Processing of emotional faces in congenital amusia: An emotional music priming event-related potential study

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ABSTRACT

Congenital amusia is characterized by lifelong impairments in music perception and processing. It is unclear whether pitch detection deficits impact amusic individuals’ perception of musical emotion. In the current work, 19 amusics and 21 healthy controls were subjected to electroencephalography (EEG) while being exposed to music excerpts and emotional faces. We assessed each individual’s ability to discriminate positive- and negative-valenced emotional faces and analyzed electrophysiological indices, in the form of event-related potentials (ERPs) recorded at 32 sites, following exposure to emotionally positive or negative music excerpts. We observed smaller N2 amplitudes in response to facial expressions in the amusia group than in the control group, suggesting that the cognitive and neural mechanisms underlying neurodevelopmental disorder of music processing, provides a unique opportunity for studying the cognitive and neural mechanisms underlying neurodevelopmental disorder of music processing. © 2017 The Authors. Published by Elsevier Inc. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

1. Introduction

Congenital amusia (amusia hereafter), commonly known as “tone deafness”, refers to lifelong musical problems that are not attributable to mental retardation, lack of exposure to music, deafness, or brain damage after birth (as distinguished from acquired amusia) (Ayotte et al., 2002; Peretz, 2008). Great difficulty in discriminating pitch differences when listening to music is regarded as the main symptom of amusia (Foxton et al., 2004). Rates of amusia in Britain and the USA have been reported to be about 4% and 5%, respectively (Kalwus and Fry, 1980; Hyde and Peretz, 2004). It is well accepted that amusia, being a neurodevelopmental disorder of music processing, provides a unique opportunity for studying the cognitive and neural mechanisms underlying language and music processing (Patel, 2008).

An intense relationship between music and language has long been recognized (Slevc and Miyake, 2006; Slevc et al., 2009), and deficits in music processing have been observed to accompany other cognitive impairments (Jones et al., 2009; Peretz, 2006). A recent study suggested that amusics individuals have deficits in processing speech prosody (Thompson et al., 2012). Speech prosody refers to the meaningful or paralinguistic acoustic attributes of speech (Selkirk, 1995). Processing human speech prosody involves important communication abilities; prosody not only expresses linguistic information, but also conveys emotional content. Thompson et al. (2012) found that amusic individuals showed reduced sensitivity to emotional prosody (e.g., happy, sad, irritated). Some researchers believe that, without other linguistic information, prosody may be processed similarly to music, and thus may be relatively incomprehensible to amusic people (Patel et al., 2005; Hutchins et al., 2010).

Music and speech prosody are both composed of acoustic cues that can express affective information via the manipulation of pitch, tempo, and volume (Dissanayake, 2000). Thus, insensitivity to music and speech prosody may share a common developmental basis (McMullen and Saffran, 2004). Similar to emotional prosody and pictures, music can convey affective information. Different varieties of music have been shown to evoke different emotions (Krumhansl, 1997; Juslin and Laukka, 2003; Tsang et al., 2001). Structural characteristics, including tone, interval, and rhythm, appear to combine together into different modalities to impact human emotion (Rigaud et al., 2005). Furthermore, it has been suggested that the intensity of evoked emotion can be affected by pitch, inharmonic chords, loudness, and tempo (Costa et al., 2000; Hevner, 1937; Maher, 1980; Maher and Berlyne, 1982), and that emotional valence may be impacted particularly strongly by tonality (e.g. major vs. minor chords) (Kastner and Crowder, 1990). Lu et al. (2016) reported recently that amusia individuals draw upon visual information implicitly...
When judging auditory information, even though they can recognize conflicts between visual channel and auditory information.

Given that individuals with amusia perform worse than normal listeners in music-related tasks (Ayotte et al., 2002; Peretz, 2008; Hyde and Peretz, 2004), it is plausible that the amusic brain may not be able to process all of the information contained within music. In this regard, it remains to be determined whether music-encoded emotional information can be processed normally by amusics. If amusics show reduced sensitivity to emotional content in music, then it needs to be distinguished whether this deficit results from impaired music processing or impaired emotion processing.

