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ORIGINAL ARTICLE

Expressiveness in musical emotions

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Abstract This study was designed to investigate how emotion category, characterized by distinct musical structures (happiness, sadness, threat) and expressiveness (mechanical, expressive) may influence overt and covert behavioral judgments and physiological responses in musically trained and untrained listeners. Mechanical and expressive versions of happy, sad and scary excerpts were presented while physiological measures were recorded. Participants rated the intensity of the emotion they felt. In addition, they monitored excerpts for the presence of brief breaths. Results showed that the emotion categories were rated higher in the expressive than in the mechanical versions and that this effect was larger in musicians. Moreover, expressive excerpts were found to increase skin conductance level more than the mechanical ones, independently of their arousal value, and to slow down response times in the breath detection task relative to the mechanical versions, suggesting enhanced capture of attention by expressiveness. Altogether, the results support the key role of the performer's expression in the listener's emotional response to music.

Introduction

The emotional meaning of music is generally linked to its musical structure, as broadly defined by the structural parameters (e.g., dissonance) of the musical piece laid down in the score by the composer (Gabrielsson & Lindström, 2001). These structural determinants are mainly what make Beethoven's Ode to Joy so easy to categorize as joyful and Albinoni's Adagio as sad. However, the emotional richness of a given musical piece is also strongly dependent of the interpretation that the performer makes of it. Indeed, many micro-variations of the musical parameters (e.g., tempo, loudness, or articulation) are introduced by the performer to enhance the emotional expressivity of the original score (Gabrielsson, 1999). This is one of the reasons why the Ode to Joy sounds somewhat more joyful and expressive when played by the Berliner Philharmoniker than by the ringtone of your cellular phone.

To date, most studies on musical emotions have examined musical structure and expressiveness separately. The studies that focus on musical structure typically eliminate micro-variations, such as those introduced by performance. Synthesized musical excerpts are used to isolate structural features like mode or tempo. These studies provide evidence that ordinary listeners succeed to accurately and immediately use changes of mode and tempo to decode basic emotions (Peretz, Gagnon, & Bouchard, 1998), the most common associations being between fast tempo, major mode and happiness, and slow tempo, minor mode and sadness. Another structural parameter of importance is dissonance, which renders musical excerpts less pleasant than their consonant counterparts (Blood, Zatorre, Bermudez, & Evans, 1999; Peretz, Blood, Penhume, & Zatorre, 2001; Gosselin, Peretz, Noulhiane, Hasboun, Baulac, & Samson, 2005. The use of these structural characteristics by ordinary listeners in the emotional categorization and evaluation of music is found to appear early in development (Dalla Bella, Peretz, Rousseau, & Gosselin, 2001; Trainor & Heinmiller, 1998; Zentner & Kagan, 1996, 1998), suggesting that it is quite a basic and widespread ability.

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In parallel, the contribution of expressive cues to musical emotion decoding has also been well documented (e.g., Gabrielsson & Juslin, 1996; Juslin, 1997a, b; Juslin, Friberg, & Bresin, 2002; Juslin & Laukka, 2003; Juslin & Madison, 1999), providing evidence that music performance represents an important determinant of emotional expression and esthetic appreciation of music (see Gabrielsson & Juslin, 2003 for a review). Using synthesized performances including manipulation of tempo, sound level, spectrum, articulation, attack, vibrato and timing, Juslin (1997b) showed that listeners use all of these available cues to decode expressions of happiness, sadness, anger, fear and tenderness. In another study, short melodies from different musical styles, played with various instruments and performed to communicate different emotional expressions (e.g., happiness, sadness, threat, tenderness) have been shown to be decoded with high accuracy (Gabrielsson & Juslin, 1996). Such findings provide evidence that expressive qualities of music emphasize the emotional dimension of music. However, none of these studies compared the effects of expressiveness in different emotional categories, leaving open the question of their joint contribution to musical emotions.

Although tempo has been referred above to as a parameter of musical structure, it can also be speeded up or slowed down by the performer in quite a flexible manner. In that case, it can also be considered as part of the expression of music, along with other more subtle timing parameters. The manipulation of these timing parameters appears to be particularly important for music's expressiveness. Using gradual removal of different expressive cues (i.e., tempo, dynamics, timing, articulation) in piano performances, Juslin and Madison (1999) showed that timing patterns play a crucial role in decoding emotional expressions of happiness, sadness, anger and fear. In another study, Juslin et al. (2002) asked musically trained listeners to evaluate synthesized musical excerpts in which several sources of expression variability were implemented (e.g., random variations reflecting internal timekeeper variance and motor delay variance). Their findings indicated that timing variations and tempo changes were recognized as the main contributors to the perceived expression. Other cues that have been shown to play a role in music expressiveness include: sound level, intonation, articulation, timbre, vibrato, tone attacks and tone decays (Juslin & Laukka, 2003). Microvariations of these cues convey different kind of expression intentions. For example, sadness portrayals are associated with slow tempo, low sound level, legato articulation, small articulation variability, slow tone attack and dull timbre.

In a recent study, the effect of music expressiveness on physiological reactions was addressed in non-musician listeners, investigating skin conductance responses and heart rate measures (Koelsch, Kilches, Steinbeis, & Schelinski, 2008). Physiological indexes were investigated in response to unexpected musical chords played either with or without expression. It was shown that unexpected musical chords elicited a larger skin conductance response in the expressive than in the non-expressive condition.

In light of these prior studies, it appears that music expressiveness has been mostly studied as a means to emphasize the intended emotion conveyed by music structure. However, there are indications that music expressiveness could be considered as an emotional determinant on its own, independently from the particular emotion conveyed by the structure of the musical excerpt. For instance, expressive relaxing music may elicit intense emotional responses such as tears, shivers or chills (see Gabrielsson, 2001).

