Musical emotions in congenital amusia: Impaired recognition, but preserved emotional intensity

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Running title: Musical emotions in congenital amusia

Abstract:

Objective: To further our understanding of the role of perceptual processes in musical emotions, we investigated individuals with congenital amusia, a neurodevelopmental disorder that alters pitch processing.

Methods: Amusic and matched control participants were studied for emotion recognition and emotion intensity ratings of both musical excerpts and faces.

Results: Emotion recognition was found to be impaired in amusic participants relative to controls for the musical stimuli only. This impairment suggests that perceptual deficits in music processing reduce amusics' access to a verbal and conscious representation of musical emotions. Nevertheless, amusics' performance for emotion recognition was above chance level, and Multidimensional Scaling analyses revealed that their categorization of musical pieces was based on similar representation spaces of emotions as for control participants. The emotion intensity ratings, non-verbal and possibly more implicit than the categorization task, seemed to be intact in amusic participants.

Conclusions: These findings reveal that pitch deficits can hinder the recognition of emotions conveyed by musical pieces, while also highlighting the (at least partial) dissociation between emotion recognition and emotion intensity evaluation. Our study thus sheds light on the complex interactions between perceptual and emotional networks in the brain, by showing that impaired central auditory processing partially alters musical emotion processing.

Keywords: tone deafness – music perception – emotion categorization - multidimensional scaling - acoustic features

Public Significance Statement

This study shows that congenital amusics are impaired in musical emotion categorization. However they are able to evaluate the emotion intensity in musical pieces. This suggests that pitch processing deficits specifically alter verbalized, conscious representations of musical emotions.

1. Introduction

Congenital amusia is a neurodevelopmental disorder that impairs music perception and production (e.g., Peretz et al., 2002; Peretz & Hyde, 2003; Stewart, 2011), while general cognitive abilities are normal (e.g., Foxton et al., 2004; Williamson & Stewart, 2010). Pitch perception and memory are crucially altered (e.g., Albouy, Schulze, Caclin, & Tillmann, 2013; Ayotte, Peretz, & Hyde, 2002; Peretz et al., 2002; Tillmann, Schulze, & Foxton, 2009; Williamson, McDonald, Deutsch, Griffiths, & Stewart, 2010; Williamson & Stewart, 2010), but timbre processing also shows anomalies (Marin, Gingras, & Stewart, 2012; Tillmann et al., 2009), and impaired rhythm processing is associated to amusia in some contexts (Foxton, Nandy, & Griffiths, 2006; Peretz, Champod, & Hyde, 2003). A set of neuroimaging studies have provided evidence for a fronto-temporal dysfunction underlying these deficits, with the right Inferior Frontal Gyrus and the right Superior Temporal Gyrus showing structural, functional and connectivity abnormalities (Albouy et al., 2013, 2015; Hyde et al., 2006, 2007, 2011; Leveque et al., 2016; Loui et al., 2009; but see Chen et al. 2015).

Anomalies of emotional circuitry/limbic system were not reported in any of these neuroimaging reports. However, the perceptual alterations observed in amusia are likely to hinder the emotional processing of music. One could hypothesize for example that the processing of musical structures and regularities, as well as the building of expectancies underlying musical emotions (e.g., Juslin & Västfjäll, 2008; Steinbeis et al., 2006), could be less efficient in amusic individuals. Congenital amusia offers a unique opportunity to investigate the impact of impaired central auditory processing on the processing of musical emotions.

First investigations of musical emotions in congenital amusics yielded mixed results. Ayotte et al. (2002) reported that the happy or sad tone of short piano clips of Western classical music was properly inferred by amusic participants, according to ratings on a subjective scale from sad to happy. However, they observed that the ratings of the amusic participants on the sad-to-happy scale were significantly less extreme than the controls' ratings. A more recent study using a larger set of emotions (happiness, sadness, fear and peacefulness) expressed by unfamiliar musical piano clips failed to reveal any difference in emotion recognition between amusic and control participants (Gosselin et al. 2015). Participants were asked to indicate on four separate scales to what extent each clip expressed each of the four emotions, and both participant groups gave the highest rating for the emotional label that corresponded to the intended emotion. Nonetheless, a possible lack of power might explain the absence of performance difference between control and amusic participants, given the marginal statistical significance reported. Moreover, in the same study, the inversion of music mode from major to minor (and vice versa) did not influence amusics' as much as controls' happiness and sadness ratings. Sensitivity to consonance and harmonicity in chords as reflected by pleasantness ratings (Ayotte et al. 2002; Cousineau et al., 2012; Marin et al., 2015) and a discrimination task (Cousineau et al. 2012) were also found partially abnormal in amusics compared to controls. Importantly, two survey studies suggested that musical emotion experience may be reduced in some congenital amusics. In these surveys, approximately half of the amusic participants reported not liking music or feeling few emotions when listening to music (MacDonald & Stewart 2008, Omigie et al. 2012), while only 6% of the controls made the same statements. Overall, this body of data suggests some abnormalities in musical and pitch-linked emotion processing in congenital amusics. However, no study has yet provided evidence for a deficit in emotion recognition with musical stimuli, as the two studies who investigated musical emotion processing in congenital amusia concluded for intact processing (Ayotte et al 2002, Gosselin et al. 2015).

In our present study, congenital amusic participants and control participants undertook a musical emotion recognition task on orchestrated musical recordings of classical music, which are expressing joy, sadness, fear, or serenity. In contrast to previous studies investigating amusic individuals that have used musical materials played by a computer-generated piano timbre, our musical excerpts were ecological, being similar to classical music we are exposed to in everyday life. Participants were asked to indicate the emotion that was evoked by each item by choosing one of the four categories (joy, sadness, fear or serenity). After this first forced-choice question, participants were then asked to rate the intensity of the evoked emotion on a subjective scale. Our hypothesis was that amusics' impairment in pitch, timbre and rhythm processing could alter emotion recognition and emotion intensity ratings for the music material. Note that this protocol enabled us to separately assess emotion recognition (cognitive ability to categorize emotions with a verbal label) by a forced-choice question, and a more global emotion evaluation thanks to the use of the intensity scale, proposed after the categorization task.

Previous studies investigating musical emotions in typical individuals have shown that various acoustic features can underlie emotion ratings, covering both sensory and tonality-related characteristics of the musical pieces (see Alluri et al., 2012; Coutinho et Cangelosi, 2011; Eerola, 2011; Quarto et al., 2014; Trochidis et al., 2011). We further investigated participants' performance by analyzing the structure of emotion categorizations with the use of 1) acoustic analyses of the musical excerpts and 2) multidimensional scaling (MDS) of the emotion judgments. By relating acoustic analyses to the behavioral responses, we aimed to provide further information about amusics' musical feature processing and their link to the evoked emotions. Previous research using MDS analyses has shown that musical emotion ratings tend to be organized along two main axes: arousal and valence (Bigand et al., 2005; Russell, 1979), and we compared here the obtained representations between amusics and controls. In line with the results of Cousineau et al. (2012), Marin et al. (2015) and Gosselin et al. (2015), we expected roughness to be an acoustic feature that amusics are able to use for the categorization task, while features related to pitch-structures, like mode and harmonicity change, would be underused in amusics compared to controls.

In addition to the musical material, participants performed the same two tasks with photos of faces expressing joy, sadness, fear, or no specific emotion (neutral). This visual control task was chosen to exclude any global anhedonia or unspecific emotion recognition deficit (including difficulty to understand instructions or emotion labels) of the amusic participants, while not involving any pitch processing.

