Emotional responses to music: The need to consider underlying mechanisms

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Abstract: Research indicates that people value music primarily because of the emotions it evokes. Yet, the notion of musical emotions remains controversial, and researchers have so far been unable to offer a satisfactory account of such emotions. We argue that the study of musical emotions has suffered from a neglect of underlying mechanisms. Specifically, researchers have studied musical emotions without regard to how they were evoked, or have assumed that the emotions must be based on the "default" mechanism for emotion induction, a cognitive appraisal. Here, we present a novel theoretical framework featuring six additional mechanisms through which music listening may induce emotions: (1) brain stem reflexes, (2) evaluative conditioning, (3) emotional contagion, (4) visual imagery, (5) episodic memory, and (6) musical expectancy. We propose that these mechanisms differ regarding such characteristics as their information focus, ontogenetic development, key brain regions, cultural impact, induction speed, degree of volitional influence, modularity, and dependence on musical structure. By synthesizing theory and findings from different domains, we are able to provide the first set of hypotheses that can help researchers to distinguish among the mechanisms. We show that failure to control for the underlying mechanism may lead to inconsistent or non-interpretable findings. Thus, we argue that the new framework may guide future research and help to resolve previous disagreements in the field. We conclude that music evokes emotions through mechanisms that are not unique to music, and that the study of musical emotions could benefit the emotion field as a whole by providing novel paradigms for emotion induction.

Keywords: affect; arousal; brain; emotion; induction; music; mechanism; memory; theory

1. Introduction

Of all the problems that may confront a music psychologist, none is perhaps more important than to explain listeners' reactions to music. Some kind of musical experience is the basis for every musical activity, regardless of whether it involves composing, performing, or listening to music. Several studies have suggested that the most common goal of musical experiences is to influence emotions: People use music to change emotions, to release emotions, to match their current emotion, to enjoy or comfort themselves, and to relieve stress (e.g., Behne 1997; Juslin & Laukka 2004; Sloboda & O'Neill 2001; Zillman & Gan 1997). Yet, music's apparent ability to induce strong emotions is a mystery that has fascinated both experts and lay people at least since ancient Greece (Budd 1985). "How do sounds, which are, after all, just sounds, have the power to so deeply move those involved with them?" (Reimer 2003, p. 73). To explain how music can induce emotions in listeners is all the more important since music is already used in several applications in society that presume its effectiveness in inducing emotions, such as film music (Cohen 2001), marketing (Bruner 1990), and therapy (Bunt & Hoskyns 2002). However, despite a recent upswing of research on musical emotions (for an extensive review, see Juslin & Sloboda 2001), the literature presents a confusing picture with conflicting views on almost every topic in the field.1 A few examples may suffice to illustrate this point: Becker (2001, p. 137) notes that "emotional responses to music do not occur spontaneously, nor 'naturally'," yet Peretz (2001, p. 126) claims that "this is what emotions are: spontaneous responses that are difficult to disguise." Noy (1993, p. 137) concludes that "the emotions evoked by music are not identical with the emotions aroused by everyday, interpersonal activity," but Peretz (2001, p. 122) argues that "there is as yet no theoretical or empirical reason for assuming such specificity." Koelsch (2005, p. 412) observes that emotions to music may be induced "quite consistently across subjects," yet Sloboda (1996, p. 387) regards individual differences as an "acute problem." Scherer (2003, p. 25) claims that “music does not induce basic emotions,” but Panksepp and Bernatzky (2002, p. 134) consider it “remarkable that any medium could so readily evoke all the basic emotions.” Researchers BEHAVIORAL AND BRAIN SCIENCES (2008) 31, 559 –621 Printed in the United States of America doi:10.1017/S0140525X08005293 # 2008 Cambridge University Press 0140-525X/08 $40.00 559 do not even agree about whether music induces emotions: Sloboda (1992, p. 33) claims that “there is a general consensus that music is capable of arousing deep and significant emotions,” yet Konecˇni (2003, p. 332) writes that “instrumental music cannot directly induce genuine emotions in listeners.” At the heart of all this controversy, we believe, lies the fact that researchers have not devoted enough attention to the question of how music induces emotions. Most writers on the subject acknowledge that this is the most important issue: “Music arouses strong emotional responses in people, and they want to know why” (Dowling & Harwood 1986, p. 202). Yet, a search of the literature reveals that surprisingly few articles make any attempt whatsoever to explain the psychological mechanisms that underlie listeners’ emotional responses to music. For instance, a search for peer-reviewed articles (in English) in PsycINFO and RILM Abstracts of Music Literature, using the query music and emotion and the time limits 1967–2007, revealed 1,033 and 423 articles, respectively, of which a single article in PsycINFO (i.e., Steinbeis et al. 2006) and none of the articles in RILM aimed to empirically test a theory about how music induces emotions; 21 articles in each database (2% and 5%, respectively) mentioned a mechanism, or the issue of emotion induction more generally, without reporting any relevant data.2 Although these searches may not have uncovered every relevant article, the point is that the great majority of studies of musical emotions have not concerned underlying mechanisms. We use the term psychological mechanism broadly in this article to refer to any information processing that leads to the induction of emotions through listening to music.3 This processing could be simple or complex. It could be available to consciousness or not. However, what the mechanisms discussed here have in common is that they become activated by taking music as their “object.” We adhere to the notion that a defining feature of emotions is that they involve intentional objects: They are “about” something (Frijda 1999, p. 191). For example, we are sad about the death of a loved one. What are musical emotions about? One problem with musical emotions is that the conditions for eliciting emotions appear to be different from those in everyday life: In the paradigmatic case, an emotion is aroused when an event is appraised as having the capacity to affect the goals of the perceiver somehow (Carver & Scheier 1998). Thus, for example, a reviewer’s criticism of a manuscript may threaten the author’s goal to get it published. Because music does not seem to have any capacity to further or block goals, it seems strange that music can induce emotions. Indeed, it has been denied by some authors that music can induce common “everyday emotions” such as sadness, happiness, and anger (Kivy 1990; Konecˇni 2003; Scherer 2003). We suspect that this view rests on the assumption that such emotions need to reflect a cognitive appraisal (see Gabriel & Crickmore [1977], Scherer & Zentner [2001], Stratton & Zalanowski [1989; 1991], and Waterman [1996]) for claims about an important role of cognitive appraisal in emotional responses to music). The main assumption of appraisal theory is that emotions arise, and are distinguished, on the basis of a person’s subjective evaluation of an event on appraisal dimensions such as novelty, urgency, goal congruence, coping potential, and norm compatibility (for an excellent review, see Scherer 1999). Occasionally, music may lead to the induction of emotions through some of the same appraisal dimensions. Thus, for example, a person may be trying to sleep at night, but is prevented from doing so by the disturbing sounds of a neighbor playing loud music on his or her stereo. In this case, the music becomes an object of the person’s irritation because it blocks the person’s goal: to fall asleep. Although there is nothing particularly “musical” about this example, it is clear that music can sometimes induce emotions in listeners in this manner (Juslin et al., in press). Such responses can easily be explained by traditional theories of emotion. However, the problem is that the available evidence indicates that this type of emotion is not typical of music listening – most emotional reactions to music do not involve implications for goals in life, which explains why they are regarded as mysterious: “The listener’s sad response appears to lack the beliefs that typically go with sadness” (Davies 2001, p. 37). Because music does not seem to have goal implications, some researchers have assumed that music cannot induce emotions at all (Konecˇni 2003) – or, at least, that it cannot induce basic emotions related to survival functions (Kivy 1990; Scherer 2003).4 Some researchers allow for the possibility that music may induce “more subtle, musicspecific emotions” (Scherer & Zentner 2001, p. 381; see also Gurney 1880; Lippman 1953; Swanwick 1985), the precise nature of which remains to be clarified. This notion is sometimes coupled with the assumption that musical emotions are induced through some unique (but yet unspecified) process that has little or nothing in common with the induction mechanisms of “ordinary” PATRIK N. JUSLIN is Associate Professor of Psychology at Uppsala University, Sweden, where he teaches courses on music, emotion, perception, and research methodology. He completed his Ph.D. in 1998 under the supervision of Alf Gabrielsson. Juslin has published numerous articles in the areas of expression in music performance, emotional responses to music, music education, and emotion in speech. In 2001, he edited the volume Music and Emotion: Theory and Research together with John Sloboda. Juslin and Sloboda are currently editing a handbook on music and emotion. Juslin is a member of the International Society for Research on Emotions. Alongside his work as a researcher, he has worked professionally as a guitar player. DANIEL VA¨ STFJA¨ LL is a Research Scientist at Decision Research, Eugene, Oregon, U.S.A., and Assistant Professor of Psychology and Psychoacoustics at Go¨teborg University and Chalmers University of Technology, Sweden. His educational history includes Ph.D.’s in both Psychology and Acoustics. His research focuses on the role of emotion in judgment, perception, and psychophysics. A common theme for his research is how emotion serves as information for judgments about objects, the self, and health. His current research focus is on the relationship between music and emotion, particularly on how acoustic parameters contribute to emotional responses. Va¨stfja¨ll is currently heading research projects on the link between music and health and on the psychoacoustics of musical emotion. emotions. We reject these views on both theoretical and empirical grounds, and claim that music can induce a wide range of both basic and complex emotions in listeners via several psychological mechanisms that emotions to music share with other emotions. The primary argument of this target article is that research on music and emotion has failed to become cumulative because music researchers have either neglected underlying psychological mechanisms or assumed that musical emotions reflect a cognitive appraisal. We argue that it is important to look beyond appraisal theory and consider alternative but less obvious ways in which music might induce emotions. While appraisal may be important for many forms of art (Silvia 2005), there are other mechanisms that are far more relevant in the case of music. We claim that if these additional mechanisms are taken into account, there is nothing particularly strange about results that suggest that music induces all kinds of emotions (Gabrielsson 2001, Table 19.2). The problem is that most researchers seem to have mistakenly assumed that musical emotions can be studied and described without regard to how they were induced. Most studies have not controlled for the underlying mechanism, despite their attempts to generalize about the nature of musical emotions. Unfortunately, as discussed further in sections 4.1 and 4.4, failure to distinguish between mechanisms may lead to apparently inconsistent findings and unnecessary controversy among researchers. We believe that the solution to this problem is a more hypothesisdriven approach that takes the characteristics of each mechanism into account. Such an approach is proposed in this article.

In the following, we (a) review evidence from different kinds of sources to show that, despite claims to the contrary, music can induce emotions, (b) present a novel theoretical framework, featuring six psychological mechanisms and 66 hypotheses, that explains how such emotions are induced, (c) consider how this framework might guide future research and help to resolve previous disagreements, and (d) discuss implications for research on emotions in general and musical emotions in particular. 2. Does music really induce emotions? Studies of music and emotion have been conducted off and on since psychology's birth at the end of the nineteenth century (Gabrielsson & Juslin 2003). The majority of studies have focused on how listeners perceive emotions expressed in the music. Similarly, most theories of music and emotion have focused on the representational features of music that enable listeners to perceive emotions (e.g., Clynes 1977; Cooke 1959; Langer 1957). However, perception of emotions is primarily a sensory or cognitive process that does not necessarily say anything about what the listener himself or herself is feeling, since perception of emotions may well proceed without any emotional involvement (Gabrielsson 2002; Harre´ 1997). Hence, induction of emotions must be studied in its own right. With an increasing number of studies devoted to exploring emotional responses to music, we are in a good position to answer more definitively the long-standing question of whether music really can induce emotions. However, the answer to this question depends on how emotion is defined. Table 1 offers working definitions of affective terms used in this article, based on the emerging consensus in research on affect (e.g., Davidson et al. 2003, p. xiii; Juslin & Scherer 2005, Table 3.1; Oatley et al. 2006, pp. 29 – 31). Although researchers may not agree on a precise definition of emotions, they largely agree on the characteristics and components of an emotional response (e.g., Izard 2007). As shown in Table 1, emotions are typically described as relatively brief, though intense, affective Table 1. Working definitions of affective terms used in this target article Affect An umbrella term that covers all evaluative – or valenced (i.e., positive/negative) – states such as emotion, mood, and preference. Emotions Relatively intense affective responses that usually involve a number of sub-components – subjective feeling, physiological arousal, expression, action tendency, and regulation – which are more or less synchronized. Emotions focus on specific objects, and last minutes to a few hours. Musical emotions A short term for "emotions that are induced by music." Moods Affective states that feature a lower felt intensity than emotions, that do not have a clear object, and that last much longer than emotions (several hours to days). Feeling The subjective experience of emotion (or mood). This component is commonly measured via self-report and reflects any or all of the other emotion components. Arousal Activation of the autonomic nervous system (ANS). Physiological arousal is one of the components of an emotional response but can also occur in the absence of emotions (e.g., during exercise). Preferences Long-term evaluations of objects or persons with a low intensity (e.g., liking of a specific music style). Emotion induction All instances where music evokes an emotion in a listener, regardless of the nature of the process that evoked the emotion. Emotion perception All instances where a listener perceives or recognizes expressed emotions in music (e.g., a sad expression), without necessarily feeling an emotion. Cognitive appraisal An individual's subjective evaluation of an object or event on a number of dimensions in relation to the goals, motives, needs, and values of the individual. Juslin & Va¨stfja¨ll: Emotional responses to music BEHAVIORAL AND BRAIN SCIENCES (2008) 31:5 561 reactions to potentially important events or changes in the external or internal environment that involve several subcomponents: (a) cognitive appraisal (e.g., you appraise the situation as "dangerous"), (b) subjective feeling (e.g., you feel afraid), (c) physiological arousal (e.g., your heart starts to beat faster), (d) expression (e.g., you scream), (e) action tendency (e.g., you run away), and (f) regulation (e.g., you try to calm yourself) (e.g., Ekman 1992a; Johnson-Laird & Oatley 1992; Scherer 2000b). Each of these six components can be used to measure emotions, though researchers debate the extent to which different components are synchronized during an emotional response (cf. Frijda 1999; Scherer 2000b). To demonstrate that music can evoke “real” emotions, one should provide evidence that music produces reactions in all of the aforementioned emotion components. Such evidence comes from many different strands of research and is summarized in Table 2. Although each source of evidence is associated with its own set of problems, the combined evidence is quite compelling. If these findings do not reflect emotions, as some have argued, what exactly do they reflect? Most of the evidence was collected in Western societies, though there is evidence from anthropology and ethology that emotional reactions to music occur in all human societies of the world and are not simply inventions of the Western world (Becker 2001; 2004; Eibl-Eibesfeldt 1989). Music appears to induce a wide range of both basic and complex emotions (e.g., Gabrielsson 2001, Table 19.2; Juslin & Laukka 2004, Table 4; Sloboda 1992, Table 1; Wells & Hakanen 1991, Table 1), something that a theory of musical emotion must be able to account for. There is also preliminary evidence of synchronization of emotion components in response to music (Lundqvist et al., in press). Most studies of musical emotions have relied merely on self-report, which could be subject to demand characteristics (i.e., the total sum of cues that convey the researcher’s hypothesis to the participant and thus may influence the participant’s behavior; Orne 1962). It is therefore promising that several studies have reported effects of musically induced emotions on indirect measures that should be less sensitive to demand characteristics (see Table 3). These findings, which suggest that music can be just as effective as other emotion-elicitation techniques, offer further evidence that music induces emotions in listeners. Though these studies are sometimes referred to as studies of mood induction, we claim that music usually induces emotions rather than moods,5 because listeners’ reactions focus on an “object” (the music, or more specifically certain information in the music processed relative to individual and situational factors), they last only for a limited duration (ca. 5– 40 mins; Va¨stfja¨ll 2002a, p. 192; see also Panksepp & Bernatzky 2002), and they involve Table 2. Summary of evidence of emotional reactions to music in terms of various subcomponents Emotion component Finding Selected references Subjective feeling Listeners report that they experience emotions while listening to music in experiments, questionnaires, diary studies, and qualitative interviews. Positive emotions are more commonly reported than negative emotions. Behne 1997; DeNora 2000; Juslin & Laukka 2004; Pike 1972; Sloboda & O’Neill 2001 Psychophysiology Music listening may give rise to physiological reactions similar to those shown to other “emotional” stimuli, including changes in heart rate, skin temperature, electrodermal response, respiration, and hormone secretion. Bartlett 1996; Krumhansl 1997; Lundqvist et al., in press; Nyklı´cˇek et al. 1997; Vaitl et al. 1993 Brain activation Listeners’ responses to music involve regions of the brain that are known from previous research to be implicated in emotional responses, including thalamus, hippocampus, amygdala, prefrontal cortex, orbitofrontal cortex, midbrain/periaqueductal gray (PAG), insula, and nucleus accumbens. Blood & Zatorre 2001; Blood et al. 1999; Brown et al. 2004; Koelsch et al. 2006; Menon & Levitin 2005 Emotional expression Music listening makes people cry, smile, laugh, and furrow their eyebrows, as indicated by self-reports, observations, and electromyographic measures of facial muscles. Becker 2004; Frey 1985; Gabrielsson 2001; Sloboda 1991; Witvliet & Vrana 2007 Action tendency Music influences people’s action tendencies, such as their tendency to help other people, to consume products, or to move – either overtly or covertly. Fried & Berkowitz 1979; North et al. 2004; Rieber 1965; Harrer & Harrer 1977 Emotion regulation Listeners attempt to regulate their own emotional reactions to music, e.g., with regard to what are deemed appropriate responses in a social context. Becker 2001; Gabrielsson 2001 Juslin & Va¨stfja¨ll: Emotional responses to music 562 BEHAVIORAL AND BRAIN SCIENCES (2008) 31:5 autonomic responses (Krumhansl 1997). These aspects are associated with emotions rather than moods (Table 1;

Beedie et al. 2005). However, there is one emotion component for which evidence is lacking – the cognitive appraisal. This raises the primary question of how, exactly, musical emotions are induced. 3. How does music induce emotions? Consider the following example of a listener's emotional responses during a concert (possible induction mechanisms are indicated within the parentheses and are further explained in section 3.1): Klaus arrived just in time for the concert on Friday evening ... He sat down and the music began. A sudden, dissonant chord induced a strong feeling of arousal (i.e., brain stem reflex), causing his heart to beat faster. Then, when the main theme was introduced, he suddenly felt rather happy – for no apparent reason (i.e., evaluative conditioning). In the following section, the music turned more quiet ... The sad tone of a voice-like cello that played a slow, legato, falling melody with a trembling vibrato moved him to experience the same sad emotion as the music expressed (i.e., emotional contagion). He suddenly recognized the melody; it brought back a nostalgic memory from an event in the past where the same melody had occurred (i.e., episodic memory). When the melody was augmented by a predictable harmonic sequence, he started to fantasize about the music, conjuring up visual images – like a beautiful landscape – that were shaped by the music's flowing character (i.e., visual imagery). Next, the musical structure began to build up towards what he expected to be a resolution of the tension of the previous notes when suddenly the harmonics changed unexpectedly to another key, causing his breathing to come to a brief halt (i.e., musical expectancy). He thought, "This piece of music is really a cleverly constructed piece! It actually made me reach my goal to forget my trouble at work." Reaching this goal made him happy (i.e., cognitive appraisal). This fictitious, although empirically inspired, example gives an idea of the phenomena that need to be explained by a satisfactory model of musical emotions. One thing should be apparent from this brief example: there is no single mechanism that can account for all instances of musically induced emotion. Yet, although several authors have acknowledged that there may be more than one mechanism (Berlyne 1971; Dowling & Harwood 1986; Meyer 1956; Robinson 2005; Scherer & Zentner 2001; Sloboda & Juslin 2001), there has been no attempt to develop a complete theoretical framework with a set of hypotheses. In fact, few of the theories proposed have even been properly tested. In the following sections of this article, we outline a new theoretical framework featuring six psychological mechanisms that we hypothesize are involved in the musical induction of emotions: (1) brain stem reflexes, (2) evaluative conditioning, (3) emotional contagion, (4) visual imagery, (5) episodic memory, and (6) musical expectancy. We suggest that these mechanisms (along with cognitive appraisal) can explain most emotions induced by music in everyday life.6 It must be noted at the outset that, though we consider it necessary to distinguish among the mechanisms for research purposes (sect. 3.2), the mechanisms are not mutually exclusive. Instead, they should be regarded as complementary ways through which music might induce emotions. Our framework builds partly on the work of pioneers in the field (Berlyne 1971; Meyer 1956), as well as on more recent ideas (Juslin & Sloboda 2001). However, by synthesizing theories and findings from several domains, we are able to provide the first set of hypotheses that may help researchers to distinguish between the mechanisms. We first describe each mechanism separately (in sect. 3.1) and then present the hypotheses (in sect. 3.2). Because few studies so far have investigated these mechanisms in regard to music, the description of each mechanism is broad and preliminary. Table 3. Examples of findings from studies that used indirect measures of musically induced emotions Measure Description Study Psychomotor Writing speed Shorter time for writing down numbers from 100 to 1 Pignatiello et al. 1986 Count time Shorter time to count from 1 to 10 Clark & Teasdale 1985 Distance approximation Smaller distances estimated Kenealy 1988 Motivational Incentives Higher ratings of willingness to participate in social activities Wood et al 1990 Information processing Word association Shorter time to produce associations to words Kenealy 1988

Coding speed Shorter time to complete a symbol-coding procedure Wood et al. 1990 Decision time Shorter time to decision Kenealy 1988 Judgmental/Behavioral Subjective probability Higher estimates of probability of success and lower estimates of failure Teasdale & Spencer 1984 Evaluative judgments More positive evaluations of ads Gorn et al. 2001 Purchase intentions Lower in-store purchase intentions Bruner 1990 Sexual arousal Stronger sexual arousal Mitchell et al. 1998 Physical attraction Higher ratings of attraction May & Hamilton 1980 Emotion perception More happiness and less sadness perceived in facial expressions Bouhuys et al. 1995 Note. Description refers to effects of positive (happy) as compared to negative (sad) emotions. Juslin & Va¨stfja¨ll: Emotional responses to music BEHAVIORAL AND BRAIN SCIENCES (2008) 31:5 563 3.1. Psychological mechanisms 3.1.1. Brain stem reflex. This refers to a process whereby an emotion is induced by music because one or more fundamental acoustical characteristics of the music are taken by the brain stem to signal a potentially important and urgent event. All other things being equal, sounds that are sudden, loud, dissonant, or feature fast temporal patterns induce arousal or feelings of unpleasantness in listeners (e.g., Berlyne 1971; Burt et al. 1995; Foss et al. 1989; Halpern et al. 1986). Such responses reflect the impact of auditory sensations – music as sound in the most basic sense. The perceptual system is constantly scanning the immediate environment in order to discover potentially important changes or events. Certain sound qualities are indicative of change, such as sudden or extreme sounds, sounds that change very quickly, or sounds that are the result of strong force or large size. Sounds that meet certain criteria (e.g., fast, loud, noisy, very low- or high-frequenced) will therefore produce an increased activation of the central nervous system. The precise physiological processes underlying such brain stem responses are not completely understood, although evidence suggests that they occur in close connection with the reticular formation of the brain stem and the intralaminar nuclei of the thalamus, which receive inputs from the auditory system. The brain stem is an ancient structure of the brain that subserves a number of sensory and motor functions including, but not limited to, auditory perception and the mediation and control of attention, emotional arousal, heart rate, breathing, and movement (Joseph 2000). The reticular system is in a position to quickly induce arousal so that attention may be selectively directed at sensory stimuli of potential importance. The system exerts its widespread influences on sensory and motor functions and arousal through neurotransmitters such as norepinephrine and serotonin. While the system may be activated and inhibited by the amygdala, hypothalamus, and orbitofrontal cortex, it may also be activated independently of these structures in a more reflex-like manner (Lipscomb & Hodges 1996; Tranel 2000). Brain stem reflexes to music rely on the early stages of auditory processing. When an auditory signal reaches the primary auditory cortex, the signal has already undergone a number of analyses by such brain structures as the superior olivary complex, the inferior colliculus, and the thalamus (Koelsch & Siebel 2005). Accordingly, alarm signals to auditory events that suggest "danger" may be emitted as early as at the level of the inferior colliculus. Brain stem reflexes are "hard-wired." Thus, for instance, the perceived pleasantness and unpleasantness of sensory consonance and dissonance reflect how the hearing system divides frequencies into critical bandwidths: If the frequency separation of two tones is either very small or larger than the critical bandwidth, the tones will be judged as consonant. If the separation is about one-fourth of a critical band, the tones will be judged as maximally dissonant (Lipscomb & Hodges 1996). Sensory dissonance is suggestive of "danger" in natural environments, because it occurs in the "threat" and "warning" calls of many species of animals (Ploog 1992). Dissonance may thus have been selected by evolution as an unlearned negative reinforcer of behavior (Rolls 2007). Brain stem reflexes are quick and automatic, as shown by evidence of rapid and pre-attentive categorization of subtle timbral differences associated with different emotions (Goydke et al. 2004), and affective priming effects of consonant and dissonant chords (Sollberger et al. 2003). Brain stem reflexes to music may function even prior to birth, as indicated by findings that playing loud music to fetuses produces heart rate accelerations and increased motor responses, whereas soft music produces moderate heart rate decelerations and reduced movement (for a review, see Lecanuet 1996). The arousal-inducing properties of music were investigated and theorized by Berlyne (1971).7 According to Berlyne's theory, listeners will prefer musical stimuli that induce an "optimum" level of physiological arousal. If the "arousal potential" of the music is too high, listeners will reject the music. Similarly, if the arousal potential is too low, listeners will reject the music. Hence, Berlyne hypothesized that listeners' preferences are related to arousal (or some aspect of it, such as speed or loudness) in the form of an inverted U-shaped curve (the Wundt curve). Berlyne's theory has received some empirical support from experimental studies (for a review, see North & Hargreaves 1997). In addition, several studies have shown that listeners use music to regulate their arousal in order to obtain optimal arousal (DeNora 2001; Thayer 1996). However, what is judged as "optimal" by a listener varies depending on the situation (North & Hargreaves 1997) and on personality characteristics of the listener (McNamara & Ballard 1999). Thus, it may be difficult to predict arousal responses without taking individual and contextual factors into consideration. Brain stem reflexes can explain the stimulating and relaxing effects of music, and how mere sounds may induce pleasantness and unpleasantness. However, it is unclear how the mechanism could explain the induction of specific emotions.

3.1.2. Evaluative conditioning. This refers to a process whereby an emotion is induced by a piece of music simply because this stimulus has been paired repeatedly with other positive or negative stimuli. Thus, for instance, a particular piece of music may have occurred repeatedly together in time with a specific event that always made you happy (e.g., meeting your best friend). Over time, through repeated pairings, the music will eventually come to evoke happiness even in the absence of the friendly interaction. Evaluative conditioning (EC) is also referred to as affective learning, fear conditioning, emotional conditioning, and preference conditioning, but regardless of the term used, it seems to refer to the same phenomenon – a special kind of classic conditioning that involves the pairing of an initially neutral conditioned stimulus (CS) with an affectively valenced, unconditioned stimulus (US). After the pairing, the CS acquires the ability to evoke the same affective state as the US in the perceiver. Regardless of the term used, and of whether positive (e.g., liking) or negative (e.g., fear) states are conditioned, the process appears to have the same characteristics. Firstly, an EC may occur even if the participant is unaware of the contingency of the two stimuli (Field & Moore 2005; Hammerl & Fulcher 2005), which may not be true for other forms of classic conditioning (e.g., Lovibond & Shanks 2002). Indeed, it has been reported that an EC response can be both established and induce emotions without awareness (Martin et al. 1984; O¨ hman & Mineka 2001). Attention may even hamper effects of EC (De Houwer et al. 2005). This characteristic of EC has some interesting implications for musical experiences: It has been found that, sometimes, pieces of music induce emotions for no apparent reason (e.g., Juslin et al., in press). EC offers a possible explanation of this phenomenon. Furthermore, it generates the prediction that we might react with positive emotions to music that we think is of poor quality simply because the music has occurred repeatedly in previous pleasant situations. Such effects could presumably be demonstrated in listening experiments that use established paradigms for conditioning (Lavond & Steinmetz 2003), along with indirect measures of emotion (Table 3). Secondly, EC seems to be more resistant to extinction than are other forms of classic conditioning (LeDoux 2002). (Extinction refers to the process whereby postacquisition presentations of the conditioned stimulus, e.g., a specific piece of music, without the unconditioned stimulus, e.g., a happy event, leads to a gradual elimination of the previously acquired response; De Houwer et al.

2001, p. 858). Hence, once a piece of music has been strongly associated with a specific emotional outcome, this association could be quite persistent. Thirdly, EC seems to depend on unconscious, unintentional, and effortless processes (De Houwer et al. 2005; LeDoux 2002), which involve subcortical brain regions such as the amygdala and the cerebellum (Balleine & Killcross 2006; Johnsrude et al. 2000; Sacchetti et al. 2005). Although this mechanism seems to be generally acknowledged as a powerful source of emotions in music (see Berlyne 1971, p. 33; Dowling & Harwood 1986, pp. 204 –5; Hanslick 1854/1986; Sloboda & Juslin 2001, pp. 94 –95), very few studies so far have investigated EC responses to music. There are two possible reasons for this. Firstly, the responses are often highly personal and idiosyncratic (i.e., different listeners have different learning histories, with a few notable exceptions), which may seem to render them more difficult to study systematically. Secondly, because EC responses are not strongly related to the music as such – the music merely acts as a conditioned stimulus – they have been regarded as "irrelevant" responses to music and, thus, unworthy of study (Hanslick 1854/1986). However, if EC is a strong and frequent source of music-induced emotions in everyday life, the mechanism should be part of a credible framework for musical emotions. Which element of the musical stimulus that best serves as the conditioned stimulus as well as its degree of generalization and discrimination are issues that remain to be investigated. The melody (or theme) of the music could be especially effective, though studies of fear conditioning have shown that even a simple tone can be effective in establishing a fear association (LeDoux 2002). Blair and Shimp (1992) reported that when participants were originally exposed to a piece of music in an unpleasant situation, they later held a less favorable affective attitude towards a product presented together with the music than did participants who had not been pre-exposed to the same conditioning. Similarly, Razran (1954) found, in a series of experiments, that affective attitudes (as indexed by ratings and characterizations) towards pieces of music, paintings, and photographs could be modified by free lunches – at least when participants were unaware of the aim to condition them. It should be noted that music commonly occurs in situations where music listening is not the only or the primary activity (Juslin & Laukka 2004; Sloboda & O'Neill 2001) and where subtle conditioning processes outside of awareness could easily occur. Thus, it seems plausible that EC could account for many of our emotional responses to music in everyday life.8 3.1.3. Emotional contagion. This refers to a process whereby an emotion is induced by a piece of music because the listener perceives the emotional expression of the music, and then "mimics" this expression internally, which by means of either peripheral feedback from muscles, or a more direct activation of the relevant emotional representations in the brain, leads to an induction of the same emotion. For instance, the music might have a sad expression (e.g., slow tempo, low pitch, low sound level) that induces sadness in the listener (Juslin 2001). Evidence that music with a specific emotional expression can give rise to the same emotion in the listener has been reported in several studies (e.g., Kallinen & Ravaja 2006; Lundqvist et al., in press). This mechanism is related to the vast literature on emotional expression in music. It has been suggested that expression may be an "iconic" source of emotion (Dowling & Harwood 1986). The term iconic refers to the fact that the structures of music show formal similarities to the structures of expressed (Kivy 1980) or felt (Langer 1957) emotions. Numerous studies have shown that listeners are able to perceive specific emotions in pieces of music (Gabrielsson & Juslin 2003), and that even children as young as 3 or 4 years may be able to recognize basic emotions in music (Cunningham & Sterling 1988). But how exactly does perception of an emotion in the music lead to induction of the same emotion in the listener? Lipps (1903) was probably the first to postulate a mechanistic account of empathy, where the perception of an emotional gesture in another person directly induces the same emotion in the perceiver without any appraisal process (e.g., Preston & de Waal 2002). Modern research has confirmed that people may "catch" the emotions of others when seeing their facial expressions (Hatfield et al. 1994) or hearing their vocal expressions (Neumann & Strack 2000). Previous research on emotional contagion has focused mostly on facial expression. For example, people exposed to pictures of facial expressions of emotions spontaneously activate the same face muscles (as shown by electromyography) even when the pictures are processed outside of awareness. Moreover, they report feeling the same emotions (Dimberg et al. 2000). It has been argued that emotional contagion facilitates the mother-infant bond (Darwin 1872), as well as social interaction in general (Preston & de Waal 2002). In support, such contagion seems to create affiliation and liking (e.g., Lakin et al. 2003), which is arguably beneficial for social interaction. Recent research has suggested that the process of emotional contagion may occur through the mediation of so-called mirror neurons discovered in studies of the monkey premotor cortex in the 1990s (e.g., di Pellegrino et al. 1992). It was found that the mirror neurons discharged both when the monkey carried out an action and when it observed another individual (monkey or human) performing a similar action (Rizzolatti & Craighero 2004). These mirror neurons appeared to be located in the ventral premotor regions of the brain, regardless of the type of stimulus. Direct evidence for the existence of mirror neurons in humans is lacking so far, but a large amount of indirect evidence suggests that a mirrorneuron system exists also in humans. For example, several studies have shown that when individuals observe an action carried out by another individual, the motor cortex may become active in the absence of overt motor activity (Rizzolatti & Craighero 2004). De Gelder et al. (2004) reported that observing fear expressions in body language increased activity in motor areas of the brain, in addition to those associated with emotion, which is consistent with the notion of a mirror mechanism. How may emotional contagion be applied to music? Because music often features expressive acoustical patterns similar to those that occur in emotional speech (for a review, see Juslin & Laukka 2003), it has been argued that we become aroused by the voice-like aspects of music via a process in which a neural mechanism responds quickly and automatically to certain stimulus features, which leads us to mimic the perceived emotion internally. According to the super-expressive voice theory (e.g., Juslin 2001), what makes a particular performance of music on, say, the violin, so expressive is the fact that it sounds a lot like the human voice, whereas at the same time it goes far beyond what the human voice can do in terms of speed, intensity, and timbre. For example, if human speech is perceived as "angry" when it has fast rate, loud intensity, and a harsh timbre, a musical instrument might sound extremely "angry" by virtue of its even higher speed, louder intensity, and harsher timbre. This aspect should render music a particularly potent source of emotional contagion. While the notion of emotional contagion admittedly remains speculative in relation to music, a recent functional magnetic resonance imaging (fMRI) study by Koelsch et al. (2006) indicated that music listening activated brain areas related to a circuitry serving the formation of premotor representations for vocal sound production (no singing was observed among the participants). Koelsch et al. concluded that this could reflect a mirror-function mechanism, and the findings render tentative support to the notion that listeners may mimic the emotional expression of the music internally. Precursors of emotional contagion via facial and vocal expression have been observed as early as the first year of development (Soussignan & Schaal 2005), but remain to be explored in relation to music. We assume that emotional contagion mainly involves "basic" emotions with distinct nonverbal expressions (Juslin & Laukka 2003; Laird & Strout 2007). Some authors have pointed out that music does not sound very much like vocal expressions, except in special cases (Davies 2001). Why, then, should we respond to music as though it were a vocal expression? One possible explanation is that the expressions are processed by a domain-specific and autonomous "module" of the brain (Fodor 1983), which reacts to certain

features in the stimulus. This module does not “know” the difference between a vocal expression and other acoustic expressions, and will react in the same way (e.g., registering anger) as long as certain cues (e.g., high speed, loud dynamics, rough timbre) are present in the stimulus. This modular theory remains to be tested, but some support, in terms of Fodor’s (1983) suggested characteristics of a module, was summarized by Juslin and Laukka (2003, p. 803). Thus, it is plausible that listeners’ emotions to music sometimes reflect social, modular responses to the voice-like and emotion-specific acoustic patterns of the music.9
3.1.4. Visual imagery. This refers to a process whereby an emotion is induced in a listener because he or she conjures up visual images (e.g., of a beautiful landscape) while listening to the music. The emotions experienced are the result of a close interaction between the music and the images.10 Visual imagery is usually defined as an experience that resembles perceptual experience, but that occurs in the absence of relevant sensory stimuli. The study of visual imagery has an old, but confused, status in psychology, marked by much controversy (Kolers 1983). Much of the controversy has concerned its ontological status: Does visual imagery involve a distinctively “pictorial” representation of events in mind, or does it reflect a “propositional” representation? Kosslyn (1980) argued that the images themselves are quasi-pictorial representations, whereas the generative, long-term structure of imagery is propositional (e.g., similar to a TV set whose output is a picture, but whose mechanisms for generating this picture are better expressed in discrete symbols of electronics). The pictorial view is supported by findings that many of the brain regions that are activated during visual perception are similarly activated when a person is involved in visual imagery (Farah 2000; Ganis et al. 2004). In accordance with theories of symbolic development (Piaget 1951), one could assume that visual imagery develops during the preschool period, when children create increasingly complex symbolic representations of the external world (Ga¨rdenfors 2003; for empirical evidence, see Kosslyn et al. 1990). Mental images have been regarded as “internal triggers” of emotions (Plutchik 1984), and studies have revealed that visual imagery associated with different emotions involves different imagery contents (Lyman & Waters 1989), as well as different patterns of physiological response (Schwartz et al. 1981). It has been suggested that musical stimuli are especially effective in stimulating visual imagery (Osborne 1980; Quittner & Glueckauf 1983), and a few studies have indicated that imagery can be effective in enhancing emotions to music (Band et al. 2001 –2002; see also Va¨stfja¨ll 2002a, p. 183). The precise nature of this visual imagery process remains to be determined, but listeners seem to conceptualize the musical structure through a metaphorical nonverbal mapping between the music and so-called image-schemata grounded in bodily experience (Bonde 2006; Lakoff & Johnson 1980); for example, hearing melodic movement as “upward.” We argue that listeners respond to mental images much in the same way as they would to the corresponding stimuli in the “real” world – for example, reacting with positive emotions to a beautiful nature scene (see Figure 2.4. in Bradley & Lang [2007], for examples of affective responses to various pictures).   Osborne (1989) reported certain recurrent “themes” in visual imagery to music, such as nature scenes (e.g., sun, sky, ocean) and out-of-body experiences (e.g., floating above the earth), but the results were probably affected by the particular musical style used (“spacey, synthesized electronic music with simple structure, some free form, and much repetition,” p. 134). Indeed, it has been suggested that certain musical characteristics, such as repetition, predictability in melodic, harmonic, and rhythmic elements, and slow tempo, are especially effective in stimulating vivid imagery (McKinney & Tims 1995). A special feature of the imagery mechanism is that the listener is very much able to influence the emotions induced by the music. Although images might come into the mind unbidden, in general a listener may conjure up, manipulate, and dismiss images at will. Larson (1995) has speculated that music offers a medium for adolescents, in

particular, through which they may conjure up strong emotional images around which a temporary sense of self can cohere. The music is like a “fantasy ground” for exploring possible selves during the important process of resolving a personal identity in late adolescence (see also Becker 2001; DeNora 2001). Visual imagery in relationship to music has been discussed most extensively in the context of music therapy (Toomey 1996). Helen Bonny developed a method, Guided Imagery and Music (GIM), where a “traveler” is invited to “share” his or her images as they are experienced in real time during a pre-programmed sequence of music (see Bonny & Savary 1973). Music-induced imagery may produce a state of deep relaxation, with health benefits such as reduced cortisol levels (McKinney et al. 1997). However, there seem to be large individual differences with regard to the ability to generate visual images (Marks 1973). Visual imagery may occur in connection with episodic memories (discussed in sect. 3.1.5), although it seems necessary to distinguish the two mechanisms, because a musical experience may evoke emotions when a listener conjures up images of things and events that have never occurred, in the absence of any episodic memory from a previous event in time. Moreover, visual imagery is more strongly influenced or shaped by the unfolding structure of the music than is episodic memory, for which the music mainly serves a retrieval cue. In the words of Meyer (1956), “it seems probable that ... image processes play a role of great importance in the musical affective experiences of many listeners” (p. 258). 3.1.5. Episodic memory. This refers to a process whereby an emotion is induced in a listener because the music evokes a memory of a particular event in the listener’s life. This is sometimes referred to as the “Darling, they are playing our tune” phenomenon (Davies 1978). Research has suggested that music often evokes memories (e.g., Gabrielsson 2001; Juslin et al., submitted; Sloboda 1992). When the memory is evoked, so also is the emotion associated with the memory (e.g., Baumgartner 1992). Such emotions can be rather intense, perhaps because the physiological reaction patterns to the original events are stored in memory along with the experiential content, as proposed by Lang (1979). Baumgartner (1992) reported evidence that episodic memories evoked by music tend to involve social relationships (e.g., past or current romantic partners, time spent with friends).11 However, the memories can involve all kinds of events, such as vacations, movies, music concerts, a victory in a boxing match, the death of a grandfather, or childhood memories (Baumgartner 1992; see further examples in Gabrielsson 2001, p. 439). Indeed, music accompanies most important human activities from the cradle to the grave (Gregory 1997), although due to childhood amnesia listeners are unlikely to recall much from the first years of their life (Reisberg & Heuer 2004). Children’s ability to recall and converse about episodic memories develops slowly across the preschool years (e.g., Fivush & Sales 2004; Perner & Ruffman 1995), and episodic memory is the type of memory that begins to decline first as a result of aging (e.g., Tulving 2002). Both kinds of developmental trends should be observable in listeners’ emotional reactions to music based on episodic memory. Episodic memory is one of the induction mechanisms that have commonly been regarded as less “musically relevant” by music theorists, but recent evidence suggests that it could be one of the most frequent and subjectively important sources of emotion in music (see Juslin et al., in press; Sloboda & O’Neill 2001). Many listeners actively use music to remind them of valued past events, which indicates that music can serve an important nostalgic function in everyday life. The music may help to consolidate a listener’s self-identity. Furthermore, a retrospective memory study by Sloboda (1989) has indicated that strong and positively valenced childhood memories of musical events may be important in determining which individuals will pursue a high level of involvement in music later in life. In previous research, most researchers have regarded both conditioning and episodic memory as cases of memory-based or associative mechanisms (Dowling & Harwood 1986; Scherer & Zentner 2001; Sloboda & Juslin 2001). However, there are good reasons to view these as partly separate and independent mechanisms. Although evaluative conditioning is a form of memory, episodic memory is different in that it always involves a conscious recollection of a previous event in time that preserves much contextual information. Also, unlike conditioning, episodic memory appears to be organized in terms of a hierarchical structure with three levels: lifetime periods, general events, and event-specific knowledge (Conway & Rubin 1993). Furthermore, the two kinds of memory have partly different process characteristics and brain substrates (sect. 3.2). Hence, they should be distinguished in research on musical emotions in order to not yield inconsistent findings. One important characteristic of episodic memory, more generally, is the common finding that people tend to recall more memories from their youth and early adulthood (15 – 25 years of age) than from those periods that precede or follow it. This is referred to as the reminiscence bump, and may be explained by the fact that many self-defining experiences tend to occur at this stage of life development (Conway & Holmes 2005, p. 513). In this context, it should be noted that music seems to play a very prominent role in adolescents' lives and, particularly, in relation to the development of a self-identity (Laiho 2004). Hence, we would expect episodic memories associated with music to be particularly emotionally vivid and frequent with regard to music from young adulthood, as indeed seems to be the Juslin & Va¨stfja¨ll: Emotional responses to music BEHAVIORAL AND BRAIN SCIENCES (2008) 31:5 567 case. Schulkind et al. (1999) found that older adults preferred, knew more about, as well as had stronger emotional responses to music popular during their youth than to music popular later in life. Further, both younger and older adults were more likely to retrieve a spontaneous autobiographical memory when they were cued by a song that moved them emotionally. Holbrook and Schindler (1989) also found that participants showed the greatest liking for music that was popular during their youth. Hence, one reasonable prediction could be that emotional reactions to music involving episodic memory more commonly involve events from one's youth and early adulthood than from other periods in one's life. Empirical evidence suggests that nostalgia may be one of the more common responses to music (Juslin et al., in press). 3.1.6. Musical expectancy. This refers to a process whereby an emotion is induced in a listener because a specific feature of the music violates, delays, or confirms the listener's expectations about the continuation of the music. For instance, the sequential progression of E-F# sets up the musical expectation that the music will continue with G# (Sloboda 1992). If this does not happen, the listener may become, for instance, surprised. This psychological mechanism has been most extensively theorized by Meyer (1956), in what could well be the most cited volume on music and emotion ever. Meyer's theory was inspired by Aiken's (1950; cited in Meyer 1956, p. 25) ideas regarding musical expectations, as well as by contemporary psychological theories of perception (e.g., the Gestalt school) and emotions (e.g., Dewey's conflict theory of emotions). However, Meyer was the first theorist to develop the notion of musical expectancy in a convincing and thorough manner. It should be noted that musical expectancy does not refer to any unexpected event that might occur in relationship to music. A simple form of unexpectedness (e.g., the sudden onset of a loud tone) would instead be an example of the mechanism called brain stem reflex (see sect. 3.1.1). Similarly, more general surprising features of an event that involves music (e.g., that a concert was better than the listener had expected) would instead be an example of the cognitive appraisal mechanism. Musical expectancy refers to those expectancies that involve syntactical relationships between different parts of the musical structure (Narmour 1991; Patel 2003). Like language, music consists of perceptually discrete elements, organized into hierarchically structured sequences according to "well-formedness" rules. Thus, it is a common view among music theorists that most musical styles are, in principle, describable by a grammar (Lerdahl & Jackendoff 1983). It is only through the perception of this syntax that the relevant musical expectations arise. These expectations are based on the listener's previous experiences of the same musical style

