

A Case of Auditory Agnosia with Impairment of Perception and Expression of Music: Cognitive Processing of Tonality

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Auditory agnosia · Amusia · Tonality

Abstract

There is fairly general agreement that the melody and the rhythm are the independent components of the perception of music. In the theory of music, the melody and harmony determine to which tonality the music belongs. It remains an unsettled question whether the tonality is also an independent component of the perception of music, or a by-product of the melody and harmony. We describe a patient with auditory agnosia and expressive amusia that developed after a bilateral infarction of the temporal lobes. We carried out a detailed examination of musical ability in the patient and in control subjects. Comparing with a control population, we identified the following impairments in music perception: (a) discrimination of familiar melodies; (b) discrimination of unfamiliar phrases, and (c) discrimination of isolated chords. His performance in pitch discrimination and tonality were within normal limits. Although intrasubject statistical analysis revealed significant difference only between tonality task and unfamiliar phrase performance, comparison with control subjects suggested a dissociation between a preserved tonality analysis and impairment of perception of melody and chords. By comparing the results of our patient with those in the literature, we may say that there is a double dis-

sociation between the tonality and the other components. Thus, it seems reasonable to suppose that tonality is an independent component of music perception. Based on our present and previous studies, we proposed the revised version of the cognitive model of musical processing in the brain.

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Introduction

The sound that we experience in daily life is classified as spoken language, environmental such as wind or a car engine, and music. A disturbance of the recognition of spoken language is called pure word deafness, which is usually caused by bilateral damage to the temporal lobes [1]. Selective difficulty in recognizing and identifying nonverbal sound is called auditory sound agnosia [1]. Though the brain regions responsible for agnosia are not well defined, some authors emphasize the importance of the right or bilateral temporal lobe(s) for the occurrence of auditory sound agnosia. Amusia is defined as an acquired deficit of music processing [2], and generally it is classified as receptive or expressive [3]. Receptive amusia is thought to be caused by dysfunction of the receptive system for music processing [4] and refers to an inability to appreciate various characteristics of heard music [1].

When pure word deafness, auditory sound agnosia, and receptive amusia occur simultaneously, the state is called auditory agnosia [1]. Peretz had proposed a model of cognitive processing of melodies with 2 hierarchical stages [5]. First, at the stage of perceptual analysis, auditory input was perceived being divided into melodic and temporal organization. Melodic organization contained the information of pitch and contour, and temporal of rhythm and meter. At the stage of representation, these 2 kinds of information were integrated, and, then, recognized. In the recent review, the author reorganized the model of cognitive processing of melodies into the cognitive model of musical processing [6]. In that model, the pitch perception was further divided into interval analysis and tonal encoding. The current review considers the neural instantiation of such components, and considers musical listening disorders in terms of deficient or aberrant operation of the components [7]. We had reported a patient of pure amusia caused by the infarction of anterior portion of bilateral temporal lobes [7]. Compared with controls, the patient manifested the impairments of the discrimination of isolated chords [7]. We had also reported a positron emission tomography (PET) study which showed that the anterior portion of bilateral temporal lobes was vital in the perception of chords [8]. Based on our previous two studies, we suggested that the anterior temporal lobes participated in the perception of chords, and the harmony might be an independent component of music perception [8].

Tonality denotes a series of relations between pitches in which one particular pitch, the 'tonic', is central [9]. In the theory of music, the melody and harmony determine to which tonality the music belongs. Therefore, one can regard the tonality as a by-product of the melody and harmony. Then, a disturbance of tonality must always accompany an impairment of melody or harmony cognition. However, Peretz [10] considered that tonality was an independent component of the perception of music. She examined in detail a patient with amusia due to a bilateral infarction of the temporal lobes. The patient was unable to perceive sequential pitch structure, particularly when pitch intervals required tonal interpretation, in the presence of accurate encoding of melodic contour and interval sizes. Peretz [10] concluded that the impairment of her patient in the perception of music derived from auditory atonia as a consequence of brain damage. Because the author did not examine the capacity for harmony perception, we may say that it is still uncertain whether tonality is correlated with harmony. We investigated the capacity for tonality by using our original test

that consisted of a progression from subdominant to dominant seventh-tonic chords. In the theory of harmony, this type of harmony progression is thought to strongly determine the tonality to which the music belongs. If a patient with amusia has a dissociation between the results of the tonality test and of the harmony and melody test, the tonality is considered, as Peretz said, to be an independent component of music perception. If there is no dissociation, the tonality can be regarded as a by-product of the harmony and melody.

