PAPER

Investigating the type and strength of emotion with music: An fMRI study

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Abstract: In this paper, we used blood oxygenation level-dependent (BOLD) signals and emotion ratings to investigate the relationship between the type and strength of emotion induced by musical stimuli. Our goal was to establish a quantitative emotional evaluation method that uses brain activity. In Experiment 1, 26 participants rated 60 pieces of music using a semantic differential scale and 20 pieces were chosen on the basis of Russell's circumplex model. In Experiment 2, we investigated the relationships between the type and strength of emotion and brain activity by asking 20 participants to listen to the pieces of music in a Magnetic Resonance Imaging (MRI) scanner. We identified brain regions for which the BOLD signal intensity was correlated with the ratings of emotions. As a result, the "Happy" rating was mainly correlated with activity in the superior temporal gyrus. The "Sad" rating was correlated with activity in the left thalamus. The "Fear" rating was mainly correlated with activity in the parahippocampal gyrus, insular cortex, and right amygdala. By focusing on activity in these brain regions, it may be possible to quantify the type and strength of emotions evoked by music.

Keywords: Emotion, Russell's circumplex model, Brain activity, fMRI, Pleasure, Arousal

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1. INTRODUCTION

A number of psychological and physiological measures have been proposed for assessing human emotions. For psychological measurements, questionnaires are frequently employed. However, questionnaires are disadvantageous in that they are often qualitative, require lengthy periods of scoring, and are subject to constraints regarding the interpretation of language. To address this, we used brain activity to investigate a quantitative emotional evaluation method.

Several studies have attempted to quantify individual emotions using brain activity, with techniques such as

electroencephalography (EEG) and functional nearinfrared spectroscopy (fNIRS). In studies based on EEG, Musha *et al.* used the emotion spectrum analysis method [1] and Sato and Nakagawa used the emotion fractal dimension analysis method [2]. In the sensibility spectrum analysis technique, θ , α , and β wave bands are used to estimate the degree of four basic emotions (anger, sadness, joy, relaxation) via the cross correlation coefficient between the electrodes. In the emotion fractal dimension analysis method, which is considered to be more accurate [2], emotions are assessed by applying the fractal dimension estimation method to brain wave difference signals. These techniques are based on EEG, which measures activity near the brain surface. However, brain regions related to emotions, such as the amygdala and hippocampus, are

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Fig. 1 Russell's circumplex model (x-axis: pleasure, y-axis: arousal).

located deep within the brain [3]. Thus, it may be difficult to accurately evaluate emotions from EEG signals.

Indeed, functional magnetic resonance imaging (fMRI) may be more effective for evaluating deep brain activity. Many fMRI studies have addressed the neurophysiological mechanisms of emotions. For instance, happy music activates the superior temporal gyrus more strongly than neutral music [4,5]. Also, the hippocampus and parahippocampal gyrus have been reportedly activated by fear-provoking music [6–11]. However, many of the above-mentioned studies focused only on the type of emotion, and only a few studies have evaluated emotion strength. For example, Trost *et al.* [12] focused on the intensity of emotions to explore a wider spectrum of affective responses reported during music listening. However, this experiment only explored the brain regions associated with the average intensity of over 31 people, and individual differences were not considered. To thoroughly assess a quantitative emotion evaluation method, it is necessary to focus on both the type and strength of individual's emotions. Therefore, in this study, we focused on brain regions associated with the type and strength of emotions elicited by music stimuli.

We conducted two experiments. In Experiment 1, we selected pieces of music to be used in an fMRI experiment by administering a questionnaire with a semantic differential (SD) scale. We performed principal component analysis and mapped each piece of music to Russell's circumplex model (Fig. 1) [13,14] to determine the type of emotion the piece evoked. Russell's circumplex model comprises two axes corresponding to pleasure and arousal. And attempts to cover the complete range of human emotions. In Experiment 2, participants listened to the pieces of music in an fMRI scanner. We then extracted the brain regions associated with both the type and the strength of emotions by comparing the emotional ratings and blood oxygenation level-dependent (BOLD) signals.

