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Note

Priming paradigm reveals harmonic structure processing in congenital amusia

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ABSTRACT

Deficits for pitch structure processing in congenital amusia has been mostly reported for melodic stimuli and explicit judgments. The present study investigated congenital amusia with harmonic stimuli and a priming task. Amusic and control participants performed a speeded phoneme discrimination task on sung chord sequences. The target phoneme was sung either on a functionally important chord (tonic chord, referred to as “related target”) or a less important one (subdominant chord, referred to as “less-related target”). Correct response times were faster when the target phoneme was sung on tonic chords rather than on subdominant chords, and this effect was less pronounced, albeit significant, in amusic participants. These data report for the first time a deficit in congenital amusia for chord processing, but also provide evidence that, despite this deficit, amusic individuals have internalized sophisticated syntactic-like functions of chords in the Western tonal musical system. This finding suggests that thanks to this musical knowledge, amusic individuals could develop expectancies for musical events, and, presumably, follow the tension-relaxation schemas in Western tonal music, which also influence emotional responses to music.

1. Introduction

Congenital amusia refers to a lifelong disorder of music perception and production. Amusic individuals are described as having severe difficulties in detecting wrong, out-of-key tones, even though these are easily detected by nonmusician listeners (e.g., Peretz et al., 2002). It has been suggested that this deficit could be caused by amusics’ impairments in pitch discrimination (e.g., Foxton et al., 2004; Hyde and Peretz, 2004; Peretz et al., 2002) and pitch memory (e.g., Tillmann et al., 2009; Williamson and Stewart, 2010), and that these impairments might lead to the impaired perception of musical structures and violations thereof (as the detection of out-of-key tones).

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Congenital amusics' deficits have been reported only for the processing of melodic material, ranging from tone pairs over short tone sequences to longer melodies (including rhythm). The need to assess amusics' capacities for harmony processing has been pointed out by Sloboda et al. (2005), but no research has investigated amusics' perception of harmonic structures so far. While melodies are monophonic tone sequences (i.e., only one tone is played at a time), harmonic structures are based on chords, that is three or four tones played simultaneously (e.g., the tones C, E and G define a C major chord). Harmonic structures add a vertical dimension to melodic structures, thus reinforcing the musical organization of a piece. Just like tones, chords differ in their structural importance inside a given tonality or key, notably with the "tonic" chord being the chord at the top of the harmonic hierarchy, followed by the "dominant" chord and then the "subdominant" chord (e.g., Bharucha, 1984). For example in the key of C major, the chords of C major, G major and F major fulfill the tonal functions of tonic, dominant and subdominant, respectively. Based on the rules defined by the Western tonal system, the use of chords (like the use of tones) leads to statistical regularities (differences in frequencies of occurrence and in frequencies of co-occurrence) that can then be internalized by listeners via mere exposure (Bigand and Poulin-Charronnat, 2006; Tillmann et al., 2000). The internalized musical structure knowledge guides listeners' perception and allows listeners to develop musical expectations for future events. As harmonic sequences provide more musical information (in particular regarding musical syntax) at any given point in time than do melodic sequences, we assessed here whether amusic individuals also show a deficit for harmonic structure processing.

To exclude problems related to the explicit nature of the required judgments (e.g., reduced confidence or awareness, response biases), we assessed amusics' capacity of harmonic processing with an implicit investigation method. Indeed, it has been shown with electroencephalography (EEG) that the amusic brain detected mistuned notes in melodies while behavioral responses were at chance level (Peretz et al., 2009). The authors argued that the difference between the amusic brain and the normal brain might be linked to limited awareness of the presence of fine-grained pitch differences. This study also recorded Evoked Related Potential (ERP)-responses for out-of-key tones, but the observed ERP-markers felt short of significance.

A large body of literature has provided evidence for the advantage of implicit, indirect investigation methods to reveal patients' perception of various materials, including faces, language – and, more recently, music. For example, a well-documented case of acquired amusia showed evidence of musical structure knowledge when tested with a priming paradigm despite all previous failures in explicit judgments and memory tasks (Tillmann et al., 2007). The priming paradigm is a behavioral method that investigates how the processing of an event can be influenced by the prior exposure of the same event (repetition or sensory priming) or a related event (here related based on tonal structures). The key point is that participants are not required to make explicit judgments on the relations between the context (prime) and the to-be-processed event (the target). They are required to make a speeded perceptual judgment on the target (e.g., a lexical decision task), and response times reveal the influence of the relatedness between prime and target.