To assess more systematically the effect of expressiveness on distinct musical structures (characterizing different emotion categories) for eliciting emotional responses to music, we compared the effects of expressive and non-expressive versions of sad, happy and scary musical excerpts on emotional ratings of felt intensity, valence/arousal judgments and physiological responses such as skin conductance, heart rate, corrugator and zygomatic activity. It is worthy to note that in the present study, emotional category is employed as equivalent to musical structure. Since happiness and nostalgia are the most common emotions experienced with music (Juslin, Liljeström, Västfjäll, Barradas, & Silva, 2008), we selected happy and sad musical excerpts as a good compromise to represent what people experience when they listen to music. While we expected expressiveness to increase the intensity of the intended emotion and, thereby, the associated facial expressions, we further predicted that the expressive versions would elicit larger physiological arousal (leading to higher heart rate and skin conductance) than the mechanical versions. Indeed, several musical cues known to play a role in music expressiveness, such as tempo, accentuation and rhythmic articulation, have been shown to be strongly correlated with skin conductance (Gomez & Danuser, 2007). More specifically, musical passages characterized by slow movements, volume increase, expansion in frequency range and unexpected harmonic progression are known to elicit large increase of the electrodermal activity (Guhn, Hamm, & Zentner, 2007). Moreover, independently from the expressiveness of the musical excerpts, sad, happy and scary excerpts should show patterns of physiological responses characteristic of their emotion category. Skin conductance and heart rate are generally related to the level of arousal induced by music (Gomez & Danuser, 2004; Kallinen, Saari, Ravaja, & Salminen, 2006; Khalfa, Peretz, Blondin, & Manon, 2002; VanderArk & Ely, 1992; Kallinen et al. (2006); Witvliet & Vrana, 2007) and are therefore generally found to be lower for sad than happy or scary excerpts

(Krumhansl, 1997). Facial expressions, however, as measured by the activity of the corrugator (i.e., frowning) and zygomatic (i.e., smiling) muscles, are mostly related to the valence of the emotions induced by the musical excerpts. Positive emotions, such as happiness, generally lead to increased zygomatic activity, while negative ones, such as sadness or fear, are more associated with increased corrugator activity (Kallinen et al., 2006; Witvliet & Vrana, 2007; Khalfa, Roy, Rainville, Dalla Bella, & Peretz, 2008).

An additional objective of this study was to assess the effects of musical structure and expressiveness on attention. The performance on a concomitant auditory detection task was used as an index of attentional engagement. Emotional stimuli typically draw larger amounts of attention than neutral stimuli and therefore may constitute a larger distraction when another task is to be performed in parallel. In a study that aimed to examine intense emotional responses to music, Rickard (2004) found that “emotionally powerful” music was judged as more ‘moving’, ‘involving’, ‘interesting’, ‘absorbing’ and ‘requiring concentration’, suggesting that such music would interfere more with the performance of a concomitant auditory detection task. However, other findings using auditory stimuli indicated that attention-demanding task is improved when participants simultaneously listen to high-tempo music (Olivers and Nieuwenhuis (2005). In this study, the authors examined whether arousal may modulate the allocation of spatial attention in a modified spatial cueing paradigm (i.e., RSVP). Their data showed that providing distraction through high-tempo music causes improvements in detecting *visual* targets in the RSVP task. Such previous findings raise the question of whether the arousal dimension could also facilitate the detection of auditory target.

According to the interference hypothesis, it would be expected that target detection would be generally slower in the expressive condition than in the mechanical one. This general effect of expressiveness should be modulated by the emotion expressed by the musical excerpts. Some emotions, such as threat, also appear to attract more attention than others (Fox, 2002; Fox, Lester, Russo, Bowles, Pichler, & Dutton, 2000; Öhman, Flykt, & Esteves, 2001a; Öhman, Lundqvist, & Esteves 2001b; Tipples, Atkinson, & Young, 2002; Vuilleumier, 2002). The automatic vigilance for threatening stimuli does not always operate via preferential engagement of attention, but may also operate via the delayed disengagement of attention. Numerous studies provide evidence that it is more difficult to disengage attention from negative stimuli than from other stimuli (e.g., Fox, Russo, Bowles, & Dutton, 2001; Yiend & Mathews, 2001). Therefore, it would also be expected here that the presentation of fearful musical excerpts will interfere more with the detection of an auditory target than the happy and sad excerpts. Alternatively, the facilitation hypothesis postulates that the effects described above would be inverted so that the target detection would be generally faster in the expressive condition than in the mechanical one and that fearful music would greater facilitate target detection than happy and sad music.

Finally, our aim was to evaluate the effects of musical expertise on emotional responses to musical structure and expressiveness. Recent findings suggest that music lessons may promote the ability to decode emotions from prosodic cues (Thompson, Schellenberg, & Husain, 2001). Yet, another stream of research indicates that emotional response to music does not differ as a function of musical expertise (Bigand, Vieillard, Madurell, Marozeau, & Dacquet, 2005. These discrepancies appear to be linked to the type of task the participants are asked to perform. Whereas some differences between musicians and non-musicians can be observed on task requiring explicit judgments, these differences tend to disappear when the task focuses on more implicit processes (Bigand & Poulin-Charronnat, 2006). Our goal here was to assess the influence of formal training in music through covert, overt and physiological measures. We expected that musical expertise would enhance the effects of expressiveness on emotional ratings as well as on the facial muscle activity, which can be controlled voluntarily as well as involuntarily. On the contrary, covert perception and physiological responses (i.e., skin conductance, heart rate) to emotion in music would not be significantly different between musicians and non-musicians.

Methods

Participants

Fifteen graduate music students referred to as musicians (age range 19–28, mean age 23 years; 4 men) and 12 students with little musical expertise (i.e., non-musicians; age range 19–40, mean age 25 years, 5 men) participated in the study. On average, musicians had 13 years of musical training and instrumental practice (range 7–20) while non-musicians had 3 years of instrumental practice (range 1–6). All participants gave their informed consent prior to their inclusion in the current study.

Material

Musical excerpts

Musical material was taken from a pool of normalized set of unfamiliar musical excerpts, which were written following the rules of the Western tonal system with the aim to convey happiness, sadness and threat (See Vieillard, Peretz, Gosselin, Khalfa, Gagnon, & Bouchard, 2008 for details on musical material). These happy, sad and scary excerpts were written in major, minor and minor chords, respectively. Five excerpts of each emotional category (happy, sad, scary) were transcribed for solo violin and interpreted by a professional violinist in two expressive versions (mechanical vs. expressive), for a total of 30 excerpts.[1] All excerpts had a duration of 10 s and were recorded in a professional studio as mono files at 16 bits and 44 kHz. Each musical excerpt was normalized to 100% of maximum amplitude.

