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Neurophysiological correlates of different moods and feelings induced by chords and harmonized scales revealed by fMRI

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***Abstract*— Activated brain areas in response to major, minor, augmented and diminished chords as well as to major and minor harmonized scales were investigated by fMRI. The activated areas for the chord experiments included regions related to emotion processing. Results of the scale experimnts were less straightforward than those of the chord experiments. Possible relationship between the known functions of the areas activated by each category of stimuli and the behavioral (emotinal) effects of the category was discussed.**

I. Introduction

Considering the history of the use of major and minor scales and chords in the western music [1], it is difficult to claim that the two kinds of scales and chords have some intrinsic neural basis in our innate brain. However, it is almost certain that ordinary exposure to the wester music from childhood is sufficient for ordinary people to develop some neural correlates for the moods and feelings induced by major and minor chords and scales. The contrasting happy and sad emotions elicited by major and minor chords, respectively, have attracted many researchers to studies of their neurophysiological correlates using fMRI (functional magnetic resonance imaging) and other techniques [2-6] because music can be a very suitable and important tool for investigating neural mechanisms of emotions. The musical scales, on the other hand, have not been associated with emotions by researchers of brain functions, though their roles in tonality have been studied using EEG [7] and MEG [8]. In our previous work [9], major and minor scales did not show differences in activation in those areas known to be related to emotions. In the present work, we extended our previous work [9] by 1) increasing the number of subjects in the chord listening experiments, 2) including diminished and augmented triads and by 3) harmonizing the scales by adding another voice.

II. Methods

A. Subjects

The results of the chord with major and minor triads experiments were integrated with those of the previous experiments (referred to as Experiment I with 17 subjects). Sixteen different subjects participated in the new experiments referred to as Experiment II and III. All the subjects were healthy without history of hearing disorders. None were musically-trained but all were familiar with both Western and traditional Japanese music. Subjects gave written informed consent in compliance with the procedures approved by the ethical committee of Tokyo Denki University.

B. Stimuli

Chords: Stimuli were made with MIDI (Digital Performer, 6, USA) in piano tone. A sequence of fundamental and inverted forms of a major, minor, diminished or augmented chord such as in Fig. 1 comprised a stimulus. As the figure indicates, these chords are defined by the intervals of major 3^{rd} – minor 3^{rd} (major chord), minor 3^{rd} – major 3^{rd} (minor), minor 3^{rd} – minor 3^{rd} (diminished) and major 3^{rd} – major 3^{rd} (augmented). The control stimulus was a sequence of repeated notes of one tone. Twelve such sequences of each chord category and control tone were made on the twelve root tones from F#3 to F4. Each eighth note lasted for 0.6 s making the whole sequence 3 s long.

Harmonized scales: Stimuli were made with MIDI in piano tone. The scales were harmonized in a standard manner by putting another voice underneath at an interval of major or minor third except for the tonic tones (C in Fig. 2). The added tones belonged to the key (tonality) of the scale. Each eighth note was 0.2 s in duration.

C. Procedures

fMRI acquisition parameters: 1.5 T whole-body Stratis II (Hitachi Medico Corp., Japan) was used with the parameters were as follows: FOV = 240 mm, TR = 3000 ms, TE = 47.2 ms, ISI =14 s, FA = 90^o, slice thickness = 5 mm, slice gap = 0 mm, 1 volume = 24 slices. The functional images were acquired using a T2* weighted echo-planar sequence using a sparse temporal sampling technique to circumvent the scanner noise interference (Fig. 3).

Presentation of stimuli: Each subject participated in 3 experimental sessions, each consisting of 64 scans. In Experiment I, 16 sequences (such as shown in Fig.1) of each of three categories, i.e., major, minor and diminished triads and of the control stimulus were presented before a scan. The order of presentation of the stimuli was random. Each category was presented $16 \times 3 = 48$ times in total. In Exp. II, augmented chords replaced the diminished chords. The onset of each stimulus was set at 5 s before that of each scan (Fig. 3). Exp. III employed the harmonized scales (Fig. 2). Otherwise the procedure was the same as that for I and II. To keep vigilance, subjects were asked to push a button when he heard a beep tone (1 kHz, 1.5 s) instead of a chord in Exp I and II and one of three buttons in Exp III according to his light, dark or neutral impression after each scale presentation.

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Figure1. Major (upper left), minor (upper right), diminished (left lower), augmented (right lower) triads used as stimuli in the chord experiments.

Figure 2. Major (top), minor (bottom) scales harmonized with another voice underneath.