In the musical priming paradigm that we have used in several prior studies including the one on acquired amusia (e.g., Bigand et al., 2001; Tillmann et al., 2007), the target is the last chord of an eight-chord sequence, and it is musically either related (and supposed to be expected as it fulfills an important musical function, the tonic) or less-related (and supposed to be less expected as it fulfills a less important musical function, the subdominant). The material is constructed in such a way that it controls for sensory priming (based on the acoustic overlap between context and target) and thus provides evidence for listeners' tonal knowledge about musical structures and subtle chord functions (see also Bigand et al., 2003, 2007). In one of the versions of the musical priming paradigm, the chords are sung on meaningless syllables and the experimental task requires a speeded syllable discrimination on the target chord. Response times are typically faster for expected tonic targets than less-expected subdominant targets (Bigand et al., 2001; Schellenberg et al., 2005; Tillmann et al., 2007, 2008b). This paradigm has shown the influence of musical knowledge on chord processing in various populations (students, children, brain-damaged patients, and elderly participants).

Here we tested a group of congenital amusics with this paradigm. The experimental conditions tested for amusics' perception of subtle differences in harmonic structures: all targets were part of the instilled key and differed solely by their degree of tonal function; the less-related targets were thus not acoustically deviant (they were not out-of-key events). In contrast to previous studies using tone sequences and explicit judgments (e.g., Peretz et al., 2002), the use of harmonic structures (with several tones played simultaneously) and the use of the more sensitive implicit investigation method (i.e., the priming paradigm) should reveal amusic individuals' tonal knowledge, if there is any.

2. Method

2.1. *Participants*

The amusic group consisted of nine adults (five women) with a mean age of 60.6 years [Standard deviation (SD) = 6.9], an average level of education of 17.0 years (SD = 2.4), and with average musical training of 1.6 years (SD = 2.6). The control group consisted of nine adults (six women) with a mean age of 58.2 years (SD = 10.4), an average level of education of 16.2 years (SD = 3.2) and musical training of .9 years (SD = 1.8). Data of four control participants have been taken from previous studies (Tillmann et al., 2007, 2008a). All participants have provided written informed consent.

All participants (except two controls) completed the Montreal Battery of Evaluation of Amusia (MBEA). To be considered as amusic, participants have to obtain an average score two SDs below the average of the normal population (Peretz et al., 2003). The amusics' average scores (61.25%; SD = 10.18; all performing below the cut-off of 76.67%) differed significantly from controls' average scores (90.2; SD = 3.7), $t(14) = 7.11$, $p < .0001$. For further details, see Table 1. While amusics' deficits also affect the processing of temporal information in about half the amusics (Peretz, 2003), the most distinctive subtests are those testing for the pitch dimension (scale, contour, interval), in particular the scale subtests (see Peretz et al., 2008), for which amusics' performance was close to chance level (50%).

2.2. Material

The eight-chord sequences of Bigand et al. (2001) were used: 24 ended on the tonally related tonic chord and 24 on the less-related subdominant chord (see Fig. 1 for one example). Each of the first seven chords sounded for 625 msec and the target chord for 1250 msec. The sequences were sung on meaningless consonant-vowel (CV)-syllable sequences to allow for the independent perceptual judgments, which required a speeded syllable discrimination (sung on /di/ or /du/). The sung CV-syllables were made with sampled voice sounds (e.g., /da fei ku ʃo fa to kei/ for the context, and /di/ or /du/ for the last syllable). Example sound files are available at http://olfac.univ-lyon1.fr/bt-sound. The experimental session consisted of 50% of sequences ending on the related target (25% sung with /di/, 25% with /du/) and 50% ending on the less-related target (25% /di/, 25% /du/). The experiment was run with Psyscope software (Cohen et al., 1993).