In short, the aim of this paper is to clarify following two points: (a) whether the tonality is an independent component of music perception? (b) If so, how is the cognitive model of music processing by Peretz and Coltheart [6] reorganized?

Subjects and Methods

Case Report

History

A 68-year-old right-handed businessman suffered from aphasia following an infarction in the left temporal lobe in 1989. The aphasia disappeared in a few years and no neuropsychological deficit remained. On the morning of January 3, 1996, he found it hard to hear spoken language. He could hear voices on the television and telephone, but he could not understand what was said. He could speak fluently and write and read correctly. He had no limb weakness. He had no sensory disturbance, no apraxia, no dyscalculia, nor any visual discrimination difficulties. When he sang familiar songs with the accompaniment of karaoke, even his favorite song that he had sung well at a party the month before, he was told by his colleagues that his singing was entirely out of tune. The music that he had enjoyed listening to before was wearisome and esthetic pleasure was gone. Two weeks later, he could understand face-to-face conversation. He consulted a hospital on January 24, and a brain MRI revealed a new infarction in the right temporal lobe. Pure tone audiometry revealed a slight deficit in the high frequency area that was within normal limits for his age. Speech audiometry revealed that the degree of maximal discrimination was only 50% in each ear. The auditory brainstem responses were normal. He had a low score (143/167) on the Token test. But, when questioned by written language, his score improved to 159. His diagnosis was pure word deafness, and receptive and expressive amusia. His ability to hear spoken language improved gradually for a year.

In June 1999, he was referred to our laboratory because of his persistent complaints concerning the disturbance of perception and expression of music. He had never taken music lessons but enjoyed listening to recorded music or live concerts. He met the criteria for Grison's third level of musical culture [11]. He had suffered from arrhythmia for 10 years.

Lesion Localization

The atlas of Duvernoy [12] was used to estimate the localization of the lesions. Figure 1 shows MRI scans performed on April

