The British Journal of Psychiatry, 199,* 132–139.

Fan, J., McCandliss, B. D., Fossella, J., Flombaum, J. I., & Posner, M. I. (2005). The activation of attentional networks. *NeuroImage, 26,* 471–479. doi:10.1016/j.neuroimage.2005.02.004

Fishman, Y. I., Volkov, I. O., Noh, M. D., Garell, P. C., Bakken, H., Arezzo, J. C., . . . Steinschneider, M. (2001). Consonance and dissonance of musical chords: Neural correlates in auditory cortex of monkeys and humans. *Journal of Neurophysiology, 86,* 2761–2788.

Flores-Gutierrez, E. O., Diaz, J. L., Barrios, F. A., Favila-Humara, R., Guevara, M. A., del Rio-Portilla, Y., . . . Del Flores-Gutiérrez, E. O. (2007). Metabolic and electric brain patterns during pleasant and unpleasant emotions induced by music masterpieces. *International Journal of Psychophysiology, 65,* 69–84. doi:10.1016/j.ijpsycho.2007.03.004

Fusar-Poli, P., Placentino, A., Carletti, F., Landi, P., Allen, P., Surguladze, S., . . . Politi, P. (2009). Functional atlas of emotional faces processing: A voxel-based meta-analysis of 105 functional magnetic resonance imaging studies. *Journal of Psychiatry and Neuroscience, 34,* 418–432.

Gabrielsson, A. (2010). Strong experiences with music. In P. N. Juslin & J. A. Sloboda (Eds.), *Handbook of music and emotion: Theory, research, applications* (pp. 547–574). New York, NY: Oxford University Press.

Gibson, J. J. (1979). *The ecological approach to visual perception*. Boston, MA: Houghton Mifflin.

Goldstein, A. (1980). Thrills in response to music and other stimuli. *Physiological Psychology, 8,* 126–129.

Gosselin, N., Peretz, I., Johnsen, E., & Adolphs, R. (2007). Amygdala damage impairs emotion recognition from music. *Neuropsychologia, 45,* 236–244. doi:10.1016/j.neuropsychologia.2006.07.012

Gosselin, N., Peretz, I., Noulhiane, M., Hasboun, D., Beckett, C., Baulac, M., & Samson, S. (2005). Impaired recognition of scary music following unilateral temporal lobe excision. *Brain, 128,* 628–640. doi:10.1093/brain/awh420

Gosselin, N., Samson, S., Adolphs, R., Noulhiane, M., Roy, M., Hasboun, D., . . . Peretz, I. (2006). Emotional responses to unpleasant music correlates with damage to the parahippocampal cortex. *Brain, 129,* 2585–2592. doi:10.1093/brain/awl240

Green, A. C., Baerentsen, K. B., Stodkilde-Jorgensen, H., Wallentin, M., Roepstorff, A., & Vuust, P. (2008). Music in minor activates limbic structures: A relationship with dissonance? *NeuroReport, 19,* 711–715. doi:10.1097/WNR.0b013e3282fd0dd8

Grewe, O., Kopiez, R., & Altenmueller, E. (2009). The chill parameter: Goose bumps and shivers as promising measures in emotion research. *Music Perception, 27,* 61–74. doi:10.1525/mp.2009.27.1.61

Grewe, O., Nagel, F., Kopiez, R., & Altenmuller, E. (2007). Emotions over time: Synchronicity and development of subjective, physiological, and facial affective reactions to music. *Emotion, 7,* 774–788. doi:10.1037/1528-3542.7.4.774

Grieser-Painter, J. G., & Koelsch, S. (2010). Can out-of-context musical sounds convey meaning? An ERP study on the processing of meaning in music. *Psychophysiology, 48,* 645–655. doi:10.1111/j.1469-8986.2010.01134.x

Haber, S. N. (2009). Anatomy and connectivity of the reward circuit. In J.-C. Dreher & L. Tremblay (Eds.), *Handbook of reward and decision making* (pp. 3–25). New York, NY: Academic Press. doi:10.1016/B978-0-12-374620-7.00001-7

Hanslick, E. (1954). *On the musically beautiful* [English translation from the 8th ed. 1891]. Indianapolis, IN: Hackett Publishing Company.