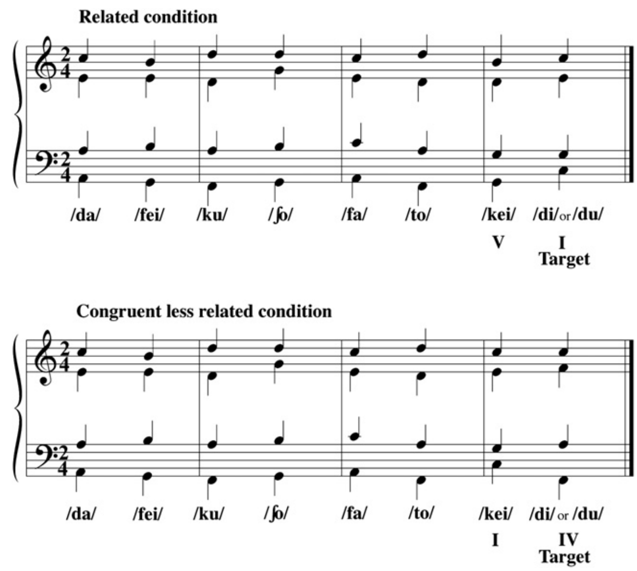

Fig. 1 – One example of the sung chord sequences used in the experiment [Figure reprinted from Cognition, 81(2), Bigand et al., B11–B20, Copyright (2001) with permission from Elsevier].

2.3. Procedure

Participants were asked to decide as quickly and as accurately as possible whether the last chord of each sequence was sung on /di/ or /du/ by pressing one of two keys. Incorrect responses were accompanied by a feedback and correct responses stopped the sounding of the target. A short random-tone sequence was presented after each response. After four

Table 1 – Characteristics of each participant in amusic (A) and control (C) groups: Gender [female (F), male (M)], Age (in years), Education (in years), Musical expertise (as measured by years of musical training), Scores on the MBEA (global test score followed by scores of the six subtests: scale, contour, interval, rhythm, meter, memory; with chance level being 50%), context effect (presented as difference between z-scores in less-related and related conditions).

	Gender	Age	Education	Musical expertise	MBEA Global	Scale	Contour	Interval	Rhythm	Meter	Memory	LessRelated – Related
A1	F	64	16	0	58.00	53.33	53.33	53.33	63.33	66.67	50.00	.38
A2	F	62	21	8	70.00	46.67	66.67	73.33	93.33	70.00	76.67	.16
A3	M	67	15	0	62.90	66.67	73.33	56.67	83.33	53.33	70.00	.25
A4	M	62	18	0	51.33	50.00	50.00	50.00	50.00	56.67	50.00	–.07
A5	F	45	17	2	66.11	53.33	70.00	50.00	76.67	70.00	76.67	.04
A6	M	67	14	2	60.00	60.00	43.33	56.67	73.33	66.67	53.33	.03
A7	F	64	15	2	69.44	66.67	70.00	70.00	66.67	66.67	76.67	.11
A8	F	58	17	0	72.67	56.67	66.67	73.33	96.67	70.00	73.33	.09
A9	M	56	20	0	40.80	53.30	53.30	50.00	63.30	50.00	56.70	.15
C1	F	53	18	0	90.56	96.67	86.67	86.67	76.67	96.67	100.00	.09
C2	M	56	13	2	88.89	96.67	80.00	90.00	80.00	90.00	96.67	.18
C3	F	45	19	0	88.33	93.33	96.67	93.33	86.67	76.67	83.33	.55
C4	F	60	18		84.45	86.67	86.67	80.00	80.00	83.33	90.00	.32
C5	F	61	18	5	93.89	100.00	100.00	96.67	90.00	86.67	90.00	.57
C6	F	53	13	0	89.44	83.33	96.67	86.67	100.00	90.00	80.00	.14
C7	F	49	11	0	95.56	96.67	93.33	100.00	100.00	100.00	83.33	.28
C8	M	79	20	0								.18
C9	M	68	16	0								.58
Amusics	Mean	60.56	17.00	1.56	61.25	56.29	60.74	59.26	74.07	63.33	64.82	.13
	STD	6.89	2.35	2.60	10.18	6.96	10.78	10.11	15.17	7.82	12.03	.13
Controls	Mean	58.22	16.22	.88	90.16	93.33	91.43	90.48	87.62	89.05	89.05	.32
	STD	10.35	3.15	1.81	3.68	6.09	7.16	6.78	9.57	7.87	7.38	.20
Comparison	t-test	.58	.56	.55	.00	.00	.00	.00	.06	.00	.00	.02

Note: One control did not provide information about musical background and two other controls have not been tested with the MBEA.

Table 2 – Average response times (ms) in related and less-related conditions for amusic and control groups (SDs in brackets).

	Related	Less-Related
Amusic group	1255 (475)	1286 (475)
Control group	1027 (446)	1123 (478)

practice sequences, the 48 sequences were presented in random order twice in two blocks, separated by a short break.