2. Methods

2.1 Participants

Thirteen amusic participants (7 females, 6 males) and thirteen control participants matched for age, gender, educational background and musical training (see Table 1) gave their written informed consent to participate in the study. Participants from both groups were first tested in a separate session with an audiometry, an adaptive pitch discrimination test (“PDT”, following the protocol described in Tillmann et al. 2009) and the Montreal Battery of Evaluation of Amusia (MBEA, Peretz et al., 2003), 23/30 being the cut-off score on the total MBEA score to consider a participant as amusic. The audiometry revealed normal peripheral hearing in all participants (loss <25dB at 250, 500, 1000, 2000, 4000 and 8000Hz). Mean MBEA scores and pitch discrimination thresholds are indicated in Table 1. The study procedures were approved by the appropriate ethics committee (CPP Sud-Est II, authorization number C08-06).

Please insert Table 1 around here

Prior to the experimental session and as part of a general screening procedure, participants filled out a questionnaire about their musical experience and their relationship to music (based on questionnaires of Mc Donald & Stewart (2008), Sloboda, Wise and Peretz (2005), and Peretz et al. (2009)). Among more than 90 questions, this questionnaire included 14 affirmations about personal experience of musical emotions (9 positive and 5 negative sentences) (e.g., “Certain music can sometimes motivate or excite me”). Participants indicated on a scale from 1 to 5 to what extent they agree with each statement (from 1: Completely disagree to 5: Completely agree). The ratings of the 14 items were averaged for each participant (after reverse coding of the responses to the negative items) to compute a musical emotion score. This musical emotion score based on a self-report did not differ significantly between amusic and control participants (Amusics’ average score: 3.76±0.8 on a 5-point scale; Controls’ average score: 4.00±0.54; $t(23)=0.85$; $p=.403$).

2.2 Material

Musical stimuli were forty orchestrated musical excerpts of 20s, selected from the Western classical repertoire and that were instrumental only, without voice (Bigand et al. 2005, Filipic et al. 2010, Liegeois-Chauvel et al. 2014). This selection was not constructed to manipulate certain acoustic parameters of interest for musical emotion, but aimed to be representative of four emotions in the framework of real classic music recordings. The set included ten excerpts strongly related to joy (e.g., an excerpt from Beethoven's Piano, Sonata 32, mvt 2), ten to sadness (e.g., an excerpt from Shostakovitch's Symphony 15, Adagio), ten to fear[1] (e.g., an excerpt from Prokovief's Sonata for piano, no. 3, op. 28) and ten to serenity (e.g., an excerpt from Scarlatti's Sonata A for Harpsichord). There were thus two positive valence emotions and two negative[2] valence emotions, with for each valence a low and a high arousal emotion. For the visual control task, 40 black and white photos of faces expressing emotions were chosen from Ekman & Friesen (1976). Ten faces were related to joy, ten to sadness, ten to fear and ten were emotionally neutral. Neutrality was used instead of serenity, an emotion difficult to express and recognize on a face.

Presentation software (Neurobehavioral systems, Albany, CA, USA) was used to control the presentation of stimuli and record participants' responses given on the keyboard.

2.3 Procedure

The experiment took place in a sound-attenuated booth. After having listened to each musical excerpt, participants were asked to indicate the emotion that was evoked by the excerpt, with only one possible response per excerpt among the four emotions: Joy, Sadness, Fear or Serenity. Participants were then asked to rate the intensity of the selected emotion on a subjective scale from 1 (weak) to 5 (strong). The following excerpt was automatically presented after a delay of 2500 ms on average (ranging from 2000 to 3000 ms). Participants were not asked to distinguish between felt and perceived emotions, a

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[1] Anger and fear may be evoked by the same musical excerpts (e.g., Johnsen et al. 2009); participants were told that one or the other had to be included under the label "Fear" presented on the screen.

[2] Sadness does not always evoke sadness in the listener (felt emotion, e.g., Taruffi & Koelsch 2014), but the negative valence is easily perceived (Bigand et al. 2005; Dalla Bella et al. 2001), and used to distinguish sadness from other emotion categories (here, for example serenity).

distinction that can be ambiguous to perform in an explicit way (e.g., Scherer, 2004), or even impossible according to theories of embodied cognition (e.g., Niedenthal et al., 2007).
For the control task, each face appeared on the screen for 3s before participants could give their responses. Participants first indicated the emotion evoked by the face (Joy, Sadness, Fear or “Neutral”). They were then asked to rate the intensity of the selected emotion on the same subjective scale as for the music material, except for the cases when the participants answered « Neutral » to the emotion recognition question. Indeed, it does not seem applicable to request participants to quantify the intensity of neutrality. The following picture was automatically presented after a delay of 1250 ms on average (ranging from 1000 to 1500 ms).

Presentation order of music and face materials was counter-balanced across participants, and item order was randomized within the modality (music or face) for each participant. The total duration of the experiment was 20 minutes, and participants were paid for their participation.

3. Results

The percentage of correct emotion recognitions and the average emotion intensity ratings for correctly categorized items were calculated for each material (music or faces), emotion and participant. The average intensity ratings only included the trials that were correctly categorized in the a priori category (see footnote 3 for analysis including all the trials). Data were analyzed with two 2x4 Analyses of Variance with Group (Amusics versus Controls) as between-participants factor, and Emotion (Joy, Sadness, Fear, Serenity/Neutral) as within-participant factor, for the Music and Face materials, respectively. Note that modality (Music versus Face) was not included as a factor in the ANOVA design because Serenity (for music) and Neutral condition (for faces) were not directly comparable.

3.1 Music material

3.1.1 Emotion recognition

The test of Kolmogorov-Smirnov applied to data for each group and emotion did not revealed any significant deviation from normality (ps>.20). No participant had outlier performance, defined as a performance under 2.5 standard deviation from their group's mean. The ANOVA (Figure 1a) on categorization scores revealed a significant main effect of Group ($F(1,24)=20.12$, $p<.001$, partial $\eta^2=0.45$), with lower performance for the amusic than the control participants. A significant main effect of Emotion was also observed ($F(2.91;69.86)=12.87$, $p < .001$, partial $\eta^2=0.36$), with Joy and Fear being better recognized than Sadness and Serenity (Joy better recognized than Sadness: p=.004; and than Serenity: p<.001; Fear better recognized than Sadness: p<.001; and than Serenity: p<.001), according to HSD Tukey post-hoc tests. There was no difference between Joy and Fear (p >.800) and between Sadness and Serenity (p > .900). The Group and Emotion factors did not interact significantly ($F(1.96,47.16)=0.98$; $p=.406$; partial $\eta^2=0.04$). Appendix C illustrates categorization hit rates corrected for the probability of detection of hits at the group level (H_u, Wagner 1993).

Despite lower performance of amusic participants, their scores were significantly above chance for the four emotions, here 25 % (ts(12)>.6.61; ps<.001).

Please insert Figure 1 around here

The participants' global MBEA scores and their mean categorization scores across emotions were significantly correlated ($r(24)=.55$; $p=.004$), but this correlation was mainly driven by the group difference and was not significant within each group (amusics: $r(11)=-.08$, $p=.777$; controls: $r(11)=-.15$, $p=.612$, see figure in Appendix B). The subtests Scale, Contour, Interval and Memory were also significantly correlated to the categorization scores (rs(24)>.48, ps<.05), but these correlations were driven by the group effect and not significant within each group (rs(24)<.53, ps>.05). Correlation between the Scale subtest and the categorization scores in amusics was however marginally significant ($r(11)=.53$, $p=.063$). No significant correlation was found between the participants' musical emotion scores and their categorization scores ($r(24)=.24$; $p=.233$), neither between the pitch discrimination thresholds and the categorization scores ($r(24)=-.26$; $p=.193$)

Confusion matrices for the music material are shown in Table 2. Off-diagonal scores of amusic and control participants (incorrect categorization percentages) were compared two-by-two using proportion homogeneity tests, and revealed no significant difference between any of them (all ps>.200).