(Carlsen 1981; Krumhansl et al. 1999). Emotional reactions to music are induced when the listener's musical expectations are somehow disrupted, for instance, by new or unprepared harmony (for examples, see Steinbeis et al. 2006). The musical expectancy mechanism is notable for its strong dependence on learning (Meyer 1956). Evidence that musical expectancies depend much on cultural learning comes from the fact that such responses are not shared by young children. For instance, Sloboda (1989) noted that 5-year-old children were unable to reject gross chordal dissonances as "wrong." By the age of 9, however, they were overtly laughing at the "wrong" chords and scoring at an adult level. Another test in the same study focused on the ordering of the chords that could be either conventional (ending with a cadence) or "scrambled" (ending without resolution). On this test, children did not achieve adult levels of performance until the age of 11. Evidence of age differences have also been reported with regard to sensitivity to tonal hierarchies (Krumhansl & Keil 1982) and implied harmony (Trainor & Trehub 1994). Although the ability to detect syntactical violations can be observed early (Jentschke et al. 2005), responses arising from musical expectancies also depend on sufficient exposure to the musical style in question. Meyer discussed emotions in an approach characteristic for his time (i.e., as undifferentiated arousal; see Duffy 1941), but he observed that mere arousal through interruption of musical expectancies has little value. To have any aesthetic meaning, the arousal or tension must be followed by a satisfying resolution of the tension. In fact, Meyer (1956) appeared open to the possibility that this musical play with expectations may lead to the induction of specific emotions, such as apprehension/anxiety (p. 27), hope (p. 29), or disappointment (p. 182), but these ideas have still not been tested. In fact, while highly influential and respected, Meyer's theory has not stimulated much research on musical emotions (but see Sloboda 1991), perhaps because the theory is difficult to test. For example, a piece of music could produce several different expectations at different hierarchical levels of the music, and these expectations could also vary for different listeners. Therefore, it is difficult to understand or predict exactly what the listener is responding to in a particular situation. In recent years, however, researchers have developed novel models of expectancy (Hellmuth Margulis 2005; see also Huron 2006), which should make it more feasible to test predictions experimentally. Neurophysiological methods might be useful in this regard. It has been found that violations of musical expectancy activate the same brain areas that have been previously implicated in violations of syntax in language (Koelsch et al. 2002a; Maess et al. 2001). Patel (2003; 2008, Ch. 5) has therefore suggested that syntactical processing in both language and music shares a common set of processes for syntactical integration (localized in Broca's area) that operate on distinct structural representations for music and language. Evidence that expectancy violations can induce emotions was recently reported by Steinbeis et al. (2006). Thus, it seems likely that some of our emotions to music reflect the disruption of style-specific expectations. 3.2. How can the mechanisms be distinguished? How may we describe the relationships among the different mechanisms? We propose that it could be useful to think of the mechanisms as consisting of a number of (more or less) distinct brain functions that have developed gradually and in a specific order during the evolutionary process, from sensations (brain stem reflexes) to syntactical processing (musical expectancy) (Ga¨rdenfors 2003). We regard the mechanisms as information-processing devices at various levels of the brain that use various means to track significant aspects of the environment, and that may produce conflicting outputs (Griffiths 2004; Teasdale 1999).12 They all take music as their "object", treating the music – rightly or wrongly – as featuring some kind of information that warrants an emotional response. However, note that the emotion induced is not the result of an appraisal of the music on several dimensions relative to the listener's motives, needs, or goals. Because the mechanisms depend on distinct brain functions with different evolutionary origins, each mechanism should possess unique characteristics. Hence, Table 4 presents a set of preliminary hypotheses regarding the characteristics of each mechanism. The mechanisms are listed in the approximate order in which they can be hypothesized to have appeared during evolution (Ga¨rdenfors 2003; see also Joseph 2000; Reber 1993; Tulving 1983).13 The hypotheses can be divided into two subgroups: The first subgroup concerns characteristics of the psychological mechanism as such. Thus, Survival value of brain function describes the most important benefit that each brain function brought to those organisms that possessed this brain function.14 Visual imagery, for example, enabled an organism to "simulate" important events internally, through self-conjured images in the absence of direct sensory input, which meant that overt and potentially dangerous action plans could be tested and evaluated before they were implemented in the external world. Information focus specifies broadly the type of information that each mechanism is processing. For instance, evaluative conditioning (EC) focuses on covariation between events. Ontogenetic development concerns the approximate time in human development when respective mechanisms might begin to have a noticeable effect on emotional responses to music. Brain stem reflexes to music could be functional even prior to birth, whereas responses involving musical expectancy do not develop fully until somewhere between the ages of 5 and 11. Key brain regions describes those regions of the brain that have been most consistently associated with each mechanism in imaging studies. Note that musical emotions can be expected to involve three kinds of brain regions: (1) regions usually involved when music is perceived, such as the primary auditory cortex; (2) regions usually involved in the conscious experience of emotions regardless of the precise cause of the emotions (e.g., the rostral anterior cingulate and the medial prefrontal cortex; e.g., Lane 2000, pp. 356–358); and (3) regions involved in emotional information-processing that partly differ depending on the mechanism inducing the emotion. Hence, although musical emotions are likely to involve several brain regions (Peretz 2001), the hypotheses in Table 4 focus on the last type of regions, especially those that can help researchers to discriminate among mechanisms. For instance, the experience of conscious recollection of an episodic memory is associated with activation of the hippocampus brain region. Cultural impact/learning refers to the relative extent to which each mechanism is influenced differently by music that varies from one culture to another. For example, brain stem reflexes reflect primarily "hardwired" responses to simple features that are not affected much by learning, whereas musical expectancy reflects learned schemata about specific styles of music that differ from one culture to another and that make listeners from different cultures react differently to the same piece of music. A second subgroup of characteristics (see Table 4) concerns the precise nature of the emotion induction process associated with each mechanism. Induced affect specifies which affective states might be expected to be induced, depending on the mechanism. For example, whereas emotional contagion might be expected to induce only "basic" emotions, which have more or less distinct nonverbal expressions of emotion, visual imagery might be expected to induce all possible human emotions. Induction speed refers to how much time each mechanism requires, in relation to other mechanisms, for an emotion to occur in a particular situation. For example, brain stem reflexes can induce emotions very quickly (in less than a second), whereas musical expectancy can be expected to require more time (at least a number of seconds) because some of the musical structure has to unfold in order for any musical expectation to occur that can be confirmed or violated. Degree of volitional influence refers to the extent to which the listener himself or herself could actively influence the induction process (e.g., through focus of attention, active recall, self-activation). For instance, reactions that involve EC may be involuntary and automatic, whereas reactions that involve visual imagery may be strongly influenced by the way the listener actively chooses to entertain some inner images and themes rather than others. Availability to consciousness is the extent to which at least some aspects of the induction process are available to the listener's consciousness, so that the listener may be able to explain his or her response. For example, if a piece of music evokes a strong episodic memory, the listener will have a conscious recollection of a previous event and some inkling of the reasons (e.g., the appraisal) that made this event evoke the emotion that is now re-experienced. Conversely, EC responses to music can be both learned and aroused outside conscious awareness. Therefore, a listener who experiences a musical emotion via this mechanism could be completely unable to explain any aspect of the induction process. Modularity refers to the extent to which the induction process of each mechanism functions as an independent and information-encapsulated module that may be activated in parallel with other psychological processes. 15 For instance, emotional contagion can be described as highly modular, because it may be activated independently of other processes, and is not influenced by the information of other modules (e.g., we respond to the expressive characteristics of the music as if they came from a person expressing emotions in the voice even if we know, at some cognitive level, that the music is not a voice). Dependence on musical structure refers to the extent to which the induction depends on the precise structure or style of the music that the listener is hearing. At one extreme, the structure of the music is not very important as such – it mainly functions as a "retrieval cue." This is the case for evaluative conditioning and episodic memory. At the other extreme, the precise pattern of the musical structure strongly determines the nature of the induced response. This is the case for musical expectancy. Empirical findings of relevance to the hypotheses shown in Table 4 could come from a broad range of research domains such as memory, development, emotional expression, evolutionary psychology, neuropsychology, learning, clinical psychology, and psychophysiology, as well as music psychology and music therapy. A selected number of representative sources that render theoretical or empirical support to each hypothesis have been included in Table 4. As much as possible, we have tried to include sources that involve music, although most sources focus on the mechanism more generally, as explored in fields other than music. Hence, further research is needed to test most of the hypotheses in regard to music. We acknowledge that some of the hypotheses are imprecise and mainly descriptive. This reflects the current lack of research on these issues. However, we argue that even simple predictions in terms of "high" and "low" can be tested in experiments that contrast one mechanism against another. Such tests could help to render the hypotheses more specific. We propose that the testing of the new framework could involve an approach consisting of an interplay between field studies (diary studies, questionnaires) and experimental studies. Field studies that enable researchers to study listeners' emotional reactions to music in their natural environment could generate hypotheses about possible causal factors. These factors could then be formalized in a preliminary model, which is evaluated in experiments. Table 4. Hypotheses regarding the characteristics of six psychological mechanisms through which music might induce emotions Nature of mechanism Characteristic Mechanism Survival value of brain function Information focus Ontogenetic development Brain stem reflex Focusing attention on potentially important changes or events in the close environment (Joseph 2000) Extreme or rapidly changing basic acoustic characteristics (Berlyne 1971, p. 69) Prior to birth (Lecanuet 1996; Shahidullah & Hepper 1993) Evaluative conditioning Being able to associate objects or events with positive and negative outcomes (Ga¨rdenfors 2003) Covariation between events (Reber 1993) Prior to birth (Feijoo 1981; Hepper 1996; Spelt 1948) Emotional contagion Enhancing group cohesion and social interaction, e.g., between mother and infant (Wilson 1975) Emotional motor expression (Lipps 1903) First year (Field et al. 1982; Sagi & Hoffman 1976; Simner 1971) Visual imagery Permitting internal simulations of events that substitute for overt and risky actions (Ga¨rdenfors 2003) Self-conjured visual images (Kosslyn 1980) Preschool years (Ga¨rdenfors 2003; Kosslyn et al. 1990; Marmor 1975; Piaget 1951) Episodic memory Enabling conscious recollections of previous events and binding the self to reality (Conway & Holmes 2005) Personal events in particular places and at particular times (Tulving 2002) 3 – 4 years (Fivush & Sales 2004; Perner & Ruffman 1995) Musical expectancy Facilitating symbolic language with a complex semantics (Schoenemann 1999) Syntactic information (Patel 2003) 5 – 11 years (Krumhansl & Keil 1982; Sloboda 1989: Trainor & Trehub 1994) Nature of mechanism Characteristic Mechanism Key brain regions Cultural impact/learning Brain stem reflex Reticular formation in the brain stem, the intralaminar nuclei of the thalamus, the inferior colliculus (Brandao et al. 1993; Kinomura et al. 1996; Martin 1975) Low (Lipscomb & Hodges 1996; Plomp & Levelt 1965; Zentner & Kagan 1996) Evaluative conditioning The lateral nucleus of the amygdala, and the interpositus nucleus of the cerebellum (Fanselow & Poulus 2005; Johnsrude et al. 2000; LeDoux 2002; Sacchetti et al. 2005) High (Berlyne 1971, p. 139; De Houwer et al. 2005) Emotional contagion Mirror neurons in the premotor regions, the right inferior frontal regions, and the basal ganglia (Adolphs et al. 2002; di Pellegrino et al. 1992; Koelsch et al. 2006) Low (Juslin & Laukka 2003; Preston & de Waal 2002) Visual imagery Spatially mapped regions of the occipital cortex, the visual association cortex, and (for image generation) the left temporooccipital regions (Farah 2000; Ganis et al. 2004) High (Ga¨rdenfors 2003) Episodic memory The medial temporal lobe, especially the hippocampus, and the right anterior prefrontal cortex (Fletcher et al. 1998; Nyberg et al. 1996; Schacter et al. 1996) (applies to memory retrieval) High (Conway & Holmes 2005) Musical expectancy The left perisylvian cortex, Broca's area, and the dorsal region of the anterior cingulate cortex (Brown et al. 2000; Maess et al. 2001; Ni et al. 2000; Somerville et al. 2006) High (Carlsen 1981; Huron 2006, p. 359; Krumhansl et al. 1999; Kuhl 2000; Meyer 1956, p. 61) (continues) These experiments may suggest the need for further knowledge about specific factors, wherefore further field studies may be needed. By combining the approaches, we may eventually arrive at general principles that can form the basis of a more detailed model of the induction process, featuring a description of the time-course and the interrelationships of the different mechanisms. Field studies are required, because if there are several mechanisms that can induce musical emotions, and their importance varies depending on the situation, only by sampling a wide variety of situations can we hope to capture all the mechanisms. On the other hand, certain mechanisms, such as conditioning, may be difficult to demonstrate other than in a controlled laboratory setting. Field studies will have to focus on self-reports – although with the possible addition of ambulatory physiological measures (see Fahrenberg & Myrtek 1996). Laboratory studies may involve any combination of the measures listed in Table 2, as well as indirect measures (Table 3), to maximize the validity of conclusions about induced emotions. 4. Implications 4.1. Resolving previous disagreements One implication of the new framework is that it can resolve many disagreements in the field. Specifically, apparent contradictions of different approaches may be reconciled by observing that they focus on different psychological mechanisms. For example, one recurring theme in Table 4. (Continued) Nature of induction process Characteristic Mechanism Induced affect Induction speed Degree of volitional influence Brain stem reflex General arousal, unpleasantness versus pleasantness (Berlyne 1971; Lane 2000, p. 362; Va¨stfja¨ll, in press) High (Goydke et al. 2004) Low (Foss et al. 1998; Joseph 2000) Evaluative conditioning Basic emotions (Joseph 2000; LeDoux 2002; Olatunji et al. 2005) High (LeDoux 2002) Low (Martin et al. 1984; De Houwer et al. 2005) Emotional contagion Basic emotions (Juslin & Laukka 2003; Lane 2000, pp. 361– 63; Laird & Strout 2007) High (Dimberg & Thunberg 1998) Low (Neumann & Strack 2000; Dimberg et al. 2002) Visual imagery All possible emotions (Lane 2000, pp. 361– 63) Low (Bunt 2000;

Decety & Jeannerod 1995) High (Bonde 2006; Farah 2000; Kosslyn 1994; Larson 1995) Episodic memory All possible emotions, though especially nostalgia (Juslin et al., submitted; Wildschut et al. 2006) Low (Conway & Holmes 2005, p. 526) Medium (Conway & Holmes 2005; Tulving 1983) Musical expectancy Surprise, awe, pleasure, “thrills,” disappointment, hope, anxiety (Meyer 1956; Huron 2006) Low (Janata 1995) Low (Koelsch et al. 2002) Nature of induction process Characteristic Mechanism Availability to consciousness Modularity Dependence on musical structure Brain stem reflex Low (Joseph 2000; Sollberger et al. 2003) High (Lane 2000, p. 362; Joseph 2000; Raloff 1982) Medium (Berlyne 1971) Evaluative conditioning Low (Krosnick et al. 1992; LeDoux 2002; Martin et al. 1984) High (O¨ hman & Mineka 2001; Reber 1993) Low (Berlyne 1971, p. 138; LeDoux 2002) Emotional contagion Low (Neumann & Strack 2000; Dimberg et al. 2002) High (Juslin & Laukka 2003, p. 803; Neumann & Strack 2000) Medium (Juslin 2001) Visual imagery High (Kosslyn 1980) Low (Farah 2000; Kosslyn 1994, p. 29) Medium (Bonde 2006, Bunt 2000) Episodic memory High (Tulving 2002) Low (Conway & Holmes 2005; Ga¨rdenfors 2003) Low (Tulving 1983) Musical expectancy Medium (Sloboda 1991; 1992) Medium (Patel 2003) High (Huron 2006; Meyer 1956)   studies of music and emotion concerns the role of the person experiencing the emotion in the causal process. At one extreme is the case where the emotion is induced automatically and involuntarily (see Peretz 2001); at the other extreme is the case where the person uses the music as a resource in a more active process of emotion construction (see DeNora 2001; see also Meyer 1956, p. 11). These different views can be reconciled by observing that different mechanisms may be involved in each case: For instance, emotion induction through evaluative conditioning may really be direct and involuntary, whereas emotion induction through visual imagery may require active engagement of the listener. Only consideration of the mechanism involved can resolve this kind of argument. The framework can also help to explain some previous disagreements about which emotions music can induce in a listener. Some researchers argue that music can induce basic emotions (Krumhansl 1997), while others deny that this is possible (Scherer 2003). Some researchers argue that music can induce only “broad” positive and negative emotions (Clark 1983), whereas others argue that music can induce a range of both basic and complex emotions (Gabrielsson 2001). However, as shown in Table 4, which emotions music can induce could depend on the precise mechanism involved. For example, emotional contagion may be limited to more basic emotions, whereas visual imagery may induce all possible emotions. Hence, although certain emotions (e.g., happiness, sadness, calm, nostalgia) may be especially common with regard to music (Juslin et al., submitted), we should be careful not to rule out the induction of other emotions. Which emotions music can induce depends on the functions of the music in a particular situation (e.g., using music to relax or to evoke nostalgic memories), and may thus vary considerably from one context to another. This implies that researchers should avoid settling prematurely on a particular conceptualization of emotions (e.g., discrete, dimensional, component, or music-specific) before more data regarding the frequency of different emotions to music in everyday life have been collected.16 4.2. Musical emotions versus other emotions A recurrent issue in research on musical emotions is whether musical emotions are somehow qualitatively different from other emotions in everyday life. Swanwick (1985), for example, suggests that “emotions in ‘life’ ... and emotions we might experience as a result of engaging with music are not the same” (p. 29) (although he admits that “we are left trying to understand how ‘feelings’ in music relate to feelings in general,” p. 35). Similarly, Lippman (1953) warns researchers not to fall into the easy trap ... of assuming that because musical and extramusical events both evoke emotions, they must evoke the same emotions ... It is no more possible for a musical composition actually to arouse an instance of ... sadness than it is for the stimulus of such an emotion to arouse the very emotion produced by a musical composition. (Lippman 1953, p. 563) In contrast, the present framework implies that music recruits largely the same mechanisms as do other stimuli that induce emotions, and that the emotions evoked by music are largely similar. Some emotions may be more common than others in response to music, but the same is true of most other types of stimuli for emotions. For instance, some emotions might be more common than others in response to animals. Some emotions might be more common than others in response to sport events. Still, we would not propose a set of qualitatively unique emotions for each of these types of events. The burden of proof lies, in our view, on those who claim that there are music-specific emotions. Which are those emotions? What is their nature? So far we have not seen any evidence for the existence of music-specific emotions. A more parsimonious view is that there is one set of emotions that can be evoked in different ways and to different degrees by different stimuli. This view is consistent with findings from several studies suggesting that music evokes mostly the same emotions as other stimuli (Gabrielsson 2001; Juslin & Laukka 2004; Juslin et al., in press; Sloboda 1992; Wells & Hakanen 1991). What is unique about musical emotions is not the underlying mechanisms or the emotions they evoke, but rather the fact that music – unlike most other stimuli for our emotions in everyday life – is often intentionally designed to induce emotions, using whatever means available. 4.3. Relationships among mechanisms Another implication of the framework is that music could induce so-called mixed emotions, because different mechanisms might be activated simultaneously at different levels. Thus, for example, a piece of music could make a listener happy because of the happy expression of the piece (emotional contagion), but at the same time make the listener sad because the piece reminds him or her of a sad event in the past (episodic memory). Thus, the end result may be a bitter-sweet feeling of both happiness and sadness. Instances of mixed emotions have been commonly reported in the literature (e.g., Gabrielsson 2001, p. 440), but no explanation has been offered previously. The current explanation requires that more than one mechanism can be activated at the same time – which remains to be demonstrated. However, this issue is not unique for musical emotions: It remains unclear to what extent emotions can generally reflect the output from many mechanisms simultaneously (Izard 1993). In any case, the existence of mixed emotions speaks against using the "circumplex model" (Russell 1980) to study musical emotions, since it precludes feeling both sad and happy at the same time (Larsen et al. 2001). The possible co-activation of different psychological mechanisms – at least those that do not interfere with each other's information processing – suggests that an important task for future research is to examine possible interactions between different mechanisms. The mechanisms proposed here may seem simple: How can the extremely diverse music experiences reported by listeners in previous studies be reconciled with the simple theories proposed to account for these experiences? Part of the answer may be that the richness of our experiences comes from the complex interactions among these mechanisms, even within a single musical event. What mechanisms may be activated depends on several factors in the music (e.g., what information is available in the music?), the listener (e.g., is the listener's attention focused on the music?), and the situation (e.g., what are the circumstances of the listening context?). Thus, individual mechanisms may be expected to correlate with specific musical styles, Juslin & Va¨stfja¨ll: Emotional responses to music 572 BEHAVIORAL AND BRAIN SCIENCES (2008) 31:5 listener states, listener activities, and listening situations. We see no a priori reason to assume that the mechanisms cannot be activated in isolation from each other, since they focus on different types of information and engage partly different brain regions (see Table 4). However, this is an empirical question to be resolved by further research. One further implication is that emotions to music should change qualitatively across the life span, as the relative impact of the different psychological mechanisms changes. Preliminary evidence that there is a developmental trajectory for emotional responses to music has been reported (Schmidt et al. 2003; Sloboda 1989), but more systematic study of such life-span changes seems warranted (see Table 4, Ontogenetic development). We would expect that emotional reactions to music proceed in a more or less orderly progression during the development, where listeners' reactions first focus on acoustic sensations (i.e., brain stem reflexes), then on the emotional expression in the music (i.e., emotional contagion), and then on more stylistic or formal characteristics of the music (i.e., musical expectancy). It should be noted that Swanwick and Tillman's model of musical skill development proposes a somewhat similar developmental trajectory (Swanwick 2001). In both cases, the trajectory might reflect a gradual maturation of the child's cognitive functioning, as well as cultural learning. Thus, we would expect musical emotions to become increasingly multifaceted during the development, with increasing occurrence of mixed emotions (see also Larsen et al. 2007; Peters et al. 2007). 4.4. The cost of neglecting mechanisms The most important implication of the proposed framework for future research in the field is that it will not be sufficient to induce and study musical emotions in general. For data to contribute in a cumulative fashion to our knowledge, researchers must try to specify as far as possible the mechanism involved in each study. Otherwise, studies will produce results that are inconsistent, or that cannot be interpreted clearly. Lack of control with respect to mechanisms may also increase individual differences in listeners' responses, because without a systematic manipulation of stimuli, different listeners may activate different mechanisms to the "same" musical stimulus, with resulting differences in response (Table 4). While a neglect of mechanisms has been the rule rather than the exception, there are areas where this problem becomes particularly salient. A case in point is provided by the recent series of brain-imaging studies of musical emotions. Numerous brain regions have been implicated in these studies – including, but not limited to, thalamus, cerebellum, hippocampus, amygdala, cingulate cortex, orbitofrontal cortex, midbrain/periaqueductal gray, insula, Broca's area, nucleus accumbens, visual cortex, and supplementary motor areas (Bauer Alfredson et al. 2004; Blood & Zatorre 2001; Blood et al. 1999; Brown et al. 2004; Gosselin et al. 2006; Koelsch et al. 2006; Menon & Levitin 2005). However, different brain regions have been activated in different studies, without any clear explanation of why these differences occur. We would argue that the main problem is that that neuropsychological studies have tended to simply present "emotional music" to listeners without manipulating, or at least controlling for, the underlying induction mechanism.17 This makes it exceedingly difficult to understand what the obtained neural correlates actually reflect in each study ("It is not possible to disentangle the different subcomponents of the activation due to limitations of this experimental design", Bauer Alfredson et al. 2004, p. 165). Given the aim of studying emotional reactions to music, one would expect the manipulation of musical stimuli to be essential to the task. Yet, stimuli have been selected non-systematically (e.g., instrumental songs of the rembetika style, joyful dance tunes, listener-selected music). The fact that different studies have reported activations of different brain regions does suggest that different mechanisms were involved. But, after the fact, there is no way of knowing. This shows that musical emotions cannot be studied without regard to how they were induced. On the other hand, if researchers could manipulate separate induction mechanisms in future listening experiments, they would be better able to explain the obtained brain activation patterns. Indeed, to the extent that we can obtain systematic relations among mechanisms and brain regions, we might eventually be able to discriminate among the mechanisms based on brain measures alone. However, no study published so far has quite the specificity needed to contribute to that goal. 4.5. Implications for emotion research The present framework might have some broader implications, as well. Thus, for instance, the study of musical induction of emotions along the lines suggested here could benefit the field of emotion as a whole. A serious problem in studying emotions has been the methodological and ethical difficulties involved in inducing strong emotions in the laboratory. Many studies in the field of emotion either lack experimental control (when using naturalistic settings) or achieve only a limited variation in target emotions and limited ecological validity (when using laboratory settings) (see Parrott & Hertel 1999). Music could evade some of these problems by offering new paradigms for emotion induction, especially with regard to positive emotions, which have tended to be neglected in previous research. Musical structure is easy to manipulate in psychological experiments and is a frequent source of emotion in everyday life. Thus, studies of music could provide an additional source of evidence concerning emotions. The unique characteristics of the various induction mechanisms (see Table 4) will be crucial when researchers design experiments that aim to induce a specific emotion. Specifically, it is important that the study involves an induction procedure that allows for the induction of that emotion. Some procedures may limit the kind of emotions that can be induced depending on the mechanism involved (e.g., Table 4, Induced affect). Some mechanisms require particular acoustic characteristics in the stimulus (e.g., emotional contagion), others require a prolonged encoding phase (e.g., evaluative conditioning), and still others require sufficient listening time in order for a sufficient amount of structure to unfold (e.g., musical expectancy). Thus, to facilitate studies of musical emotions, we should try to create standard paradigms and tasks that reliably induce specific emotions in listeners through each of the mechanisms outlined here earlier. This would be analogous to the different tasks used to measure distinct memory systems (Tulving 1983). A more systematic and theoretically informed approach to the manipulation of musical stimuli would be a significant advance compared to the mostly intuitive selection of stimuli in current studies using music as an emotion-elicitation technique (Eich et al. 2007; Va¨stfja¨ll 2002a). Possible stimuli and procedures for inducing different kinds of musical emotions can already be found in the literature, although they need further evaluation and refinement. For instance, paradigms aimed at activating brain stem reflexes could rely on psycho-acoustic models that specify quantitative relationships between sound stimuli and auditory perception (Zwicker & Fastl 1999). Paradigms aimed at activating the evaluative conditioning mechanism could use established procedures from studies of conditioning (Lavond & Steinmetz 2003). Paradigms aimed at activating the emotional contagion mechanism could create stimuli based on similar emotion-specific patterns of acoustic cues in speech and music (Juslin & Laukka 2003, Table 7), perhaps also using timbres that are "voice-like," such as those of the cello and the violin. Paradigms aimed at activating the visual imagery mechanism could rely on extensive programs of music developed especially for the purpose of stimulating imagery to music in therapy (Bruscia & Grocke 2002, e.g., Appendices B–L). Paradigms aimed at activating the musical expectancy mechanism could rely on both stimuli and procedures that have already been used to explore syntactical processing in music perception (Koelsch et al. 2000). Perhaps the most difficult mechanism for musical emotion induction to activate in a controlled way in the laboratory is episodic memory, because the laboratory situation is not conducive to establishing the strong personal significance needed to encode an emotional episodic memory. To explore the mechanisms and test the hypotheses in Table 4 fully, we need not only be able to activate each mechanism. To separate the effects of different mechanisms, we must also be able to suppress or eliminate particular mechanisms in individual cases. Although space does not permit a detailed exposition of experimental set-ups in this target article, we propose that this could be done in two principal ways. Firstly, one could manipulate stimuli in such a way as to withhold or eliminate information required for a specific mechanism to be activated (the principle of information impoverishment). Musical structures are easy to manipulate, and there are sophisticated techniques in acoustics that enable researchers to standardize a stimulus with regard to certain acoustic features, while leaving others intact. Secondly, one could design the procedure in such a manner that it will prevent the type of information processing required for a particular mechanism to be activated (the principle of interference). This could be done in a number of ways. One approach could be to force listeners to allocate the cognitive resources needed for a specific mechanism to a task instead; for instance, one could use an experimental task that recruits attentional resources to such an extent that visual imagery, also dependent on these resources, will be made impossible. Another possibility could be to use a neurochemical interference strategy; for example, it has been shown that blocking of a specific class of amino acid receptors (N-methyl-D-aspartate or NMDA) in the lateral amygdala can interfere with the acquisition of evaluative conditioning (Miserendino et al. 1990). Yet another form of interference involves the use of transcranial magnetic stimulation (Pascual-Leone et al. 2002). By disrupting brain activity at crucial times and locations, one may prevent specific mechanisms from becoming activated by a musical stimulus. Another implication concerns the role of cognitive appraisal relative to other mechanisms. A common characteristic of human behavior is that it is multiply determined (Brunswik 1956). This is true also for emotions, although the possibility of multiple induction mechanisms that interact has been somewhat neglected in previous research (but see Izard 1993). It is usually assumed that appraisals account for the lion's share of emotions in everyday life, but there is little formal evidence so far to support this notion – primarily because it is difficult to test the notion using the type of "post hoc" self-reports of emotions that have dominated in studies of cognitive appraisal to date (Frijda & Zeelenberg 2001). A crucial question is to what degree the additional mechanisms described here play a role in non-musical emotional episodes. The present framework implies that there is no simple "one-to-one" relationship between cognitive appraisals and emotions. Instead, there are several mechanisms that – singularly or together – determine emotional outcomes, according to the precise conditions of the situation. Ellsworth (1994) acknowledges that musical emotions pose "a real threat to the generality of appraisals as elicitors of emotion" (p. 195). To the extent that a great deal of our emotional responses in everyday life involve mechanisms such as conditioning, contagion, and episodic memory, an approach similar to that advocated in this target article could be fruitful also in understanding nonmusical emotions. Does this mean that what we claim about music – that emotions cannot be studied without regard to how they were evoked – is true of non-musical emotions as well? To the extent that the received view is correct – namely, that non-musical emotions are mostly induced through cognitive appraisal (Ellsworth 1994; Scherer 1999) – the issue of controlling for the underlying mechanism may not be as important outside the musical domain. However, this is an empirical question that awaits further research. 5. Concluding remarks It could appear that our claim that musical emotions must be investigated with regard to their underlying mechanisms is uncontroversial, and that all music researchers would agree. Yet, this is not how research has been conducted, which is ultimately what counts. Studies thus far have produced data that are collectively confusing and internally inconsistent, mainly because researchers have been considering only the induced emotions themselves, instead of trying to manipulate the underlying mechanisms in a systematic manner. We argue that much progress may be achieved, provided that more rigorous theoretical and methodological approaches are adopted. Considering the crucial implications that such an endeavor could have for both basic and applied research in music psychology and psychology in general, this opportunity should not be missed. For instance, it has been increasingly recognized that music may have positive effects on physical health and subjective well-being (e.g., Khalfa et al. 2003; Pelletier Juslin & Va¨stfja¨ll: Emotional responses to music 574 BEHAVIORAL AND BRAIN SCIENCES (2008) 31:5 2004). We suggest that many of these effects are mediated by the emotions that the music induces. A better understanding of the mechanisms underlying these emotions could therefore be of great importance for applications, such as music therapy. Meyer (1956), one of the pioneers in this field, argued that “given no theory as to the relation of musical stimuli to affective responses, observed behavior can provide little information as to either the nature of the stimulus, the significance of the response, or the relation between them” (p. 10). In other words, amassing data on listeners’ emotional reactions to music is not fruitful, unless one is able to interpret these data in the light of an explanatory theory. In this target article, we have proposed a theoretical framework and a set of hypotheses that may aid researchers in exploring the manifold and different mechanisms that relate music to emotions – all musical emotions are not created equal. ACKNOWLEDGMENTS This research was supported by the Swedish Research Council through a grant to Patrik N. Juslin. Part of this article was first presented at the EuroScience Open Forum, Stockholm, Sweden, August 2004. We are grateful to John Sloboda, Barbara Finlay, Aaron Williamon, Petri Laukka, Simon Liljestro¨m, and a number of anonymous reviewers for useful comments on previous versions of the article. We dedicate this article to the memory of Leonard Meyer, who passed away on December 30th, 2007. NOTES 1. Musical emotions is used here as a short term for “emotions that are induced by music.” 2. Five of the articles occurred in both PsycINFO and RILM, which means that there were 37 non-overlapping articles across the two databases that mentioned a mechanism or discussed the induction process while reporting other types of findings. 3. We refrain from calling the information processing cognitive, because this term could give the misleading impression that we exclude subcortical mechanisms (see also Izard 1993). 4. It is noteworthy that these claims were made on rational rather than empirical grounds, and that the claims appear to be inconsistent with recent findings (see sect. 2). 5. We do not rule out the possibility that music could influence moods also (e.g., the repeated occurrence of noisy music in the background in combination with hunger might produce an irritated mood). However, we argue that the lion’s share of our affective responses to music are better characterized as emotions, although they are not always intense. Moods are more related to factors such as hunger, fatigue, weather, and accumulated events over a day (Thayer 1996). 6. The present framework focuses on the emotions evoked while listening to music, rather than the emotions that might be evoked while composing or performing music. The latter activities are likely to involve a somewhat different set of psychological processes. 7. Berlyne (1971) did not limit his work to the psychophysical properties (p. 69) considered here. He also discussed two other processes (i.e., conditioning and syntactic processes) that are treated separately in this article. 8. It should be noted that several composers have intentionally used this mechanism in their compositions (for examples, see Dowling & Harwood 1986, pp. 204– 205). 9. This could perhaps partly explain the documented tendency of some listeners to use music as a “social companion” to reduce feelings of loneliness (Juslin & Laukka 2004; Juslin et al., in press). 10. The focus here is on visual imagery, because we regard it as unlikely that listeners are able to engage in auditory imagery at the same time as they are listening to music. 11. One possible explanation may be that emotional events are usually easier to recall than non-emotional events (Reisberg & Heuer 2004), and that emotional episodes often involve social interactions (Johnson-Laird & Oatley 1992). 12. However, unlike Griffiths (2004), we refrain from calling the different forms of information processing “emotional appraisal.” We reserve the term appraisal for higher-level evaluations of events in terms of several dimensions relative to goals, needs, and motives of the organism (Scherer 1999, p. 637; see also the target article’s Table 1). Referring to other mechanisms – such as evaluative conditioning or emotional contagion – as “appraisal” undermines the precision and usefulness of the term. 13. A similar set of hypotheses for the cognitive appraisal mechanism does not yet exist, but could presumably be developed based on one of the available theories (Scherer 1999). 14. As noted earlier, some mechanisms of potential importance have been ignored previously, because they have been regarded as “unmusical” or "irrelevant" by music theorists. However, as suggested here, all six mechanisms could have their origins outside the musical domain. 15. The notion information-encapsulated refers to the fact that the module is "not having complete access to a person's expectations, beliefs, presumptions, or desires" (Coltheart 1999, p. 119). 16. However, when studying a specific mechanism in the laboratory, where practical demands may limit the number of emotion labels that can be used, hypotheses about induced affect (see Table 4) could, if confirmed, be useful in guiding researchers with respect to what response format to use in a particular experiment. 17. We claim that the same is true of studies of physiological responses to music (Bartlett 1996) and studies that use sounds in general to induce emotions (Bradley & Lang 2000). Open Peer Commentary How music fills our emotions and helps us keep time doi:10.1017/S0140525X0800530X Patricia V. Agostinoa , Guy Peryerb , and Warren H. Meckc a Laboratory of Chronobiology, Department of Science and Technology, National University of Quilmes, Bernal B1876BXD, Buenos Aires, Argentina; bDepartment of Psychology – Music, Mind and Brain Group, Goldsmiths College, University of London, London SE14 6NW, United Kingdom; cDepartment of Psychology and Neuroscience, Genome Sciences Research, Duke University, Durham, NC 27708. pagostino@unq.edu.ar http://cronos.unq.edu.ar/ g.peryer@gold.ac.uk www.goldsmiths.ac.uk/music-mind-brain/ meck@psych.duke.edu http://fds.duke.edu/db/aas/pn/faculty/meck Abstract: Whether and how music is involved in evoking emotions is a matter of considerable debate. In the target article, Juslin & Va¨stfja¨ll (J&V) argue that music induces a wide range of both basic and complex emotions that are shared with other stimuli. If such a link   exists, it would provide a common basis for considering the interactions among music, emotion, timing, and time perception. It is clear that music perception is the result of complex sound processing and involves a wide spectrum of cerebral responses, including interval timing and motor control (Buhusi & Meck 2005). Indeed, the preference for specific pitch intervals in music appears to be related to the relationships of the formants in speech that determine the perceptions of distinct vowels (Ross et al. 2007). Such environmental influences and evolutionary constraints indicate that the relationship between music and movement is paramount and occurs very early in processing. In this regard, the basal ganglia and cerebellum are crucial to timing and time perception (Meck 2005; Schirmer 2004). Although Juslin & Va¨stfja¨ll (J&V) mention expectancy, there is virtually no consideration of (1) how events unfold over time, (2) how the timing of events relates to emotion and emotional response, and (3) where these mechanisms are located in the brain. It is tempting to think of a slow dance with a loved one where tempo and rhythm relate to movement and emotion, or the difference between a 3 : 4 waltz rhythm and a 4 : 4 marching rhythm. The tempo/timing in these examples would seem key to the resulting emotion. Consequently, one could argue that specific tempos and rhythmic structures resonate with specific body parts and movements – leading to a complex interplay between rhythmic motor entrainment to music and the resulting emotion (Grahn & Brett 2007; Jones 1981; Molinari et al. 2003; Schubotz et al. 2000). The appreciation of music engages virtually every major region of the brain (Levitin 2006). One of the most remarkable aspects of music is its ability to elicit emotional responses in the listener. The major question is to determine how music creates these emotions. In the target article, J&V have endorsed this question and propose six additional mechanisms through which music listening may induce emotions: (1) brain stem reflexes, (2) evaluative conditioning, (3) emotional contagion, (4) visual imagery, (5) episodic memory, and (6) musical expectancy. The authors provide an extensive analysis and summary of data related to the different emotions induced by music. It is clear that music has the power to evoke a wide variety of emotions, and the target article provides a roadmap that should prove useful for future research related to the identification of the brain mechanisms

