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Research report

Sensitivity to musical emotions in congenital amusia

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ABSTRACT

The emotional experience elicited by music is largely dependent on structural characteristics such as pitch, rhythm, and dynamics. We examine here to what extent amusic adults, who have experienced pitch perception difficulties all their lives, still maintain some ability to perceive emotions from music. Amusic and control participants judged the emotions expressed by unfamiliar musical clips intended to convey happiness, sadness, fear and peacefulness (Experiment 1A). Surprisingly, most amusic individuals showed normal recognition of the four emotions tested here. This preserved ability was not due to some peculiarities of the music, since the amusic individuals showed a typical deficit in perceiving pitch violations intentionally inserted in the same clips (Experiment 1B). In Experiment 2, we tested the use of two major structural determinants of musical emotions: tempo and mode. Neutralization of tempo had the same effect on both amusics' and controls' emotional ratings. In contrast, amusics did not respond to a change of mode as markedly as controls did. Moreover, unlike the control participants, amusics' judgments were not influenced by subtle differences in pitch, such as the number of semitones changed by the mode manipulation. Instead, amusics showed normal sensitivity to fluctuations in energy, to pulse clarity, and to timbre differences, such as roughness. Amusics even showed sensitivity to key clarity and to large mean pitch differences in distinguishing happy from sad music. Thus, the pitch perception deficit experienced by amusic adults had only mild consequences on emotional judgments. In sum, emotional responses to music may be possible in this condition.

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1. Introduction

The most common motive for listening to music is its rich emotional content (Sloboda & O'Neill, 2001). Such an emotional appeal may not resonate for those who have a lifelong disorder in processing the pitch structure of music. The disorder, known as congenital amusia, is typically expressed by poor musical pitch perception and impoverished musical experiences in an otherwise normally developing system (Peretz, 2013). In particular, individuals with amusia (amusics hereafter) can hardly detect a semitone difference, which is the smallest pitch interval and the building block of everyday music (Hyde & Peretz, 2004; Vuvan, Nunes-Silva, & Peretz, 2015). As a result, amusics are indifferent to dissonance (Ayotte, Peretz, & Hyde, 2002; Cousineau, McDermott, & Peretz, 2012). They should also show little differentiation between the major and minor modes that underlie the happy-sad distinction in Western musical culture. From a music-theoretic perspective, both dissonance and mode discrimination depend on a semitone difference. Thus, a central question in the study of congenital amusia is to what extent the perception of musical emotions is affected by amusics' poor discrimination of semitone differences.

Indeed, the diagnosis of congenital amusia is dependent on the inability to discriminate melodies that differ by a semitone or more. In general, an amusia diagnosis rests on a global score lying two standard deviations below the mean of the normal population on a battery of six tests, the Montreal Battery of Evaluation of Amusia (MBEA; Peretz, Champod, & Hyde, 2003). These tests require same/different discrimination of melodies that may contain single-note changes in pitch or duration, metrical judgments (i.e., if a melody is a march or waltz), and the recognition of novel melodies against those previously presented. Under standard use, the MBEA does not cover emotion discrimination in music. A prior attempt to do so showed that the emotion discrimination subtest used in the MBEA lacked sensitivity: amusics and controls both performed at ceiling (Sloboda, Wise, & Peretz, 2005). Thus, the question of whether the ability to recognize emotions from music is retained in cases of congenital amusia remains open.

Emotion recognition has both clinical and neurological relevance since congenital amusia is a neurogenetic disorder. It is characterized by impoverished connectivity between the auditory cortex and the inferior frontal gyrus of the right hemisphere (Albouy et al., 2013; Hyde et al., 2007; Hyde, Zatorre, Griffiths, Lerch, & Peretz, 2006; Hyde, Zatorre, & Peretz, 2011; Loui, Alsop, & Schlaug, 2009). A brain marker of this poor connectivity is the absence of normal late positivities (P300/P600) when detecting a pitch deviation that is smaller than a semitone in a simple tone sequence (Moreau, Jolicoeur, & Peretz, 2013; Peretz, Brattico, & Tervaniemi, 2005) or that is mistuned in a melody (Peretz, Brattico, Jarvenpaa, & Tervaniemi, 2009; Zendel, Lagrois, Robitaille, & Peretz, 2015). This electrical marker of congenital amusia can be observed even in children (Lebrun, Moreau, McNally-Gagnon, Mignault-Goulet, & Peretz, 2012; Mignault-Goulet, Moreau, Robitaille, & Peretz, 2012). Such biomarkers consistently accompany the congenital amusia phenotype, which is characterized by difficulty detecting out-of-key notes in melodies (Peretz, Cummings, & Dubé, 2007). The phenotype is found in 39% of first-degree relatives of amusic individuals, whereas only 3% have such a deficit in the control families (Peretz et al., 2007). The family aggregation pattern of transmission coupled with the observation of reduced connectivity and thicker cortex (Hyde et al., 2007) suggest the presence of defects in neuronal migration that can be caused by a single gene mutation.

However, music abilities, as with most complex cognitive abilities, owe their ultimate functional properties not only to genetic factors but also to experience-based plasticity. One important factor that could influence plasticity in amusia is the degree of enjoyment amusics can get from listening to music, and therefore, their level of engagement with music. Amusics vary widely in their musical interest. A few report irritation, many feel indifferent, and a minority are music lovers (Ayotte et al., 2002; McDonald & Stewart, 2008; Omigie, Mullensiefen, & Stewart, 2012). Curiously, this variability in music interest appears unrelated to the severity of the disorder (McDonald & Stewart, 2008). These observations may reflect dissociations between emotional and cognitive processing of music. For example, a lack of interest in music, termed musical anhedonia, can occur in individuals who have both normal music perception abilities and normal music emotion recognition (Mas-Herrero, Zatorre, Rodríguez-Fornells, & Marco-Pallarés, 2014). Another intriguing dissociation between emotion and perception can be observed after brain damage. For example, I.R., a case we have described previously, enjoyed listening to music and was normal at discriminating happy from sad music, but was unable to recognize those same musical excerpts (Peretz & Gagnon, 1999; Peretz, Gagnon, & Bouchard, 1998). The possibility of finding patterns of dissociation between perception, emotions, and appreciation in music processing provided an incentive for a detailed assessment of music emotion recognition in congenital amusia.