Please insert Table 2 around here

3.1.2 Emotion intensity ratings

Participants' emotion intensity ratings for musical stimuli covered the entire scale (from 1 to 5), showing that participants actually used the whole range of proposed intensity levels to evaluate the excerpts. The ANOVA on these emotion intensity ratings (Figure 1c) revealed no effect of Group ($F(1,24)=1.71; p=.212$, partial $\eta^2=0.07$), a marginal effect of Emotion ($F(2.46,59.21)=2.58$; $p=.072$, partial $\eta^2=0.10$) and no Group*Emotion interaction ($F(2.46,59.21)=0.29$; $p=.787$, partial $\eta^2=0.01$)[3].

A marginal positive correlation was found across all participants between MBEA scores and emotion intensity ratings ($r(24)=.33$, $p=.093$, but not within the amusic group: $r(11)=.25$, $p=.406$ or within the control group: $r(11)=.22$, $p=.461$).

An analysis by excerpt showed that emotion intensity was variable between excerpts for both amusic and control participants (the average ratings for each excerpt across controls ranged from 2 to 4.36 and across amusics from 1.75 to 4.50). Musical emotion intensity ratings of control and amusic participants were significantly correlated ($r(38)=.55$, $p<.001$, see Figure 2). The inter-rater reliability in musical emotion intensity ratings (calculated across all excerpts, whether correctly or incorrectly categorized) did not differ between amusics and controls: Cronbach alpha= 0.61 for amusics and 0.75 for controls (Fisher-Bonett test: $Z=0.72$; $p=.767$).

[3] This ANOVA was run again with intensity ratings of all the trials –and not just the correctly categorized ones, and additionally on the subset of trials correctly categorized by each amusic participant and his/her matched control. In both cases, there was no Group effect ($p>.110$), a significant Emotion effect ($p<.032$), and no interaction between Group and Emotion ($p>.237$). Serenity and Fear excerpts were rated as more emotionnally intense than Joy and Sadness excerpts.

Correlation between emotional intensity ratings and percentage of correct categorizations did not reach significance in the control group ($p=.102$), probably due to a ceiling effect, but was significant in the amusic group ($r(38)=.52$, $p<.001$). Furthermore, percentage of amusic participants who failed to properly categorize the excerpt increased for excerpts that were rated as less intense by the controls: $r(38)= -.32$, $p=.046$. This means that amusics' confusions occurred particularly on excerpts that were judged as less emotionally intense by the controls.

No significant correlation was found between the participants' musical emotion scores and mean intensity ratings ($r(24)=.27$; $p=.171$).

Please insert Figure 2 around here

3.2 Face material

3.2.1 Emotion recognition

The test of Kolmogorov-Smirnov applied to data for each group and emotion revealed that data for the Joy and Fear conditions deviated from normality (ps<.05), reflecting a ceiling effect in performances, for the amusic as for the control group. An ANOVA was nonetheless conducted on performance for the four emotions in the Face task, in order to maintain a parallel analysis to music data[4]. No participant had outlier performance, defined as a performance under 2.5 standard deviation from their group's mean. Data are synthesized on Figure 1b. The ANOVA revealed a significant effect of Emotion ($F(1.68,40.40)=15.04$, $p<.001$, partial $\eta^2=0.38$), with Joy and Fear better recognized than Sadness and Neutrality (all ps<.001 according to Tukey post-hoc tests), while no difference was found between Joy and Fear recognition, neither between Neutrality and Sadness recognition (ps>.9). There

[4] A non-parametric analysis gave similar results: Mann-Whitney Test U with a Group factor, after averaging across emotions: $U=81.5$, $p=.898$.

was no difference in group performances (Group main effect: ($F(1,24)=0.54$; $p=.471$, partial $\eta^2=0.02$), and no interaction between Group and Emotion ($F(1.68,40.40)=0.45$; $p=.609$, partial $\eta^2=0.02$). However, given the very high scores measured for joy and fear recognition, a ceiling effect may underlie these results. Appendix C also illustrates categorization hit rates corrected for the probability of detection of hits at the group level (H_u, Wagner 1993).

No correlation was found between MBEA scores and emotion recognition from faces (averaged across emotions): $r(24)=-.0002$ (Pearson correlation coefficient), $p>.8$; or between emotion recognition in face and emotion recognition in music: $r(24)=.04$.

Confusion matrices for the Face material are showed Table 4. Off-diagonal scores of amusic and control participants (incorrect categorization percentages) were compared two by two using a proportion homogeneity test, and revealed no significant difference between any of them (all $ps>.5$).

Please insert Table 3 around here

3.2.2 Emotion intensity ratings

The ANOVA on intensity ratings (Figure 1d) revealed a significant effect of Emotion ($F(1.96,47.16)=22.64$; $p<.001$, partial $\eta^2=0.48$), with Joy and Fear rated higher than Sadness (all $ps<.001$), while no difference was found between Joy and Fear ratings ($p>.9$), similarly as for the musical material. There was no difference in group performance ($F(1,24)=1.21$; $p=.281$, partial $\eta^2=0.05$), and no interaction between Group and Emotion ($F(1.96,47.16)=0.97$; $p=.385$, partial $\eta^2=0.04$).

An analysis by item revealed that facial emotion intensity ratings of control and amusic participants were significantly correlated ($r(28)=.92$, $p<.001$, see Figure 3). Correlation between emotional intensity ratings and percentage of correct categorizations was significant in the control group ($r(28)=.43$; $p=.016$), and in the amusic group ($r(28)=.45$, $p<.012$). Note that neutral items were not included in these analyses because they did not require an emotion intensity rating.

Please insert Figure 3 around here

The inter-rater reliability in facial emotion intensity ratings did not differ between amusics and controls: Cronbach alpha= 0.95 for amusics and 0.97 for controls (Fisher-Bonett test: Z=0.66; p=.746).

3.3 Bayesian analyses

Data were reanalysed using a bayesian model (software JASP 8.0.1.2) with a Group (Amusics versus Controls) and a Modality (Music versus Face) factor. Data were averaged across the three overlapping emotions categories across modalities (Serenity and Neutrality were discarded from this analysis).

For emotion categorization scores, the best-fitted model was the combination of the main effects of Group and Modality and their interaction, associated to a Bayes Factor (BF) superior to 8000000. Following the guidelines provided by Lee and Wagenmakers (2014), we considered that a Bayes Factor gives an anecdotal evidence of an effect when lower than three, a positive evidence when comprised between three and 10, a strong evidence between 10 and 100 and a decisive evidence when higher than 100. Combination of both main effects gave a BF superior to one million; Modality alone a BF of 789242, while the Group effect alone gave a BF of 0.8 only. Overall, the full model thus gave a “decisive evidence” in favor of the effects reported in previous sections.

For intensity ratings, the amount of evidence for the null hypothesis was quantified: no Group effect and no interaction between Group and Modality were expected given the results reported in previous sections. The absence of effect of both main factors and their interaction was sustained by an BF of 11 (“strong evidence”) in favor of no effect of this model, in line with the results reported in previous sections.

3.4 Multidimensional scaling

To get more insight into the structure of musical emotion categorization in congenital amusia, we performed MDS of participants' ratings. In order to obtain a MDS representation, musical excerpt categorization was represented by a 40x40 proximity matrix for each participant, indicating 1 when a pair of excerpts was categorized with the same emotion label, and 0 otherwise. These individual matrices were summed across amusic participants and across control participants respectively, and MDS (as implemented in Statistica software, StatSoft 2011 v10, www.statsoft.fr) was run on each group matrix. To determine how many dimensions were necessary to explain the data, the stress-values from one to four dimensions were plotted. An elbow in the plots indicated that a 2D model best explained the data for the amusic group and for the control group. Observation of these spaces confirmed that the data were organized along a valence and an arousal axis in both participant groups (as also observed in Bigand et al., 2005, using a subset of the stimuli used here). As MDS solutions are invariant by rotation, we were thus able to align the axes of the MDS solutions in meaningful directions using a procrustean rotation towards a 2D valence and arousal space (see Fig. 4). The category borders were found fuzzier in amusics than in controls: an ANOVA on the distance between each excerpt and the barycenter of its a priori category in the MDS solutions yielded a significant Group effect ($F(1,36)=11.92$, $p=.001$, partial $\eta^2=0.24$), with fuzzier categories in the amusic group, and a significant Emotion effect ($F(3,36)=3.06$; $p=.040$, partial $\eta^2=0.20$), with Sadness and Serenity-evoking excerpts being more scattered than Fear-evoking excerpts (respectively $p=0.014$ and $p=.032$ according to a Fisher LSD post-hoc test). The interaction between Group and Emotion was not significant ($p=.108$).