2. EXPERIMENT 1 MUSIC SELECTION EXPERIMENT

2.1. Materials and Methods

Professional sound engineers chose 50 pieces of music. The selections were intended to cover all areas included in Russell's circumplex model. Then, three experimenters performed preliminary experiments and added 10 pieces of music. Twenty six participants (22 men and four women, age 24–57, mean age 39.7, standard deviation 10.1) evaluated the 60 pieces of music individually using headphones. Each musical piece was about 30 s long and included instrumentation without vocals. The participants listened to the music and then rated the pieces via a questionnaire. Participants were instructed to evaluate their emotions absolutely after listening. The questionnaire, which had a seven-level SD scale, was written in Japanese on response sheets generated on the basis of previous reports [15]. The questionnaire included 19 adjective pairs such as “Merry–Solemn,” “Happy–Sad,” “Calm–Fear.” Participants were allowed to adjust the music volume to a comfortable level. Participants were prohibited from rating the music while listening and were asked to rest as necessary. The pieces of music were presented in a random order that was different for each subject.

2.2. Results

We performed principal component analysis using a correlation matrix. Table 1 shows the results of the factor loadings. The contribution rate of the first and second components was 64%, and the contribution rate was 71% when the third component was included. The first principal component included adjectives such as “Merry,” “Lively,” and “Up tempo,” which accounted for pleasure and arousal. The second component included adjectives such as “Fear,” “Tension,” and “Anxiety,” which accounted for displeasure and arousal. The third main component included “Fresh,” which was not related to pleasure or arousal. We constructed Russell's circumplex model using the first and second principal components, which were associated with pleasure and arousal. Specifically, we placed the first principal component on the y-axis and the second principal component on the negative x-axis. We then rotated the function by 26.1° clockwise to move the adjective “Pleasure” as close as possible to the x-axis and the adjective “Aroused” as close as possible to the y-axis [16]. This process served to associate the x-axis with ‘Pleasantness’ and the y-axis with ‘arousal.’ Figure 2 shows the emotional space created by the rotation. The adjective “Happy” is in the first quadrant, and “Calm” is located in the fourth quadrant, as in Russell's circumplex model (shown in Fig. 1). The other adjectives are located similarly to in Russell's circumplex model. Therefore, we

Table 1 Semantic differential (SD) scales and factor loadings.

SD scale		Factor		
English	Japanese	Component 1	Component 2	Component 3
Merry-Solemn	うきうきした-しんみりした	0.86	-0.15	-0.13
Lively-Quiet	にぎやかな-静かな	0.86	0.16	-0.13
Up tempo-Slow tempo	アップテンポの-スローテンポの	0.85	0.16	-0.10
Happy-Sad	楽しい-悲しい	0.78	-0.42	-0.01
Energetic-Peaceful	勢いのある-落ち着いた	0.77	0.41	-0.11
Cheerful-Dismal	陽気な-陰気な	0.74	-0.51	-0.04
Bright-Dark	明るい-暗い	0.72	-0.55	-0.07
Comical-Tearful	笑える-泣ける	0.70	-0.16	-0.23
Aroused-Sleepy	覚醒する-鎮静する	0.68	0.45	-0.12
Hot-Cool	熱い-さめた	0.65	0.05	0.28
Fierce-Gentle	激しい-穏やかな	0.64	0.57	-0.04
Powerful-Weak	力強い-弱弱しい	0.54	0.35	0.36
Fear-Peace	恐れ-安らぎ	-0.01	0.87	-0.18
Tension-Relax	緊張-リラックス	0.11	0.87	-0.12
Anxiety-Ease	不安-安心	-0.16	0.86	-0.19
Unpleasure-Pleasure	不快な-快適な	-0.26	0.76	-0.32
Heavy-Light	重量感のある-軽量感のある	-0.34	0.57	0.39
Exciting-Boring	刺激的な-平凡な	0.48	0.49	0.42
Fresh-Predictable	新鮮な-ありきたりな	0.37	0.22	0.60
Contribution rate		0.38	0.64	0.71

Fig. 2 Configured space.

confirmed that we were able to construct a space similar to that in Russell's circumplex model.

By placing the average scores for each piece of music into this space, we were able to consider the strength of the emotion that each piece evoked. Figure 3 shows the average values for the 60 pieces of music, located in the above-mentioned space. Happy music tended to be located in the first quadrant, fearful music was located in the second quadrant, sad music was located in the third

Fig. 3 Locations of all 60 pieces of music (black dots: 20 pieces chosen for MRI experiment).

quadrant, and calm music was located in the fourth quadrant. The musical stimuli with a fast tempo were rated as having high arousal (happy or fearful music), and the musical stimuli with a slow tempo were rated as having low arousal (sad or calm music). Also, musical stimuli in a major scale were rated as having high pleasantness and musical stimuli in a minor scale were rated as having low pleasantness. Finally, we chose five pieces of music from each quadrant. We attempted to maximize the number of different instruments used, thus focusing on brain regions

Table 2 Twenty pieces of music chosen for MRI experiment.