To this aim, in the present study we assessed groups of amusics and matched controls with the same tests of musical emotions that we have used in brain-damaged populations in prior studies (e.g., Gosselin et al., 2005; Peretz et al., 1998). For example, the emotional clips (Experiment 1A) have been validated in the normal adult population (Vieillard et al., 2008) and have been shown to be sensitive to the resection of the medial temporal lobe (Gosselin, Peretz, Hasboun, Baulac, & Samson, 2011; Gosselin et al., 2005) and to damage to the amygdala (Gosselin, Peretz, Johnsen, & Adolphs, 2007). The test, unlike the emotional test once used in the MBEA, does not present ceiling effects and is sensitive to the presence of a selective deficit. The test probes the recognition of four emotions: happiness, sadness, peacefulness and fear. Since amusics are able to use the temporal dimension in music discrimination to some extent, they may be able to use tempo (corresponding to the speed or pace of a given piece) and probably other non-pitch based cues such as dynamics, articulation and timbre to guide their perceptual judgments (Gabrielsson & Lindström, 2010). Accordingly, they are expected to be only mildly impaired in the identification of the emotions conveyed in the music presented in Experiment 1A. In contrast, amusics are expected to fail to detect out-of-key notes in those same stimuli. This is assessed in Experiment 1B.

In order to test the contribution of mode to amusics' perception of musical emotions, another validated set of musical excerpts was used in Experiment 2. Using this set with I.R., the case of acquired amusia mentioned above, we observed that emotional judgments based on either tempo or mode can be intact despite the presence of severe music perception and memory deficits (Peretz et al., 1998). However, I.R. was also able to perceive pitch differences as small as a semitone (Peretz, Blood, Penhume, & Zatorre, 2001). In contrast, congenital cases of amusia have difficulties detecting a semitone change in pitch, as described previously. Thus, musical mode was expected to be a poor structural cue for amusics. We predicted that amusics might recognize emotions from music to some extent when other structural characteristics, such as tempo, are available, but would have difficulties when mode is the principal determinant.

2. Method

2.1. Participants

In total, 13 amusics (of which 10 took part in all experiments) and 15 controls (of which eight completed all experiments) participated (Table 1). Amusics and controls were matched for age, number of years of education, and years of musical training. The only known difference between the two groups was that each amusic individual performed more than two standard deviations below both the global score and the melodic composite score obtained by controls on the MBEA (with 22 and 20.3/30, respectively, as cut-off scores adjusted for age and education). Individual performance on the pitch change detection task (Hyde & Peretz, 2004) is also provided in Table 1. While amusics differed in the severity of their impairment in the pitch change detection task, all were impaired, with scores at least 2 SDs below controls' mean.

To get a better grasp of the subjective experience of musical emotions, we asked 12 (all but A11) amusics and 14 controls to complete the *Affective Responses to Music* questionnaire used by McDonald and Stewart (2008). This questionnaire includes 10 questions (Appendix 1), of which 5 are similar to those used by Mas-Herrero, Marco-Pallarés, Lorenzo-Seva, Zatorre, and Rodríguez-Fornells (2013) in their assessment of anhedonia. Participants were asked to indicate whether they agreed with each statement, such as "certain music can put me in a good mood or match my current mood", by selecting (1) strongly agree, (2) agree, (3) unsure, (4) disagree, or (5) strongly disagree. We computed the average of the 10 ratings provided by each participant. The higher the average score, the more the participant was emotionally disengaged or anhedonic. The amusics' scores ranged from 1.2 to 4.2 (Table 1) and confirmed the heterogeneity of self-reports. This variability may explain why their scores did not differ reliably from controls' scores [range 1–3.1; $t(25) = 1.89$, $p = .07$]. When considering a score lying 2 SD above the normals' mean (that is, above 2.8) as indicative of anhedonia, only two amusics (A6 and A7) and one control qualified as anhedonic.

Table 1 – Characteristics of participants and individual scores obtained by amusics on the six tests (global score) and on the scale, contour and interval tests (melodic composite score) on the Montreal Battery of Evaluation of Amusia (MBEA; Peretz et al., 2003). Scores obtained on the online out-of-key test (Peretz et al., 2008), the pitch change detection task (Hyde & Peretz, 2004), and the *Affective Response to Music* questionnaire (McDonald & Stewart, 2008) are also provided. Preserved (+; within 2 SD of normal scores) or altered (−; 2 or more SD away from normal mean) performances observed in Experiment 1 and 2 are also included for each amusic participant. Group characteristics and scores are expressed as the mean (SD).

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	Amusics	Controls
Characteristics															
Gender	F	F	F	F	F	F	M	M	M	F	M	F	M	8F, 5M	10F, 5M
Age (years)	62	68	68	66	62	69	62	65	66	57	54	69	67	64.2	62.9 (3.8)
Education (years)	18	15	8	14	20	15	19	19	14	19	15	21	19	16.6	15.6 (2.6)
Musical training[a]	1	2	0	2	1	0	1	1	1	3	1	4	1	1.4	1.6 (1.6)
MBEA															
Global score (/30)	22.2	20.8	18.8	18.8	21.8	18	19	15.3	18	19	16	22.3	17	19	27.2 (1.3)
Melodic composite score (/30)	22.7	20.7	15.7	19.3	19.7	17	17.7	15	17.7	16	16.3	20	16.3	18	27.2 (1.7)
Pitch change detection[b] (% hits − false alarms)	80	65.7	51.5	69.3	57.1	35.6	75.2	50.9	72.2	63.9	n.a.	70.4	87.4	64.9	96.7 (2.6)
Online out-of-key test (% correct)	63	29.2	46	45.8	62.5	54	50	20.8	37.5	50	45.8	79.2	45.8	48.4	90.1 (6.4)
Affective questionnaire (/5)	2.4	1.4	1.9	1.8	1.8	4.2	3.0	2.5	1.3	2.7	n.a.	2	1.2	2.2	1.7 (.6)
Experiment 1															
Emotion recognition	+	−[sc]	+	+	+	−[sc, pe]	+	+	+	+	−[pe]	+	n.a.		
Pitch shift detection (A′)	−	−	−	−	−	−	−	−	−	−	n.a.	−	−		
Time error detection (A′)	+	−	+	−	+	−	+	−	+	+	n.a.	+	+		
Experiment 2															
Raw ratings original condition	−[ha]	+	+	+	+	+	+	+	+	n.a	n.a	+	+		
Mode change condition	+	+	+	+	+	+	+	−[sa, ha]	−[sa]	n.a.	n.a.	−[sa]	−[sa]		
Tempo change condition	−[sa]	+	+	+	+	+	+	+	−[sa]	n.a	n.a	+	+		

Note: F = female; M = male; sc = scary; pe = peaceful; ha = happy; sa = sad.