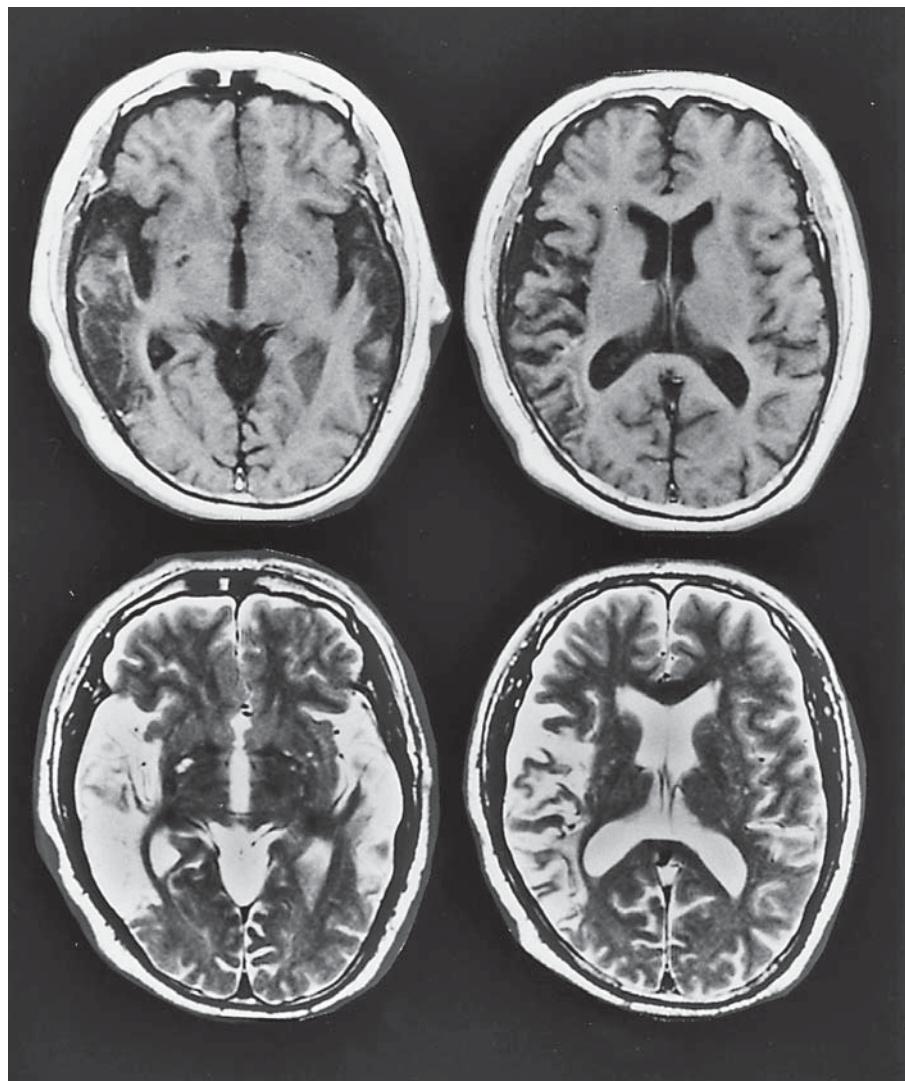


Fig. 1. Axial MRI images of the patient carried out 2 years after the onset of auditory agnosia. Upper and lower images show the T₁- and T₂-weighted images, respectively. The left side of images shows the right side of the brain. Old infarcted lesions are observed in bilateral temporal lobes more extensive on the right. The left lesion is situated in the middle temporal gyrus. The right lesion includes the superior, middle, inferior temporal gyri, transverse gyrus of Heschl and insula.

13, 1998, which revealed that the left lesion was situated in the middle temporal gyrus. Most of the left superior temporal gyrus, inferior temporal gyrus, transverse gyrus of Heschl, and the insula were spared. The right lesion, more extensive than the left lesion, was in the superior, middle, and inferior temporal gyri, transverse gyrus of Heschl, and the insula. The scan also showed altered signal areas in the white matter of the right hemisphere.

Control Subjects

Eight male and 4 female right-handed subjects with no history of neurological or psychiatric disease served as controls for the tests of musical capacity. Their ages were from 55 to 72 years (mean age 62 years). Control subjects were office workers in our laboratory or volunteers with musical background and education similar to those of our patient.

Methods

As mentioned in the 'Introduction', it is supposed that music is perceived as being divided into pitch and temporal organization [5, 6]. In order to clarify the impairments of music capacity of our patient, we have to assess the ability about the perception of pitch, rhythm, and meter. Music also has the relationship with long- and short-term memory which is investigated by the discrimination of familiar and unfamiliar melodies, respectively. Related to the cognitive processing of tonality, the assessment of the chord is necessary, because the music theory regards tonality as a by-product of melody and harmony. As for the expression of music, the information of the literature is quite limited and much still remains to be done. In musically naïve patients, it was hard for examiners to know what their singing ability was before illness. So, besides singing familiar songs, which is the common way to investigate musical expression ability in the reported literature [13, 14], we added two simple singing tasks that every musically naïve subjects could readily perform. Subjects were asked to reproduce single sounds

and two-note phrases. Each test was extensively described in our previous paper describing another amusia patient [7].

General Procedures

The patient and all control subjects gave informed consent to all tests administered. All stimuli were presented in a quiet room at a loudness level that was comfortable and customary for the listeners.

Recognition of Environmental Sounds

Twenty-four environmental sounds were presented, and subjects were required to answer what each sound meant. The materials contained following sounds: trumpet, phone, cat, crow, drum, male voice, wind, cow, passing train, dog, female voice, car's engine, clock, waves, music, horse, baby, English, river, firing pistol, chicken, sawing, male laughing, and footstep.