Music No	Emotion Type	Music Title	Tempo	Tonality	Instrument
31	Happy	All Wrapped Up	128	C Major	organ, sax, drum, bass
33	Happy	SAMBA de Koisite	118	D Major	saxophone, drum, bass
34	Happy	Garden Party	120	D Major	trumpet, drum, bass
37	Happy	FESTA!!	118	D Major	guitar, percussion
38	Happy	Tijuana Taxi	102	F Major	trumpet, drum, guitar
5	Sad	Cancer	87	D minor	piano
8	Sad	Tuioku	51	A minor	cello, strings
9	Sad	Naval	90	D minor	piano
10	Sad	Solitude	85	G minor	strings, bass
18	Sad	Inside Elevation	78	D minor	accordion, synthesizer
40	Calm	Captain's Café	88	C Major	ukulele, guitar, bass
46	Calm	Emma	67	F Major	piano
48	Calm	Soothing	90	F Major	synthesizer, guitar, bass
52	Calm	Olema Waltz	85	D Major	piano, strings
53	Calm	GendouNoSekai	70	C Major	harp, synthesizer, strings
14	Fear	Half Day	73	Atonal	synthesizer
21	Fear	Disc Wars	82	D minor	synthesizer, timpani
58	Fear	Weird and Scary	110	A $\flat$ minor	synthesizer
24	Fear	False Awakening Suite	133	D minor → F minor	bass
19	Fear	High Volume	171	C minor	synthesizer, drum

related specifically to emotion, rather than make the brain process different types of musical sounds. Table 2 shows the 20 pieces of music that were chosen for Experiment 2.

3. EXPERIMENT 2 MRI experiment

3.1. Materials and Methods

A total of 20 pieces of music were chosen from Experiment 1 to be presented inside the MRI scanner. Participants listened to the music via MRI-compatible piezoelectric ceramic headphones (Kiyohara Optics Inc.). All 20 participants (18 males and two females, age 22–55, mean age 31.3, standard deviation 10.7), different from those in Experiment 1, were right-handed and had no history of hearing problems. The experiment had a block design, designed by Presentation software (Neuro-behavioral Systems, Ltd.), which began with 30 s of rest, after which the subject listened to a piece of music (presented in random order) for 30 s. The subjects then rated their emotions within 12 s using MRI-compatible buttons (Package 904: Current Designs, Inc.). A questionnaire was projected onto a screen using a projector. To reduce the mental burden on the participants, we presented only two adjective pairs (“Happy–Sad,” “Calm–Fear,” also used in Experiment 1). The participants rated their emotions absolutely using an 11-point visual analogue scale (VAS). Experiments were performed in two trials, and each subject evaluated a total of 20 pieces of music.

3.2. fMRI Measurement Conditions

fMRI measurements were conducted using a 1.5T

scanner (Echelon Vega: Hitachi Medical Corporation) at Doshisha University. Participants were placed on the scanner bed in a supine position. To prevent postural adjustments and to attenuate the noise and vibration of the scanner, foam cushions were placed around the arms of the participants. We acquired 27 oblique slices covering the whole brain (field of view 192 mm; thickness 5 mm) using a sequential gradient echo-planar imaging (EPI) sequence (TR 3,000 ms; flip angle 90°) sensitive to BOLD contrast. Before the fMRI measurement, participants were informed about the study protocol, signed a written consent form, filled in a safety questionnaire, and were required to remove any ferromagnetic material before entering the magnet bore. Participants were encouraged to relax in the magnet bore while concentrating on the music stimuli. The study procedures were approved by the ethical committee of Doshisha University (No. 1365) and complied with the Helsinki Declaration.

3.3. Data Analysis

We excluded data for two participants that exhibited a head movement of more than 2.5 mm. Thus, we analyzed data for a total of 18 participants (17 males and one female, age 22–55, mean age 31.3, standard deviation 11.2). We used MATLAB 2012b (The MathWorks, Natick, MA) and SPM12 (Wellcome Department of Cognitive Neurology, London) software. Images for each subject were realigned, slice timing was corrected to the 14th slice, and the images were spatially normalized onto the Montreal Neurological Institute (MNI) template and spatially smoothed (Gaussian

Fig. 4 Comparison of ratings from Experiments 1 and Experiments 2.

filter with an FWHM of 7 mm). fMRI responses were modeled using a canonical hemodynamic response function (HRF) with time dispersion and temporally filtered using a high-pass filter of 128 Hz to minimize scanner drift. The six parameters for residual movement were modeled as regressors of no interest. Specifically, using parametric modulation, we analyzed the BOLD signals collected for all participants to determine the brain regions for which activity corresponded to the ratings of emotion obtained from the questionnaire ($p < 0.001$, none).