[a] Musical training is classified with level 1 = < one year; 2 = 1–3 years; 3 = 4–6 years; and 4 = 7–10 years.

[b] Average over ±1/4, 1/2, 1 semitone changes.

All participants provided informed consent and the protocol was approved by the Ethics committee of the University of Montreal.

3. Experiment 1A: recognition of happy, sad, scary and peaceful music

In order to measure the ability to recognize musical emotions, we presented a validated set of musical clips expressing happiness, sadness, fear, or peacefulness (Vieillard et al., 2008) to amusics and matched controls. Their task was to judge to what extent each clip expressed each of the four emotions, allowing mixed emotions and ambiguity to be expressed in the ratings.

3.1. *Participants*

Twelve amusics (A1 to A12) and 12 matched controls participated in this first experiment.

3.2. *Material*

The full set of 56 musical clips was used here (see Vieillard et al., 2008, for a detailed description and validation). The clips were composed for research purposes in the genre of movie soundtracks and followed the rules of the Western tonal system. Each clip contains a melody with accompaniment and has a regular rhythm, with the exception of seven scary excerpts that were judged to have irregular rhythms in a previous study (Gosselin et al., 2005). The happy excerpts are in a major mode with a relatively fast tempo (137 beat per minute, BPM; range 92–196). In contrast, the sad excerpts are in a minor mode at a slow tempo (46 BPM; range 40–60). The peaceful music is composed in a major mode with an intermediate tempo (74 BPM; range 54–100), while the scary music (fear) is more variable (range 44–172 BPM) and composed with minor chords. The mean duration of the clips is 12.4 sec (range 9.2–16.4), and the duration is matched across the four emotion categories. The clips are computer-generated with a piano timbre. A full description, including the music notation, can be found at www.brams.umontreal.ca/short/emotional_clips.

The musical clips were further analyzed and quantified for the presence of various acoustical features known to affect judgments (Quarto, Blasi, Pallesen, Bertolino, & Brattico, 2014). The values are presented in Table 2. To measure the mean pitch, we averaged all of the notes in MIDI where each number from 0 to 127 corresponds to a semitone. The lowest note (A0) of a standard piano is 21 in MIDI and the highest (C8) is 108. These values were computed with the MIDIToolbox (Eerola & Toiviainen, 2004). Values for key and pulse clarity, as well as timbre, defined by brightness or amount of energy above 3000 Hz (Juslin, 2000), root mean square (RMS) energy, and roughness (beating), were extracted with the MIRToolbox 1.5 (Lartillot & Toiviainen, 2007). Note that there are slight variations in RMS energy within each melody, which are captured by the MIR toolbox, even though the stimuli were normalized using the maximum peak value of each stimulus.

The musical clips can be distinguished on the basis of all considered acoustical characteristics except brightness, as assessed with ANOVA and Bonferroni correction for multiple comparisons. For the mean pitch, a main effect of Emotion (happy, sad, scary, and peaceful) was observed, $F(3, 52) = 6.30$, $p < .002$, $\eta^2_{partial} = .27$. The happy musical stimuli were on average seven semitones higher than the sad stimuli and eleven semitones higher than the scary stimuli, $t(26) = 5.59$ and 3.18, respectively, both $p < .004$. Similarly, a main effect of Emotion was observed for key clarity, $F(3, 52) = 5.85$, $p < .003$, $\eta^2_{partial} = .25$, and pulse clarity, $F(3, 52) = 18.54$, $p < .001$, $\eta^2_{partial} = .52$. Both pulse and key were less clear in the scary clips than in the happy and peaceful clips (all $p < .009$). Pulse clarity was also less clear in the scary excerpts compared to the sad ones, $t(26) = 4.25$, $p < .001$. Finally, the clips differed on at least two timbral qualities: RMS energy, $F(3, 52) = 8.59$, $p < .001$, $\eta^2_{partial} = .33$, and roughness, $F(3, 52) = 5.17$, $p < .004$, $\eta^2_{partial} = .23$. For both characteristics, the happy stimuli obtained higher values than the sad and peaceful stimuli ($p < .008$). These differences in timbral qualities may be related to the higher number of tones in the happy clips. Brightness did not reach significance, $F(3, 52) = 1.96$, $p = .131$, $\eta^2_{partial} = .10$.

3.3. *Procedure*

The clips were presented in one of two random orders (as in previous validation studies; Vieillard et al., 2008; Gosselin et al., 2005). They were played at a comfortable listening level through BeyerDynamic DT 990 Pro headphones in a sound-attenuated booth. Each participant was tested individually and asked to judge to what extent each clip expressed each of the four emotions (happiness, sadness, fear and peacefulness) using a 10-point scale, from 0 = absent to 9 = present. Specifically, each participant recorded four ratings for each clip, one for each emotion, since each musical clip could potentially express more than one emotion. No

Table 2 – Mean pitch, or F0, and pitch range (in parentheses), expressed in MIDI code, with pitch names, and in Hz, as well as acoustic values extracted with the MIR Toolbox for the musical clips of Experiment 1, as a function of emotion.

	Mean pitch			Acoustic value				
Emotion	MIDI	Label	Hz	Key clarity	Pulse clarity	Brightness	RMS energy	Roughness[a]
Happy	65.9 (60.5–71.3)	F#5 (C#5-B5)	431.9 (302.5–589.7)	.82 (.74–.96)	.80 (.65–.88)	.25 (.21–.28)	.17 (.12–.21)	.09 (.06–.13)
Sad	59.3 (55.1–65.7)	B4 (G4-F#5)	299.4 (234.2–464.7)	.80 (.58–.92)	.80 (.65–.89)	.25 (.23–.28)	.14 (.12–.17)	.05 (.02–.10)
Scary	56.1 (41.3–74.1)	G#4 (F3-D6)	318.3 (94.7–718.8)	.68 (.45–.87)	.56 (.30–.87)	.24 (.19–.33)	.13 (.07–.19)	.07 (.01–.13)
Peaceful	62.1 (55.4–66.9)	D5 (G4-G5)	388.4 (252.8–574.7)	.80 (.66–.89)	.83 (.77–.89)	.24 (.22–.26)	.15 (.10–.18)	.07 (.02–.09)

[a] Normalized with minimum and maximum roughness values of the dataset.

feedback regarding the emotion intention was given, with the exception of the two practice examples (one intended to convey sadness and one fear). The experiment lasted approximately 45 min.