Hargreaves, D. J., & North, A. C. (2010). Experimental aesthetics and liking for music. In P. N. Juslin & J. A. Sloboda (Eds.), *Handbook of music and emotion* (pp. 513–546). New York, NY: Oxford University Press.

Helmholtz, H. L. F. v. (1985). *On the sensations of tone as a physiological basis for the theory of music* (A. J. Ellis, Trans.). [English translation from the 4th ed. 1877]. New York, NY: Dover Publications.

Heyduk, R. G. (1975). Rated preference for musical compositions as it relates to complexity and exposure frequency. *Perception and Psychophysics, 17,* 84–91. doi:10.3758/BF03204003

Höfel, L., & Jacobsen, T. (2007). Electrophysiological indices of processing aesthetics: Spontaneous or intentional processes? *International Journal of Psychophysiology, 65,* 20–31. doi:10.1016/j.ijpsycho.2007.02.007

Hunter, P. G., Schellenberg, G., & Schimmack, U. (2008). Mixed affective responses to music with conflicting cues. *Cognition & Emotion, 22,* 327–352.

Huron, D. (2003). Is music an evolutionary adaptation? In I. Peretz & R. Zatorre (Eds.), *The cognitive neuroscience of music* (pp. 57–75). New York, NY: Oxford University Press. doi:10.1093/acprof:oso/9780198525202.003.0005

Huron, D. (2006). *Sweet anticipation: Music and the psychology of expectation*. Cambridge, MA: MIT Press.

Huron, D. (2010). Aesthetics. In S. Hallam, I. Cross, & M. Thaut (Eds.), *Oxford Handbook of Music Psychology* (pp. 151–162). New York, NY: Oxford University Press.

Ilie, G., & Thompson, W. (2006). A comparison of acoustic cues in music and speech for three dimensions of affect. *Music Perception, 23,* 319–329. doi:10.1525/mp.2006.23.4.319

Ishizu, I., & Zeki, S. (2011). Toward a brain-based theory of beauty. *PloS ONE, 6,* e21852. doi:10.1371/journal.pone.0021852

Istok, E., Brattico, E., Jacobsen, T., Krohn, K., Mueller, M., & Tervaniemi, M. (2009). Aesthetic responses to music: A questionnaire study. *Musicae Scientiae, 13,* 183–206. doi:10.1177/102986490901300201

Istók, E., Brattico, E., Jacobsen, T., Ritter, A., & Tervaniemi, M. (2012). 'I love Rock 'n' Roll' - Music genre preference modulates brain responses to music. *Biological Psychology, 92,* 142–151.

Jacobsen, T. (2004). The primacy of beauty in judging the aesthetics of objects. *Psychological Reports, 94,* 1253–1260.

Jacobsen, T. (2009). On the psychophysiology of aesthetics: Automatic and controlled processes of aesthetic appreciation. In I. Czigler & I. Winkler (Eds.), *Unconscious memory representations in perception, processes and mechanisms in the brain* (pp. 245–257). Amsterdam, the Netherlands: John Benjamins Publishing Company.

Jacobsen, T., Schubotz, R. I., Hofel, L., & Cramon, D. Y. (2006). Brain correlates of aesthetic judgment of beauty. *NeuroImage, 29,* 276–285. doi:10.1016/j.neuroimage.2005.07.010

Janata, P. (2009). The neural architecture of music-evoked autobiographical memories. *Cerebral Cortex, 19,* 2579–2594. doi:10.1093/cercor/bhp008

Juslin, P. N., & Laukka, P. (2004). Expression, perception, and induction of musical emotions: A review and a questionnaire study of everyday listening. *Journal of New Music Research, 33,* 217–238. doi:10.1080/0929821042000317813

Juslin, P. N., Liljeström, S., Västfjäll, D., & Lundqvist, L.-O. (2010). How does music evoke emotions? Exploring the underlying mechanisms In *Handbook of music and emotion: Theory, research, applications* (pp. 605–642). New York, NY: Oxford University Press. doi:10.1093/acprof:oso/9780199230143.003.0022

Juslin, P. N., & Västfjäll, D. (2008). Emotional responses to music: The need to consider underlying mechanisms. *Behavioral and Brain Sciences, 31,* 559–621.