3.4. Results

Figure 4 shows the correlation between the ratings of emotion for the 20 pieces of music in Experiments 1 and 2. The rating of “Happy–Sad” had $R^2 = 0.9527$ and the rating of “Calm–Fear” had $R^2 = 0.9574$. Thus, we were able to confirm that the stimuli elicited nearly identical emotions in the two experiments.

Table 3 shows the brain regions with a voxel size of $k \geq 3$ for which BOLD signals were correlated between emotional ratings. Each brain region was labeled using automated anatomical labeling (AAL) [17]. As parts of the brain associated with the rating of “Happy,” we identified the angular gyrus, calcarine sulcus, middle cingulate gyrus, posterior cingulate gyrus, precuneus, and superior temporal gyrus. The brain region associated with the rating of “Sad” was the left thalamus. As the parts of the brain associated with the rating of “Fear,” we extracted the right amygdala, inferior frontal gyrus, middle frontal gyrus, insula, lingual gyrus, parahippocampal gyrus, precuneus, gyrus rectus, rolandic operculum, supplementary motor area, superior temporal gyrus, left thalamus, and vermis. No region was associated with the rating of “Calm” (Fig. 5).

4. DISCUSSION

In Experiment 1, we administered a questionnaire based on the SD scale and then conducted principal component analysis. As a result, the first principal component was associated with pleasure and arousal, and the second principal component was associated with displeasure and arousal. In many previous studies, pleasure and arousal were extracted as first or second principal components. However, in this experiment, they were mixed in the first and second components. This is likely because principal component analysis determines the largest dispersion of the data with respect to the first principal component. The axis for the second largest dispersion of the data is correlated with the second principal component and not with the first principal component. Because of the wide range of emotions elicited by the music chosen in this experiment, we found that both pleasure and arousal were widely dispersed. Accordingly, the mixed components were extracted as the first and second principal components. Therefore, we rotated the space formed by the first and second components to situate “Pleasure” near the x -axis and “Arousal” near the y -axis. As a result, we formed a space that mirrored Russell’s circumplex model. By locating the evaluated music in this space, we were able to classify the 60 pieces of music more accurately than if we had done so according to the emotions that each piece evoked.

In Experiment 2, we used only two pairs of adjectives (“Happy–Sad,” “Calm–Fear”). As both pairs of adjective ratings produced $R^2 > 0.95$ for the correlation between Experiment 1 and Experiment 2, we were able to verify that the emotions in Experiment 1 were the same as those elicited in Experiment 2.

Table 3 Brain regions associated with emotional ratings ($p < 0.001$, none).

Emotion	Brain region	MNI coordinates $x\ y\ z$ (mm)	k	BA	Z value	T	$p(\text{unc})$
HAPPY	Angular_L	[-42 -58 24]	4	39	3.19	3.85	0.0007
	Calcarine_R	[2 -64 16]	4	31	3.15	3.78	0.0008
	Cingulum_Mid_L	[-2 -12 40]	3	24	3.23	3.92	0.0006
	Cingulum_Post_L	[-2 -38 24]	3	23	3.13	3.74	0.0009
	Precuneus_L	[-12 -40 2]	9		3.36	4.13	0.0004
	Temporal_Sup_L	[-44 -6 -10]	6	21	3.37	4.15	0.0004
	Temporal_Sup_L	[-46 -34 16]	11	41	3.28	4.00	0.0005
SAD	Thalamus_L	[-12 -20 14]	7		3.15	3.75	0.0008
FEAR	Amygdala_R	[24 2 -16]	11	34	3.28	4.12	0.0005
	Insula_R	[34 -8 14]	92		4.07	5.80	0.0000
	Insula_R	[36 2 14]		13	3.68	4.90	0.0001
	Rolandic_Oper_R	[44 -6 12]		13	3.31	4.18	0.0005
	Frontal_Inf_Tri_L	[-34 32 12]	5	46	3.32	4.20	0.0004
	Frontal_Mid_R	[40 26 20]	34	46	3.39	4.32	0.0004
	Frontal_Inf_Tri_R	[48 28 20]		46	3.29	4.14	0.0005
	Frontal_Med_Orb_R	[6 54 -8]	3	10	3.45	4.44	0.0003
	Frontal_Mid_R	[26 48 26]	11	10	3.64	4.82	0.0001
	Insula_L	[-36 10 6]	12	13	3.54	4.62	0.0002
	Lingual_R	[18 -36 -4]	40	30	3.50	4.54	0.0002
	Parahippocampal_R	[20 -14 -22]	22	28	3.32	4.19	0.0005
	Precuneus_L	[-8 -52 18]	13	30	3.76	5.07	0.0001
	Rectus_L	[-18 12 -16]	6	47	3.48	4.49	0.0003
	Rolandic_Oper_R	[50 6 14]	19	44	3.65	4.83	0.0001
	Supp_Motor_Area_R	[14 -6 70]	3	6	3.16	3.90	0.0008
	Temporal_Sup_L	[-58 -6 0]	4	22	3.19	3.95	0.0007
	Thalamus_L	[-14 -30 8]	5		3.28	4.11	0.0005
	Vermis_4_5	[-2 -46 -4]	16		3.34	4.23	0.0004
CALM	no region						