Please insert Figure 4 around here

3.5 Acoustical measures

To investigate whether amusic and control participants used different acoustic and/or tonal features to categorize the musical excerpts, we described each excerpt by a set of acoustic and tonal features using the MIR toolbox (Lartillot & Toiviainen 2007). The used parameters (see Appendix A and Figure 5) selected on the basis of the work by Fornari and Eerola (2013) and Quarto et al. (2014), can be separated in four sensory, acoustic-based feature information and six higher-level, cognitive features. The sensory features included the standard deviation of Intensity (based on the root-mean-square energy RMS), mean spectral Roughness (or sensory dissonance; based on Plomp and Levelt, 1965), mean spectral Brightness (high frequency energy, based on Juslin, 2000), and mean Spectral novelty (based on the similarity of the harmonic spectrum between consecutive time points). The cognitive features included the mean tonal Mode (estimate of the modality, i.e., major vs. minor key), maximum Key Strength (best fitting key, Krumhansl, 1990), mean Pulse Clarity (estimation of the strength of the beat, Lartillot et al. 2008), Harmonic change (mean tonal Harmonic Change Detection Function, which corresponds to the flux of the tonal centroid; Harte & Sandler, 2006), and Chromagram novelty standard deviation (based on the similarity of the chromagram between consecutive time points). The sensory and cognitive features are related to pitch structure (Mode, Key Strength, Harmonic Change), timbre (Roughness, Brightness, Spectral Novelty, Chromagram novelty: mean and SD), intensity (SD of Intensity) and rhythm (Pulse Clarity). They were computed after frame decomposition with a frame length of 50 ms and half overlapping (see Figure 5 and Table A in appendix). They were correlated to the coordinates of the 40 excerpts on the two axes of the MDS space for the amusic group and the control group, respectively.

Please insert Figure 5 around here

Several correlations between MIR features and the two axes of the emotion spaces (i.e., valence and arousal) recovered with this MDS were significant, in both amusics and controls. Coordinates of the excerpts on the Valence axis were positively correlated to Key strength, Mode and Chromagram Novelty ($rs(38)>.45$; $ps<.004$ in amusics, $rs(38)>.45$; $ps<.003$ in controls) and negatively correlated to Roughness ($r(38)=-.45$; $p=.004$ in amusics, $r(38)=-.45$; $p=.003$ in controls); coordinates of the excerpts on the Arousal axis were correlated to Brightness, Roughness, Pulse Clarity and Harmonic Change (rs(38)>.52; ps<.001 in amusics, rs(38)>.44; ps<.004 in controls). Correlations did not differ significantly between amusics' and controls' ratings.

4. Discussion

The present study investigated the ability to recognize emotions in musical excerpts and in faces by a group of individuals with congenital amusia and a group of control participants. The goal of the study was to pinpoint whether and how much the perceptual deficits in amusia, reflected by altered MBEA scores and elevated pitch discrimination thresholds, alter music emotion recognition and emotional intensity judgments. Performance in the musical emotion recognition test was found to be significantly lower in the amusic group than in the control group, while no group difference was shown in facial emotion recognition. However, amusic participants were able to recognize musical emotions above chance level, and they rated the emotional intensity of the musical and facial stimuli in a similar way as did the control participants. Furthermore, correlations between a set of MIR features extracted from the musical excerpts and coordinates of the excerpts in a MDS space defined by a Valence and an Arousal dimensions based on participants' emotion recognition did not differ significantly between amusics and controls.

4.1 Impaired musical emotion recognition in amusia

The present study revealed that the perceptual impairments characterizing congenital amusia affect emotion recognition in music. This result differs from previous studies on musical emotion recognition in amusia (see Introduction). The use of orchestrated music instead of piano tunes as in previous studies (Ayotte et al. 2002; Gosselin et al. 2015) possibly made the task more sensitive to the slight, but significant impairment of amusic participants. This result is in line with the observation of less extreme judgments in a happy/sad categorization task (Ayotte et al. 2002) for amusic participants compared to controls, even though Ayotte et al.'s observation could also be interpreted as reflecting a lower response confidence in the amusic group. Impairment in musical emotion recognition is also congruent with impairment in speech emotion recognition observed in amusia. Thompson et al. (2012) demonstrated poor decoding of emotional prosody with semantically neutral sentences in congenital amusics. Lima et al. (2016) confirmed this observation on prosody and extended the results to nonverbal vocalizations. For example, amusic participants were found impaired at judging emotional authenticity of laughing. Results of Lolli et al. (2015) on speech perception also suggest that amusics' impairment in pitch discrimination have an impact on emotion processing. Note that these studies on emotion in speech were not associated to data on emotion in music. Normal performance in the face task show that emotion categories were well known and that amusics' impairment was not domain-general. It is however possible that a ceiling effect in joy and fear recognition prevented us to measure a subtle alteration in amusic performance on facial emotions. For instance, Lima et al. (2016) found an impairment in emotion categorization in amusics with muted vocalization videos. However, using muted vocalization videos linked visual processing to auditory processing -or auditory mental imagery, while our task was purely visual, which might also explain amusics' preserved performances. Music-specificity or domain-generality of the emotional deficit found in amusics should be more extensively investigated by a complete battery of auditory, visual and multimodal tests (including testing the effect of processing static versus dynamic emotional stimuli).

The poorer ability to categorize musical emotions in amusics compared to controls may be due to weaknesses in extracting musical syntactic rules and a poorer implicit knowledge of the musical system (Balkwill & Thompson, 1999; Jiang, Liu & Thompson, 2016; Tillmann, Gosselin, Bigand & Peretz, 2012). In particular, processing of a complex set of dynamic acoustic features linked to pitch and rhythm, impaired in amusia, is necessary to follow the tension-relaxation schemas characteristic of the Western tonal music and modulating musical emotions (e.g., Alluri et al., 2012; Coutinho &

Cangelosi, 2011; Eerola, 2011; Juslin & Laukka, 2003; Krumhansl, 1996; Quarto et al., 2014; Steinbeis et al., 2006; Trochidis et al., 2011).

In previous studies, congenital amusia was associated to a deficit in a perceptual and cognitive network, the fronto-temporal network, with a key role of the right Inferior Frontal Gyrus. From a neuropsychological perspective, the here observed musical emotion recognition impairment in amusia suggests that a deficit in the fronto-temporal network is likely to impact performance in a task previously associated to emotional and evaluative networks (e.g., Omar et al. 2011; Pan & Sakagami, 2012). In particular, the Inferior Frontal Cortex might play a role in music emotion processing, congruently with its supposed involvement in emotional vocalization processing (see Fruehholz & Grandjean 2013 for a review). Fecteau et al. (2005) have for instance found activations of a subregion of the left Inferior Frontal Gyrus when listening to nonverbal vocalizations[5]. This subregion, pars orbitalis (BA47), was modulated by emotion. Abnormalities were pinpointed in this same region in congenital amusia, regarding cortical thickness and functional connectivity (Hyde et al. 2007, 2011). Functional MRI data of Tabei (2015) support the hypothesis of an involvement of the bilateral Inferior Frontal Gyrus in a music emotion recognition task (with passive listening as the baseline condition).

