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Original Article

Evaluating the Effects of Singing Songs in Ethnic Music Therapy for Dementia Patients with a Novel Near-infrared Spectroscopy (Data Analysis Method)☆

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SUMMARY

Background: Dementia is already critical issues in the world. This situation requires establishment of rehabilitation for relieving symptoms of patients. We have done research based on our assumption that most effective music therapy differs from culture, because music is dependent on cultural context. In this paper, we focus on active behavior (sing a song) of music therapy, and studied its effects. We used Near-Infrared Spectroscopy (NIRS) as a method for evaluating effectiveness of music therapy, though standard procedures of NIRS data processing has not been established. This is the reason why we here propose a new analysis method of NIRS data for evaluating effectiveness of music therapy.
Methods: We collected 87 volunteers including 79 dementia patients. We let the volunteers hear music prepared by us as follows: 2 famous nursery songs, 2 famous play songs, 2 original music, and 2 classical scale. We observed their response in 2 ways: one is a physiological response measured by NIRS, and the other is a subjective response measured by questionnaires.
Results: Our result showed dementia patients prefer Japanese old melodies, but they don't understand tonality of the Japanese music. This tendency is strengthened by adding Song task. Also, dementia patients are poor at careful control of the blood volume change. Our result displayed singing a song induces out-of-control state of brain blood flow in every stage. Our results revealed characteristic responses of dementia patients onto Japanese music.
Conclusion: We expect our result provides an evidence for better music therapy for dementia patients with Japanese culture.

1. Introduction

Our research goal is to prove the effectiveness of music by quantifying human responses to hearing music. Fig. 1 shows our research goal. In this figure, we show three features of our research. The first feature is that our research requires profound interdisciplinary knowledge in three distinguished research fields (i.e., music theory, acoustic engineering, and medicine). The second features is that our research analyzes biological information in two aspects (1) by objective data (biological reaction) and (2) by subjective data (i.e., emotional reaction). The third feature is that our research utilizes two kinds of music analysis methods: (1) using music theory and (2) using acoustic engineering. In this study, the input is music and the output is human subjective and objective responses. Based on this scheme, we discuss the most effective music therapy for dementia patients using Japanese music.

In recent years, the elderly portion of the population has increased significantly, which has led to a related increase in the number of patients with dementia[1,2]. For this reason, prevention, effective rehabilitation, and treatment/therapy for dementia are most required in a super-aging society. Each of these aspects is equally important. However, the current work focuses on the

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rehabilitation and treatment/therapy aspects of dementia. We chose music therapy for the method of treatment/therapy. In our research, we are investigating the effects of Japanese music on alleviating dementia symptoms in Japanese patients, compared to the effects of classical music[3–6].

Music therapy has some serious problems because (1) only the people who are in a setting realize the clinical response of music therapy, (2) music therapy involves trial and error, and (3) music therapy does not have objective proof. This situation caused us to believe the effect of the music therapy should be proven.

Furthermore, near-infrared spectroscopy (NIRS) has disadvantages. However, the primary advantages of NIRS are that it is performed in real-time, it is noninvasive, and it has low cost in the view of researchers who design experiments. The four disadvantages of NIRS are (1) poor spatial resolution, (2) a lack of an established numerical analysis method, (3) lack of reference values, and (4) noise contamination. Because of these disadvantages, previous researchers had to develop numerical analysis methods of NIRS data on their own accord. In addition, standard analysis procedures of NIRS data for intersubject comparison have not been established. This situation has caused a short of experiments in which intersubject NIRS data is analyzed.

Various studies have investigated the utility of music therapy in alleviating dementia. Several authors have proposed non-pharmaceutical methods for treating dementia[7,8], which include music therapy for dementia patients[9]. These reports suggest that such care for dementia patients alters underlying physiologic, psychosocial, and environmental factors. Several empirical studies have reported significant effects of music therapy on dementia patients[10]. Music therapy lowers the agitation level of patients. These studies show that music intervention is effective, facilitates the recollection of long-term memories[11], and improves the management of verbally disruptive behavior. In addition, some studies displayed that agitation levels fell significantly in response to music therapy.[12–15] Studies using music therapy have reported an improvement in language functioning[15] a reduction in depressive symptoms[16], an increased recognition of music-based exercises[17], and a sparing of melodic recognition in dementia patients[18]. The overarching aim of these studies is to reduce the burden of the care staff in charge of these patients. These studies do not examine music therapy as a brain rehabilitation for the patients. What is more important is that these studies are not objective, but subjective. Furthermore, the music used in these studies was selected without considering the effect of each music choice (i.e., the music choice was random or by trial and error).