Justus, T., & Hutsler, J. J. (2005). Fundamental issues in the evolutionary psychology of music: Assessing innateness and domain specificity. *Music Perception, 23,* 1–27. doi:10.1525/mp.2005.23.1.1

Kameoka, A., & Kuriyagawa, M. (1969). Consonance theory Part I: Consonance of dyads. *Journal of the Acoustical Society of America, 45,* 1451–1459. doi:10.1121/1.1911623

Kawabata, H., & Zeki, S. (2004). Neural correlates of beauty. *Journal of Neurophysiology, 91,* 1699–1705. doi:10.1152/jn.00696.2003

Khalfa, S., Peretz, I., Blondin, J.-P., & Robert, M. (2002). Event-related skin conductance responses to musical emotions in humans. *Neuroscience Letters, 328,* 145–149. doi:10.1016/S0304-3940(02)00462-7

Khalfa, S., Schon, D., Anton, J. L., & Liegeois-Chauvel, C. (2005). Brain regions involved in the recognition of happiness and sadness in music. *NeuroReport, 16,* 1981–1984. doi:10.1097/00001756-200512190-00002

Khalfa, S., Guye, M., Peretz, I., Chapon, F., Girard, N., Chauvel, P., & Liégeois-Chauvel, C. (2012). Evidence of lateralized anteromedial temporal structures involvement in musical emotion processing. *Neuropsychologia, 46,* 2485–2493.

Kim, S. G., Kim, J. S., & Chung, C. K. (2011). The effect of conditional probability of chord progression on brain response: An MEG study. *PLoS One, 6,* e17337. doi: 10.1371/journal.pone.0017337

Kirk, U., Skov, M., Christensen, M. S., & Nygaard, N. (2009). Brain correlates of aesthetic expertise: A parametric fMRI study. *Brain and Cognition, 69,* 306–315. doi:10.1016/j.bandc.2008.08.004

Kivy, P. (1989). *Sound sentiment: An essay on the musical emotions*. Philadelphia, PA: Temple University Press.

Kivy, P. (2002). *Introduction to a philosophy of music*. New York, NY: Oxford University Press.

Kivy, P. (2006). Critical study: Deeper than emotion. *British Journal of Aesthetics, 46,* 287–311. doi:10.1093/aesthj/ayl007

Koelsch, S. (2010). Towards a neural basis of music-evoked emotions. *Trends in Cognitive Sciences, 14,* 131–137. doi:10.1016/j.tics.2010.01.002

Koelsch, S., Fritz, T., & Schlaug, G. (2008). Amygdala activity can be modulated by unexpected chord functions during music listening. *NeuroReport, 19,* 1815–1819. doi:10.1097/WNR.0b013e32831a8722

Koelsch, S., Fritz, T., Schulze, K., Alsop, D., & Schlaug, G. (2005). Adults and children processing music: An fMRI study. *NeuroImage, 25,* 1068–1076. doi:10.1016/j.neuroimage.2004.12.050

Koelsch, S., Fritz, T., von Cramon, D. Y., Muller, K., & Friederici, A. D. (2006). Investigating emotion with music: An fMRI study. *Human Brain Mapping, 27,* 239–250. doi:10.1002/hbm.20180

Koelsch, S., Kasper, E., Sammler, D., Schulze, K., Gunter, T., & Friederici, A. D. (2004). Music, language and meaning: Brain signatures of semantic processing. *Nature Neuroscience, 7,* 302–307. doi:10.1038/nn1197

Koelsch, S., Kilches, S., Steinbeis, N., & Schelinski, S. (2008). Effects of unexpected chords and of performer's expression on brain responses and electrodermal activity. *PLoS One, 3,* e2631. doi: 10.1371/journal.pone.0002631

Koelsch, S., Offermanns, K., & Franzke, P. (2010). Music in the treatment of affective disorders: An exploratory investigation of a new method for music-therapeutic research. *Music Perception, 27,* 307–316. doi:10.1525/mp.2010.27.4.307

Koelsch, S., Schmidt, B.-H., & Kansok, J. (2002). Effects of musical expertise on the early right anterior negativity: An event-related brain potential study. *Psychophysiology, 39,* 657–663. doi:10.1111/1469-8986.3950657

Konecni, V. J. (2005). The aesthetic trinity: Awe, being moved, thrills. *Bulletin of Psychology and the Arts, 5,* 27–44.