Facial expressions have been widely used as stimuli in emotion research, and the ability of an individual to recognize and respond appropriately to emotional information from facial expressions is vital to everyday social interactions (Wang and Luo, 2004). It has been reported that event-related potential (ERP) components recorded by electroencephalography (EEG), such as P1, N1, and P3a, are related to the neurobiological bases of emotional face processing (Wild et al., 2001; Morita et al., 2001). The N2 component, a negative-going wave that peaks 200–350 ms after a conflict between stimulus representations (Yeung et al., 2004), appears to correlate with an individual’s attentional orienting towards emotional stimuli (Folstein and Petten, 2008; Cuthbert et al., 2000; Bartholow et al., 2005). Because the N2 component, which reflects conflict but appears to be unrelated to stimulus type, is a stable composition of endogenous neural activity that reflects brain information processing (Wang et al., 2004, 2003) it can be used as the investigation target of music emotion priming effect. Meanwhile, because the late-positive component (LPC) has been associated with emotional memory retrieval and encoding (Paller and Kutas, 1992), it is a useful probe for emotional information processing.

To examine the ability of amusics to process emotional information, in the present study, we asked individuals with and without amusia to make judgments on emotional faces using a priming paradigm. Our goal was to determine how amusics individuals perform in emotional priming tasks, while at the same time exploring the underlying electrophysiological mechanisms of emotional information processing in these individuals. The N2 component and LPC were measured as indices of musical emotion and facial emotion processing after emotional face was presented in each correct trial. We hypothesized that we would observe reduced sensitivity to musical emotion in amusics relative to controls, but intact facial emotion processing ability.

2. Materials and methods

2.1. Participants

Participants in the current study were college students and post-graduates between 18 and 25 years of age. Montreal Battery of Evaluation of Amusia (MBEA) (Peretz and Hyde, 2003) was administrated to all participants. The MBEA is widely used to diagnose amusia, and includes six subtests: Scale, Contour, Interval, Rhythm, Meter, and Memory (Peretz and Hyde, 2003). For the first four subtests, listeners are presented with pairs of melodies and asked to judge whether they are “same” or “different”. For the last two subtests, listeners are only presented with one single melody on each trial and required to judge whether the presented melody is “March” or “Waltz” in the Meter subtest, and whether it is the one that they have heard before on the previous subtests in the Memory subtest. Full score of each subtest is 30 points; individuals whose mean globe scores are below 25D to that of general population are diagnosed as congenital amusics. To reduce the impact of the fatigue effect and shorten the whole experimental time, only pitch-related subtests (i.e., Scale, Contour, and Interval) were used. Twenty-one participants whose mean scores of three subtests were at or lower than 21.4 were placed in the amusia group, according to the Chinese norm (Nan et al., 2010). Another 23 participants were recruited to serve as controls. Given the fact that people with depression are reported to have significant reductions in musical ability compared to healthy individuals (Paul et al., 2014), participants who had ever been diagnosed with an affective disorder were excluded from further participation. Furthermore, we evaluated the emotion status of all participants with the Self-rating Depression Scale (SDS) and the Self-rating Anxiety Scale (SAS) (Zung, 1971; Zung, 1965); those whose scores were >40 points (out of 80) on either scale were excluded. With these criteria, 2/21 amusics and 2/23 control participants did not take part in the main experiment. The two groups did not differ in terms of age, gender, or years of education; but amusics performed significantly worse than controls in each subtest of the MBEA (see Table 1). None of the subjects had ever received professional training in music or music research. Participants were all confirmed to be right-handed via self-report and had normal or corrected-to-normal vision. None of them had a history of psychiatric problems, brain, auditory, or severe physical disease, or had been exposed to electric shock, anti-psychotics, anti-depressants, anti-manic drugs, sedative hypnotic drugs, or psychoactive substances in the preceding four weeks. All participants were paid for their participation and given written informed consent in accordance with the procedures and protocols approved by the Ethical committee of the Second Xiangya Hospital of Central South University.