3.4. *Results and comments*

For each labeled emotion, we calculated the mean rating given by each participant. Although there was an order effect, $F(1, 20) = 4.70$, $p = .042$, $\eta^2_{partial} = .19$, it did not interact with the factors of interest (Order × Group: $F < 1$; Order × Emotion: $F < 1$). Therefore, the ratings were averaged across the two orders. As shown in Table 3, participants gave the highest rating for the emotional label that corresponded to the intended emotion. Amusics' and controls' ratings overlapped for the happy and sad clips (Fig. 1). However, a few amusics rated peaceful and scary stimuli lower than controls (peaceful: A6 and A11; scary: A2 and A6).

The ratings were analyzed by a two-way mixed-design ANOVA considering Group (amusic *vs* control) as the between-subjects factor and Emotion (happiness, sadness, fear, and peacefulness) as the within-subject factor. The analysis revealed no significant effect of Group $F(1, 22) = 3.19$, $p = .09$, $\eta^2_{partial} = .13$, nor significant interaction between Group and Emotion, $F(3, 55) = 1.47$, $p = .24$, $\eta^2_{partial} = .06$ (with Greenhouse-Geisser correction factor, $\varepsilon = .84$). While the possibility that larger group sizes would have led to a significant result cannot be discounted, the musical impairments that characterize congenital amusia do not seem to have a large impact on emotional judgments at the group level.

The main effect of Emotion was significant, $F(3, 55) = 29.53$, $p < .001$, $\eta^2_{partial} = .57$ (with Greenhouse-Geisser correction factor, $\varepsilon = .84$). Happiness was given higher scores on the 0 to 9 scale indicating how much each clip expressed happiness, when compared to how much the sad, scary, and peaceful music was thought to express sadness, fear, and peacefulness, respectively, $t(26) = 7.30$, 8.93, 6.99, for the comparison of happy with sad, scary and peaceful music, respectively, all $p < .008$ with Bonferroni correction. Sad music was also given higher scores than scary music, $t(26) = 3.68$, $p < .002$. The scary clips were generally given low scores across all emotions, which could be due to the older age of the participants (Lima & Castro, 2011).

Table 3 – Recognition by amusics and matched controls of happiness, sadness, scariness (fear) and peacefulness evoked by music, demonstrated with mean ratings (on a scale of 0–9) of how much each clip expressed each of the four intended emotions. Means (and standard errors) are presented in bold for the match between the intended and perceived emotion.

Intended emotions	Perceived emotions			
	Happiness	Sadness	Scary	Peacefulness
Amusics				
Happiness	**7.8 (.2)**	.1	.1	2.6
Sadness	1	**5.6 (.4)**	.8	2.8
Fear	1.7	2.4	**4.2 (.6)**	.7
Peacefulness	3.2	2.8	.1	**4.9 (.5)**
Controls				
Happiness	**7.8 (.3)**	.2	.1	1.9
Sadness	.8	**6.1 (.5)**	.6	4.4
Fear	1.2	3.1	**5.2 (.4)**	.5
Peacefulness	3.3	3.1	.2	**6.2 (.4)**

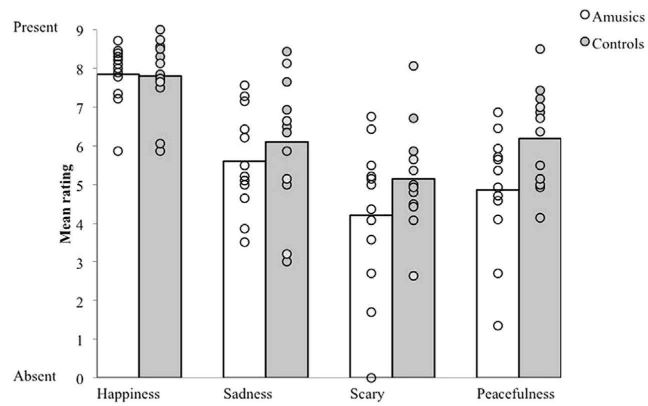

Fig. 1 – Individual average rating as a function of group and intended emotion in Experiment 1A. Mean group values are indicated by columns.

Finally, we did not find relationships between the ratings and the acoustical characteristics considered in Table 2. The only correlation to reach significance concerned the ratings obtained for the peaceful music and their RSM energy values, $r(12) = .59$, $p < .03$.

We also computed correlations between participants' pitch discrimination abilities (using the scores obtained in the pitch change detection task; see Table 1) and the ratings provided for each intended emotion. The only correlation to reach significance was obtained in amusics for the scary clips [$r(9) = .60$, $p = .047$]. In this case, the larger the pitch discrimination deficit, the lower the ratings of fear expressed in the clips.

4. Experiment 1B: error detection in emotional clips

The near-normal performance of the amusic group in musical emotion discrimination raised the possibility that the clips were easier to process than the stimuli usually used for the diagnosis and the characterization of amusia (that is, the melodies of the MBEA). To assess this possibility, we presented here the same musical clips used in Experiment 1A, but in the form of an error detection task, as in our prior studies of acquired amusia (Peretz et al., 1998) and of temporal lobe excision (Gosselin et al., 2005). In the error detection task, a semitone pitch-shift was applied to one entire measure of the melody while the accompaniment remained unchanged for half of the clips presented. This manipulation creates local (sensory) dissonance, which is typically difficult for amusics to detect, whereas it is easily picked up by controls (Ayotte et al., 2002; Cousineau et al., 2012). For comparison, we also presented the same clips with a local temporal change.

4.1. *Participants*

Twelve amusic (all amusics but A11) and 12 matched controls (10 of whom participated in Experiment 1A) were tested here.

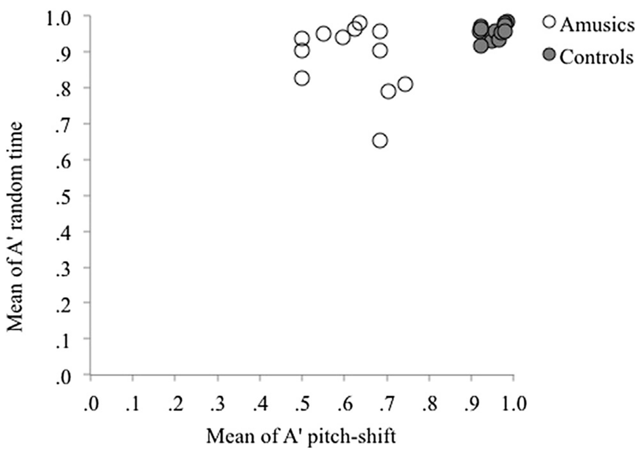

Fig. 2 – Individual mean A′ obtained in the detection of a pitch-shift as a function of the detection of a random time change in Experiment 1B.