Several acoustic cues were examined to measure to what extent the mechanical versions differed from the expressive ones. Intensity, attack, articulation and tempo were examined via the Praat software (Boersma & Weenink, 2000). Intensity was the maximum peak of an excerpt's intensity (db). Attack was quantified by the rise time ratio (%) between the duration of the attack and the note duration. Articulation was the proportion (%) of sound to silence in successive notes: the higher the proportion, the more articulation (legato) there was. The mean tempo of musical performance corresponded to the total duration of the excerpt divided by the number of beats and was expressed in beats per minute (bpm). The extracted values were then averaged for each emotion category and level of expressiveness (Table 1). To evaluate the effect of music expressiveness on these parameters, the mechanical and expressive versions of each emotion category were compared with Wilcoxon matched-pairs tests. As can be seen in Table 1, acoustical values differed to some extent as a function of expressiveness, reaching significance for sad excerpts on the tempo parameter and marginally so for scary music on articulation, intensity and tempo (see *p* values in Table 1). In accordance with Juslin et al.'s (2002) findings, tempo appears as the most discriminant parameter among expressive cues.

To assess the emotional properties of the musical excerpts, we asked 12 pilot participants (4 musicians and 8 non-musicians) to rate the 30 excerpts on the dimensions of valence (from 0 "désagréable"/unpleasant to 9 "agréable"/pleasant), arousal (from 0 "relaxant-morne"/relaxing-mournful to 9 "stimulant"/stimulating), and Expressiveness (from 0 "pas du tout expressif"/not expressive at all to 9 "très expressif"/very expressive)[2]. In this pilot study, the

Table 1 Mean value and standard error of acoustic measures of intensity (maximum peak of excerpt's intensity in dB), attack (rise time ratio, in percentage, between the duration of the attack and the note duration), articulation (proportion, in percentage, of sound to silence between successive notes) and tempo (beats per minute) as a function of Emotion Category and Expressiveness

	Happy music				Sad music				Scary music			
	General structure	Mechanical version	Expressive version	p^1	General structure	Mechanical version	Expressive version	p^1	General structure	Mechanical version	Expressive version	p^1
Acoustic cues												
Intensity (dB)	79 (2)	80 (1)	78 (2)	0.22	81 (1)	81 (1)	81 (2)	0.89	77 (3)	78 (1)	76 (4)	0.07
Attack (%)	34 (3)	34 (4)	33 (3)	0.5	33 (9)	30 (5)	36 (12)	0.22	28 (6)	29 (4)	27 (8)	0.68
Articulation (%)	86 (10)	91 (13)	81 (4)	0.22	95 (5)	96 (5)	95 (6)	0.46	95 (4)	96 (3)	93 (4)	0.07
Tempo (bpm)	112 (16)	110 (15)	114 (19)	0.27	41 (12)	51 (8)	31 (3)	0.04	88 (25)	94 (27)	82 (24)	0.06

[1] Wilcoxon matched pairs test for comparison between mechanical and expressive versions

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[1] We asked the violinist to play in three ways: mechanical (machine like), with expression and with too much expression (like a caricature). These three levels of expressivity were difficult to achieve for the violinist, especially for the scary music. Therefore, we selected the best renditions of expressivity depending on the target version (mechanical versus expressive).

[2] To be sure that all participants understood the term 'expressiveness' in the same way, we indicated that they had to estimate to what extent each musical excerpt powerfully evoked emotions.

Table 2 Mean and standard error of valence (from 0, unpleasant, to 9, pleasant), arousal (from 0, relaxing, to 9, stimulating) and expressiveness (from 0, not expressive at all, to 9, very expressive) ratings as a function of Emotion Category and Expressiveness

	Happy music			Sad music			Scary music		
	Mechanical	Expressive	Mean	Mechanical	Expressive	Mean	Mechanical	Expressive	Mean
Ratings (max. 9)									
Valence	5.9 (1.8)	6.4 (1.8)	6.1	4.7 (1.5)	5.0 (1.3)	4.8	4.0 (1.0)	3.6 (1.3)	3.8
Arousal	6.5 (1.5)	7.2 (0.9)	6.8	3.6 (1.3)	3.4 (1.7)	3.5	4.6 (0.8)	4.9 (0.7)	4.8
Expressiveness	6.5 (1.3)	7.1 (1.3)	6.8	5.2 (1.3)	6.1 (1.7)	5.7	5.6 (0.9)	6.2 (1.1)	5.9

musical excerpts were presented in two different orders counterbalanced across participants. An analysis of variance was conducted on these three dependent variables, respectively, with Emotion Category and Expressiveness as the within-subject factors. Significant main effect of Emotion Category was found for Valence [$F(2, 24) = 23.63$; $p < 0.001$; $\eta_p^2 = 0.66$], Arousal [$F(2, 24) = 77.62$; $p < 0.001$; $\eta_p^2 = 0.87$] and Expressiveness ratings [$F(2, 24) = 8.18$; $p < 0.05$; $\eta_p^2 = 0.41$] respectively. As shown in Table 2 and confirmed by post hoc Bonferroni correction (p's < 0.001): (a) happy excerpts were judged as more pleasant than sad ones which, in turn, were rated as more pleasant than scary excerpts, (b) happy excerpts received higher arousal ratings than scary ones, which in turn received higher ratings than sad excerpts, (c) happy music was judged as more expressive than sad and scary music. There was also a main effect of Expressiveness on expressiveness ratings [$F(1, 24) = 8.30$; $p < 0.05$; $\eta_p^2 = 0.26$] indicating that expressive versions were rated as more expressive ($M = 6.49$, $SE = 0.18$) than mechanical ones ($M = 5.77$, $SE = 0.18$). So, musical excerpts were clearly distinguished in terms of arousal (relaxing vs. stimulating) and valence (pleasant vs. unpleasant), supporting recent findings on the listeners' abilities to finely discriminate emotions from music along these two main dimensions (Bigand et al., 2005; Vieillard et al., 2008). As expected, mechanical and expressive versions were distinguished by listeners.

Procedure

The experiment was performed in a quiet room at stable ambient temperature and was divided into two parts conducted one after the other with the same participants. In the first part, physiological responses were recorded while participants listened to the musical excerpts and rated the emotional intensity of the emotion felt during music listening. In the second part, the participants performed an auditory target detection task without physiological recordings or emotional ratings. The detection task was performed in a separate phase to avoid the habituation effects of physiological responses and to prevent any motor response's interference on the physiological measurements.

