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From Sound to Significance: Exploring the Mechanisms Underlying Emotional Reactions to Music

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Abstract

A common approach to study emotional reactions to music is to attempt to obtain direct links between musical surface features such as tempo and a listener's responses. However, such an analysis ultimately fails to explain *why* emotions are aroused in the listener. In this article, we we explore an alternative approach, which seeks to explain musical emotions in terms of a set of psychological mechanisms that are activated by different types of information in a musical event. This approach was tested in four experiments that manipulated four mechanisms (Brain stem reflex, Contagion, Episodic memory, Musical expectancy), by selecting existing musical pieces that featured information relevant for each mechanism. The excerpts were played to 60 listeners, who were asked to rate their felt emotions on 15 scales. Skin conductance levels and facial expressions were measured and listeners reported subjective impressions of relevance to specific mechanisms. Results indicated that the target-mechanism conditions evoked emotions largely as predicted by a multi-mechanism framework and that mostly similar effects occurred across the experiments that included different pieces of music. We conclude that a satisfactory account of musical emotions requires consideration of how musical features and responses are mediated by a range of underlying mechanisms.

Key words: Music, Emotion, Listening, Mechanism, Psychophysiology

From Sound to Significance:

Exploring the Mechanisms Underlying Emotional Reactions to Music

Mere sound can have profound effects on listeners. It can be argued that sound is more 'intimate' than sight - "more inside our 'heads'" (Thompson, 2009, p. 125). Nowhere is this impact more apparent than in the case of music. Still, it is often regarded as one of the great mysteries in life that music, which consists only of abstract tone sequences, is able to arouse such strong emotions. What is more, listeners differ considerably in their emotions to music (Sloboda, 1996). Thus, Gutheil (1952) asked whether music and emotion research "can ever reach the goal of science, namely to *discover laws of cause and effect* in order to *predict the results*" (p. 11). In this article, we explore some of the principal ways in which music might evoke emotions and show that despite their elusiveness, emotional reactions to music can be predicted to a greater extent than is usually believed.

Music and Emotion Research

Music is ubiquitous in today's society (North & Hargreaves, 2008). It often occurs in a variety of social contexts, and accompanies people's activities "from the cradle to the grave" (Gregory, 1997, p. 124). In a significant proportion of these life episodes (Juslin et al., 2008), the music arouses an *emotion* in the listener. Indeed, the intense emotions that music arouses helps to explain why people spend more money on music than on prescription drugs (Huron, 2001). Accordingly, an account of the attraction music holds for most people must at least in part be an account of emotions.

Emotions belong the broad field of 'affect', which also includes moods, preferences and personality traits (see Keltner, Oatley, & Jenkins, 2006, Chapter 1). While there are numerous definitions of emotion (e.g., Izard, 2010; Kleinginna & Kleinginna, 1981), Juslin (2011) offers a 'working definition' that captures how many contemporary emotion researchers conceive of the phenomenon:

> Emotions are relatively brief, intense, and rapidly changing reactions to potentially important events (subjective challenges or opportunities) in the external or internal environment - often of a social nature - which involve a number of subcomponents (cognitive changes, subjective feelings, expressive behavior, and action tendencies) that are more or less ‘synchronized’ during an emotional episode. (p. 114)

In a musical context, ‘emotion’ is one out of several aspects of music experience (that also encompass physical, behavioural, perceptual, cognitive, existential and developmental aspects; see Gabrielsson, 2011), which may or may not be present in any individual instance of music listening. As far as lay listeners are concerned, however, it may be one of the most important aspects (Juslin & Laukka, 2004, p. 232).

Hence, researchers have used a wide variety of methods, such as listening experiments (Waterman, 1996), questionnaires (Juslin & Laukka, 2004), the experience sampling method (Sloboda, O’Neill, & Ivaldi, 2001), qualitative interviews (DeNora, 2000) and brain imaging (Salimpoor, Benovoy, Larcher, Dagher, & Zatorre, 2011), to support the idea that music may arouse emotions. Strong empirical evidence has been slow to emerge, although an increasing number of studies have documented effects of music on various emotion components: *feeling* (Pike, 1972), *emotional expression* (Witvliet & Vrana, 2007), *psychophysiology* (Krumhansl, 1997), *brain activation* (Brown, Martinez, & Parsons, 2004), and *behavior tendency* (Fried & Berkowitz, 1979).

A few recent experimenrs have also reported evidence of a so-called *synchronization* between the various components (see Juslin, Harmat, & Eerola, 2013; Lundqvist, Carlsson, Hilmersson, & Juslin, 2009). Juslin and Zentner (2002) note that “inclusion of measures of different sub-components might increase our ability to decide exactly what kind of reaction has occurred to a musical event" (p. 7). This is especially important in experimental studies since emotions are not easy to arouse in artificial laboratory environments (Plutchik, 1994).

Obtaining cases of 'genuine' emotions to music is less of a problem in field studies, which have shown that musical emotions occur in a wide range of settings in everyday life. Survey and experience sampling studies[1] to date suggest that music evokes a wide range of emotional states, including *calm*, *happiness*, *nostalgia*, *interest*, *pleasure*, *sadness*, *arousal*, *love* and *pride*, and numerous synonymous terms (e.g., Juslin & Laukka, 2004; Juslin et al., 2008, 2011; Sloboda, 1992; Wells & Hakanen, 1991; Zentner, Grandjean, & Scherer, 2008). These states, which may be conceptualized as both 'everyday emotions' (e.g., *sadness*) and 'aesthetic emotions' (e.g., *awe*) (Juslin, 2013), represent the findings that a theory of music and emotion must be able to explain.

Still, it needs to be acknowledged that we often hear music, without actually feeling any emotion at all - at least not one aroused by the music. According to some estimates, the music arouses emotions in only about 55-65% of the episodes, and there seem to be large individual differences in overall prevalence (Juslin & Laukka, 2004; Juslin et al., 2008). Moreover, there are considerable individual differences between listeners regarding the precise emotional state a musical event will arouse (e.g., Gowensmith & Bloom, 1997). Thus, though few researchers today would deny "that some music is capable of exciting some emotion in some people some of the time" (Ball, 2007, p. 257), a more delicate issue is to explain *why* the emotion occurred in the first place. If only some musical events succeed in arousing an emotion, and if different listeners might respond differently to the same piece of music, what are the precise conditions that cause a specific emotion to occur?

The Causes of Musical Emotions

Emotional reactions to music are viewed as puzzling (cf. Dowling & Harwood, 1986). Part of the puzzle is that the conditions of emotion-elicitation in music and in real life seem different (Krumhansl, 1997), at least on the surface. In the paradigmatic case, an emotion is aroused when an event is appraised as having the capacity to influence the goals or plans of the perceiver. The main problem is that, when we listen to a piece of music, the music does not usually have implications for our goals or plans in life.[2] Appraisal researchers have thus expressed concerns over the limitations of appraisal theory in a musical context:

> Explaining emotional responses to instrumental music is a real problem for appraisal theories, and may be a real threat to the generality of appraisals as elicitors of emotion. (Ellsworth, 1994, p. 195)

A challenge for researchers has thus been to come up with alternative accounts. Some authors have argued that musical features affect listeners 'directly' (Robinson, 2005, p. 392), but the use of the word 'directly' really only goes to show that no causal explanation has yet been offered. The belief that objects or events 'directly' cause our emotions is referred to as the 'nativist fallacy' (Silvia, 2012). It appears to be particularly common in music research - maybe because we tend to think of music as abstract sequences of notes, devoid of semantic meaning. Thus, many scholars have aimed to obtain direct links between surface features of the music and evoked emotions. But such correlations do not constitute an explanation: they simply move the burden of explanation from one level ('Why does the second movement of Beethoven's 'Eroica' symphony arouse sadness?'), to another level ('Why does slow tempo arouse sadness?'). This approach confuses (re)description with explanation (Juslin, in press). To describe the features of the music is only a first step towards a psychological explanation. Moreover, a 'direct' or 'surface' approach immediately runs into problems, when confronted with the finding that different listeners may react differently to the same piece of music.

We submit that real progress in studies of music and emotion can only be made if we try to understand the the underlying process that 'mediates' between surface features and aroused emotions. A good theory of emotion causation should explain both why a given event arouses an emotion ('elicitation') and why the aroused emotion is of a specific kind ('differentiation'). The psychological process through which this is achieved is here referred to as the underlying *mechanism*. It comprises a functional description of what the mind is doing, in principle (e.g., 'retrieving a memory'), which should *not* be confused with its implementation in the brain, or with the phenomenological experience it seeks to explain (Dennett, 1987).

Theories of Underlying Mechanisms

Though few studies have attempted to test theories of possible mechanisms underlying emotional reactions to music (for a discussion, see Juslin & Västfjäll, 2008), several scholars have proposed possible mechanisms over the years, typically limiting themselves to one or a few. Meyer (1956) was arguably the first modern scholar who understood the important role of psychological theory in unraveling relationships between musical structure and emotional response, and offered a useful theory of 'musical expectancy'. Dowling and Harwood (1986) argued that 'conditioned responses' form part of the composer's toolkit for evoking emotion, and provided several examples of this principle. Baumgartner (1992) proposed that 'episodic memory' plays an important role in emotional responses to music, and presented survey data to back up the claim. Waterman (1996) made an early attempt to apply 'appraisal theory' (the version outlined by Ortony, Clore & Collins, 1988) to musical events. Juslin (2000) proposed that 'emotional contagion' via voice-like features of the music are responsible for a subset of musical emotions. Sloboda and Juslin (2001) and Scherer and Zentner (2001) discussed some of the above mechanisms, but did not attempt to formulate an integrated framework featuring a set of hypotheses that could guide researchers in the field. The most comprehensive attempt to describe a set of mechanisms was begun in the mid 2000s and resulted in the BRECVEMA framework (Juslin, 2004, 2005, 2013; Juslin & Västfjäll, 2008; Juslin, Liljeström, Västfjäll, & Lundqvist, 2010).[3]

The BRECVEMA framework takes as point of departure an evolutionary perspective. An evolutionary perspective on human perception of sounds suggests that the survival of our ancient ancestors depended on their ability to detect patterns in sounds, derive meaning from them, and adjust their behavior accordingly. Proceeding from this assumption, it is theorized that there are several emotion mechanisms implemented by a number of more or less distinct 'brain networks' which developed gradually and in a particular order during evolution - from simple reflexes to complex judgments. Each mechanism is responsive in its own unique way to specific configurations of information in the *music*, the *listener*, and the *situation*, referred to jointly as 'the musical event' (Juslin, 2013). Eight mechanisms are currently featured in the framework:

(1) *Brain stem reflex*, a hard-wired attention response to simple acoustic features such as extreme or increasing loudness or speed (Sokolov, 1963);

(2) *Rhythmic entrainment*, a gradual adjustment of an internal body rhythm (e.g., heart rate) towards an external rhythm in the music (Harrer & Harrer, 1977);

(3) *Evaluative conditioning*, a regular pairing of a piece of music and other positive or negative stimuli leading to a conditioned association (Blair & Shimp, 1992);

(4) *Contagion*, an internal 'mimicry' of the perceived voice-like emotional expression of the music (Juslin, 2001);

(5) *Visual imagery*, inner images of an emotional character conjured up by the listener through a metaphorical mapping of the musical structure (Osborne, 1980);

(6) *Episodic memory*, a conscious recollection of a particular event from the listener's past that is triggered by the music (Baumgartner, 1992);

(7) *Musical expectancy*, a response to the gradual unfolding of the syntactical structure of the music and its expected (or unexpected) continuation (Meyer, 1956); and

(8) *Aesthetic judgment*, a subjective evaluation of the aesthetic value of the music based on an individual set of weighted criteria (Juslin, 2013).

By synthesizing theory and data from many domains mostly outside music, Juslin and Västfjäll (2008) were able to develop the first set of hypotheses that may help researchers to distinguish among the mechanisms. The hypotheses concern such aspects as the information focus, key brain regions, representations, and extent of cultural impact. (For an update of the hypotheses, see Juslin, 2013.) One clear implication is that in order for data to contribute in a cumulative fashion to our knowledge, music researchers need to specify as far as possible the underlying mechanism involved in each case of musical emotion.[4]

Empirical Approaches to Mechanisms

Given the crucial role of theories of underlying mechanisms in explaining emotions to music, there is an urgent need for empirical studies that attempt to test specific mechanisms. To date, most data come from field studies that rely on self-report. Baumgartner (1992) and Janata, Tomic and Rakowski (2007) explored episodic memories linked to music. A broader selection of mechanisms were surveyed by Juslin et al. (2008) and by Dingle, Savill, Fraser, and Vieth (2011). In the experience sampling study by Juslin et al. (2008), participants were asked what they believed caused their emotion in each episode. They could choose from ten alternatives based on previous studies and particularly the framework outlined by Juslin and Västfjäll (2008). The results suggested that all of the psychological mechanisms occurred in at least some episodes. The most commonly self-reported causes were *Emotional contagion*, *Brain stem reflex*, and *Episodic memory*. The least commonly reported cause was *Cognitive appraisal*, confirming that music rarely has any implications for life goals. Juslin, Liljeström, Laukka, Västfjäll, and Lundqvist (2011) similarly explored the occurence of a wide range of psychological mechanisms, using a randomized and statistically representative sample of the Swedish population. They reported similar findings: *Episodic memory*, *Contagion* and *Brain stem reflex* were all among the mechanisms rated as most frequent by music listeners. In both studies, *musical expectancy* was rated as occurring rarely.