Nonetheless, the percentage of correct recognition in amusic participants was significantly above chance (average performance being superior to 53% for each participant, with chance level being at 25%), suggesting that, despite more frequent errors than observed for controls, the intended emotion was recognized in the majority of the excerpts by the amusics. Confusion matrices revealed that error patterns were qualitatively similar between amusic and control participants, with confusions between emotions having similar valence or arousal properties (e.g., Joy with Serenity, Serenity with Sadness). Interestingly, the confusion pattern was similar for musical and facial emotions. Amusics' confusions for the music material occurred particularly on items less emotionally intense, as shown by the correlation between amusics' recognition score and emotion intensity rating (with controls' ratings

[5] Note however that BA47 emotion-sensitivity according to Fecteau et al. (2005) is mostly left-sided, while amusics' abnormalities are mostly right-sided.

taken as the reference). Excerpts were also organized by the two participant groups in similar emotional spaces with arousal and valence axes, as revealed by the MDS analyses. Furthermore, we did not find any differences between both groups in the high-level and acoustic MIR features explaining oppositions between the four emotion categories: a dominance of timbral features was found for the Arousal dimension and a dominance of tonal and rhythmic features for the Valence dimension in both groups. Future studies could further investigate the psychoacoustic features under- or overused by amusic listeners to categorize musical emotion with a direct measure of perception of arousal and valence. As suggested by the results of Cousineau et al. (2012) and Marin et al. (2015), roughness might be preserved in amusia, while the processing of harmonicity cues would be impaired. Gosselin et al. (2015) also suggest that mode would influence the amusic listeners to a lesser extent than the controls (but note that this experimental observation was not reflected by any correlation between participant emotion rating and mode as computed by MIR in Gosselin et al. (2015)). However, this is probably not the processing of a given acoustical feature that distinguishes amusic individuals from controls but how the different acoustical features are integrated. This could explain why it is difficult to pinpoint impairment in processing of a given feature (here, as in Gosselin et al., 2015). A less efficient synthesis of the relevant features may add to weaknesses in musical memory, and prevent amusics from shaping clear and stable emotion categories for music.

4.2 Unimpaired emotion intensity ratings and self-reported musical emotion

In congenital amusics, emotion intensity ratings were as high as in controls on average, suggesting there was no general musical anhedonia, neither domain-general anhedonia as suggested by the ratings on the faces. Note that a patient with acquired musical anhedonia, who was tested with the same paradigm as used here, gave significantly lower emotion intensity ratings than did age- and education-matched controls (Hirel et al. 2014). The finding that the congenital amusic participants were able to perceive emotion intensity in music is congruent with their subjective reports in the musical emotion questionnaire. Twelve out of thirteen amusic participants (92%) reported feeling emotions when listening to music in their daily life (e.g., "*Some music makes me sad*"). This percentage is larger than percentages previously reported by McDonald & Stewart (2008) and Omigie et al. (2012), suggesting sample differences, but also underlining the potential contribution of subjective questionnaires to disentangle subgroups of congenital amusia according to their relationship to music (Stewart 2011, Tillmann et al. 2015, Pfeifer & Hamann 2015). The recent study of Gosselin et al. (2015) also reported that 11 out of 13 amusics gave control-like answers on a very similar questionnaire, suggesting that a large majority of congenital amusics experiences musical emotions. Importantly, in our study, amusics' intensity ratings were not randomly distributed across items but were correlated with controls' intensity ratings. Items judged emotionally intense by controls were also judged as emotionally intense by amusics. This finding suggests that the claim of our amusic participants to feel musical emotions in their daily life[6] was not a "social" claim, but reflects a real ability to catch the emotional intensity in music, even though categorization accuracy was impaired. Interestingly, Tabei et al. (2015) reported activation of the Inferior Frontal Gyrus during music emotion categorization, but not during felt emotion evaluation. Congruently, Inferior Frontal Gyrus abnormalities reported in congenital amusia (Hyde et al., 2006, 2007; Albouy et al., 2013) would not prevent amusic individuals from feeling emotion and evaluating music emotion intensity.

Given the consecutive presentation of the two tasks (emotion recognition and intensity judgement) following the presentation of a stimulus in our study, it might be argued that the intensity evaluation was influenced by the perceiver's confidence in the judgment for the categorization task. In this case, as amusics are likely to be more unsure about their emotion categorization than controls, one would expect that amusic participants give lower emotion intensity ratings than controls would. Our results do not validate this hypothesis, as emotion intensity ratings did not differ between groups. Nonetheless, we found a significant correlation between intensity ratings and emotion categorization, probably reflecting the fact that easily categorizable emotions are intrinsically prone to be emotionally intense. For instance, an excerpt clearly expressing fear will probably be rated as very intense compared to a less prototypical excerpt.

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[6] This observation also reflects the fact that amusia is diagnosed according to performance at perceptual tests, and not on emotional criteria.

4.3 A dissociation between emotion recognition and emotion intensity judgment?

Dissociation between impaired emotion categorization and preserved subjective emotion intensity judgment in congenital amusia is congruent with previously reported clinical cases, notably patients with an acquired amusia who were still enjoying music (Lechevalier, et al, 1983; Peretz & Gagnon, 1999; Peretz, Gagnon, & Bouchard, 1998). We propose three non-exclusive levels of interpretation of the dissociation between impaired emotion recognition and preserved emotion intensity judgment in amusia.

The first one is in terms of the strength and the precision of the representations required to perform an explicit task (e.g., Morrison, Bruce, & Burton, 2000; Tillmann et al. 2007). Categorizing musical emotions requires an explicit access to stable representations of music categories, and a comparison of presented excerpts to mental prototypes of each musical emotion. Representations of an excerpt and its characteristics in short term memory could be weaker and less accessible to consciousness in amusic participants than in control participants, making more difficult their use in a categorization process. A more implicit task, such as rating the intensity of the evoked emotions might require less precise representations. Although representation of the category chosen just before probably remains “activated”, the participant is mentally manipulating a more global and non-verbal appreciation of emotion when they are asked about emotion intensity. Interestingly recent studies have revealed that some implicit processes are preserved in amusics: sensitivity to harmonic or melodic structures (Omigie et al. 2012; Tillmann et al. 2012; Tillmann et al., 2016) was demonstrated, as well as the presence of an electrophysiological response to pitch differences that were smaller than amusics’ conscious pitch discrimination threshold (Peretz et al. 2009). Further evidence for a dissociation between implicit (preserved) versus explicit (impaired) pitch processing in amusia was also recently provided for the detection of tonality violation (Zendel et al. 2015). This implicit level of processing could here underlie the emotion intensity judgment, as previously suggested for other preserved musical abilities in amusia (Albouy et al., 2013b, Tillmann et al., 2014, 2016).

The second interpretation of the observed dissociation involves the hypothesis of a hierarchy of emotional processing (Balkwill & Thompson, 1999; Omar et al. 2011; Stewart et al., 2006): some universal or “primitive” responses to music (such as acoustic features mimicking emotions in the voice) would be preserved, while responses requiring more culture-dependent or higher cognitive processing demands (e.g., related to tonal structures) could be impaired. In our present study, cues of the first category (e.g., the perception of roughness, rhythm entrainment or the detection of features mimicking voice production) may have been used by the amusic participants to evaluate emotion intensity, while subtler information linked to the musical system of our culture would be partially missing for a precise emotion categorization in amusia.