Other studies on music therapy for dementia patients focus on the neurological aspects of processing musical input, specifically the role of the temporal lobes. These reports have shown that the auditory cortex influences recognition of pitch and tempo[19], and that the ability to understand a melody is reduced when the temporal lobe is damaged[20]. In these experiments, the patients had an injury to or excision of the temporal lobe. Other work has examined the relationship between psychological stress and music[10,21]. The application of music therapy led to a reduction in the levels of salivary cortisol, a stress hormone. In addition, several studies report significant emotional responses to music. Mental fatigue is reduced more by major modern music than minor modern music[21]. In healthy adults, happy and sad moods are mediated by different neural correlates[22], and retrieval of memories with happy or sad affects activates separate areas of the prefrontal and hippocampus[23]. However, the mechanisms for musical processing and the generation of emotional responses to music in dementia patients remain unknown.

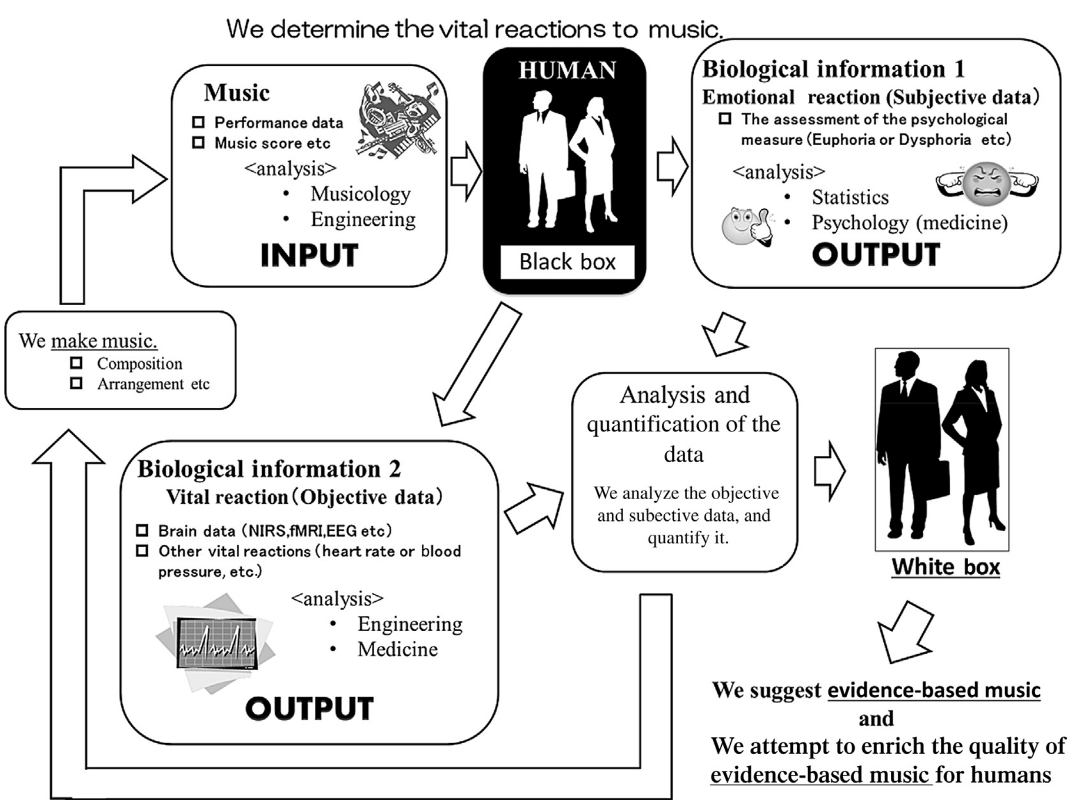

Fig. 1. Research aims. The major goal of this work was to objectively quantify the musical input and the physiological/biological output in response to music therapy. The final aim of our research was to increase quality of life by establishing evidence-based medicine. EEG = electroencephalogram; fMRI = functional magnetic resonance imaging; NIRS = near-infrared spectroscopy.

Table 1
Differences between Japanese music and classical music.