Kornysheva, K., von Cramon, D. Y., Jacobsen, T., & Schubotz, R. I. (2010). Tuning-in to the beat: Aesthetic appreciation of musical rhythms correlates with a premotor activity boost. *Human Brain Mapping, 31,* 48–64.

Kraus, N., & Chandrasekaran, B. (2010). Music training for the development of auditory skills. *Nature Review Neuroscience, 11,* 599–605. doi:10.1038/nrn2882

Kringelbach, M. L. (2005). The human orbitofrontal cortex: Linking reward to hedonic experience. *Nature Neuroscience Reviews, 6,* 691–702. doi:10.1038/nrn1747

Krumhansl, C. L. (1997). An exploratory study of musical emotions and psychophysiology. *Canadian Journal of Experimental Psychology, 51,* 336–352. doi:10.1037/1196-1961.51.4.336

Langer, S. K. (1953). *Feeling and form: A theory of art*. London, United Kingdom: Routledge and Kegan.

Laukka, P. (2007). Uses of music and psychological well-being among the elderly. *Journal of Happiness Studies, 8,* 215–241. doi:10.1007/s10902-006-9024-3

Leder, H., Belke, B., Oeberst, A., & Augustin, D. (2004). A model of aesthetic appreciation and aesthetic judgements. *British Journal of Psychology, 95,* 489–508. doi:10.1348/0007126042369811

Levitin, D. J., & Tirovolas, A. K. (2009). Current advances in the cognitive neuroscience of music. *Annals of the New York Academy of Sciences, 1156,* 211–231. doi:10.1111/j.1749-6632.2009.04417.x

Livingstone, M., & Hubel, D. H. (2002). *Vision and art: The biology of seeing*. New York, NY: Harry N. Abrams.

Logeswaran, N., & Bhattacharya, J. (2009). Crossmodal transfer of emotion by music. *Neuroscience Letters, 455,* 129–133. doi:10.1016/j.neulet.2009.03.044

Loui, P., Grent-'t-Jong, T., Torpey, D., & Woldorff, M. (2005). Effects of attention on the neural processing of harmonic syntax in Western music. *Cognitive Brain Research, 25,* 678–687. doi:10.1016/j.cogbrainres.2005.08.019

Loui, P., Wu, E. H., Wessel, D. L., & Knight, R. T. (2009). A generalized mechanism for perception of pitch patterns. *Journal of Neuroscience, 29,* 454–459. doi:10.1523/JNEUROSCI.4503-08.2009

Maidhof, C., & Koelsch, S. (2011). Effects of selective attention on syntax processing in music and language. *Journal of Cognitive Neuroscience. 23,* 2252–2267.

McCrae, R. R. (2007). Aesthetic chills as a universal marker of openness to experience. *Motivation and Emotion, 31,* 5–11. doi:10.1007/s11031-007-9053-1

McDonald, C., & Stewart, L. (2008). Uses and functions of music in congenital amusia. *Music Perception, 25,* 345–355. doi:10.1525/mp.2008.25.4.345

Menon, V., & Levitin, D. J. (2005). The rewards of music listening: Response and physiological connectivity of the mesolimbic system. *NeuroImage, 28,* 175–184. doi:10.1016/j.neuroimage.2005.05.053

Meyer, L. B. (1956). *Emotion and meaning in music*. Chicago, IL: The University of Chicago Press.

Meyer, L. B. (1957). Meaning in music and information theory. *Journal of Aesthetics and Art Criticism, 15,* 412–424. doi:10.2307/427154

Miller, G. A., & Bukhout, R. (1973). *Psychology: The science of mental life*. New York, NY: Harper & Row.

Mitterschiffthaler, M. T., Fu, C. H., Dalton, J. A., Andrew, C. M., & Williams, S. C. (2007). A functional MRI study of happy and sad affective states induced by classical music. *Human Brain Mapping, 28,* 1150–1162. doi:10.1002/hbm.20337

Müller, M., Höfel, L., Brattico, E., & Jacobsen, T. (2010). Aesthetic judgments of music in experts and laypersons–an ERP study. *International Journal of Psychophysiology, 76,* 40–51. doi:10.1016/j.ijpsycho.2010.02.002

Nadal, M., & Pearce, M. T. (2011). The Copenhagen Neuroaesthetics conference: Prospects and pitfalls for an emerging field. *Brain and Cognition, 76,* 172–183.