Ratings and physiological recordings

A 3-min rest period followed the placement of the electrodes and preceded the onset of the experiment. Participants were seated comfortably in front of a computer and asked to remain as still as possible. Physiological activity was monitored continuously during the listening and the rating phases. Eprime software (Schneider, Eschman, & Zuccolotto, 2002) was used for excerpt presentation and rating recording. Musical excerpts were presented binaurally over the Professional Beyer Dynamic DT 770 headphone.

Musical excerpts were presented in two pseudorandom order presentation sets. The first 12 musical excerpts were similar across the two order presentations. For each set, the restriction was that the emotion category could not be the same on more than two consecutive trials. These first 12 excerpts comprised an equal number of each type of musical excerpt (i.e., there were 2 happy excerpts, 2 sad excerpts and 2 scary excerpts, each played in the mechanical and expressive version) to permit the analysis of the responses to these excerpts only in the likely event of a strong habituation of the physiological responses. Each musical excerpt was preceded and followed by two baseline periods of at least 10 s of silence. The experimenter initiated each trial by clicking on a mouse when the skin conductance level (SCL) had stabilized.[3] After each trial, a four-point scale was displayed on the screen and listeners were asked to report the emotional intensity they felt when listening to the music (with 0 meaning "très faible"/very weak, and 4 meaning, "très forte"/very strong).

Auditory target detection task

In the target detection task, we used a natural breathing sound—taken from the recording of the violinist's respiration during the performance—as a target inserted into musical excerpts. All other breathings were removed from the

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[3] The 10-s duration of the rest period between pieces was the *minimum* time allocated to the return to the baseline. At the end of each trial, the experimenter carefully scrutinized the SCL and initiated the next trial only when it had stabilized, making sure that measure did return to baseline between pieces.

sound files. The breath duration was of 250 ms with a 25-ms fade-in and fade-out. In each of the 30 musical excerpts (i.e., 5 happiness, 5 sadness and 5 scary played in the two versions of expressiveness), the target was inserted either at 1,500, 4,500 or 7,500 ms after the beginning of the excerpts. Targets occurred in all three different locations for the mechanical and expressive version of the same excerpt, leading to a total of 90 trials. To match those 90 trials comprising an auditory target, the 30 original excerpts were presented three times each without the auditory target.

Item presentation and response time recordings were done using Macintosh-compatible computers running Psyscope software (Cohen, MacWhinney, Flatt, & Provost, 1993). As in the first part, the musical excerpts were presented binaurally over Professional Beyer Dynamic DT 770 headphone. Participants were informed that excerpts may contain a breath that they had to detect as quickly as possible by pressing on the space bar of the keyboard. Two examples of the breath and five practice trials were presented before the experiment began. Then, the 180 experimental stimuli were presented randomly without allowing the repetition of the same melody on two successive trials. Each trial began with a 1,000-ms fixation point displayed in the middle of the screen. The musical excerpts stopped immediately when the participants pressed on the space bar to indicate that they had detected a breath, and the next trial began immediately with the 1,000-ms fixation point.

Data acquisition and analysis

Physiological responses

SCL, facial EMG activity and ECG were monitored simultaneously and continuously using Biopac amplifiers. Data were digitized with a sampling rate of 200 Hz, recorded and processed using the MP150 system and AcqKnowledge software (Biopac Systems Inc.). SCL was recorded from the right hand, with two Ag–AgCl electrodes attached to the palmar surface of the medial phalange of the index and the middle fingers, and filled with isotonic gel. The skin conductance signal was smoothed using the mean of a 1-s moving window. Facial EMG activity was recorded over the left corrugator and zygomatic sites, using two pairs of Ag–AgCl electrodes filled with isotonic gel. The EMG data were band-pass filtered from 100 to 500 Hz and processed with a root mean square algorithm over 20 samples (with a 100-ms window). ECG data were collected using a standard three leads montage (Einthoven lead 2 configuration). Instantaneous R–R intervals (the time elapsing between two consecutive R-waves in the ECG) were automatically calculated from the ECG using a template-matching autocorrelation function (template centered on the R-wave) and a peak detection algorithm to obtain a continuous RR tachogram.

Recording artefacts were visually identified and discarded from the sample. These corresponded to less than 0.5% of all measurements. Because SCL tends to decline progressively throughout the session (i.e., there is a drift in the signal), we need to assess the amplitude of skin conductance responses using a baseline that is as close as possible to the onset of the SCL. For this reason, SCLs were computed as the difference between the skin conductance level at the onset of the musical excerpts, which served as a baseline, and the mean amplitude of skin conductance recorded between 3 s (changes in the form of SCLs occur 1–4 s after discrete stimuli) and 10 s post-stimulus onset. Because EMG responses can be rapidly triggered (in the order of 100 ms) after the onset of the stimulus, facial EMG responses were calculated as the difference between the integrated signal over the whole time course of the musical excerpt. The baseline EMG level was measured from 1 s prior to the onset of the excerpt (time −1 to 0 s) to the beginning of the excerpt. For heart rate, responses were extracted in two distinct phases of reaction to the excerpts: a reactivity period corresponding to the cardiac activity during music presentation and the recovery period, which is related to the cardiac activity during the following 10 s of silence after music presentation. The reactivity period was computed as the difference between the mean R–R intervals obtained during the presentation of the excerpts and the mean R–R intervals of the 10 s preceding the excerpt (10 s excerpt − 10 s pre-stimulus), whereas the recovery period was calculated by subtracting the mean R–R intervals of the musical excerpt from the mean R–R intervals of the 10 s following the excerpt (10 s post-stimulus − 10 s excerpt).

SCLs, facial EMGs, R–R intervals reactivity and R–R intervals recovery were then log-transformed to reduce the skewness of their distribution. The distribution of each variable was finally examined to identify possible remaining outliers (mean ± 3SD). Based on this criterion, about 3% of all measurements were excluded from the analysis.

Response time in auditory target detection task

For each trial where an auditory target was presented, response times were registered as the time between the onset of the auditory target and the detection of the target. For each subject, response times higher than 3SD from the mean of their respective target time position condition were excluded. This resulted in 1.7% of the total responses being excluded for this reason.