4.2. *Material*

A subset of 24 (8 happy, 8 sad, and 8 peaceful) clips were selected. The clips intended to express fear were excluded because detection of errors was difficult in these clips, even for controls. Pitch-shift modified versions of the 24 original clips were created in which the melodic line of one entire measure was shifted either up or down by one semitone. Similarly, 18 original clips (6 happy, 6 sad, and 6 peaceful) were modified by changing the tone onset times randomly in one measure. The mean duration of the pitch-shift was 3.07 sec (range: 1.0–5.6) and the mean duration of the random time onsets was 3.25 sec (range: 1.24–6.06). The mean duration of the clips was 12.9 sec (range: 9.7–16.4) in the pitch-shift condition and 12.4 sec (range: 9.3–16.4) for the random time condition. Examples of both the pitch-shifted and random timing clips can be heard at www.brams.umontreal.ca/plab_download.

4.3. *Procedure*

The type of modification was blocked and consisted of 48 trials in the pitch-shift condition and 36 trials in the random-time condition. The two conditions were presented to amusics and controls in counterbalanced order. The instruction was to monitor each excerpt so as to detect whether the pianist was “off-the-track or absent-minded” at some point during the performance. Participants responded “yes” if they detected an error and “no” otherwise. They were not informed of the nature of the changes, and no feedback was provided, with the exception of the practice examples (one example for each condition and for each emotion). The task lasted approximately 30 min.

4.4. *Results and comments*

We computed the nonparametric index of sensitivity A′ (MacMillan & Creelman, 1996) for each participant in each condition, by considering a “yes” response as a hit when there was a change and a “yes” response to an unchanged stimulus as a false alarm. Responses bias (B″) was also computed for each individual. As expected, amusics performed poorly in the pitch-shift condition, and significantly worse than controls, $t(22) = 13.10$, $p < .001$ (Fig. 2). While most amusics performed within the normal range in the random-time condition, their scores still fell significantly below controls for the detection of time errors, $t(22) = 2.44$, $p < .05$. The responses bias measure (B″) indicated that amusics were significantly more conservative than controls in the pitch-shift condition [amusics' mean (SD): .22 (.22); controls' mean (SD): .46 (.25); $t(22) = 2.46$, $p < .05$], but not in the random-time condition [amusics' mean (SD): .14 (.41); controls' mean: .30 (.37); $t(22) = .99$, $p = .33$].

These results confirm that amusics' perceptual difficulties are not restricted to the melodies used for diagnosis. Performance on the pitch-shift condition was correlated with both the scores obtained on the MBEA scale test (Peretz et al., 2003), $r(22) = .93$, $p < .002$, and the scores obtained in the online out-of-key test (Table 1; Peretz et al., 2008), $r(22) = .85$, $p < .001$. These correlations failed to reach significance when only amusics were considered, $r_s(10) = .44$ and .17, both $p = .16$. Nevertheless, the results show that the perceptual deficit that characterizes amusics extends to the processing of the musical clips from which amusics appear to be able to derive the emotional tone.

This dissociation between perception (Experiment 1B) and emotion recognition (Experiment 1A) is consistent with the lack of correlations between the average score obtained in the pitch-shift and random-time condition and the emotional ratings, $r(19) = .11$, .38, .33, and .36, for happy, sad, scary and peaceful clips, respectively, $p > .05$. Note that the lack of correlation was also observed when the pitch-shift and random-time condition were considered separately. Similar results were obtained when considering amusics only, $r_s(9) = .04$, .05, .36, and .16, respectively; all $p > .05$.

5. Experiment 2: the contribution of mode and tempo

What has not yet been explained is how amusics can judge emotions in music, despite their difficulty in detecting obvious semitone pitch shifts in the same music. One hypothesis that we examine here experimentally is that amusics may rely more heavily on tempo (as suggested by Ayotte et al., 2002), since their pitch deficit might prevent them from using the musical mode, which critically depends on the semitone distinction, to distinguish major/happy from minor/sad music. The central objective of this experiment was to evaluate this hypothesis with a set of musical excerpts in which mode and tempo have been selectively manipulated (Peretz et al., 1998).

5.1. *Participants*

Eleven amusics (all amusics but A10 and A11) and 11 matched controls took part in this experiment.

5.2. Material

The 32 excerpts used in this experiment (previously employed in Dalla Bella, Peretz, Rousseau, & Gosselin, 2001; Peretz et al., 2001, 1998, and Schellenberg, Peretz, & Vieillard, 2008) were selected from pre-existing Western classical music so that half of the excerpts evoked happiness and half evoked sadness. The excerpts were transcribed for piano and computer-generated using a piano timbre. The happy excerpts were in a major mode and played at a relatively fast tempo (between 80 and 255 BPM), while the sad excerpts were in a minor mode and played at a relatively slow tempo (between 20 and 100 BPM; for more details, see Peretz et al. 1998, and www.brams.umontreal.ca/plab_download). Each original excerpt was manipulated electronically to create a mode inversion from major to minor and vice versa, using the same conventional procedure as Hevner (1935). Depending on the musical excerpt, this manipulation introduced variable frequency of semitones changes (from 2.7 to 46.3). After data collection, one sad excerpt was discarded from the analyses as its mode was ambiguous. The inclusion or exclusion of this excerpt did not affect the results. A neutralized tempo version was also created by adjusting all tempi to a unique value (with the quarter note = 84 M.M.) that corresponded to the median of all original tempi.

We performed the same acoustical analyses on the stimuli for this experiment as that done previously for the musical clips of Experiment 1A. The values are presented in Table 4 and showed that a number of acoustical characteristics differed between the original sad and happy stimuli as in Experiment 1. The mean pitch was higher, $t(29) = 5.27$, $p < .001$, the key was clearer, $t(29) = 2.70$, $p < .05$, roughness was greater, $t(29) = 3.64$, $p < .005$, and RMS energy was greater, $t(29) = 3.31$, $p < .005$, in happy than in sad stimuli. Pulse clarity, $t(29) = -1.89$, $p = .07$, and brightness, $t(29) = 1.02$, $p = .32$, did not differ significantly.