2.1.1. Emotional music excerpts

To select positive and negative pieces of music, 31 (14 female) untrained normal volunteers were asked to rate the valence and arousal of music excerpts from (Vieillard et al., 2008) on a 9-point scale (1 = most negative/least arousing; 9 = most positive/most arousing). Based on those ratings, 25 positive (i.e., happy) and 25 negative (i.e., sad) music excerpts were selected. The average valence rating scores differed significantly between the positive (6.51 ± 1.76) and the negative (2.90 ± 1.31) excerpts (t = 26.838, p < 0.001), whereas the average arousal rating scores did not (positive: 5.52 ± 1.94; negative: 5.21 ± 1.97; t = 1.812, p = 0.071). Excerpt durations ranged from 9 s to 15 s, and the duration of positive melodies (12.39 ± 1.81 s) did not differ from that of negative ones (12.22 ± 2.03 s; t = 0.297, p = 0.769). All of the excerpts were saved as binaural wave audio files (bit rate, 128 kbps) in Audition editing software (Adobe Systems Inc., USA).

2.1.2. Emotional faces

A set of 50 “happy” and “joyful” facial expressions were used as “positive” stimuli and a set of 50 “sad”, “fear” and “angry” facial expressions were used as “negative” stimuli. The emotional face images were selected from the Chinese Facial Affective Picture System (CFAPS) (Gong et al., 2011) and normalized for brightness and size. The individuals in CFAPS have given written informed consent to publish these case details. Similar arousal ratings were obtained for positive (5.52 ± 0.71) and negative (5.74 ± 0.69) stimuli (t = −1.526; p = 0.13).

2.1.3. Procedure

Participants were seated in a comfortable chair in a darkened, sound-attenuated room during testing. Stimuli were presented on a 19-inch

| Characteristic      | Amusics          | Healthy controls | t value | p value |
|---------------------|------------------|------------------|---------|---------|
| Age (y)             | 19.6 (1.07)      | 20.6 (2.38)      | 1.813   | 0.080   |
| Gender (no. males)  | 6                | 8                | 0.1862  | 0.666   |
| Education level     | 13.4 (1.07)      | 14.5 (2.16)      | 1.986   | 0.056   |
| SDS mean score      | 32.1 (3.33)      | 29.3 (4.68)      | −1.991  | 0.054   |
| SAS mean score      | 29.8 (3.94)      | 27.3 (4.68)      | −1.785  | 0.082   |
| MBEA                |                  |                  |         |         |
| Mean score          | 19.2 (2.24)      | 26.7 (1.93)      | 11.365  | <0.001  |
| Scale               | 18.6 (2.65)      | 26.7 (2.13)      | 10.600  | <0.001  |
| Contour             | 19.5 (2.92)      | 27.1 (2.35)      | 8.679   | <0.001  |
| Interval            | 19.3 (2.71)      | 26.4 (2.40)      | 8.050   | <0.001  |

Note: standard deviation is in parentheses.
monitor (resolution 1024 x 768 pixels) via STIM 2 stimulus-presenting software. The monitor was located half of a meter from the participants' eyes. The face pictures were presented at a size of 140 x 69 pixels on a black background. Every participant conducted a total of 100 trials, including 25 in each of the four following conditions: positive music-positive face (P-P), positive music-negative face (P-N), negative music-positive face (N-P), and negative music-negative face (N-N). Hence, there were 50 congruent trials (P-P or N-N) and 50 incongruent trials (P-N or N-P). As shown in Fig. 1, each trial started with a 200-ms alarm sound (2000 Hz, sinusoidal) with a white fixation point on the monitor. Subsequently, an emotional music excerpt played, and 500 ms after music ends, participants were presented with an emotional face, the valence of which may or may not have been consistent with that of the preceding music. The participants' task was to listen to the music attentively and judge the valence of the face as positive or negative by pressing one of two response buttons as rapidly and accurately as possible. The button assignments for positive versus negative judgments were counterbalanced across participants. The face disappeared after the button-press response or sufficient time elapsed (1800–2200 ms randomly). All participants completed practice trials until they were performing with 90% accuracy before entering in the actual experiment. Recordings from all correct trials during the experiment were included in the analysis. The entire experiment lasted about 45 min for each participant.