3. Results

Percentages of errors were overall low (2.89% for amusics, 1.16% for controls). Average correct response times did not differ significantly between the amusic group (1270 msec ±475) and the control group (1075 msec ±461), $p = .39$. Because of differences in average response latency between participants (ranging from 556 msec to 2223 msec) and with the goal to focus on differences between related and less-related targets, correct response times were individually normalized to z-scores with a mean of 0 and a SD of 1 (see Table 2 for response times in *ms* for each condition in each group).

A 2 × 2 ANOVA computed on z-scores (Fig. 2) with Group (amusic/control) as between-participants factor and Context (Related/Less-Related) as within-participants factor revealed a significant main effect of context, $F(1,16) = 32.04$, $p < .0001$, $MSE = .014$, with faster processing for related targets than for less-related targets. The interaction between Group and Context was significant, $F(1,16) = 6.18$, $p = .02$, $MSE = .014$: The context effect was larger for controls [$F(1,16) = 33.18$, $p < .0001$] than for amusics, but still significant for amusics [$F(1,16) = 5.04$, $p = .04$]. Note that a supplementary ANOVA with target type (di/du) as additional within-participants factor did reveal neither a main effect nor an interaction of this factor with context or group ($ps > .14$), thus justifying the averaging of the data over target types.

Visual inspection suggests that three controls showed larger context effects than the other six controls; similarly, one amusic showed a stronger context effect than the other amusics. A supplementary analysis – excluding these four participants – confirmed the presence of an interaction between Group and Context, just falling short of significance, $p = .057$, probably due to the smaller and unequal group sizes.

For amusic participants, the differences between less-related and related targets (i.e., the context effect) did not correlate with the MBEA scores (total score and each of the subtests), $-.03 < r(7) < +.21$. When calculated over participants of the two groups, correlations reached significance ($p < .05$) for the scale [$r(14) = .54$], contour [$r(14) = .59$] and interval [$r(14) = .53$] subtests, but not for rhythm, meter and memory subtests [$r(14) < .35$]. It should be noted that this should be expected as performance on the melodic tests (scale, contour, interval), mainly determined group classification, with deficits on the pitch dimension having been described as the major deficits in congenital amusia (e.g., Peretz, 2003; Hyde and Peretz, 2004). Moreover, exclusion of the two control participants with larger context effects (one control did not complete the MBEA) considerably reduced the size of the correlation. In sum, performance variability on the MBEA cannot explain the variability of the priming effect.

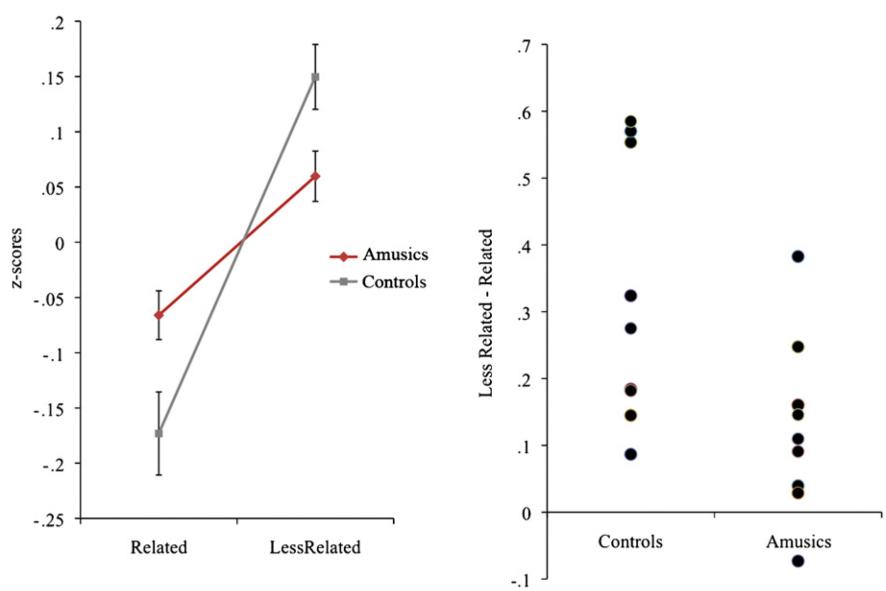

Fig. 2 – (Left) Normalized correct response times (z-scores) for amusic and control participants, presented as a function of the context (related/less-related), error bars indicate between-participants standard errors. (Right) Individual data points for controls (left) and amusics (right) showing the context effect, that is the difference between response times of less-related and related targets: the stronger the difference, the stronger the context effect (with a positive difference indicating faster processing for related targets). Note that one point represents two control participants, with scores of .184 and .182, respectively.