5.3. Procedure

The participants were presented with the original versions, as well as the mode and tempo change versions, of the same 32 excerpts. The presentation order of the excerpts was pseudo-randomized so that the same excerpt was never presented twice in succession and that the same intended emotion (happy or sad) was not repeated more than 3 times. Four stimuli (2 sad, 2 happy), which were not used in the study, served as examples; no feedback was provided. The task was to judge to what extent the excerpts expressed sadness or happiness on a scale from 1 (sad) to 10 (happy). The stimuli were presented in a soundproof room through Genelec 8040A speakers. We also recorded the activity of the zygomatic and corrugator facial muscles and measured galvanic skin responses. Since these physiological measurements were too variable to be meaningful in both amusics and controls, the data will not be presented.

5.4. Results and comments

Amusics' mean ratings were similar to those of controls (Fig. 3A). The two-way mixed-design ANOVA computed on the mean raw ratings for the original version of the stimuli as a function of Group (amusic *vs* control) and intended Emotion (happy *vs* sad) confirmed that there was no reliable effect of Group, $F(1, 20) = 3.69$, $p = .07$, $\eta^2_{partial} = .16$, but a large effect of Emotion, $F(1, 20) = 671.06$, $p < .001$, $\eta^2_{partial} = .97$, and no interaction [$F(1, 20) = 1.97$, $p < .18$, $\eta^2_{partial} = .09$]. We also computed correlations between participants' pitch discrimination abilities (using the scores obtained in the pitch change detection task, Table 1) and the ratings provided for the original version of the stimuli. No relationships were found [for happy stimuli: $r(20) = -.14$, $p = .52$; sad stimuli: $r(20) = -.35$, $p = .12$], even in amusics when considered separately [$r(9) = -.22$ and $-.14$, respectively].

In order to focus on the individual contributions of mode and tempo to the emotional judgments, we subtracted each rating given to the manipulated versions of an excerpt in the mode and tempo change conditions from the rating given to its original version. A mean score of 0 would indicate that there is no effect of the manipulation, while a negative score would indicate a change in ratings toward happiness, and a positive score a change toward sadness. As shown in Fig. 3B, amusics' ratings seemed to differ from controls' on the mode change version. This was supported by a three-way mixed-design ANOVA computed on the mean subtracted ratings with Group (amusic *vs* control), intended Emotion (happy *vs* sad), and Structure (mode *vs* tempo) as factors. The ANOVA revealed a triple interaction, $F(1, 20) = 5.47$, $p < .05$, $\eta^2_{partial} = .22$. Below, we report the results of follow-up ANOVAs performed on the tempo and mode change versions separately.

The groups showed similar sensitivity to the change of tempo, $F(1, 20) = 231.73$, $p < .001$, $\eta^2_{partial} = .92$. There was no Group effect ($F < 1$) nor interaction between Group and intended Emotion ($F < 1$). Thus, neutralization of tempo had the same effect on both amusics and controls' emotional ratings. In contrast, amusics did not respond to a change of mode as markedly as controls did, with a significant interaction

Table 4 – Mean pitch, or F0, and pitch range (in parentheses), expressed in MIDI code, with pitch names, and in Hz, as well as the acoustic values extracted with the MIR Toolbox, for the happy and sad music clips of Experiment 2.

	Mean pitch			Acoustic value				
Emotion	MIDI	Label	Hz	Key clarity	Pulse clarity	Brightness	RMS energy	Roughness[a]
Happy	66.2 (61.4–71.4)	F#5 (C#5-B5)	473.4 (343.2–652.8)	.85 (.67–.96)	.79 (.63–.90)	.15 (.08–.20)	.17 (.13–.22)	.11 (.05–.22)
Sad	59.6 (50.9–68.4)	C5 (D#4-G#5)	315.8 (181.3–524.1)	.75 (.52–.93)	.69 (.16–.91)	.16 (.14–.20)	.14 (.11–.21)	.07 (.04–.14)

[a] Normalized with minimum and maximum roughness values of the dataset.

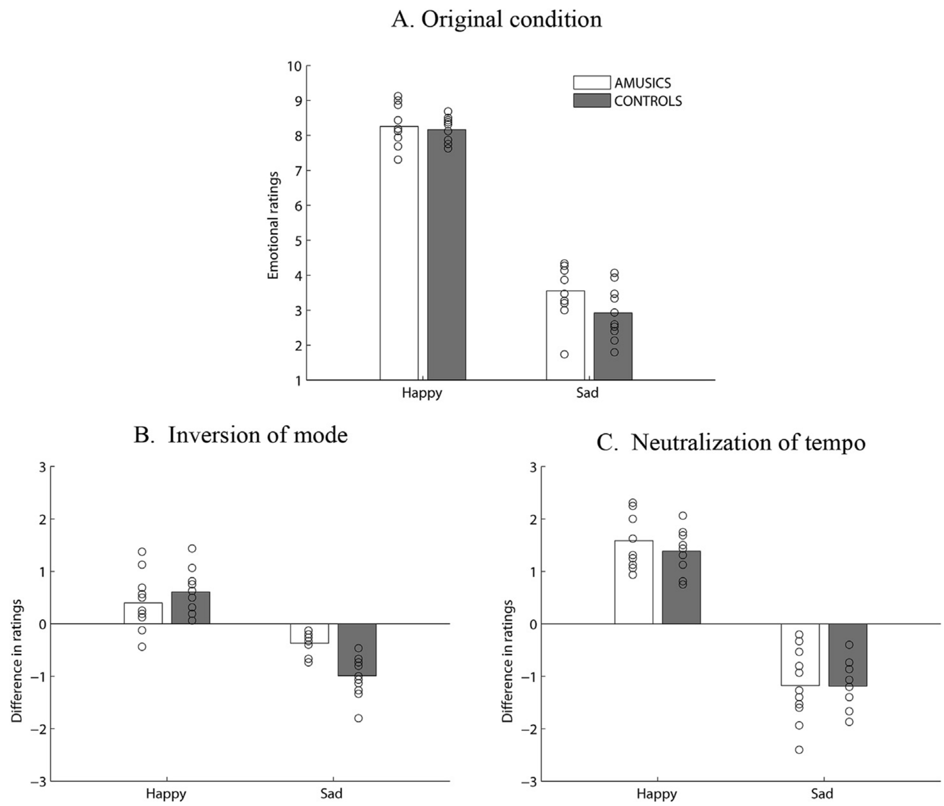

Fig. 3 – Individual average rating as a function of group and intended emotion in Experiment 2 for the original stimuli (A). Difference ratings for the original stimulus minus the manipulated stimulus are presented for the inverted mode in (B) and the neutral tempo in (C). Mean group values are indicated by columns.

between Group and intended Emotion, $F(1, 20) = 10.49$, $p < .005$, $\eta^2_{partial} = .34$. The group difference reached significance for the sad excerpts, $t(20) = 4.71$, $p < .001$, but not for the happy ones, $t(20) = -1.04$, $p = .31$. Nevertheless, amusics were sensitive to the mode manipulation; their ratings differed significantly from zero for both the happy and sad stimuli, $t(10) = 2.50$ and -5.63, respectively, $p < .05$, two-tailed tests. Although amusics were less sensitive to mode changes than controls were, there was no evidence that they relied more heavily on tempo at the group level. However, at the individual level, one can see that a few amusics (Happy: A4, A6 and A12; Sad: A4) were more affected (on the order of 2 SD) by the tempo neutralization (Fig. 3C).