	Japanese music	Classical music
Rhythm	Irregular rhythm (no specific beat) (Basically two beats without strength and weakness)	Regular rhythm (specific beat)
Harmony	No regular harmony (i.e., several discords) (Some noise, *souon*, coexists in Japanese music. It is difficult for Japanese music to produce a chord; however, Japanese music has a small measure of heterophony and polyphony)	Specific rules of harmony
Melody	Gagaku and Zokugaku (These are in "minor mode", based on the meaning of melody in classical music)	30 keys (30 diatonic scales = 15 major scales + 15 minor scales)
Tempo	The tempo setting is not strict	The tempo setting is strict
Tradition	Oral instruction and demonstration (No written scores of traditional Japanese music)	Musical notation was established early (Scores exist)
Scale	Pentatonic scale	Diatonic scale
Tonal center tone	Japanese music does not necessarily end on the tonal center of a musical mode (e.g., *Kimigayo*, the national anthem of Japan)	Most classical music ends on the tonal center of the musical mode

Several studies have been performed using NIRS[24–26]. These studies focus primarily on reducing the burden on care staff because the reduction of a nursing staff's burden was the most important in the conventional study. These studies reported the patients' stresses were effectively reduced, but failed to show objective evidence on an increase in brain activity and the effectiveness in rehabilitation. Only a few studies on dementia use NIRS; however, a recent trial study used NIRS to measure prefrontal lobe activity in dementia patients in Japan[27]. Based on these situations, we propose to measure objectively the effectiveness of musical therapy on dementia patients by using NIRS.

In our series of studies, we propose two hypotheses regarding music therapy for dementia: (1) effective brain rehabilitation will show increased activity that spreads through the prefrontal lobe after or during rehabilitation, and (2) Japanese music will have better effects on Japanese patients, compared to Western music. On the first hypothesis, we have already shown positive results in our past study[22]. On the second hypothesis, we have proposed four methods and have shown interesting results in past research[25–27,28]: (1) patterning of the music is possible, (2) the prefrontal lobe is activated by music therapy, (3) dementia patients recognize that Japanese music is a major key though it is a minor key, (4) for Japanese dementia patients, Japanese music is effective, and (5) a specific frequency was found at which dementia patients respond most. In our previous studies, the effects of active behavior of music therapy (e.g., singing a song) have not been examined. In this paper, we focus on active behavior (i.e., singing a song) in music therapy, and studied its effects on dementia patients. We also propose a new NIRS data analysis method for evaluating the effects of active behaviors.

Japanese music is different from Western music, and we have summarized its difference in our previous work[3–6,27]. The mode of Japanese music is controlled by some unclear rules. Japanese music has a mode dilative from Gagaku, Zokugaku, and mode of Okinawa. Gagaku is the traditional court music (i.e., formal music). Zokugaku is popular music. In addition, we focused on Zokugaku in this study. Zokugaku can be divided into three classes: In-Senpou (called "Metropolitan" mode in our notation), You-Senpou (called "Countryside" mode in our notation), and Yonanuki-Senpou (called "Modem" mode in our notation). Table 1 summarizes the differences in Japanese music and classical music, and shows differences in every aspect of music components.

2. Methods

Informed written consent was obtained from the Chief Director of the Day Service Center of the Hamamatsu Early Dementia Research Center (Hamamatsu, Japan) We performed the experiment on July 3, 2008.

2.1. Experiment using questionnaires

In this experiment, we conducted questionnaire surveys to examine subjective data.

2.2. Participants

There were 86 participants in this study which included 77 dementia patients. Dementia patients were assorted by the degree of requiring care (Japanese systems). Users of care service were assorted by seven phases of levels. The lightest level is requiring support 1 (RS1) and the heaviest level is requiring care 5 (RC5). At this time, RC1 (the average of MMSE is 19.7) comprised 37 individuals; RC2 (17.2), 22 individuals; RC3 (16.6), 16 individuals, and RC4, 2 individuals.

2.3. Music used

Musical pieces used two scales (C-dur and c-moll) and five songs (3 children's songs and 2 original music pieces).Three children's songs were *Edo Komoriuta* (a folklore song that is best known through many lullabies in Japan) using the Modem mood; *Touryanse* (the song of a barrier play in the Edo period) using the Metropolitan mood; and *Kagome Kagome* (a children's song that spread to Japan a long time ago) using the Countryside mood. Two original music pieces were produced in the Modem mood by the author. The purpose for using original music is to examine whether the patient's reaction depends on his or her recollection[3–6].

Table 2 shows the experimental time protocol. The experimenter played a melody with a piano. In addition, we showed the lyrics of the song (Table 2).

Table 2
Time protocol.