Though field studies such as these provide some clues about the occurrence of various mechanisms in real-life contexts, these data should be treated with caution: Field data do not enable researchers to draw strong conclusions with regard to *causal* relationships because of insufficient experimental control. It has been demonstrated that people generally have a poor understanding of the causes of their own behavior, and that it is problematic to rely solely on subjective self-reports of causes of emotions, since we could be unaware of the 'trigger' that elicit our emotion. Stimuli that occur outside our conscious awareness can still influence our behavior (Fox, 2008). This applies to music as well. Because some mechanisms, at least, are implicit in nature and may occur in parallel (Juslin, 2013), researchers cannot rely merely on phenomenological report to explain musical emotions. Mechanisms that are more implicit in nature (e.g., musical expectancy) will probably be underreported. Therefore it is necessary to conduct experiments in a laboratory setting, where specific mechanisms may be manipulated so as to produce immediate effects on behavioral measures. Being able to predict and control aroused emotions in terms of specific mechanisms is the ultimate evidence of a valid process-description. This task is challenging, however, and requires a set of strategies.

To separate the effects of distinct mechanisms, we need to be able to activate as well as suppress specific mechanisms in each case by manipulating different aspects of the *music*, the listening *situation*, and the *listener*. This could be done in at least three principal ways: Firstly, one might select or manipulate pieces of music in such a manner as to provide or withhold the information required for a certain mechanism to be activated, while leaving or removing other information (*the principle of information selection*). Secondly, one can design the specific test procedure in such a way that it will prevent the type of 'information-processing' required for a mechanism to be activated (*the principle of interference*). One can for instance give listeners a task that recruits attentional resources to such an extent that visual imagery, also dependent on these resources, will be made impossible. *Thirdly*, one can manipulate the listener, by creating new memories during the test procedure prior to presenting the 'target' stimulus (*the principle of procedural history*), to enable study of mechanisms such as evaluative conditioning. In this study, we focused on the first of these principles (i.e., information selection).

As should be apparent from the above, exploring mechanisms must entail experimental studies, and there are at least two complementary experimental strategies that might be used: First, one may attempt to directly manipulate musical features or situational circumstances to activate particular mechanisms by means of highly controlled synthesized (or re-synthesized) pieces. This approach permits strong conclusions about causal relationships, but suffers from low ecological validity. Specifically, the musical stimuli could bear little relation to music as experienced by most listeners in the real world. Thus, a second approach is to attempt to find existing pieces of music that include musical characteristics relevant to specific mechanisms. Though the internal validity could be reduced, the use of real music makes it easier to arouse intense emotions in listeners, plus the ecological validity is enhanced.

Only the synthesis approach has been used in studies so far. A pioneering experiment by Steinbeis, Koelsch and Sloboda (2006) used subjective and physiological measures to capture emotional reactions to unexpected harmonic progressions. Stimuli consisted of three matched versions of six Bach chorales, which differed only in terms of one chord - harmonically either expected, unexpected, or very unexpected. Results showed that felt tension, overall subjective emotionality, and electrodermal activity all increased with increases in unexpectedness. These results rendered support for the musical expectancy mechanism in terms of stylistic violations of Western classical music (Meyer, 1956).

In a recent study (Juslin, Harmat, & Eerola, 2013), we also used a synthesis approach. We manipulated a piece of music to activate four mechanisms: brain stem reflex, emotional contagion, episodic memory, and musical expectancy. This was done by means of a careful editing of computerized although natural-sounding performances, inserting or removing the information needed for specific mechanisms. The resulting musical excerpts were played to 20 listeners, who were asked to rate felt emotions on 12 scales. Pulse rate, skin conductance and facial expressions were also measured. The results showed that target mechanisms were activated and aroused emotions in accordance with theoretical predictions.

This was the the first experiment to manipulate and contrast different target mechanisms in the induction of emotions through music listening. However, the study used merely a single (original) piece of music. Although it might be argued that the original piece mainly served as a ‘carrier’ of different types of information, the results clearly need to be replicated with other pieces. Moreover, the synthesized stimuli were fairly simple compared to most ‘real’ music in order to achieve experimental control. It is thus crucial to demonstrate that such effects can be obtained with ‘real’ pieces of music by ‘real’ composers, and not merely with artificial stimuli created by experimenters.

Rationale for the Present Study

The main aim of this study was to make an attempt to selectively manipulate four of the mechanisms that underlie emotions to music, through a careful selection of existing and more ecologically valid pieces of music, to see if it is still possible able to obtain predictable effects on listeners’ responses. To render studies comparable, we featured the same four mechanisms as were manipulated in Juslin et al. (2013). Three of these - Brain stem reflex, Contagion, and Episodic memory - appear to be among the most commonly occurring in everyday life (Juslin et al., 2008, 2011), whereas the fourth - Musical expectancy - is often regarded as particularly important by music researchers (Thompson, 2009). They can be summarized as follows:

Brain stem reflex is a process whereby an emotion is induced in the listener because one or more simple acoustic features exceed a certain cut-off value, for which the auditory system has been 'designed' to quickly alert the brain to a (potentially) important event. In music, this may involve sounds that are sudden, loud, or dissonant, or that feature fast and accelerating patterns. The responses are quick, automatic, and unlearned. The name 'brain stem reflex' serves to highlight that the reflex occurs very *early* in the auditory processing (e.g., in the inferior colliculus of the brain stem; Brandao et al., 1993), before one has even recognized the object of attention. Simons (1996) offers a number of examples of startling musical events such a diminuendo followed by a crash in von Weber's overture to *Oberon*. We argue that brain stem reflexes typically increase *arousal* and evoke feelings of *surprise* in the listener (Juslin et al., 2013).

Emotional *contagion* is a process whereby an emotion is induced by a piece of music because an independent module of the mind reacts to certain musical features *as if* they were coming from a human voice that expresses an emotion, which leads the listener to mimic the moving expression internally (Juslin, 2000). The process could be implemented by means of a 'mirror-neuron system' (Rizzolatti & Craighero, 2004). Preliminary support comes from a brain imaging study by Koelsch et al. (2006) that indicated that listening to expressive music activated brain regions associated with pre-motor representations for vocal sound production. Field data suggest that contagion responses are common in everyday life (Juslin et al., 2008), which might not be surprising considering that most music heard today *is* vocal music, where singers attempt to achieve expressivity. However, recent results show that voice-like features of a violin or cello can also arouse a matching emotion in the listener (Juslin et al., 2013).

Episodic memory is a process whereby emotion is induced in a listener because some feature of the music (e.g., the melody) serves as a 'retrieval cue' for a personal memory of a specific event in the listener's life (Baumgartner, 1992). This is sometimes referred to as the 'darling, they are playing our tune' phenomenon (Davies, 1978). When an episodic memory is evoked, so is also the emotion associated with the memory. Such emotions can be intense, perhaps because the physiological response pattern to the original event is stored in memory, along with the memory trace (Lang, 1979). Studies indicate that episodic memories linked to music commonly arouse *nostalgia* (Janata et al., 2007), but the response will be reflective of whatever emotion is associated with the memory. Field studies, using representative samples of listeners (Juslin et al., 2011) or situations (Juslin et al., 2008), show that episodic memory is one of the most common sources of emotions to music in everyday life.

Musical expectancy is a process whereby an emotion is induced in a listener because a specific feature of the music violates, delays, or confirms the listener's expectation about the continuation of the music. However, this mechanism 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. Musical expectancy refers to those expectancies that involve syntactical relationships among different parts of the musical structure (Narmour, 1991). These expectations are based on the listener's previous experience of the same musical style (Pearce et al., 2010), as suggested by Meyer (1956). Patel (2008) has argued that syntactical processing in both language and music shares a common set of processes for syntactical integration that operate on distinct structural representations for music and language. We submit that violations of expectancies can arouse *anxiety* due to the uncertainty created in the listener (Meyer, 1956, p. 27).

Could predictable emotional responses be produced by systematically selecting pieces of music that include information of relevance to each of the above mechanisms? To provide 'affordances' (Gibson, 1979) for the above mechanisms to be activated in music listeners, we selected pieces of music that included extreme acoustic events (brain stem reflex), voice-like emotional expressions (contagion), unexpected musical sequences (musical expectancy), and pieces linked with significant life events for most people (episodic memory), respectively. To avoid that any effect of a target mechanism would be merely an artefact of a specific piece of music, we included four pieces of music to represent each mechanism, and also conducted an aggregated analysis across pieces. For each mechanism, we tried to include pieces that would differ in various respects, apart from the specific features or information that was required for the target mechanism in question. For instance, the musical expectancy pieces had in common that they featured unpredictable tonal, harmonic, or rhythmic music sequences; however, they differed from each other in many other respects (e.g., tempo, mode, pitch, instrumentation).

We selected prominent pieces of music by eminent composers to be able to produce as intense emotions as possible. At the same time, we wanted to isolate the effects of individual mechanisms as much as possible, so that not mechanisms other than those targeted in a given condition would 'diffuse' the effect of the target mechanism. Most problematic in this regard are memories or personal associations with particular pieces that have been heard previously. To facilitate selective activation of the non-memory mechanisms, we featured pieces likely to be unfamiliar to the listeners. As correctly observed by Hargreaves (1986, p. 7; see also North & Hargreaves, 2008), classical music is a "minority interest" among music listeners – even in the Western world. Roughly 90% of the episodic memories obtained in the study by Janata et al. (2007) featured music that was familiar to the participant. In Baumgartner's (1992) survey, featuring college students, all pieces of music associated with an episodic memory except two involved pop/rock or folk music. Hence, we expected that using classical music would tend to minimize unwanted memory effects – as verified also by having listeners rate their familiarity with each piece and report whether the music evoked any memories. Conversely, the memory condition would feature pieces that *were* likely to be highly familiar to the listeners.

In sum, then, the aim of this study was to selectively manipulate four of the mechanisms believed to underlie emotions to music, through careful selection of existing and ecologically valid pieces of music, in order to explore whether listeners' responses would show predictable patterns. Four experiments were carried out, seeking to demonstrate similar effects despite the use of different pieces featuring partly different musical features. The decision to conduct four separate experiments (as opposed to a single experiment including four blocks) was due to the fact that the latter option would require a three-hour experiment, thereby increasing the risk of fatigue effects in listeners.

We used converging evidence from multiple measures, to draw more valid conclusions about evoked emotions than would be possible from a single index. Hence, in addition to self-reports of emotions, we obtained post-hoc self-reports with regard to mechanisms (*MecScale*), psychophysiological measures (skin conductance level and facial electromyography), and also used a 'control' condition in the form of a 'neutral' piece of music, to help rule out alternative explanations. The following predictions (similar across the experiments) were tested, grouped according to type of measure:

Emotion ratings: Listeners rated feelings on 15 scales (based on earlier studies of music and emotion). We predicted that the brain stem reflex condition would mainly evoke *surprise*; the contagion condition would mainly evoke *sadness*; the expectancy condition would mainly evoke *anxiety*; and the memory mechanism would mainly evoke *nostalgia* and *happiness* (for further description, see Method section). These predictions were mostly similar to those of the earlier study, which relied on computer-manipulations of a piece (Juslin et al., 2013).[5]

MecScale: This scale (Juslin et al., 2013) purported to capture the mechanisms that had occurred and consisted of eight simple questions, each targeting one of the mechanisms in the BRECVEM framework (Juslin et al., 2010), plus appraisal. The idea was that, although some of the mechanisms are implicit in nature, they may co-occur with subjective impressions that can be reported by listeners. For instance, a listener influenced by the expectancy mechanism might find the music difficult to predict, whereas a listener who becomes aroused through the episodic memory mechanism might report conscious recollections of the previous event. Self reports of this type cannot be taken as 'veridical', but they can complement other indices. The scale was predictive of target-mechanism conditions in the previous study (Juslin et al., 2013). Hence, we expected the *MecScale* items to be predictable of the target-mechanism conditions in the present study also.