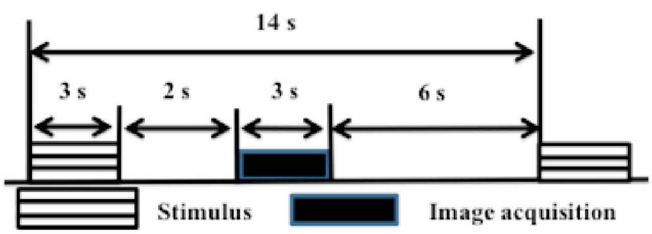


Figure 3. Sparse temporal sampling technique

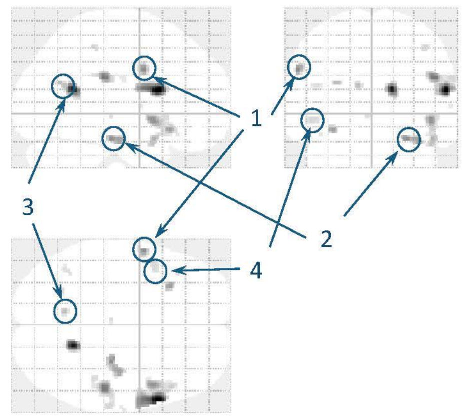
D. Analysis

SPM 8 (Wellcome Department of Cognitive Neurology, London, UK) was used for analysis. The images were realigned, coregistered and normalized according to the standard procedure and spatially smoothed by Gaussian kernel with FWHM=8 mm. Second level analysis was carried out for all the results. All the results presented below were obtained by contrasting against the activation to the control stimuli with significance level p < 0.005 being uncorrected for multiple comparison. Anatomical names of the regions were determined by referring the SPM coordinates to the Talairach standard brain.

III. Results

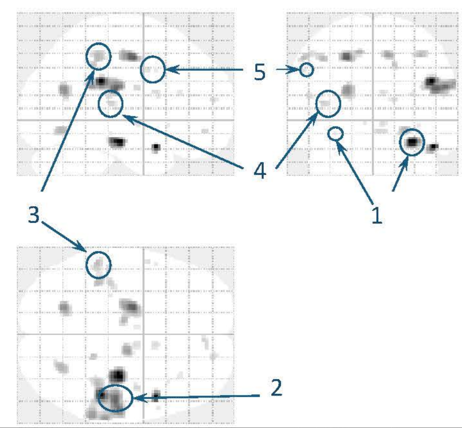
A. Chords

Fig. 4 is the result of the second level analysis of 33 subjects in Exp. I and II combined and shows the areas activated by the major chords with region names in the Talairach brain. The regions included the left inferior frontal gyrus (BA9), right parahippocampal gyrus (BA35), left posteririor cingulate (BA31) and left superior temporal gyrus (BA38). Fig. 5 shows the both parahippocampal gyri, both insulas (BA13/41), both postcentral gyri (BA40), and left middle frontal gyrus (BA9) activated by the minor chords. Fig. 6 shows the right amygdala, left putamen, left insula (13/41), and right insula (13/45) in response to the diminished triads. Fig. 7 shows that the augmented triads activated the left inferior parietal lobule (BA40), left supramarginal gyrus (BA 40), left precuneus (BA5/7) and right parahippocampal gyrus and amygdala (BA35/36).



	Region	BA	MNI coordinates (x,y,z)			z-score
1	Inferior Frontal Gyrus-L	9	-58	4	34	3.13
2	Parahippocampal Gyrus-R	35	28	-22	-20	3.10
3	Posterrior Cingulate-L	31	-10	-58	22	2.85
4	Superior Temporal Gyrus-L	22	-48	12	-6	2.71

Figure 4. Regions and their coordinates showing larger activities to major chords than to the control. The result of second level analysis of 33 subjects in Experiment I and II combined (p < 0.005, uncorrected).

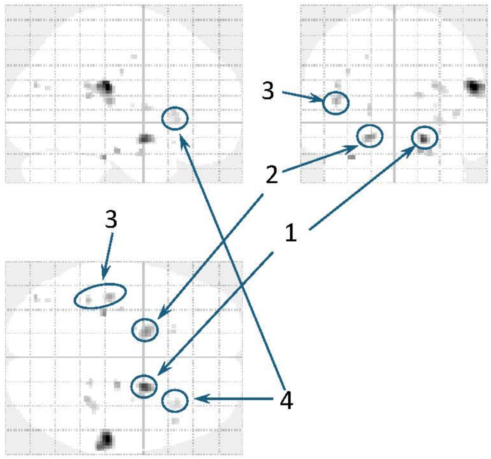


	Region	BA	MNI coordinates (x,y,z)			z-score
1	Parahippocampal Gyrus-R	N/A	32	-20	-16	3.86
	Parahippocampal Gyrus-L	N/A	-30	-26	-10	2.59
2	Inferior Parietal Lobule-R Insula-R Postcentral Gyrus-R	13/40	50	-22	24	3.49
3	postcentral Gyruus-L	40	-54	-36	48	2.95
4	Insula-L Transverse Temporal Gyrus-L	13/41	-40	-26	14	2.83
5	Middle Frontal Gyrus-L	9	-54	10	38	2.58