Results

For each measure, mixed model ANOVAs were performed with Emotion Category (happy, sad or fearful) and Expres-

Table 3 Mean and standard error of physiological measures (change scores from baseline) by Emotion Category, Expressiveness and Musical Expertise

	Happy music		Sad music		Scary music	
	Mechanical	Expressive	Mechanical	Expressive	Mechanical	Expressive
Physiological measures for musicians						
Skin conductance response (µsiemens)[a]	0.39 (0.21)	0.50 (0.26)	0.30 (0.22)	0.40 (0.23)	0.30 (0.21)	0.39 (0.22)
Corrugator activity (mV s)	0.12 (0.10)	0.07 (0.14)	0.27 (0.08)	0.50 (0.15)	0.49 (0.10)	0.14 (0.09)
Zygomatic activity (mV s)	0.15 (0.15)	0.15 (0.18)	0.02 (0.09)	0.09 (0.13)	−0.05 (0.06)	0.00 (0.11)
Interbeat interval (s)[b]						
Reactivity	−1.21 (1.50)	0.81 (1.01)	0.06 (1.52)	0.49 (0.72)	0.39 (1.33)	1.48 (1.28)
Recovery	−2.96 (1.10)	−3.03 (0.84)	−2.42 (0.83)	−2.70 (0.70)	−4.76 (0.95)	−4.78 (1.19)
Physiological measures for non-musicians						
Skin conductance response (µsiemens)[a]	0.25 (0.19)	0.92 (0.24)	0.20 (0.21)	0.45 (0.22)	0.17 (0.20)	0.13 (0.21)
Corrugator activity (mV s)	0.03 (0.11)	−0.11 (0.16)	0.17 (0.09)	0.09 (0.17)	−0.01 (0.11)	−0.04 (0.10)
Zygomatic activity (mV s)	−0.15 (0.16)	0.04 (0.19)	−0.02 (0.09)	−0.09 (0.14)	−0.02 (0.06)	0.05 (0.12)
Interbeat interval (s)[b]						
Reactivity	0.05 (1.75)	−0.46 (1.18)	1.86 (1.77)	−0.34 (0.84)	0.38 (1.55)	0.17 (1.49)
Recovery	−1.06 (0.85)	−0.93 (0.99)	−1.68 (0.97)	−2.81 (0.81)	−2.32 (1.11)	−2.74 (1.39)
Physiological measures mean						
Skin conductance response (µsiemens)[a]	0.32 (0.14)	0.71 (0.18)	0.26 (0.15)	0.43 (0.16)	0.24 (0.15)	0.26 (0.15)
Corrugator activity (mV s)	0.08 (0.08)	−0.02 (0.11)	0.22 (0.06)	0.30 (0.11)	0.24 (0.08)	0.05 (0.08)
Zygomatic activity (mV s)	0.00 (0.11)	0.09 (0.13)	−0.00 (0.06)	−0.00 (0.09)	−0.04 (0.04)	0.03 (0.08)
Interbeat interval (s)[b]						
Reactivity	−0.58 (1.15)	0.17 (0.78)	0.96 (1.17)	0.08 (0.56)	0.39 (0.02)	0.83 (0.98)
Recovery	−2.01 (0.85)	−1.99 (0.65)	−2.05 (0.64)	−2.76 (0.54)	−3.54 (0.73)	−3.76 (0.92)

[a] Calculated for the first 12 musical stimuli

[b] A low IBI means high cardiac rhythm

siveness (mechanical vs. expressive) as within-subject factors, and Musical Expertise (musicians vs. non-musicians) as between-subjects factor.

Physiological measurements

The average and the standard errors for each physiological response are reported in Table 3 as a function of Emotion Category, Expressiveness and Musical Expertise. Figure 1 illustrates the mean values of each physiological measure for each Emotion Category as function of Expressiveness and Musical Expertise.

Skin conductance response

Four participants who did not show any electrodermal responses were classified as non-responders and excluded from this analysis. The analyses were thus performed on the SCL of 23 participants (11 musicians) and for the first 12 trials only due to the presence of a clear habituation effect. The mean electrodermal responses were then entered in a mixed model ANOVA. A main effect of Expressiveness showed that SCL were higher for the expressive versions of the musical excerpts [$F\,(1, 21) = 4.78$, $p < 0.05$; $\eta_p^2 = 0.19$]. No other main effect or interaction was significant.

Facial EMG activity

Two participants (one musician and one non-musician) who had mean EMG responses lying 3 standard deviations over the group average were considered as outliers and excluded from the analysis. Two separate mixed model ANOVAs using the Huynh–Feldt corrected degree of freedom were conducted on the mean corrugator and zygomatic responses. A main effect of Emotion Category was found on the corrugator activity [$F\,(2, 46) = 3.45$, $p < 0.05$; $\eta_p^2 = 0.13$]. Post hoc tests using Bonferroni corrections indicated that sad excerpts elicited more frowning than happy excerpts ($p < 0.05$), but not scary excerpts ($p = 0.67$), and there was no difference between happy and scary excerpts ($p = 0.42$).