The third interpretation of the dissociation is related to the involved brain networks (e.g., Blood & Zatorre 2001; Koelsch 2014; Tabei et al. 2015). Emotion intensity ratings are possibly closer to emotion experience than to emotion categorization, and would rely more on the response of limbic and paralimbic regions and less on cognitive networks (see Salimpoor and Zatorre, 2013, for a review of cognitive and emotional networks involved in music listening). Summarized differently, and based on the proposition of Janata (2010): an internal network might be recruited more strongly for the emotion intensity rating (e.g., midline areas), while an “external” network (e.g., frontal and temporal brain regions) might be recruited more strongly for the emotion categorization. This external network has been demonstrated to be under-functioning in amusia. Evidence of structural and functional abnormalities in the frontal and temporal brain regions, as well as in the connection between both areas have been found convergently across behavioral, fMRI and neurophysiology studies (e.g., Albouy et al., 2013, 2015; Hyde et al., 2006, 2007, 2011; Leveque et al., 2016; Loui et al., 2009). For instance, abnormalities in grey and white matter have been reported in the Inferior Frontal Gyrus and supra-temporal auditory areas (Hyde et al., 2007, Albouy et al., 2013), as well as previous studies reported for amusics decreased activity in frontal areas during music processing (Hyde et al. 2011, BOLD effect) and decreased or delayed response in auditory areas during tone encoding (Albouy et al., 2013, evoked magnetic fields). In the same line, brain connectivity data at rest in amusic participants (Leveque et al., 2016) suggest that the amusic auditory cortex is under-connected to the fronto-temporal, cognitive music network, and over-connected to a more internal network (the Default Mode Network) compared to control participants.

Altogether our results suggest that non-verbal auditory information might be propagated less easily towards executive networks in congenital amusia (fronto-temporal network dysfunction) than towards the limbic system and self-related areas. We have recently reported a case of acquired amusia following a right-temporal lobe lesion exhibiting the reverse pattern: a moderate amusia associated with a severe musical anhedonia (Hirel et al., 2014). This case study adds further support to this interpretation of different routes for music processing in the brain. The ability to memorize and manipulate musical stimuli in perceptual or memory tasks, to recognize musical emotions and to feel musical emotions can be altered in association or independently.

5. Conclusion

Our data bring evidence that congenital amusia, known to be linked to a right lateral fronto-temporal dysfunction, reduces musical emotion recognition, while sparing emotion intensity judgments. Atypical neurodevelopment modulates interactions between perceptual, emotional and evaluative networks, affecting musical processing, musical hedonia and/or emotion evaluation. Relationships between these networks are complex and their investigation should continue using protocols targeting the respectively involved skills (emotion recognition, judgment of emotion intensity, subjective evaluation of aesthetic or psychophysics properties of music) and their underlying neural networks, in the healthy and pathological brain.

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Table 1: *Characteristics of the participants (means ± standard-deviations). Musical education corresponds to years of formal instruction on an instrument. Results on the Montreal Battery of Evaluation of Amusia (MBEA) are expressed as number of correct responses on average across the subtests and for each sub-test of the battery (maximum score = 30; 15 is the chance level). Note that 23 is the cut-off for the MBEA mean score (based on Peretz et al., 2003). Pitch discrimination threshold was determined using the procedure described in Tillmann et al. (2009).*
Group data were compared with independent t-tests (two-sided).

	Amusics	*Controls*	*t-test*
Age (years)	38±14.76 [min:20; max:61]	34.07±9.86 [min:23; max:52]	t(24)=0.79, p=.43
Education (years)	14.61±2.36 [min:11; max:20]	14.76±1.78 [min:12; max:18]	t(24)=-0.18, p=.85
Musical education (years)	0.53±1.12 [min:0; max:4]	0.15±0.55 [min:0; max:2]	t(24)=1.1, p=.28
MBEA (mean score)	21.2±1.42 [min:18; max:22.83]	26.26±1.44 [min:23.83; max:28.67]	t(24)=-8.99, p<.001
MBEA (scale)	20.15±2.08	26.23±1.88	t(24)=7.82, p<.001
MBEA (contours)	21.31±3.66	26.69±2.53	t(24)=4.36, p<.001
MBEA (interval)	20.62±3.15	25.77±2.35	t(24)=4.73, p<.001
MBEA (rhythm)	24±3.63	27.15±2.54	t(24)=2.57, p=.017
MBEA (meter)	20.15±4.81	26.85±2.27	t(24)=4.54, p<.001
MBEA (memory)	23.54±3.57	26.85±2.27	t(24)=4.58, p<.001
Pitch discrimination threshold (semitones)	0.77±0.76 [min: 0.1; max: 2.41]	0.29±0.20 [min: 0.09 ; max:0.71]	t(24)=-2.21, p=.036

Table 2. Percentage of correct (along the diagonal) and incorrect recognitions of target musical emotions in the categorization task. Standard deviations are indicated between brackets.

Expected \ Answered	Joy	Sadness	Fear	Serenity
Amusics				
Joy	**79.23 (16.56)**	4.62 (7.76)	1.54 (3.76)	14.62 (10.50)
Sadness	0.00 (0.00)	**56.75 (19.53)**	19.32 (10.30)	23.93 (21.75)
Fear	11.54 (9.87)	7.69 (11.66)	**78.46 (21.15)**	2.31 (4.39)
Serenity	9.23 (9.54)	36.15 (16.60)	0.77 (2.77)	**53.85 (16.09)**
Controls				
Joy	**85.38 (12.66)**	2.31 (4.39)	3.85 (6.50)	8.46 (9.87)
Sadness	0.77 (2.77)	**71.54 (15.19)**	19.23 (11.88)	8.46 (8.01)
Fear	2.31 (5.99)	3.08 (4.80)	**93.85 (9.61)**	0.77 (2.77)
Serenity	8.46 (6.89)	17.69 (10.92)	0.00 (0.00)	**73.85 (15.02)**

Table 3. Percentage of correct (along the diagonal) and incorrect recognitions of target facial emotions for the amusic and control participants. Standard deviations are indicated between brackets.

Expected \ Answered		Joy	Sadness	Fear	Neutrality
Amusics					
	Joy	**96.15 (9.61)**	0.00 (0.00)	0.77 (2.77)	3.08 (8.55)
	Sadness	1.54 (3.76)	**80.88 (17.74)**	7.78 (9.30)	9.81 (15.96)
	Fear	0.77 (2.77)	0.00 (0.00)	**98.46 (3.76)**	0.77 (2.77)
	Neutrality	9.23 (10.38)	10.00 (11.55)	3.08 (4.80)	**77.69 (17.87)**
Controls					
	Joy	**99.23 (2.77)**	0.00 (0.00)	0.00 (0.00)	0.77 (2.77)
	Sadness	0.00 (0.00)	**78.38 (16.70)**	12.97 (12.72)	8.65 (9.93)
	Fear	0.00 (0.00)	0.77 (2.77)	**98.46 (3.76)**	0.77 (2.77)
	Neutrality	3.25 (6.81)	5.56 (7.03)	7.78 (8.35)	**83.42 (17.59)**