underlying these processes. Indeed, for many of us, the emotions induced by music may be overwhelming. Studies by Zatorre and colleagues have identified some of the specific neurobiological basis of these emotions. Using neuroimaging techniques, they have shown that imagining music can activate the auditory cortex as strongly as listening to it. They have also demonstrated that emotional responses to music implicate the activation of numerous brain regions (e.g., Blood & Zatorre 2001; Chen et al. 2008). J&V also emphasize that different brain regions have been activated in different studies, showing that musical emotions cannot be studied without regard to how they were induced. Humans are continually engaged in emotionally driven behavior in everyday life. Music, like emotions, has the ability to affect cognitive tasks such as our perception of time. Timing and emotion are inextricably linked by the rhythm and tempo of a myriad of external and internal events that comprise music, film, dance, sports, courtship, social conflict, and everyday activities (Droit-Volet & Meck 2007). According to scalar timing theory (MacDonald & Meck 2004), timing of intervals in the seconds-to-minutes range entails three stages of sequentially performed processes; namely, the registration of the duration, maintenance of the temporal information in memory, and a decision based on a comparison of the accumulated duration(s) with other temporal information maintained in memory. Those listeners with at least some musical training typically exhibit better performance in timing tasks than do listeners with little or no musical training (e.g., Berens & Pastore 2005). Moreover, activation induced by brief emotional stimuli affects the processing of subsequent signal durations. In this sense, while irrelevant sounds – whether speech, tones, or music – do not affect timing performance (Franssen et al. 2006), emotional sounds can influence our time perception. Noulhiane et al. (2007) found that emotional sounds were perceived as being longer than neutral ones, at least for short durations (up to around 3 – 4 sec). This agrees with results related to emotions evoked by visual stimuli. Thus, emotional faces – especially angry faces – are judged longer than neutral ones (Droit-Volet & Meck 2007). Overall, these data suggest that music, in the same manner as other stimuli that increase arousal, affects the perception of time. In the section "The Melancholy Mirror" from her essay The Bloody Countess, the Argentinean poet Alejandra Pizarnik (1971; for translations, see also Baldick 1993; Golombek & Yannielli 1996) describes melancholy as a musical problem related to timing disruption: Melancholia is, I believe, a musical problem: a dissonance, a change in rhythm. While on the outside everything happens with the vertiginous rhythm of a cataract, on the inside is the exhausted adagio of drops of water falling from time to tired time. For this reason the outside, seen from the melancholic inside, appears absurd and unreal, and constitutes "the farce we must all play." But for an instant – because of a wild music, or a drug, or the sexual act carried to a climax – the very slow rhythm of the melancholic soul does not only rise to that of the outside world: it overtakes it with an ineffably blissful exorbitance, and the soul then thrills animated by delirious new energies (Pizarnik, p. 472). Consequently, analysis of the complex interplay between emotion, music, and time perception remains to be elucidated. In summary, we agree that a better understanding of the mechanisms underlying emotions could be of great importance for clinical applications like music therapy. Thus, the identification of the neural mechanisms involved in emotional responses to music is likely to tell us a great deal about functions of the auditory system that are currently obscure. Our main point is to encourage the search for common representations of abstract quantities involving the impact of time, space, and number on the emotional response to music (Cordes et al. 2007). Ritual harmony: Toward an evolutionary theory of music doi:10.1017/S0140525X08005311
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Abstract: Juslin & Va¨stfja¨ll (J&V) advance our understanding of the proximate mechanisms

underlying emotional responses to music, but fail to integrate their findings into a comprehensive evolutionary model that addresses the adaptive functions of these responses. Here we offer such a model by examining the ontogenetic relationship between music, ritual, and symbolic abstraction and their role in facilitating social coordination and cooperation. Juslin & Vastfjall's (J&V) work represents an important step forward in our understanding of the proximate mechanisms involved in emotional responses to music. What is missing from their model, however, is an overarching evolutionary theory that coherently integrates the ontogenetic, neuropsychological, and cultural elements identified by the authors into an adaptive Commentary/Juslin & Va¨stfja¨ll: Emotional responses to music 576 BEHAVIORAL AND BRAIN SCIENCES (2008) 31:5 whole capable of explaining not only how, but also why we have such strong, emotional responses to music. As noted by the authors, humans appear to be genetically predisposed to respond to music. Changes in pulse, respiration, heart rate, skin conductance, motor patterns, neuroendocrine response, and even immunological function can be induced by music (Harrer & Harrer 1977; Hirokawa & Ohira 2003; Khalfa et al. 2003). Like the ritualized displays of many nonhuman species, the formality, pattern, sequence, and repetition of human music appears to engage basic brain functions, including brain stem, limbic, and cortical regions, and to activate specific pathways related to autonomic, emotional, and motor behaviors (Blood & Zatorre 2001; Patel 2008). In nonhuman species, ritualized displays serve to communicate reliable information between sender and receiver regarding the sender's condition, intention, and motivation (Alcock 2005). This information impacts the autonomic, endocrine, and behavioral responses of the receiver, ultimately engendering either approach or withdrawal responses. Music clearly elicits similar neurophysiological responses in humans. In contrast to nonhuman ritual, however, music amplifies and symbolically abstracts the component elements of ritual, thereby providing a transformative mechanism for engendering and entraining specific autonomic and emotional responses across groups of individuals, as well as across time and space. Patel has noted "humans are the only species to spontaneously synchronize to the beat of music" (2008, p. 100). Such musically induced synchronization promotes congruent motor and autonomic responses which, in turn, impact both emotions and subconscious social judgment and decision-making (Bargh et al. 1996; Bar-On et al. 2005; Clore & Huntsinger 2007; Damasio 1994). These congruent states, and the mirror neuron activation they are likely to initiate, have been positively correlated with empathy (Carr et al. 2005; Levenson 2003), an important building block of both inter-individual trust and social cooperation. It is important to note, however, that not all human emotional responses to music are universal. Many of the emotions evoked by music are culturally specific, suggesting an important role for learning in the development of musico-emotional associations. The inclusion of ontogenetic factors in emotional responses to music is a significant contribution of the target article. Recent findings regarding brain plasticity and the role of experiential influences on the development of neural networks, particularly during adolescence and infancy (Giedd et al. 1999; Koelsch et al. 2005), offer important insights into how genetic predispositions for music may be shaped through socialization processes. Music is at once individual and social, innate and learned (Cross 2003). Universal human pitch preferences and an innate sensitivity to consonance and dissonance (Hannon & Trainor 2007) set the stage for developing musical expectancy. Throughout the world, newborns prefer song to speech, particularly songs that are slower, higher-pitched, and exaggerated in rhythm (Trehub 2001). Such songs are likely to optimize the autonomic and motor entrainment of infant and caregiver, thereby contributing to empathic attachment. During childhood, these innate musical preferences and capacities are channeled and elaborated into specific cultural forms. By age 6, children readily employ both tempo and mode in the music of their cultures to identify basic emotions of happiness, sadness, fear, and anger (Trehub 2001). By age 10, they are able to identify and neurologically respond to syntactic irregularities in the music of their culture (Koelsch et al. 2005). It is during adolescence, however, that emotional response to music seems to peak. Adolescent brain changes, including the heightened activity of limbic and dopaminergic reward systems, and the maturation of temporal and prefrontal cortices (Spear 2000), are likely to drive this heightened emotional response to music. Simultaneously, many of the brain areas activated by music, including the amygdala, insula, anterior cingulate cortex, prefrontal cortex, and superior temporal sulcus (Blood & Zatorre 2001; Koelsch et al. 2005), are also integral to social cognition and behavior (Blakemore 2008). The synaptic pruning and myelination occurring throughout these brain regions during adolescence make this a particularly sensitive developmental period for creating associational networks across sensory, social, and symbolic domains. Simultaneous shifts in the dopaminergic reward system of the adolescent brain, and heightened amygdala activity, provide unique opportunities for the "evaluative conditioning" proposed by J&V (Alcorta 2006; Alcorta & Sosis 2005). It is becoming increasingly clear that brain stem reflexes (Boso et al. 2007), musical expectancy (Huron 2006; Koelsch et al. 2005), emotional contagion (Hatfield et al. 1994; Juslin 2001), and evaluative conditioning (De Houwer et al. 2001) all have important roles to play in the ontogenetic development of neural networks linking the sensory stimuli of music with motor, cognitive, emotional, and social functions. Although such evaluative conditioning may result in the emotional "tagging" of music as the authors propose, we believe that the converse – that is, the evaluative conditioning of neutral stimuli through association with emotionally evocative music – is likely to be the more frequent and evolutionarily adaptive response (Alcorta, in press). The intimate association of music and religious ritual across all cultures, and the crosscultural prevalence of religious rites of passage during adolescence (Alcorta 2006; 2008), suggest an important role for music in the evaluative conditioning of religious beliefs and symbols. Emotional responses to music may be instrumental in imbuing abstract symbols and beliefs with sacred and motivational meaning, particularly during adolescence. Brainimaging data have demonstrated activation of the brain's reward circuitry in response to familiar music (Blood & Zatorre 2001; Menon & Levitin 2005). The ability of music to engender and entrain autonomic responses, evoke emotions, engage reward circuitry, elicit empathy, and associate motivational responses with socially salient stimuli renders it a powerful emotive and mnemonic mechanism for creating cohesive groups among non-kin. The social salience of music receives only passing attention in the target article. The authors largely limit their scope to contemporary secular music and consider music principally from the perspective of the individual listener. Yet, historically and cross-culturally music is neither individual nor secular (Alcorta, in press; Becker 2001; 2004). Music has been and continues to be intimately associated with communal and religious ritual in societies as diverse as Australian hunter-gatherers, African agriculturalists, and American industrialists. In traditional societies, the relationship between music and religion is not only intimate, but often inseparable (Becker 2001). Even in modern, secular societies, music continues to play a fundamental role in both communal (Huron 2003) and religious ritual (Chaves et al. 1999). This close relationship between sociality, sanctity, and music offers important insights into emotional responses to music and suggests possible adaptive functions for those responses that shed light on both proximate and ultimate causes (Alcorta & Sosis 2005). J&V assert that "most emotional reactions to music do not involve implications for goals in life" (target article, sect. 1, para. 7, emphasis theirs). However, just as we may be largely unaware of the subconscious processes that drive many of our life choices (Bargh et al. 1996; Damasio 1994), we are also likely to be consciously unaware of the life goals involved in emotional reactions to music. There is strong psychological, neurological, ontogenetic, and crosscultural evidence to suggest that our emotional reactions to music have important and far-reaching adaptive implications for our beliefs, goals, and actions as members of social and cultural groups.   Musical emotions in the context of narrative film doi:10.1017/S0140525X08005323 Matthew A. Bezdek and Richard J. Gerrig Department of Psychology, Stony Brook University, Stony Brook, NY 11794-2500. mbezdek@notes.cc.sunysb.edu rgerrig@notes.cc.sunysb.edu http:// www.psychology.sunysb.edu/psychology/index.php?people/ faculty/richard_gerrig Abstract: Juslin & Va¨stfja¨ll's (J&V's) discussions of evaluative conditioning and episodic memory focus on circumstances in which music becomes associated with arbitrary life events. However, analyses of film music suggest that viewers experience consistent pairings between types of music and types of narrative content. Researchers have demonstrated that the emotional content of film music has a major impact on viewers' emotional experiences of a narrative. Two of the mechanisms Juslin & Va¨stfja¨ll (J&V) identify that are critical to music's ability to generate emotions rely particularly on memory processes. Evaluative conditioning involves unconscious processes: Through repeated pairings, people learn associations between particular pieces of music and pleasant or unpleasant events. Conscious episodic memories may also yield emotional responses: Music often evokes memories, thereby also evoking the emotions associated with those memories. Although these discussions of memory processes are compelling, they are incomplete because they exclude mention of the many circumstances in which music is explicitly associated with narrative content that independently generates emotional responses. For example, music is often accompanied by lyrics that tell stories with overt emotional messages (Ali & Peynircioglu 2006; Morton & Trehub 2007; Stratton & Zalanowski 1994). Our particular focus, however, is on circumstances in which music is associated with the narrative content of film. Consider John Williams's famous theme from the movie Jaws (1975). The film provides viewers with an opportunity to associate a particular piece of music – a repetition of two notes in an ascending pattern – with the narrative arrival of the Great White Shark. This pairing isn't accidental. Williams's theme, presumably, is intended to match or amplify the narrative content. Moreover, as the film progresses, the music begins to foreshadow particular narrative content. More generally, it seems quite likely that people acquire correlations between types of music and types of narrative situations. Those correlations are presumably more consistent than those implied by J&V's discussion of evaluative conditioning and episodic memory. Research on film strongly suggests that emotional music has a reliable effect on viewers' interpretation of narrative content. For example, Vitouch (2001) asked participants to view the opening scene of a film accompanied by music pre-tested to convey either positive or negative affect. Participants then wrote open-ended continuations of the narrative. Analyses revealed that the plot continuations were colored by the emotional content of the opening scene's music: The positive music made participants more likely to use happy words in their continuations and the negative music made participants more likely to use sad words. Given the same visual information, modifying the emotion of the musical soundtrack caused differences in viewers' expectations about how the narrative would unfold. Even when it does not occur concurrently with the main action of a scene, music can influence viewers' perceptions of film narrative. Tan et al. (2007) paired scenes of characters displaying neutral emotions – sampled from commercial films – with music that participants in an earlier study had rated as happy, sad, angry, or fearful (Spackman et al. 2005). However, the music did not accompany the character's actions. Rather, the music occurred either before or after the character appeared on screen. In addition, the experiment's instructions asked participants to focus their attention toward the visual techniques, such as changes in lighting, that directors use to convey emotions. Thus, participants were discouraged from attending directly to the music. After viewing each film, participants evaluated the emotions of the characters on several scales. Even though the music was presented before or after the actor was onscreen,

participants’ judgments of characters’ emotions were consistent with the emotional content of the music. Emotional attributions were stronger for music presented before a scene than for music presented after a scene. The music provided viewers with interpretations of the characters’ neutral affect. Music can also establish a context for understanding films through broader associations (Boltz 2004). For example, Bullerjahn and Gu¨ ldenring (1994) commissioned original musical scores representative of several different genres, such as crime and melodrama, to accompany the same 10-minute film. Participants viewed the film with one of the scores and completed open-ended questionnaires about the intentions and relationships of the characters. Changes in the emotional content of the music brought about differences in how participants interpreted the film. An encounter with the “crime” soundtrack, for example, led some participants to attribute violent intentions to the characters in the film. This study suggests that film music genres can serve as an emotional framework, preparing viewers for what they are likely to experience during the narrative. Finally, researchers have documented processing consequences for matches versus mismatches between the emotional content of film music and the emotional content of narrative elements. For example, in a study by Boltz et al. (1991), participants showed greater recall for films in which music emotions and narrative emotions matched than for films in which one was positive and the other was negative. When music was played before the outcome of a scene, the opposite effect was observed: A mismatch in emotions led to better overall recall, possibly because of the surprise generated by expectancy violations. Subsequent research suggested that participants encoded emotionally matched music and narrative elements into integrated representations, whereas they encoded emotionally mismatched music and narrative elements separately (Boltz 2004). One of the strengths of J&V’s analysis is the focus on the developmental trajectories of the collection of mechanisms they outline. The studies we have described support rather strongly the conclusion that adults make use of associations between types of music and types of narrative content to generate expectations or interpretations of film narrative. However, the studies do not indicate how much experience, if any, is necessary for music to begin to function in this fashion. We can wonder, that is, at what age children begin to perceive matches or mismatches between emotional music and narrative content. Note also that the research we reviewed examined the extent to which emotional music has an impact on viewers’ interpretation of narrative. We could also wonder, as another topic for developmental research, to what extent experiences of narrative content have an impact on the extent to which viewers perceive music as having a particular emotional tone. Over time, as J&V have suggested, music could retain its emotional tone independent of its original narrative context. ACKNOWLEDGMENTS This material is based upon work supported by National Science Foundation Grant No. 0325188. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. We thank Matthew Jacovina for helpful comments. Affective spectra, synchronization, and motion: Aspects of the emotional response to music doi:10.1017/S0140525X08005335 Jamshed J. Bharuchaa,b and Meagan Curtisb aOffice of the Provost, Tufts University, Medford, MA 02155; bMusic Cognition Lab, Psychology Department, Tufts University, Medford, MA 02155. jamshed.bharucha@tufts.edu http://provost.tufts.edu/1174149598956/Provost-Pageprov2w_1174149599184.html Meagan.curtis@tufts.edu http://ase.tufts.edu/psychology/music-cognition/curtis.html
Abstract: We propose three extensions of the theory developed by Juslin & Va¨stfja¨ll (J&V). First, motion should be considered as an additional mechanism. Second, synchronization plays a role in eliciting emotion. And, third, the spectrum of musical affect or feelings is denser and broader than the spectrum of emotions, suggesting an expansion of the scope of

the theory beyond emotions. Juslin & Va¨stfja¨ll (J&V) cut through a veritable thicket of research on emotion in music by wielding two powerful weapons. One is the claim that emotion in music is not a unitary phenomenon. The other is the claim that only by tracing the underlying mechanisms can we understand it. By disaggregating the variety of musical experiences that we call emotion, and by unearthing the numerous causal mechanisms responsible for this multiplicity, a messy field starts to sort itself out. Many of the apparent contradictions and inconsistencies in the literature are due to the failure to recognize that all these mechanisms – not just one – are at work. Collectively they account for a wide spectrum of emotional experiences in music. The target article therefore constitutes an immensely important contribution, and enables future research on music and emotion to be more lucidly framed. Elsewhere we have argued that there are at least three categories of conscious musical experience: affect, motion, and structure (Bharucha et al. 2006). Music serves to communicate conscious experience, and the spectrum of such experience is more varied and dense than is often acknowledged. In this commentary, we suggest three possible extensions of the theory developed by J&V: First, motion is another critical mechanism that leads to the elicitation of emotion in music. Second, emotions may be elicited by synchronization of conscious experience or motion. Third, emotions constitute only a subset of a denser and more richly textured spectrum of musical feelings. Motion. Much has been written about the role of motion in music, and a review of this work is beyond the scope of this commentary. Suffice it to say that music can drive movement – which may or may not be inhibited, depending upon whether we want to move and it is socially appropriate to do so. J&V discuss movement in the context of social contagion. But movement that is not directly expressive of emotion, as well as its inhibition, may elicit emotion. If visual imagery qualifies as a mechanism for eliciting emotion in music, motion is surely even more powerful as a mechanism. Synchronization. We have argued elsewhere that mere synchronization may be a powerful elicitor of emotion (Bharucha et al. 2007). To the extent that music promotes group cohesion, one of the mechanisms by which this is achieved is through synchronization, or perceived synchronization, of conscious musical experience. Emotion need not be what is synchronized, but is a consequence of the recognition that a group is synchronized in some way. Motion and structure may also serve as vehicles for synchrony. People moving in synchrony can have powerful emotions not as a direct result of the music, but as a result of the recognition that they are moving in synchrony; music serves to elicit the synchronous movement, which in turn may elicit emotion in a derivative way. Similarly, even the recognition of musical structure can trigger the emotion that stems from synchronization. If I know that people are perceiving the same structural manipulations as I am, that recognition of the synchronization of our perceptual experience can elicit the kinds of emotions that promote group cohesion. Spectrum of affective musical experience. If emotions are "about something" and last from a few minutes to a few hours, then we would argue that emotions represent only a subset of the spectrum of affective experience. J&V define affect as an "umbrella term that covers all evaluative ... states such as emotion, mood, and preference" (see target article, sect. 2, Table 1). And they define feeling as the "subjective experience of emotion (or mood)" (sect. 2, Table 1). Yet, music may evoke feelings that are neither emotions, nor moods, nor preferences. Musical feelings need not be about something, may or may not be valenced, and, unlike emotions (which are nameable, e.g., sad and happy), may not be readily nameable. Yet, they may have an affective quality in that they are felt and not just perceived. Some musical feelings that don't count as emotion can be named easily: for example, warm. Others may be more nuanced and possibly ineffable in the sense of defying verbal description; for example, Raffman (1993) argues that musical experience is more finegrained than the categories available to describe it. Other musical experiences may be gestures that aren't necessarily about objects and don't lend themselves to easy description but feel a certain way. And some may be more fleeting than the time span that characterizes emotions (minutes to hours). They may include sensory qualities; for example, the distinctive sound of an oboe, a particular singer's voice, or a plagal cadence. In other words, music may engage a dense spectrum of feelings of which emotions form a subset. The theoretical framework proposed by J&V might extend beyond emotions to other affective states or feelings. For example, some of the categories of feelings described in the previous paragraph may be involved in evaluative conditioning and episodic memory in ways that are analogous to emotion. What role might these more subtle musical feelings play? Even though they may not be about something and may not be nameable, they nevertheless advance the cause of group cohesion. For example, culturally learned musical gestures, and the feelings or sensory qualities they evoke (however nuanced, fleeting, and possibly ineffable), may signal group membership. Furthermore, they increase the number of channels available for synchronization beyond just happy, sad, angry, and so on. The benefits of synchronization require only that people be having similar experiences; those experiences need not have any communicative utility in and of themselves, and need not be emotions. In conclusion, we argue that the proposed framework is a significant theoretical advance in understanding emotion. We also believe that the framework can support a spectrum of musical feeling that is denser and broader than emotion. Therefore, the larger question is not how we explain the role of emotion in music, but how we explain the role of all affective experience – or feelings – in music. The role of semantic association and emotional contagion for the induction of emotion with music doi:10.1017/S0140525X08005347 Thomas Fritza and Stefan Koelschb aMax Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany; bDepartment of Psychology, University of Sussex, Brighton BN1 9QU, United Kingdom. fritz@cbs.mpg.de http://www.cbs.mpg.de/staff/fritz-2064 mail@stefan-koelsch.de http:// stefan-koelsch.com/ Abstract: We suggest that semantic association may be a further mechanism by which music may elicit emotion. Furthermore, we note that emotional contagion is not always an immediate process requiring little prior information processing; rather, emotional contagion contributing to music processing may constitute a more complex decoding mechanism for information inherent in the music, which may be subject to a time course of activation. In addition to the six mechanisms by which emotion is evoked, as pointed out by Juslin & Va¨stfja¨ll (J&V), we believe that there is another mechanism by which music may elicit emotional responses: semantic association. Music may activate meaningful concepts that give rise to an emotional response. Some musical information has a defined meaning, such as the drum figures of many African cultures that go way beyond speech mimicking (Nzewi et al. 2001), Wagner's wedding march, or a national anthem. Other musical information might evoke associations to meaningful concepts because it resembles the sound or the quality of an object, or because it represents stereotypical forms (e.g., a church anthem and the word devotion). Because many of these semantic concepts also have an emotional connotation, a decoding of such concepts may elicit an emotional response (Steinbeis & Koelsch, 2008). Moreover, emotional contagion was defined by Hatfield et al. (1994) as a "tendency to automatically mimic and synchronize facial expressions, vocalizations, postures and movements with those of another person and, consequently, to converge emotionally" (p. 5). Although no satisfactory account on the workings of emotional contagion has yet been proposed (as noted by J&V), considerable effort has been invested into the investigation of mental processes underlying empathy, including emotional contagion. In this context, earlier work by Lipps (1903) and MerleauPonty (1966) that already anticipated mutual mental facilities for perception and action has been rediscovered. "Common-coding" (Prinz 1990), "simulation theory" (Carruthers & Smith 1996; Gordon et al. 1995), and the "perception-action model of

empathy” (Preston & de Waal 2003) are concepts proposed by more recent lines of research that can also account for mental mechanisms underlying emotional contagion. During the investigation of mirror neurons in recent years, some progress has been achieved that may offer perspectives on a neural substrate underlying this phenomenon (see the target article): Mirror neurons seem to discharge both during an action and during the perception of an action, even in the auditory domain (Kohler et al. 2002). We agree with J&V that emotional contagion plays a role in music processing, but we would also like to complement their conception: Whereas the current opinion seems to be that emotional contagion, and its underlying neural mirror system, is an immediate mechanism, recent data suggest that emotional contagion may actually have a temporal dynamic of activation (Koelsch et al. 2006). In the Koelsch et al. study, an auditory mirror mechanism (premotor activation of the larynx representation) was activated by the perception of musical stimuli with positive emotional valence. This mechanism was not immediate, but instead was shown to be increasingly engaged with the duration of the pleasant music stimuli, so that it showed a robust engagement of premotor regions between 30 seconds of music listening until the end of the stimuli that lasted for approximately 60 seconds. Such “auditory mirror resonance” was not involved during the perception of aversive, unpleasantly modified musical stimuli. This corresponds to the concept of emotional contagion, in that the latter is likely more strongly associated with approach behaviour (when, for example, attention is directed towards others) than with withdrawal behaviour (brought about by the perception of unsettling information) (Hatfield et al. 1994). This supports the idea that this mechanism may indeed correspond to a neural underpinning of emotional contagion. Because the engagement of the neural mechanism putatively underlying emotional contagion was related to emotional valence, and because it showed a temporal dynamic of activation, it is likely that emotional contagion is a more complex mechanism serving music processing than previously assumed.
Responses to music: Emotional signaling, and learning doi:10.1017/S0140525X08005359
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Abstract: In the target article, Juslin & Va¨stfja¨ll (J&V) contend that neural mechanisms not unique to music are critical to its capability to convey emotion. The work reviewed here provides a broader context for this proposal. Human abilities to signal emotion through sound could have been essential to human evolution, and may have contributed vital foundations for music. Future learning experiments are needed to further clarify engagement underlying musical and broader emotional signaling.
Music in its totality is a unique component of human ecology and experience (Gardiner 2003). Nevertheless, there is evidence that how the brain engages (Gardiner 2008) with music may well include adaptations of, and associations with, brain mechanisms not unique to music alone. Musical brain engagement producing emotional experience (Dewey 1980) may be one among many ways in which musical and other aspects of brain engagement can become deeply interrelated (Gardiner 2000; 2008a). Evidence reviewed here supports the proposal of Juslin & Va¨stfja¨ll (J&V) that mechanisms that are not unique to music are fundamental to emotional responses to music, but it also suggests that music adapts rather than adopts such mechanisms. The evidence concerns the selective influence of the learning of specific musical skills on the learning of specific non-musical skills (Gardiner 2003; 2008a). For example, as discussed in Gardiner (2000) and Gardiner et al. (1996), learning musical capability has been associated with improved progress at learning arithmetic skills in first and second graders. Current work extends this to third graders as well (Gardiner et al. 2008b). By contrast, effects of the same musical training on progress at reading in first and second graders have been much smaller (Gardiner 2000). Capability involving musical pitch was significantly related to progress in first and second grade math, but not to progress in first and second grade reading (Gardiner 2000). Rhythm skill, by

comparison, was correlated weakly, but more evenly, to progress both in reading and in math. Classroom behaviors among students learning individual and group musical skills improved (Gardiner 2000; Gardiner et al. 1996), but those improvements did not correlate significantly to improvements either in pitch or in rhythm skills. The many skills involved in self-control and interaction with others that had to be developed as these students learned to sing alone and together, are all candidates to help explain the many improvements in students' progress in classroom behaviors that were documented (Gardiner 2000). Other investigators provide further examples of selective interaction between musical and other skill learning. Rauscher et al. (1997) have shown effects of keyboard training on preschooler's capability at assembling whole figures from parts, but not on other visuo-spatial skills. Recent studies relating musical and language development concern improvements at engagement with rapidly changing signals (Gaab et al. 2005; Tallal & Gaab 2006). Selective associations between musical and other skill learning cannot be explained by changes affecting processing globally; but the associations can be due to, and signal similarities in, the ways in which the brain of a learner becomes engaged through related processing in order to achieve capabilities in different skill domains (Gardiner 2000; 2002; 2008a). Capability in every skill can depend critically on finding a way of engaging mentally to support what is desired (Gardiner 2008a). As chess studies have illustrated, improvements can be caused by and even depend on qualitative changes in how engagement is carried out (Chase & Simon 1973; DeGroot 1965). The selective cross-relationships between musical and other learning can show that an important strategy within our development of mental engagement is learning how to adapt similar, though typically not identical, brain processing components and strategies to different applications. The human development of music could, indeed, have depended on capability for such adaptation. Our survival as a species has depended on evolving and developing certain means of mental engagement that support the personal and social capabilities critical to our survival. Music can be explained as illustrating that our inventive brains can adapt brain capabilities we needed to evolve in order to survive to develop new opportunities that we discover to enrich our lives, even if not in ways as critical to our survival (Gardiner 2003; 2008a). Many of J&V's examples relating musical engagement and emotion can viewed in this way. What J&V term "emotional contagion" seems the most important of the ways proposed to connect music listening to emotional experience. I propose a way of framing that can aid further investigation of such emotional reactions to music: this is, to think of such reactions to music as an adaptation of a more general capability for detecting and reacting to signaling by sounds that express emotion. This ability could have been critical to human evolution. Emotion and physiological and behavioral changes are deeply interconnected, as James and Lange (1922), Cannon (1929), and many others more recently have emphasized. Emotional expression refers to such changes perceivable by an observer. An individual may try to hide evidence of his or her emotion; but emotional expression can have enormous communicative value as well. Facial expression has been especially well studied (Ekman 1997); but, likewise, a baby's cry, a scream of fear, or a sigh of pleasure can be not only emotional reactions but also signals. Our success as a species – physically weaker, individually, but stronger in our group interactions than our competitors – could have been aided enormously by developing rich capabilities both at expressing and perceiving signs of emotion as signals. We should not think of music in the abstract merely as sound, but rather remember that it has developed as a product of human acts, part of whose purpose has often included the communication of emotion. J&V propose that the processes involved in the emotional experience of a music listener are "somewhat different" from those involved in generating emotional expression in the music. Nevertheless, I doubt that an engagement with music that detects emotional signals is unrelated to an engagement with music that produces signals conveying emotion. Thus, studies that relate the emotions perceived by people to the acts they make (e.g., Clynes 1977) may be very linformative. Learning experiments involving music may help to illuminate the connection between emotional expression and emotion as signal. The ability to compose or perform music that conveys emotion improves with learning. Musicians have to learn to judge from their own and listeners' reactions in what way, and how effectively, they are communicating emotion. Comparing music-making gestures when emotional signaling seems especially powerful with instances when music becomes "just notes" may well provide useful clues to differences in the underlying engagement. Our languages for emotional communication are rich and subtle. Music may be of great aid in their investigation.

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Evidence from young children regarding emotional responses to music

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Abstract: Juslin & Va¨stfja¨ll (J&V) propose a theoretical framework of how music may evoke an emotional response. This commentary presents results from a pilot study that employed young children as participants, and measured musically induced emotions through facial expressions. Preliminary findings support certain aspects of the proposed theoretical framework. The implications of these findings on future research employing the proposed framework are discussed.

This commentary presents results from a pilot study of emotional response to music. These results lend support to some aspects of the hexpartite theoretical model proposed by Juslin & Va¨stfja¨ll (J&V). Interpreting these preliminary findings through the lens of the model framework opens new avenues of inquiry demanding fuller exploration in future research. The pilot study proceeded from a rejection of "the common assumption that musical emotions must be based on a cognitive appraisal," as J&V write in their short abstract (not printed here). Because young children are less likely to form cognitive appraisals of emotionally inductive stimuli (Harris et al. 1981; Stein & Levine 1999), they were selected as participants for the pilot. Twenty excerpts of "classical music" – Western art music composed between the twelfth century and the present – ranging in length from 27 sec to 62 sec were presented in random order to 42 children, ages 3 to 5 years. Variability of section length was allowed to accommodate complete musical phrases or sections. Pieces with Englishlanguage texts were excluded, given that children are more likely to respond emotionally to the lyrical, as opposed to musical, content of such works (Morton & Trehub 2007). In selecting excerpts, emotional valence was not assumed: music was not chosen because it was happy or sad, but rather because it was deemed evocative. Instead of selfreport, facial expressions, vocalizations, and body movement were recorded as the dependent variables (Izard 1994; Sloboda 1991; Witvliet & Vrana 2007) for later analysis using Izard's Maximally Discriminative Facial Movement Coding System (Max) (Izard 1995). The same set of excerpts was presented in the same order through a series of iterative pilot phases. In phase 1, the excerpts were played through speakers for an entire preschool classroom. In phase 2, a single child listened through a pair of noise-canceling headphones in an experimental room. Phase 3 repeated this procedure, but with the child in a more familiar, classroom setting. In the fourth and final phase of the pilot, children listened to music through headphones while remaining in their classroom, and were free to put on or take off the headphones whenever they chose. Across all phases of the pilot study, results were broadly similar – a brief period of initial interest gave way to disengagement, marked by an apparent decrease in interest (no facial expressive movement), minimal vocalization, and little body movement. Approximately 4 – 6 minutes after the music began, children would either remove

BRAIN SCIENCES (2008) 31:5 581 their headphones (in phases 2 – 4 of the pilot) or seek another activity. This "attentional curve" may in part be explained by the first component of J&V's model: brain stem reflex. The initial spike in interest may be less a function of emotional response to the music itself than attenuation to a novel auditory stimulus – a response to "music as sound" (sect. 3.1.1, para. 1). As this novelty wears off, the child's attention falls to a baseline level. Subsequent and fleeting spikes (Fig. 1d) accompany the beginning of new excerpts, and may again be a function of novelty. This pattern of attention also lends further support to Berlyne's theory that listener preferences are related to arousal by the Wundt curve (an inverse parabolic relationship; see Berlyne 1971). Berlyne posited that if the arousal potential of a piece of music is misaligned (either too high or too low) relative to the listener's preferences, it will be rejected. The children in this study – well rested following naptime and well fed following a snack – were likely to have a preference for music with a high arousal potential. When the musical excerpts failed to deliver, the children rejected them, less through a demonstration of displeasure than of disinterest or apathy. This rejection may also be a function of genre: Classical music cannot match commercial music for gross aspects of arousal potential such as frenetic energy or volume. A "genre effect" also lends tentative support to two other mechanisms underlying emotional response. In conversations with children's teachers and parents it was revealed that the primary (and in many cases only) time children listened to classical music was when it was time to go to sleep. The repeated pairing of classical music (conditioned stimulus [CS]) with sleep (unconditioned stimulus [UCS]) would explain a relaxation response through evaluative conditioning. Another aspect of the model, musical expectancy, may also help explain this result. As J&V note, both the pleasure of fulfilled expectation and the displeasure of frustrated expectation are predicated on the listener possessing sufficient knowledge to form an expectation – knowledge that is gained through learning. With limited exposure to classical music, children would not possess the knowledge requisite to forming an expectation. Gaining such knowledge in a relatively rapid fashion might be possible with other genres, but classical music, which does employ self-referential techniques to create coherent structural wholes, makes little use of literal repetition – the sort that would allow expectations to be quickly formed. In part, young children were chosen for this study to control for the role of emotional contagion and episodic memory, judged (perhaps incorrectly) to be secondary or tangential aspects of emotional response. It was reasoned that young children would be less likely to perceive the emotional character in a piece music and mimic that emotion (Stein & Levine 1999); their emotional responses would be genuinely their own. They also have had relatively little time to form episodic memories, musically linked or otherwise. The subdued emotional response displayed by children in this study could be taken as preliminary support for either assertion. However, it is interesting to note that when children listened to music in the company of their classmates – as in pilot phases 1 and 4 – they were far more emotionally responsive than when they listened alone. Some degree of emotional contagion may be less one's mimicry of the music than of those nearby. Considering these preliminary results in the context of J&V's theoretical framework suggests a path for future research. Understanding – even in a hypothetical sense – the mechanisms underlying emotional response to music suggests that studies should be designed to isolate and explore the proportionate role of individual mechanisms in total response. For example, using musically trained and untrained individuals, and varying the level of structural complexity of musical excerpts, could enable a more direct assessment of the role of musical expectancy. In this way, it may eventually be possible to estimate the relative strength of each mechanism in producing emotional response, both in terms of direct and of interaction effects. With a testable model guiding these efforts, it should be possible to produce more consistent and interpretable results. A skeptical position on "musical emotions" and an alternative proposal doi:10.1017/S0140525X08005372 Vladimir J. Konecˇni Department of Psychology, University of California–San Diego, La Jolla, CA 92093-0109. vkonecni@ucsd.edu http://psy.ucsd.edu/pages/people/faculty/vkonecni.html Abstract: Key premises of the target article by Juslin & Va¨stfja¨ll (J&V) are challenged. It is also shown that most of the six "psychological mechanisms" proposed by the authors as underlying the induction of emotion by music involve nonmusical proximal causes. As a replacement for "musical emotions," the state of being-moved – from the recently developed Aesthetic Trinity Theory – is proposed. Introductory sections of the target article by Juslin & Va¨stfja¨ll (J&V) contain important information but are based on three erroneous premises. In the first premise, stated in the opening sentence of the Abstract ("Research indicates that people value music primarily because of the emotions it evokes") and in the lead paragraph, "people" refers exclusively to youths listening to pop music (Behne 1997; Sloboda & O'Neill 2001; Zillmann & Gan 1997).1 Such evidence from adolescent self-reports – generally permeated by lay music-emotion (M-E) theories – is treated as relevant to the genuinely important theoretical question: Can instrumental (especially non-referential, "absolute") music directly induce emotion? Meanwhile, the methodologically sound empirical evidence about this relationship is miniscule, weak, and limited to classical music (Konecˇni 2008; Konecˇni et al. 2008). The second erroneous premise is that there is inexplicable disagreement among M-E researchers although the explanation is straightforward: The neuroscientists cited (Ko¨lsch, Peretz, and Panksepp & Bernatzky) generally define emotion exclusively as brain events (in a reductionist manner) – with no or little reference to subjective experience and verbal report, whereas others (Gabrielsson, Kivy, Konecˇni, Scherer) consider subjective experience indispensable – usually without ignoring the physiological response. An additional aspect of the rather misleading way of setting the stage is the neglect of the terms "directly" and "mediation" in the rendering of some researchers' views (for a review, see Konecˇni 2003) – which is that music does not directly induce emotions and that the M ! E effect is typically mediated by memories, associations, and various social emotioninducing behaviors, such as dance (Fig. 1). The authors suspect, disapprovingly, that the skeptical position on M ! E stems from its over-reliance on cognitive appraisal; this is odd because major, perhaps dominant, emotion theories emphasize appraisal and it is unclear why they should accommodate "musical emotions" – a term Zangwill (2004, p. 35) calls "obscurantist." Furthermore, J&V themselves assign a key role to cognitive mediators (see examples in the central ellipse in Fig. 1) in at least four of the six "psychological mechanisms" that they believe underlie M ! E. Figure 1 diagrams the third of the article's inaccurate premises. J&V state that providing evidence that music affects all of the components in their Table 2 would "demonstrate that music can evoke 'real' emotions" (sect. 2, para. 4). But most of Commentary/Juslin & Va¨stfja¨ll: Emotional responses to music 582 BEHAVIORAL AND BRAIN SCIENCES (2008) 31:5 the studies in Table 2 are limited to a single component, and my Figure 1 shows how certain measures taken singly (e.g., psychophysiological thrills/ chills) may be dead ends that do not escalate to emotion unless mediated (Konecˇni et al. 2007). Turning to the article's core, nonmusical mediation of the possible M ! E effect is involved in the following proposed psychological mechanisms: visual imagery (the visual image, not the music that gives rise to it, is the proximal cause in the induction of emotion); episodic memory (memories of real-world emotional situations, not music, are the proximal causal factor); emotional contagion – whereby emotion might be induced by the music's expressiveness being mimicked internally – "admittedly ... remains speculative" (sect. 3.1.3, para. 6) and seems unlikely to be effective without some episodic-memory involvement; evaluative conditioning (a nonmusical emotional event with which music has been temporally paired is the true cause of emotion); finally, there are no rational grounds to hypothesize dissonant chords (re: brain stem reflex; see the left ellipse in Fig. 1) and

violations of musical expectancy to induce emotions without nonmusical enhancement. In summary, in causal-modeling terms, if these nonmusical mediators (images, memories, associations) were to be kept constant, there would be no effect of music on emotion. This being so, and given that all of the proposed concepts are well known in psychology and aesthetics, one must conclude that the target article's proposals are neither innovative nor conducive to a deeper understanding of the direct M ! E effect. However, having acknowledged the key role of nonmusical mediators, and rejected the term "musical emotions"2 (Konecˇni, 2008), what about the subjectively real and sometimes profound quasi-emotional state that (even) absolute music can produce, one that is different from "real-life" emotions (right-hand ellipse, Fig. 1)? It might be advantageous to use the term being-moved or being-touched. This concept (quasi-emotional state) is one of the three hierarchically arranged, dynamically related, components (along with thrills/chills and aesthetic awe) of the recently developed aesthetic trinity theory (ATT; Konecˇni 2005; 2008) shown in Figures 1 and 2. Being-moved (authentic substantives exist in many languages) is proposed as a distinct and reportable (measurable) state inducible by non-aesthetic (e.g., witnessing selfless sacrifice; Konecˇni et al. 2007) and aesthetic events; among the latter, music is perhaps foremost – because of its temporal nature and rich network of mediators outlined in the target article (cf. Konecˇni 2005; 2008). The nuances in being-moved may be due to two sources: (a) contemplation simultaneous with listening (e.g., on infinity or on exquisite musical skill) and (b) subtle expressive attributes of music, such as nobility, grace, or serenity. Colorations of being-moved may thus effectively capture the meanings desired by terms like "less terrible," "less coarse," and "refined" emotions (Darwin 1871/1902, p. 735; James 1884; Frijda & Sundararajan 2007), whereas the overlap, in Figure 2, of beingmoved and the fundamental emotions suggests that the cognitive mediators listed in the central ellipse of Figure 1 may convert the state of being-moved into (low-intensity) sadness or joy. Figure 1 (Konecˇni). Relationships relevant to the induction of emotion by music. The thickest arrows show the central route. From Konecˇni et al. (2008). (#2008 Sage, with permission.) Figure 2 (Konecˇni). Quasi-emotional, emotional, and nonemotional responses to music and a hypothetical comparative estimate of their prevalence. From Konecˇni (2008). (#2008 American Psychological Association, with permission.)   NOTES 1. Mood (defined in Table 1 of the target article) might be a more appropriate term for much of what J&V discuss, but they are evidently not content with it. Apart from perhaps yielding to "convention ... [and] force of habit" (Stravinsky 1936/1998, p. 54), there is the irresistible siren call of the evolutionary basis of the (fundamental) emotions. 2. J&V (in their Note 1) define "musical emotions" as "emotions that are induced by music," which unjustifiably commandeers the effects of nonmusical mediators. There are other imprecise and misleading uses of the term in the literature. Musical expectancy: The influence of musical structure on emotional response doi:10.1017/S0140525X08005384
Carol L. Krumhansl and Kat R. Agres Department of Psychology, Cornell University, Ithaca, NY 14853. clk4@cornell.edu katagres@gmail.com http://www.psych.cornell.edu/people/ Faculty/clk4.html Abstract: When examining how emotions are evoked through music, the role of musical expectancy is often surprisingly under-credited. This mechanism, however, is most strongly tied to the actual structure of the music, and thus is important when considering how music elicits emotions. We briefly summarize Leonard Meyer's theoretical framework on musical expectancy and emotion and cite relevant research in the area. Our starting point is the very last entry in the target article's Table 4, which indicates that musical expectancy is the only mechanism that depends strongly on musical structure. Fortunately, the field of music theory provides conceptual tools for analyzing music, and this raises the question of what musical structures give rise to expectations and what are the emotional consequences.