Task	Music
1	*Edo Komoriuta* (major)
2	*Touryanse*
3	*Kagome Kagome*
4	Original music (major)
5	*Edo Komoriuta* (minor)
6	Scale of C-Dur
7	*Edo Komoriuta* (major) with song
8	*Touryanse* with song
9	*Kagome Kagome* with song
10	Original music (minor)
11	*Edo Komoriuta* (minor) with song
12	Scale (c-moll)

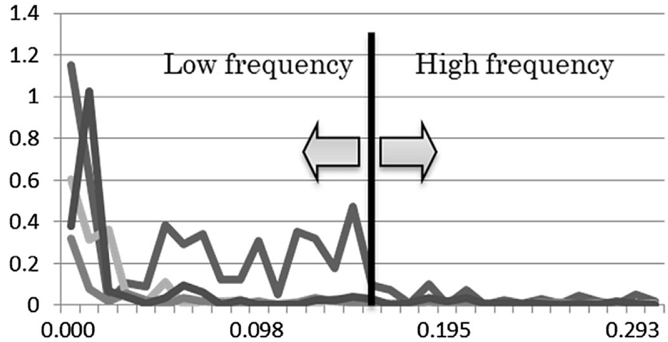

Fig. 2. Sample of the power spectrum. We converted the time-series data of activated value (T-AV) into power spectrum by fast Fourier transform and Wiener-Khinchin theorem. We set the frequency from 0 Hertz (Hz) to 0.146484375 Hz for the low frequency and from 0.146484375 Hz to ∞ Hz for the high frequency.

2.4. Questionnaires

The questionnaires contained four questions to be answered for each musical piece:

[1] Do you know this music? (Answer: "I know it" or "I do not know it").
[2] Do you like this music? ("I like it" or "I do not like it").
[3] How do you think of melody of this music? ("Bright" or "Dark").
[4] How do you feel when you hear this music? ("Happy" or "Sad").

The questions "how do you think of melody of this music?" and "how do you feel when you hear this music?" are equivalent to "rhythm" and "melody" in the three primary elements of classical music (i.e., rhythm, melody, and harmony). In addition, the questionnaire was administered in the Japanese language.

2.5. Calculation

In the questionnaires, the left responses (i.e., [1] "know", [2] "like", [3] "bright", and [4] "happy") are considered "positive", and the right responses (i.e., [1] "don't know", [2] "don't like", [3] "dark", and [4] "sad") are considered "negative". The positive rate was determined by Expression (1):

$$\textit{The positive rate}\ [\%] = \frac{\textit{The number of the ``positive'' respondents}}{\textit{The number of the effective respondents}} \times 100 \tag{1}$$