Perception of Music

Pitch Discrimination

After presenting a pure tone of 440 Hz as the standard, we presented a second tone and measured the range in which the standard and second tones were heard as the same pitch. The first and second tones, in which the interval was 2 s, were presented for 5 s.

Discrimination and Recognition of Familiar Songs

Thirty familiar nursery songs, all of which had the major key, were chosen and in 20 of these songs, a part of the melody was locally altered. The alterations were limited to only one or two tones and consisted of changes in the rhythm and the pitch. The latter brought the change of the key, in 5 songs, from major to minor. Among 20 altered songs, the contour of the melody was preserved in 13. All tunes were played by piano-tones of a Yamaha PSR-330 synthesizer and recorded onto a minidisc. Each song lasted for 10–15 s, and contained the whole or a half length of the original tune. Two different response modes were used: (a) song decision; (b) 'familiar-unfamiliar' decision.

Discrimination of Unfamiliar Phrases

We used an item of the tonal memory test of Seashore's measures of musical talents [15], which contained 30 pairs of short phrases consisting of 3–5 notes. Subjects were presented with 2 serial phrases and were asked which tone was altered in the second phrase.

Rhythm Discrimination

The rhythm test from Seashore's measures of musical talents [15] was used. Thirty pairs of rhythm patterns were presented, and subjects were asked to make a same-different discrimination. The tasks were divided into 3 groups, referred to as columns A, B and C, with progressively more complex sequences in the latter 2 columns.

Meter Discrimination

We used items from the meter test of a test for assessment of musical capacity for school children [16]. Following an example of 2 pieces of music that had double or triple time, the examiner presented 4 pieces of music that had double or triple time. The subject was then required to answer 'two' or 'three' for each piece of music.

Discrimination of Isolated Chords

A pair of chords in which the interval was 1 s was presented and subjects were asked to make a same-different discrimination. We used an item from the harmony test from a test for the assessment of musical capacity for schoolchildren [16]. Among 14 pairs, 7 pairs were consonant and the others dissonant.

Judgment of Tonality

In the reported literature, tonality perception was investigated by the scale task, which assessed the ability of subjects to detect notes that are out of key [17, 18]. It must be noted that these notes do not always bring the sense of incongruity, because melodies or tonal sequences sometimes sound musically natural even if they possess some notes out of key. So we used the following original test about tonality perception. The progression of the subdominant to dominant seventh-tonic chord is thought to be the strongest determinant of tonality. We made 20 kinds of sequences of 3 chords in which 2 chords had subdominant to dominant seventh progression. The last chords of 8 tasks were the tonic chords of each key which induced a natural feeling of an end. In 12 tasks, the last chords were irrelevant to the preceding 2 chords, which induced an unfinished, peculiar feeling. The chords were produced as piano tones with a Yamaha PSR-330 synthesizer, and subjects were asked to make a finished/unfinished response for each task.

Expression of Music

Singing Familiar Songs

The patient and control subjects were asked to sing 10 well-known Japanese nursery songs without accompaniment with the help of written lyrics. The performance of the patient and controls was recorded on minidiscs.

Reproduction of Single Sounds

Subjects were required to reproduce vocally single tones presented by the examiner. The pitch of the sound was set within the preferred range of each subject and the sound was presented as a pure tone using a Yamaha PSR-330 synthesizer. Five tones were tested. The examination was performed under two conditions: (a) while the tone was sounding, and (b) immediately following the end of the tone presentation.

Reproduction of Two-Note Phrases

Subjects were presented with 3 two-note phrases and were asked to sing each phrase. The phrases consisted of two notes whose pitches were separated by 3, 4 or 5 degrees (e.g. D-F sharp, D-G, and D-A).

Reproduction of Simple Rhythm

Ten simple rhythm patterns 2 bars long in 4/4 time were presented and subjects were required to reproduce the rhythm by hand clapping.