Psychophysiology: Though psychophysiological reactions are not related to emotions in a one-to-one fashion (for a review, see Larsen et al., 2008), it appears feasible to link specific indices to broad dimensions of *arousal* and *valence*. Thus, based on the assumptions that skin conductance level is a reliable measure of autonomic arousal (Andreassi, 2007) and that brain stem reflexes would arouse *surprise* (an emotion with a high arousal level; Russell, 1980), we expected that the brain stem reflex condition would produce higher levels of skin conductance than would the contagion condition, which was expected to arouse *sadness* (an emotion with a lower arousal). Further, based on the assumptions that zygomaticus muscle activity in the face might reveal the valence of a response (e.g., Lang et al., 1993), and that the memory condition would arouse *happiness* and *nostalgia* (i.e., positive emotions), we predicted that the memory condition would produce more zygomatic muscle activity than would the contagion condition (*sadness* involves negative valence). Finally, based on the assumptions that corrugator muscle activity is reflective of negative emotions (Lang et al., 1993), and that the contagion condition would arouse *sadness*, we predicted that the contagion condition would show more corrugator activity than the memory condition.

Method

Participants

Sixty participants (29 males and 31 females, age 19-58 years, $M = 26.2$, $SD = 7.7$) took part in the study as a whole, and were either paid or given course credits for their anonymous and voluntary participation. Most participants were students, who were recruited by means of posters throughout Uppsala University. Sixty-three percent of the participants played (at least) one musical instrument, and fifty-five percent had received some music education. They were randomly distributed across the four experiments with the only provision that there must be an equal number of participants in each experiment: Experiment 1 featured 7 males and 8 females (age: 19-44 years, $M = 26.7$, $SD = 7.3$); Experiment 2 featured 7 males and 8 females (age: 20-36 years, $M = 25.0$, $SD = 4.0$); Experiment 3 featured 8 males and 7 females (age: 19-58 years, $M = 29.9$, $SD = 12.1$); and Experiment 4 featured 7 males and 8 females (age: 19-27 years, $M = 22.9$ ($SD = 2.2$).

Statistical tests (a one-way ANOVA, between-subjects, for the *age* variable; Cochran's non-parametric Q test for $k > 2$ experimental treatments, binary coded, in the cases of *gender*, *musical instrument*, and *music education*) revealed no significant difference between the four listener samples with regard to either gender, age, experience of playing a musical instrument, or music education.

Design

The design was similar across the four experiments. We used a within-subjects design including target mechanism as independent variable (5 levels: Brain stem reflex, Contagion, Episodic memory, Musical expectancy, and Neutral condition) and self-reported feeling (15 scales), mechanism impressions (*MecScale*), facial expression (zygomaticus and corrugator muscles), and autonomic activity (skin conductance level) as dependent variables. The only difference between the experiments was that distinct pieces of music were used to represent each target mechanism.

Musical Material

Sixteen pieces of music - four in each experiment - were selected for inclusion in the study on the basis that they featured information deemed relevant for the activation of each target mechanism. We used fairly short musical excerpts ($M = 72$ seconds) for two reasons:

First, we wanted the (retrospective) self-reports to be reflective of local events in the music, which prevented the use of longer excerpts. Second, emotions could change rapidly (see the working definition above), which means that use of longer excerpts might produce series of emotions, which would seriously complicate the statistical analyses. The pieces were edited with respect for musical form in order to preserve the integrity of the pieces. As a result, the excerpts were not exactly identical in length.

A detailed description of each excerpt in terms of frequently analyzed features (tempo, dynamics, tone attacks, spectrum, mode, pitch, tonal novelty), as estimated using the Music Information Retrieval (MIR) toolbox (Lartillot, Toiviainen, & Eerola, 2008), is provided in Appendix A. Included there are also reference levels, based on an extensive analysis of 482 pieces of classical music. Note the wide variability in features across pieces of music which represent the same target mechanism. Table 1 presents (overall) correlations between target mechanism conditions and musical features. Below, we list all pieces, grouped according to target mechanism.

Brain stem reflex.

The brain stem reflex mechanism is thought to be activated by extreme features such as high sound level, quick attack, and sharp timbre, which occur locally and cannot be predicted from the syntactical structure of the music. This mechanism was thus targeted by selecting the following pieces of music (mean length: 48.5 s):

EXP 1: Symphony No. 2 in D major, fourth movement (*Allegro con spirito*), composed by Johannes Brahms in 1877 (performed by Berliner Philharmoniker, conducted by Herbert von Karajan). After busy-sounding but quiet strings, a loud section breaks in suddenly in bar 23 with the full orchestra (length: 66 s).

EXP 2: Symphony No. 10, First movement (*Adagio*), composed by Gustav Mahler in 1910 (performed by Bournemouth Symphony Orchestra, conducted by Simon Rattle). The excerpt features the moment where the restatement of the theme culminates in a shattering dissonance, an organ-like chord (length: 60 s).

EXP 3: The Firebird, *Infernal Dance of all Kashchei's Subjects*, section of a ballet and orchestral concert work composed by Igor Stravinsky in 1910 (performed by the Berlin Radio Symphony Orchestra, conducted by Lorin Maazel). The excerpt begins with a loud drum and brass chord, which is repeated intermittently five times (length: 30 s).

EXP 4: Symphony No. 94 in G major, Second movement (*Andante*), written by Franz Joseph Haydn in 1971 (performed by Wiener Philharmonic Orchestra, conducted by Leonard Bernstein). A *forte* kettledrum stroke occurs at the end of the (*pianissimo*) repeat of the first section (length: 38 s).

Special care was taken to calibrate the sound level of the target events, but pre-testing indicated that the peak sound level did not quite have to reach the levels used in research on the acoustic startle response (Levenson, 2007) to produce a reliable effect on the listener. A peak sound level of 75 dBa was sufficient. For these excerpts, we expected listeners to react primarily with *surprise* and autonomic arousal to the sudden extreme events, consistent with an early reaction that occurs before any elaborate classification of the sound event has taken place (Simons, 1996). Figure 1 presents the amplitude wave form of each excerpt. Note that target events vary in terms of the location and the amplitude relative to the rest of the signal. The target events are reflected in the correlations featuring dynamics and spectrum (Table 1).

Contagion.

The contagion mechanism is thought to be activated by a particularly moving emotional expression in the music, and it is assumed that the effect is strengthened by a 'voice-like' lead part, either a real voice or an instrument reminiscent of the human voice. It has been proposed that the cello and the violin are the closest-sounding instruments to the human voice, in terms of register, tone attack, timbre and vibrato (for some empirical support, see Mores, 2009), and previous results indicate that performances with a sad expression are perceived as particularly ‘expressive’ (Juslin, 1997, Figure 3). This mechanism was targeted by selecting the following pieces, which include a sad expression and solo voices performed on the cello (excerpts 1 and 3) or the violin (excerpts 2 and 4) (mean length: 106 s):

EXP 1: *Prayer*, from Jewish Life No. 1, written by Ernest Bloch in 1924 (performed by Jay Bacal, using the Vienna Symphonic Library[6]). A lyrical and expressive piece, composed for cello and piano, marked as *andante moderato* and expressing an inward feeling of sadness. (length: 50 s).

EXP 2: Concerto for Two Violins in A minor, Op. 3 No. 8, II. *Larghetto e Spiritoso*, written by Antonio Vivaldi in 1711 (performed by Accademia Ziliniana, featuring František Figura). After a brief introduction, a solo line played with heavy vibrato on the violin begins and is soon joined by a second violin in a moving, vocal-like duet (length: 122 s).

EXP 3: *Vocalise*, Op. 34, No. 14, written by Sergei Rachmaninoff in 1912 (performed by Mischa Maisky and Lily Maisky). Originally written for voice (without lyrics) with piano accompaniment, this version was arranged for cello and piano. The (modal) e-minor tonality, the chromatic motion of the harmony, and the melody all suggest melancholy (length: 126 s).

EXP 4: *Heart’s Ease* (Three lyrics No. 1), written by Frank Bridge in 1921 (work 161a) (performed by Jay Bacal, with Vienna Symphonic Library). A short, slow, and contemplative piece, written for violin and piano, marked *andante tranquillo* and featured here in its entirety (length: 128 s).

For these excerpts, we expected a matching or ‘mimicry’ response in listeners. In other words, that they would show an ‘empathic’ reaction to the emotional expression of the music. Because the music featured a ‘sad’ expression, we expected it to arouse mainly *sadness* in the listeners. The ‘sad’ expression of the excerpts is reflected, for instance, in the minor mode, the slow tone attacks, and the subtle dynamics, as indicated by the correlations shown in Table 1.

Episodic memory.

The episodic memory mechanism is thought to be activated by salient melodic themes, which are associated with emotionally-charged events that the listener remembers. To evoke music-associated episodic memories, without having to encode them during this experiment, we selected four pieces likely to be highly familiar to the present listener sample due to their frequent occurrence in social events (e.g., ceremonies) in Sweden (mean length: 60 s):

EXP 1: Wedding March in C major, from Suite of Incidental Music (Op. 61) to William Shakespeare's play *A Midsummer Night's Dream*, written by Felix Mendelssohn-Bartholdy in 1842 (performed by Margareta Lindgren). This is the most commonly used wedding march in Sweden, typically performed on a church pipe organ (length: 56 s).

EXP 2: *Sommar, Sommar, Sommar*, written by Sten Carlberg in 1952 (performed by Åke Jelvings orkester). For over 50 years, this piece has been the signature song of a highly popular radio program in Sweden, *Sommar* (Eng. *summer*), which is broadcast daily during the summer months (length: 39 s).

EXP 3: *Den Blomstertid Nu Kommer*, written by Israel Kolmodin in 1894 (performed by Adolf Fredriks Bachkör). This is one of the most well-known psalms in Sweden, which is typically sung in every graduation (length: 81 s).

EXP 4: *Studentsången*, written by Herman Sätherberg (lyrics) and Prins Gustaf (music) in 1852 (performed by Capella Cantica). This piece, marked 'marsch', is often sung by choirs at joyous events that celebrate graduation in the late spring (length: 64 s).

As will be clear later (Results section), the episodic memory pieces were significantly more familiar to the listeners and evoked significantly more episodic memories, than did the other mechanism pieces, which confirms that this manipulation was effective. The emotions aroused by this mechanism are theorized to reflect the emotional tone of the memory evoked. The excerpts selected were thought to be associated with both nostalgic and happy memories of fun, holidays, relaxation, spring/summer, festivities, and graduations. For these excerpts, we expected listeners to respond mainly with *nostalgia* and *happiness*, due to the memories evoked by the familiar music.

Musical expectancy.

The musical expectancy mechanism is believed to be activated by unexpected melodic, harmonic, or rhythmic sequences (Huron, 2006; Meyer, 1956). Thus, in order to activate this mechanism, and more specifically to ‘confound’ listeners’ musical expectations, we selected the following pieces of music (mean length: 75 s):

EXP 1: The Symphony of Psalms, II. *Expectans Expectavi Dominum*, composed by Igor Stravinsky in 1930 (performed by the Russian State Academy Orchestra and Choir, conducted by Igor Markevitch). This excerpt, from Stravinsky’s ‘neoclassical’ period, consists of a fugue theme that begins with a four-note cell in the oboe in measure one (length: 84 s).

EXP 2: Lyric Suite, Three Pieces for String Orchestra, Part III: *Adagio Appassionato*, written by Alban Berg in 1926 (performed by Wiener Philharmoniker, conducted by Claudio Abbado). The excerpt follows (but does not strictly adhere to) Arnold Schoenberg’s ‘twelve-tone practice’, which abandons harmonically conceived tonality (length: 70 s).

EXP 3: Three pieces for Orchestra, Op. 6, *Praeludium*, written by Alban Berg in 1915 (performed by Steffen Fahl, with Vienna Symphonic Library). An ‘impressionistic’ prelude, which begins in vagueness with unpitched percussion sounds. When the kettledrums enter in the third measure, indeterminate pitch is replaced by uncertain pitch (length: 60 s).

EXP 4: Rite of Spring, Part 1: *Les Augures Printaniers,* written by Igor Stravinsky in 1913 (performed by Berliner Philharmoniker, conducted by Herbert von Karajan). An avant-garde piece characterized by a repetitive stamping chord in the horns and strings, based on E-flat superimposed on an triad of E, G-sharp, and B. The rhythm is ‘disturbed’ by the constant shifting of the accent, on and off the beat (length: 86 s).

Acoustic analyses confirmed that these excerpts showed higher degrees of tonal novelty (see Table 1) than the pieces included in the other conditions. For these excerpts, we expected listeners to respond mainly with *anxiety* to the unresolved uncertainty created by the syntactic sequences of the musical structure (Meyer, 1956, p. 27).

In addition to the above pieces, we selected an unknown piece that served as a ‘neutral’ condition. The piece, titled ‘minimalist music’, was composed by the alias *Mihangeliago* and downloaded from the Internet. It was was selected on the basis that it did not feature any type of information deemed necessary to arouse an emotion through one of the mechanisms in the BRECVEMA framework. Pilot tests confirmed that the piece was ‘emotionally incompetent’. Its musical characteristics are shown in Appendix A. (The ‘neutral’ piece occurred in all four experiments (length: 59 s), whereas the other pieces were unique to each experiment.)