Our approach is to begin on the musical side and consider how understanding musical processes leads to a somewhat different perspective on musical emotions than that associated with Juslin & Va¨stfja¨ll's (J&V's) other five mechanisms. We identify Leonard Meyer's (1956) monograph, Emotion and Meaning in Music, as the most influential theoretical framework for studying musical emotions. Its success stems from his shift from the question "Why does music produce emotions?" to the more tractable question, "How does music produce emotions?" This focuses attention on the music itself and how it is constructed. Another important aspect of Meyer's theory is that it deemphasizes the general mood (such as happy, sad, or peaceful) engendered by passages, movements, or entire musical pieces, and emphasizes instead the moment-to-moment response to the ongoing flow of music. The theory's essential claim is that music produces emotions because listeners actively generate expectations (mostly unconsciously) for what is to follow. Depending on the relationship between these expectations and what actually happens, listeners experience varying degrees of tension or relaxation. In Meyer's words, "Thus in a very general way expectation is always ahead of the music, creating a background of diffuse tension against which particular delays articulate the affective curve and create meaning" (Meyer 1956, p. 59). The feeling of tension is not necessarily negative, nor is the feeling of resolution necessarily positive. Rather, the response depends on the particular way expectations are fulfilled, perhaps in a particularly artful way or at an unexpected delay. Meyer emphasizes three different sources of expectation. The first, extra-opus knowledge or style knowledge, refers to quite general patterns in a musical style. These are codified in music theory, and empirical research extensively documents that listeners' knowledge about melody, harmony, and rhythm influences what they expect in a given musical context (e.g., Bharucha & Stoeckig 1986; Boltz 1993; Jones 1990; Jones et al. 2006; Krumhansl 1990; Schmuckler 1989). This knowledge does not depend strongly on explicit musical training; non-musicians internalize it through passive exposure. A second source of expectations, called intra-opus knowledge, refers to the listener's experience of a particular piece of music and the expectations that are based on its characteristics. For example, if a piece of music begins with a particular theme, then the listener will expect that the theme is likely to recur later in the piece or reappear in variations. Meyer also emphasizes the influence of Gestalt principles of perceptual organization on music perception. In this tradition, Narmour (1990; 1992) proposed what is called the implicationrealization model. Its five principles for melodic expectations have been tested using a fairly wide variety of musical styles and listeners in different cultures (e.g., Krumhansl 1995; Krumhansl et al. 1999; 2000; Thompson & Stainton 1998). The results find support for principles such as: Generally expect small changes in pitch, but if there is a large jump expect a tone that fills the gap. To study the rise and fall of tension, real-time measures have been developed in which listeners move a device to indicate the amount of tension they experience throughout the course of a piece or a segment of music (e.g., Fredrickson 1995; Krumhansl 1996; Nielsen 1983). Theoretical models, especially Lerdahl's (2001) tonal pitch-space model, have been developed to provide a precise account of the degree to which musical structures produce tension (see Lerdahl & Krumhansl 2007). But how does this relate to the more usual sense of emotion? Several studies suggest music results in changes in emotion physiology associated with real-life emotions. For example, respondents in Sloboda's (1991) questionnaire study were able to pinpoint the particular moment in pieces where they experienced, on repeated occasions, a strong emotion, and these coincided with points in the music where an expectation of some kind was violated. Different physiological reactions (such as tears or shivers down the spine) were produced by different kinds of violations. Real-time judgments of tension in the study by Krumhansl (1997) correlated most strongly with real-time judgments of fear, but judgments of happy and sad also made a contribution. Changes in emotion physiology showed a similar pattern. This suggests that tension is a multivalent attribute influenced by different emotions. Supporting this, Krumhansl and Schenck (1997) found that judgments of tension were almost identical with judgments of the overall amount of emotion for both music and dance. Early event-related brain potential (ERP) studies (Besson & Faita 1995; Janata 1995) found correlates of the degree to which expectations are violated, a result replicated in other studies (e.g., Koelsch et al. 2000). A recent study (Steinbeis et al. 2006) bridged the gap between musical expectancy and emotion by measuring listeners' physiological responses to music. Tension, subjective emotionality of the music, an early negativity ERP response, and electrodermal activity (EDA) increased with harmonic unexpectedness. Blood and Zatorre's (2001) positron emission tomographic (PET) study showed brain responses at specific listener-identified time points with strong emotions, as well as other physiological changes. In an functional magnetic resonance imaging (fMRI) study, areas of secondary auditory cortex were active when listeners heard violations of expectations for pitch and rhythm (Krumhansl 2005). Lastly, a study using irregular, unexpected chords (Koelsch et al. 2005) found that unexpected chords elicited orbital frontolateral cortex activation, an area shown to support emotional processing. In summary, empirical evidence, using a variety of behavioral and neuro-cognitive measures, strongly supports the idea that listeners develop constantly changing expectations while listening to music, and these give rise to waves of tension and relaxation. At present, however, it appears that these moment-to-moment responses do not map in a simple way onto the traditional emotional states studied within psychology. Although the emotions evoked by music may be different or more complex than real-life emotions, they are fundamental to the musical experience. ACKNOWLEDGMENT The authors thank Michael Spivey for his comments on an earlier draft. Why we experience musical emotions: Intrinsic musicality in an evolutionary perspective doi:10.1017/S0140525X08005396 Daniela Lenti Boeroa and Luciana Bottonib a Faculty of Psychology, Universite´ de la Valle´e d'Aoste, I-11100 Aosta, Italy; bDepartment of Environmental Sciences, University of Milano Bicocca, 1-20126 Milan, Italy. d.lentiboero@univda.it bioacust.lab@unimib.it luciana.bottoni@unimib.it www.disat.unimib.it/bioacoustics/it Abstract: Taking into account an evolutionary viewpoint, we hypothesize that music could hide a universal and adaptive code determining preferences. We consider the possible selective pressure that might have shaped, at least in part, our emotional appreciation of sound and music, and sketch a comparison between parameters of some naturalistic sounds and music. In accordance with the brilliant article by Juslin & Va¨stfja¨ll (J&V) about inner human response to music, we suggest some considerations from an evolutionary perspective. Using set theory for maximum exemplification, music, a most specialized and peculiar human cultural artifact (Andrade 2004; Beament 2001), can be considered a subset of all the sounds reaching our auditory system. Principles of brain evolution (Striedter 2005) suggest that our brain, essentially homologous to that of primates (Klump 2006), has the power of specialized modules for language and music (Geschwind 1979; Liberman & Mattingly 1989; Mithen 2005; Peretz & Zatorre 2003; Suga 2006) wired and superimposed on basic mammalian (and especially primates') auditory paths (Attias & Scheiner 1998). Psychological data confirm that the analysis of the auditory scene (biotic and abiotic sounds and species-specific sounds) is basically processed according to the same Gestalt rules that govern vision (Bregman 1999); and research on both music and biotic sound suggests that aversion to a sound should first involve some inherent characteristics of the sound itself (Beament 2001; Borchgrevink 1975; Lenti Boero & Nuti 2006; Lenti Boero et al. 2007; Miraglia 2007; Zentner & Kagan 1996). Scherer and Zentner (2001) speculate that some universal criteria of beauty are evaluated automatically on the basis of visual and auditory stimulation and arouse an affective response. Our hypothesis is that hominids' evolutionary past (Orians & Heerwagen 1992) shaped, at least in part, our sound preferences and our predisposition to respond affectively to sounds, priming aesthetic and emotional feelings toward sound appreciation or avoidance. This is analogous to how viewing a natural landscape enhances an "aesthetic" evaluation that drives settlement choices (Herzog 1985; Kahn 2001; Kaplan & Kaplan 1989; Kaplan et al. 1989; Tuan 1984). Research on the evolutionary psychology of auditory scene analysis might profit from other fields, especially landscape ecology and environmental and music psychology. To our knowledge, musician William Gardiner (1771 – 1853) was the first to propose a relationship between natural sounds and music in his futuristic book titled The Music of Nature; or An Attempt to Prove that what is Passionate and Pleasing in the Art of Singing, Speaking, and Performing upon Musical Instruments, is Derived from the Sounds of the Animated World (Gardiner 1832). Gardiner took into account tempo, rhythm, and intonation, and analyzed from a musician's perspective many naturalistic sounds such as birdsongs and mammalian utterances, transposing many of them into musical scores; many compositions from famous musicians (e.g., Mozart and Ha¨ndel) were reported to have been inspired by or to imitate birdsong. One hundred and thirty years later, the Canadian composer R. Murray Schafer launched the World Soundscape Project (WSP) that inspired a seminal book The Music of the Environment (1973), confirming soundscape research as an established field. According to an evolutionary psychology hypothesis, both biotic and abiotic sounds should be emotionally appreciated in terms of the potential (positive or negative) value of the specific resource or environmental situation in which our ancestors experienced them; that is, in terms of the harm or advantage these sounds suggest (Lewis et al. 2004). The association between the sound and the specific emitter is very important: the link is made automatically by our brain and, once acquired, might be extremely useful in conditions in which sight is limited (e.g., a deep forest), provided that some sound is produced. Current research in environmental psychology supports the idea of evolutionary primers – in fact a strong cross-cultural concordance in people's basic reaction to the sounds of natural environment has been demonstrated (McAndrew et al. 1998). Here, we examine some results and speculate about some sound characteristics whose aesthetic and emotional value might be explained adaptively. The sound of water, fundamental for biological life, is universally appreciated, as evidenced by the many fountains in our cities and people's attraction to streams and falls (Schafer 1977). With regard to sound characteristics, we might consider at least the following parameters: Periodicity versus aperiodicity. Though the advent of the Industrial Revolution produced many changes in the human acoustic environment (Schafer 1977), we still prefer natural soundscapes in comparison with human-influenced ones: Natural soundscapes are more valued and associated with pleasant feelings and well-being (Guille´n & Lopez-Barrio 2004); they also add value to residential sites, where the sounds of a downtown street and traffic noise detract most (Anderson et al. 1983). This possibly relates to the presence of more aperiodic sounds in an artificial soundscape. Psychophysical and neurophysiological experiments have shown that the human brain has a natural preference for harmonic and periodic sounds (Langner & Ochse 2006). An interesting analogy is that of instrumental classical music with its periodic sounds, which were apparently preferred by our ancestors (Beament 2001), whereas the most threatening sounds from mammalian predators show aperiodic spectra perceived as harsh sounds, like the aperiodic spectra of thunderstorms. Pitch. An analogous consideration might involve pitch, and the following hypothesis should be tested in the light of what is known (or still unknown) in the music emotion literature (Peretz 2001): Low-pitched sounds emitted by large animals (or large instruments) might be associated with fear or anxiety. Loudness. The intensity of a sound emitted by an animal gives us information about its location in respect to ours. Also, highintensity sounds evoke higher arousal. In fact, the quality of sound's intensity from lowest to highest might be used

as an expressive musical tool (e.g., as in Ravel's Bolero). Sound variation and abundance. As with human orchestras, the most appreciated biotic soundscapes are those that include many sounds (Oba 1994; 1995). For modern ecologists (as for ancient hunter-gatherers), a territory with many sounds means species (and prey) abundance. Melody variation. The history of domestication and species selection of songbirds suggests that melody variation is the characteristic most appreciated by humans; in contrast, non-singing   birds (e.g., gulls) were never domesticated (Catchpole & Slater 1995). Timbre. Some mammalian utterances, such as a wolf's howls or even a dog answering a wolf's howls, convey deep emotions of anxiety and fear in people (personal observation). The same is true for other large herbivore calls (e.g., stags rutting). These examples are not exhaustive – many others could be added, were it not for space limits. In conclusion, our contribution might be a first step in evaluating how sound (and music) emotions are at least in part shaped by selective pressures of evolution. Emotional responses in mother-infant musical interactions: A developmental perspective doi:10.1017/S0140525X08005402 Elena Longhi School of Human and Life Sciences, Roehampton University, Whitelands College, London SW15 4JD, United Kingdom. E.Longhi@roehampton.ac.uk http://www.roehampton.ac.uk/index.html
Abstract: With this commentary, I raise two issues relevant to the theoretical framework from a developmental perspective. First, the infants' emotional responses are induced by the music as well as by the multimodal information they perceive in interaction with their mothers, and these responses change with time. Second, contrary to what is suggested in the target article, musical expectancy is already experienced by young infants. In the target article, Juslin & Va¨stfja¨ll (J&V) eloquently propose a fascinating theoretical framework and mechanisms to explain the emotional responses to music, but they do so predominantly from an adult perspective. I raise two issues: (1) In musical interactions, infants' emotional responses are elicited not only by the music they listen to but also by the information they perceive from several modalities, and these responses change with time. (2) In singing interactions, mothers convey the hierarchical structure of the song so that the infants create musical expectancy. When mothers sing or play taped music in interactions, their infants not only listen to the music but are also exposed to information from multiple modalities. In a study on mother–infant interactions in musical contexts during the first year of life, Longhi (2003) performed an in-depth analysis of the temporal structure of the songs mothers sing to their infants and on the partners' non-verbal behaviours. She found that when mothers sing and play taped music, they nod their head and bounce their body, as well as move and touch their infants' limbs and body. Thus, during musical interactions, mothers use several modalities (e.g., auditory, visual, tactile, and kinaesthetic), and these seem to affect the infants' emotional responses. For instance, when mothers were asked to sing to their infants without touching them, 3-month-old infants displayed mostly neutral emotional states, no engagement, frequent self-touch, and never smiled, compared to when the mothers sang touching them. Similar emotional responses were displayed by 4-monthold infants when mothers played taped music without touching them. Interestingly, the mothers' multimodal information seems to evolve with the infant's development. At 3 months, physical contact and face-to-face communication are crucial for the interaction, whereas, at 7 months, the focus of attention changes from the partners to the object, and toy activity, in particular. In this way, the mothers' multimodal participation is performed according to the infants' abilities. Also, infants' emotional responses change during the first year of life. In fact, Longhi (2003) found that, at 7 months, infants smiled longer and showed mostly happy and very happy emotional states compared to when they were 3 months of age. However, at 3 months, infants showed more engagement than at 7 months. Thus, the function of musical interactions and the emotions they induce seem to change in relation to an infant's age. Perhaps, at 3 months

songs are central in the interaction, helping the partners to communicate. At 7 months, by contrast, songs are less crucial to the interaction, and they become a way of sharing and having a good time together. Therefore, musical interactions, either with live or recorded music, are a multisensory experience of different modalities where the infants' emotional responses are elicited by the music, as well as the integration of this information, and change with development. An important mechanism featured in the theoretical framework is musical expectancy, which, contrary to what has been suggested, is observed early in life. When mothers sing to their 3-month-old infants, they emphasise the hierarchical structure of the songs. A detailed analysis of the temporal structure of the songs revealed that mothers emphasise the metrical and phrasing structure of the songs, both acoustically through their singing and behaviourally by synchronising with the beats relevant to the temporal structure of the song (Longhi, in press). Extending the duration of certain beats over others, the mothers mark the boundaries between phrases and within phrases, facilitating the infants' processing of the musical event. Through their singing, touching, and moving their own as well as their infants' bodies, the mothers use synchronised multimodal channels to provide a temporally coherent segmentation of the musical event (Longhi, in press). As the infants are sensitive to repetition and redundancy of information (Bahrick & Lickliter 2000), this might be more effective for conveying the segmentation of the musical event so that the structure of the songs becomes predictable. In fact, at 3 months of age, infants seem to have a mental representation of the musical interaction, synchronising significantly more often with certain beats rather than others, in particular those in the middle and at the end of the phrases (Longhi, in press). Another level of the temporal structure of the songs that has an impact on the interaction is the phrasing structure, which, together with musical tempo, seems to help infants to create musical expectancy. When analyzing the duration of the phrases of the song, Longhi (2003) found that mothers modify the length of the phrase according to their position in the song across the different tempos. In particular, when using allegro tempo, mothers significantly extend the duration of the fourth phrase, whereas, with andante tempo songs, the second phrase is significantly longer. In this way, mothers make themselves more predictable to their infant. Moreover, musical tempos appear to play an important role in aiding the partners to organise and co-ordinate their responses with the beat, as well as with each other. So, during andante tempo, mothers and infants synchronise with each other very accurately and significantly match their responses in the third phrase of the song compared to the others. On the other hand, during allegro tempo, both partners perform numerous synchronous behaviours with the musical beat, but only the mothers synchronise significantly with it. These findings suggest that musical tempos, allegro and andante in particular, might be of importance in the interactions, and that infants might use these tempos to anticipate the structure of the musical interaction. In fact, mothers may more often sing songs at these tempos, because the actual pace of the songs enables both partners to temporally organise their behaviours and interlock with each other. Therefore, the hierarchical structure of the songs together with their tempos are vital in creating musical expectancy already when infants are 3 months of age – favouring the flow of the interaction between mothers and infants, and promoting their attunement and harmonious communication. In sum, a developmental perspective, in particular regarding musical interactions, can help in further understanding the emotional responses to music and offer the new framework more supportive avenues for consideration and investigation than the ones suggested by Juslin & Va¨stfja¨ll. What about the music? Music-specific functions must be considered in order to explain reactions to music doi:10.1017/S0140525X08005414 Guy Madison Department of Psychology, Umea˚ University, 901 87 Umea˚, Sweden. guy.madison@psy.umu.se http://www.psy.umu.se/staff/guy_madison_eng.htm Abstract: The

mechanisms proposed in the target article are quite general and do not address variables specific for music. I argue that reactions to music include motivational mechanisms related to functions of music. To further the field, as the authors envision, consideration of internal mechanisms must be paired with specific hypotheses that include musical and musically relevant variables. Music is a human universal, although it serves no apparent adaptive function. This is cause for curiosity and speculation about its motivational and functional basis. Folk psychology asserts that music "has something to do with" emotions, presumably based on the incidence of musical behaviors paired with pleasurable experiences. This implies little about causality, however: Just for the sake of argument, it could mean that music induces pleasurable experiences, that a happy state of mind prompts me to sing and dance (or to put on a CD), or that this association is the effect of other, underlying factors. Juslin & Va¨stfja¨ll (J&V) argue that it is important to explain listeners' reactions to music. I emphatically agree, but note that several different levels of explanation may obtain. For example, one might want to understand why music induces reactions. One might also be interested in the specific effects of various musical features: If some mapping from musical or sound features to reactions could be made, it might help design and improve therapies. But then one would also need to know to what extent and in which ways contextual variables affect reactions induced by the same stimulus. Perhaps experiencing music in a group setting induces stronger or different reactions than being alone (Merker et al., in press). All these questions represent levels of explanation that are not directly addressed by the systematization of psychological mechanisms and their characteristics provided by the target article, which purports to "explain[s] how such emotions are induced" (sect. 1, para. 11) – rather than why. To be sure, none of the 66 hypotheses listed in J&V's Table 4 include music-specific variables. Emotional reactions due to brain stem reflexes, episodic memory, and evaluative conditioning could all be induced by a wide range of stimuli. Emotional contagion is a possibility for any stimulus perceived as emotionally expressive, and whether visual imagery is more effective in response to music than to other stimuli remains an open question (Aleman et al. 2000). Inasmuch as it yields predictions and helps to organize knowledge (in the sense of a theory), this systematization is therefore relevant to the measurement and understanding of emotion in general, not specifically to emotions induced by music (cf. Scherer 2004). The only mechanism proposed that is clearly music-specific is musical expectancy. I think that discussing additional mechanisms would be very fruitful, and might lead to a number of testable hypotheses (cf. Peretz 2006). A commentary does not provide space for developing such hypotheses, so I will instead summarize a few key aspects that emerge from adopting a functional perspective on the relation between music and affective responses (Madison, in press). The function of emotions and affective responses in general is to guide action, with negative feelings directing us away from that which may ultimately threaten well-being and positive feelings directing us to that which ultimately facilitates well-being (Frijda 1986). Everyday observations as well as research show that affective responses in connection with music are overwhelmingly positive (Juslin & Laukka 2004; Scherer et al. 2001– 2002), even when the music is characterized as sad (Schellenberg et al. 2008), or when musicians try to express different emotions (Juslin & Madison 1999). In contrast, the valence of affective responses that act on associations acquired through personal life experience, such as those provided by evaluative conditioning, episodic memory, and visual imagery, is on average likely to be neutral. An innate ground for affective responses to music seems, therefore, to be in play, presumably as a motivational machinery for engaging in musical behaviors. The function of music, in contrast, is a matter of debate (e.g., Fitch 2006; Kivy 2002; Miller 2000; Pinker 1997), but this does not preclude the formulation of quite specific ideas. Common themes include: (1) that the induction and communication of emotion constitutes a function of music and a reason why we are attracted to it (Cooke 1959;

Juslin 2001; Meyer 1956); (2) that music evolved as a sexually selected courtship display (Darwin 1871/1902; Miller 2000); (3) that music may have a bonding effect that facilitates cooperative activity and social organization (Freeman 2000; Roederer 1984; Ujhelyi 2000); and (4) that language and music likely have been cooperative, in the sense that music might have supported the evolution of language, or vice versa, or both, during some period of their common evolutionary history (Brown 2000; Mithen 2005; Molino 2000; Richman 2000). These themes include both proximal and ultimate functions; some of them indicate a direct selection pressure for the evolution of musical faculties, and others do not. For the purpose of the present commentary, however, the point is that they implicate testable hypotheses regarding the interaction between musical behaviors, the conditions in which they occur, and their motivational mechanisms. For example, it has been suggested that our capacity to entrain to a common pulse occurred during the period of speciation between chimpanzees and early hominids (Merker 2000). This is a key feature of dance, as well as of performing and listening to music, and is associated with pleasurable feelings (Madison 2006). We can therefore posit that an additional entrainment mechanism contributes to reactions to music. Links between sensory and reward systems suggest that actually entraining to an external signal might be more pleasurable than passively listening to it (e.g., Todd & Cody 2000), which is but one example of such an hypothesis. The main contribution of the target article is to emphasize that one should discriminate between mechanisms on the basis of their characteristics so as to reduce discrepancies in results and interpretations. It is my impression that students of emotion already do so, and that the "cognitive appraisalist" that J&V challenge may be more of a straw man than a dominant character. This may not be the case in the field of music, however, and, if so, the article serves a useful purpose for reducing possible measurement and interpretation problems in future research. But to explain affective responses to music requires us to come to grips with the different properties or functions of music, in addition to analyzing the mechanisms that convey the affective responses it may induce.

Identifying and individuating the psychological mechanisms that underlie musical emotions

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Abstract: Juslin & Va¨stfja¨ll (J&V) have suggested a promising theoretical framework for understanding musical emotions. However, the way they classify the hypothetical underlying psychological mechanisms suffers from certain weaknesses, both in principle and when it comes to details. It is proposed that the authors consider incorporating ideas from a recent dissertation that has advanced another multimechanism theory of musical emotions.

Juslin & Va¨stfja¨ll's (J&V's) article is an impressive feat and will certainly have a profound influence on the scientific community's thinking about musical emotions. I agree with its basic tenet that one must care about the mechanisms by which music evokes emotions. However, identifying and distinguishing different psychological mechanisms is a delicate task. My criticism of J&V's proposal in this respect is partly based on a recent dissertation (Vickhoff 2008). Vickhoff 's theory is another attempt to clarify the different ways in which music evokes emotions, and maps nicely onto that of J&V in several respects. An important desideratum on any classification is that it uses a uniform principle. It is not obvious that J&V's classification fulfills this desideratum. In the ordinary use of the terms, brain stem reflexes refers to an anatomical locus and visual imagery describes a certain phenomenology, whereas emotional contagion stands for a sociopsychological chain of events. To be fair to the authors, it is clear that they intend these labels to stand for psychological mechanisms. However, despite their careful attempt in section 3.2 to describe the mechanisms in terms of a number of dimensions, it never becomes clear which of these dimensions are essential, in cases of conflicts between criteria, for distinguishing one mechanism from another. Here are a few detailed comments on the three aforementioned categories: “Brain stem reflexes” is anatomically a misnomer for events that may include thalamic neural commands (sect. 3.1.1, para. 3). Apart from that, tying psychological concepts to brain structures always entails a great risk of conceptual confusion when new discoveries change our views about brain function. The authors’ discussion of the category “visual imagery” in my view shows clearly that they are after something quite different from what the term usually represents. They should be, since explaining a musical emotion by reference to visual imagery leaves open why the music evoked the imagery in the first place. Consequently, the authors try to pinpoint a specific process leading to visual imagery that they refer to as a “metaphorical nonverbal mapping” (sect. 3.1.4, para. 4) and that they consider especially relevant for musical emotions. Therefore, it is the latter process, not the nature or significance of visual imagery per se, that the authors ought to characterize in detail. Much of their discussion about visual imagery is actually redundant, given this aim. Regarding “emotional contagion,” the authors argue that when an emotion is perceived in music (e.g., through a similarity with the human voice), the same emotions are evoked in the listener via internal mimicry of the emotional expression. A parallel is drawn with empathy. However, empathy is not simply mimicry; it includes a complementary emotion that we may call “pity” and is also evoked without any effort or intervention of cognitive mechanisms. In my view, the explanation why we can bear hearing very sad music is that similar complementary emotions are evoked automatically by the music. And note that it is the rule rather than the exception that we like sad music. In subconsciously controlled joint action (Seebanz et al. 2006), it is also the rule rather than the exception that our actions are complementary to those of the others – not the same. In line with this, many of our spontaneous emotional reactions while playing together or listening to music in a group cannot be characterized as emotional contagion or explained by simple neuronal mirroring. Vickhoff ’s solution to the problem of finding a unitary principle of classification is to relate the emotion-evoking mechanisms to different ways of perceiving music. These ways of perceiving are in turn characterized in terms of “perspectives.” A perspective is a perceptual filter that selects certain traits of the stimulus as relevant. Perspectives are heavily context dependent and can therefore be identified through situations where they typically occur. For example, the dyadic perceptual perspective is activated when we perceive another person and her emotions. It is also used when we perceive music as if it were a person. The dyadic perspective entails a mobilization of all the emotion-inducing mechanisms that we know from empathy. The tribal perspective is typical of many group encounters and is active when we listen to music in a group to which we belong. Together, these two perceptual perspectives can possibly explain all the phenomena that “emotional contagion” in J&V’s theory is intended to explain. Finally, the nature of the specific mechanism for visual imagery that J&V hint at may be illuminated by Vickhoff ’s concept of the allocentric perspective. This means perceiving the music as a landscape one can navigate in. I think that it would be worthwhile for J&V to consider whether some of Vickhoff ’s conceptual innovations could be integrated in their continued effort to refine their own theory. I end this commentary with a few minor critical remarks: 1. The psychological mechanisms are said to “become activated by taking music as their ‘object’” (sect. 1, para. 5). In the next sentence, the authors confess their adherence to the view that emotions have intentional objects in the sense of being “about” them. But this signals a confusion, because musical emotions certainly do not always have music as their intentional object: Think, for example, of film music. The source of the confusion may be the standard cognitivist error of anthropomorphizing neural mechanisms (cf. also sect. 3.2, para. 1). 2. The characterization of moods as having low intensity (Table 1) is improper. A severe depression is a mood disturbance and is as such felt very intensely. 3. The characterization of preferences as being of low intensity (Table 1) is also difficult to understand. Preferences are not essentially conscious phenomena that can be compared with other conscious phenomena. And if some kind of behavioral measure of intensity is intended here, preferences can certainly be intense. 4. Some common musically induced emotions are not covered by the theory in the target article: for example, the joy of movement, the sense of flow, and the sense of grace in a technical performance. Distinguishing between two types of musical emotions and reconsidering the role of appraisal doi:10.1017/S0140525X08005438 Agnes Moorsa and Peter Kuppensb aDepartment of Psychology, Ghent University, 9000 Ghent, Belgium; bDepartment of Psychology, University of Leuven, 3000 Leuven, Belgium. agnes.moors@ugent.be http://users.ugent.be/~akmoors/ peter.kuppens@psy.kuleuven.be http://ppw.kuleuven.be/okp/people/Peter_Kuppens/ Abstract: The target article inventories mechanisms underlying musical emotions. We argue that the inventory misses important mechanisms and that its structure would benefit from the distinction between two types of musical emotions. We also argue that the authors' claim that appraisal does not play a crucial role in the causation of musical emotions rests on a narrow conception of appraisal. The objective of the target article is to present an inventory of mechanisms that can cause musical emotions. The authors have succeeded in covering a broad range of mechanisms that are important in the causation of musical emotions. A first point we would like to make is that the inventory can be further improved in terms of both exhaustiveness and structure.   Mechanisms that are overlooked are those underlying the mere exposure effect (Zajonc 1968) and those underlying emotions that constitute a reaction to, rather than an imitation of, the emotions expressed in music. With regard to structure, we suggest that the organization of the inventory would benefit from distinguishing between two types of musical emotions (cf. Bell 1914; Frijda 1986; Gabriel & Crickmore 1977; Langer 1942; Payne 1980; Swanwick 1975), which we define below. A first type is that of musical emotions that have as their object the music itself (i.e., music considered on the reality level). This type of musical emotions involves an appreciation of the music; the music is liked or disliked. The presence/absence of liked/ disliked music can lead to positive emotions such as happiness, admiration, and relief. The absence/presence of liked/disliked music can lead to negative emotions such as anger or sadness, depending on the presence of other conditions such as coping potential and agency. A second type of musical emotions has as its object the content of the music, that which is represented or invoked by the music (i.e., music considered on the symbolic level). Music can represent emotions such as sadness, anger, fear, and happiness, or it can represent emotion-eliciting events such as hurricanes and carnivals. Musical emotions of the second type can be similar to the emotion expressed in the music, or they can constitute a reaction to the emotion or event invoked by the music. Distinguishing between both types of musical emotions is important because it helps disentangle mechanisms responsible for the causation of musical emotions. For Type 1 emotions, we should consider mechanisms involved in liking/disliking of musical stimuli and those involved in evaluating the presence/ absence of liked/disliked stimuli. Liking/disliking can be accounted for by mere exposure (music is liked more after multiple hearings), evaluative conditioning (music is liked better/less when paired with positive/negative events), and appraisal (music is compared with aesthetic goals or standards). Appraisal seems also suited for the further evaluation of the presence/ absence of liked/disliked stimuli, as well as additional information about agency (e.g., who stopped the music?) and coping options (e.g., can we start the music again?). The causation of Type 2 emotions consists of two steps. In a first step, the listener perceives an emotion or an emotioneliciting event expressed in the music. For example, a piece of music can be perceived as expressing sadness, or it may evoke in the listener the image of a hurricane. In a second step, the emotion or emotion-eliciting

event represented in the music evokes in the listener a similar emotion or an emotion that constitutes a response to it. For example, a sad piece of music can elicit sadness, and a musical fragment that expresses anger or that evokes the image of a hurricane can elicit fear. The two steps in the elicitation of Type 2 emotions rest on different mechanisms. In the first step, perceiving the emotional content of a piece of music can be based on similarities between features of the music and features of emotions. For example, the slow tempo of sad music is similar to the slow tempo of sad speech and behavior. These similarities can be picked up with episodic memory and imagery. In the second step, contagion accounts for emotions that are similar to the emotion expressed, and appraisal accounts for emotions that constitute a response to the emotion or emotion-eliciting event expressed in the music. According to our analysis, both types of musical emotions seem to recruit appraisal at some point. This brings us to our next point. The authors of the target article have argued that appraisal is not crucially involved in the causation of musical emotions. We argue that this argument rests on a narrow conception of appraisal. If appraisal is understood according to current theoretical consensus, there is no reason to minimize the role of appraisal. Appraisal theories assume that emotions are caused by a process of appraisal in which the stimulus is evaluated on a number of variables, such as goal relevance, goal conduciveness, coping potential, and agency. Values on these variables form a pattern of appraisal, and this pattern determines the quality of the ensuing emotion. For example, fear occurs when a stimulus is appraised as goal relevant, goal inconducive, and difficult to cope with. Anger occurs when a stimulus is appraised as goal relevant, goal inconducive, and caused by another person. According to modern appraisal theories (Clore & Ortony 2000; Leventhal & Scherer 1987; Smith & Kirby 2001), appraisal can take the shape of (a) a comparison operation, (b) the activation or reinstatement of previous appraisal outcomes, or (c) activation of innate associations between stimuli and emotions. In addition, appraisal can be automatic (i.e., occur under suboptimal conditions) or nonautomatic (i.e., occur only under optimal conditions). Following our conceptualization, appraisal is involved in both types of musical emotions discussed earlier. Moreover, it should be considered playing a role in some of the mechanisms discussed in the target article. For example, brain stem reflexes, to the extent that they signal inconduciveness with the goal of safety, can be considered an example of appraisal of the form described in (c) above. Another example is Meyer's (1956) musical expectancy mechanism. We argue that the violation/ confirmation of musical expectations does not directly lead to positive/negative emotions. Otherwise, after multiple hearings when a piece of music becomes entirely predictable, it would lose its emotion-eliciting power. We argue instead that the violation/confirmation of musical expectations is similar to the violation/confirmation of goals in real life (cf. the first step in Type 2 emotions) and that appraisal of it can lead to emotions (cf. the second step in Type 2 emotions).
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Aniruddh D. Patel The Neurosciences Institute, San Diego, CA 92121. apatel@nsi.edu http://www.nsi.edu/users/patel Abstract: Are the neural systems involved in recognizing affective prosody in language also used for emotion recognition in instrumental music? One way to test this idea is to study musical affect perception in patients with receptive affective aprosodia (RAA). Music perception in RAA is totally unexplored and could provide a powerful way to test the idea that we perceive music as a kind of emotional voice.
Philosophers and theorists as far back as Plato have speculated that part of music's expressive power lies in acoustic cues related to the sounds of emotive voices (Kivy 2002). From the standpoint of modern cognitive neuroscience, the idea is intriguing because cues to vocal affect include musical aspects of speech, such as pitch, tempo, loudness, and timbre (voice

quality; Ladd et al. 1985; Johnstone & Scherer 1999; 2000), and because the patterning of these cues in emotionally expressive speech and music shows striking commonalities (Ilie & Thompson 2006; Juslin & Laukka 2003; Patel 2008). In the target article, Juslin & Va¨stfja¨ll (J&V) argue that one mechanism underlying emotional responses to music is emotional contagion based on speech-like affective cues in music. That is, they postulate that listeners implicitly recognize a basic emotion in music (such as sadness) from speech-like cues to affect (e.g., low tempo, pitch level, intensity, and pitch variability), and then the listeners themselves come to feel that same emotion. Of course, the link between the perception of emotion in music (emotions expressed by music) and the subjective experience of emotion (emotions felt by the self) is not obligatory. One can, for example, perceive a piece of music as expressing sadness without feeling sad. Indeed, one can respond with an emotion different from that expressed by the music (Gabrielsson 2002). Yet empirical research suggests that for the majority of individuals there is an alignment between emotions expressed by the music and emotions felt by the listener (Evans & Schubert 2008). This enhances the plausibility of the emotional contagion hypothesis. Another factor favoring the emotional contagion hypothesis for music is neurobiological evidence for emotional contagion in a different expressive domain, namely, face perception. Using functional magnetic resonance imaging (fMRI), Keysers and colleagues have found that the perception of affect in faces triggers activity in brain regions involved in experiencing similar emotions (the anterior insula and adjacent frontal operculum), particularly in empathic individuals (Jabbi et al. 2007; cf. Keysers & Gazzola 2006; van der Gaag et al. 2007). This internal simulation of emotions expressed by another is thought to be part of the brain's mechanisms for empathy, giving an observer access to the subjective state of another by recruiting the observer's own neural representations of that state (Preston & de Waal 2002). De Waal (2007) has argued that such mechanisms have deep evolutionary roots in primates and other highly social species, whereby they help foster social bonds which promote survival in a group setting. Given the importance of both the face and the voice in conveying emotion in humans, it seems plausible that people may also experience emotional contagion from the sounds of expressive voices, though this idea awaits confirmation from neurobiological research. Hence, what is needed at this point in order to test J&V 's ideas about affect in music and speech are two kinds of neurobiological studies. First, it is necessary to test the idea that listeners recognize musical affect using neural circuitry also involved in vocal affect perception (cf. Schirmer & Kotz, 2006). Second, it is necessary to determine whether listening to emotionally expressive music activates brain regions involved in experiencing similar emotions. This comment focuses on the first kind of study, and seeks to draw attention to a clinical disorder that could be a productive tool in this regard. This disorder is "affective aprosodia" (Ross 2000). Deficits in the ability to either recognize or produce affect in spoken utterances were first described more than 30 years ago in patients who had suffered right-hemisphere lesions (Heilman et al. 1975; Tucker et al. 1977). Patients with receptive affective aprosodia (RAA) provide an opportunity to test the idea that musical and vocal affect perception have shared neural substrates. Specifically, such patients could be tested for their ability to recognize certain basic emotions expressed by instrumental music, such as happiness, sadness, or fear. Indeed, in testing such patients, one could use stimuli from previous studies of musical emotion recognition in normal individuals (e.g., Krumhansl 1997). If affect recognition in music and speech relies on similar brain circuits, then individuals with RAA should be impaired in recognizing the emotions expressed by music. To my knowledge, musical affect perception in RAA is totally unexplored; yet the topic is attractive from both theoretical and practical perspectives. In terms of the latter, the salient point is that the disorder is not uncommon clinically, even though it is relatively rarely studied (K. Heilman, personal communication). In conducting research on musical affect perception in RAA, a number of conceptual and methodological issues require careful attention. The remainder of this commentary discusses a few of these issues. First, patients with RAA should be tested for their ability to perceive affect in other modalities (e.g., faces, gestures), in order to determine whether they have a general deficit in emotion recognition or a more specific deficit in recognizing vocal affect. From the current standpoint, it is the latter deficit that is of interest. (Existing research suggests that RAA often co-occurs with problems in recognizing affect in the face, although there are cases where vocal affect perception is disproportionately affected [e.g., Adolphs et al. 2002; Charbonneau et al. 2002].) Second, patients with RAA will need to be tested for auditory discrimination skills, in order to determine whether they have deficits in processing of basic auditory attributes shared by speech and music, such as timbre or pitch contours (cf. Heilman et al. 1984). Thus, for example, if a patient cannot judge emotion in speech and music because of a lowlevel problem in timbre processing that impacts auditory perception in general, this would not point to a specific link between emotional recognition in music and speech, but simply indicate that both processes rely on similar low-level auditory attributes of sound. Third, since RAA often (but not always) involves right-hemisphere damage, control experiments for musical memory deficits will be needed (cf. Zatorre et al. 1994). If these methodological challenges can be met, then RAA could form the basis of a powerful test of the vocal affect hypothesis for musical expressiveness.

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The need to consider underlying mechanisms: A response from dissonance

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Abstract: Current research on emotional responses to dissonance has yielded consistent data in both developmental psychology and neuroscience. What seems to be lacking is a definition of what might constitute dissonance in non-musical domains. Thus, contrary to Juslin & Va¨stfja¨ll's (J&V) proposal for the need to distinguish between six broad mechanisms, I argue that future research should rather focus on perceptual determinants of each basic emotion.