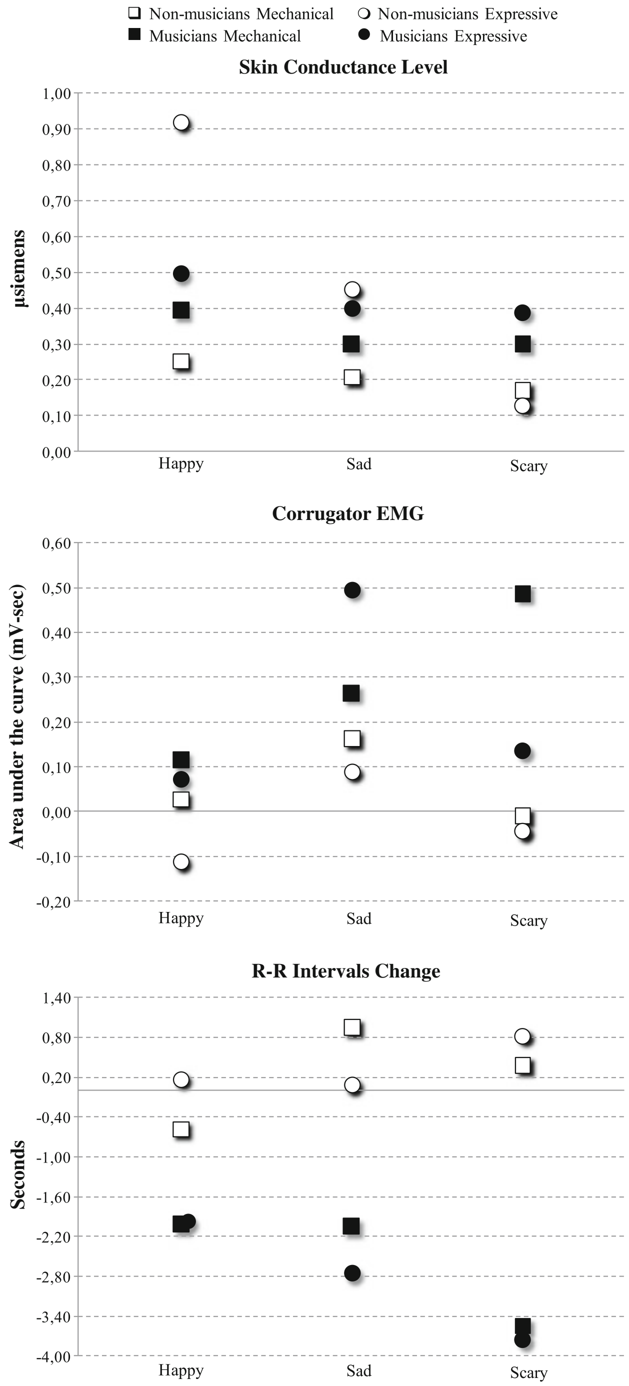

Fig. 1 Mean score (change scores from baseline) of skin conductance level, corrugator EMG and R–R intervals (whatever the reactivity and recovery period) for each Emotion Category (happy, sad, scary) as a function of Expressiveness (mechanical, expressive) and Musical Expertise (musicians, non-musicians)

A main effect of Musical Expertise indicated that musically trained listeners had a larger corrugator EMG activity than the non-musicians [$F(1, 23) = 7.22$, $p < 0.05$; $\eta_p^2 = 0.24$]. There were no significant effects of any of the independent variables on zygomatic activity.

Heart rate activity

One non-musician participant was excluded from the analysis because his data comprised too many values above or below 3 SDs of the grand mean of all subjects' responses. A mixed model ANOVA was performed on the mean R–R interval difference, adding Period of Response (reactivity vs. recovery) as within-subject factor. A main effect of Period [$F(1, 24) = 9.59$, $p < 0.05$; $\eta_p^2 = 0.29$] showed that R–R interval difference was lower (heart rate was faster) during the recovery compared with the reactivity period. Moreover, this effect interacted with the Emotion Category [$F(2, 48) = 4.55$, $p < 0.05$; $\eta_p^2 = 0.16$]. To decompose the effects of the Period of Responses by Emotion Category, two one-way ANOVAs with Emotion Category (happiness, sadness and threat) as the within-subject factor were performed separately for the reactivity and recovery period. There were no effect of Emotion Category during the reactivity period, whereas the recovery period showed a significant effect of Emotion Category [$F(2, 50) = 4.53$, $p < 0.05$; $\eta_p^2 = 0.15$]. As illustrated and confirmed by post hoc tests, R–R interval difference decreased more (i.e., faster heart rate) following scary music than happy ($p < 0.05$) and sad music ($p < 0.05$). There was no significant difference in R–R interval difference between happy and sad music ($p = 1.00$).

Ratings

To assess the effects of the different variables and musical expertise on emotional ratings, a mixed model ANOVA was performed on the mean ratings of emotional intensity felt. A main effect of Expressiveness confirmed that ratings of emotional intensity felt were higher for expressive versions [$F(1, 24) = 25.33$, $p < 0.001$; $\eta_p^2 = 0.51$] and that this effect varied as a function of Emotion Category [Expressiveness × Emotion Category interaction: $F(2, 48) = 3.65$, $p < 0.05$; $\eta_p^2 = 0.13$]. As depicted in Table 4, and confirmed by simple effects analyses, the effects of Expressiveness were higher for sad [$F(1, 24) = 34.95$, $p < 0.001$] than happy [$F(1, 24) = 9.77$, $p < 0.05$] and scary [$F(1, 24) = 7.13$, $p < 0.05$] musical excerpts. The effect of Expressiveness on ratings of emotional intensity felt also interacted with the Musical Expertise [$F(1, 24) = 6.04$, $p < 0.05$; $\eta_p^2 = 0.20$]. Simple effects analyses indicated that the expressiveness of the musical excerpts had a large effect on musicians' ratings [$F(1, 24) = 36.48$, $p < 0.001$], while it had little effect on non-musicians' ratings [$F(1, 24) = 2.70$, $p = 0.11$].

Correlation analyses

To assess the relation between the intensity of the felt emotion and the listeners' physiological responses while music was performed, we evaluated, for each Emotion Category

Table 4 Mean and standard error of emotional intensity felt (from 0, very weak, to 4, very strong) as a function of Emotion Category and Expressiveness

	Happy music		Sad music		Scary music	
	Mechanical	Expressive	Mechanical	Expressive	Mechanical	Expressive
Emotional intensity felt (max. 4)						
Musicians	2.40 (0.10)	2.88 (0.13)	2.32 (0.12)	3.14 (0.10)	2.40 (0.14)	2.82 (0.16)
Non-musicians	2.62 (0.13)	2.71 (0.17)	2.44 (0.16)	2.74 (0.14)	2.47 (0.18)	2.67 (0.20)

Table 5 Mean and standard error of response time to target detection as a function of Emotion Category, Expressiveness and Musical Expertise

	Happy music		Sad music		Scary music	
	Mechanical	Expressive	Mechanical	Expressive	Mechanical	Expressive
Response time (ms)						
Musicians	353.51 (15.15)	369.47 (14.96)	353.01 (15.95)	345.43 (12.96)	354.97 (14.58)	370.62 (15.14)
Non-musicians	360.66 (17.70)	377.10 (17.47)	370.83 (18.62)	367.59 (15.14)	370.17 (17.03)	387.31 (17.68)
Mean	357.09 (11.65)	373.28 (11.50)	361.92 (12.26)	356.51 (9.96)	362.57 (11.21)	378.96 (11.63)

(happiness, sadness and threat) and Expressiveness (mechanical vs. expressive), the correlations between each participant's mean rating of emotional intensity and his/her mean SCL, facial EMG corrugator and ECG. No significant correlation was found except for mechanical sad excerpts (see Appendix). For the latter, SCL were positively and significantly correlated with the ratings ($r = 0.56$; $df = 22$, $p < 0.05$), indicating that the more intense the emotion, the higher the SCL to mechanical sad excerpts was. Such correlation was not observed for the expressive version of the sad stimuli. Furthermore, R–R Interval difference during the reactivity period was negatively correlated with the emotional intensity felt ($r = -0.42$; $df = 25$, $p < 0.05$), suggesting that the higher the emotional intensity, the lower was the R–R Intervals (higher heart rate) in the reactivity period. These relations were independent from the listeners' musical expertise.