Experiential Measures

We measured the subjective feeling component of the aroused emotions in listeners by means of a 15-item adjective scale, which was developed at Uppsala University specifically for the measurement of emotions to music (see Appendix B). The scale represents a kind of compromise among the response formats currently used in the music-emotion field (Zentner & Eerola, 2010) since the selected terms includes ‘basic’ emotions characteristic of discrete emotion theories (Izard, 1977), covers all four quadrants of a Circumplex model in terms of valence and arousal (Russell, 1980), and features possibly more music-related terms such as *nostalgia*, *expectancy*, and *awe* (Juslin & Laukka, 2004). (The selected terms roughly cover the nine factors of GEMS-9, proposed by Zentner, Grandjean, and Scherer (2008), but since there exists no validated version of GEMS-9 in Swedish, and the scale lacks terms that were needed in this study (e.g., *surprise*), we decided to use a customized scale.) The list features the emotions most commonly reported in previous studies (Juslin & Laukka, 2004; Juslin et al., 2011; Wells & Hakanen, 1991; Zentner et al., 2008). In addition to 12 discrete emotions, listeners also rated *liking* and *familiarity* for each version, and whether they experienced any ‘chills’ (defined as *piloerection*; *gåshud* in Swedish everyday terminology). All ratings were made on a scale from 0 (*not at all*) to 4 (*a lot*) – except for ‘chills’, which were reported in a dichotomous fashion.

In addition to reporting their feelings, the participants also filled out a second response scale (*MecScale*) for each musical excerpt (see Appendix C). This scale purported to capture the mechanisms that had occurred and consisted of eight simple questions, each targeting one of the mechanisms in the BRECVEM framework (Juslin et al., 2010) plus appraisal: (1) Brain stem reflex, (2) Rhythmic entrainment, (3) Episodic memory, (4) Evaluative conditioning, (5) Visual imagery, (6) Contagion, (7) Musical expectancy, and (8) Cognitive appraisal. All items were rated on a scale from 0 (*not at all*) to 4 (*a lot*). A follow-up item in *MecScale* (not shown in Appendix C), which only appeared on the computer screen if a stimulus happened to evoke a memory, asked whether the memory was mainly positive, mainly negative, or a combination of both. This item was featured to enable us to check whether the valence of evoked memories was consistent with the valence of the emotions reported in the memory conditions.

Psychophysiology: Facial Expression and Autonomic Activity

To enhance the validity of the measurement of emotion, we also measured physiological indices. The goal was to obtain evidence of an emotional response, in order to distinguish *felt* emotions from mere *perception* of emotions. In the former case, we would expect to discover some *changes* in physiological indices (as part of an emotional reaction), whereas in the latter case there would be no reason to expect such changes. Moreover, we aimed to test predictions with regard to specific contrasts between conditions, as explained in the Introduction.

Psychophysiological indices were obtained using the BIOPAC MP 150 System (Biopac Systems, Santa Barbara, CA) and the AcqKnowledge version 4.1 software. *Skin conductance level* (SCL) was measured using the GSR100C Electrodermal Activity Amplifier module and

EL507 disposable snap electrodes that were placed on the palmar surface of the non-dominant hand, at the thenar and the hypothenar eminences (Fowles et al., 1981). Skin conductance was recorded in microSiemens (μmho).

Bipolar *facial electromyography* (EMG) recordings were made from the left corrugator and zygomatic muscle regions in accordance with Fridlund and Cacioppo's (1986) guidelines. Before attaching the 4 mm miniature surface Ag/AgCl electrodes, filled with EMG gel (GEL 100, Biopac Systems), we cleansed the participant's skin to reduce interelectrode impedance. All impedance was reduced to less than 10 kΩ (Fridlund & Cacioppo, 1986). The electrodes were connected to the EMG100C amplifier module with low- and high-pass filters set at 500 Hz and 10 Hz, respectively, and notch filters set at 50 Hz were used to diminish interference with the electric mains. The sampling rate was set at 2.000 Hz. Facial EMG was measured in microvolts (μV) and analyzed using the root mean square (RMS). The 'raw' EMG data were filtered, using an FIR filter between 28 and 250 Hz, in order to increase signal-to-noise ratio (Fridlund & Cacioppo, 1986).

Mean values for SCL and EMG (zygomaticus and corrugator muscles) were calculated for baseline and experimental conditions. (The baseline recordings were obtained prior to the listening test during relaxation under silent conditions.) During the listening test, there was a break between musical excerpts to allow levels to return to baseline before the next stimulus.

Procedure

When participants arrived at the laboratory, they were seated in a comfortable armchair and received the following instructions (translated from Swedish), which were the same in all four experiments:

"Welcome to the music laboratory. You will soon listen to a selection of short pieces of music. After each piece we want you to describe your experience of the music. This should be done in two ways: first we want you to describe your feelings during the music on a computer screen. The screen consists of twelve emotions. *Your task is to rate how much of each emotion you felt on a scale from 0 ('not at all') to 4 ('a lot').* You also report whether you experienced 'chills', as well as how much you *liked* the music and how *familiar* you were with it. Then we want you to attend to a second screen, which features eight questions concerning other aspects of your music experience. You will also be fitted with some electrodes so that we can conduct physiological measurements. These electrodes are completely harmless and do not emit strong radiation or electricity. However, in order to obtain as accurate measurements as possible, it is important that you don't touch any of the electrodes during the experiment. Watches and rings have to be removed and your cell phone must be switched off. First, you will be asked to relax for a while during silence. Then, the actual listening test begins. When the playback of a piece of music ends, there will be a brief intermission before the next piece begins, to give you time to fill out the two response sheets. Then, you will relax again for a while before the next piece begins. Note that any emotion you may experience during listening need not correspond to the music's emotional expression. That is, you should rate your *own* emotions, not what the music expresses. After the experiment you will be asked to respond to a set of background questions. Don't hesitate to ask the experimenter, if you have any questions."

Participants were tested individually in a soundproofed room, and listened to the music through a pair of high-quality loudspeakers (*Dali Ikon 6 MK2*). Stimulus administration and data collection was handled using the *MediaLab*© software. The sound level was pre-set to a comfortable level[7], which was held constant across listeners. Stimulus order was randomized for each participant, whereas the order of rating scales was kept constant across participants. After the listening test, the participants filled out a short questionnaire with regard to various background variables (e.g., age, gender, music education). The participants were not fully de-briefed about the purpose of the experiment until all had been tested, to prevent confounding effects (Neale & Liebert, 1986). An experimental session lasted about 50 minutes.

Results

To give a more concise presentation, we report the data from the four experiments in a joint section. First, we present separate analyses for every measure in each experiment, then we report combined analyses, which capture broader trends across the experiments.

Separate Analyses: Experiments 1-4

Emotion ratings.

The most important data concern the listeners' ratings of felt emotions on the 15 rating scales. To evaluate the effect of target mechanism on listeners' self-reports, we conducted an Analysis of Variance (ANOVA) with *mechanism* as within-subjects factor (5 levels) on each scale. We used an experiment-wise Bonferroni adjustment for multiple tests (n = 15), from $\alpha = .05$ to $\alpha = .0033$. Tables 2-5 present the results for Experiments 1-4, respectively. As can be seen, the five scales involved in our predictions (i.e., *happiness-elation*, *sadness-melancholy*, *surprise-astonishment*, *nostalgia-longing*, *anxiety-nervousness*) showed significant effects in all instances except one (95%, n = 20): *anxiety-nervousness* in Experiment 1. The right-most column of Tables 2-5 shows effect sizes, in terms of eta-squared. As can be seen, effect sizes for the predicted emotions ranged from 'moderate' ($\eta^2 \geq .25$) to 'strong' ($\eta^2 \geq .64$) according to Ferguson's (2009) guidelines for interpretation. Similarly, the non-discrete scales *emotion intensity*, *liking*, and *familiarity* showed significant effects of *mechanism* with one exception: *intensity* fell short of significance in Experiment 3 (Table 4). Note further the large effects of target mechanism on the *familiarity* scale (mean eta-squared across experiments = .817).

Further inspection of Tables 2-5 reveals that some additional emotion scales featured in the self-report instrument (see Appendix B) showed significant effects in the ANOVAs. Note however, that the effects of these seven scales were smaller overall (mean eta-squared, across scales and experiments = .272), than those for the five scales of the predicted emotions (.460). The effects were also inconsistent. Thus, for instance, *interest-expectancy* and *anger-irritation* showed no significant effects, and *disgust-contempt* and *admiration-awe* showed a significant effect in some experiments, albeit not in others. The only recurring tendencies were that *calm-contentment* and *love-tenderness* were (mostly) significant across experiments. Ratings on the former scale were inversely correlated with ratings of *anxiety-nervousness* (r = -.52), whereas ratings on the latter scale were correlated with ratings of *nostalgia-longing* (r = .60) and *liking* (r = .59), respectively (r computed across experiments, N = 60, all ps < .05).

Due to the generally smaller and more inconsistent effects of the additional scales, and in order to give a more concise presentation of the data, we will henceforth focus on the five emotion scales involved in our theoretical predictions. Recall that the predictions concerned which emotions the four target-mechanism conditions would evoke in listeners, for instance that the Brain stem reflex condition would evoke predominately *surprise* in listeners. To test this, we conducted planned comparisons (t tests) between the (predicted) target mechanism and the other four conditions (the three mechanisms and the 'neutral' condition), to explore whether the predicted mechanism received the highest mean rating. Table 6 summarizes the results. Careful inspection of Table 6 shows that in 67 of the 80 contrasts (84% of the cases) the results were in line with our predictions; that is, the rating on the scale was significantly higher for the predicted mechanism, than for the other condition. In the remaining cases, the rating for the predicted mechanism was either still the highest, although not significantly so (10 cases), or the second-highest of the conditions (3 cases). Descriptive statistics and more elaboration are provided in the combined analysis below.

The self-report data regarding 'chills' (piloerection) were analyzed separately due to the dichotomous nature of the data. To evaluate the effects of target mechanism on the proportion of 'chills' reported, we used Cochran's Q test which is a non-parametric test for three or more matched sets of frequencies or proportions where data are dichotomous (Conover, 1999). After Bonferroni-adjustment (α = .0033, mentioned above), the effect of target mechanism condition was not significant in any of the four experiments (Qs = 3.00-14.13, all ps > .007). The overall trend was that most 'chills' occurred in the Brain stem reflex (27%) condition, followed by the Contagion (20%), Memory (12%), Expectancy (10%), and Neutral (2%) conditions. However, given that 'chills' occurred rarely overall (M = 14%), and did not reliably discriminate among the experimental conditions, these data are not discussed further.

MecScale.

The listeners also responded to eight items, which targeted specific mechanisms (see Appendix C). To evaluate the effects of target-mechanism condition on listeners' ratings of these items, we conducted an ANOVA with *mechanism* as within-subjects factor (5 levels) for each item. We used an experiment-wise Bonferroni adjustment for multiple tests (n = 8), from α = .05 to α = .0064. The results showed significant effects of *mechanism* for all items in all four experiments (values of $F_{4, 56}$ = 5.11-59.51, all ps < .0064), except *visual imagery* (significant in Experiments 2-4) and *cognitive appraisal* (significant only in Experiment 1). Further results concerning *MecScale*, including the directions of the effects, are provided in the combined analysis.

Psychophysiology.

To evaluate the manipulation of target mechanism on psychophysiology, we conducted an ANOVA with *mechanism* as within-subjects factor (6 levels: baseline, neutral, brain stem reflex, contagion, musical expectancy, episodic memory) on each physiological measure. All data were z-transformed prior to analyses to reduce the impact of differences in baseline. The results for Experiments 1-4 are presented in Table 7. Note that *mechanism* yielded significant effects on all measures in all experiments, except skin conductance level in Experiment 2 and corrugator muscle activity in Experiment 3. Inspection of the right-most column suggests that these effects were 'small' to 'moderate' in size (Ferguson, 2009). To test our predictions with respect to specific contrasts between the target-mechanism conditions for these measures (see

Introduction), we conducted planned comparisons (*t* tests). Table 8 presents the results. It can be seen that only 58% of the predictions received support, with better results for zygomaticus (75%) and corrugator (75%) activity predictions than for skin conductance predictions (25%). Only in two of the contrasts, however, was the direction of the observed effect contrary to the prediction. Descriptive statistics are provided in the combined analysis.

Combined Analyses: Experiments 1-4

Since there were no significant differences between the four experimental groups with respect to age, gender, experience of playing an instrument, or music education (see Method section), and because there were no significant difference between the groups with regard to how they rated the common musical stimulus (‘neutral’ piece) on any of the 15 rating scales (as indicated by one-way ANOVAs, between-groups, $F_{3,56} = 0.083\text{-}1.995$, *p*s = .13-.97), we felt it was justified to treat the participants as ‘matched’ subjects and to combine data across experiments for exploratory purposes.

Emotion ratings.