In order to assess the potential influence of musical training on priming, the correlations between the size of the context effect and the reported years of musical expertise were calculated. These were not significant for the entire group [r(15) = .002; note that one Montreal control did not provide an answer for this question], for amusics [r(7) = −.04] or for controls [r(6) = .28].

4. Discussion

The present results extend amusics' musical impairments to the processing of harmonic structures. Compared to control participants, amusic participants showed a reduced harmonic context effect. However, amusics' and controls' performances largely overlapped and the context effect was also significant in amusics. For both participant groups, target processing was faster for related tonic target chords than for less-related subdominant target chords. The observed individual differences could not be related with performance on the MBEA or with musical training. The latter result is in agreement with previous data that either did not show group differences (when comparing musicians and nonmusicians, e.g., Bigand et al., 2001) or did not observe correlations between priming effects and years of musical expertise (e.g., Bharucha and Stoeckig, 1987). Although we cannot explain the individual differences observed in each group, the main finding was that the amusic group did show a musical priming effect.

Our experimental material controlled for sensory priming influences (Bigand et al., 2001, 2003), and allows us to conclude that the amusic individuals processed the musical structures at a cognitive level. This finding thus goes beyond the previously reported EEG findings, which have been also discussed in terms of sensory pitch memory mechanisms (with mistuned pitches being less frequent in the melody than the in-tune pitches) (Peretz et al., 2009).

Our results show that, despite the previously reported pitch perception deficits (including the failure to detect out-of-key tones), amusic individuals have acquired musical knowledge about statistical regularities of the musical system. The unconscious pitch tracking capacities (as revealed by EEG in Peretz et al., 2009) together with coarse pitch discrimination capacities might be sufficient to capture some of the regularities of associations between pitches, leading to some tonal knowledge (including the harmonic relations tested in the priming paradigm), even if sparse and only functional at an implicit level. This finding calls for the investigation of amusics' capacities of implicit learning, notably whether amusic individuals could learn implicitly statistical regularities between tones. Omigie and Stewart (2011) provide a first data set suggesting intact implicit learning of new tone material in amusia, but the use of relatively strong violations in the test phase restricts interpretations and requires further investigation of amusics' implicit learning capacities.

In the present study, the observed harmonic priming effect suggests that amusic individuals process subtle differences in harmonic structures and functions. Based on the tonality established by the prime context (the beginning of the chord sequences), listeners' develop expectations for future musical events, and these expectations influence target chord processing, with facilitates processing of the tonic chord (e.g., Bigand et al., 2001; Tillmann et al., 2008b). The differences in response times for the two target chord types (tonic and subdominant), which are both plausible events in the instilled tonality, further suggest that amusics have some understanding of musical structures and musical syntax.

Understanding musical structures and developing musical expectations influences not only perception, but is related to musical expressivity and emotions. Musical structure knowledge allows listeners to follow the tension-relaxation schemas in Western tonal music (Lerdahl and Jackendoff, 1983), which influence emotional responses (e.g., Krumhansl, 1996; Steinbeis et al., 2006). Musically expressive moments have been described to arise from the composers' play with listeners' (unconscious) expectations, which are fulfilled (or not), violated or delayed (Meyer, 1956). The musical structure knowledge revealed here might thus be part of the processes leading to the recently reported intact emotional perception in amusia (Gosselin et al., 2011; Paquette et al., 2011). Interestingly, the case of acquired amusia, who showed harmonic priming effects, also showed intact emotional responses to music (Peretz et al., 1998).

Future research should test how much can be learned from implicit investigation methods on the musical processing capacities in amusia. It would be important to assess whether priming effects extend to melodic lines, or to tasks requiring musical short-term memory, for which amusics failed in comparison to controls (Tillmann et al., 2009; Williamson and Stewart, 2010).

Finally, revealing tonal knowledge in amusic individuals, even with an implicit, indirect investigation method, provides a valuable basis for the development of rehabilitation programs in amusia, similarly to previous efforts in rehabilitation based on patients' spared processing capacities, which were revealed by implicit investigation methods (e.g., Bier et al., 2002).

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