Juslin & Va¨stfja¨ll (J&V) acknowledge in their concluding remarks that scientists will generally find their proposal uncontroversial. I concur. As a neuropsychologist, I find the proposed framework sound and clear. One provocative claim, however, is that the field has made little progress due to the lack of control for mechanisms underlying musical emotions. I do not share this view. For example, emotional responses to dissonance have been studied for a long time in musical acoustics, and the studies have yielded consistent data in both developmental psychology and neuroscience. In what follows, I examine to what extent the six proposed mechanisms by J&V are needed to understand emotional responses to dissonance. I also highlight what remains to be understood to develop a theory of emotional responses to dissonance, in particular, and to unpleasant sounds, in general. Perception of dissonance is a striking and distinct experience in music listening. To experience it, it suffices to play together two adjacent keys on a keyboard – forming a minor second in musical terminology – or to imagine the initial tuning of an orchestra. Both sound complexes are dissonant, and usually judged unpleasant by ordinary listeners. In contrast, striking together two keys that lie 12 keys (i.e., an octave) apart or

hearing the first chord of Beethoven's Fifth Symphony produce sound experiences that are usually judged pleasing or consonant. Ordinary listeners, including infants, easily distinguish consonant from dissonant pitch combinations and consider the former more pleasant than the latter (Hannon & Trainor 2007; Plomp & Levelt 1965). Even musicians who sometimes claim that dissonance can be highly pleasant, exhibit enhanced electrodermal activity in response to dissonant music as compared to the consonant versions of the same pieces (Khalfa & Peretz 2004). The mechanism underlying responses to dissonance arises from the roughness created at the level of the basilar membrane in the inner ear. The overlap in vibration patterns compromises the resolution of pitches of different frequency on the basilar membrane, leading to beating and the perception of roughness (von Helmholtz 1954). Hence, in the absence of detailed analysis of the music, a sudden dissonant event may elicit a rapid, reflexlike reaction in the neural pathway. This mechanism is referred to as a brain stem reflex by J&V (sect. 3.1.1). Neuropsychologists would rather qualify this type of fast emotional responses as a subcortical reflex, to acknowledge the possibility that the response may arise from a number of different subcortical structures, not just the brain stem. There is ample evidence from both neuroimaging and brain lesion studies that subcortical structures are involved in emotional responses to dissonance. Neuroimaging studies have identified the parahippocampal gyrus (Blood et al. 1999; Koelsch et al. 2006) and the amygdala (Ball et al. 2007; Koelsch et al. 2006) as key brain structures. Lesion data have confirmed the critical involvement of the parahippocampal cortex rather than the amygdala (Gosselin et al. 2006). Thus, and contrary to J&V's claims, dissonance has been controlled for in these studies and the available data converge nicely on the involvement of one critical brain structure. More importantly, the data do not suggest that different mechanisms are involved in the emotional responses to dissonance or that the underlying mechanisms have been neglected. Such reflex-like responses to dissonance may be innate or result from evaluative conditioning (J&V's mechanism 2 [sect. 3.1.2]). Indeed, there are early and multiple opportunities for consonance calibration at all levels along the auditory pathways. Consonance is ubiquitous in the auditory environment. Most natural sounds, and speech in particular, are composed of consonant harmonic intervals. Thus, central neural networks may be preferentially attuned to consonant intervals by a process of generalization because of their prevalence or biological significance in the environment, and not simply because of hard-wired constraints of the peripheral hearing system. Here again, the data are consistent and informative. In three different laboratories, infants have been shown to prefer consonance over dissonance (Masataka 2006; Trainor & Heinmiller 1998; Zentner & Kagan 1996). More importantly, this preference for consonance is not dependent on prenatal or early postnatal experience. Hearing newborns from deaf parents prefer consonance over dissonance (Masataka 2006). Thus, the mechanism underlying the unpleasant sounding of dissonance appears to be innate. Here, too, there is no need to consider additional mechanisms underlying dissonance to resolve inconsistencies. What is needed, however, is an account for the fact that preference for consonance (or avoidance of dissonance) appears specific to humans. Although many species discriminate dissonance from consonance, nonhuman primates (tamarins) do not prefer consonant over dissonant chords (McDermott & Hauser 2004). Rather, tamarins prefer species-specific feeding chirps over species-specific distress calls. The latter category of sounds, suggestive of danger, is qualified as dissonant by J&V (sect. 3.1.1). Indeed, the increased tension of the vocal chords in distress calls introduces many subharmonics in the vocal sounds that are otherwise harmonic signals. These distortions in screams sound unpleasant to both humans and animals and would trigger an avoidance response in the listeners (who will try to stop the screams). Thus, there would be an evolutionary advantage to have such dissonant screams in the vocal repertoire, especially in the youngsters (Fitch et al. 2002). Nonetheless, the research with tamarins suggests that dissonance in music and dissonance in vocal sounds might be different phenomena. What is needed is a definition of the acoustical correlates of dissonance so that we can measure it in non-musical sounds (J. McDermott, personal communication). In other words, we need to learn more about the acoustical properties of emotional vocal sounds in order to understand better the neurobiological mechanism that accounts for the avoidance of dissonance. The need to examine perceptual determinants of emotional responses within and across domains should not be minimized. They provide grounds to generalize a theory. For example, within the musical domain, one would think that dissonance is the major perceptual determinant of threat (consider the soundtrack of Hitchcock's Psycho [1960]). Yet, current research points to the recruitment of a different neural structure in response to dissonance (i.e., the parahippocampal cortex) compared to musical threat (i.e., the amygdala; Gosselin et al. 2005; 2006; 2007). More research is needed to identify the perceptual determinants of scary music and to distinguish the neural correlates of perception from those of emotion. Similarly, defining perceptual determinants of dissonance in vocal communication would enable us to examine the relevance of emotional contagion, visual imagery, and episodic memory (J&V's mechanisms 3, 4, and 5) in driving emotional responses to dissonance. If dissonance is to music what screams are to vocal communication, one can easily conceive how these broad categories of mechanisms might come into play. For the moment, consideration of these mechanisms is premature. More work is needed to specify the acoustical determinants of unpleasantness in particular, and the perceptual triggers of emotions in general. Notation and expression of emotion in operatic laughter doi:10.1017/S0140525X08005463 Robert R. Provine Department of Psychology, University of Maryland, Baltimore County, Baltimore, MD 21250. provine@umbc.edu Abstract: The emotional expression of laughter in opera scores and performance was evaluated by converting notation to temporal data and contrasting it with the conversational laughter it emulates. The potency of scored and sung laughter was assayed by its ability to trigger contagion in audiences. Notation of operatic laughter. Among the murder and mayhem, yearning, lusting, and dying in the musical melodrama of opera, singers perform the occasional chuckle, yuk, or titter. Such theatrical emoting is data encoded in the musical score and is subject to quantitative analysis. The musical score is a set of instructions to a vocalist or instrumentalist about the duration, pitch, and shape of a sound to be produced. If you know the time signature, metronome marking, note value, and pitch, you can represent and reproduce a sonic event such as laughter with reasonable accuracy. Can we tap the fabled musical powers of Mozart and colleagues to capture the essence of laughter? Teamed with fellow musicians Helen Weems and Lisa Griesman, I set out to answer these and related questions (Provine 2000). After considering the description of laughter via musical notation, we close the circle by evaluating the potency of notated and musical laughter to trigger contagious laughter in audiences. The starting point of our analysis was the sound of laughter itself that composers and singers seek to emulate. Waveform   and spectrographic analyses (Provine & Yong 1991) defined laughter as a series of "laugh notes" ("ha," etc.), bursts of sound that last about one-fifteenth second and repeat every one-fifth second or so ("ha-ha," etc.). A sigh-like aspiration is present before the first laugh note, and between all others. If laugh notes are digitally removed from recordings of laughter and the gap closed, all that remains is a long, breathy sigh. In addition, laughs, particularly lengthy ones, proceed with a decrescendo, a progressive decrease in loudness. Our analysis produced a variety of notation schemes, time signatures, and metronome markings that accurately describe laughter (Provine 2000). But the present focus is on existing opera scores, not our proposals for new ones. We found 57 operas with laughter notated in the score, but focused on 20 operas for which we had both scores and at least two different recorded performances. We then mathematically converted scored laughter into laugh-note durations and internote intervals in milliseconds, or, metronome in hand, converted the actual performance of laughter into similar data. A wide variety of notation schemes was encountered, ranging from an occasional thirty-second, half, and whole note to the more usual sixteenth, eighth, and quarter note. The pitch of laugh notes was usually scored, but sometimes only a rhythmic marking was given. Of course, these notations have meaning only in the context of time signature and tempo. Leoncavallo avoids notation altogether in I Pagliacci, simply instructing the murderous clown Canio to "laugh bitterly" in the Italianate Ah! Ah! Ah! Ah! Ah! Most composers, Mozart included, usually overestimated the duration of laugh notes ("ha") and inter-note intervals ("ha-ha"). Thus, composers typically notate and singers perform laughter more slowly than it really is. In contrast to the stereotypy of conversational laughter, there is a greater range of cadence of notated laughter between composers, and even for the same composer within a song or opera. For example, in Mussorgsky's Boris Godunov, the tempi of four different laughter-bearing songs range from about 35% too slow to 50% too fast. Scoring laughter carries a built-in trap for composers; they are constrained by the tempos of a song already in full flight, and by the demands of the dramatic and musical moment. With a few exceptions, composers did not acknowledge the silent interval separating laugh notes ("ha-ha"), or laughter's natural decrescendo. In performance, some singers took liberty with the score, perhaps in the interest of dramatic context, or necessity of vocal production. The most flagrant variance was in adding laughter where none was scored, as typical in the aria "E Scherzo od e Follia" from Verdi's Un Ballo in Maschera. No cases were found of omitting scored laughter. When it comes to emoting, opera singers would rather giveth than taketh away. At study's end, we learned more about opera than about laughter. In opera, too many concessions are made to the tyranny of the musical moment, and laughter is in the service of song, not vice versa. Thus, the fabled ears of Mozart and colleagues never got a full test and we are left musing about their analytic prowess. Singing in the primal chorus. One of the strangest human rituals is our joining fellow Homo sapiens in the primal chorus of ha-ha-ha. We repeat the sound of laughter when we hear it, producing a chain reaction of neurologically primed levity (Provine 1992). Similar contagion is characteristic of yawning (Provine 2005). Like laughter in conversation, contagious laughter "just happens." It is not a conscious choice. We do not speak "ha-ha" as we choose a word in speech. Laughter, like crying, is difficult to produce on command. Beginning with theatrical performances in ancient Greece, contagion has been recognized and used to enhance, and sometimes to suppress, audience response (Provine 2000). So-called claques of stooges were planted in the audience to prompt the audience into greater laughter, cheering, and sometimes jeering. Emperor Nero, an avid actor, ordered thousands of Roman soldiers to attend his performances and applaud loudly. Wise judges always awarded Nero first prize. The use of claques, formal and informal, continues in opera to influence audiences and newspaper reviewers, in political rallies, religious revivals, and other settings where a mass emotional reaction is desired. Opera is occasion to another historical precedent: the use of contagious laughter in musical and theatrical performance. Michael Kelly, Irish tenor and friend of Mozart, was performing the delightful "Haste Thee, Nymph" from Handel's L'Allegro, il Penseroso ed il Moderato, a song featuring some sung laughter. After being unsatisfied with stiff performances by other singers, Kelly, according to his own report, laughed all through it, as I conceived it ought to be sung, and as must have been the intention of the composer: the infection ran; and their Majesties, and the whole audience, as well as the orchestra, were in a roar of laughter, and a signal was given by the royal box to repeat it, and I sang it again with increased effect. (Provine 2000, p. 146–47) Handel and Kelly tapped an aspect of human nature that was exploited by the entertainment technology over a century later. Contagion was the theme of the 1922 "Okeh Laughing Record," a trumpet performance interrupted by highly infectious laughter that became one of the most effective and successful novelty records of all time (Provine 2000). Louis Armstrong, Jelly Roll Morton, Sidney Bechet, Spike Jones, and others followed with their own variants. In 1950, television's Hank McCune Show added "canned laughter" to its

broadcasts to compensate for the show being recorded in a studio without a live audience. "Laugh tracks" continue on television sitcoms because they actually do produce audience laughter and increased ratings of humorousness. The mechanism of contagious laughter and yawning may involve a specific sensory detector that triggers these acts. Contagion requires no mirror neurons. This light-hearted musical interlude is offered in the belief that the scientific and artistic issues in music and emotion are broad, deep, and will most likely yield to unanticipated, interdisciplinary approaches, even one including opera. The target article prompted my musing about such topics as singing, laughing, yawning, chanting, poetry reading, talking, dancing, and other rhythmic, stereotyped, and sometimes contagious acts that may or may not be social. An alternative commentary was "Movements of Note," a consideration that all vocalizations and sonic acts are movements that produce sounds, with contagious sounds being movements that cause movements in observers. I favor approaches that treat sound-making as an objective, observable act, like walking, breathing, or flying, and that avoid a long slog through the semantic swamp of music definition. We may think more clearly about music when we make it less special. Do all musical emotions have the music itself as their intentional object? doi:10.1017/S0140525X08005475 Jenefer Robinson Philosophy Department, University of Cincinnati, Cincinnati, OH 45221-0374. Jenefer.Robinson@uc.edu http://www.artsci.uc.edu/philosophy/faculty/robinson.html
Abstract: Juslin & Va¨stfja¨ll (J&V) think that all emotions aroused by music have the music itself as their "intentional object." Some of the mechanisms they discuss almost certainly involve both cognitive appraisals and intentional objects. But some of the mechanisms are non-cognitive: they involve neither cognitive appraisals nor intentional objects. Partly for this reason they may produce moods rather than emotions proper. Most theorists of emotion believe that emotional responses are caused by cognitive appraisals and that the objects of these appraisals are the "intentional objects" of the corresponding emotions. Since "pure" instrumental music without words cannot normally specify the requisite object, it is widely believed that music can arouse only moods rather than emotions proper (Carroll 2003). Juslin & Va¨stfja¨ll (J&V) have usefully pointed out that emotions too can be evoked by non-cognitive means. On the other hand, such emotions, although responses to information in the music, are not directed towards the music as a "cognitive object" but are simply caused by it as a "stimulus object" (Kivy 1990). 1. "Brain stem reflexes" are caused by "sounds that are sudden, loud, dissonant, [etc.]" (sect. 3.1.1, para 1). These responses are "preattentive" (sect. 3.1.1, para. 4), very fast, and automatic, like the startle mechanism (Robinson 1995). In a sense, they "appraise" the situation – as one that needs to be attended to – but the music is not the intentional object of the emotion; the emotion is not about the music. 2. "Evaluative conditioning" also achieves its effects without being about the music. In LeDoux's (1996) experiments with rats, fear is elicited by the conditioned stimulus (CS), which is a tone. The thalamo-amygdala route in the brain identified by LeDoux conveys only very crude information about the stimulus; the response is caused by, without being directed at, the tone. 3. In discussing "emotional contagion" (Hatfield et al. 1994), J&V focus on the way that internal mimicry of vocal expressions of emotions such as sadness may induce the emotion mimicked. A more powerful and widespread mechanism would seem to be the internal and external mimicry of bodily movements and action tendencies characteristic of particular emotions (Bharucha et al. 2006; Nussbaum 2007; Robinson 2005). Sad music moves in a slow, lethargic way, as sad people tend to do, and if the music induces mimicry of such movements, it may be able to induce sadness itself. There is a wealth of evidence that inducing people to adopt a facial expression, bodily stance, or action tendency characteristic of some emotion induces the emotion itself (Laird 2007; Strack et al. 1998). Again, there is no intentional object involved. Of course, the

feeling of emotion induced may be categorized or labeled after the fact with an emotion term (Schachter 1959), and an intentional object may then be confabulated for the emotion (Robinson 2005). 4. In contrast to these three mechanisms, which typically operate beneath awareness, emotions deriving from "musical expectancies" are the result of focusing consciously on the way the music unfolds and appraising it as either meeting or failing to meet one's expectations (Meyer 1956; Sloboda & Juslin 2001). When the listener is surprised by a move away from the tonic, bewildered when the music moves into key areas ever more distant from the tonic, and delighted when the tonic at last returns, these musical developments are the intentional objects of the emotions aroused. Indeed, they are not only the object of focused attention but also of some sort of appraisal, such as "this is unexpected or expected." 5. Emotions aroused by "episodic memories" also have an intentional object towards which the emotion is directed, but in this case the primary object of the emotion is not the music itself but the remembered episode. The music arouses emotion only through association with the episode. 6. "Visual imagery" also evokes emotions, which are then associated with the music. When the music leads me to picture a tranquil landscape, say, it is hard to know whether it is the imagined landscape or the music itself that is having the emotional effect. Things are also complicated by the fact that sometimes the visual imagery we form in listening is guided by the music (as in successful Guided Imagery and Music [GIM] therapy), whereas at other times it may be little more than free association with the music. I start to listen to L'apre`s-midi d'un faune (The Afternoon of a Faun), and I imagine relaxing on the warm sand by the sea, and then I start to think about my last vacation in the south of France, and before I know it I am no longer paying attention to the music but simply wool-gathering (Kivy 2007). Any experiments designed to study the imagery that music encourages and perhaps guides and manages has to be able to rule out this kind of free association. One other point: Music does not induce only visual imaginings. Much instrumental music of the Romantic period encourages more abstract imaginings, such as Beethoven's Fifth, which enacts the drama of a struggle leading to victory (Newcomb 1984). Despite all their evidence, J&V have not ruled out the possibility that some of the mechanisms discussed may arouse moods rather than emotions. The data in their Table 3 demonstrating various psychomotor, motivational, cognitive, and behavioral effects of music are consistent with the hypothesis that it is moods that are being induced rather than simply emotions. That is because the primary function of moods is precisely to "bias cognition" (Davidson 1994). Moods are "biases and modulations in the operation of processes such as attention allocation, memory retrieval, and categorization" (Sizer 2000), as well as emotion (Ekman 1994; Frijda 1993). In an irritable mood one has a propensity to become angry, for example. And, of course, the absence of an intentional object suggests that the emotional contagion mechanism, for example, could be arousing a mood rather than an emotion proper. It seems likely that some types of music are more likely to produce moods than emotions. Mood music in a horror movie is designed to induce a mood of suspense rather than any specific emotion: The music induces a propensity to get into an emotional state of fear or excitement, and it affects how we attend to the film (we are on the look-out for sinister events). By contrast, Beethoven's Fifth is designed to elicit emotions that are attendant on the musical structure, including the expressive structure of the piece. Different kinds of music are designed for different modes of listening. The formalist music-appreciator listening to Beethoven focuses on musical syntax – melodic, harmonic, and rhythmic – and the emotions aroused by "musical expectancies" may well be a mode of understanding the piece itself. But for the horror-movie aficionado getting in the right mood for the story about to unfold or the teenager listening to rap in order to reinforce his sense of membership in the "in" group, the details of the musical structure are more-or-less irrelevant (Kivy 2007). Feelings and the enjoyment of music doi:10.1017/S0140525X08005487 Alexander Rozina and Paul Rozina,b aSchool of Music, West Chester University, West Chester, PA 19383; bDepartment of Psychology, University of Pennsylvania, Philadelphia, PA 19104-6196. arozin@wcupa.edu rozin@psych.upenn.edu http://www.wcupa.edu/CVPA/som/mt_faculty_arozin.html http://www.psych.upenn.edu/~rozin/ Abstract: We wonder about tying the universal appeal of music to emotion as defined by psychologists. Music is more generally about feelings, and many of these, such as moods and pleasures, are central to the enjoyment of music and fall outside the domain of emotion. The critical component of musical feelings is affective intensity, resulting from syntactically generated implications and their outcomes. We like Mozart. Although this might in part be because his music arouses particular "emotions" in us, the satisfaction we get from music must be considered under a much broader affective umbrella, perhaps best summarized as "feelings." Mozart takes us on a cascade of feelings, entailing ups and downs of affective intensity. Such feelings do not often fit comfortably in the   categories that psychologists use to describe emotion. Music produces aesthetic pleasure, a sense of peace and relaxation and/or stimulation and arousal, along with the narrow category of entities that psychologists have carved out and called emotions. Juslin & Va¨stfja¨ll (J&V) have accurately described what psychologists mean by emotion, but by limiting the feelings aroused by music in this way, they have missed much of the appeal of music. Pleasure itself, and its companion liking, do not fall under the heading of emotion, but are surely an important part of understanding music. Music produces a sense of aesthetic pleasure (e.g., Berlyne 1971) that defies our linguistic categories. Psychologists distinguish pleasure, pain, and moods from emotions. This is a very questionable set of distinctions; "emotion" is not even represented as a word in all languages. And pleasure itself is multifaceted, including sensory, mastery, and aesthetic pleasure (summarized in P. Rozin 1999). The single defining feature of emotion and pleasure is feeling. If someone feels sadness or pleasure, regardless of physiology and expression, affect has occurred. If someone does not feel sadness or pleasure, regardless of physiology and expression, there is no affect. Either, then, we should consider emotion a broader term, encompassing more than the standard set of discrete phenomena that psychologists study, or we should study musical affect rather than musical emotion. Perhaps, then, Leonard Meyer's (1956) groundbreaking take on the subject should have been called Affect and Meaning in Music (instead of Emotion...). J&V have done us all a favor by putting a diverse set of material about music and emotion in one place and in highlighting the different ways that music can generate emotion. In so doing, they break out of some field-wide ruts that have limited our ability to comprehend how an abstract string of sounds could possibly arouse sadness, hope, and other emotions. J&V reasonably oppose the accepted definition of emotion as necessarily the result of cognitive appraisal. That said, we disagree with the authors' insistence that all emotions, including musical emotions, must have intentional objects. Certain musical emotions are not about the music. One is not sad about Barber's Adagio for Strings or angry at a punk song. Other musical "emotions" do take music as an object. One can feel disgust for the quality of a performance, awe at compositional virtuosity, or joy about the sequence of musical feelings experienced throughout a piece. Such meta-emotions are important phenomena that do not fit into J&V's taxonomy. Their six mechanisms help distinguish between very different sources of musical affect. All contribute to musical affect. But we feel that one of these, which they label "musical expectancy," has an especially important and powerful role in accounting for the universal appeal of music. Consider the following examples: 1. We hear a foghorn. Surprising, emotional. A brain stem reflex. The foghorn reminds us of a ferry on Puget Sound (visual imagery) and the day we crossed the sound in a pouring rain (episodic memory). This scenario shows many of the mechanisms for the induction of musical emotion, and yet, this situation is not musical. Yes, brain stem reflexes, evaluative conditioning, emotional contagion, and, in a much more idiosyncratic way, visual imagery and episodic memory, all contribute to musical affect. But, in our view, music is more like a novel or well-crafted meal than it is like a foghorn; that is, it is the structure as incorporated implicitly in the listener, in accordance with the implication-realization model pioneered by Meyer (1956) and furthered by Narmour (1990; 1991; 1992). 2. We hear a Mozart piano sonata. The lightness of texture, major key, and fast tempo help create positive feelings. We hear a cadence coming: The dominant chord (e.g., a G-major triad in the key of C major) sounds as though it will resolve to the tonic chord (e.g., a C-major triad in the key of C major) but instead progresses to an Ab-major triad. This deceptive cadence, as it is called in music theory, surprises us and instantly changes our affective response to the music. All of these effects are feelings, but many don't qualify as emotions according to the definitions of psychologists. This is music, and the aesthetic affect induction is due primarily to our appreciation of the implications in the music. What both of these examples demonstrate is the importance of temporal sequence for the experience of musical affect. The affective responses to the foghorn and to the deceptive cadence derive from the same basic source: surprise. The distinction between the two is that we react to the foghorn without any need for prior exposure, whereas we react with surprise and aesthetic pleasure to the deceptive cadence only if we have experience listening to specific musical styles. As Narmour (1990; 1991; 1992) argues, expectations, musical and otherwise, stem from both innate (bottom-up) and learned (top-down) processing. We are born with the ability to detect changes in our environment such as a sudden loud (or sudden soft) sound, or the violation of a continuing repetitive event (accounting for a reaction to the AAB sequence in music of humor) (Rozin et al. 2006). We develop a sense of musical expectations within a specific style such as those that derive from tonal hierarchies (e.g., major and minor). Thus, one could combine these two – brain stem reflexes and musical expectancies – into one more general category of implications. Without the realizations and denials of implications, music might be sad or joyous, but it would not be an affective, aesthetic experience. The flow of the music, its temporal sequence, is the essential ingredient. Loud and fast music tends to make us happy, but it is primarily the structure that gives us the affective character and intensity. We agree with J&V about ways that sounds, and that subset of them that we call music, can produce emotions. It is important to understand all six of the affect induction features of sounds and music, and to understand how they interact, usually to reinforce one another. But while we do this, we should remember that, at its core, music is about aesthetic pleasure linked principally to musical structure, its implications, and their probable realizations. Emotion, as a category in psychology, subtly limits our conception of music, and misses much of the story. The role of exposure in emotional responses to music doi:10.1017/S0140525X08005499 E. Glenn Schellenberg Department of Psychology, University of Toronto at Mississauga, Mississauga, ON, L5L 1C6, Canada. g.schellenberg@utoronto.ca http://www.erin.utoronto.ca/~w3psygs/ Abstract: A basic aspect of emotional responding to music involves the liking for specific pieces. Juslin & Va¨stfja¨ll (J&V) fail to acknowledge that simple exposure plays a fundamental role in this regard. Listeners like what they have heard but not what they have heard too often. Exposure represents an additional mechanism, ignored by the authors, that helps to explain emotional responses to music. At the most basic level, emotional responses to stimuli, including music, involve simple evaluations. Such evaluations are often measured with self-reports, typically by using rating scales with like a lot or extremely pleasant at one end, and dislike a lot or extremely unpleasant at the other end. If a perceiver likes one stimulus more than another, or considers one stimulus to be more pleasant, liking and pleasantness judgments extend readily to preferences.   These evaluative responses are more basic than so-called basic

emotions (Ekman 1992b), such as happiness and sadness. This claim is supported by evidence of approach and avoidance behaviors in nonhuman species, and by the fact that brain imaging and lesion studies reveal differential activation solely on this basis. In the musical domain (for a review, see Peretz, in press), different brain areas are activated in response to consonant (pleasant sounding) and dissonant (unpleasant sounding) stimuli (Blood et al. 1999; Gosselin et al. 2006; Koelsch et al. 2006) and to music that sounds scary or threatening (Gosselin et al. 2005; 2007). To date, however, there is no evidence of differential activation patterns in response to, say, happy and sad sounding music,[1] probably because these responses do not map directly onto evaluations (i.e., valence; Russell 1980).
Although listeners typically exhibit a preference for happy-sounding over sad-sounding music (Gosselin et al. 2005; Hunter et al. 2008; Husain et al. 2002; Schellenberg et al. 2008; Thompson et al. 2001), people often like and choose to listen to sad-sounding music. Indeed, listeners' typical preference for happy-sounding over sad-sounding music disappears as a consequence of manipulations that induce fatigue and frustration (Schellenberg et al. 2008).
For many years, researchers have documented the role that exposure plays in stimulus evaluations (for a review, see Bornstein 1989). For reasons that seem obvious from an evolutionary perspective, people and animals have an adaptive fear of the unknown (neophobia) that extends across modalities. After exposure to a particular stimulus reveals that it is relatively benign (i.e., with no adverse consequences), evaluative responses become more favorable (Zajonc 2001). In line with this view, listeners respond more favorably to music and music-like stimuli they have heard previously compared to novel music (Peretz et al. 1998; Schellenberg et al. 2008; Szpunar et al. 2004; Thompson et al. 2000), even if they do not recognize the stimuli (see Zajonc 1980; 2001). Because the to-be-exposed and novel stimuli are assigned randomly for each listener, favorable evaluations can be attributed to exposure rather than to stimulus differences. Such favorable responding is related to Juslin & Va¨stfja¨ll's (J&V's) second mechanism (evaluative conditioning), but it differs substantially in that the association involves learned safety (Kalat & Rozin 1973), which stems from the absence of negative consequences. Liking often increases with additional exposure, a phenomenon that is typically attributed to perceptual fluency (Jacoby 1983). On this view, a previously encountered stimulus is processed quickly and effortlessly, compared to a novel stimulus, because of the reactivation of an existing mental representation. When asked to make evaluations, people misinterpret this ease of processing as a favorable disposition toward the previously encountered stimulus. This perspective helps to explain increased liking as a function of exposure to stimuli that are aesthetically impoverished or highly controlled (e.g., line drawings: Kunst-Wilson & Zajonc 1980; random tone sequences: Szpunar et al. 2004). Nonetheless, positive misattributions should become less likely with further increases in exposure and explicit memory for the stimulus, such that processing fluency is an obvious consequence of exposure (Bornstein 1989). For real music, however, there is evidence contrary to the hypothesis that liking and memory are associated negatively. Listeners often like pieces they remember (Schellenberg et al. 2008; Szpunar et al. 2004).
Berlyne's (1970; 1974) two-factor model (which J&V mention in a different context) describes liking as a consequence of the arousal potential of a stimulus, which should be neither too great nor too small. Initial wariness towards a novel stimulus results from its arousal potential being too great. With additional exposure that has benign consequences, arousal potential is reduced to optimal levels. Finally, over-exposure leads to boredom as the arousal potential of the stimulus becomes less than optimal. In other words, Berlyne's first factor refers to increases in liking that accompany decreases in arousal potential, due to learned safety; the second factor refers to decreases in liking that accompany further decreases in arousal potential, due to satiety. Berlyne's model is under-specified in describing interactions between liking and memory, yet it explains increases in liking for music that

accompany a moderate amount of exposure (e.g., recall when you heard The Macarena for, say, the third time), as well as decreases that occur as a consequence of overexposure (when you heard The Macarena for the umpteenth time). Indeed, there is abundant anecdotal evidence of increases followed by decreases in liking for music as a function of exposure. This inverted U-shaped function has also been documented systematically with real music (Schellenberg et al. 2008; Szpunar et al. 2004). Again, because the musical stimuli were assigned randomly to different exposure frequencies (i.e., 0, 2, 8, or 32) separately for each listener, the same stimulus was novel for some listeners, presented at moderate frequencies for other listeners, and over-exposed for still others. In short, the design ensured that liking ratings were independent of differences among stimuli and can be attributed solely to exposure frequency. In sum, any consideration of mechanisms that underlie emotional responding to music must include exposure as a very basic mechanism, and learned safety, perceptual fluency, and satiety as sub-mechanisms that are related directly to exposure. As J&V acknowledge, failing to account for underlying mechanisms could lead to "inconsistent or non-interpretable" findings (target article, Abstract). This problem is likely to be particularly acute when a well-documented mechanism is ignored. NOTE 1. Mitterschiffthaler et al. (2007) compared brain activity when participants listened to happy-sounding or sad-sounding music. These authors did not control for liking or pleasantness, however, and several of their findings parallel those from studies that compared activation to pleasant and unpleasant music. Music evoked emotions are different – more often aesthetic than utilitarian doi:10.1017/S0140525X08005505 Klaus Scherer a and Marcel Zentner b aCentre Interfacultaire des Sciences Affectives (CISA), University of Geneva, CH-1205 Geneva, Switzerland; bDepartment of Psychology, University of York, YO10 5DD York, United Kingdom. Klaus.Scherer@pse.unige.ch http://www.affective-sciences.org m.zentner@psychology.york.ac.uk http://www.unige.ch/fapse/emotion/members/zentner/zentner.html Abstract: We disagree with Juslin & Va¨stfja¨ll's (J&V's) thesis that musicevoked emotions are indistinguishable from other emotions in both their nature and underlying mechanisms and that music just induces some emotions more frequently than others. Empirical evidence suggests that frequency differences reflect the specific nature of music-evoked emotions: aesthetic and reactive rather than utilitarian and proactive. Additional mechanisms and determinants are suggested as predictors of emotions triggered by music. We applaud Juslin & Va¨stfja¨ll's (J&V's) comprehensive overview of mechanisms of music-induced emotion, which is reminiscent of our production rule framework (Scherer & Zentner 2001). However, whereas we distinguished between central and peripheral route mechanisms (appraisal, memory, and empathy vs. proprioceptive feedback and facilitation), the authors' description of mechanisms tends to confound levels of analysis by addressing phenomena (emotional contagion), content (memory schemata), procedures (visual imagery), and substrata (brain stem). For example, the term emotional contagion describes a phenomenon: the spread of an emotion from one person to another. Yet, the mediating procedures and substrata can be quite different. In our 2001 chapter, we showed how contagion can occur through centrally mediated empathy or peripherally routed rhythmic motor entrainment, a biological mechanism synchronizing body oscillators to external rhythms, including music. Such coupling of rhythms may have powerful emotion-inducing properties. Thus, infants between 6 and 16 months who showed vigorous and synchronized motor entrainment to music and to rhythmic sounds also smiled more frequently (Zentner & Russell 2006). Hence, a more important role should be assigned to peripherally mediated emotion induction, especially entrainment. The overview of potential mechanisms of musical emotion induction provides surprisingly little insight into the conditions necessary to musical emotion induction. Why does music sometimes evoke emotions but often fails to do so? To promote understanding of this important issue we formulated testable hypotheses about determinants and moderators of emotion induction by music (Scherer & Zentner 2001). Specifically, music emotion experience is conceived as the result of a multiplicative function of structural features (e.g., rhythm, melody, harmony), listener features (e.g., personality, music preference), performer features (e.g., performer skills, state), and contextual features (e.g., type of event, environment). Most likely, these determinants and moderators interact with the respective induction mechanism; for example, rhythm being important for entrainment, performance for empathy, and listener experience for memory. In some cases, the significance of the authors' claims is difficult to evaluate. For example, the claim that the nature of the induction mechanism is essential for understanding musical emotions (sect. 1, para. 10) remains unsubstantiated if it means that the induction mechanism determines the nature of the ensuing emotion. Different mechanisms of musical emotion induction may lead to similar emotive states, just as different elicitation routes can lead to similar forms of guilt. The statement that "music recruits largely the same mechanisms as do other stimuli that induce emotions" (sect. 4.2, para. 2) is obvious if it means that music, like words, can evoke memories or images and that similar brain mechanisms are involved. However, the statement remains unsubstantiated if it means that there is nothing special about the process of emotion induction by music. Similarly, the second part of that sentence "and that the emotions evoked by music are the same" is obviously true if it means that hearing music can sometimes function like any other emotion-inducing stimulus (one can get angry about loud music or unpleasant grill odors coming from a neighbor's balcony) but is unsubstantiated if it means that emotional experiences evoked by music are completely interchangeable with emotions triggered by other elicitors. Given the paucity of current empirical knowledge about the nature of music's emotions, theory-building about mechanisms of musical emotion induction can go easily astray. For example, when describing emotional contagion as a possible mechanism, the authors note that, compared with angry speech, "a musical instrument might sound extremely 'angry' by virtue of its even higher speed, louder intensity, and harsher timbre. This aspect should render music a particularly potent source of emotional contagion" (sect. 3.1.3, para. 5, emphasis J&V's). This implies that anger should be easy to induce by music through emotional contagion; however, evidence shows that anger is in fact only very rarely induced by music (Laukka 2007; Zentner et al., in press). Similarly, the musical expectancy mechanism (sect. 3.1.6) should, in theory, give surprise special prominence among musically induced emotions. However, in practice, surprise is not a frequently reported response to music (Laukka 2007; Zentner et al., in press). To provide a more solid base for theory building, we empirically studied music-evoked emotions. In a study of music experts, we showed that music typically generates emotional states other than the standard basic emotions (Scherer et al. 2001-2002). In support of these initial results, we found in a series of laboratory and field studies that emotive states evoked by music can be differentiated into nine categories (wonder, transcendence, tenderness, peacefulness, nostalgia, power, joyful entrainment, tension, and sadness). We developed a scale to assess these music emotions: the Geneva Emotional Music Scale (GEMS). We showed that a domain-specific model such as that represented by GEMS accounts more powerfully for ratings of music-induced emotions than do instruments derived from basic emotions or affective circumplex theories (Zentner et al., in press). Although the authors claim not to have seen any evidence for the existence of music-specific emotions (sect. 4.2, para. 2), our past work provides such evidence and suggests that concepts and measures from non-musical areas of emotion research cannot simply be transposed to music. In consequence, we suggested distinguishing between utilitarian and aesthetic emotions. Utilitarian emotions are triggered by the need to adapt to specific situations that are of central significance to the individual's interests and well-being.

Such emotions tend to be high-intensity reactions, preparing for action. In contrast, aesthetic emotions are triggered in situations that usually have no obvious material effect on the individual's well-being and only rarely lead to specific goal-oriented responses (Scherer 2004; Zentner et al., in press). In the case of aesthetic emotions, appraisal tends to be intrinsic to the visual or auditory stimulus, based on forms and relationships. As a consequence, aesthetic emotions are more diffusely reactive than proactive. In aesthetic experiences, the individual can savor the nuances of the emotional stirrings for their own sake – just as the wine taster savors the delights of different vintages. In conclusion, J&V have produced an excellent and thoughtprovoking survey of the issues. However, some of their claims remain unsubstantiated. Their tendency to blur the boundaries between aesthetic and utilitarian emotions risks further encouraging the widespread reliance on categorical or dimensional emotion models in the study of music's emotions, when, as we have shown, music is capable of inducing a much more nuanced range of emotive states than these traditional models of emotions imply. Super-expressive voices: Music to my ears? doi:10.1017/S0140525X08005517 Elizabeth A. Simpson, William T. Oliver, and Dorothy Fragaszy Department of Psychology, University of Georgia, Athens, GA 30602. simpsone@uga.edu http://simpsone.myweb.uga.edu woliver@uga.edu doree@uga.edu http://www.uga.edu/psychology/primate Abstract: We present evidence from neuroimaging and brain lesion studies that emotional contagion may not be a mechanism underlying musical emotions. Our brains distinguish voice from non-voice sounds early in processing, and dedicate more resources to such processing. We argue that super-expressive voice theory currently cannot account for evidence of the dissociation in processing musical emotion and voice prosody. Juslin & Va¨stfja¨ll (J&V) present a framework within which "musical emotions" can be organized. They propose six mechanisms to explain how music elicits emotions in listeners. One mechanism J&V propose is the process of emotional contagion, whereby we internally mimic the emotional content of music via mirror neurons, resulting in the experience of the same emotion as conveyed through the music. They argue that the voice-like qualities in music arouse us, and that we process music as we would a super-expressive voice. According to super-expressive voice theory (Juslin et al. 2001), we process a musical piece as if it were a voice. Although there is preliminary evidence that perception of emotion in music and in the voice share some of the same brain areas (e.g., Nair et al. 2002), we report evidence of distinctions.   Recent functional magnetic resonance imaging (fMRI) studies indicate that there are specific parts of the brain, including the superior temporal sulcus, that respond selectively to human voices (Belin et al. 2000). Moreover, electroencephalogram (EEG) research reveals that such processing is faster and more extensive for vocal than for non-vocal sounds (Schirmer et al. 2007). These two findings suggest that our brains can differentiate between emotional voice sounds, and emotional musical sounds, very early in processing. Studies of patients with brain injuries provide further evidence of the distinction between the processing of voices and nonvoices. Griffiths et al. (2004) describe a patient who underwent a stroke that resulted in damage to his left insula and left amygdala, and consequently possessed a deficit in "musical emotion" processing, while retaining normal music perception and voice prosody perception. If the same mechanism is responsible for both processes, how can one be impaired and the other intact? This indicates that separate neural networks may underlie voice prosody and musical emotion perception. A dissociation was also found in patient I.R., who suffered damage to her left superior temporal gyrus and left insula, among other regions, resulting in the loss of music recognition, while leaving musical emotion perception and speech prosody intact (Patel et al. 1998; Peretz et al. 1998). Although patient I.R. correctly discriminated the emotional nature of musical excerpts, she claimed that she was only guessing, and was surprised to learn that she was doing well. It therefore appears that her discrimination ability was outside of her awareness or intention (Peretz et al. 1998). This is strikingly similar to the phenomenon of blindsight, in which patients are able to respond to visual stimuli, but are not consciously aware of perceiving them (Weiskrantz et al. 1974). Interestingly, I.R.'s speech prosody judgments were normal (she did not have to "guess"). The fact that emotion perception in music was outside of awareness, while emotion perception in the voice was within awareness, is further evidence of distinct systems for voice prosodic processing and musical emotion processing. Another problem with the emotional contagion mechanism is that it fails to explain emotional reactions to music that are not congruent with the emotional content of the music. For example, when watching a frightening movie and you hear an angry voice, or a "threatening" musical excerpt, this theory predicts that you should also feel angry. However, this is not the case; instead, we feel fearful. From an evolutionary perspective, it would not be adaptive to possess a simulation mechanism that causes you to become angry upon hearing an angry voice or other threatening sound. Therefore, this theory fails to take into account all types of emotional expressions. J&V present a thoughtful list of mechanisms responsible for musical emotions. Such a framework is much needed, and undoubtedly will be informative for guiding future studies. However, there are weaknesses in one of the proposed mechanisms – emotional contagion – that need to be addressed. One possibility is that the same underlying mechanism is responsible for both musical and vocal emotional expressions, assuper-expressive voice theory postulates, but that the former is more sensitive to damage than the latter. Further studies must directly compare "musical emotions" and vocal emotions to elucidate these differences. The role of signal detection and amplification in the induction of emotion by music doi:10.1017/S0140525X08005529 William Forde Thompson and Max Coltheart Department of Psychology, Macquarie University, Sydney, NSW 2109, Australia. Bill.Thompson@mq.edu.au max@maccs.mq.edu.au http://www.psy.mq.edu.au/staff/bthompson/ Abstract: We propose that the six mechanisms identified by Juslin & Va¨stfja¨ll (J&V) fall into two categories: signal detection and amplification. Signal detection mechanisms are unmediated and induce emotion by directly detecting emotive signals in music. Amplifiers act in conjunction with signal detection mechanisms. We also draw attention to theoretical and empirical challenges associated with the proposed mechanisms. We consider Juslin & Va¨stfja¨ll's (J&V's) article from the perspective of a distinction we propose between two classes of mechanisms: signal detection and amplification. Signal detection mechanisms are unmediated sources of emotion, including brain stem responses, expectancy, and evaluative conditioning. They are unmediated because they induce emotion by directly detecting emotive signals in music. Amplifiers act in conjunction with signal detection mechanisms. They include episodic memory, visual imagery, and possibly emotional contagion. Signal detection mechanisms. J&V distinguish brain stem responses from the other mechanisms proposed. This neuroanatomical classification presents a source of confusion, however, because the brain stem has multiple functions and may be implicated in the other five mechanisms. An alternative conception is the psychophysical signal detector, which encompasses brain stem responses and evaluative conditioning. Balkwill and Thompson (1999) defined psychophysical signals as sound attributes having consistent emotional connotations across domains (e.g., music and speech prosody) and cultures. The signals may be learned or congenital. Learned signals arise through evaluative conditioning, acting on attributes correlated with emotion. Congenital signals trigger hard-wired affective responses including, but not restricted to, brain stem activity. J&V restrict discussion of expectancy to syntax, but syntactic structure represents only one attribute relevant to expectancy. Expectancy implicates multiple mechanisms at several processing levels. Huron's (2006) expectancy model includes imagination, tension, prediction, reaction, and appraisal, underscoring the challenge of defining expectancy as a unified mechanism operating solely on syntactic structure. For example, the tension response is a physiological preparation for any imminent event and involves changes in arousal that likely arise from brain stem activity and are adjusted according to the degree of uncertainty about the outcome. Prediction responses are transient states of reward or punishment arising in response to accuracy of expectations. Accurate expectations lead to positive states. Inaccurate expectations lead to negative states. The mechanism of evaluative conditioning proposed by J&V conflates a process of learning following long-term exposure to environmental regularities with an emotional-induction mechanism that detects signals and induces emotion. However, feedback mechanisms that establish learned associations are usefully distinguished from signal detection mechanisms that decode emotions during listening. Learning mechanisms act both on musical pieces and on psychophysical attributes of sound. The sadness of Shakespeare's monologue "Tomorrow and tomorrow . . ." nurtures associations between emotions communicated by verbal information and statistical parameters of the acoustic signal, such as slow delivery and little pitch variation. Such psychophysical signals are correlated with emotional states and connote them even when embedded in nonverbal stimuli such as music. Amplification mechanisms. J&V posit visual imagery as an independent cause of emotional experience. But imagery primarily accompanies or amplifies emotional experience; emotional states induced by music are conducive to imaginative processes that elaborate and amplify that experience. Moreover, imaginative processes are not restricted to visual images. Some music has a conversational quality that stimulates an auditory image of talking; other music can stimulate a kinesthetic image such as floating. Music can even generate conceptual imagination, such as the idea of death. Imagery during music listening may have less to do with music than with the absence of visual stimulation to which a listener must attend.