Table 9 shows correlations between emotion ratings and target-mechanism conditions across experiments 1-4. These correlations confirm that the results were mostly in line with the predictions, but also highlight the problem with regard to a clear separation of emotions. Most importantly, it can be seen that, contrary to our predictions, the Contagion mechanism aroused *nostalgia-longing*, and the Expectancy mechanism aroused *sadness-melancholy*. In both cases, however, the correlation for the predicted emotion was significantly larger, than the one for the non-predicted emotion ($p < .05$). It can further be observed that the ‘neutral’ piece was *negatively* correlated with all emotions. Presented in the lower section of Table 9 are also the results for *intensity*, *liking*, and *familiarity*. The former confirm that the ‘neutral’ piece yielded a lower emotional intensity than the mechanism conditions, which on average aroused a relatively intense emotional response ($M = 2.66$). The Brain stem reflex conditions produced the most intense reactions. With regard to *liking*, it can be seen that the Contagion pieces were best liked overall (i.e., despite the fact they tended to evoke *sadness* in listeners) and the Expectancy pieces were least liked overall, except for the 'neutral' piece. Finally, the correlations for *familiarity* confirm that only the music in the Memory conditions was highly familiar to the listeners.

MecScale.

Table 10 shows correlations between *MecScale* items and target-mechanism conditions across Experiments 1-4. Of particular interest are those correlations that are both statistically significant and positive in direction. The results are mainly as could be expected, if the items have predictive value regarding mechanisms: the Brain stem reflex condition correlated most strongly with the Brain stem item; the Contagion condition correlated most strongly with the Contagion item; the Expectancy item correlated most strongly with the Expectancy item; and the Memory condition correlated most strongly with the Memory item. Note that the Neutral condition was negatively correlated with all items, suggesting that this piece did *not* activate any of the mechanisms.

However, Table 10 also shows some further correlations, in addition to those related to the target mechanism. Note in particular that the Memory conditions yielded a larger number of significant correlations, than the other condition types. The Memory conditions correlated not only with the Episodic memory item, but also with the Entrainment, Conditioning, Visual imagery, and Appraisal items, though the correlations of these were significantly smaller than the correlation of the Episodic memory item ($p < .05$), with the exception of the Conditioning item ($p = .07$). The follow-up item to the Episodic memory item (see Method section) showed that 76% of the memories were positive in nature, 0% were negative in nature, and 24% were a mixture of both positive and negative. Notably, these results are consistent with the positive (*happiness*) or 'bitter-sweet' (*nostalgia*) emotions reported in the Memory conditions.

To test the predictive power of the listeners' *MecScale* ratings, we conducted a multiple discriminant analysis. This analysis focused on predicting the target-mechanism condition (4 levels: Brain stem reflex, Contagion, Memory, Expectancy) based on the listeners' ratings of the eight *MecScale* items. Benefiting from the combined analysis across all four experiments featuring 240 cases, we were able to obtain a ratio of 30 observations for each predictor, and 60 observations in each category (a ratio of at least 20 observations for each predictor and 20 observations in each category is recommended; Hair, Andersen, Tatham, & Black, 1998). The predictors were entered into the analysis using a simultaneous estimation and assuming equal probabilities of occurrence (.25). With four categories, we could estimate three discriminative functions: Function 1, canonical $R = .83$, Wilks' Lambda = .16, $\chi^2 = 433.78$, $p < .001$; Function 2, canonical $R = .62$, Wilks' Lambda = .50, $\chi^2 = 163.12$, $p < .001$; and Function 3, canonical $R = .44$, Wilks' Lambda = .80, $\chi^2 = 51.24$, $p < .001$).

Tables 11 and 12 present the results, in terms of a classification matrix and a summary concerning the importance of different predictors, respectively. The four conditions could be predicted with an overall hit ratio of 75% correct – compared to a hit ratio of 25% that would be expected by chance alone. As can be seen in Table 11, classification accuracy ranged from 57% to 94%, depending on the mechanism, with the best result for Memory and the worst for Expectancy.

There are no generally accepted guidelines for how to interpret classification accuracy relative to chance, but Hair et al. (1998) argue that the accuracy should be at least one-fourth greater than that achieved by chance (6.3% in this case), and the currently observed increase in accuracy relative to chance is approximately 12 times greater than this criterion. It should be noted, however, that in the absence of a cross-validation procedure due to a small sample, the estimate is likely to be positively biased to some extent.

Table 12 offers further results from the multiple discriminant analysis, with a focus on the individual predictors (the eight *MecScale* items). As can be seen, all items except Visual imagery and Cognitive appraisal yielded significant values of partial Wilks' Lambda, which shows that they made unique contributions to the discrimination. However, inspection of the table also reveals that some items made a larger contribution to predictive power than others. Specifically, most variance was explained by the Brain stem reflex, Musical expectancy, and Contagion items, in that order.

Psychophysiology.

Figure 2 presents means and standard errors (z scores) for listeners' skin conductance level, zygomaticus activity and corrugator activity as a function of target mechanism, across Experiments 1-4. With regard to skin conductance level, it can be seen that the experimental conditions were clearly separated from baseline, but that they were not clearly differentiated amongst themselves. However, the Brain stem reflex and Memory conditions tended to show higher levels of skin conductance, than did the Contagion and Expectancy conditions. Facial EMG suggested a clearer differentiation between the conditions. In particular, the Contagion and Expectancy conditions showed lower levels of zygomaticus activity and higher levels of corrugator activity, than did the Brain stem reflex and Memory conditions. Further, note that the Contagion conditions showed lower levels of zygomaticus activity than Baseline and that the Memory conditions showed lower levels of corrugator activity than Baseline.

Discussion

In this study, we aimed to selectively manipulate four mechanisms believed to underlie emotions to music, through a careful selection of existing pieces of music, to see if we would be able to demonstrate predictable effects on listeners' emotional responses. The results from our four experiments can be summarized as follows:

First, we conclude that the target mechanisms aroused emotions in listeners largely in accordance with our theoretical predictions: the listeners' self reports revealed that the Brain stem reflex conditions aroused the most *surprise*; the Contagion conditions aroused the most *sadness*; the Episodic memory conditions aroused the most *nostalgia* and *happiness*; and the Musical expectancy conditions aroused the most *anxiety*. Although the effects varied slightly between the experiments, planned comparisons showed that the ratings were in line with our theoretical predictions in 84% of the contrasts (i.e., the mean rating was significantly higher for the predicted mechanism, than for the other condition). In the remaining cases, the rating for the predicted mechanism was either still the highest, although not significantly so (12%), or the second-highest of the conditions (4%). It should further be noted that the effects of the experimental manipulation on the (predicted) emotions were 'moderate' to 'large' (Ferguson, 2009), and that rated overall intensity was relatively high ($M = 2.66$, on a scale from 0 to 4).

Secondly, the above results were supported by psychophysiology in terms of autonomic activity and facial expression. Measures of skin conductance and zygomaticus and corrugator activity were significantly influenced by target mechanism condition in the majority (83%) of cases. These data are important for at least two reasons: They serve to validate the conclusion that the listeners actually *experienced* emotions rather than merely perceiving emotions in the music, and they display patterns consistent with the emotion ratings. Although these findings were not as clear-cut as we had hoped, it could be seen that the conditions that were predicted to evoke negative emotions (i.e., contagion → *sadness*, expectancy → *anxiety*) produced more corrugator muscle activity and less zygomaticus muscle activity, than the conditions that were predicted to evoke a neutral (brain stem reflex → *surprise*) or positive (memory → *happiness*, *nostalgia*) emotion, as expected from their relative position in the *Circumplex model* (Russell, 1980). The data for skin conductance did not distinguish among target-mechanism conditions quite as clearly. All experimental conditions tended to produce higher autonomic activity than baseline, but expected contrasts between specific emotions (e.g., *surprise* ← → *sadness*) were generally not significant. Note, however, that when data from the experiments were collapsed (Figure 2), data suggested that typically high-arousal emotions such as *surprise* and *happiness* *did* produce higher levels of skin conductance than did typically low-arousal emotions such as *sadness*. These findings are clearly worthy of further investigation, ideally using a design with better statistical power, since many of the effects appear to be subtle.

Thirdly, the results regarding emotion ratings and psychophysiology were extended by the data for *MecScale*; that is, the eight self-report items focusing on subjective impressions (e.g., Did the music evoke a memory of an event from your life? Were you 'touched' by the emotional expression of the music?). Results indicated that the items were reliably related to the corresponding target mechanism. A multiple discriminant analysis showed that the items could predict the target-mechanism condition with an overall classification accuracy of 75%. Thus, even though self-reports regarding causes of emotions cannot be treated as 'veridical', the reports are not completely arbitrary either. If music listeners are given targeted questions, their responses can provide indices, which complement other forms of evidence. As could be expected, the classification based on *MecScale* worked somewhat better for mechanisms that by definition are 'explicit' in nature (e.g., episodic memories) than for mechanisms that have been conceptualized as more 'implicit' in nature (e.g., musical expectancy; see Juslin, 2013). This should be taken into account when using self-reports to explore underlying mechanisms in future field studies.

Problems and Future Directions

This is the first study to contrast mechanisms using only existing pieces of music, and the present results can be compared with those of our previous study, which used computer-manipulated versions of a piece (Juslin et al., 2013). This study corroborates the findings in that study, by showing that (reasonably) predictable response patterns may be obtained also with existing pieces of music. However, it is also clear that the evoked emotions were not as neatly differentiated here as in the previous study. This might be symptomatic of the greater difficulty in clearly separating different mechanisms when using real pieces of music, which typically feature several different kinds of emotionally relevant information. One promising approach to better separate the effects of distinct mechanisms when using ecologically valid music may be to combine real compositions with *resynthesis* (Juslin & Madison, 1999), for instance by digitally editing specific features to reduce or enhance the effects of a particular mechanism.

Not all results were less clear in the present study, however. In the previous study, the musical expectancy version did not arouse *anxiety* to the extent we had predicted, but in the present investigation, which featured real compositions by highly accomplished composers, the induction of *anxiety* was far more successful. Even so, musical expectancy is one of the mechanisms that need closer attention in future work. Though it is often claimed that this is one of the most powerful mechanisms (e.g., Thompson, 2009), effects in studies so far have generally been modest compared to those of other mechanisms. It is possible that the use of an unfamiliar musical genre reduced the amount of stylistic expectancies that listeners could bring to listening situation, thereby reducing the effect of the expectancy manipulation.

Although the present manipulation of mechanisms did arouse the predicted emotions, it is apparent that some other emotions were also aroused to some extent, albeit in weaker form. In most cases, these effects were consistent with the predicted emotions, for instance in terms of valence. For example, it is not surprising that the manipulations yielded significant effects on *calm-contentment*, given that the ratings of this emotion were (negatively) correlated with *anxiety-nervousness* – one of our predicted emotions. Other tendencies were more intriguing. The Contagion conditions, in particular, aroused *nostalgia-longing*, which is more commonly associated with episodic memories linked to music (cf. Janata et al., 2007; Juslin et al., 2008).

This finding appears quite puzzling, considering that the music was unfamiliar to the listeners and that they thus presumably did not have specific memories associated with the music. One possible explanation could be that the *nostalgia* was a by-effect of the music-evoked *sadness*, rather than an effect of the music. It has been reported previously that one common trigger of *nostalgia* is negative affect such as *sadness* (Wildschut, Sedikides, Arndt, & Routledge, 2006), and these emotions have been hard to disentangle in previous studies (Vuoskoski et al., 2012). Thus, Juslin et al. (2013) speculate that, once the listener becomes *sad* through contagion, this emotion may evoke *nostalgia-longing* also. This notion could perhaps be tested by using even shorter musical excerpts, or by adopting a continuous-response technique (Schubert, 1999).

It could seem odd that the Memory conditions (which evoked mainly positive emotions) received lower ratings of liking than the Contagion conditions (which evoked mainly negative emotions). However, this finding may arguably reflect that the two processes - preference and emotion - are partly independent. Thus, the listeners experienced positive emotions as a result of the memories evoked, even though they did not particularly like the *music*. Conversely, the pieces featured in the Contagion conditions were liked to a greater extent, despite the fact that they aroused a great deal of sadness.

The most uniform results across the present experiments occurred for the Brain stem reflex mechanism. This is what we would expect, based on the ‘BRECVEMA framework’ (Juslin, 2013), which holds that this mechanism is mainly ‘hard-wired’ and subject to little effect of individual experience. Conversely, we would expect larger variability and effects of personal experience with regard to the Memory condition, which is also what we found. *MecScale* data indicated that the Memory condition ‘scattered’ its effects to a larger extent than the other three conditions, evoking not only episodic memories, but also more general associations and images. It is not surprising that the Memory condition correlated with the visual imagery item since episodic memories frequently involve imagery. Had the reported imagery not been due to episodic memories, we would have expected to find much greater incidence of imagery in the other mechanism conditions that did *not* evoke memories. The correlation with cognitive appraisal may seem surprising, but makes sense since memories often involve memories of the appraisal to the original event (Ellsworth, 1994). Again, had the reported appraisals not been tied to episodic memories, we would have expected to find greater incidence of appraisals in the other conditions also. Of the episodic memories, 25% were described as both positive and negative in valence. This may be related to the fact that *nostalgia* is commonly regarded as a 'bitter-sweet', mixed emotion (Wildschut et al., 2006). In any case, further research is needed to clarify the nature of memory-induced emotions to music in various contexts.