2.2. EEG recording

A QuickCap Ag/AgCl 32 electrode cap (Neuroscan Inc., USA) was used to obtain EEG signals. EEG data were recorded continuously and processed offline in Neuroscan 4.3 software (Neuroscan Inc., USA). Horizontal electrooculograms (HEOGs) were recorded using lateral electrodes from both eyes, while vertical HEOGs were recorded from the upper and lower canthus of the left eye. An electrode on the left mastoid served as the online reference electrode and then the data were re-referenced to the linked mastoids offline. Electrode impedance was kept below 5 kΩ during the test. The sampling rate was 500 Hz. Data were stored on a hard disk and filtered online with a 0.05–100 Hz band-pass. Trials containing artifacts from eye blinks or body movements and those with muscle potentials exceeding ±50 μV at any electrode(s) were excluded from the averages (Jasper, 1958).

2.3. Statistical analysis

All data were analyzed in SPSS 17.0 statistical software (SPSS, Inc., Chicago, IL). Means are reported with standard errors (SEs). Reaction time (RT) data were analyzed with repeated-measures analyses of variance (ANOVA), with musical valence (positive and negative), face valence (positive and negative), and group (amusia and control) as variables. EEG data were first analyzed with Neuroscan 4.3 software. Epochs encompassing 1200 ms (200-ms pre-stimulus baseline) after face-picture onset were computed. Mean amplitudes of the N2 components (200–350 ms poststimulus) and LPCs (450–800 ms poststimulus) elicited on six channels (F3, Fz, F4, C3, Cz, and C4) in response to face stimuli were analyzed with repeated-measures ANOVAs with the variables of music valence (positive and negative), face valence (positive and negative), region (frontal and central), and brain hemisphere (left, central, and right). Group (amusia vs. control) was treated as a between-participants variable; all other factors were regarded as within-participant variables. The Greenhouse-Geisser correction was applied to detect violations of sphericity, when necessary, and p < 0.05 was considered statistically significant.

3. Results

3.1. Behavior

The overall RTs (across all four conditions) of amusics (585.645 ± 28.924 ms) did not differ significantly from those measured in controls (546.944 ± 25.610 ms; F1,38 = 1.085, p = 0.304). The mean RTs for amusics and controls in each of the four different conditions (see legend) are presented in Fig. 2. There was not a significant three-way group × music × face interaction (F1,38 = 1.559, p = 0.219), and there were not significant two-way music × face (F1,38 = 0.752, p = 0.391), music × group (F1,38 = 0.008, p = 0.928), or face × group (F1,38 = 0.732, p = 0.398) interactions. Simple effects analysis indicated that

![Fig. 1](image-url)
participants in both groups had slower RTs in response to negative faces (591.462 ± 19.919 ms) than in response to positive faces (541.126 ± 18.269 ms; F1,42 = 3.638, p < 0.001).

3.2. ERPs

3.2.1. N2 amplitude

Amusics showed a significantly reduced face-elicited N2 amplitude (10.103 ± 1.194 μV) compared to controls (5.053 ± 1.135 μV; F1,38 = 9.398, p = 0.004), and a repeated-measures ANOVA revealed a significant music × face interaction (F1,38 = 6.533, p = 0.015). Independent of group, larger N2 amplitudes were elicited in response to positive faces following positive music (7.659 ± 0.861 μV, overall mean of both groups' subjects) versus in response to negative faces following the positive music (7.881 ± 0.809 μV). Conversely, when face stimuli followed negative music, negative faces elicited larger N2 amplitudes (6.759 ± 0.922 μV) than did positive faces (8.013 ± 0.847 μV). The mean N2 amplitude recorded at each electrode for the amusic and control groups in each of the four conditions are presented in Fig. 3.

3.2.2. LPC amplitude

Overall, mean LPC amplitudes were similar for the amusia group (16.776 ± 1.632 μV) and the control group (14.205 ± 1.552 μV; F1,38 = 1.303, p = 0.261). A significant two-way face × lateralization interaction was found (F2,37 = 15.521, p < 0.001). Positive facial expressions elicited a larger LPC amplitude in the left hemisphere (14.764 ± 1.097 μV) than in the right hemisphere (14.252 ± 1.162 μV), whereas negative faces elicited a larger LPC amplitude in the right hemisphere (15.876 ± 1.131 μV) than in the left hemisphere (14.953 ± 1.071 μV). A significant main effect of face valence was observed (F1,38 = 6.626, p = 0.014). Larger LPC amplitudes (mean of all participants) were elicited by negative faces (15.986 ± 1.115 μV) than by positive faces (14.995 ± 1.169 μV). Grand average ERP waveforms for each of the six electrodes, by group and face stimulus valence, are shown in Fig. 4. The mean LPC amplitude of each electrode for amusics and controls in each of the four conditions are presented in Fig. 5.