Like visual imagery, episodic memories are rarely an independent cause of musically induced emotion but primarily amplify emotional experience. Episodic memory is powerful precisely because there is typically congruence in the emotional connotations of the music and episode. More generally, because selfreport studies are susceptible to demand characteristics, the prevalence of episodic memory and imagery is probably overestimated. Most music listening accompanies activities such as driving, reading, and socializing, with little opportunity for imagery and episodic memory. Emotional effects of music are subtle but they occur continuously. In contrast, tangible visual images (a meadow) or episodic memories (a day at the beach) – because they are extraordinary – are over-reported. According to the authors, emotional contagion is triggered by voice-like qualities of music, including intensity, rate, and pitch contour ("super-expressive voice"). However, such musicspeech associations must be established in the first place through conditioning, and then decoded by psychophysical signal detectors. Once signals are decoded, emotional contagion converts perceived into felt emotion through a process of mimicry, amplifying the output of perceptual mechanisms. It is feasible that emotional contagion is directly activated by acoustic signals with no mediating process, but it should be engaged not only by voice-like attributes, but any emotional signal. Conclusions. J&V characterize the literature as confused. A more optimistic interpretation is that the field is developing, and the target article is a valuable stimulus for this progress. Researchers have carefully controlled musical attributes, and cross-cultural studies have elucidated the capacity of people to interpret emotional connotations of music or speech from foreign cultures by relying on psychophysical signals that are culture-transcendent (Balkwill & Thompson 1999; Thompson & Balkwill 2006) and that have similar connotations in music and speech (Ilie & Thompson 2006). Emotional responses to music seem to arise from three broad sources: psychophysical signal detection, expectancies, and emotional amplifiers. Many issues remain unresolved. The difference between perceived and felt emotion – not explored here – has implications for theories of music and emotion (Schubert 2007). Moreover, research suggests that emotional responses to music implicate multisensory processes not acknowledged in the target article (Thompson et al. 2005; in press). Finally, it is important to define modularity explicitly (Peretz & Coltheart 2003) since this is a much-misunderstood concept (Coltheart 1999). Music as a dishonest signal doi:10.1017/S0140525X08005530 Sandra E. Trehub Department of Psychology, University of Toronto – Mississauga, Mississauga, ON, Canada L5L 1C6. sandra.trehub@utoronto.ca http://www.utm.utoronto.ca/7041.0.html Abstract: Instead of the discrete emotions approach adopted by Juslin & Va¨stfja¨ll (J&V), the present perspective considers musical signals as functioning primarily to influence listeners in ways that are favorable to the signaler. Viewing music through the lens of social-emotional regulation fits with typical uses of music in everyday contexts and with the cross-cultural use of music for infant affect regulation. Given widespread disagreement on the existence and nature of musical emotions, their links to non-musical emotions, and the conditions under which they are elicited, Juslin & Va¨stfja¨ll's (J&V's) attempt to specify induction mechanisms for such disputed emotions may be unwarranted or premature. Although the notion of discrete emotions has faced increasing challenges in the general emotion literature (Barrett 2006; Russell 2003; Scherer 2000a), it continues to prevail in the literature on music cognition. Moreover, it remains central to J&V's conceptualization. It is odd, indeed, that the basic emotions (e.g., happiness, sadness, anger, fear), which concern automatic, innate responses to highly significant stimuli (Izard 2007; Tomkins 1962), have been co-opted for emotions expressed in music and for feelings experienced while listening to music. Typical studies provide listeners with preselected musical materials (based on expert agreement regarding the intended emotion) and highly constrained response choices. High levels of agreement in such contexts are viewed as confirmation of similarities in the perception of emotion in music, both within and across cultures (Balkwill & Thompson 1999; Juslin & Laukka 2003). Open-ended response formats would undoubtedly generate unruly individual differences. For appraisal theorists (e.g., Ellsworth & Scherer 2003), however, who regard specific emotions as arising from subjective appraisals of events, individual differences in affective responses are to be expected. Bachorowski and Owren's (2003) selfish-gene (Dawkins 1989) account of vocal (nonverbal) emotion offers an alternative to conventional discrete emotions or appraisal approaches. These authors dispute the notion of emotive vocalizations as honest signals reflecting the emotional state of the signaler, even its valence. In their view, the primary function of emotive signals is to influence listeners' affect, attitudes, and behavior in ways that are favorable to the signaler. It follows that the signaling process was shaped over evolutionary time by such consequences. These consequences can be direct, arising from signal acoustics (e.g., amplitude, variability), or indirect, arising from familiarity with the signal or prior affective experiences. Similarly, musical signals are unlikely to reflect the affective state of the composer or performer, and they may not express emotion in any simple sense. Presumably, composers and performers strive to influence the affective state of listeners – to move them or connect with them in one way or another. It is possible, then, that emotional responses to music can be approached more productively within the broad context of communication. Diversity in listeners' responses would not be surprising in view of the diversity of personal and musical histories, as well as the variable network of associations with music in general or with specific musical pieces. Indeed, when listeners are given the option of selecting from dozens of empirically derived descriptors of feelings in response to various pieces of music, relaxed, happy, dreamy, transcendent, enchanted, nostalgic, and touched are among the most frequently endorsed terms, whereas sad, angry, and fearful are among the least common (Zentner et al., in press). Nevertheless, the same listeners use such negative terms to characterize emotions expressed by the music. Viewing music through the lens of social and emotional regulation (including self-regulation) fits with typical uses of music in everyday contexts, whether as background or foreground (DeNora 2000; Sloboda & O'Neill 2001). It also fits with the cross-cultural use of maternal vocalizations for regulating infant affect and promoting attachment. Mothers use a distinctly musical style when they speak to their preverbal infants (Fernald 1991), a style that includes individually distinctive, or signature, tunes (Bergeson & Trehub 2007). The efficacy of maternal vocal signals is evident in infants' enchantment with this speech style (Fernald 1991; Werker & McLeod 1989) – its positive affect, in particular (Singh et al. 2002). Mothers across cultures also sing to their infants, doing so by means of a distinctive musical genre (lullabies and play songs) and a distinctive singing style (Trehub & Trainor 1998). Divergent social-regulatory goals are reflected in divergent song choices, with lullabies prevailing in cultures that value calm, contented infants, and play songs prevailing in cultures that value infant vitality and expressiveness (Tsai 2007). Infants prefer such infant-directed singing to typical informal singing (Trainor 1996). They also exhibit greater engagement and more prolonged attention to maternal singing than to maternal speech (Nakata & Trehub 2004), perhaps because the former is especially effective in modulating arousal (Shenfield et al. 2003). In short, mothers' spoken and sung signals achieve the intended affective consequences. Despite the presumption that infants are moved by music, especially vocal music, the principal index of their engagement is interest, for example, staring at their singing mother while maintaining a relatively still body and face (Nakata & Trehub 2004). Ellsworth (2003) views interest as the prototypical human emotion because of its developmental and cross-cultural ubiquity and its undeniable contribution to learning. For Silvia (2008), interest is central to aesthetic emotions. Interest may help bridge the gap between the emotions of everyday musical experience and those of the concert hall. Presumably, interest, which can vary in intensity, is related to core affect (Russell 2003), but it does not seem to occupy a fixed region on the pleasure-displeasure continuum. In principle, one could be moved by or intensely interested in a work of art that depicts or generates disturbing images. The conception of music as a signal designed primarily to influence the affective state and behavior of listeners raises different questions than those suggested by J&V. For example, does music accomplish some of its selfish goals by making the listener feel more connected to or more disarmed by the performer or by others who are listening simultaneously? Are these feelings intensified by participatory actions such as singing or dancing? Is music more effective than other cues in reactivating emotional memories? These questions, although admittedly modest, seem much less daunting than J&V's quest for multiple induction mechanisms of musical emotions. Progress in answering these little questions could provide the impetus for tackling big questions about the origins of music.

Anticipation is the key to understanding music and the effects of music on emotion

doi:10.1017/S0140525X08005542 Peter Vuusta,b and Chris D. Fritha,c aCenter of Functionally Integrative Neuroscience, Aarhus University Hospital, 8000 Aarhus C, Denmark; bRoyal Academy of Music, 8000 Aarhus, Denmark; cWellcome Trust Centre for Neuroimaging, University College, London, WC1 N 3BG, United Kingdom. pv@pet.auh.dk http://www.musik-kons.dk/foku/pvuust.php skaacfr@ucl.ac.uk http://www.interacting-minds.net Abstract: There is certainly a need for a framework to guide the study of the physiological mechanisms underlying the experience of music and the emotions that music evokes. However, this framework should be organised hierarchically, with musical anticipation as its fundamental mechanism. Juslin & Va¨stfja¨ll (J&V) claim that the study of musical emotions has suffered from a neglect of the underlying psychological mechanisms evoking these emotions and propose that these mechanisms can be summarized as (a) brain stem reflexes, (b) evaluative conditioning, (c) emotional contagion, (d) visual imagery, (e) episodic memory, and (f) musical expectancy. A problem with these categories is that they are not ordered hierarchically, are not mutually exclusive, and only category (f) – musical expectancy – directly links musical and psychological mechanisms as such. This limits the scope of the proposed framework somewhat, especially if its purpose is to act as a guideline for experiments trying to identify the modularity for the brain structures involved in the processing of musical emotions. We believe that the framework would be more useful if the mechanisms for evoking musical emotions were organized hierarchically such that musical expectancy was seen as the most fundamental mechanism underlying the other mechanisms. It is hard to imagine that musical emotions are evoked without some sort of musical meaning assigned to what is heard, unless we think of emotions, such as fear, evoked by the mere advent of a sudden loud, scary sound. However, in such a case, it is questionable whether one would define this as music. Most music theoreticians (Cooper & Meyer 1960; Lerdahl & Jackendoff 1977; 1999; Meyer 1956; Monelle 1992) consider musical anticipation as one of the principal means by which music conveys meaning and emotion. According to this point of view, understanding music (Cooper & Meyer 1960; Lerdahl 1971; Lerdahl & Jackendoff 1999, pp. 145–60; Meyer 1956; Monelle 1992) is related to the anticipatory interplay between local auditory events and a deeper structural layer partly inherent in the music itself, and partly provided by mental structures in the listeners that is induced by the music (Palmer & Krumhansl 1990; Vuust et al. 2006a). In short, the musical experience is dependent on the structures of the actual music, as well as on the expectations of the interpreting brain. These expectations are dependent on long-term learning of musical structures (culture-dependent statistical learning), familiarity with a particular piece of music, and short-term memory for the immediate musical history while listening to a musical piece, as well as on deliberate listening strategies (Huron 2006; Vuust et al. 2006b). Brain structures underlying musical expectation are thus shaped by culture, as well as by personal listening history and musical training (Vuust et al. 2005). Moreover, as soon as one hears the first sound of a musical piece, anticipational structures enabling anticipation, such as meter, tonality, and memory for particular musical pieces, seem to be in place already and therefore unavoidable (e.g., see Brochard et al. 2003). Thus, it is difficult to imagine any of the proposed mechanisms acting without the involvement of musical expectation. Judging from their Table 4, J&V believe that musical expectation is something that develops slowly over time during listening experience and is not fully developed until the ages of 5 to 11 years. This may well be correct if musical expectation is restricted to anticipation of complex musical structures, such as the hierarchy of harmony dependent on long-term learning (see, e.g., Leino et al. 2007). However, expectation of the more simple repetitive sound patterns, such as pitch deviants in successive pitch trains, which is a part of all music, has been detected even before birth, as indicated by the mismatch negativity (MMN) measured by electroencephalography (EEG) or magnetoencephalography (MEG) (Huotilainen et al. 2005). Moreover, in an elegant study, Winkler et al. (1996) showed that the auditory predictive model is updated for each new acoustic event in the sound environment, indicating that the anticipatory structures of music are in constant flux during the listening experience. These results demonstrate that anticipation has a role at many levels in the hierarchy of musical structure. Furthermore, J&V also claim that the degree of volitional influence on musical anticipation is low. However, we recently conducted a study in which musicians were asked to maintain either the main meter or a countermeter while listening to Sting's "The Lazarus Heart" (Vuust et al. 2006b). In this experiment, the subjects could volitionally impose two very different anticipatory frameworks onto the music. Deliberately listening to a melody from the perspective of two different tonalities would be another example of volitional control of the anticipatory framework. The relationship between musical expectancy and emotion was originally explored by Meyer (1956) and has recently been elaborated upon convincingly by Huron

(2006) in his book Sweet Anticipation. If we consider music expectation/anticipation as the fundamental mechanism for the musical experience, then this maps nicely onto recent theories of how the brain works. Karl Friston (2005) has provided a promising model of brain function, in which predictive coding, as a central principle of brain function, provides an account of how the brain identifies and categorizes the causes of its sensory inputs (for similar viewpoints, see Shepard 2001; Tononi & Edelman 1998). The model posits a hierarchical organization whereby lower-level brain regions estimate predictions of their expected input based on contextual information through backwards connections from higher-level regions. A comparison between prediction and Commentary/Juslin & Va¨stfja¨ll: Emotional responses to music BEHAVIORAL AND BRAIN SCIENCES (2008) 31:5 599 actual input produces an error term that, if sufficiently large, will be fed back to call for an update of the model. This generates a recursive process, which aims at minimizing the difference between input and prediction. As the representational capacity of any neuronal assembly in this model is dynamic and context sensitive, this, among other issues, addresses the problem of top-down control (Frith & Dolan 1997; Roepstorff & Frith 2004). Lately, we have argued that processing violations of musical anticipation in different aspects of the music (e.g., rhythm/harmony) evokes different error messages (MMN/ early anterior negativity [EAN]) and networks (Vuust et al., in press). These effects are training dependent and can be explained by the predictive coding theory. Thus, in our opinion, musical expectation is a good candidate for the fundamental mechanism guiding the experience of musical meaning as well as emotion. Anticipation in itself may evoke a wealth of emotions, such as awe, surprise, discomfort, the sensation of swing, and so on. According to Huron (2006), this is due to a variety of different survival-related responses to anticipation, in particular the "prediction response" that rewards fulfilled expectations. However, anticipatory structures such as meter and tonality act indirectly on the other proposed mechanisms, in that they form the basis for musical memory, as well as for musical meaning. If we consider the vast amount of neuroscientific research on music that has been published in recent years, it is certainly true that the studies of musical emotions seem to be pointing in different directions. Consider, for instance, the very different activation patterns reported in studies of major and minor mode music (Green et al. 2008; Khalfa et al. 2005; Pallesen et al. 2005) supposedly evoking very simple emotions (happy/sad). Even though these results may be due to many different factors contributing to the emotional state of the subjects under different experimental conditions, we agree with the J&V that one of the reasons for these contradictory results may be the lack of a theoretical framework. However, this framework needs to be organized hierarchically with music anticipation as the guiding mechanism.

Authors' Response All emotions are not created equal: Reaching beyond the traditional disputes doi:10.1017/S0140525X08005554 Patrik N. Juslina and Daniel Va¨stfja¨llb aDepartment of Psychology, Uppsala University, SE-75142 Uppsala, Sweden; bDepartment of Psychology, Go¨teborg University, SE-40530 Go¨teborg, Sweden. patrik.juslin@psyk.uu.se http://www.psyk.uu.se/hemsidor/musicpsy2/ daniel.vastfjall@psy.gu.se http://www.psy.gu.se/Personal/DaneilV.htm Abstract: Most commentators have agreed with our thesis, that musical emotions cannot be studied without regard to underlying mechanisms. However, some commentators have expressed concerns that are addressed in this response. Others have suggested directions for future research. Topics discussed in our response include terminology, elaborations on particular mechanisms, possible additional mechanisms, ways of distinguishing among emotions and mechanisms, the prevalence of musical emotions, the relationship between perceived and felt emotions, developmental issues, and evolutionary perspectives. We end our response with a plea for researchers to reach beyond the traditional disputes in the field to pave the way for more theory-driven studies that can facilitate a deeper understanding of musical emotions.

We are grateful to the commentators for providing interesting suggestions and raising several important issues that might help to refine work in this area. In this response, we try to address as many of their comments as possible, but we focus particularly on those that (a) are most important for the field and (b) offer the most serious criticism of our framework. R1. Do we need to control for underlying mechanisms? We note that few of the commentators have disputed our central claim, that musical emotions cannot be studied without regard to how they are evoked. Indeed, many have explicitly agreed with our claim. Bharucha & Curtis, for example, observe that: By disaggregating the variety of musical experiences that we call emotion, and by unearthing the numerous causal mechanisms responsible for this multiplicity, a messy field starts to sort itself out. Many of the apparent contradictions and inconsistencies in the literature are due to the failure to recognize that all these mechanisms – not just one – are at work. Collectively they account for a wide spectrum of emotional experiences in music. The target article therefore constitutes an immensely important contribution, and enables future research on music and emotion to be more lucidly framed. Other commentators are more skeptical. Scherer & Zentner argue that our claim that the nature of the induction mechanism is essential for understanding musical emotions is "unsubstantiated if it means that the induction mechanism determines the nature of the ensuing emotion" (emphasis in their commentary). Yet the framework that we outlined clearly implies that the underlying mechanism will influence the kind of affective state that is evoked. To take a simple example: It seems quite clear that brain stem reflexes initiated at the level of the inferior colliculus are not able to evoke complex emotions such as nostalgia. Thus, the nature of the mechanism (i.e., the way in which the emotion is evoked) does influence the ensuing emotion. Preliminary evidence that specific mechanisms are associated with specific emotions has already been reported (Juslin & Liljestro¨m, in press). We are surprised that Scherer & Zentner question our claim, because it is a crucial implication of Scherer's previous work on appraisal (Scherer 2001) that the stimulus object, and in particular how it is processed, will strongly influence the precise affective state evoked. Yet somehow this important principle is abandoned by Scherer in the case of music. Note further that the importance of controlling for underlying mechanisms does not concern only the experienced feeling: It concerns a range of characteristics that were captured by our set of hypotheses. Even more puzzling in some ways are Peretz's comments. She claims that she finds our framework "sound and clear" (para. 1 of her commentary), yet what she proposes goes entirely against the message of our article. She basically argues that researchers can continue to investigate musical emotions simply by looking at direct relationships among physical characteristics (e.g., dissonance) and emotions, without any consideration of underlying mechanisms: "Future research should rather focus on perceptual Response/Juslin & Va¨stfja¨ll: Emotional responses to music 600 BEHAVIORAL AND BRAIN SCIENCES (2008) 31:5 determinants of each basic emotion" (Peretz's Abstract). Note that which acoustic cues are associated with the perception of basic emotions in music has already been mapped in previous research (Gabrielsson & Juslin 2003; Juslin & Timmers, in press). Still, which emotions are evoked in the listener by such music is a different question that, we believe, cannot be explained simply in terms of acoustic characteristics. One person's "favorite music" is another person's "noise." Hence, an approach that focuses only on the perceptual characteristics of the music is doomed to fail in explaining the wide variety of emotions evoked by music (Juslin, in press). This problem remains even if we consider a fairly simple psychophysical aspect such as dissonance. Peretz calls for a deeper understanding of the acoustic correlates of dissonance in non-musical sounds. There are in fact several psychoacoustic models that deal with roughness perception – the basis of dissonance perception (e.g., Hutchinson & Knopoff 1978; Kameoka & Kuriyagawa 1969; Pressnitzer & McAdams 1999; Terhardt 1974) – but such models do not always correlate highly with emotional reactions (Mashinter 2006). Indeed, a recurrent finding in psychoacoustic research is that focusing solely on the acoustic determinants captures only a small percentage of variance in emotional responses to sounds, whereas including nonacoustical factors (e.g., listener, situation) dramatically increases the explained variance (e.g., Va¨stfja¨ll et al. 2003). Peretz argues that, “contrary to J&V’s claims, dissonance has been controlled for in these studies” (para. 4). However, what we actually claimed was that the underlying mechanism has not been controlled for – dissonance is not a mechanism. Also, surely there is more to musical emotions than merely the perception of dissonance. Is Peretz suggesting that musical emotions that do not involve the perception of dissonance should be ignored in future research? Peretz’s suggestion to focus on the acoustic determinants of unpleasantness appears strange in view of the fact that music evokes mostly positive emotions (see Fig. 1 and 2 in sect. R6.2 further on). Trehub suggests that, “Given widespread disagreement on the existence and nature of musical emotions, their links to non-musical emotions, and the conditions under which they are elicited, Juslin & Va¨stfja¨ll’s (J&V’s) attempt to specify induction mechanisms for such disputed emotions may be unwarranted or premature.” This comment seems to entirely miss our point that the widespread disagreement in the field is precisely the result of a neglect of underlying mechanisms. Therefore, continuing to neglect the underlying mechanisms is not likely to improve the situation. Trehub’s view of music as a “dishonest signal” designed mainly to influence the affective state of the listener does not explain how music evokes emotions. Accordingly, it is not directly relevant to the current discussion. Konecˇni did not directly oppose our claim that music cannot be studied without regard to mechanisms, but challenged three “erroneous premises” of our article. First, he claims that our statement that “research indicates that people value music primarily because of the emotions it evokes” (target article, Abstract) was based only on studies of adolescents. This claim is simply incorrect: a reading of some of the references included to support our statement, such as Juslin and Laukka (2004) and Sloboda and O’Neill (2001), would reveal that these studies feature data based on adults. Second, Konecˇni claims that the disagreements among various researchers of musical emotions could be explained simply in terms of an opposition between brain researchers and researchers who emphasize “subjective experience.” This is also inaccurate. Although Konecˇni creates the impression that there is “agreement” among “others (Gabrielsson, Kivy, Konecˇni, Scherer),” who “consider subjective experience indispensable” (para. 2 of the commentary), in fact the authors cited do not agree at all: Konecˇni (2003), for instance, claims that music cannot directly induce emotions; Scherer (2003) claims that music evokes emotions, but not basic emotions; and Gabrielsson (2001) claims that music evokes both basic and complex emotions. All of these are psychologists who consider subjective experience “indispensable,” and none is a brain researcher. Even so, they clearly disagree. Numerous other examples could be offered. However, the important point is that the disagreements in the field cannot be dismissed that easily. Finally, Konecˇni claims that a third “inaccurate premise” is our statement that, providing evidence that music has effects on all of the components in Table 2 of the target article would demonstrate that music can induce “real” emotions. He notes that “most of the studies in Table 2 are limited to a single component.” The operative word here is “most,” because clearly there are studies that provide evidence of so-called synchronization or coherence among several emotion components in response to music (Lundqvist et al., in press; Steinbeis et al. 2006). For example, Lundqvist et al. (in press) report evidence of a coherent manifestation in the experiential (feeling), expressive (facial electromyography), and physiological components (e.g., skin conductance, finger temperature) of the emotional response system, demonstrating that music can evoke happiness and sadness under controlled laboratory conditions using non-classical music. However, not all emotion researchers today believe that an emotion (necessarily) requires a synchronized response (Frijda 1999; Russell

2003); and Konecˇni himself appears content with self-reports (Konecˇni et al. 2008), in which case current evidence based on self-report (see sect. R6) should suffice to convince him that music can evoke many different emotions. One cannot argue that subjective experience is indispensable for an understanding of responses to music, while simultaneously dismissing all evidence that music evokes emotions based on such experience. R2. Is the framework internally consistent? In this section, we address comments regarding overall aspects of our framework, such as terminology and internal consistency. Scherer & Zentner argue that we "confound levels of analysis by addressing phenomena (emotional contagion), content (memory schemata), procedures (visual imagery), and substrata (brain stem)." This is not really accurate, because, as the philosopher Malmgren notes, "to be fair to the authors, it is clear that they intend these labels to stand for psychological mechanisms." Scherer & Zentner's "confounding" charge is faulty also in other ways: First, their claim that emotional contagion is a "phenomenon" and not a "mechanism" is strange, considering that they have labeled it a mechanism themselves: "a mechanism often called emotional Response/Juslin & Va¨stfja¨ll: Emotional responses to music BEHAVIORAL AND BRAIN SCIENCES (2008) 31:5 601 contagion" (Scherer & Zentner 2001, p. 369). Our use of the term is consistent with previous definitions of contagion as a form of automatic "mimicry": the tendency to automatically mimic and synchronize facial expressions, vocalizations, postures, and movements with those of another person and, consequently, to converge emotionally. (Hatfield et al. 1994, p. 5) We agree with Scherer & Zentner that "memory schemata" might be regarded as a form of "content" – but our mechanism was labeled "episodic memory," not "memory schemata." The latter is involved in the process by which music may evoke an emotion through the recall of a memory, but it cannot be equated with the memory process, as a whole. Scherer & Zentner also refer to visual imagery as a "procedure." This is puzzling because imagery has been studied as a psychological mechanism for many years (Kosslyn 1994). Each of the mechanisms in our target article was explicitly defined as an induction process. Thus, Scherer & Zentner's claim that we confound levels of analysis is not convincing. However, we admit that it can be tricky to separate various levels of analysis in the field. Indeed, highlighting this difficulty is the fact that Scherer and Zentner's (2001) own overview is guilty of the charge of confounding levels of analysis, since it divides the "routes" into "appraisal" (clearly a mechanism) and "empathy" (which is rather a phenomenon that occurs through many different mechanisms, including but not limited to emotional contagion), as well as "facilitating existing emotions" (which is not a mechanism at all). We emphasize that we think Scherer and Zentner's (2001) review was excellent in many ways, though when Scherer & Zentner claim that their overview is reminiscent with our framework, we disagree. Their review includes four "routes" (mechanisms), if we exclude "facilitating existing emotions" (which is not actually a mechanism), whereas our framework includes seven mechanisms, if we include appraisal. They do not clearly distinguish different memory systems, whereas we separate evaluative conditioning from episodic memory. Most importantly, however, Scherer & Zentner provide a casual theoretical overview, whereas our attempt was to develop an integrated framework featuring a set of hypotheses. Malmgren states that "an important desideratum on any classification is that it uses a uniform principle," but that "it is not obvious that J&V's classification fulfills this desideratum ... Despite their careful attempt in section 3.2 to describe the mechanisms in terms of a number of dimensions, it never becomes clear which of these dimensions are essential, in cases of conflicts between criteria, for distinguishing one mechanism from another." Malmgren fails to recognize that the essential and uniform principle that serves to distinguish the mechanisms lies in the definitions of the mechanisms themselves: that is, the process by which each mechanism evokes emotions. Although some mechanisms may share certain characteristics, they do not share the basic principle by which they evoke an emotion.

Similarly, we are not convinced by Malmgren's critique of our (single) use of the word "empathy." He neglects the fact that emotional contagion is commonly regarded as one of many forms of empathy (Preston & de Waal 2002), as recognized by Patel, who refers to contagion as "part of the brain's mechanisms for empathy." Malmgren also appears to confuse empathy, as commonly defined, with sympathy. Hoffman (2008) defines empathy as "an emotional state triggered by another's emotional state ... in which one feels what the other feels" (p. 440). That is, the experienced feeling is the same – not a contrasting one. Malmgren also suggests that we should consider incorporating ideas from a recently presented doctoral dissertation, by Vickhoff (2008), into our theoretical framework. The most original aspect of this dissertation seems to be the notion of perspective: that music listeners implicitly or explicitly choose a certain perspective, which then functions as a "filter" whereby "some information becomes relevant and some becomes irrelevant ... We are presented with only one proposal at the time" (p. 64). There are two problems with the perspective metaphor in our view: First, it implies that only one mechanism can operate at a time, since one perspective per definition excludes another perspective. This may not be conducive with how the mechanisms work (in principle, more than one mechanism could be activated at different levels) and makes it hard to explain the occurrence of "mixed" emotions in listeners' reactions to music (Gabrielsson 2001). Second, the idea that a listener chooses a specific perspective introduces the problem of how, precisely, this choice is made – something that the dissertation does not quite explain. Further, we find it problematic to propose that the choice – if that is the appropriate word – lies entirely with the listener, since each mechanism in our framework is dependent on certain information in the music, and how this information relates to personal characteristics of the listener. If certain required information is not available, the mechanism cannot be activated, no matter what the listener would like to "choose." As suggested by our hypotheses in Table 4 of the target article, many of the mechanisms cannot be influenced by the listener's will. Hence, with the exception of, for instance, the visual imagery mechanism, the "choice" of mechanism is largely made by the music, rather than by the listener as implied by Vickhoff's notion of perspective choice. The foregoing discussion raises the important question of which labels to use – for instance, to refer to different mechanisms. This question admittedly does not have a simple answer. We selected labels that we thought would help researchers to quickly grasp the nature of each mechanism, and it is our impression that most commentators have done that: Only a few of the commentators have expressed any concerns over the labels we used in our article. Malmgren argues that brain stem reflexes is "anatomically a misnomer" (para. 4) for responses that may also involve the thalamus, and Thompson & Coltheart suggest that the term is confusing, "because the brain stem has multiple functions" (para. 2). Although the mechanism could easily be renamed "reflexes," the above arguments miss the point that the responses in question are the only ones that can be initiated at the level of the inferior colliculus of the brain stem. Hence, labeling the mechanism in terms of its "substrata" (Scherer & Zentner) serves to highlight a defining characteristic of the mechanism not shared with other mechanisms. In principle, we are open towards other labels that may improve the communication among music-emotion researchers, though we note that none of the commentators proposed alternative labels. R3. How could particular mechanisms be elaborated? R3.1. Emotional contagion Several commentators elaborate on the emotional contagion mechanism. Some have offered evidence for the mechanism (Fritz & Koelsch, Provine), whereas others have offered evidence against it (Simpson, Oliver, & Fragaszy [Simpson et al.]). Patel provides suggestions on how we could test some of the assumptions associated with contagion, and Gardiner provides a way of framing the mechanism in terms of communication of emotions, where encoding and decoding are strongly related. (This is consistent with the views on expression of emotions in music performance and the nonverbal aspects of speech suggested by Juslin & Laukka [2003].) Bharucha & Curtis, Malmgren, Holochwost & Izard, Madison, and Provine suggest that emotional contagion in musical contexts could also occur as a result of catching the emotions of other persons present. We agree that this is an interesting possibility that may be particularly relevant in contexts such as rock concerts. This should perhaps not be described as an emotional reaction to music, however. It is rather one of many contextual factors that may modulate musical emotions. Thus, we focus here on those comments that concern emotional contagion from music. Fritz & Koelsch provide a valuable discussion of empirical support for the emotional contagion mechanism in relation to music, in terms of recent findings of an auditory "mirror" mechanism (i.e., premotor activation of the larynx representation), which was activated by the perception of expressive music (Koelsch et al. 2006). We are intrigued by their proposal that the contagion mechanism could have a more complex time resolution, or temporal dynamic of activation, such that the emotional "resonance" is gradually increasing. We welcome further research that may clarify this feature, but note that Koelsch et al.'s result seems to contradict results from previous studies of emotional contagion involving facial expressions, where the response is faster (Dimberg & Thunberg 1998). Time aspects of musical emotions are also discussed by Agostino, Peryer, & Meck [Agostino et al.], who note that there was virtually no consideration in our target article of how events unfold over time, or of how the timing of events relates to emotional responses. Agostino et al. neglect, however, that our framework included explicit hypotheses about the speed of the emotion-induction process (Table 4) for different mechanisms, thus highlighting how different mechanisms could have different time frames.1 Patel's suggestion to test patients with receptive aprosodia with regard to both musical stimuli and speech stimuli, in order to check whether emotion recognition in music relies on the same resources as emotion recognition from vocal affect, is highly interesting. (However, it should perhaps be noted that, in principle, the neural mechanism responsible for the induction of the emotion could be the same, even if the neural mechanisms for the recognition are different.) Designing relevant tests is not entirely straightforward, as indicated by Patel's carefully stated requirements. However, when he proposes that "in testing such patients, one could use stimuli from previous studies of musical emotion recognition in normal individuals (e.g., Krumhansl 1997)," Patel is neglecting the fact that the stimuli used in studies such as Krumhansl (1997) feature several expressive features beyond those cues that are shared with the voice. Thus, in principle, emotions in such stimuli could be recognized based on non-voice cues (e.g., harmonic progression), even if the voice-based emotion recognition module is damaged. Hence, we would like to add one further requirement: Musical stimuli must be designed such that the recognition of different emotions involves only acoustic cues shared with vocal affect expressions; for instance, by asking music performers to play the same musical composition in different versions by manipulating tempo, sound level, and timbre (Juslin 2000). This is in accordance with the boundary conditions of our hypothesis about speechmusic parallels (Juslin & Laukka 2003, p. 774). Simpson et al. discuss evidence that they regard as problematic for the emotional contagion mechanism, particularly evidence that the brain distinguishes voices from music at early stages of processing. We are aware of such findings, but do not necessarily regard them as problematic, either for the "super-expressive voice" theory or the contagion mechanism in general. It should be noted that most music heard today involves voices (in singing), which eliminates the problem altogether, and renders emotional contagion via music even more likely. To be fair to Simpson et al., they focus on the case of instrumental music. They seem to be forgetting, however, that our theory involves the notion of an independent module and that it is part of the notion of a module that it is information-encapsulated (Fodor 1983),2 which means that it is perfectly plausible that the module treats the expressive instrument in the music as a voice, even if other parts of the brain "know" that this is a musical instrument, not a voice. However, Thompson & Coltheart's comment about the importance of defining modularity explicitly is well taken. Support for a modular theory, in terms of Fodor's (1983) description of modules as being domain specific, fast, innately specified, autonomous, "hard-wired," automatic, and information-encapsulated, was described by Juslin and Laukka (2003, p. 803). Simpson et al. also argue that it is a problem that emotional contagion cannot explain cases where the experienced emotion is not the same as the emotion expressed in the music; but this is not a problem at all: There are six other mechanisms that can explain emotional responses to music that the contagion mechanism cannot account for. All of the mechanisms require certain information and depend on certain "brain resources." Thus, contrary to what is claimed by Scherer & Zentner, our framework may clearly contribute to an understanding of why music does not evoke emotions in some instances. This can be explained in terms of lack of certain information or available brain resources. We did not claim that emotional contagion (or any other of the mechanisms for that matter) is always involved during music listening. In cases where the evoked emotion is different from the one expressed in the music, the emotion was simply evoked by another mechanism, such as musical expectancy. R3.2. Musical expectancy Many of the commentators (e.g., Krumhansl & Agres, Longhi, Rozin & Rozin, Vuust & Frith) appeared to advocate a "privileged role" for musical expectancy in Response/Juslin & Va¨stfja¨ll: Emotional responses to music BEHAVIORAL AND BRAIN SCIENCES (2008) 31:5 603 the induction of emotions to music. It is easy to see why, given the extensive research on musical expectancy (albeit mostly not related to emotion) in the field of musicology (Huron & Hellmuth Margulis, in press; Meyer 1956; Narmour 1992). We appreciate Krumhansl & Agres's elaboration on the musical expectancy mechanism, delineating some if its characteristics in a manner that we were unable to do within the space limitations of our target article. However, we do not agree with their statement in the commentary Abstract, that "when examining how emotions are evoked through music, the role of musical expectancy is often surprisingly under-credited." We find that few papers on music and emotion fail to mention Meyer's (1956) seminal book. A literature search would probably reveal that it is the single mostcited source in this field. We further think that Huron's (2006) revisit to Meyer's theory is interesting, original, and laudable, though it may be over-reaching in its attempt to cram in all different kinds of affective response under the umbrella of "music and expectancy." Hence, while Thompson & Coltheart argue that our view on expectancy is narrow because it (in line with Meyer's original work) focuses mainly on syntactic relations, we might counter that Huron's view is over-inclusive by featuring responses that we believe are better characterized in terms of other mechanisms. However, to be fair to Huron (2006), he did acknowledge that "music can also evoke emotions through many other means – apart from whether sounds are expected or not" (p. 365). Krumhansl & Agres argue that concentrating on the musical expectancy mechanism is good, because it "focuses attention on the music itself and how it is constructed." What about the listener? All mechanisms require both a musical structure and a listener who perceives the structure. Moreover, we sense a common misconception that mechanisms other than musical expectancy do not involve musical structure, but, clearly, all mechanisms in the target article relate to musical structure in their own particular way. One obvious example is the emotional contagion mechanism, which depends on the emotional expression of the music, as specified by numerous global and local acoustic cues in the music (Juslin 2005). Our recommendation for the future is that, instead of limiting musical emotion studies to expectancy, musicologists should expand their structural analyses to include the other mechanisms also. Which features of the musical structure are important in establishing a conditioned response? Which features of the musical structure tend to facilitate some mental images rather than others? The analysis of musical structure in musical emotions does not begin or end with expectancy. Vuust & Frith suggest that musical expectancy is the most fundamental mechanism in our framework, although they fail to convince us why the expectancy mechanism is most fundamental. It is not sufficient to invoke anticipation as the special feature of the expectancy mechanism: All human cognition and behavior are future-oriented. Profound as this may seem, this human characteristic could hardly be different. It simply reflects that time is moving in a forward direction. We remain reluctant to consider any mechanism more important than the others. We argued in our target article that all six mechanisms in the framework (even musical expectancy) have their origins outside the musical domain. To assign a higher "value" to some mechanisms because they are more commonly investigated in musicology appears to us questionable. Note also that, depending on their background, different commentators propose different mechanisms as the most important. Gardiner, for example, argues that the emotional contagion mechanism "seems the most important," whereas Bezdek & Gerrig emphasize the mechanisms evaluative conditioning and episodic memory, because of their focus on music in film. Hence, researchers regard particular mechanisms as important depending on their focus, not because of evidence of the mechanism's large impact on listeners' responses. For instance, empirical evidence from a number of studies indicates that those emotions that we would expect from the musical expectancy mechanism, based on previous and current theoretical models (Meyer 1956: apprehension/anxiety, p. 27, hope, p. 29, disappointment, p. 182; Huron 2006: surprise, anticipation, awe, boredom, p. 356), occur only rarely in listeners' emotions to music (e.g., Juslin & Laukka 2004; Juslin et al., in press; Zentner et al., in press). If musical expectancy is really of particular significance, would we not expect to see more of its impact on listeners' emotions? One could counter that musical expectancy does not evoke what we call "emotions," but that would largely exclude it from the current discussion.3 The strong emphasis on musical expectancy in several commentaries may partly reflect the training of musicologists, who spend much of their time analyzing musical scores. We get the impression that they sometimes forget that not all listeners hear music in the same way as music theorists do. Music psychologists – simply due to the nature of their discipline – might get closer to the way that music is actually heard and used to evoke emotions in everyday life (e.g., Juslin et al., in press; Sloboda & O'Neill 2001). By studying music listening in its real-world contexts, we can explore a larger view that may include a wider range of mechanisms. R4. Are there additional mechanisms? In our target article, we outlined seven mechanisms through which music may evoke emotions. However, we remain open to proposals about other mechanisms that could be relevant. Several commentators have addressed this question, and their proposals can be grouped in terms of mere exposure, semantic association, and rhythmic entrainment. R4.1. The mere exposure effect Schellenberg argues that "exposure represents an additional mechanism, ignored by the authors, that helps to explain emotional responses to music" (his commentary Abstract). Clearly, however, the term mere exposure refers to a phenomenon and a certain paradigm (Zajonc 2001), not a psychological mechanism. In principle, this effect may be explained by more than one mechanism. This is recognized by Moors & Kuppens, who note that "mechanisms that are overlooked are those underlying the mere exposure effect." They do not specify any of these mechanisms, though. Fortunately, the mere exposure effect can actually be explained by our theoretical framework, without adding any further mechanisms. According to Zajonc, who is arguably the first to bring the mere exposure effect to psychologists' attention (e.g., Zajonc 1968), the exposure effect is "a robust phenomenon that cannot be explained by an appeal to recognition memory or perceptual fluency" (Zajonc 2001, p. 224) (The latter, i.e., perceptual fluency, is invoked in Schellenberg's commentary.) Instead, Zajonc (2001) argues that the exposure effect can be regarded as a form of conditioning if one assumes that the absence of aversive events constitutes the "unconditioned stimulus." In other words, stimuli that we have encountered repeatedly, without suffering negative consequences, will produce positively valenced responses. Thus, the mere exposure effect may be accounted for by the evaluative conditioning mechanism in our proposed framework. The fact that mere exposure effects have been obtained even when the stimuli exposed are not accessible to the participants' awareness (Zajonc 2001), and even prenatally (Rajecki 1974), is consistent with our theoretical hypotheses about the evaluative conditioning mechanism (Table 4 in the target article). Indeed, exposure effects are even more pronounced when subliminal, like some of the results obtained in evaluative conditioning studies (De Houwer et al. 2005). We do not agree with Schellenberg's argument that the evaluative conditioning response outlined by Zajonc is substantially different because it involves "learned safety." It may be argued that all positively valenced associations by definition are indicative of "safety." We conclude that our framework may account for the mere exposure effect without adding further mechanisms. R4.2. Semantic association Fritz & Koelsch propose an additional mechanism which they refer to as "semantic association." They suggest that music can "activate meaningful concepts that give rise to an emotional response." We agree. The emotional contagion mechanism, for instance, focuses on information in the music that might be described as "semantic." Indeed, Steinbeis and Koelsch (2008) reported evidence suggesting that affect expressed in music is represented in the brain in a manner slightly similar to how language meaning is represented. Clearly, however, music does not have a "semantics" in the same sense that language has it (Davies 2001; Patel 2008, Ch. 6). Moreover, we feel that Fritz & Koelsch do not actually explain how such meaning in music might produce an emotion. Is it not likely that these semantic associations gain their emotional impact through mechanisms such as evaluative conditioning and episodic memory? Notable in this respect is Bezdek & Gerrig's discussion of how these two mechanisms might explain the associations that listeners make between music and the narrative content in films. Both Fritz & Koelsch and Bezdek & Gerrig have dealt with how listeners assign meaning to music and how this can create an emotional response.4 However, we maintain that such associations rely on the individual's previous learning history (including culture). Hence, the phenomena described by Bezdek & Gerrig and Fritz & Koelsch can probably be subsumed under some of the mechanisms in our framework. We conclude that it is unclear whether semantic association is really an additional mechanism, though we welcome further research that may elucidate this aspect. R4.3. Rhythmic entrainment Another suggestion for a neglected mechanism, which we find more plausible, is that of rhythmic entrainment. This is mentioned by several commentators, such as Agostino et al., Alcorta, Sosis, & Finkel [Alcorta et al.], Bharucha & Curtis, Madison, and Scherer & Zentner. We have mentioned entrainment as a possible induction mechanism in previous articles (Juslin & Laukka 2004), and it is also discussed in many ethnographic accounts of musical ceremonies (Becker 2004). However, we submit that this candidate for a mechanism is currently not well understood, and that there is not yet any strong evidence that rhythmic entrainment through music can induce an emotion. Yet, in principle, we remain open to the idea of expanding the framework to include a rhythmic entrainment mechanism. Further study is needed to elucidate the characteristics of this mechanism, such that hypotheses similar to those included in Table 4 of our target article may be formulated and subjected to testing. Bharucha & Curtis have proposed that "motion" may be an additional mechanism, though without specifying how. We argue that motion effects on the listener could be due to rhythmic entrainment – perceived motion in music stimulates self-movement, which through entrainment and its effects on the physiology of the listener evokes an affective response (see also Agostino et al.). R5. How should emotions and mechanisms be distinguished? Several commentators have offered distinctions to help organize and distinguish subsets of emotions and mechanisms. Although we may not agree with these proposals, we regard all of them as interesting, because they have forced us to deeply consider the similarities and differences among different mechanisms. R5.1. “Mediated” versus “unmediated” emotions Konecˇni makes a distinction between “mediated” and “unmediated” emotions. However, this distinction does not make sense in the current framework (and probably not in any other framework either), because there is no such thing as an unmediated emotion. There can be no emotion without some kind of information processing (and hence “mediation”) of the stimulus features. Even very simple brain stem reflexes to music involve some information processing. What distinguishes the mechanisms is partly what kind of information is processed, as well as how it is processed. Hence, we argue that all emotions are “mediated,” one way or the other, and that it could hardly be any other way (for further discussion, see Lazarus 1999). R5.2. “Cognitive” versus “non-cognitive” states A different suggestion, although equally problematic, is to separate “cognitive” emotions from “non-cognitive”   moods. Thus, Robinson argued that “some of the mechanisms are non-cognitive.” This obviously raises the question of what “cognitive” means here. Davies (2001) has pointed out that “the term ‘cognitive’ has a somewhat different meaning in philosophical theories of emotion than it has in psychological theories. In the latter, the term implies a focus on underlying information-processing mechanisms, whereas in philosophical theories, it refers to beliefs, imaginings, thoughts, intentions, desires, and like states of consciousness” (p. 26, footnote 2). Indeed, that this is how Robinson is using the term is confirmed by her rejection of three mechanisms as “non-cognitive” because they “typically operate beneath awareness,” whereas, for instance, musical expectancy is regarded as “cognitive” because the listener is “focusing consciously on the way the music unfolds.” (The latter is not necessarily true, since musical expectations may evoke responses pre-attentively; see Koelsch et al. 2002b.) In contrast, as psychologists, we are not inclined to equate the term cognitive with the contents of our conscious awareness, but rather with various forms of information processing in the brain and in particular the “functional design” of such processing (see Sloboda & Juslin 2001). In this sense of the term, Robinson’s distinction becomes problematic because there is, of course, no simple or clear-cut boundary between “cognitive” and “non-cognitive” processes, as suggested by the LazarusZajonc debate (see Lazarus 1999). This is a matter of arbitrary definition, and, as explained in an endnote in our target article, we have hence avoided the use of the term cognitive to not rule out subcortical information-processing mechanisms. Perhaps, the same terminological confusion underlies Robinson’s discussion of “intentional objects” of emotions. We wrote in our target article that: “what the mechanisms discussed here have in common is that they become activated by taking music as their ‘object’” (sect. 1, para. 5); that is, it is the mechanism that takes the music as its “object.” In contrast, Robinson seems to emphasize conscious awareness of an intentional object. The latter usage would rule out the notion of “unconscious emotions” – a phenomenon that is recognized by psychologists (O¨ hman 1999). A distinction in terms of conscious awareness of stimulus objects cannot distinguish emotions from moods. Hence, we find that the distinction between “cognitive” emotions and “non-cognitive” moods is not likely to advance our understanding of musical emotions. R5.3. “Signal detection” versus “amplifiers” Thompson & Coltheart proposed that we should distinguish between signal detection and amplifiers, but their distinction is not wholly convincing. First, several of their claims about the so-called amplifiers appear inaccurate. For example, they claim that imagery and episodic memories are “rarely an independent cause of musically induced emotion but primarily amplify emotional experience,” yet they offer no evidence to support this view, so this is merely speculation. In fact, what evidence currently exists indicates that episodic memories are among the most common causes of musically induced emotions (Juslin et al., in press). In