Limitations of the Present Study

One limitation of this study is that the listener sample was relatively small and featured listeners from only a single Western culture. There is an urgent need for cross-cultural studies adopting a psychological perspective which explore the role of various mechanisms in diverse cultures. How may psychological mechanisms manifest themselves in diverse cultures? Juslin (2012) argues that an account of the induction of emotions can be cross-culturally valid at the level of mechanisms, despite cross-cultural diversity in musical 'surface features' and evoked emotions. (Although music that arouses *nostalgia* in listeners in one culture may *sound* rather distinct from music that arouses *nostalgia* in listeners in another culture, this does not rule out that the emotion was aroused for the same reasons in both cases.) However, it seems plausible that different mechanisms are important in different cultures depending on both the music and the functions of the music (e.g., Saarikallio, 2012). Thus, for instance, we could speculate that the rhythmic entrainment mechanism is particularly important for the arousal of emotions that occurs through *Samba* music heard in carnivals, street parades, and outdoor dancing in Brazil, whereas the episodic memory and contagion mechanisms are more important for the nostalgic and vocally expressive *Fado* music played in small *Fado* clubs in Portugal. The prevalence of specific mechanisms and its relationship to the functions of the music in various cultures need further investigation.

In real-world settings, musical emotions occur in a complex interplay between the *music*, the *listener* and the *situation*. It should be noted that several important moderators (e.g., in the context) were held constant in this investigation. Prediction of musical emotions will be more complex if contextual variables are taken into consideration. It is promising in this regard that contextual variables also seem to involve systematic relationships with experienced emotions (for an attempt to predict emotions based on contextual variables, see Juslin et al., 2011). One might perhaps design field experiments that, to some degree at least, include both mechanism manipulations and contextual variables that are brought into the analysis. The important point is that there are no 'pure' effects of music that will invariably occur, regardless of the specific listener or situation. The reaction will depend on the listener's music preferences and previous experiences, as well as on the circumstances of the context (e.g., current activity, other people present, functions of the music, the physical environment). Note, however, that the underlying mechanism is key, as it serves as the 'mediator' of all these influences.

The Primary Role of Mechanisms

Closer focus on underlying mechanisms is important for empirical studies of music and health (for a review, see MacDonald, Kreutz, & Mitchell, 2012). Most studies have sought to obtain 'direct' links between music and physiological response. Implicit in this approach are the assumptions - not borne out by empirical research - that (a) every listener will respond in the same way to the music, (b) the listener's response depends solely on musical features, (c) there is only one 'causal route' from music to response, and (d) the emotions experienced are not relevant in explaining the physiological response.

In fact, it seems plausible that music can affect health through the emotions it evokes in listeners. Experimental, observational, and animal studies suggest that emotions are related to physical health (e.g., Kubzansky, 2009), not only with respect to the subjective well-being of the individual, but also with respect to bodily responses, which may influence physical health (e.g., changes in dopamine, serotonin, cortisol, endorphin and oxytocin levels; van Eck et al., 1996; Fibinger et al., 1984). However, there are individual differences in response, which are due to the fact that emotions may be aroused in different ways. Juslin (2011) has thus argued that only an understanding of underlying mechanisms will enable the practitioner to apply the music in a manner that actively manipulates specific mechanisms so as to achieve predictable effects on emotions, health, and well-being. What matters is not musical features as such, but what meaning they are given by psychological mechanisms: a distinction between *sound* and *significance*.

An important question is what determines which mechanism (if any) is 'activated' by a particular musical event. This depends, in fact, on several factors. Some information could be provided by the *music* (e.g., extreme sound events, emotional expressions), other information might derive from the *context* (e.g., an aesthetic framing), or the *listener* (e.g., that a piece has frequently occurred in a particular context in the person's life). But most reflect a *combination* of these factors (e.g., music-listener: a tone sequence that's very unexpected for one particular listener, but not necessarily for another listener, depending on the notes themselves, as well as the listeners' previous experiences). A musical event may 'afford' (Gibson, 1979) a particular emotional response, by featuring information relevant to a particular mechanism - but whether this information will activate the mechanism depends on the listener's attention, which in turn may depend on the context (focused listening or background music?), and on what other types of (potentially competing) information occurs at the same time. It remains to be explored what types of information have priority and why. For instance, will a melodic theme associated with a certain emotion for a listener be overridden by a perceptually more salient drumstroke which happens to occur at the same time?

Consistent with the above, we may assume that if a given musical event *fails* to include information relevant for the activation of any mechanism, then consequently no emotion will be aroused - which does seem to be common (see, e.g., Juslin et al., 2008). In other words, if the music does *not* include extreme sound events (brain stem reflex), a quite pronounced and catchy rhythm (entrainment), a passionate and voice-like expression (contagion), a structural feature that invites metaphorical analogies to external events (visual imagery), an unexpected tonal, harmonic, or rhythmic sequence (musical expectancy), an aesthetic quality such as vast beauty (aesthetic judgment), or has been linked with emotionally-laden life events (evaluative conditioning, episodic memory), or - less plausibly - have crucial implications for one's goals in life (appraisal), then chances are slim that the music will evoke an emotion. Precisely these circumstances applied to the 'neutral' piece used in this study, which apparently succeeded in avoiding to activate any of the mechanisms. To a very modest extent, at least, we were able to 'switch on' mechanisms at will, in order to arouse predicted emotions in listeners.

Concluding Remarks

Several years ago, Gutheil (1952) noted that "emotional reactions which music may arouse are as numerous as the individuals reacting" and that "the subjectivity of emotional experiences...is the core of our problem" (p. 15). Empirical studies of specific mechanisms are still in their infancy. However, even though emotions to music continue to defy simple conclusions, the results of the present study are sufficiently encouraging to suggest that the multiple-mechanism approach is a promising avenue toward understanding the mystery of emotional reactions to music.

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Footnotes

[1] The *Experience Sampling Method* means that the participants are provided with small palmtop computers that they carry with them at all waking hours during a week or so. During the week, the palmtop emits sound signals at certain predetermined or random intervals. Each time the participant hears the signal, he or she should respond to some questions administered by the palmtop about his or her latest experience.

[2] Of course, music is often *used* to achieve various goals (e.g., relaxation). To avoid confusion, we emphasize that there is a distinction between using music to achieve a goal (e.g., to get distracted) and a goal being involved in the actual emotion induction (i.e., the exact process that aroused the emotional reaction). The focus here is on the latter process, because the former process is irrelevant to a model of how music *per se* arouses emotions.

[3] The acronym BRECVEMA derives from the first letter of each of the mechanisms (listed below).

[4] The mechanisms described here do not address the lyrics of music. However, data from survey and ESM studies suggest that lyrics are rarely the cause of emotions to music (Juslin et al., 2008, 2011).

[5] The only difference is that, because the present stimuli used to activate the Musical expectancy mechanism are less extreme than the manipulated stimuli in Juslin et al (2013), we did not expect listeners to respond with *anger-irritation*.

[6] This version of the piece was the same as the (original) Contagion version featured in Juslin et al. (2013).

[7] A notable exception is the Brain stem reflex condition, which was perceived as 'loud' by listeners.

Appendix A: Musical Features for Excerpts in Experiments 1-4

		Musical Feature						
EXP	ME	Tempo	Dynamics	Attack	Spectrum	Mode	Pitch	Novelty
1.	Bra	113	.117	.073	1562	.006	410	1.94
	Con	129	.027	.242	973	-.091	280	1.45
	Mem	119	.034	.137	1337	-.021	293	1.46
	Exp	115	.017	.161	1703	-.060	851	1.36
2.	Bra	128	.126	.069	1892	-.184	503	1.60
	Con	121	.028	.146	1786	-.058	563	1.98
	Mem	137	.040	.070	1614	-.010	545	1.28
	Exp	129	.021	.101	1262	-.045	331	1.91
3.	Bra	150	.070	.102	1397	-.099	463	1.54
	Con	127	.030	.199	849	-.053	350	1.90
	Mem	120	.025	.104	1178	.035	497	1.99
	Exp	137	.033	.110	546	.029	229	1.46
4.	Bra	111	.009	.172	1246	-.053	389	1.44
	Con	127	.019	.191	1349	-.075	372	1.69
	Mem	115	.036	.082	1484	.048	371	1.90
	Exp	105	.039	.151	1055	.001	262	3.26
	Neut	99	.017	.071	1349	-.116	905	1.02
	Ref	127	.047	.095	1282	-.035	416	1.00

Note. Me = mechanism; Bra = brain stem reflex; Con = contagion; Mem = memory; Exp = expectancy; Neut = neutral; Ref = reference level. Tempo = mean tempo in bpm (beats per minute); Dynamics = root mean square value of the amplitude; Attack = mean attack time in seconds; Spectrum = centroid of the frequency spectrum in Hz; Mode = arbitrary units where negative value is minor mode; Pitch = mean pitch in Hz; Novelty = arbitrary units where higher number denotes higher tonal novelty (see Lartillot, Toiviainen, & Eerola, 2008).

Appendix B: Response Sheet for Self-reported Feelings

Rate the intensity with which you *felt* each of the following feelings.

		0	1	2	3	4
		Not at all				*A lot*
1.	happiness - elation	0	1	2	3	4
2.	sadness - melancholy	0	1	2	3	4
3.	surprise - astonishment	0	1	2	3	4
4.	calm - contentment	0	1	2	3	4
5.	interest - expectancy	0	1	2	3	4
6.	nostalgia - longing	0	1	2	3	4
7.	anxiety - nervousness	0	1	2	3	4
8.	pride - confidence	0	1	2	3	4
9.	anger - irritation	0	1	2	3	4
10.	love - tenderness	0	1	2	3	4
11.	disgust - contempt	0	1	2	3	4
12.	admiration - awe	0	1	2	3	4

13. Did you experience 'chills' to the music?

Yes ☐ No☐

14. How much did you like the music?

Not at all 0 1 2 3 4 *A lot*

15. How familiar were you with the music?

Not at all 0 1 2 3 4 *A lot*

Appendix C: Response Sheet for Mechanism Indices (*MecScale*)

1. Did the music feature an event that startled you?

Not at all 0 1 2 3 4 *A lot*

2. Did the music have a strong and captivating pulse/rhythm?

Not at all 0 1 2 3 4 *A lot*

3. Did the music evoke a memory of an event from your life?

Not at all 0 1 2 3 4 *A lot*

4. Did the music evoke more general associations?

Not at all 0 1 2 3 4 *A lot*

5. Did the music evoke images while you were listening?

Not at all 0 1 2 3 4 *A lot*

6. Were you touched by the emotional expression of the music?

Not at all 0 1 2 3 4 *A lot*

7. Was it difficult to guess how the music (e.g., melody) would continue over time?

Not at all 0 1 2 3 4 *A lot*

8. Did the music have any practical consequences for your goals or plans in life?

Not at all 0 1 2 3 4 *A lot*

Table 1

Correlations Between Target Mechanism Conditions and Musical Features for Excerpts in Experiments 1-4

	Musical Feature						
Mechanism	Tempo	Dynamics	Attack	Spectrum	Mode	Pitch	Novelty
Brain stem	.09	.68	-.32	.33	-.46	.08	-.16
Contagion	.11	-.28	.73	-.15	-.30	-.11	-.01
Memory	-.07	-.15	-.39	.13	.54	.03	-.12
Expectancy	-.13	-.25	-.01	-.31	.22	-.01	.30

Note. Tempo = mean tempo in bpm (beats per minute); Dynamics = root mean square value of the amplitude; Attack = mean attack time in seconds; Spectrum = centroid of the frequency spectrum in Hz; Mode = arbitrary units where negative value is minor mode; Pitch = mean pitch in Hz; and Novelty = arbitrary units where higher number denotes higher tonal novelty. Values show the point-biserial correlations (r_{pb}) between target-mechanism condition (coded dichotomously) and musical feature (coded continuously) across experiments 1-4. For more detailed descriptions of how each musical feature is computed, see Lartillot, Toiviainen, and Eerola (2008).