To illustrate group differences in the ERPs, we subtracted averaged control group waveforms from averaged amusia group waveforms, with the group averages encompassing all four conditions; the subtraction curves for each electrode site are shown in Fig. 6. Note that the group difference was most pronounced in the N2-component time window (200–300 ms poststimulus). Furthermore, as shown in Fig. 7,
topographical maps of activation showed maximal activation differences between the groups (deep red) in the same time window.

4. Discussion

The present study examined whether emotional priming effects are observed in amusics and what behavioral and ERP differences may exist between amusic and control subjects with a normal musical sense when performing an emotional face judgement task with an integrated emotional music primer. Overall, we found that the RTs of the amusic group were similar to the RTs of controls, suggesting that amusics do not have an impairment of facial emotion judgement. This finding is consistent with prior reports indicating that amusics do not have severe social adaption dysfunctions (Ayotte et al., 2002; Peretz et al., 2002; Peretz et al., 2003), as would be expected if they had a facial emotion judgement impairment given that processing of facial expressions is integral to everyday social interactions (Wang and Luo, 2004). Gosselin et al. (2015) found that individuals with congenital amusia have a detectable, albeit subtle, musical emotion processing deficit, which can be compensated for by the use of large mean pitch differences, tempo, pulse clarity, and timbre in most circumstances.

In accordance with the work of Chen et al. (2008), our behavioral results provide further support for negative bias theory (Baumeister et al., 2001; Stenberg et al., 2010). According to negative bias theory, unpleasant or threatening information is afforded more intensive and concerted cognitive processing, resulting in harm-avoidance and behavioral inhibition in the context of potentially threatening stimuli. This apparent negative bias was present in both amusics and controls in our study.

Our observation of similarly larger N2 amplitudes in response to negative versus positive faces in both groups further indicates that amusics have normal facial emotion processing patterns—that is, processing similar to controls. A prior study did not reveal significant differences in musical emotion discrimination and processing between control and amusia subjects, even though the amusics struggled with pitch detection (Sloboda et al., 2005). The disparity between those findings and ours could be related to differences in task difficulty and the characteristics of the materials and stimuli used. Meanwhile, others have reported evidence suggesting that that amusics may have an impaired ability to discriminate among attitudes of anger, indifference, or irony in relation to characteristic changes in vocal tone (Thompson et al., 2012; Sloboda et al., 2005; Jiang et al., 2012). Lu et al. (2015) found impaired processing of speech prosody in a cohort of Chinese amusics and the deficits could not be compensated for by emotional linguistic information.

The current work has some limitations. Firstly, although we found that mean N2 amplitude differed between the amusic and control groups, we could not quantitate a priming effect due to the lack of neutral (face and/or music) conditions. Secondly, we did not divide our amusic subjects into subgroups. Also, we did not evaluate amusia-associated brain impairments with neuroimaging methods. In this regard, it should be noted that Albouy et al.’s (2013) findings suggest that amusics may have auditory cortex deficits as well as perhaps reduced global connectivity, as indicated by a decreased clustering coefficient (Cp) and increased normalized shortest path length (λ) compared to normal controls (Zhao et al., 2016). Encouraged by the results of the current work, in future studies, we will add more precise, standardized methods to further probe emotional processing in amusia.
Fig. 5. Mean LPC amplitude of amusics and healthy controls by experimental condition (P-P, P-N, N-P, N-N). Error bar = 1 SE.

Fig. 6. Subtracted ERP waveforms from six electrodes. Each curve represents the difference in response to faces (positive or negative) between amusics and controls (i.e. control group mean data subtracted from amusic group mean data).
5. Conclusion

Based on our behavioral and ERP results, including differential brain activation characterized by a reduced N2 component, we believe that deficits in amusics’ musical emotion perception may result from their reduced sensitivity to music-related information per se, rather than from an emotion processing impairment. These findings support the hypothesis that music and language share processing mechanisms as well as the valence emotion hypotheses, which posits that there is a valence-dependent hemispheric lateralization of emotional stimulus processing.

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