Target detection

Hit rate, false alarm rate and corrected detection score (hit minus false alarm) reached 0.99, 0.01 and 0.99, respectively, indicating that the detection task was very easily performed. Data from one musician were excluded from the analysis because his mean RT was 3 SD above the mean of all participants. The mean response times of the other participants were entered in a mixed model ANOVA. This analysis yielded an interaction between Emotion Category and Expressiveness with $F(2, 48) = 6.97$, $p < 0.05$; $\eta_p^2 = 0.23$. As reported in Table 5, simple effects analyses indicated that the increase of RTs observed in expressive music compared to mechanical music was significant for happy [$F(1, 24) = 10.03$, $p < 0.05$] and scary music [$F(1, 24) = 9.07$, $p < 0.05$], but not for sad music [$F(1, 24) = 0.98$, $p = 0.33$].

Further correlation analyses did not show a significant relationship between detection performances and physiological measures except for the sad mechanical excerpts in musicians. Accordingly, the more corrugator activity there was, the longer musicians' RTs detections were, with $r = 0.83$; $df = 10$, $p < 0.05$.

Discussion

One important goal of this study was to examine the joint influences of structural and expressive cues on emotional responses to music. The results show that musical structure and musical expressiveness have different effects on physiological activity, ratings of emotional intensity felt and target detection response times. Although emotion category and expressivity were manipulated in a laboratory context environment, we did observe changes in subjective and physiological responses to music, corroborating the findings that musical emotions may occur regardless of a specific context (Juslin et al., 2008).

The effects of musical structure on physiological responses appeared to be independent from the effects of musical expressiveness. SCLs were only found to be affected by musical expressiveness. As a consequence, even sad excerpts displayed larger SCLs when played with expressiveness, although sad excerpts are typically associated with low SCLs. This is consistent with a study by Rickard (2004) showing that musical excerpts considered as 'emotionally powerful' induced higher skin conductance levels as compared to musical excerpts rated as more arousing, but not as 'emotionally powerful'.

In contrast, the activity of the corrugator was influenced by musical structure: sad music elicited larger corrugator activity than happy stimuli. This effect indicates that listeners showed spontaneous facial expression that matched the emotion conveyed by the music, suggesting a mirroring reaction (i.e., frowning when listening to sad music) and opening the possibility of emotional contagion mechanism (Davies, 2011; Juslin & Västfjäll, 2008). Musical expressiveness did not affect corrugator activity and did not interact with the musical structure, suggesting that musical structure and expressiveness have distinct effects on corrugator activity. The lack of effects of musical structure on zygomatic activity is consistent with previous findings in the visual domain showing the zygomatic to be less sensitive to the valence of stimuli than the corrugator (Bradley, 2000; Larsen, Norris, & Cacioppo, 2003).

Heart rate was also influenced by musical structure, independently from musical expressiveness. Acceleration of the cardiac activity in the recovery period was larger after hearing scary than sad music, which in turn was larger than after happy music. This suggests that the valence of music influences cardiac activity in the form of an acceleration during the recovery period for the most unpleasant music (i.e., scary). These findings extend previous data in the visual and auditory domain by showing that unpleasant pictures/sound lead to a significant change of cardiac activity (Bradley, Codispoti, Cuthbert, & Lang, 2001); Bradley, Greenwald, Petry, & Lang, 1992; Bradley & Lang, 2000, 2001; Lang, Bradley, & Cuthbert, 1998a; Lang, Bradley, Fitzsimmons, Cuthbert, Scott, & Moulder, 1998b). The acceleration of cardiac activity observed here after listening to scary music is also compatible with a defensive reaction that typically occurs when an individual experiences fear. In addition to the effects of musical structure, results showed that the more intense the mechanical sad excerpts were, the quicker the heart rate was. This suggests that emotionally powerful excerpts may produce cardiac acceleration, independently of expressiveness.

When one considers the relationship between the physiological indexes of emotional reactions and subjective feelings, very few correlations were found. One explanation may be that, contrary to the physiological indexes, the ratings are discrete measurements which cannot continuously capture all the variations of the emotions felt. This makes the use of ratings difficult to account for the between-subject differences in physiological reactivity. Studying the continuous ratings of the emotion felt intensity to examine more closely the relationship between subjective feeling and physiological reactivity could be addressed in the future. Another explanation would be that explicit (i.e., ratings) and implicit (i.e., physiological indexes) measures may be sensitive to different processes, which would be consistent with the observations that more musical training has an influence on explicit but not implicit measures.

In the target detection task, listeners' attention was also modulated by the emotion expressed by the musical excerpts. Expressiveness was found to increase target detection times for dynamic excerpts like happy and scary ones, but not for sad stimuli. This suggests that expressiveness alone is not sufficient to draw more attention, but needs a certain level of arousal. The reason why expressive scary and happy excerpts attracted more attention than their mechanical versions can be thought to be quite different. Scary stimuli attract more attention because fear may be considered as a phylogenetically important reaction for the survival of the organism. This is compatible with the well-established fact that fearful stimuli attract more attention (Fox, 2002; Fox et al., 2000; Öhman et al., 2001a, b; Tipples et al., 2002; Vuilleumier, 2002). On the other hand, the expressive versions of happy excerpts might have enhanced their appeal, and hence may have attracted more attention. These current findings do not corroborate previous data (Olivers and Nieuwenhuis (2005) showing that high-tempo musical excerpts such as happy and scary music cause improvements in detecting (visual) target in indirect attention task. This apparent discrepancy might be attributed to a difference of cross versus intramodal attention. The current results indicate that expressive and arousing musical context interferes with the detection of auditory target, suggesting that in intramodal attention, an affective stimulus (i.e., expressive happy or scary music) competes with a neutral auditory stimulus (i.e., breathing sound) that one can observe in any other visual context.