Nadal, M., Munar, E., Capo, M. A., Rossello, J., & Cela-Conde, C. J. (2008). Towards a framework for the study of the neural correlates of aesthetic preference. *Spatial Vision, 21,* 379–396. doi:10.1163/156856808784532653

Nieminen, S., Istók, E., Brattico, E., Tervaniemi, M., & Huotilainen, M. (in press). The development of aesthetic responses to music and their underlying neural and psychological mechanisms. *Cortex*.

North, A. C., & Hargreaves, D. J. (1997). Liking, arousal potential, and the emotions expressed by music. *Scandinavian Journal of Psychology, 38,* 45–53. doi:10.1111/1467-9450.00008

Nusbaum, H. C., & Silvia, P. J. (2011). Shivers and timbres: Personality and the experience of chills from music. *Social Psychological and Personality Science, 2,* 199–204. doi:10.1177/1948550610386810

Oram, N., & Cuddy, L. L. (1995). Responsiveness of Western adults to pitch-distributional information in melodic sequences. *Psychological Research, 57,* 103–118.

Pallesen, K. J., Brattico, E., Bailey, C., Korvenoja, A., Koivisto, J., Gjedde, A., & Carlson, S. (2005). Emotion processing of major, minor, and dissonant chords: A functional magnetic resonance imaging study. *Annals of the New York Academy of Sciences, 1060,* 450–453. doi:10.1196/annals.1360.047

Pallesen, K. J., Brattico, E., Bailey, C. J., Korvenoja, A., Koivisto, J., Gjedde, A., . . . Carlson, S. (2010). Cognitive control in auditory working memory is enhanced in musicians. *PLoS One, 5,* e11120. doi:10.1371/journal.pone.0011120

Panksepp, J. (1995). The emotional sources of "chills" induced by music. *Music Perception, 13,* 171–207. doi:10.2307/40285693

Pearce, M. T., Ruiz, M. H., Kapasi, S., Wiggins, G. A., & Bhattacharya, J. (2010). Unsupervised statistical learning underpins computational, behavioural, and neural manifestations of musical expectation. *NeuroImage, 50,* 302–313. doi:10.1016/j.neuroimage.2009.12.019

Pearce, M. T., & Wiggins, G. A. (2006). Expectation in melody: The influence of context and learning. *Music Perception, 23,* 377–405. doi:10.1525/mp.2006.23.5.377

Pereira, C. S., Teixeira, J., Figueiredo, P., Xavier, J., Castro, S. L., & Brattico, E. (2011). Music and emotions in the brain: Familiarity matters. *PLoS One, 6,* e27241. doi: 10.1371/journal.pone.0027241

Peretz, I. (2010). Towards a neurobiology of musical emotions. In P. N. Juslin & J. A. Sloboda (Eds.), *Handbook of music and emotion: Theory, research, applications* (pp. 99–126). New York, NY: Oxford University Press.

Peretz, I., Gosselin, N., Belin, P., Zatorre, R. J., Plailly, J., & Tillmann, B. (2009). Music lexical networks: The cortical organization of music recognition. *Annals of the New York Academy of Sciences, 1169,* 256–265. doi:10.1111/j.1749-6632.2009.04557.x

Peretz, I., & Zatorre, R. (Eds.). (2003). *The cognitive neuroscience of music*. Oxford, United Kingdom: Oxford University Press. doi:10.1093/acprof:oso/9780198525202.001.0001

Plailly, J., Tillmann, B., & Royet, J. P. (2007). The feeling of familiarity of music and odors: The same neural signature? *Cerebral Cortex, 17,* 2650–2658. doi:10.1093/cercor/bhl173

Plomp, R., & Levelt, J. M. (1965). Tonal consonance and critical bandwidth. *Journal of the Acoustical Society of America, 38,* 549–560. doi:10.1121/1.1909741

Raichle, M. E., & Snyder, A. Z. (2007). A default mode of brain function: A brief history of an evolving idea. *NeuroImage, 37,* 1083–1090; discussion 1097–1089.

Reber, R., Wurtz, P., & Zimmermann, T. D. (2004). Exploring "fringe" consciousness: The subjective experience of perceptual fluency and its objective bases. *Consciousness and Cognition, 13,* 47–60. doi:10.1016/S1053-8100(03)00049-7

Robinson, J. (2005). *Deeper than reason: Emotion and its role in literature, music, and art*. New York, NY: Oxford University Press.