Results

The summary of tests of musical ability is shown in table 1. For the statistical analysis with a control population, the general linear model was used. In order to com-

Table 1. Results of tests of musical abilities

	Patient	Control
Perception of music		
Pitch discrimination, Hz	438–446	434–446
Discrimination and recognition of familiar songs, /30	21***	27.7 (26–30)
Discrimination of unfamiliar phrases, /30	9***	21.8 (17–27)
Rhythm discrimination, /30	20	24.8 (20–29)
Meter discrimination, /4	3	3.8 (3–4)
Discrimination of isolated chords, /14	9**	12.6 (11–14)
Judgment of tonality, /20	13	15.6 (12–19)
Expression of music		
Singing familiar songs	out of tune	well
Reproduction of single sounds	impossible	well
Reproduction of two-note phrases	impossible	well
Reproduction of simple rhythm	possible	well

The range of scores of control subjects are given parenthetically. ** p < 0.01, *** p < 0.001.

pare the results within the subject, namely intrasubject statistical analysis, Fisher's exact test was used.

Recognition of Environmental Sounds

The patient could not identify 4 environmental sounds among 24 familiar sounds. He identified the sounds of wind and the river as the sounds of a train and waves, respectively. He could not recognize the sounds of a firing pistol and foot steps at all. The mean score of 10 old healthy subjects was 22.7 (range: 21–24), so we diagnosed auditory sound agnosia.

Perception of Music

Pitch Discrimination

No significant difference was seen between the ranges of control subjects and the patient. The patient could discriminate pitch differences as well as normal subjects.

Discrimination and Recognition of Familiar Songs

All of the control subjects reported that they were very familiar with all of the songs, and their mean score was 27.7 out of 30 (range: 26–30). The score of the patient was significantly lower than those of the controls (p < 0.0001). Among 9 melodies he mistook, 5 melodies he regarded as wrong were actually correct. He regarded 4 altered songs as correct, where the alteration consisted of a change of the pitch (2 songs, with spared contours) or the rhythm (2 songs). He correctly answered all of 5 songs whose keys were altered. He stated that he was familiar with the songs which he mistook.

Discrimination of Unfamiliar Phrases

Control subjects answered 21.8 out of 30 tasks correctly (range: 17–27). In the tasks of 3, 4, and 5 notes (columns A, B, and C), the control mean scores were 9.3 (range: 7–10), 6.6 (range: 5–9), and 6.1 (range: 3–8), respectively. The patient had significant impairment in this test (p < 0.0001). Among correct answers, 5 tasks were in column A, 2 tasks in column B, and the others in column C.

Rhythm Discrimination

The mean score of the control subjects was 24.8 out of 30 (range: 20–29). The score of the patient was on the border of the normal limits.

Meter Discrimination

The mean range of the control subjects was 3.8 (range: 3–4). The patient gave correct responses in 3 out of 4 tasks.

Discrimination of Isolated Chords

The score of the patient was significantly lower than the score of the controls (p < 0.01).

Judgment of Tonality

The score of the patient was within normal limits.

Statistical Analysis within the Subject

We performed intrasubject comparison as follows: between (a) tonality task and isolated chord performance, (b) tonality task and unfamiliar phrase performance, and

(c) tonality task and familiar song performance. The results of statistical analysis of (a) and (c) were insignificant (Fisher's exact test; $p = 1.0$, a; $p = 0.76$, c). The comparison between tonality task and unfamiliar phrase performance revealed significant difference ($p = 0.021$).

Expression of Music

Singing Familiar Songs

The singing of the patient was entirely out of tune, even of songs he knew well. The rhythm and the contour of the melody were mostly preserved. The pitch was severely impaired, as if frequent disordered transposition occurred. He was not aware of the inaccuracy of his own singing. Accompaniment by keyboard did not improve his performance.

Reproduction of a Single Sound

All control subjects could readily reproduce the single tone during and following the termination of the tone presentation. The patient could not reproduce a single sound presented by the examiner following the termination of tone presentation, in spite of his effort for about 10 min. He could not fix the pitch of tones, and he did not notice that. In the reproduction during the tone presentation, he complained that he could not hear the sounding tone, and he could not judge whether his own singing was correct or not.