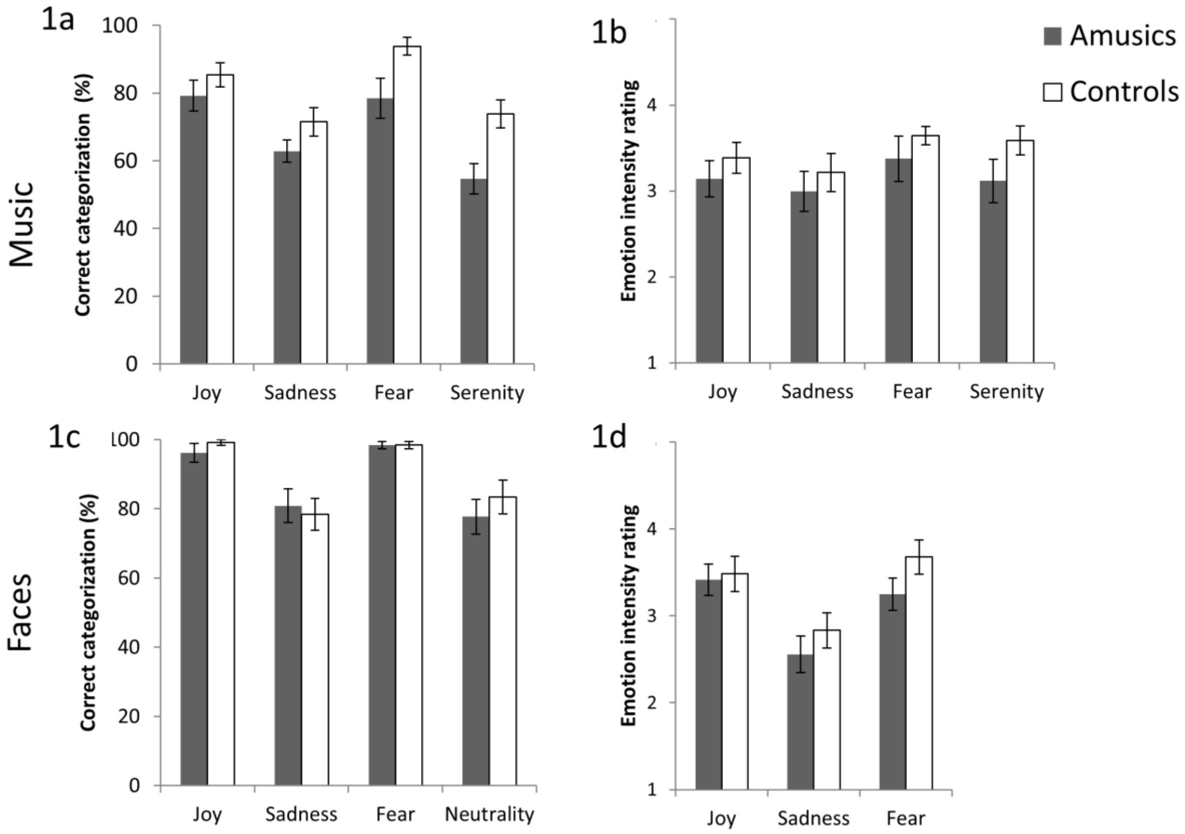


Figure 1. a and c: *Performance of amusic and control groups in terms of percentage of correct categorizations, in the Music (1a) and the Face (1c) emotion categorization tasks. See Appendix C for a representation of the same data in terms of unbiased Hit rate* H_u. *Figure 1b and 1d: Mean emotion intensity rating of amusic and control groups on a scale from 1 (weak) to 5 (strong), in the Music (1b) and the Face (1d) tasks. Error bars indicate the standard error of the mean.*

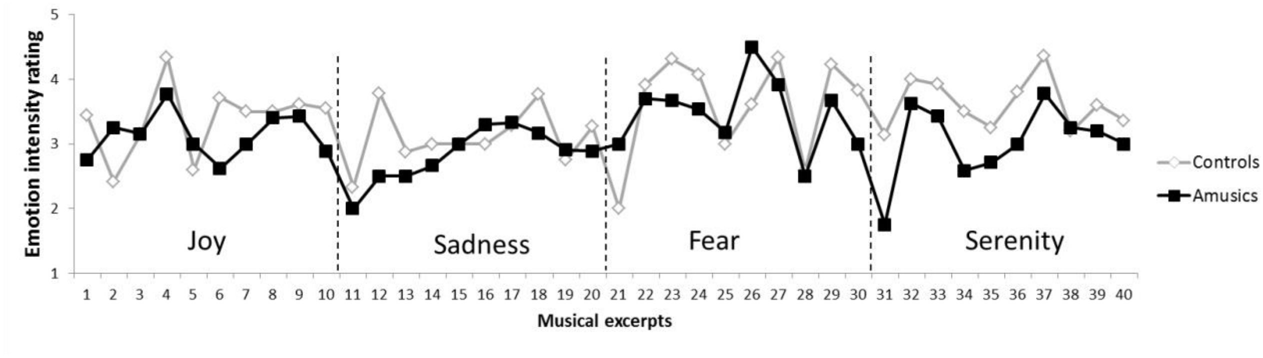


Figure 2: *Musical emotion intensity ratings by item for the amusic and control group. Ratings were given on a scale from 1 (weak emotion) to 5 (strong emotion). Items are classified by emotion.*

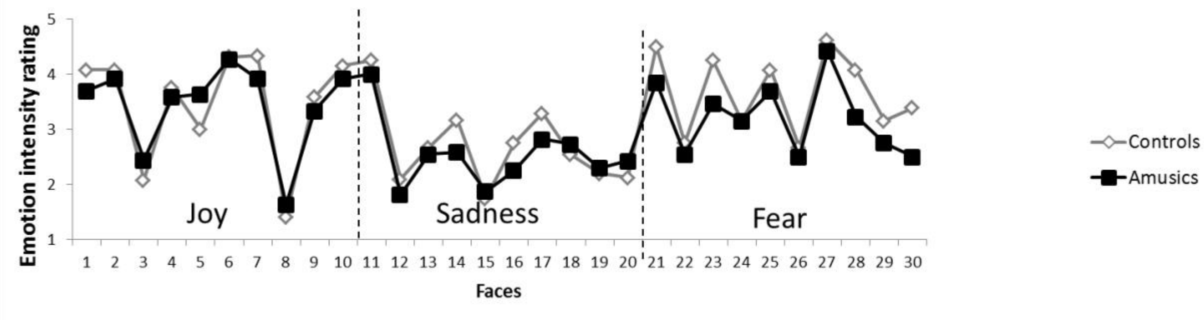


Figure 3: *Facial emotion intensity ratings by item for the amusic and control group. Ratings were done on a scale from 1 (weak emotion) to 5 (strong emotion). Items are here classified by emotion.*

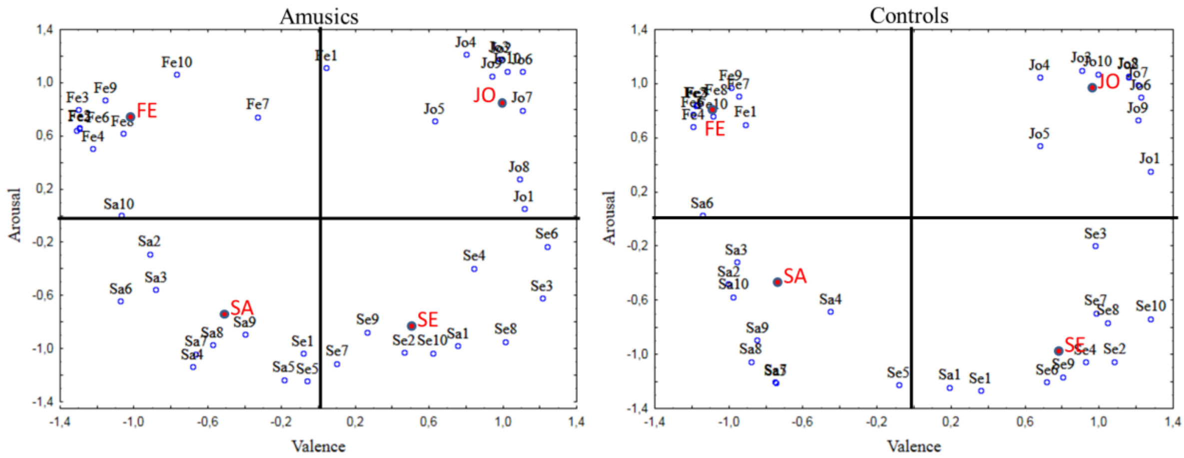


Figure 4: *Geometrical solution for the 40 musical excerpts, resulting from MDS of amusics' and controls proximity matrices, built on the categorization data. Raw stress for the amusics' data = 40.17; for the controls' data = 37.16. Fe = Fear, Jo = Joy, Sa = Sadness, Se = Serenity.*