Russell, J. A. (1980). A circumplex model of affect. *Journal of Personality and Social Psychology, 39,* 1161–1178. doi:10.1037/h0077714

Russell, J. A. (2003). Core affect and the psychological construction of emotion. *Psychological Review, 110,* 145–172. doi:10.1037/0033-295X.110.1.145

Salimpoor, V. N., Benovoy, M., Larcher, K., Dagher, A., & Zatorre, R. J. (2011). Anatomically distinct dopamine release during anticipation and experience of peak emotion to music. *Nature Neuroscience, 14,* 257–262. doi:10.1038/nn.2726

Särkämö, T., Tervaniemi, M., Laitinen, S., Forsblom, A., Soinila, S., Mikkonen, M., . . . Hietanen, M. (2008). Music listening enhances cognitive recovery and mood after middle cerebral artery stroke. *Brain, 131,* 866–876. doi:10.1093/brain/awn013

Satoh, M., Takeda, K., Nagata, K., Shimosegawa, E., & Kuzuhara, S. (2006). Positron-emission tomography of brain regions activated by recognition of familiar music. *American Journal of Neuroradiology, 27,* 1101–1106.

Scherer, K. R., & Zentner, M. R. (2008). Music evoked emotions are different: More often aesthetic than utilitarian. *Behavioral and Brain Sciences, 31,* 595–596. doi:10.1017/S0140525X08005505

Schimmack, U., & Grob, A. (2000). Dimensional models of core affect: A quantitative comparison by means of structural equation modeling. *European Journal of Personality, 14,* 325–345. doi:10.1002/1099-0984(200007/08)14:4<325::AID-PER380>3.0.CO;2-I

Schmidt, L. A., & Trainor, L. J. (2001). Frontal brain electrical activity (EEG) distinguishes valence and intensity of musical emotions. *Cognition & Emotion, 15,* 487–500.

Schön, D., Regnault, P., Ystad, S., & Besson, M. (2005). Sensory consonance: An ERP study. *Music Perception, 23,* 105–117.

Schubert, E. (1996). Enjoyment of negative emotions in music: An associative network explanation. *Psychology of Music, 24,* 18–28. doi:10.1177/0305735696241003

Schubert, E. (2007). The influence of emotion, locus of emotion and familiarity upon preference in music. *Psychology of Music, 35,* 499–515. doi:10.1177/0305735607072657

Schubert, E. (2010). Affective, evaluative, and collative responses to hated and loved music. *Psychology of Aesthetics, Creativity, and the Arts, 4,* 36–46. doi:10.1037/a0016316

Schulze, K., Zysset, S., Mueller, K., Friederici, A. D., & Koelsch, S. (2011). Neuroarchitecture of verbal and tonal working memory in nonmusicians and musicians. *Human Brain Mapping, 32,* 771–783. doi:10.1002/hbm.21060

Simonton, D. K. (1980). Thematic fame, melodic originality, and musical zeitgeist: A biographical and transhistorical content analysis. *Journal of Personality and Social Psychology, 38,* 972–983. doi:10.1037/0022-3514.38.6.972

Simonton, D. K. (1987). Musical aesthetics and creativity in Beethoven: A computer analysis of 105 compositions. *Empirical Studies of the Arts, 5,* 87–104. doi:10.2190/B94K-CP9N-VUT8-RLKH

Sloboda, J. A. (1986). Cognition and real music: The psychology of music comes of age. *Psychologica Belgica, 26,* 199–219.

Sloboda, J. A. (1991). Music structure and emotional response: Some empirical findings. *Psychology of Music, 19,* 110–120. doi:10.1177/0305735691192002

Sloboda, J. A. (1992). Empirical studies of emotional response to music. In M. R. Jones & S. Holleran (Eds.), *Cognitive bases of musical communication* (pp. 33–46). Washington, DC: American Psychological Association. doi:10.1037/10104-003

Sloboda, J. A. (2010). Music in everyday life: The role of emotions. In *Handbook of music and emotion: Theory, research, applications* (pp. 493–514). New York, NY: Oxford University Press.

Steinbeis, N., & Koelsch, S. (2008). Comparing the processing of music and language meaning using EEG and FMRI provides evidence for similar and distinct neural representations. *PLoS One, 3*.