Reproduction of Two-Note Phrases

Control subjects could discriminate and reproduce 3 simple phrases easily. The patient could discriminate 3 simple phrases, but sang them entirely out of tune.

Reproduction of a Simple Rhythm

Control subjects and the patient could reproduce all patterns correctly.

Discussion

The patient had pure word deafness, auditory sound agnosia, and impairment of both perception and expression of music. We diagnosed auditory agnosia and expressive amusia. The summary of deficits of receptive musical ability is as follows: (a) discrimination of familiar melodies; (b) discrimination of unfamiliar phrases, and (c) discrimination of isolated chords. His performance in pitch discrimination and tonality were within normal limits. The former suggested that his ability of the perception of single sounds was spared. As for expression of

music, singing familiar songs and reproduction of single sounds and two-note phrases were impaired. Rhythm perception and expression was preserved, which is consistent with other reported amusic cases [7, 19]. In the following paragraphs, we discuss the cognitive processing of the tonality and some aspects of music processing in the brain.

Tonality: The Independent Component for Music Processing

It is assumed that tonality is an independent component of music perception. We compared the results of our patient for judgment of tonality with those for discrimination of isolated chords, discrimination and recognition of familiar songs, and discrimination of unfamiliar phrases. The result for judgment of tonality was within normal limits. We may say that he could feel and lead out the characteristic of the sound of the harmony progression of subdominant to dominant seventh-tonic chord, though the result for the discrimination of the isolated chords was significantly below normal. This is strange, because the grasp of the characteristic of harmony progression is more difficult than the same-different discrimination of a pair of isolate chords: the percentage of correct answers in controls was 78% in judgment of tonality and 90% in discrimination of isolated chords. Discriminations of familiar songs and unfamiliar phrases were also impaired, but, in the former task, he could discriminate all of 5 songs in which the keys were changed from major to minor. Intrasubject analysis between tonality task and unfamiliar phrase performance revealed significant difference, but the difference was insignificant between tonality task and isolated chords or familiar song performance. Although direct comparison does not show dissociation, comparison with control subjects suggests that a dissociation between a preserved tonality analysis and impairment of perception of melody and chords exists. These findings suggested that the feeling of the tonality could be organized separately, at least to some extent, from the perception of chords and melody. By comparing the results of our patient with those of Peretz's patient [10], we can identify a double dissociation between the impairment of tonality and of the other components. The patient reported by Peretz had an impairment of tonality with the absence of perception of melody, whereas our patient retained the feeling of tonality with an impairment of perception of melody and chord. This double dissociation suggested that tonality might be an independent component of the perception of music. It is suggested that deficits in tonality analysis have been