Figure 5. Regions and their coordinates showing larger activities to minor chords than to the control. The result of second level analysis of 33 subjects in Experiment I and II combined (p < 0.005, uncorrected).

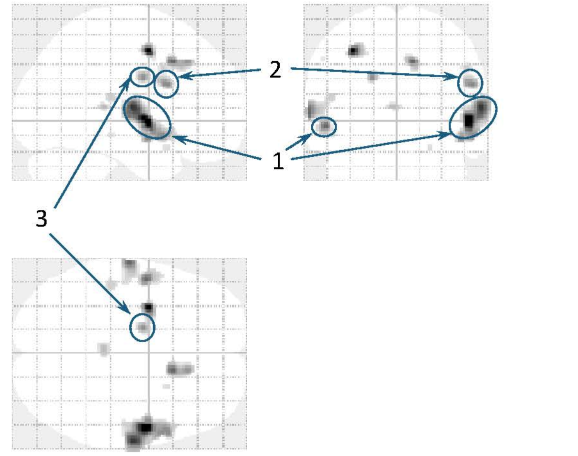
B. Harmonized scales

Fig. 8 shows the areas activated by the harmonized major scales (Exp. III) and include the right superior and middle temporal gyri (BA21/22), left superior temporal gyrus (BA22), right inferior frontal gyrus (BA9) and the left caudate body. Fig. 9 shows areas activated by the minor scales and include the left superior temporal gyrus (BA22), right inferior frontal gyrus (BA46), left insula in transverse temporal gyrus (BA13/41) and left parahippocampal gyrus (BA35) and left medial geniculate body.



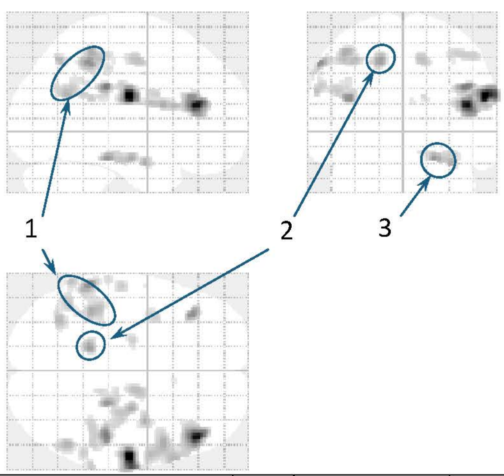
	Region	BA	MNI coordinates (x,y,z)			z-score
1	Parahippocampal Gyrus-R Amygdala-R	N/A	20	0	-12	3.33
2	Putamen-L Lateral Globus Pallidus-L	N/A	-18	2	-10	3.09
3	Insula-L Transverse Temporal Gyrus-L	13/41	-42	-24	16	2.97
	Superrior Temporal Gyrus-L Insula-L	13/41	-40	-40	18	2.86
4	Insula-R Inferior Frontal Gyrus-R	13/45	32	24	2	2.73

Figure 6. Regions and their coordinates showing larger activities to diminished triads than to the control stimuli. The result of second level analysis of 17 subjects in Experiment I ($p < 0.005$, uncorrected).



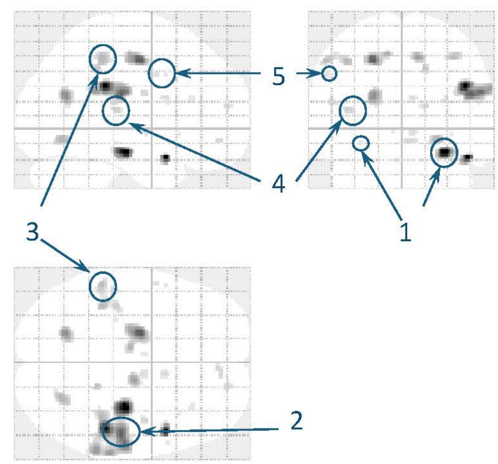
	Region	BA	MNI coordinates (x,y,z)			z-score
1	Superior Temporal Gyrus-R Middle Temporal Gyrus-R	21/22	54	-2	0	3.82
	Superior Temporal Gyrus-L	22	-52	-2	-4	3.47
2	Inferior Frontal Gyrus-R	9	56	14	26	3.29
3	Caudate Body-L	N/A	-18	-4	30	3.26

Figure 8. Regions and their coordinates showing larger activities to the harmonized major scales than to the control. The result of second level analysis of 16 subjects in Experiment III ($p < 0.005$, uncorrected).