Given that we used fixed time intervals for auditory targets (i.e., natural breathing sound), it might result in their presence in positions where they usually do not occur, especially in expressive stimuli. This raises the question whether the listeners' expectations might not be fulfilled more in the expressive condition than in the mechanical one. To test this possibility, we computed an additional mixed model ANOVA analysis on the mean response time with the target location (1,500, 4,500 and 7,500 ms) and the musical version (mechanical vs. expressive) as within-subject factors. The data showed that the increase of RTs observed in expressive music compared to mechanical music was significant when the target was located at the beginning of the musical excerpt and not at later locations (4,500, 7,500 ms). These results suggest that the listeners' expectations were not systematically violated (through the different locations) more in the expressive than in the mechanical condition. Rather, these data indicate that the effect of expressiveness is stronger when the breathing is located at a position where its apparition is the most unpredictable (i.e., at the beginning of the musical excerpt, i.e., 1,500 ms).

Musical expertise also appeared to be an important variable to take into consideration when testing the effects of musical expressiveness. Musical expressiveness had a much larger influence on musicians' ratings of emotional intensity compared to non-musicians. This is compatible with musical expressiveness relying on much subtler cues than musical structure, which can be picked up more easily or consciously by a trained ear. In contrast and as expected, musical expertise did not have any effect on covert measures of emotion, such as physiological responses. The only difference between musicians and non-musicians was observed in corrugator activity, which was larger in musicians as compared to non-musicians. Interestingly, the facial EMG activity is the only physiological measure considered here that can be controlled voluntarily as well as involuntarily. This effect might reflect a general dislike of the experimental musical stimuli by professional musicians. Alternatively, increased frowning to excerpts might reflect a more attentive and analytic disposition in musicians compared to non-musicians. Apart from this effect, musical expertise had no effects on heart rate, SCLs or RT in target detection. These differential effects of musical expertise on explicit and implicit measures are consistent with the view that musicians are usually more sensitive to explicit tasks (Bigand & Poulin-Charronnat, 2006).

In sum, the effect of expressiveness was found on ratings on motor responses (i.e., frowning) and on autonomic responses (i.e., heart rate) especially for sad excerpts. This effect might be related to the fact that the violin has a timbre and expressive features that are particularly well suited to convey sadness. Whether particular instrumental timbres (i.e., violin, trumpet, timpani) are better at expressing one emotion than another (i.e., sadness, anger, threat) has been addressed by Behrens and Green (1993). In their study, the authors showed that listeners were relatively accurate in decoding emotions and intentions. However, differences appeared depending upon the performing instrument and the expressed emotion. Listeners were most accurate in identifying sadness and threat when played on violin as compared to a trumpet or on timpani. In the future, it would be worthwhile to extend the current study to other musical instrumentations and styles.

Regarding the expressiveness factor, our analyses indicated that acoustic changes between expressive and mechanical versions of happy stimuli were quite subtle, making them more difficult to distinguish in terms of expressivity (Tables 1, 2). However, despite the absence of significant difference in expressiveness ratings between the expressive and the mechanical versions of happy stimuli, the mean value of expressiveness rating was higher for expressive version than for the mechanical one. Furthermore, assessments of felt emotional intensity showed that expressiveness had a positive effect on these ratings also for happy music. Altogether, these data indicate that despite the slight acoustic differences between the mechanical and the expressive versions of the happy musical excerpts, ratings indicate an influence of expressivity.

Given the relatively short duration of musical stimuli, one may argue that this may challenge their ability to induce emotions, leading participants to recognize them rather than experience them. Although it is likely that longer musical excerpts may convey stronger felt emotions, this is not to say that current excerpts were not successful to induce emotions. First of all, our results indicated that participants reported moderate intensity of felt emotion as well as significant differences in physiological reactivity. Furthermore, previous data demonstrated that music as short as a 13-s piece may recruit neural mechanisms involved in pleasant/unpleasant emotional responses (Blood et al., 1999). Taken together, these findings allow us to reasonably assume that the musical emotions were not only recognized, but indeed felt.

In conclusion, the present study supports the notion that music interpretation has an important impact on listeners. The fact that music expressiveness sometimes affects emotional responses (i.e., SCL) across emotion categories suggests that a real performance might, to a certain extent, supplant the musical structure in determining its emotional impact. Expressiveness not only amplifies the intended emotion conveyed by music structure, but also makes music more engaging and more emotionally intense. Numerous anecdotal evidences suggest that music performance is the key to the expressive power of music. It would be interesting to further investigate the respective influence of music performance and structure with an orthogonal control of these two factors (e.g., musical excerpts written to communicate happiness but performed with sad intent). Such approach would permit distinguishing the respective effect of performance and structure both on the overt (i.e., judgments) and covert (i.e., indirect measures) emotional reactions to music. Moreover, beyond the control of musical characteristics and listeners' musical expertise, the understanding of how music conveys emotions also requires investigations on the role of individual factors (Juslin et al., 2008). Future works are needed to test whether personality traits may determine emotional responses to musical excerpts controlled on their emotional meaning and expressivity.

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Appendix

See Table 6

Table 6 Correlations between the mean rating of emotional intensity and the mean SCL, facial EMG corrugator activity and ECG (for reactivity and recovery period) as a function of Emotion Category (happiness, sadness and threat) and Expressiveness (mechanical vs. expressive)

	Happy music		Sad music		Scary music	
	Mechanical	Expressive	Mechanical	Expressive	Mechanical	Expressive
Physiological measures						
Skin conductance response ($n = 22$)	0.19	−0.09	0.56*	0.18	0.28	0.12
Corrugator activity ($n = 24$)	−0.16	−0.03	0.14	0.15	0.23	0.10
R–R intervals difference (reactivity) ($n = 25$)	0.12	−0.33	−0.42*	−0.36	−0.18	0.08
R–R intervals difference (recovery) ($n = 25$)	0.26	0.17	0.19	−0.00	0.16	0.11

*$p < 0.05$

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