Sloboda and O'Neill (2001, p. 420, Table 18.1), "reminder of valued past event" was the single most commonly reported function of the music. Therefore, Thompson & Coltheart's suggestion that ordinary music-listening activities offer little opportunity for episodic memory seems empirically false. Thompson & Coltheart further argue that contagion is an amplifier simply because "such music-speech associations must be established in the first place through conditioning." This neglects that emotional contagion may involve an innate code, rather than learned associations (e.g., Juslin 2001; Juslin & Laukka 2003), based on how emotions influence physiological responses, which in turn affect various aspects of the voice production (Juslin & Scherer 2005). Indeed, this biological basis might explain the reported difficulty of re-training individuals to express basic emotions in ways different from the innately specified expressive patterns (Clynes 1977, p. 45). Second, we are slightly concerned over whether and how one could define anything in the music as an "emotional signal" independently of the individual listener. For instance, if we consider the evaluative conditioning mechanism, it is clear that information in the music may be a source of emotion for one listener, but not for another – in which case there is no inherent "signal" in the music to be "detected" for any listener. In this sense, then, the notion of "signal" is misleading. In addition, grouping brain stem reflexes, evaluative conditioning, and musical expectancy together appears suboptimal, given that they have such different characteristics (see Table 4 in the target article). In the case of musical expectancy, it is inaccurate to say that this involves "directly detecting emotive signals in music" (Thompson & Coltheart) in an unmediated fashion, because it is apparent that emotional responses to music based on schematic expectations (Meyer 1956) depend on semantic memory schemata, which are different for different listeners. In sum, it is not clear to us what the distinction between signal detection and amplifiers is achieving. R5.4. "Type 1" versus "Type 2" emotions Moors & Kuppens suggest that our theoretical framework would benefit from making a distinction between "Type 1" and "Type 2" emotions, where the former take the music as their object at the reality level (e.g., we are glad that we happen to come across music that we like at a store), while the latter are a response to the music's content at a more symbolic level (e.g., reacting to the emotion expressed in the music). This distinction is interesting and was in fact present in our target article in our division between emotions induced by cognitive appraisals and emotions induced by our "alternative" mechanisms. We noted that, for example, a person may be trying to sleep at night, but is prevented from doing so by the disturbing sounds of a neighbor playing loud music on his or her stereo. In this case, the music becomes an object of the person's irritation because it blocks the person's goal: to fall asleep. Although there is nothing particularly "musical" about this example, it is clear that music can sometimes induce emotions in listeners in this manner. (target article, sect. 1, para. 7) We added, in the sentence immediately following, that: "Such responses can easily be explained by traditional theories of emotion." This comment implicitly referred to appraisal theories. However, we also pointed out in our target article that the evidence to date suggests that emotions to music are very rarely evoked by cognitive appraisals relative to goals in life (e.g., Juslin et al., in press; submitted), which is precisely why musical emotions have seemed to require "some special explanation" (Kivy 1990, p. 149). Thus, "Type 2" emotions are more important in a musical context, and our framework focused on this type. Moors & Kuppens argue that both types of emotions require appraisal at some point. We strongly disagree. For instance, it seems clear to us that, if music evokes emotion through the emotional contagion mechanism, there is no cognitive appraisal involved, whatsoever. (That musical emotions do not require cognitive appraisals is acknowledged by some appraisal theorists, such as Ellsworth [1994].) Moors & Kuppens claimed that our conception of appraisal is "narrow." We think that their conception is overly broad, incorporating appraisal into virtually every mechanism. We argue that such an excessively broad definition of the term appraisal runs the risk of making the term meaningless – because it could cover anything. If the appraisal process could be both "automatic" and "voluntary," both "conscious" and "subconscious," both "fast" and "slow," both involve "a very large number of appraisal dimensions" and "only a few appraisal dimensions," both involve "innate goals" and "momentary goals," and both occur "at the moment of induction" and as "reinstated" by other processes, then what exactly does appraisal refer to? How could a theory ever be tested if it can always have it both ways? Although Scherer (2001) has argued that appraisal could also involve "widely different mechanisms" (p. 371), fortunately most of Scherer's extensive research program on this topic actually seems to equate the term appraisal with a rather specific process, through which a situation, object, or event is evaluated in terms of its personal significance on a number of dimensions or criteria that usually concern its goal significance, the coping potential of the person, and the compatibility with internal or external standards (Scherer 1999). We believe that a "narrow" definition of appraisal renders the term more useful and the theory more amenable to scientific investigation. The notion of appraisal is important and useful, and even more so if its meaning is not overextended so as to include widely different phenomena that are better described by other terms. A precise definition also suggests that appraisal is rarely the mechanism underlying emotional responses to music. R5.5. "Aesthetic" versus "utilitarian" emotions Scherer & Zentner propose one further distinction between "aesthetic emotions" and "utilitarian emotions." Our thesis that all emotions are not created equal is directly relevant to this distinction. Indeed, it turns out that the distinction largely corresponds to the aforementioned one between appraisal-based emotions (which involve evaluations in relationship to goals and action-oriented coping) and emotions evoked by other mechanisms (which do not involve goals). Appraisal-based emotions (Type 1) may indeed lead to goal-oriented action responses even with music (e.g., getting your neighbors to turn off that loud music!), whereas non-appraisal emotions (Type 2) mostly do not. Scherer & Zentner's mistake is to assume that the latter kind of emotions is "unique" to music – or art more generally. Clearly, it is not. (Most) musical emotions differ from (most) non-musical emotions in that they do not depend on cognitive appraisals, and this aspect may indeed affect their characteristics to some extent. However, the critical feature is the mechanism and not the music, because non-musical emotions can also be evoked through mechanisms other than appraisal. That this type of "non-appraisal" emotion is not unique to art becomes clear if we consider which emotions music evokes in everyday life. R6. Which emotions does music evoke? R6.1. Inclusive versus reductionist approaches Current views on which emotions music might evoke could be placed along a dimension ranging from the most inclusive to the most reductionist. Among the most inclusive approaches is our own framework, which posits that music may evoke a wide range of basic and complex emotions, ranging from mere arousal and pleasantness via discrete emotions to more complex emotions such as nostalgia, as well as "chills." Other examples of a similarly inclusive approach are presented by Huron (2006, p. 25): "Listening to music can give rise to an enormous range of emotions"); and by Gabrielsson (2001), whose "strong experiences with music" (p. 446) feature a wide variety of emotions. Slightly more reductionist in approach are Zentner et al. (in press), who exclude a number of emotions that, in our view, might be induced by musical events. (In particular, Zentner et al. seem to forget that we routinely experience negative emotions to music we do not like in everyday life.) Considerably more reductionist is Peretz's argument to limit future research to basic emotions. Even further on the reductionist side, we find those commentators who argue that music may induce only a few emotional (or "quasi-emotional") states, such as "being moved" or "awe" (see Konečni). Researchers who endorse a dimensional approach limited to pleasure (valence) and activation (arousal) (Trehub et al., in press) also belong to the reductionist side. We prefer to let the evidence do the talking in resolving this issue. R6.2. Prevalence of musical emotions While speculation is rife about which emotions music can induce, few studies have explored the prevalence of musical emotions.5 Such studies are important, however, because they provide a sense of the phenomena that any theory of musical emotions must be able to explain. Scherer & Zentner argue that theory building about mechanisms might go astray without empirical knowledge about the phenomenon under investigation. We could not agree more. However, they also suggest that their approach differs from ours because they offer a more solid basis for theory building by studying musical emotions empirically. This is simply inaccurate. We have conducted four separate studies of the prevalence of emotional responses to music (i.e., Juslin & Laukka 2004; Juslin et al., in press; submitted; Laukka 2007), using both survey and experience sampling techniques, and representative random samples of listeners and real-life situations, Response/ Juslin & Va¨stfja¨ll: Emotional responses to music BEHAVIORAL AND BRAIN SCIENCES (2008) 31:5 607 respectively. This is perhaps the most ambitious attempt thus far to examine which emotions are evoked by music. Because the findings from these studies are relevant to the current debate, we briefly outline some results in the following. In a recent survey study based on a randomized and statistically representative sample of the Swedish population, 763 participants described their most recent emotional experience of music (Juslin et al., submitted). The resulting reports, of which 70% referred to an emotion episode that had occurred less than 24 hours before answering the survey, produced the distribution of emotions experienced to music shown in Figure R1. Note that the listeners could describe their emotions in their own words rather than by using a pre-selected list. As can be seen in Figure R1, the self-reports featured a wide range of both basic and complex emotions. To estimate the prevalence of musical emotions as reliably as possible, one may need to capture the emotions as they spontaneously occur. An experience sampling study of emotions in everyday life by Juslin et al. (in press) provided estimates of the prevalence of emotions in response to music, as well as to other stimuli, during a two-week period. The emotion labels included basic emotions typical of discrete emotion theories, such as anger, surprise, interest, and fear (Izard 1977); covered all four quadrants of the circumplex model in terms of arousal and pleasure (Russell 1980); and featured terms often discussed in regard to music, such as pleasure, nostalgia, and expectancy. Furthermore, participants could select the alternative "other emotion" if none of the emotion terms provided was found suitable. A broad range of emotions was included in order to not prejudge the issue of which emotions music might evoke. Figure R2 presents the prevalence (percentage) of emotions caused by music and emotions caused by other stimuli, respectively. As can be seen, emotions such as calm-contentment, happiness-elation, and interest-expectancy were common in general, whereas emotions such as disgust-contempt were not so common. A comparison of musical with non-musical emotion episodes suggested that happiness-elation and nostalgia-longing were significantly more frequent in episodes with musical emotions, whereas anger-irritation, boredom-indifference, and anxiety-fear were significantly more frequent in episodes with nonmusical emotions. The remaining differences were not significant. In only 3% of the musical emotion episodes did the listener select the "other emotion" alternative, suggesting that the emotion labels provided covered the listeners' responses reasonably well. Overall these results highlight that musical emotions and non-musical emotions differ mainly with regard to their frequency distributions. R6.3. Are there music-specific emotions? Scherer & Zentner claim that they have offered evidence of music-specific emotions, but clearly this is not the case: The states mentioned (e.g., tenderness, nostalgia, peacefulness, tension) are not unique to music, but occur in several other spheres of life as well. We agree that these emotions could be more common in regard to music, and this is what we claimed in our target article. Interestingly, however, even Zentner et al. (in press) are forced to concede that "results from Study 2 showed that emotion states relating to nostalgia, love, wonder, and transcendence [all part of their music-specific emotion scale] are not experienced much less often in everyday life contexts compared to music contexts" (p. 34). Hence, the hypothesis of music-specific emotions remains unproven to date. However, because of the different frequency distributions of musical and non-musical emotions (Figure R2), it could in some circumstances be suitable to measure musical emotions by using other instruments than the traditional scales used in research on emotion. We discussed this issue previously in Juslin and Laukka (2004) and proposed, based on our prevalence findings, a list of 15 terms that could be useful in measuring musical emotions. This list is quite similar to the terms included in the emotion scale subsequently presented by Zentner et al. (in press). There are some problems with this kind of domainspecific approach, however. First, because the emotion labels have been pre-selected, a domain-specific scale cannot be used to study the prevalence of different musical emotions and to support the basis of the scale itself. Any result that would run counter to the approach is prevented since other possible emotions have been removed from the scale. We are concerned that 80% of the emotion terms reported in Alf Gabrielsson's (2001) Figure R1. Prevalence of freely reported emotions to music from a randomized and statistically representative sample of the Swedish population (N ¼ 763). Note: Only the ten most common emotions are shown. Figure R2. Relative frequency (in percent) of specific emotions in nonmusical emotion episodes (dark bars) and musical emotion episodes (striped bars). From Juslin et al. (in press). Response/Juslin & Va¨stfja¨ll: Emotional responses to music 608 BEHAVIORAL AND BRAIN SCIENCES (2008) 31:5 studies of "strong experiences with music" are not featured in Zentner et al.'s scale. Gabrielsson himself notes that "hasty conclusions should be avoided" (p. 446) when deciding which emotions music may evoke. It may ultimately be too early to limit ourselves to a restricted set of domain-specific labels. However, since evidence shows that music may evoke a wide range of emotions, long lists of emotion labels are more useful than lists with only a few emotion labels or dimensions. This is not evidence of music-specific emotions, however, as implied by Scherer & Zentner. Furthermore, there is a danger in developing a musical emotion scale in the "bottomup," theory-less fashion used by Scherer & Zentner. We believe it is more fruitful to develop a novel measurement scale based on both theoretical considerations and prevalence data from several listening contexts. R6.4. "Being moved": When? How? Why? Konecˇni, Trehub, and Scherer & Zentner discussed the state of "being moved" as one of the most characteristic emotional states induced by music. We find this notion problematic. First, it seems to us that, so far, the concept of "being moved" has brought us nowhere in our understanding of musical emotions. Despite scholars having suggested the importance of this concept for approximately 20 years (Kivy 1990), we still do not have any definition of the state. We do not know how it is evoked, and we do not know what function, if any, it serves. Moreover, some scholars (Zentner et al., in press) appear to regard it as a specific emotion; others take it to mean simply that one is emotionally affected (Robinson 2005). Still others such as Konecˇni regard it as a "quasi-emotion" rather than an emotion, which would seem to remove the concept from the scope of the current discussion of music and emotion altogether. Although music listeners regularly mark this label in studies using pre-selected emotion terms (Juslin & Laukka 2004; Zentner et al., in press), it is noteworthy that when listeners may describe the induced states in their own words, the frequency of the term drops markedly. Indeed, only 11 of 763 listeners in the extensive survey study by Juslin et al. (submitted) mentioned "being moved" as their response. Hence, Konecˇni's suggestion that emotional responses to music should be limited to only the state of "being moved" is not supported. R6.5. Chills, thrills, and frisson One of the last resorts for those who believe that there are music-specific emotions has been the finding that music may evoke a certain sensation alternatively referred to as "chills" (Panksepp 1995), "thrills"

(Goldstein 1980), or “frisson” (Huron 2006; Sloboda 1992). This reaction involves a “bodily rush” commonly described as “a spreading gooseflesh, hair-on-end feeling that is common on the back of the neck and head, and often moves down the spine” (Panksepp 1995, p. 173). In our framework, “chills” are most likely to be induced by the musical expectancy mechanism, as argued by Huron (2006) and Sloboda (1991). Patel (2008) suggests that this may be an emotional state that is uniquely evoked by music, in contrast to “everyday emotions” such as happiness and sadness, and Konecˇni (2005) argues that “thrills” along with “being moved” and “awe” are the most “profound” states evoked by music. Clearly, it is somewhat of an irony, then, that the most elaborate and sophisticated theoretical account of musical “chills” so far shows that both “chills” and “awe” are strongly related to the very basic emotion of fear: “spine-tingling chills, and the expansive sensation of ‘awe’ begin by engaging the physical machinery for fear” (Huron 2006, p. 373). Further, such “chills” are not restricted to music in any way. They may be encountered “standing on the edge of a cliff, encountering a snake, observing a thunder storm” (Huron 2006, p. 288). It appears, then, that the more some researchers attempt to advocate an “elitist aesthetic” view of musical emotions, the closer they get to the primitive core of human affect. Note further that only about 50% of the population experiences “chills” to music, and that “awe” also occurs rarely in responses to music (e.g., Huron 2006, p. 290; Juslin et al., submitted). We can hardly base a theory of musical emotions only on affective states that occur rarely in response to music. R6.6. Implications for emotion approaches It is difficult to review evidence on the prevalence of musical emotions without touching on its implications for different emotion approaches – several commentators have addressed this issue. First, let us be clear about one thing: Neither the first author (Juslin) nor the second author (Va¨stfja¨ll) has ever suggested that music evokes only “basic” emotions or even that music evokes mostly basic emotions (or “discrete” or “primary” emotions, which are usually used as synonyms for basic emotions). Hence, Trehub’s claim that discrete emotions theory is “central” to our approach is incorrect. It is also ironic that, after dismissing discrete emotions, Trehub focuses on the emotion “interest,” which was included in Izard’s (1977) and Tomkins’s (1962) discrete emotions theories, but that has been neglected in most other theories of emotion. As seen in Table 4 (induced affect) of our target article, we propose that two of the six mechanisms in our framework induce mainly basic emotions. This implies, in turn, that four (or actually five, if cognitive appraisal is included) of the mechanisms are not tied to basic emotions in any way.6 Thus, the framework presented in our target article is not limited to discrete emotions or basic emotions, nor is it limited to a dimensional approach in terms of valence and arousal. As noted in the target article, the existence of mixed emotions to music speaks against using the “circumplex model” (Russell 1980) to study musical emotions, since it precludes feeling both sad and happy at the same time (Larsen et al. 2001). Beyond that, however, we recommend that researchers adopt an open attitude and do not restrict themselves to a particular approach, whether it is discrete emotions, prototype approaches, cognitive appraisal theories, or domain-specific approaches. To capture the wide range of affective states evoked by music, we cannot afford to cling to one approach rigidly. R7. What is the relationship between perceived and felt emotions? An important distinction, known since ancient Greece, is that music may both “express” or “represent” emotions (that are perceived by the listener) and “induce” emotions (that are felt by the listener). Thompson & Coltheart noted that this distinction is worthy of discussion in the present context. Indeed, the theoretical framework outlined in the target article has several implications for this relationship. For example, whether a given piece of music that expresses a particular emotion will induce the same emotion or a different emotion is not a simple issue, but rather depends on the precise mechanism involved. For instance, emotional contagion will per definition involve the same emotion, whereas this is not necessarily the case for episodic memory: A “happy” piece might evoke a “sad” episodic memory. Furthermore, it should be noted that we frequently perceive music without actually feeling any emotion at all – at least not one evoked by the music. According to recent estimates, music evokes emotions in only about 55% – 65% of the music episodes (Juslin & Laukka 2004; Juslin et al., in press). A few laboratory studies recently compared perception and induction of emotions by using music mostly unfamiliar to the listeners. These studies found that emotions evoked tended to be similar to emotions perceived (Kallinen & Ravaja 2006; Schubert 2007). This is the kind of pattern we would expect if emotional contagion is involved, but not if episodic memory or musical expectancy is involved. Unfortunately, it is rarely realized that the context will affect the results. The artificial laboratory environment will create conditions that permit only some mechanisms and emotions to occur. In real life, musical emotions can be evoked by different mechanisms in different situations, and different mechanisms can evoke different emotions. Thus, only by sampling a variety of situations can we hope to capture all relevant mechanisms and thereby achieve an accurate understanding of the relationship between perceived and felt emotions in music. R8. How do musical emotions develop? Several commentators addressed developmental aspects of our framework. Holochwost & Izard have reported a pilot study which used the framework of our target article to help interpret the results, and found that the results supported various aspects of the framework. Their study is interesting because, instead of relying on self-report, it utilized several nonverbal measures of emotions, such as facial expressions, vocalizations, and body movements. This highlights a promising avenue for studies regarding our predictions about the ontogenetic development of musical emotions, although it might be added that, ideally, such studies should involve stimuli created to selectively activate particular mechanisms, rather than interpreting the results from experiments in a “post hoc” manner. Longhi notes that infants’ emotional responses to music are strongly modulated by the multimodal information they perceive in interactions with their mothers (or caregivers). We agree with this point, and propose that this is one of the early “scenarios” in which emotional responses to music are beginning to be shaped by learning (via the evaluative conditioning mechanism). Longhi also argues that emotions to music that involve the musical expectancy mechanism are observed earlier in life than what we suggested. This argument contrasts with Holochwost & Izard’s claim that, “with limited exposure to classical music, children would not possess the knowledge requisite to forming an expectation.” Although the specific age at which musical expectancy is fully developed is still debated, we would like to point out that Longhi’s findings that mothers “emphasize the hierarchical structure of the songs” in their singing, and that infants synchronize “significantly more often with certain beats rather than others” (see Longhi’s commentary, para. 4) are not themselves evidence that infants respond emotionally to the thwarting of stylespecific musical expectancies – it is important to be precise about what is hypothesized. Further research will hopefully indicate precisely at which age the musical expectancy mechanism is beginning to produce emotional responses to pieces of music within a particular culture. None of the commentators picked up on the fact that our framework is consistent with developmental theories of emotion, which hypothesize that the development of affect begins with relatively broad affective reactions of arousal, as well as pleasure and displeasure, followed by basic emotions such as happiness, sadness, and anger, which in turn are followed by more complex emotions (Harris 1989). Our framework is also consistent with the finding that people tend to experience more emotional complexity as they grow older (Magai 2008). However, Alcorta et al. observe that it is during adolescence “that emotional response to music seems to peak. Adolescent brain changes, including the heightened activity of limbic and dopaminergic reward systems, and the maturation of temporal and prefrontal cortices (Spear 2000), are likely to drive this heightened emotional response to music" (para. 5 of their commentary). It is only natural, then, that many studies of musical emotions have focused on adolescents and their emotional uses of music (e.g., Roe 1985; Wells & Hakanen 1991; Zillman & Gan 1997). R9. What can evolutionary perspectives offer? Alcorta et al. acknowledge that our research "represents an important step forward in our understanding of the proximate mechanisms involved in emotional responses to music," but argue that we failed to integrate our findings into a comprehensive evolutionary framework. It should be noted that this was not the aim of our article or the framework. These commentators also state that we had argued that humans seem to be genetically predisposed to anatomically and emotionally respond to music. That is incorrect: We did not claim that humans are predisposed to react emotionally to music. Our evolutionary claims focused solely on the survival value of the proposed psychological mechanisms in regard to non-musical behaviors. Accordingly, our framework is not dependent on assumptions about evolutionary functions of music, but rather involves a broader range of stimuli – including sounds in general. Lenti Boero & Bottini have offered some valuable observations on sound perception. They argue that "hominids' evolutionary past (Orians & Heerwagen 1992) shaped, at least in part, our sound preferences" (note the use of the word "sound" here, not "music"), based on how sounds signaled potential "harm or advantage our ancestors could experience." Lenti Boero & Bottini note that basic psychoacoustic parameters such as loudness, sharpness, and inter-aural time difference may reflect attributes such as size, distance, and openness of the space. We concur that Response/ Juslin & Va¨stfja¨ll: Emotional responses to music 610 BEHAVIORAL AND BRAIN SCIENCES (2008) 31:5 many of the basic sound parameters that activate brain stem reflexes may do so because they signal alarm (Va¨stfja¨ll & Kleiner 2002). The extent to which evolution shaped this is, however, a matter of debate (Beament 2001; Va¨stfja¨ll 2002b), and a more parsimonious explanation is that the auditory system is sensitive to "deviations from the normal." Thus, we react to loud, aperiodic, and harsh sounds because they represent change and potential danger rather than danger in itself. However, we do agree that the relationship between emotional response and sound deserves much more attention. It should perhaps be noted that these observations are mainly relevant to one of the mechanisms in our framework – brain stem reflexes – which is based on the kind of innately specified sound preferences discussed by Lenti-Boero & Bottini. The focus on functions of sound perception in Lenti-Boero & Bottini's commentary contrasts with the views of other commentators. Madison suggests that we should consider the functions of music from an evolutionary perspective. However, this is problematic, because – as Madison acknowledges – researchers have not been able to agree on what "function" music might have. This appears to render any basing of a theory of musical emotion on music's functions highly arbitrary. Moreover, it has been questioned whether music is an evolutionary adaptation (i.e., whether human bodies and brains have been shaped by natural selection for music). Patel (2008, Ch. 7) reviewed the evidence to date, and concluded that, although the issue is not settled yet, there is currently no compelling evidence that music represents an evolutionary adaptation. Thus, Madison neglects to consider the possibility that music does not have any evolutionary function at all, but rather is a human invention that has transformed human existence (see Patel 2008, pp. 400–401). If music is not actually an evolutionary adaptation, then it also appears unlikely that the psychological mechanisms that underlie musical emotions have been shaped by biological functions of music. In contrast, it seems more plausible that the mechanisms have been shaped by natural selection with respect to emotional behaviors. That music does not appear to be an evolutionary adaptation could, of course, explain the ultimate failure in finding music-specific emotions (see sect. R6.3). R10. Is music special? Of course, music is special in many ways. The first author of this article (Juslin) would not have spent the whole of his adult life so far on this topic if it were not a fact that music is very fascinating. Both of us, Juslin and Va¨stfja¨ll, also play music. But the facts that we love music, that music is a unique art form, and that many circumstances surrounding music are peculiar, should not automatically lead to the conclusion that the mechanisms that underlie music are "unique." A crucial principle in science is that of parsimony: We should not invoke a complicated explanation if a simpler one suffices to explain the phenomenon. In this context, there is no need to postulate music-unique mechanisms or emotions if our emotions to music can be explained within current theories of emotion. Even Meyer's (1956) theory was based on contemporary theories of emotion in psychology. The null hypothesis should be that music induces common emotions (even if it is usually a subset of those emotions) through common mechanisms (even if their relative importance may be different in music), and we should abandon this null hypothesis only in the face of strong evidence. As we have demonstrated in this response, such evidence is missing. Madison asserts that our framework is "relevant to the measurement and understanding of emotion in general." We agree, and, as suggested in our target article, we believe that this is a good thing. As stated by Provine in his commentary, "We may think more clearly about music when we make it less special." This sentiment is "echoed" by one of the other commentators, Gardiner, who observes that: "Music in its totality is a unique component of human ecology and experience ... Nevertheless, there is evidence that how the brain engages ... with music may well include adaptations of, and connections to, brain mechanisms not unique to music alone." Gardiner suggests that "an important strategy within our development of mental engagement is learning how to adapt similar, though typically not identical, brain processing components and strategies to different applications." This boils down to the need to separate music as a unique cultural artifact from its underlying mechanisms, which may have a longer evolutionary history. The unique thing about music may be the way that music can recruit and combine mechanisms according to the intentions of composers, performers, and listeners. We agree with Bharucha & Curtis and Rozin & Rozin that there are several important aspects of musical experiences that are not captured by the concept of emotion, but the goal of our framework was to explain emotions, not musical experience as a whole. The latter is a far greater and immensely more complex domain. We should hardly be faulted for not addressing other aspects than those we explicitly set out to address in our target article. We are intrigued by Bharucha & Curtis's proposal to expand our framework to cover other forms of "feelings" evoked by music. This may be possible with some of the mechanisms, whereas others may be more strongly tied to specifically emotional response systems. We think it is true that musical experiences are rich and multifaceted, and that we experience many sensory qualities that are not emotions. However, referring to these other aspects as "feelings" may be unfortunate since the notion of "feeling" is so strongly tied to emotion (see the working definitions in Table 1 of our target article that are based on current views in the "affective sciences"). Perhaps we should be more open to the possibility that much of what makes musical experiences "special" are truly non-emotional aspects, such as the conscious perception of musical form and its dynamic changes over time. By avoiding referring to such experiential qualia as "affect," "emotion," or "feeling," we can also avoid some of the controversy that surrounds such concepts in the context of music. R11. Concluding remarks: Reaching beyond the traditional disputes As illustrated by some of the discussion raised by our target article, research on musical emotions has sometimes a tendency to fall into the trap of asking overly simplified questions: Are musical emotions learned or innate? Are musical emotions "unique"? Are musical emotions categorical, dimensional, or domain-specific? Are musical emotions "cognitive"? Are musical emotions passive reactions or active constructions? As we have explained in the target article and in our response to the 25 commentaries, there are no simple "yes" or "no" answers to these questions: Ultimately, the answers depend on what mechanisms are involved in particular musical events. Hence, we hope that future research in this field can rise beyond these outdated and simple disputes that in many cases have already been empirically resolved, such that further speculation is not necessary. We recommend that researchers focus on more subtle issues concerning the nature of the musical emotion-induction process, in a hypothesis-driven effort that involves both field studies that capture musical experiences as they naturally occur in "real life" and experiments that test causal relationships under controlled conditions. Exploring how musical emotions are evoked through the interactions of multiple mechanisms, as well as various factors in the listener, the music, and the situation, is an exciting endeavor that has only just begun. NOTES 1. Much of Agostino et al.'s discussion actually focuses on how emotion may affect time perception, rather than on how time is relevant to the induction process itself. This aspect was highlighted in our target article through the inclusion of a set of indirect measures of emotions, many of which are likely to partly reflect how emotions influence time perception (see Table 3 in our target article). 2. As explained in the target article, "information-encapsulated" refers to the fact that the module is "not having complete access to a person's expectations, beliefs, presumptions, or desires" (Coltheart 1999, p. 119). 3. Krumhansl & Agres suggest that the musical-expectancy responses "do not map in a simple way onto the traditional emotional states studied within psychology." However, this view is apparently not shared by either Meyer (1956) or Huron (2006), who both suggest a variety of common emotional states that can be evoked by musical expectancy responses. 4. Alcorta et al. argue that evaluative conditioning most often involves emotion-evoking music that is associated with affectively "neutral" material. This assumes that the music is already inducing an emotion that can be paired with another stimulus, and is therefore not relevant in explaining how music evokes emotions. 5. The term prevalence, borrowed from epidemiology, refers to the proportion or relative frequency of occurrence of a given phenomenon (e.g., specific emotions) in the population of interest. 6. The first author has applied a basic emotions approach to musical performance, but exclusively in the context of expression and perception of emotions, not induction of felt emotions (Juslin 2000; 2003). It is important to separate these processes theoretically, as noted by several researchers (Gabrielsson, 2002; Juslin & Sloboda 2001).