	Region	BA	MNI coordinates (x,y,z)			z-score
1	Inferior Parietal Lobule-L Postcentral Gyrus-L	40	-42	-40	54	3.35
	Supramarginal Gyrus-L	40	-62	-54	28	3.15
2	Paracentral Lobule-L Precuneus-L	5/7	-16	-42	50	3.51
3	Parahippocampal Gyrus-R Amygdala-R	35/36	26	-12	-18	3.35

Figure 7. Regions and their coordinates showing larger activities to augmented triads than to the control stimuli. The result of second level analysis of 16 subjects in Experiment II ($p < 0.005$, uncorrected).



	Region	BA	MNI coordinates (x,y,z)			z-score
1	Superior Temporal Gyrus-L	22	-52	-16	8	4.45
2	Inferior Frontal Gyrus-R	46	46	28	12	3.65
3	Insula-L Transverse Temporal Gyrus-L	13/41	-46	-24	14	3.03
4	Parahippocampal Gyrus-L	35	-20	-20	-14	2.85
	Medial Geniculum Body-L	N/A	-14	-28	-10	2.82

Figure 9. Regions and their coordinates showing larger activities to the minor scales than to the control stimuli. The result of second level analysis of 16 subjects in Experiment III ($p < 0.005$, uncorrected)

IV. Discussion and Conclusions

Major chords vs. minor modes are generally said to induce light vs. dark or happy vs. sad feelings. This could not be accounted for by music theory alone, because it must have its roots in the brain. The present study agreed with the results of the previous works on many points but there were new findings as well. At least to our knowledge, no work was previously reported concerning brain's emotional activities to musical scales except for our pilot study [9].

A. Chord experiments

The results of the integrated analysis of tour previous and present experiments for major and minor chords were basically the same as the previous experiments; the increase in the number of subjects from 17 to 33 slightly intensified the SPM images. All the chords used in this study caused some activities near the parahippocampal gyrus which has been reported to be correlated with negative emotions, which was understandable for minor, diminished and augmented triads because these chords did not sound happy like major chords. The reason for the contribution of major chords is not clear but the parahippocampal area activated by major chords was in the entorhinal cortex which was associated with the emotion of happiness[12]. The other areas activated by the major chords have not been widely recognized as affective sites, but the (right) IFG and the PC have been associated with positive emotions [11]. The minor and diminished triads caused activations in the insula. The diminished triads further activated the putamen, amygdala and glubus pallidus. The insula and amyglada are known to be associated with disgust, pain and saddness. The ventral pallidum in the globus pallidus has recently been found to be important in affecive reactions [11]. These activated areas seemed to be concordant with the dark and sad colors implied by these chords. The diminished triad is darker and more dissonant than the minor chord, and its close relative, diminished seventh chord was almost abused by 19th century opera composers for effects of horror, rage, astonishment and terror [13]. The precuneus activated by the augmented triad has also been associated with unstableness of a chord [14] but also with positive emotional pictures and words [15]. The augmented triad has traditionally been used as a chord with a dark color, but also can express excessive joy (for example Walkyre's cry in R. Wagner's Ring). It can sound even ambiguous in the whole tone scale effectively used by C. Debussy. Thus it may be difficult to categorize the behavioral effects of the chord and fMRI studies may give some clue to understand it.

B. Scale experiments

Although the scales were harmonized by adding another voice, the results were somewhat different from those of chord experiments and more difficult to find direct connections to emotions. The major scales activated the superior temporal gyrus strongly. It has the primary auditory cortex but also has been associated with happiness [12]. The left caudate body, activated by the major scale was also associated with happiness [16]. The activities in the insula and parahippocampal gyrus are probably due to the sad and dark colors of the minor scale.

In the present study, amygdala was activated only during the dimished and augmented triads, which was a sign of aversion by the subjects' brain. The amygdala stands out as one site processing such emotions [10][11]. In general, strong negative emotions are more easily detected in brain activities. More neurophysiological investigations should be done in subtler feelings expressed in music, especially the sense of beauty and happiness. The apparent difference in brain responses to chords and scales are also intriguing.

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