We found that the activity in the superior temporal gyrus correlated with the rating of “Happy.” This region has been implicated in sound perception and spoken-language processing. In addition, a significant increase in activity in this site is often reported during exposure to happy versus neutral music [4,5]. Thus, this region may be important for evaluation of the enjoyment of music.

We also found that the activity in the left thalamus correlated with the rating of “Sad.” This site is known to be a relay point for sensory information and also controls arousal. Additionally, this region is more significantly

Fig. 5 Examples of brain regions associated with emotions ($p < 0.001$, none).

activated in response to sad versus neutral music [5]. Interestingly, a large meta-analysis of 105 neuroimaging studies of facial expressions found that the left thalamus is one of the few structures (along with a region in the visual cortex and the left insula) that are consistently active when processing sad faces [18]. This consistency hints at the cross-modal nature of basic emotions evoked by visual or auditory stimuli [19].

We found that the activity in the insular cortex was associated with the rating of “Fear.” This region is known for sensory processing, such as pain sensation and discomfort. Additionally, this region is involved in impulses, such as hunger and craving, and is activated by a combination of fearful images and music [20]. Furthermore, we found that the activity in the right amygdala was associated with fear. This region is known to be involved in emotional reactions and emotional memory. The right part of the amygdala has also been previously associated with fear [21]. We identified fear-related activation in the parahippocampal gyrus. This region is related to learning and memory [6–11] and shows diminished emotional sensitivity to dissonant music [22,23]. In addition, this region is activated when viewing unpleasant images [24]. Furthermore, this site is strongly coupled with the amygdala [25] and is relevant to emotional expression.

We found that no region whose voxel size was $k \geq 3$ was associated with the evaluation of “Calm.” However, the lower frontal lobe, which voxel size was $k = 1$, was associated. This site is a part of the Broca’s area, which is known to be involved in speech and grammar. In addition, this site is activated when listening to highly pleasurable music [26]. “Calm” is related to high ratings of pleasure and sleep in Russell’s circumplex model. Thus, it is

reasonable that the lower frontal lobe was identified as related to this dimension. However, since this region had a voxel size of $k = 1$, we must consider that this result is not significant.

Many previous studies have reported on brain regions associated with emotion types. In these studies, brain regions are generally identified by comparing brain activity between two types of emotions or by comparing an emotion with a 'neutral' state, and differences in emotional ratings between individuals were not considered. However, in this experiment, we revealed that the regions listed above are related not only to the type of emotion but also to the strength of the emotion. By analyzing these brain regions, it may be possible to determine the type and strength of individual emotions evoked by music. The limitation of this study is that our findings are only applicable to the emotions evoked by auditory stimuli. Furthermore, it is necessary to confirm whether similar results can be obtained even when musical stimuli are played by speakers rather than headphones.

5. CONCLUSION

In Experiment 1, we rated the emotion evoked by 60 pieces of music using Russell's circumplex model. We then chose 20 pieces of music for our fMRI experiment (Experiment 2). We confirmed that the same emotions were evoked in Experiments 1 and 2. For the 20 pieces of music, we extracted the brain regions for which the type and strength of emotions were correlated. As a result, the "Happy" rating was mainly correlated with activity in the superior temporal gyrus, "Sad" with the left thalamus, and "Fear" with the right amygdala and parahippocampal gyrus.

The brain regions extracted in this experiment were associated with both the type and strength of emotions. Furthermore, these regions exhibited greater activation when the emotions were more strongly expressed. By analyzing activity in these brain regions, it may be possible to determine the type and strength of emotions evoked by music.

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