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Neuron NeuroView Investigating the Neural Encoding of Emotion with Music Stefan Koelsch1, * 1Department of Biological and Medical Psychology, University of Bergen, Norway *Correspondence: stefan.koelsch@uib.no https://doi.org/10.1016/j.neuron.2018.04.029 Does our understanding of the human brain remain incomplete without a proper understanding of how the brain processes music? Here, the author makes a passionate plea for the use of music in the investigation of human emotion and its brain correlates, arguing that music can change activity in all brain structures associated with emotions, which has important implications on how we understand human emotions and their disorders and how we can make better use of beneficial effects of music in therapy. Are Emotions Evoked by Music Real? Curiously, I often have to justify that I use music to investigate the brain. It is not an uncommon notion, even among some scientists, that a psychological process evoked by music is merely an aesthetic phenomenon and thus not really suitable for the study of human behavior in the real world. This notion is so fallacious that it hurts. In most musical traditions, the two fundamental structural principles of music are ‘‘beat’’ (i.e., a tactus, the fundament of meter and rhythm) and scale (i.e., an organization of a few pitch classes in ascending or descending order). The ability to synchronize movements (including vocalizations) flexibly in a group to an external pulse (the tactus) is uniquely human, and I believe that this ability is the simplest cognitive function that just separates us from animals. This would make music the decisive evolutionary step of the Homo sapiens, maybe even of the genus homo. Music immediately affords, by virtue of its fundamental structural principles, that several individuals produce sounds together; this is in contrast to language, which also has many musical features (such as speech melody, timbre, rhythm, etc.) but is best understood when produced by one individual at a time. In this sense, language is the music of the individual, and music is the language of the group. Making music in a group is a potent elicitor of social bonding, associated with emotions that are often very intense, pleasurable, and moving, and the power of music to promote cooperation and social cohesion was (and still is) probably an important evolutionarily adaptive function of music. Thus, at its core, music is not a cultural epiphenomenon of modern human societies, but at the heart of what makes us human. Music can evoke changes in all five organismic subsystems (or components) of emotion: (1) the evaluation, or appraisal, of music gives rise to emotions such as pleasure or displeasure (cognitive component); (2) music can induce strong action tendencies such as dancing or participating (motivational component); (3) music can change peripheral physiological activity associated with relaxation or arousal (physiological component); (4) music affects the expression of emotion, e.g., facial expression of emotion while music making or while listening to music (expression component); and (5) music evokes feelings such as joy, being moved, courage, nostalgia, peacefulness, sadness, surprise, tension, etc. (subjective feeling component). In addition, as will be described below, music can change activity in virtually all brain structures implicated in emotions. In some cultural practices, such as listening to classical music in a concert hall, the motivational and expression components are only minimally engaged. However, other cultural practices, such as dancing and grooving together to music in a dance club or at a rock concert, can powerfully fulfill the need to experience social connection and express social belonging, and it can give rise to clear expressions of emotions (other principles underlying the evocation of emotions with music are reviewed in Juslin et al., 2014). Thus, emotions evoked by, or with, music are ‘‘real’’ emotions, and these emotions can be exceptionally intense (as, e.g., when accompanied by goosebumps or tears). This makes music a highly valuable tool for the investigation of emotions. In fact, given the ubiquity of music across cultures, and most probably across human history, our understanding of emotions will remain incomplete without a proper understanding of music-evoked emotions. Neural Correlates A meta-analysis of functional neuroimaging studies on music and emotion published in 2014 (Koelsch, 2014) reported activity changes in numerous brain structures known to be crucially involved in emotion (Figures 1A–1C). The functional neuroimaging studies published since then are consistent with the findings of that metaanalysis, and they substantiate the findings that music-evoked emotions change activity in the (anterior) hippocampal formation, the amygdala, the auditory cortex, the nucleus accumbens/ventral striatum, the dorsal striatum, the medial and lateral orbitofrontal cortex, and the anterior cingulate cortex as well as in the anterior insula, pre-SMA, rostral cingulate zone, and mediodorsal thalamus. In addition, brainstem structures of the auditory pathway are involved in music-evoked emotions: for example, the very first auditory processing stages in the brainstem, the cochlear and vestibular nuclei, project into the reticular formation (contributing to the arousing or calming effects of music). Moreover, the inferior colliculus encodes consonance and dissonance (as well as auditory signals evoking fear or feelings of security), and this encoding is associated with preference for consonant over dissonant music. Notably, in addition to its projections to Neuron 98, June 27, 2018 ª 2018 Elsevier Inc. 1075 the auditory thalamus, the inferior colliculus hosts numerous other projections, e.g., into both the somatomotor and the visceromotor (autonomic) system, thus initiating and supporting activity of skeletal, smooth, and cardiac muscles. These brainstem connections are part of the basis of the visceral reactions to music. The findings of neuroscience studies on music-evoked emotions thus show that music can change activity in the brain structures known to be crucially involved in emotion. Figure 1D illustrates the four affect centers as proposed recently in the ‘‘Quartet Theory of Human Emotions’’ (brainstem-, diencephalon-, hippocampus-, and orbitofrontal-centered affect systems) (Koelsch et al., 2015). The Quartet Theory proposes that these four affect centers generate different classes of emotions (such as activation and deactivation, pain and pleasure, attachmentrelated emotions, and moral emotions), and that their activity is coordinated by limbic/paralimbic coordination structures such as the amygdala, basal ganglia, striatum, insula, and cingulate cortex. It is important to note that, as reported above, music can change activity in all of these affect and coordination systems. This renders music, on the one hand, a valuable toolfor the investigation of the neural correlates of emotions; on the other, it opens exciting new avenues for the use of music in the therapy of psychiatric and neurological disorders and diseases associated with dysfunction in these systems. For example, the finding that music can change activity in the anterior hippocampus gives rise to the investigation of the effects of music interventions on functional and plastic changes in this brain structure in patients with Alzheimer's disease, depression, post-traumatic stress disorder, and chronic diseases of the immune system such as Crohn's disease. Recent meta-analyses suggest positive effects of music therapy in patients with depression (Aalbers et al., 2017) and patients with dementia (Fusar-Poli et al., 2017), but there is dire need for randomized controlled trials substantiating these reports, and there is a shocking absence of high-quality neuroscience studies on these topics. Politicians and funding organizations need to be made aware of this nuisance and establish funding schemes for neuroscientific research on therapeutic effects of music. The Role of the Auditory Cortex in Emotions Importantly, activity differences in the auditory cortex associated with different emotions are not simply due to acoustical differences between, e.g., happy- and sad-sounding music: several recent music studies show that the auditory cortex plays a much more important role in emotions than previously believed, beyond the traditional view that sensory cortices have merely perceptual functions. For example, a recent study from my research group (Koelsch et al., 2018) suggests that the auditory cortex hosts regions that are influential within emotion networks associated with the processing of music evoking feelings of joy or fear. That study identified computational hubs with high eigenvector centrality in different regions of the auditory cortex and found that the functional connectivity between such processing hubs in the auditory association cortex and a number of limbic/paralimbic regions (ventral striatum as well as orbitofrontal, cingulate, parahippocampal, and insular cortex) interacted with the emotions elicited by the musical stimuli (joy or fear). Thus, it appears that neurons in the Figure 1. Brain Correlates of Emotions Evoked by Music (A–C). Results of a meta-analysis of functional neuroimaging studies on music-evoked emotions (Koelsch, 2014). (A) indicates clusters of activity changes reported across studies in the anterior hippocampal formation (cornu ammonis, CA, and subiculum), the amygdala (with local maxima in the left superficial amygdala, SF, and the right laterobasal amygdala, LB). (B) shows clusters in the orbitofrontal cortex (OFC), mediodorsal thalamus (MD), pre-supplementary motor area (SMA), and rostral cingulate zone (RCZ). (C) shows clusters in the right ventral striatum (with a local maximum in the nucleus accumbens, NAc) and the left caudate nucleus. Additional clusters were observed in both left and right auditory cortex, anterior insula, anterior cingulate, and lateral orbitofrontal cortex (not shown). The results of this meta-analysis have been corroborated by studies published since then (see main text). Images are shown according to neurological convention, and coordinates refer to Talairach space. (D) illustrates four affect systems according to the Quartet Theory (Koelsch et al., 2015): brainstemcentered (orange), diencephalon-centered (green), hippocampus-centered (blue), and orbitofrontalcentered (red) systems. Music can change activity in all these affect systems as well as in emotional coordination systems (including the amygdala, basal ganglia, insula, and cingulate cortex). This capacity of music needs to be investigated in the future with regard to its therapeutic effects in the treatment of psychiatric, neurological, and somatic disorders and diseases. Neuron NeuroView 1076 Neuron 98, June 27, 2018 auditory cortex directly incite and modulate emotional processes, consistent, e.g., with work from LeDoux (2000) and colleagues showing that inputs from the auditory cortex to the (lateral) amygdala mediate fear conditioning. This sheds new light on the role of sensory cortices in emotion and suggests that the auditory association cortex not only processes perceptual information, but also influences emotional processes as a function of perceptual input (the neural origins of the appraisal processes that give rise to such influence remain to be specified—possible candidates are brainstem, thalamus, auditory cortex, and higher-order cortices). Consistent with these results, a study by Liu et al. (2017) reported auditory-limbic functional connectivity during listening to pop/rock songs, and a study by Salimpoor et al. (2013) reported increased functional connectivity between the (right) auditory cortex and the ventral striatum/nucleus accumbens with increasing reward value of music (as measured by the amount of money participants were willing to spend on the music they heard in the fMRI scanner), thus predicting reward value. Correspondingly, functional connectivity between the auditory cortex and the nucleus accumbens is reduced in individuals with ‘‘specific musical anhedonia,’’ whereas individuals with average or greater-than-average reward sensitivity to music show enhanced connectivity between these structures. The Role of the Hippocampus in Emotions Most studies on the hippocampus have investigated its role in cognitive functions such as memory, navigation, and exploration (leading to a Nobel Prize in 2014, awarded to John O’Keefe, May-Britt Moser, and Edvard I. Moser). Notably, neuroscience studies on emotion with music reveal that the (anterior) hippocampus also plays a crucial role in human emotions. This became evident in the substantial proportion of music studies reporting activity changes in the anterior hippocampal formation: the largest clusters in the meta-analysis on musicevoked emotions (Koelsch, 2014) were located in the anterior hippocampal formation (see Figure 1A), a finding that is substantiated by the fact that a large number of studies on music-evoked emotions published since then have also reported activity changes in this structure. Future research needs to specify the emotions associated with activity changes in the hippocampus (beyond negative emotions such as anxiety reported in animal studies). I have previously put forward the notion that the (anterior) hippocampus is the neural substrate of attachment-related emotions (Panksepp’s CARE system), which give rise to subjective feelings such as joy, happiness, and being moved when social attachments are experienced, or to feelings such as sadness when social attachments are severed. The activation of hippocampal activity with music might be due to the extraordinary capacity of music to engage social functions associated with social attachment and social bonding. Music and Social Bonding Increasing evidence also shows us that music is a potent elicitor of social bonding. For example, synchronization of movements to a beat with other individuals has social effects such as increase in trust and cooperation (Tarr et al., 2014) and is associated with positive emotional effects (Trost et al., 2017) and possibly with activation of the endogenous opioid system (Tarr et al., 2014). Correspondingly, intranasal application of oxytocin can improve synchronized tapping. Thus, experiments on music and emotion are often social bonding experiments (even if not intentionally designed that way). This is relevant for the interpretation of functional neuroimaging results: for example, it is tempting to speculate that the activity changes in the anterior hippocampus (as reported above and shown in Figure 1A) are, at least in part, due to social bonding and social attachment associated with synchronization of sensorimotor processes to the beat of the music (including neurochemical processes such as enkephalinergic innervation of the hippocampus, hippocampal innervation of the paraventricular nucleus of the hypothalamus and associated oxytocin release, and changes in hypothalamo-pituitary-adrenal axis activity). Given the scarce knowledge on the neural correlates of social bonding in humans, music appears to be a highly useful tool for a more systematic investigation of this issue—for example, with regard to the capacity of music to facilitate the emergence of trust, cooperation, sympathy, and empathy. The Influence of Music on Conscious Cognition and the Unaware Mind It is well known that consciously controlled thought can modulate and regulate emotions (an important cornerstone of clinical psychology). How emotions influence thought, on the other hand, is not well studied. It is, therefore, an interesting development that several studies during the past years have begun to investigate effects of music-evoked emotions on cognition, e.g., on evaluative processes, risk taking, or ‘‘mind wandering.’’ For example, a behavioral study by Schulreich et al. (2014) suggests that music-evoked emotions modulate probability weighting during risky choices. In that study, participants chose riskier lotteries significantly more often after listening to happy-sounding music compared with sad-sounding music or random tones (specifically, participants showed significantly higher decision weights associated with larger payoffs after listening to happy-sounding music). Consistent with this finding, a neuroimaging study by Halko et al. (2015) reported that the hedonic value of music modulates risky choices and associated reward responses in amygdala and dorsal striatum. Finally, a study from my research group (Taruffi et al., 2017) suggests that musicevoked emotions modulate mind wandering (i.e., spontaneous, non-intentional thought). In that study, happy-sounding music (compared with sad-sounding music) was associated with lessmind wandering and lower centrality of ''default mode'' network hubs (e.g., medial orbitofrontal, anterior cingulate, and posterior cingulate cortex). These findings are consistent with findings by Wilkins et al. (2014), who reported that the default mode network is most strongly connected when listening to preferred music. The latter findings have a particular clinical relevance, because recurring spontaneous thoughts with negative content are a crucial problem in individuals with psychological disorders such as depression. Even in healthy individuals, ''mind-wandering'' is often associated with negative thought content, therefore making individuals often unhappy. The use of music to evoke emotions and moods influencing Neuron NeuroView Neuron 98, June 27, 2018 1077 thoughts thus has huge potential for health and well-being. On the other hand, research on this topic (such as work by Emily Carlson and Suvi Saarikallio) can also inform us about unhealthy ways of using music for mood regulation, e.g., when music elicits rumination. Future studies on this topic should consider that it is important to differentiate between consciously controlled thought (i.e., deliberate thought, with awareness of the control over thoughts) and ''subconscious'' thought (without awareness of the control over thoughts). With regard to neural correlates, we have described in our Quartet Theory (Koelsch et al., 2015) that the orbitofrontal-centered affect system (see red color in Figure 1D) is a system characterized by fast, effortless, emotional thought and absence of logical thought (the orbitofrontal cortex is not neocortex, but mostly 5-layered palaeocortex). We have proposed (Koelsch et al., 2015) that many cognitive biases (as, e.g., described in the prospect theory) are due to sub-conscious thoughts performed by the orbitofrontal cortex and that one type of cognitive operation processed in this system is the fast and automatic evaluation of objects and circumstances with regard to internalized social norms, values, and self-concept. Such sub-conscious cognitions can lead to the generation of moral emotions such as guilt, blame, shame, embarrassment and disgrace. Others have used the term ''the unconscious mind'' for this system, or the ''sub-consciousness,'' and we have suggested the term ''the unaware mind.'' The observation that music can change activity in the orbitofrontal cortex (see Figure 1B) and the observation that music can influence mind wandering both suggest that music can change sub-conscious thought, i.e., the activity of ''the unaware mind.'' Thus, music is a highly interesting and promising tool for the investigation of the effects of emotions and moods on both sub-conscious and conscious thought. In particular, it will be a major advance to elucidate neural networks of negative versus positive non-intentional, spontaneous (sub-conscious) thought, and how the activity of these networks can be modulated by music. Musical Anhedonia Another interesting development during the last years was the discovery of ''specific musical anhedonia'' in healthy individuals by Ernest Mas-Herrero, Robert Zatorre, and colleagues. Specific musical anhedonia refers to the absence of feelings of pleasure in response to music, while pleasure and reward experiences to other stimuli (e.g., food, sex, or exercise) are normal. This phenomenon is associated with reduced activity changes in the nucleus accumbens (NAc) in response to music (and auditory-NAc functional connectivity), highlighting the role of the mesolimbic dopaminergic system in musical reward. A study by Mallik et al. (2017) found that both positive and negative emotions to music were attenuated after administration of naltrexone (NTX), a m-opioid antagonist, suggesting that ''endogenous opioids are critical to experiencing both positive and negative emotions in music, and that music uses the same reward pathways as food, drugs and sexual pleasure'' (Mallik et al., 2017). Moreover, a study byKeller et al. (2013)reported that trait anhedonia is associated with reduced reactivity and connectivity of mesolimbic and paralimbic reward pathways in response to music. These findings are consistent with the observation that transcranial magnetic stimulation (TMS) over the left dorsolateral prefrontal cortex modulated fronto-striatal function bidirectionally together with measures of pleasure and motivation during music listening (Mas-Herrero et al., 2018). In the latter study, perceived pleasure, psychophysiological measures of emotional arousal, and the monetary value assigned to music were all increased by exciting fronto-striatal pathways, whereas inhibition of that system led to decreases in these variables. However, lesion studies on musical anhedonia do not yet provide a coherent picture: Belfi et al. (2017) recently reported one anhedonic patient with focal damage to the right striatum who showed a marked musical anhedonia following brain injury, but other cases of striatal damage (both right and left) did not develop full-blown musical anhedonia, and a previous case study by Satoh et al. (2011) reported musical anhedonia after damage of the inferior parietal lobule. Methodological Advances The investigation of emotion with music has methodologically advanced considerably during the last years, using, e.g., measures of real-time emotion ratings during listening to entire pieces and using such measures as continuous regressors in the analysis of functional neuroimaging data. Results of such studies provide insight into neural correlates of inter-subject correlation of emotional processes during music listening; of musical tension, pleasure, and arousal; or of emotional processes that take a while to unfold (e.g., stress reduction and associated hypothalamic activity). In a study of my own research group (Koelsch and Skouras, 2014), we used one single stimulus block of 4 min duration for each experimental condition (e.g., music evoking joy or fearevoking music) and then performed eigenvector centrality mapping on the fMRI data to identify computational hubs in the brain that are influential within the brain networks of interest. We found, e.g., high eigenvector centrality in different nuclei of the amygdala during joy (compared with fear), supporting the notion that the amygdala is an emotional coordination structure with an influential, or central, position within emotion networks. Other Recent Developments and Future Challenges Other recent developments and future challenges include, for example, the investigation of aesthetic emotions (such as feelings of beauty or the sublime, being moved, tension and suspense, amusement, fascination, awe, wonder, boredom, anger, interest, etc.). Recently, we proposed to define ''aesthetic emotions'' as emotions that are associated both with subjectively felt aesthetic pleasure or displeasure and with subjectively perceived and evaluated aesthetic appeal—and thus with subjectively perceived aesthetic liking or disliking. Surprisingly, only little research has investigated aesthetic emotions with regard to both aesthetic evaluation and subjectivefeeling, calling for more systematic research in this area. A thorough investigation of aesthetic emotions and their neural correlates is relevant for several reasons: aesthetic emotions are frequently elicited in our everyday lives, they are often exceptionally strong, they have a clear positive preponderance, and their potential for therapy is not well understood. Aesthetic emotions also provide a new means to investigate neural Neuron NeuroView 1078 Neuron 98, June 27, 2018 correlates of ''mixed emotions.'' For example, an artwork such as music can be evaluated as positive, despite evoking negative emotions such as sadness, and different brain networks can be identified associated with the experience of sad and happy emotions on the one hand (including, e.g., the orbitofrontal cortex), and (dis)liking on the other (including, e.g., the amygdala) (Brattico et al., 2016). Likewise, neural correlates of emotions associated with predictive processes have so far received only little attention. Investigations within the predictive coding framework have a certain cognitive bias, often neglecting affective processes such as surprise, anticipation, tension, and resolution. For example, it is not known whether the (un)expectedness of musical events is associated with feelings of pleasure and activity of the reward network (including, e.g., mesolimbic dopaminergic projections to the nucleus accumbens) or which brain structures are associated with the (un)certainty of musical predictions. Finally, two recent fMRI studies by Pehrs and colleagues (Pehrs et al., 2014, 2017) have used music in combination with film clips. Music accompanying film clips of romantic kissing scenes was reported to lead to a suppressive gating effect of the (mid-)superior temporal gyrus on fusiform-amygdalar connectivity. This suggests that film music modulates emotion elicitation by differentially changing preprocessed visual information to the amygdala. In a study using empathic film clips paired with sad music, preceded by some text providing information about the character in the film clip, it was observed that fusiform-amygdalar connectivity is also modulated by the temporal pole. This suggests that the temporal pole integrates different sources of socially relevant information (text, film, music) and that it top-down modulates lower-level perceptual areas in the ventral visual stream during social cognition. Conclusions and Perspectives Music is a highly valuable, valid, and reliable stimulus for the investigation of both everyday emotions and aesthetic emotions in the laboratory. This does not mean that music is ideal to investigate each and every different type of emotion (neither is any other experimental stimulus). For example, disgust or jealousy are difficult to evoke with music. However, emotions evoked by music can be highly intense, and music-evoked emotions can change activity in virtually all emotion structures in the brain. This has important therapeutic implications, because it suggests that music can help in the therapy of disorders and diseases with emotional components, or with dysfunction in limbic/paralimbic brain structures. This calls for more evidence-based research investigating these issues and for new funding schemes that support high-quality research on the therapeutic effects of music in the brain.

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Without it no music: cognition, biology and evolution of musicality

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Abstract

Musicality can be defined as a natural, spontaneously developing trait based on and constrained by biology and cognition. Music, by contrast, can be defined as a social and cultural construct based on that very musicality. One critical challenge is to delineate the constituent elements of musicality. What biological and cognitive mechanisms are essential for perceiving, appreciating and making music? Progress in understanding the evolution of music cognition depends upon adequate characterization of the constituent mechanisms of musicality and the extent to which they are present in non-human species. We argue for the importance of identifying these mechanisms and delineating their functions and developmental course, as well as suggesting effective means of studying them in human and non-human animals. It is virtually impossible to underpin the evolutionary role of musicality as a whole, but a *multicomponent perspective on musicality* that emphasizes its constituent capacities, development and neural cognitive specificity is an excellent starting point for a research programme aimed at illuminating the origins and evolution of musical behaviour as an autonomous trait.

1. Introduction

Why do we have music? What is music for, and why does every human culture have it? Is it a uniquely human capability, as language is? Are some of its fundamental components present in non-human animals? What biological and cognitive mechanisms are essential for perceiving, appreciating and making music?

Some years ago, it became popular to address such questions from an evolutionary perspective [1–5], but disagreement remains about whether music is grounded in our biology, whether it played a role in our survival as a species and, if so, whether musicality resulted from natural or sexual selection.

Steven Pinker provided the most influential critique of music as an adaptation: ‘As far as biological cause and effect are concerned, music is useless. (…) Music could vanish from our species and the rest of our lifestyle would be virtually unchanged' and 'it is a technology, not an adaptation' [6, pp. 528–529]. These words, including the reference to music as 'auditory cheesecake'—a mere pleasure-producing substance—revitalized interest in the origins of music and its relevance for the biological and cognitive sciences [7–11].

At least three adaptationist accounts of music have been proposed [12–15]. Charles Darwin first suggested a role for sexual selection in the origins of music [16], a view that was revived and elaborated in recent years [17,18]. For Darwin, music had no survival benefits but it offered a means of impressing potential partners, thereby contributing to reproductive success. He, like other subsequent scholars [13,19], argued that musical vocalizations preceded language.

Another view considers music to have its origins in carers' music-like vocalizations to infants, which are thought to enhance parent–infant bonds, ease the burdens of caregiving and promote infant well-being and survival [14,20]. Such vocalizations are considered to have paved the way for language as well as music [19].

A third view stresses the role of music in promoting and maintaining group cohesion. Music is thought to be the 'social glue' that enhances cooperation and strengthens feelings of unity [15,21]. According to Dunbar [22], group singing and dancing in our hominin ancestors replaced social grooming (i.e. grooming of others involving touch) as a means of maintaining social connections as groups expanded in size. Song and dance mimic the neurochemical effects of social grooming, such as endorphin release [23], which have important social consequences.

A prominent non-adaptationist view considers music as a technology or 'transformative invention' that makes use of existing skills and has important consequences for our culture and biology [24]. This notion has parallels to the transformative control of fire by early humans, making it possible to cook food and obtain warmth, which had important cultural and biological consequences [25]. Viewed in this manner, music is an exaptation, spandrel or evolutionary by-product of other skills.

The possible adaptive function of music is one of several indispensable levels of analysis of cognitive and biological phenomena that might underlie musicality. In addition to the possible survival or reproductive value of music (adaptation), one can examine the neurobiological substrates (mechanisms), their developmental trajectory (ontogeny) and their evolutionary history (phylogeny) [26]. Accordingly, one can study various levels of information processing relevant to the perceptual and cognitive processing of music [27] or find support for the cognitive and biological origins of music in psychological, physiological, genetic, medical, phylogenetic, hunter–gatherer and cross-cultural perspectives (cf. [28]). These divergent perspectives are necessary for understanding the full complexity of music and musicality, making the study of musicality a truly interdisciplinary endeavour.

Before proposing a *multicomponent perspective* on the origins of musicality, we discuss the notions of biology and culture, music and musicality, as well as important methodological issues. Finally, we outline a number of issues that are vital to advancing the scientific study of musicality.

2. Biology and culture

Until relatively recently, most scholars were wary of the notion that music could have a biological basis:

> There is no reason to believe there is a universally shared, innate basis for music perception. Although the possible survival value of music has often been speculated about, music has not been around long enough to have shaped perceptual mechanisms over thousands of generations. Clearly, music is a cultural artifact, and knowledge about it must be acquired. Moreover, in contrast to speech, this knowledge is acquired relatively slowly and not equally by all individuals of a given

nature. [29, p. 260]

This position is typical of scholarly thought in musicology over the last 50 years, with music viewed as a cultural product with no evolutionary history and no biological constraints on its manifestation.

The available fossil record dates musical activity to at least 45 000 years ago [30,31], which is a modest time frame in evolutionary terms. It is impossible, however, to conclude that music has not been around long enough to shape perception or cognition. Vocal music and percussive use of the body leave no physical traces, so the archaeological record can only provide evidence of musical instruments and only those instruments made of durable material such as bone. Opposing claims that ‘we may safely infer that music is among the most ancient of human cognitive traits' [32, p. 10 430] are equally indefensible. For the moment, at least, definitive conclusions about the prehistory and origins of music cannot be formulated.

Many scholars embrace Western perspectives on music, viewing music as the exclusive domain of professional musicians who have honed their skills with years of practice [33]. Such approaches are obviously inappropriate for considering the music of all cultures and time periods. Instead of music being *special* or for highly trained individuals, there is increasing evidence that humans share a predisposition for music, especially when the focus is perception rather than production. To recognize a melody and move to (or perceive) the beat of music are trivial skills for most humans and, at the same time, fundamental to our musicality [20,34]. Even infants and young children are sensitive to a number of musical features that are common across cultures [35–38]. Although we are learning more and more about our own musical skills [39,40], the biological origins and evolutionary history of these apparent predispositions remain unclear.

Before discussing prospects for studying the evolution of musicality, we address the notions of music and musicality that are central to this volume.

3. Music and musicality

Definitional issues are especially problematic because there are no conventional defining criteria of music. Within a culture, people agree, more or less, on what constitutes music, but there is considerably less agreement across cultures. Venturing across species is even more contentious. Although some contend that the songs of some birds (e.g. nightingales), those of humpback whales, a Thai elephant orchestra or the interlocking duets of gibbons are examples of music (cf. [1]), most would argue, instead, that human listeners can use a musical frame of reference to make many sound patterns seem musical. A more productive perspective is to consider the basic components of musicality and the extent to which we share those components with various non-human animals.

Addressing these issues productively depends on distinguishing between the notions of music and musicality [28,31,35]. *Musicality* in all its complexity can be defined as a natural, spontaneously developing set of traits based on and constrained by our cognitive and biological system. *Music* in all its variety can be defined as a social and cultural construct based on that very musicality. This distinction demarcates two divergent approaches to the cognition and biology of music.

One approach is to study the *structure of music*, seeking key similarities and differences in musical form and activity across a variety of human cultures [41,42]. Although there is no widely shared definition of music [43], the presence of several cross-cultural similarities supports the notion of musicality as a prominent characteristic of humankind. The similarities are suggestive of underlying cognitive and biological mechanisms that may constrain and shape musical behaviours across cultures.

An alternative approach is to study the *structure of musicality* by attempting to identify the basic underlying mechanisms, cognitive and biological, their function and developmental course, and effective ways to study those mechanisms in human and non-human animals. The major challenge of this approach, and of the current issue, is to delineate the traits that constitute the musicality phenotype.

4. Evolution of (music) cognition

There is much scepticism about the possibility of gaining insight into the evolution of cognition in general [28,44,45] and, by extension, musicality. According to Lewontin [44], evolutionary theory stands on three principles—variation, heredity and natural selection—that limit scientific inquiry into cognition. To understand the evolution of cognition, it is necessary to understand the variation in cognitive traits in ancestral times. Because cognition does not fossilize, we cannot acquire the requisite evidence about variability [44]. On the issue of heritability, many studies provide such evidence (see Gingras *et al.* [46]), but it is difficult to specify the genes because cognitive traits are polygenic. It is also important to gather evidence about the possibility that cognitive traits were the target of natural selection. Without reconstructing the minds of our hunter–gatherer predecessors, for example, we can only guess at the selection pressures they faced [47].

Despite the apparent impossibility of studying the evolution of complex mental processes such as cognition, we argue that a bottom-up approach involving the search for basic mechanisms that combine into a multicomponent trait like musicality can be fruitful. Such an approach has resulted in important insights in the domains of animal cognition [48–50] and the evolution of language [51].

5. Multicomponent perspective

Some cognitive functions like language and music are viewed as typically human. It is possible, however, that other species share one or more component mechanisms of musicality. A bottom-up perspective [52] focusing on the constituent capacities underlying musicality could reveal such common mechanisms. Instead of asking which species are musical, we ask how musicality works, its essential ingredients, which ingredients are shared with other species, and how these evolved.

In essence, we are combining functional, developmental, phylogenetic and mechanistic approaches [26] to generate a theory of musicality while focusing on the constituent capacities underlying the musicality phenotype. In fact, we propose to address Tinbergen's [26] four questions by first describing the mechanisms, functions and developmental course of musicality in a variety of animals and cultures, with input from anthropological, neuroscientific and genetic sources. By doing so, we hope to learn more about how music evolved.

A *multicomponent perspective*, which involves studying the constituents of musicality in the ‘here and now’ by means of a comparative approach across cultures and species, is one means of addressing the critique that the evolution of musicality cannot be studied (§4). This approach is based on the neo-Darwinian assumption that if closely related species, whether humans and apes or walruses and sea lions, exhibit similar solutions to similar problems, they are probably engaging similar mechanisms (figure 1). When two species share a particular musical trait, one can infer that their common ancestor (CA) also had that trait. By examining these homologous traits in a natural group of species (i.e. clade), one can date the origin of that particular trait. This is the principal motivation for studying music perception in closely related species [53].

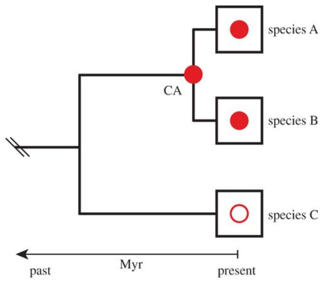

Figure 1. Neo-Darwinian perspective on the evolution of musicality. Diagrammatic representation of a hypothetical phylogenetic tree illustrating the Darwinian assumption that closely related species share similar traits. When two species (A and B) share a certain musical trait, one can infer that their CA also had that trait (referred to as a homologous trait). Filled circles represent a trait; open circles indicate the absence of that trait. (Online version in colour.)

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Species that are closely related to humans can be assumed to share some cognitive abilities and might therefore be good experimental models for teasing apart various neurological, genetic or epigenetic contributions to a certain trait. The study of more distant or unrelated species that share a similar trait (that is not homologous) can also contribute to an understanding of underlying mechanisms. The convergent evolution of particular traits in distant species (analogous trait or homoplasy; figure 2) is the main motivation for studying music perception in such species [54].

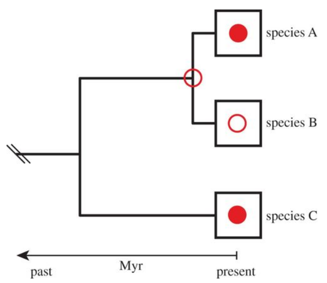

Figure 2. Convergent evolution of musicality. Diagrammatic representation of a hypothetical phylogenetic tree illustrating an analogous trait (homoplasy) in which a distant species (C compared to A) developed a musical trait that is lacking in a more closely related species (B compared to A). Filled circles represent a trait; open circles indicate the absence of that trait. (Online version in colour.)

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The study of homologous and analogous traits is the key tool of comparative biology. Although an observable phenotype might have evolved independently in different lineages (i.e. a CA lacked such a phenotype), it is possible that this trait involves a ‘deep homology’ in which distant species share underlying genetic and developmental mechanisms that generated the trait [55]. Consider the role of the *FOXP2* gene in the vocal learning mechanisms of humans and songbirds [56]. Further research into neural mechanisms and biological substrates is necessary to pinpoint the mechanisms that are essential to musicality. This can reveal the extent to which humans share some of the components of musicality with other species and will inform a phenomics of musicality [46].

Combining these views, we propose to study musicality as a composite of several traits, each with its own underlying neural mechanisms and evolutionary history (figure 3) that can be studied at the present time (avoiding the critique in §4). Potential candidates for the basic components of musicality are relative pitch [2,35], tonal encoding of pitch [57], beat perception [34,58] and metrical encoding of rhythm [58]. Some of these traits may be common to humans and other species, with others being uniquely human.

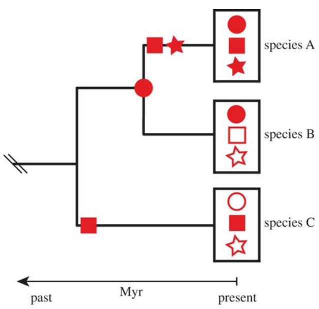

Figure 3. Multicomponent perspective on musicality. Diagrammatic representation of the evolution of the musicality phenotype. It illustrates the hypothesized contributions of several traits to musicality as a complex or *multicomponent* phenotype. Filled shapes represent the presence of a trait; open shapes indicate the absence of that trait. Shapes that are positioned on the tree are hypothesized dates of origin of that trait. (Online version in colour.)

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In summary, the research agenda for studying the cognitive, biological, cultural and social origins of musicality (and the aim of this Theme Issue) is twofold. The primary aim is to identify the basic mechanisms that contribute to musicality, their functions and developmental course, as well as effective ways to study them in human and non-human animals. A secondary aim is to constrain evolutionary theories of musicality by evaluating recent findings from the fields of biology, musicology, neurology, genetics, computer science, anthropology and psychology.

6. Lorentz workshop on musicality and its relation to this theme issue

During a Lorentz Workshop on this subject (from which this issue arose), held in April 2014, it became clear that reframing the available empirical evidence and proposing a research agenda on musicality were both important and timely. Moreover, 23 experts from a wide range of disciplines (cognitive biology, cognitive neuroscience, neurobiology, animal cognition, molecular genetics, anthropology, developmental psychology and computational cognition) agreed on many facets of such a research agenda, providing the momentum for this theme issue.

Together, the papers assembled in this issue set a research agenda for the study of musicality in the years to come, an endeavour that is multidisciplinary, as is the background of the authors. The topics of the 11, mostly co-authored, papers resulted from a bottom-up selection process during the workshop, prompted by a series of position statements and reviews. These topics formed the basis of Working Sessions in which the key ingredients of the papers were formulated.

Below we introduce and discuss each selected topic, its history and the resulting paper. In **table 1**, we summarize the key questions for a future research agenda on musicality.

Table 1.

Some key questions for a future research agenda on musicality.

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(a) Four principles of bio-musicology

The first paper in this issue is one of four position papers that outline the key issues in the study of musicality. Tecumseh Fitch [59] proposes four principles as prerequisites for a future discipline of 'bio-musicology', a term coined by Nils L. Wallin [1] to encompass several branches of music psychology and musicology, but that is used here to refer to the biological study of musicality in all its forms.

In addition to these four principles, which incorporate Tinbergen's four ethological questions, the paper argues for a revitalized search for musical universals, a topic that has been explored extensively by scholars such as Bruno Nettl [60] and, more recently, by Brown and Jordania [61].

Some of these ideas are widely accepted in one or more disciplines, like the multicomponent approach or Tinbergen's four levels of explanation. Others have less agreement, like the notion of universals of musical structure (cf. [43]) or the focus on overt behaviour (cf. [54]).

Fitch continues by proposing four core components of musicality, which differ somewhat from the four components proposed in this paper. Instead of the current focus on perceptual and cognitive mechanisms that might be fundamental to musicality (e.g. relative pitch, beat perception, tonal encoding of pitch and metrical encoding of rhythm; §5), he argues for four musical behaviours as the central focus of bio-musicology: song, drumming, social synchronization and dance. In so doing, he suggests a bridge from cognitive biology to fields like anthropology and social psychology. In short, he proposes bio-musicology as a rich field for interdisciplinary and comparative research on musicality.

(b) The origins of music in auditory scene analysis and the roles of evolution and culture in musical creation

Trainor [62] considers the possibility that music originated either as an evolutionary adaptation or as a product of culture. The uniqueness of music to humans, its universality across cultures and its early emergence in development are consistent with music as an evolutionary adaptation. However, the flexibility and generativity of music and its rapid change over time are consistent with cultural transmission rather than adaptation. According to Trainor, adaptation *and* cultural transmission underlie the origins of music. Although the processing of musical pitch and timing are presumed to have evolutionary origins, she argues that they did not evolve specifically for music but rather for identifying and locating sounding objects in the environment (i.e. auditory scene analysis [63]). In other words, the creation of music capitalized on preexisting auditory processes. Trainor argues, however, that the emotional and social consequences of music may have conferred survival benefits, leading to adaptations that promoted and enhanced musical behaviour.

(c) Searching for the origins of musicality across species

Hoeschele *et al.* [54] pose critical questions such as what species to study and how to study them in searching for the components of musicality and their biological origins. They outline the contributions of artificial laboratory experiments to our understanding of various aspects of musicality such as absolute and relative pitch processing, rhythm processing and timbre processing. They also indicate how studies of the natural behaviour of species have revealed important skills relating to musicality and have also informed laboratory studies. For example, detailed descriptions of the songs of black-capped chickadees—their variability [64] and the preferences of female conspecifics [65]—revealed the relative pitch processing capabilities of this species, prompting training studies that delineated the limits of these abilities [66]. The authors suggest new directions for future research, including the search for musically relevant behaviours in species that have received little attention to date and the use of more ecologically valid stimuli and tasks in the laboratory.

(d) Five fundamental constraints on theories of the origins of music

The uniqueness and universality of music raise questions of how and why the human ability to appreciate and produce music evolved. To avoid ‘just-so stories' for the evolution of music, Merker *et al.* [67] argue for constraints on evolutionary theorizing. They propose five such constraints, chosen for their generality and their consequences for the structure of music: (i) cultural transmission, so that any transfer of musical traits must pass through an inter-generational ‘learner bottleneck’; (ii) generativity, such that music can generate infinite pattern diversity by finite means; (iii) vocal production learning; (iv) entrainment with perfect synchrony; and (v) a motivational basis for the universal human propensity to sing and dance together in a group. Some of these constraints are not specific to music, with the first three being applicable to the evolution of language. Like other contributors to this issue, these authors draw parallels between language and music processing. They suggest that some distinguishing features of music do not require Darwinian explanations for their widespread occurrence, arising instead from constraints and characteristics of the learning mechanisms involved. Other features may be subject to Darwinian selection. In those cases, it is important to consider the modes of selection that might be operative as well as the features on which they are operative, the latter issue often receiving insufficient attention.

(e) Cross-cultural perspectives on music and musicality

This paper by Trehub *et al.* [43] issues an invitation to conduct more socially oriented research on music cognition as it may hold keys to the evolutionary origins of musicality. It is proposed that music promotes social and pro-social behaviour through a variety of mechanisms such as jointly experienced arousal and synchronous action across cultures. The argument is original and thought-provoking. For example, the paper covers musical universals from a fresh perspective. One universal, which is particularly novel and interesting, is repetition (of motifs and themes). Repetition is ubiquitous in music and has no clear parallel in language. Similarly, the paper presents vivid examples of social behaviours that may be akin to what is experienced while being musically engaged in a group. A vivid example is the empathy and arousal elicited by watching fire-walkers, in particular those who are relatives or friends. In sum, the authors make a convincing case for further study of the social aspects of musical engagement, which may account for the perpetuation of music. Music may outperform language in this respect because it can be shared simultaneously with more individuals and over longer distances than can speech.

(f) Neural overlap in processing music and speech

While there is a growing literature on the relationship between music and language, especially with regard to the underlying brain processes that facilitate music and speech (cf. [63]), there are at least four competing views on how music and speech are processed in the brain: (i) music and speech make use of identical brain networks (*identity hypothesis*), (ii) music and speech processing occur in overlapping brain regions (*neural sharing hypothesis*), (iii) music and speech have neural overlap but do not share neural circuitry (*neural overlap hypothesis*) or

(iv) they are distinct (*dissociation hypothesis*).

The paper by Peretz *et al.* [68] elaborates the third hypothesis that stresses the distinction between brain locations and brain networks. The authors argue that part of the neural circuitry that has been established for language may have been recycled during evolution for musicality or, alternatively, that musicality served as a springboard for the emergence of language.

In the second half of this paper, Peretz *et al.* review some of the evidence in support of this interpretation, suggesting methods for disentangling neural overlap and neural sharing perspectives on music and language. While the neural overlap hypothesis is an attractive alternative to the neural sharing hypothesis (cf. [64]), the idea of neuronal recycling as applied to the evolution of musicality needs further research. Interestingly, if a core component of musicality is found to share a brain region or network involved in language, it may reveal a novel pathway by which some animals, most notably humans, achieved their highly sophisticated use of sound.

(g) Defining the biological bases of individual differences in musicality

Humans differ in their music-related skills, as they do for most other skills. While some of this variation is clearly linked to experiential differences, including exposure and training, there is accumulating evidence for the involvement of genetic variation and an emerging consensus that musicality has deep biological foundations. The impressive advances in molecular technologies have made it possible to explore these foundations.

Gingras *et al.* [46] provide a synthesis of research on the genetic correlates of musicality and the methods by which current insights have emerged. Entry points for exploring the genetic basis of components of musicality range from the examination of clustering in families or co-occurrence in twins of extreme levels of ability, like congenital amusia or absolute pitch perception, to genome-wide genotyping to capture the polymorphic content of a large phenotyped population sample, using advanced genomic and statistical methods. They sketch the prospects of new technologies for tracing the effects of particular genes on musicality. Moreover, they provide concrete suggestions for online test procedures that may improve the phenotyping of musical abilities and that can be combined with genome-wide genotype data on specific human populations.

(h) Finding the beat: a neuro-computational approach

One of the core mechanisms of musicality, as acknowledged by contributors to this issue, is the ability to perceive and synchronize movements to the beat of music. This skill is variously termed beat perception and synchronization [**65**], beat induction [**66**], or pulse perception and entrainment [**58**]. The skill is spontaneously developing [**38**], music-specific [**69**] and present in humans [**58**] but apparently lacking in other primates.

Merchant *et al.* [**53**] review the ever-increasing literature on beat perception and entrainment in monkeys, apes and humans [**70**]. They evaluate several brain imaging methods, including functional and electrophysiological techniques, for investigating the underlying mechanisms. The neurophysiology of rhythmic behaviour is also discussed, informed largely by recent findings in monkeys using direct intracortical [**71**] and non-invasive techniques [**72**].

Finally, the authors address the consequences of these findings for computational models of beat induction. Computational modelling is a long-standing promise of cognitive science, so a concrete mechanism like beat perception seems ideal for revealing the network required for perceiving regularity. The authors suggest questions that should be addressed in the near future.

(i) Principles of structure building in music, language and animal vocalization

This paper by Rohrmeier *et al.* [73] brings together a thorough review of the literatures on animal song, music and formal models of language. It provides an overview of the Chomsky hierarchy and discusses a number of ways in which formal language models can be extended. Throughout, it suggests links to language, music and animal vocalization. Interestingly, like Trehub *et al.* [43], the authors ground their discussion of building blocks on Brown and Jordania's recent work on cross-cultural universals in music [61], including repetition. By doing so, they strengthen the importance of a crosscultural perspective and point to limitations of other approaches. The rough tutorial material on grammar formalisms provides an important service for scholars of musicality. The paper should be useful to researchers from various fields of inquiry, prompting the possibility of new and fruitful connections.

(j) Affect induction through musical sounds: an ethological perspective

Music often induces emotional responses in listeners, some of which seem to be universal and others not. Huron [74] explores these phenomena by drawing upon parallels from animal communication. For example, there is often a close linkage within a species between an evolved signal and the response it evokes. Variation in a particular signal within and among species is sometimes tightly linked to physiological constraints. For example, the production of low-pitched sounds is often linked to a large body size or resonance cavity. Low pitch may have been selected as a threat signal providing honest information about the size and potential strength of the sender. For the receiver, such a signal might evoke fear. These and other evolved associations might be used in music to induce emotion in listeners.

Huron addresses five so-called ‘puzzles’ regarding music-induced emotions: Why can music induce certain emotions but not others? Why are some induced emotions similar to the displayed emotions in some cases but not others? Why do listeners often report feeling mixed emotions? Why are some emotions similar across musical cultures while others are not? And why do musicians rely on some emotion-inducing mechanisms more than others? Huron uses concepts and mechanisms from animal communication studies to explore why specific associations between sounds and emotions are more or less likely.

(k) The evolutionary roots of creativity: mechanisms and motivations

Wiggins *et al.* [75] endeavour to relate creativity and its principles, as exercised in human music, to parallels in other species as a means of shedding light on the evolution of cognition and the emergence of creative behaviour. This endeavour entails analysis of creativity at the phenomenological level. The authors decompose creativity into an objective process of generation, coupled with a combination of relative value judgements, some of which, notably novelty, can be modelled objectively. One unbiased approach to novelty is to identify it in non-human animals. For example, non-human creativity can be found in the novelty of humpback whale singing in Australia and the Pacific. A similar argument can be made for birdsong. In sum, the authors make a case for considering creativity as an evolutionary pressure, proposing a research programme involving animal communication (bird and whale song, specifically) to investigate this possibility.