Steinbeis, N., Koelsch, S., & Sloboda, J. A. (2006). The role of harmonic expectancy violations in musical emotions: Evidence from subjective, physiological, and neural responses. *Journal of Cognitive Neuroscience, 18,* 1380–1393. doi:10.1162/jocn.2006.18.8.1380

Sutoo, D., & Akiyama, K. (2004). Music improves dopaminergic neurotransmission: Demonstration based on the effect of music on blood pressure regulation. *Brain Research, 1016,* 255–262. doi:10.1016/j.brainres.2004.05.018

Suzuki, M., Okamura, N., Kawachi, Y., Tashiro, M., Arao, H., Hoshishiba, T., . . . Yanai, K. (2008). Discrete cortical regions associated with the musical beauty of major and minor chords. *Cognitive, Affective, & Behavioural Neuroscience, 8,* 126–131.

Tallis, R. (2008). The limitations of a neurological approach to art. Review of neuroarthistory: From Aristotle and Pliny to Baxandall and Zeki by John Onians (Yale University Press, 2008). *Lancet, 372,* 19–20. doi:10.1016/S0140-6736(08)60975-7

Tervaniemi, M., Rytkönen, M., Schröger, E., Ilmoniemi, R. J., & Näätänen, R. (2001). Superior formation of cortical memory traces of melodic patterns in musicians. *Learning and Memory, 8,* 295–300. doi:10.1101/lm.39501

Thayer, R. E., Newman, R., & McClain, T. M. (1994). Self-regulation of mood: Strategies for changing a bad mood, raising energy, and reducing tension. *Journal of Personality and Social Psychology, 67,* 910–925. doi:10.1037/0022-3514.67.5.910

Tillmann, B., Bharucha, J. J., & Bigand, E. (2000). Implicit learning of tonality: A self-organizing approach. *Psychological Review, 107,* 885–913. doi:10.1037/0033-295X.107.4.885

Tramo, M. J., Cariani, P. A., Delgutte, B., & Braida, L. D. (2003). Neurobiology of harmony perception. In I. Peretz & R. Zatorre (Eds.), *The cognitive neuroscience of music* (pp. 127–151). New York, NY: Oxford University Press. doi:10.1093/acprof:oso/9780198525202.003.0009

Trost, W., Ethofer, T., Zentner, M., & Vuilleumier, P. (2012). Mapping aesthetic musical emotions in the brain. *Cerebral Cortex, 22,* 2769–2783. doi:10.1093/cercor/bhr353

Vieillard, S., Peretz, I., Gosselin, N., Khalfa, S., Gagnon, L., & Bouchard, B. (2008). Happy, sad, scary and peaceful musical excerpts for research on emotions. *Cognition & Emotion, 22,* 720–752. doi:10.1080/02699930701503567

Vitz, P. (1966). Affect as a function of stimulus variation. *Journal of Experimental Psychology, 71,* 74–79. doi:10.1037/h0022619

Vuoskoski, J. K., & Eerola, T. (2011). Measuring music-induced emotion: A comparison of emotion models, personality biases and intensity of experiences. *Musicae Scientiae, 15,* 159–173. doi:10.1177/1029864911403367

Wallin, N. L., Meyer, B., & Brown, S. (2000). *The origins of music*. Cambridge, MA: The MIT Press.

Wiesmann, M., & Ishai, A. (2011). Expertise reduces neural cost but does not modulate repetition suppression. *Cognitive Neuroscience, 2,* 57–65. doi:10.1080/17588928.2010.525628

Wundt, W. (1874). *Grundzüge der physiologischen Psychologie* [Principles of Physiological Psychology]. Leipzig: Wilhelm Engelmann.

Zajonc, R. B. (1968). Attitudinal effects of mere exposure. *Journal of Personality and Social Psychology Monograph Supplements, 9,* 1–27. doi:10.1037/h0025848

Zeki, S. (1999). *Inner vision: An exploration of art and the brain*. Oxford, United Kingdom: Oxford University Press.

Zentner, M., Grandjean, D., & Scherer, K. R. (2008). Emotions evoked by the sound of music: Characterization, classification, and measurement. *Emotion, 8,* 494–521. doi:10.1037/1528-3542.8.4.494

Received May 22, 2011
Revision received August 23, 2012
Accepted September 5, 2012 ■