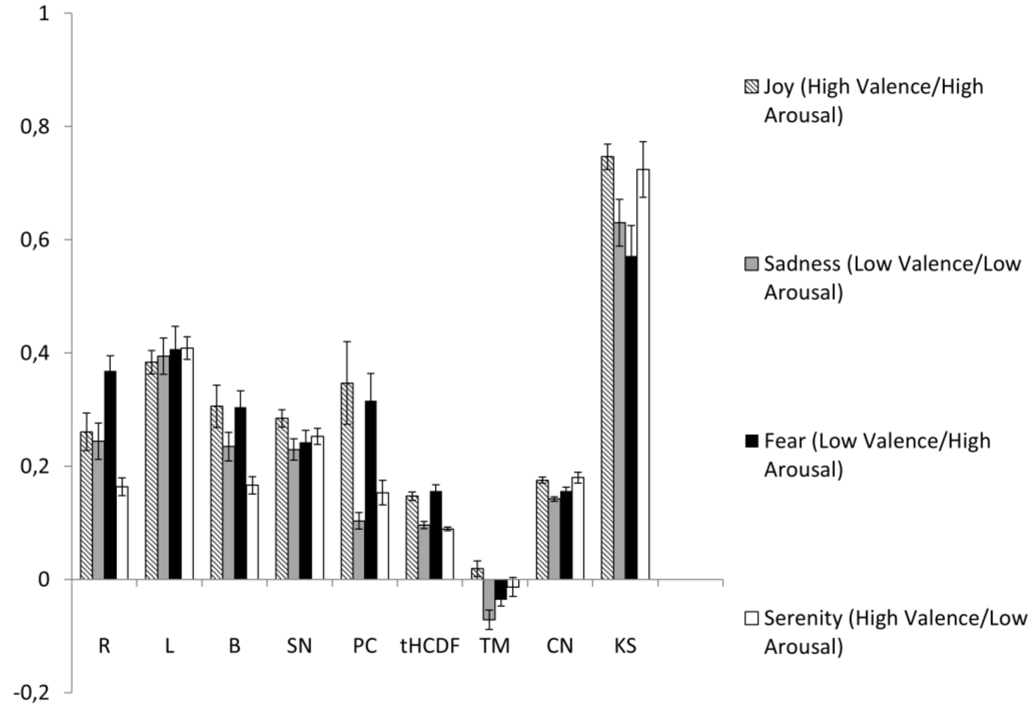


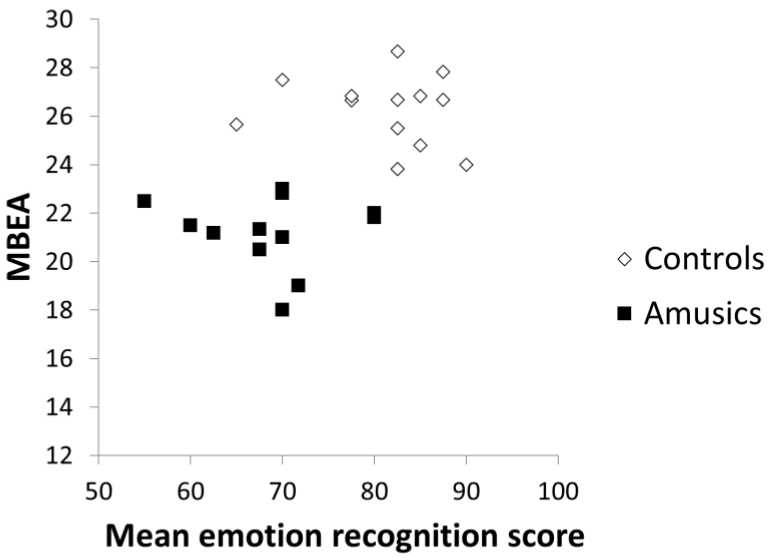
Figure 5: *Characteristics of the musical excerpts according to the 9 psychoacoustical descriptors. R: Roughness ; L: Loudness; B: Brightness; SN: Spectral Novelty; PC: Pulse Clarity; tHCDF: tonal Harmonic Change Detection Function; TM: Tonal Mode; CN: Chroma Novelty; KS: Key strength. Measures are computed with the MIR toolbox (Lartillot et al., 2007). Error bars indicate standard error.*

APPENDIX A

Table A: Characteristics of the musical stimuli. Mean ± standard deviation for the nine MIR parameters and for each emotion. Minimum and maximum are indicated between brackets.

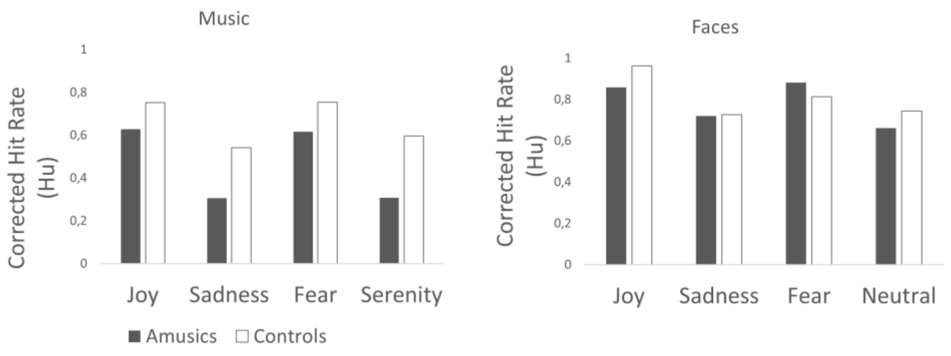
	Joy	Sadness	Fear	Serenity
Intensity (RMS STD)	0.38±0.06	0.39±0.10	0.40±0.12	0.40±0.06
	[0.25;0.47]	[0.26;0.64]	[0.27;0.67]	[0.26;0.47]
Roughness	26061±10427	24415±10088	36859±8423	16381±4975
	[6119;37785]	[8916;41676]	[22620;49713]	[6373;22485]
Brightness	0.31±0.1	0.23±0.07	0.30±0.09	0.16±0.04
	[0.19;0.53]	[0.08;0.34]	[0.18;0.46]	[0.07;0.22]
Spectral Novelty	0.28±0.04	0.22±0.05	0.24±0.06	0.25±0.04
	[0.20;0.38]	[0.11;0.33]	[0.14;0.33]	[0.19;0.33]
Mode	0.38±0.11	0.37±0.04	0.43±0.11	0.38±0.07
	[0.25;0.64]	[0.33;0.45]	[0.27;0.67]	[0.26;0.47]
Key strength	0.74±0.07	0.62±0.13	0.57±0.17	0.72±0.15
	[0.64;0.87]	[0.41;0.85]	[0.29;0.86]	[0.48;0.97]
Pulse Clarity	0.34±0.23	0.10±0.04	0.31±0.15	0.15±0.06
	[0.00;0.73]	[0.04;0.20]	[0.06;0.56]	[0.08;0.27]
Harmonic Change	0.14±0.02	0.09±0.02	0.15±0.03	0.08±0.00
	[0.12;0.18]	[0.06;0.13]	[0.10;0.22]	[0.07;0.11]
Chromagram Novelty	0.17±0.01	0.14±0.01	0.15±0.02	0.17±0.02
	[0.15;0.21]	[0.12;0.15]	[0.12;0.20]	[0.10;0.21]

APPENDIX B



Relationship between MBEA and mean emotion recognition score (across the four emotions) for musical stimuli, for control and amusic participants.

APPENDIX C



Performance of amusic and control groups in terms of unbiased Hit rate H_u (Wagner, 1993), in the Music and the Face emotion categorization tasks. H_u is the product of the probability of detection and the frequency of Hits.