N = 16

Table 2

Analysis of Variance for Listeners' Ratings: Experiment 1

Scale	*MS*	*F*	*p* [a]	eta-squared
Happiness-Elation				
Mechanism	7.880	9.746	.000005	.410
Sadness-Melancholy				
Mechanism	18.113	33.425	.000001	.705
Surprise-Astonishment				
Mechanism	14.167	14.655	.000001	.511
Calm-Contentment				
Mechanism	3.847	3.068	.023497	.180
Interest-Expectancy				
Mechanism	2.487	2.467	.055225	.150
Nostalgia-Longing				
Mechanism	7.513	6.705	.000175	.324
Anxiety-Nervousness				
Mechanism	4.883	4.160	.005087	.229
Pride-Confidence				
Mechanism	3.333	3.341	.015964	.193
Anger-Irritation				
Mechanism	2.113	3.614	.010878	.205
Love-Tenderness				
Mechanism	9.513	9.455	.000007	.403
Disgust-Contempt				
Mechanism	0.987	1.791	.143531	.113
Admiration-Awe				
Mechanism	4.647	5.442	.000897	.280

(Table 2 continued)

Scale	*MS*	*F*	*p* [a]	eta-squared
Emotion intensity				
Mechanism	4.413	4.650	.002597	.249
Liking				
Mechanism	7.220	7.848	.000043	.359
Familiarity				
Mechanism	33.353	71.326	.000001	.836

Note. df = Mechanism (4), Error (56)

[a] Bonferroni-adjusted from $\alpha = .05$ to $\alpha = .0033$

Table 3

Analysis of Variance for Listeners' Ratings: Experiment 2

Scale	*MS*	*F*	*p* [a]	eta-squared
Happiness-Elation				
Mechanism	15.420	14.706	.000001	.512
Sadness-Melancholy				
Mechanism	19.913	18.002	.000001	.562
Surprise-Astonishment				
Mechanism	15.447	11.232	.000001	.445
Calm-Contentment				
Mechanism	11.420	9.821	.000004	.412
Interest-Expectancy				
Mechanism	1.667	1.064	.383029	.071
Nostalgia-Longing				
Mechanism	15.113	10.914	.000001	.438
Anxiety-Nervousness				
Mechanism	15.147	13.460	.000001	.490
Pride-Confidence				
Mechanism	4.920	5.655	.000678	.288
Anger-Irritation				
Mechanism	2.533	2.778	.035465	.166
Love-Tenderness				
Mechanism	17.787	16.368	.000001	.539
Disgust-Contempt				
Mechanism	1.613	2.630	.043751	.158
Admiration-Awe				
Mechanism	4.753	3.667	.010097	.208

(Table 3 continued)

Scale	*MS*	*F*	*p* [a]	eta-squared
Emotion intensity				
Mechanism	5.680	7.349	.000079	.344
Liking				
Mechanism	9.153	8.995	.000011	.391
Familiarity				
Mechanism	37.720	189.957	.000001	.931

Note. df = Mechanism (4), Error (56)

[a] Bonferroni-adjusted from $\alpha = .05$ to $\alpha = .0033$

Table 4

Analysis of Variance for Listeners' Ratings: Experiment 3

Scale	*MS*	*F*	*p* [a]	eta-squared
Happiness-Elation				
Mechanism	5.500	5.347	.001018	.276
Sadness-Melancholy				
Mechanism	5.647	6.452	.000242	.315
Surprise-Astonishment				
Mechanism	17.987	19.058	.000001	.576
Calm-Contentment				
Mechanism	16.187	15.832	.000001	.530
Interest-Expectancy				
Mechanism	2.067	1.307	.278505	.085
Nostalgia-Longing				
Mechanism	21.767	21.260	.000001	.603
Anxiety-Nervousness				
Mechanism	5.753	6.742	.000168	.325
Pride-Confidence				
Mechanism	3.980	2.756	.036611	.164
Anger-Irritation				
Mechanism	0.713	1.450	.229694	.094
Love-Tenderness				
Mechanism	16.313	15.765	.000001	.530
Disgust-Contempt				
Mechanism	0.487	1.446	.231135	.094
Admiration-Awe				
Mechanism	3.767	2.830	.032938	.168

(Table 4 continued)

Scale	*MS*	*F*	*p* [a]	eta-squared
Emotion intensity				
Mechanism	3.553	4.164	.005058	.229
Liking				
Mechanism	6.447	5.355	.001007	.277
Familiarity				
Mechanism	34.047	47.413	.000001	.772

Note. df = Mechanism (4), Error (56)

[a] Bonferroni-adjusted from α = .05 to α = .0033

Table 5

Analysis of Variance for Listeners' Ratings: Experiment 4

Scale	*MS*	*F*	*p* [a]	eta-squared
Happiness-Elation				
Mechanism	8.313	11.314	.000001	.447
Sadness-Melancholy				
Mechanism	5.820	4.557	.002949	.246
Surprise-Astonishment				
Mechanism	19.567	31.011	.000001	.689
Calm-Contentment				
Mechanism	11.480	11.546	.000001	.452
Interest-Expectancy				
Mechanism	1.700	2.380	.062469	.145
Nostalgia-Longing				
Mechanism	20.880	20.703	.000001	.597
Anxiety-Nervousness				
Mechanism	11.020	14.180	.000001	.503
Pride-Confidence				
Mechanism	6.280	10.963	.000001	.439
Anger-Irritation				
Mechanism	3.447	4.405	.003629	.239
Love-Tenderness				
Mechanism	13.833	25.261	.000001	.643
Disgust-Contempt				
Mechanism	4.420	8.057	.000033	.365
Admiration-Awe				
Mechanism	4.247	5.798	.000562	.293

(Table 5 continued)

Scale	*MS*	*F*	p^{a}	eta-squared
Emotion intensity				
Mechanism	2.847	6.584	.000205	.320
Liking				
Mechanism	6.120	7.948	.000038	.362
Familiarity				
Mechanism	28.553	37.547	.000001	.728

Note. df = Mechanism (4), Error (56)

[a] Bonferroni-adjusted from $\alpha = .05$ to $\alpha = .0033$

Table 6

Summary of Planned Comparisons Between Predicted Target Mechanism and Remaining Conditions for Emotion Ratings in Experiments 1-4

Scale	Contrast	EXP 1	EXP 2	EXP 3	EXP 4
Happiness-Elation	M vs. B	.486[a]	.001*	.229	.002*
	M vs. C	.006*	.001*	.068	.001*
	M vs. E	.002*	.001*	.001*	.001*
	M vs. N	.041*	.001*	.001*	.001*
Sadness-Melancholy	C vs. B	.001*	.188	.004*	.003*
	C vs. M	.001*	.001*	.006*	.039*
	C vs. E	.003*	.905	.265	.002*
	C vs. N	.001*	.001*	.004*	.006*
Surprise-Astonishment	B vs. C	.001*	.001*	.001*	.001*
	B vs. M	.001*	.001*	.001*	.001*
	B vs. E	.001*	.001*	.001*	.003*
	B vs. N	.001*	.005*	.001*	.001*
Nostalgia-Longing	M vs. B	.006*	.001*	.001	.001*
	M vs. C	.556[a]	.055	.116	.132
	M vs. E	.032*	.001*	.001	.001*
	M vs. N	.001*	.001	.001*	.001*
Anxiety-Nervousness	E vs. B	.103	.499	.849[a]	.001*
	E vs. C	.002*	.001*	.010*	.001*
	E vs. M	.023*	.001*	.007*	.001*
	E vs. N	.018*	.002*	.030*	.003*

Note. Data indicate *p* values. B = brain stem reflex; C = contagion; M = memory; E = expectancy; N = neutral.

[a] Contrasts where the predicted target mechanism did not receive the highest mean rating

* $p < .05$

Table 7

Analysis of Variance for Psychophysiology in Experiments 1-4

Exp	Measure	*MS*	*F*	*p*	eta-squared
1	*Skin conductance level*				
	Mechanism	2.383	2.644	.030128*	.159
1	*Zygomatic muscle activity*				
	Mechanism	4.014	5.115	.000469*	.268
1	*Corrugator muscle activity*				
	Mechanism	3.539	4.324	.001740*	.236
2	*Skin conductance level*				
	Mechanism	1.823	1.937	.099117	.122
2	*Zygomatic muscle activity*				
	Mechanism	2.333	2.579	.033680*	.156
2	*Corrugator muscle activity*				
	Mechanism	4.413	5.836	.000146*	.294
3	*Skin conductance level*				
	Mechanism	6.229	9.944	.000001*	.415
3	*Zygomatic muscle activity*				
	Mechanism	5.478	8.055	.000005*	.365
3	*Corrugator muscle activity*				
	Mechanism	0.348	0.333	.891575	.023
4	*Skin conductance level*				
	Mechanism	6.518	10.757	.000001*	.435
4	*Zygomatic muscle activity*				
	Mechanism	0.001	2.620	.031404*	.158
4	*Corrugator muscle activity*				
	Mechanism	2.884	3.334	.009294*	.192

Note. df = Mechanism (5), Error (70)

* $p < .05$

Table 8

Summary of Planned Comparisons for Psychophysiology in Experiments 1-4

Measure	Contrast	EXP 1	EXP 2	EXP 3	EXP 4
SCL	B vs. C	.225	.648	.001*	.716[a]
Zyg	M vs. C	.007*	.002*	.091	.002*
Corr	C vs. M	.001*	.001*	.962[a]	.038*

Note. Data indicate *p* values. SCL = skin conductance level; Zyg = zygomaticus muscle activity; and Corr = corrugator muscle activity; B = brain stem reflex; C = contagion; M = memory.

[a] Contrasts where the predicted target mechanism did not receive the higher mean value

* $p < .05$

Table 9

Correlations Between Emotion Ratings and Target Mechanism Conditions Across Experiments 1-4

Emotion Scale	Condition				
	Neutral	Brain stem	Contagion	Expectancy	Memory
Happiness-Elation	-.11	.07	-.09	-.31*	**.43***
Sadness-Melancholy	-.27*	-.13	**.44***	**.19***	-.23*
Surprise-Astonishment	-.02	**.59***	-.39*	.01	-.20*
Nostalgia-Longing	-.30*	-.19*	**.28***	-.23*	**.44***
Anxiety-Nervousness	-.11	.12	-.17	**.42***	-.26*
Intensity	-.41*	**.20***	.13	-.04	.11
Liking	-.33*	.02	**.32***	-.19*	.18
Familiarity	-.31*	-.16	-.15	-.22*	**.84**

Note. Values show point-biserial correlations (r_{pb}) between listener's emotion ratings (coded continuously) and target-mechanism conditions (coded dichotomously). Correlations that are both statistically significant and positive in direction are shown in boldface. (Alpha level was Bonferroni-adjusted from α = .05 to α = .00125.)

* $p < .00125$

$N = 300$

Table 10

Correlations Between MecScale Items and Target Mechanism Conditions Across Experiments 1-4

	Condition				
Scale item	Neutral	Brain stem	Contagion	Expectancy	Memory
Brain stem	-.32*	**.75***	-.20*	-.01	-.23*
Entrainment	-.06	**.23***	-.16	-.21*	**.19***
Memory	-.25*	-.15	-.02	-.11	**.54***
Conditioning	-.32*	-.16	-.01	.03	**.45***
Visual Imagery	-.30*	-.13	.07	-.01	**.38***
Contagion	-.48*	.04	**.38***	-.12	.18
Expectancy	-.05	**.28***	-.06	**.36***	-.53*
Appraisal	-.19*	-.06	.05	.32	**.32***

Note. Values show point-biserial correlations (r_{pb}) between ratings of *MecScale* items (coded continuously) and target-mechanism conditions (coded dichotomously). Correlations that are both statistically significant and positive in direction are shown in boldface. (Alpha level was Bonferroni-adjusted from α = .05 to α = .00125.)

* $p < .00125$

$N = 300$

Table 11

Classification Matrix for the Multiple Discriminant Analysis: Prediction of Mechanism Condition from MecScale items

	Predicted condition			
	Brain stem	Contagion	Expectancy	Memory
Actual condition				
Brain stem	**88**	2	7	3
Contagion	7	**62**	16	15
Expectancy	22	20	**57**	1
Memory	3	3	0	**94**

Note. The percent (rowwise) of correctly predicted emotions are given on the main diagonal.

The off-diagonal cells show the confusions. Overall accuracy = 75%.

$N = 240$

Table 12

Summary of the Multiple Discriminant Analysis: Prediction of Mechanism Condition from MecScale Items

Predictors (*MecScale*)	Standardized coefficients (β)			Partial Lambda	*F* to remove[1]
	Function 1	Function 2	Function 3		
Brain stem reflex	-.69	.59	.20	.564	58.95*
Rhytmic entrainment	-.06	.35	-.25	.948	4.18*
Episodic memory	.28	.36	-.29	.910	7.51*
Evaluative conditioning	.16	.09	-.43	.963	2.88*
Visual imagery	.09	-.05	.09	.995	0.37
Emotional contagion	.06	-.21	.90	.851	13.39*
Musical expectancy	-.51	-.50	-.41	.717	30.18*
Cognitive appraisal	.14	.10	-.02	.985	1.15

[1] This refers to the *F* value associated with the respective partial Wilks' Lambda ($df = 3, 229$) * $p < .05$.