In order to examine whether the reduced use of mode by amusics in emotional judgments compared to controls originated from their poor pitch discrimination, we examined the influence of the number of semitones changed by the mode manipulation in a given musical excerpt on its corresponding rating. We predicted that the more semitone changes in an excerpt, the more that would influence the ratings. Interestingly, only controls were found to be sensitive to the frequency of semitone changes, $r(29) = .38$, $p < .05$ (Fig. 4A). The frequency of semitone changes did not affect amusics' ratings, $r(29) = .00$, $p = .99$.

To examine what other features could have influenced amusics' judgments in the mode change condition, we compared the subtracted ratings with the values of the acoustical cues that were computed for the original versions minus their mode change versions. Of note, the mode change did not create any major differences in mean pitch. For example, the mean pitch of the original Vivaldi excerpt was 61.8, and it was 61.5 in the mode-change version. Nevertheless, controls showed sensitivity to these small pitch differences, $r(29) = .67$, $p < .001$, whereas amusics did not, $r(29) = .27$, $p = .15$ (see Fig. 4B). Similarly, amusics' judgments did not show sensitivity to key clarity, $r(29) = .21$, $p = .26$, while controls' differences in rating did, $r(29) = .39$, $p < .05$ (Fig. 4C). In contrast, amusics were sensitive to timbral differences, as were controls. Differences in brightness, $r(29) = -.38$, $p < .05$, in RMS energy, $r(29) = -.43$, $p < .05$, and in roughness, $r(29) = -.40$, $p < .05$, predicted the difference in ratings between the original and the mode change version in amusics. The correlations in controls for these characteristics were $r(29) = -.50$, $p < .01$; $-.48$, $p < .01$; and $-.51$, $p < .005$, respectively. Neither amusics' nor controls' judgments showed sensitivity to pulse clarity, $r(29) = .16$, $p = .39$; $r(29) = .02$, $p = .93$, respectively.

Additionally, we performed correlations between the raw ratings obtained for the original stimuli and the acoustical characteristics. In this case, both amusics' and controls' ratings correlated with mean pitch [$r(29) = .73$ and $.72$, $p < .001$, respectively], RMS energy [$r(29) = .67$ and $.61$, $p < .001$], pulse clarity [$r(29) = .36$ and $.37$, $p < .05$], key clarity [$r(29) = .44$ and $.42$, $p < .05$] and roughness [$r(29) = .61$ and $.61$, $p < .001$], but not brightness [$r(29) = -.18$ and $-.19$, $p = .35$ and $.31$, respectively], as observed in Experiment 1.

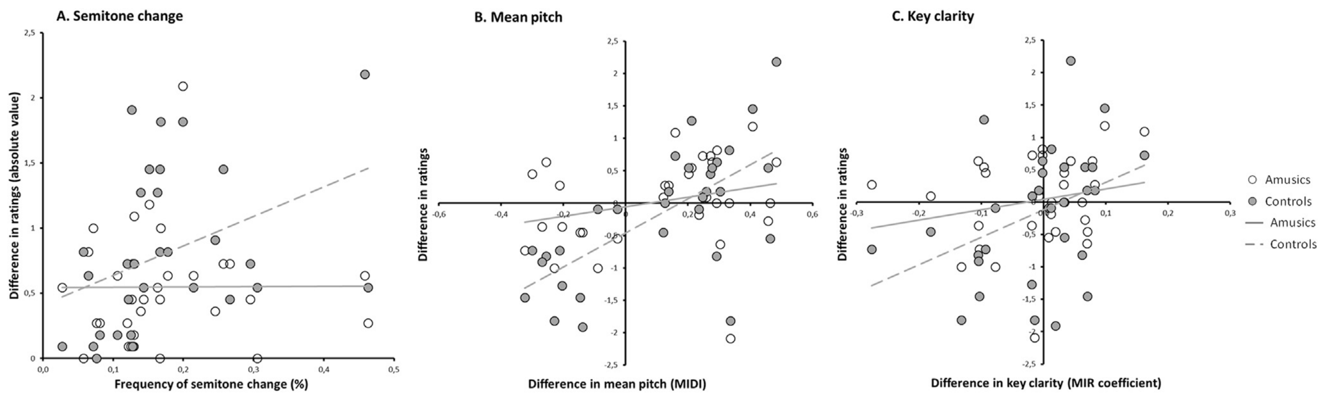

Fig. 4 – Individual average difference ratings for the original minus the inverted mode stimulus as a function of the frequency of semitone changes (A), the difference in mean pitch (B) and in key clarity (C) for amusics and controls in Experiment 2. Note that negative differences were obtained when the acoustical value was higher in the mode change condition than in the original version. A mean score of 0 indicates no effect of the manipulation.

6. General discussion

The results show that many amusic individuals have a remarkable sparing of emotional responses to music in the context of severe and lifelong deficits in processing music (see Table 1 for a summary of individual data). The finding of spared emotion recognition in a perceptually impaired system raises the fundamental question of the separability between emotion and cognition. This is not a new consideration. As mentioned in the introduction, a similar dissociation had been observed in I.R., a middle-aged woman without musical education, who suffered from irreversible deficits in music perception and memory as a consequence of a sudden brain accident (Peretz, Belleville, & Fontaine, 1997; Peretz & Gagnon, 1999). I.R. was found to be able to use the mode (major and minor) in which music was played in order to judge if its emotional tone was happy or sad, as normal participants did (Peretz et al., 1998). However, I.R. did not have the pitch deficit experienced by the amusics tested here, as I.R. was able to discriminate two successive tones a semitone apart (Peretz et al., 2001). Nevertheless, the present findings extend the dissociation between emotions and perception in music to congenital amusia and raise a set of novel questions regarding its origin.