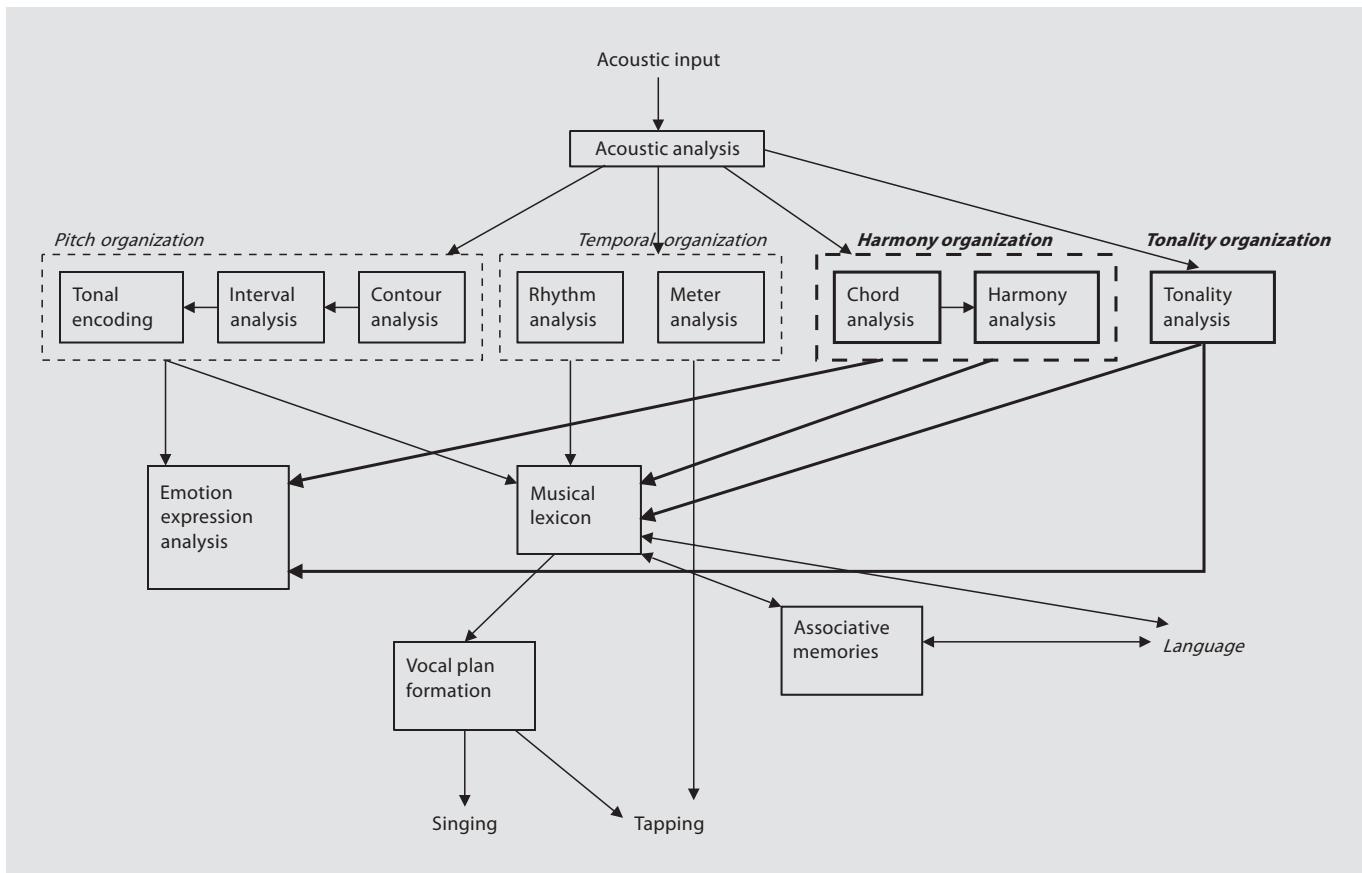


Fig. 2. Revised version of the cognitive model of musical processing [6]. Thick characters, lines, and arrows are newly added. The present case study reveals that the tonality is an independent component of music perception. Our previous case [7] and activation study [8] showed that the chord is also perceived independently.

associated with damage involving a predominantly right-sided network of nonprimary auditory cortical areas including lateral Heschl's gyrus, planum temporale, parietotemporal junction, insula, anterior superior temporal gyrus, and frontal operculum [17]. Functional imaging of neurologically normal individuals suggests a particular involvement of the frontal lobes in tonality analysis [17, 20, 21]. The lesion of our patient whose ability of tonality perception was spared affected almost all areas in right temporal lobes mentioned above, but not frontal areas. We may say that frontal lobes might play a crucial role in tonality analysis.

Revised Cognitive Model of Musical Processing

Based on findings of the present case, reported literature, our previous amusic case [7], and our PET study [8], we reorganized the cognitive model of musical pro-

cessing proposed by Peretz [6] (fig. 2). The pitch and rhythm are the independent components of music perception [6]. The double dissociation of the tonality perception in the present and Peretz's patient [10] revealed that the tonality is also an independent component of the perception of music. A chord is defined as the simultaneous sounding of two or more notes [9], and Takeuchi and Hulse [22] suggested that the perception of the single sound and the pitch interval, namely the pitch and chord, had different cognitive processing in the brain. This suggestion was reinforced by findings of our amusic case [7] and PET study [8]. We may say that the chord is also the independent component of music perception. Therefore, we can be fairly certain that musical analysis is divided into four distinct neuropsychological components: pitch, temporal, tonality, and harmony organization.

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