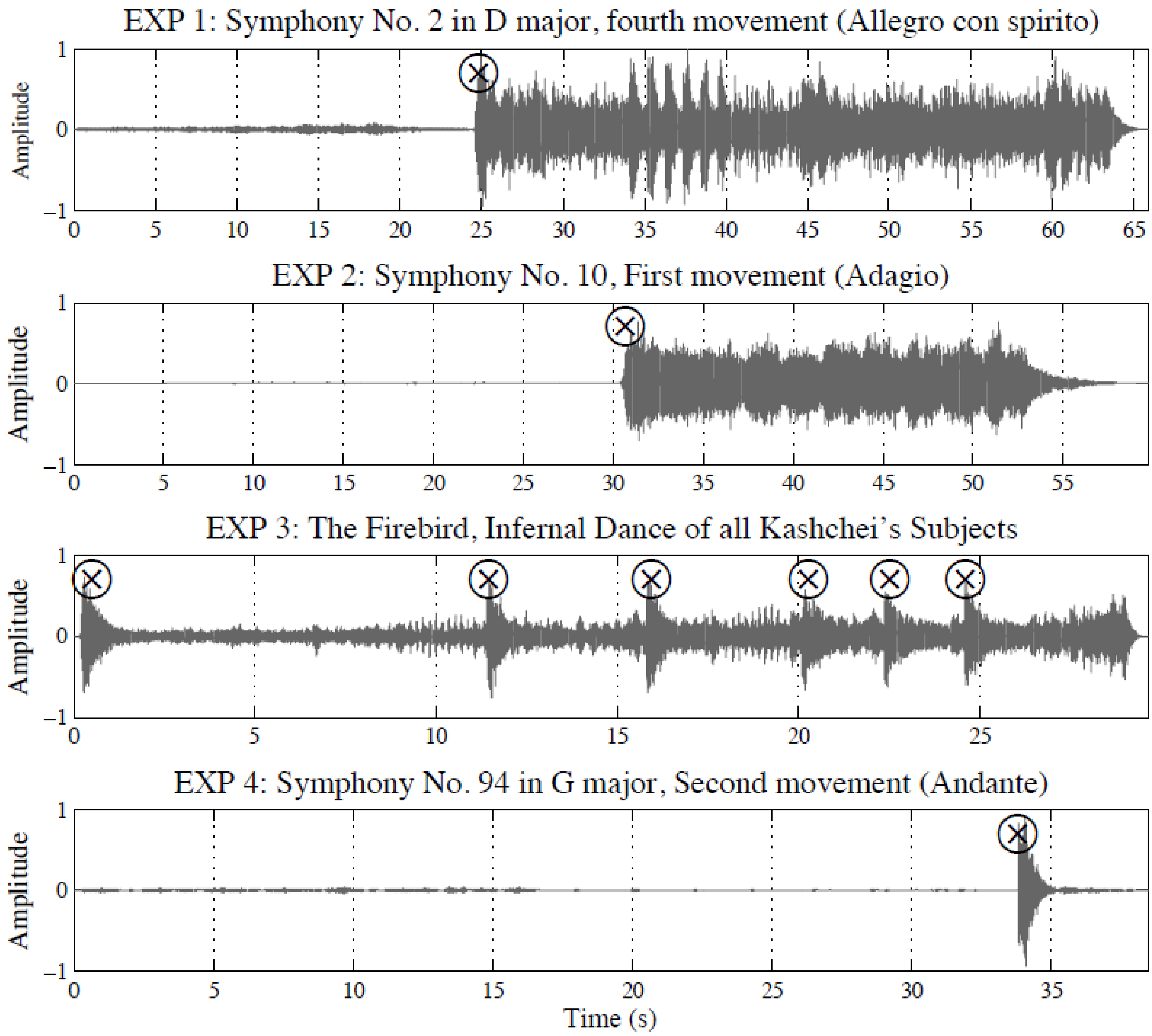
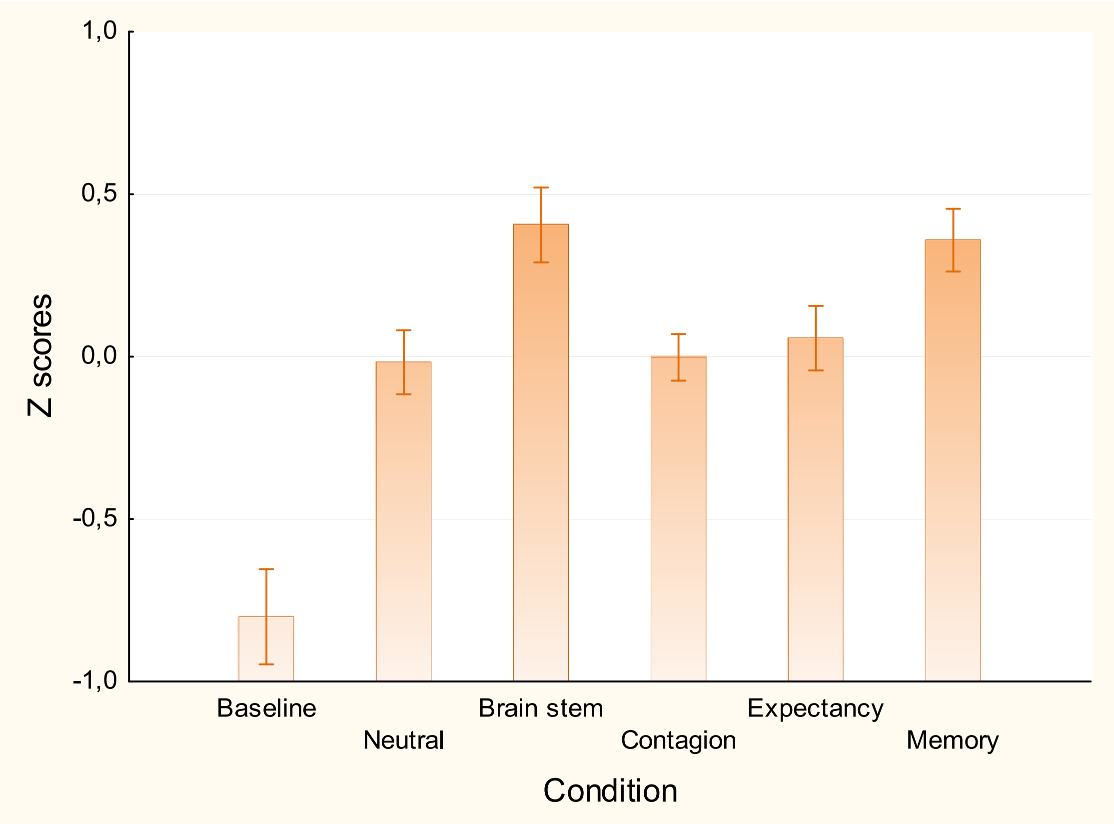
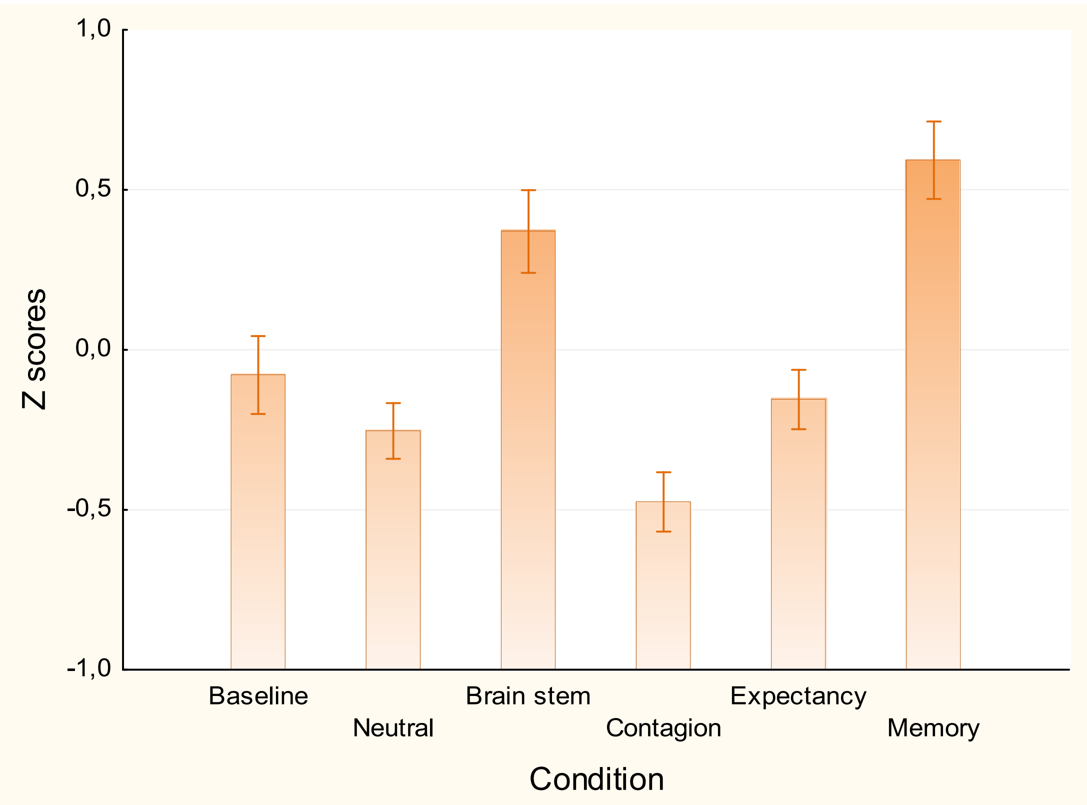


Figure 1: Amplitude wave forms for the musical excerpts used in the brain stem reflex condition in Experiments 1-4.

Skin conductance level



Zygomaticus muscle activity



Corrugator muscle activity

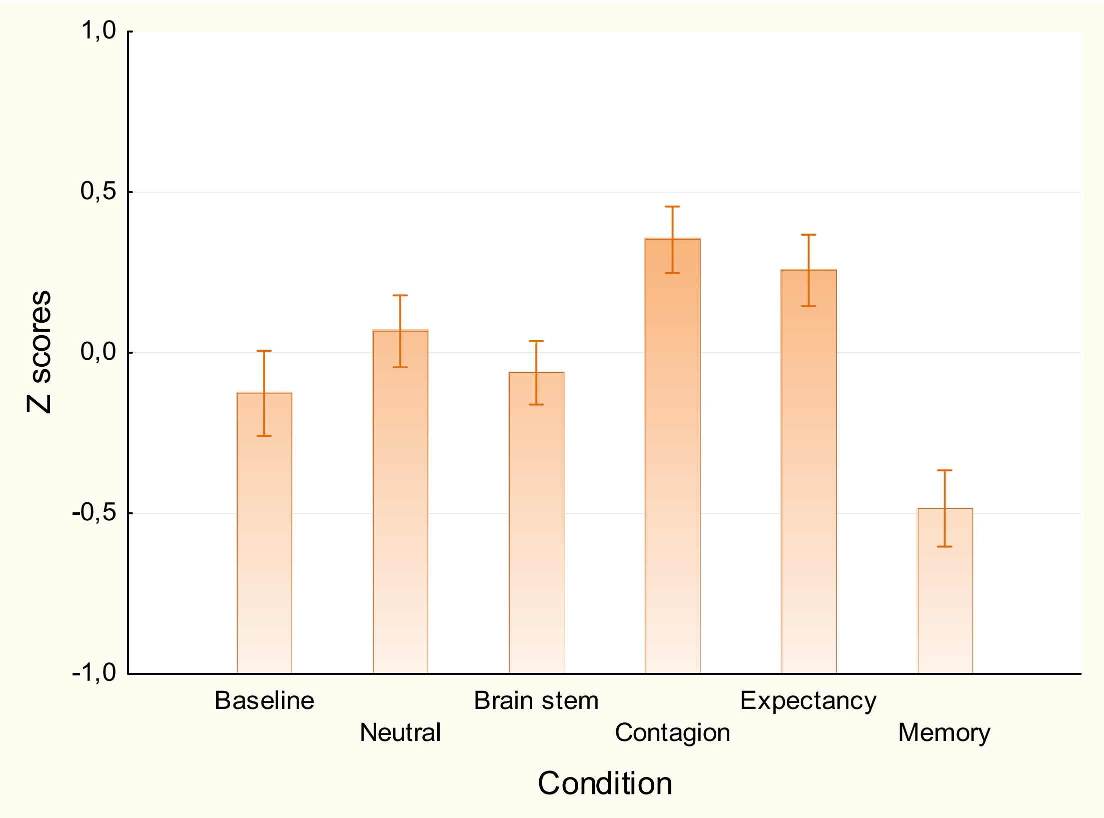


Figure 2: Means and standard errors for the listeners' skin conductance level, zygomaticus muscle activity, and corrugator muscle activity (z-scores), as a function of target-mechanism condition, across Experiments 1-4.