The dissociation between the perceptual and emotional processing of music is important for theoretical models. For example, we (Peretz & Coltheart, 2003) have posited a common perceptual system for both music identity recognition and emotion expression recognition. In other domains, such as facial processing, it has been proposed that perceptual processing is distinct and is implemented in a separate functional (and neural) system for identity than that used for emotion processing of faces (e.g., Bruce & Young, 1986; Haxby, Petit, Ungerleider, & Courtney, 2000). According to the classical view, prosopagnosic individuals suffer from deficits in facial identity processing with no difficulties in processing other aspects of faces, particularly facial expressions (Duchaine, Parker, & Nakayama, 2003; Humphreys, Avidan, & Behrmann, 2007).

In the music domain, the task characteristics may play a more critical role than in facial processing. Asking participants whether music evokes some basic emotion makes sense to nonmusicians because this is one of the primary reasons why most people listen to music. Asking nonmusicians to detect an error in music is much less common and is probably never done intentionally. Thus, by being closer to everyday listening experiences, emotional judgments may be more appropriate to reveal the content and the organization of the listeners' implicit knowledge of music structure than most non-emotional judgments (Peretz et al., 1998).

Emotional judgments rely on a large variety of structural cues. The most potent musical cues, also the most frequently studied (Gabrielsson & Lindström, 2010), are mode, tempo, dynamics, articulation and timbre. Here, we examined the role of mode and tempo experimentally (Experiment 2) and assessed the contribution of correlated attributes, such as mean pitch, key and pulse clarity, and timbral cues (brightness, energy, and roughness) in both Experiment 1A and 2. Amusics' judgments were mostly influenced by temporal (tempo, pulse clarity) characteristics and timbre. There was no evidence that amusics could use semitone differences. In contrast, controls' emotional judgments exhibited sensitivity to these features. This difference in access to subtle emotional cues may explain why amusics were impaired but still above chance in judging the happy-sad character of the music when the mode was experimentally changed. The deficit was expected as a result of their impaired pitch perception system, which affects their ability to detect the critical semitone difference that differentiates the minor from the major mode (e.g., Hyde & Peretz, 2004) and the pitch salience (harmonicity) that differentiates consonant from dissonant chords (Cousineau et al., 2012). Our novel finding here is that amusics are able to use other timbre-related features to judge the emotion conveyed by music. In sum, a musical emotion processing deficit is present but subtle in congenital amusia, and can be compensated for by the use of tempo, pulse clarity, large mean pitch differences, and timbre in most circumstances.

One implication of the present findings is that most amusic individuals should enjoy listening to music. Yet, as noted in the introduction, amusics vary widely in their interest in music (Ayotte et al., 2002; McDonald & Stewart, 2008; Omigie et al., 2012) and this variability appears unrelated to the severity of the disorder (McDonald & Stewart, 2008). Here, we replicate this observation and support it in a quantified manner, as evident through close examination of the individual data (Table 1). For example, while a relationship seems to exist in participant A6 between the severity of the musical pitch deficit, the emotion recognition performance, and musical appeal, there is no clear relationship in participant A8. A6 seems impaired in all music-related activities and dislikes music. In contrast, participant A8, who is a severe case of amusia, exhibits normal recognition of emotions and responds to music as controls do according to his questionnaire responses. Such a dissociation pattern is consistent with the recent discovery of music anhedonia, a deficit that can occur in isolation in 20% of the normal population (Mas-Herrero et al., 2014). Thus, perception, emotion and enjoyment are possibly distinct components in music processing. Understanding their inter-relationship remains a major challenge for future studies in neuroscience of music.

An interesting issue raised by the present findings concerns domain specificity. From a music-theoretic perspective, the perception of a mode change relies on the detection of a scale degree difference, hence on knowledge of the rules of the Western tonal system. Such knowledge would be both culture- and music-specific. Accordingly, a fine-grained pitch deficit should affect music selectively. However, recent findings question the domain specificity of the present findings. First, a mild deficit in identifying happiness and sadness from speech prosody has been observed in congenital amusia (Thompson, Marin, & Stewart, 2012). Second, the spectra of major intervals have been found to be more similar to the spectra of excited speech, whereas the spectra of minor intervals were more similar to the spectra of subdued speech (Bowling, Gill, Choi, Prinz, & Purves, 2010; Bowling, Sundararajan, Han, & Purves, 2012; Curtis & Bharucha, 2010). These similarities may reflect a common evolutionary origin for music and vocal emotions (Spencer, 1857) or a musical neural invasion ("neural recycling", to adopt the terminology of Dehaene & Cohen, 2007). Musical emotions might recruit the same circuits that have evolved for vocal emotions (e.g., Peretz, 2010). Further comparative study of music and prosody in amusia may shed further light on this issue.

We can conclude from the present study that severe difficulties in music discrimination and memory can spare emotional processing of music to a large extent. This preservation may serve as a springboard for intervention, whereas systematic research on the residual difficulties may open new avenues for testing theories regarding the biological origins of musical emotions.

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Appendix 1. Affective responses to music questionnaire

Part two of the *Uses and Function questionnaire* (McDonald & Stewart, 2008).

1. A certain song/tune can often evoke nostalgic memories of past times or a past event for me.

Strongly agree	Agree	Unsure	Disagree	Strongly disagree
1	2	3	4	5

2. I have never experienced tingles/goose pimples/shivers from any kind of music.

Strongly agree	Agree	Unsure	Disagree	Strongly disagree
5	4	3	2	1

3. Certain music can put me in a good mood or 'match' my current mood.

Strongly agree	Agree	Unsure	Disagree	Strongly disagree
1	2	3	4	5

4. I have never felt that music has moved me to tears/catharsis/or emotional release.

Strongly agree	Agree	Unsure	Disagree	Strongly disagree
5	4	3	2	1

5. Music can calm/soothe/relax or relieve my stress at times.

Strongly agree	Agree	Unsure	Disagree	Strongly disagree
1	2	3	4	5

6. I rarely experience the feeling of music uplifting my mood.

Strongly agree	Agree	Unsure	Disagree	Strongly disagree
5	4	3	2	1

7. Occasionally, certain music can sadden my mood.

Strongly agree	Agree	Unsure	Disagree	Strongly disagree
1	2	3	4	5

8. I don't find that music can comfort me in uncertain times.

Strongly agree	Agree	Unsure	Disagree	Strongly disagree
5	4	3	2	1

9. Certain music can sometimes motivate or excite me.

Strongly agree	Agree	Unsure	Disagree	Strongly disagree
1	2	3	4	5

10. I don't associate music with the onset of spiritual feeling/experience.

Strongly agree	Agree	Unsure	Disagree	Strongly disagree
5	4	3	2	1

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