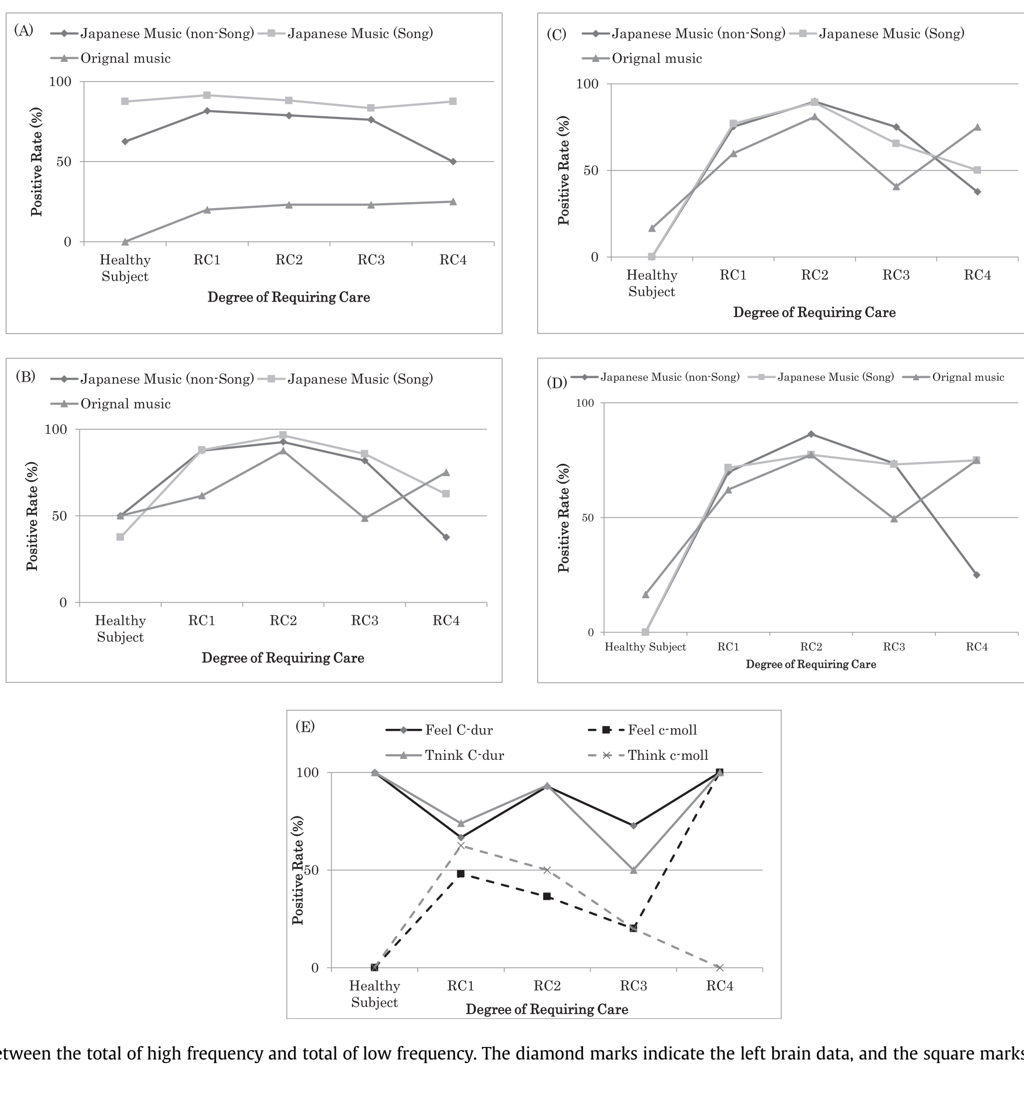

Fig. 3. Relationship between the total of high frequency and total of low frequency. The diamond marks indicate the left brain data, and the square marks indicate the right brain data.

We compared the positive rate this time in the four groups, not for every piece. The four groups were (1) Japanese music without a song or lyrics card (i.e., non-Song); (2) the Japanese music with a song and lyrics card (i.e., Song); (3) original music; and (4) the classical scale.

2.6. Experiment using NIRS

In this experiment, we measured NIRS data to examine the objective data.

2.7. Participants

The study participants were six volunteers; one dementia patient (RC2 and 81 years old), two border region individuals (79 years old and 70 years old), and three healthy people (78 years old, 54 years old, and 34 years old). The border region person had mild cognitive impairment.

2.8. Instrument used and measurement location

An experimental device noninvasively monitored tissue oxygenation using the theory of near-infrared spectroscopy. The OM-220 made in Shimadzu Corporation (Kyoto, Japan) has two probes. We measured two areas of the prefrontal lobe (Fp_1 and Fp_2 of the international 10–20 electrode system). We focused on the concentration of total hemoglobin because the brain is activated when total blood volume increases. The experiment repeats a task group in which a 90 second rest task is done at first and then a music task is performed. The rest means a state in which the participants closed their eyes and thought about nothing. We took a break between the tasks to allow the brains of the participants to rest.

2.9. Calculation

We assumed the NIRS data is a wave stimulated by biological responses such as electroencephalography (EEG). This analogy of NIRS to EEG led us to apply power spectrum analysis onto the NIRS data because power spectrum analysis of the EEG is widely applied. At first, we calculated time-series data of the activated value (T-AV) by Expression (2), where Hb means hemoglobin.

$$T - AV = C_{total-Hb}(t_i)_{(music)} - \overline{C_{total-Hb(relax)}} \quad (2)$$

We then converted the T-AV into a power spectrum by fast Fourier transform (FFT; Fig. 2). We calculated the power spectrum by the Wiener–Khinchin theorem. On the expressions, we put the signal in time-series data of AV with g(t), the autocorrelation function of g(t') with C(t'), and power spectrum with P(f).

$$C(t) = \lim_{T\to\infty} \frac{1}{T} \int_{-T/2}^{T/2} g\left(t'\right) g\left(t' + t\right) dt' \quad (3)$$

$$F[C(t)] = \int_{-\infty}^{\infty} C(t) e^{-2\pi i f t} dt = \lim_{T\to\infty} \frac{1}{T} |G(f)|^2 = P(f) \quad (4)$$

We then set the frequency from 0 Hertz (Hz) to 0.146484375 Hz for the low frequency and from 0.146484375 Hz to ∞ Hz for the high frequency (Fig. 3). We determined a frequency of 0.146484375 Hz from 72 data; we calculated the power spectrum from six people and used 12 data per head. We calculated a total of two pattern frequencies by Expressions (5) and (6).

$$Total\ of\ High - frequency = \int_{x}^{\infty} P(f) \quad (5)$$

$$Total\ of\ Low - frequency = \int_{0}^{x} P(f) \quad (6)$$

3. Results

3.1. Experiment using questionnaires

In the questions for subjective data, Fig. 4A shows the results of “known” (i.e., question [1]); Fig. 4B shows the results of “like” (i.e.,

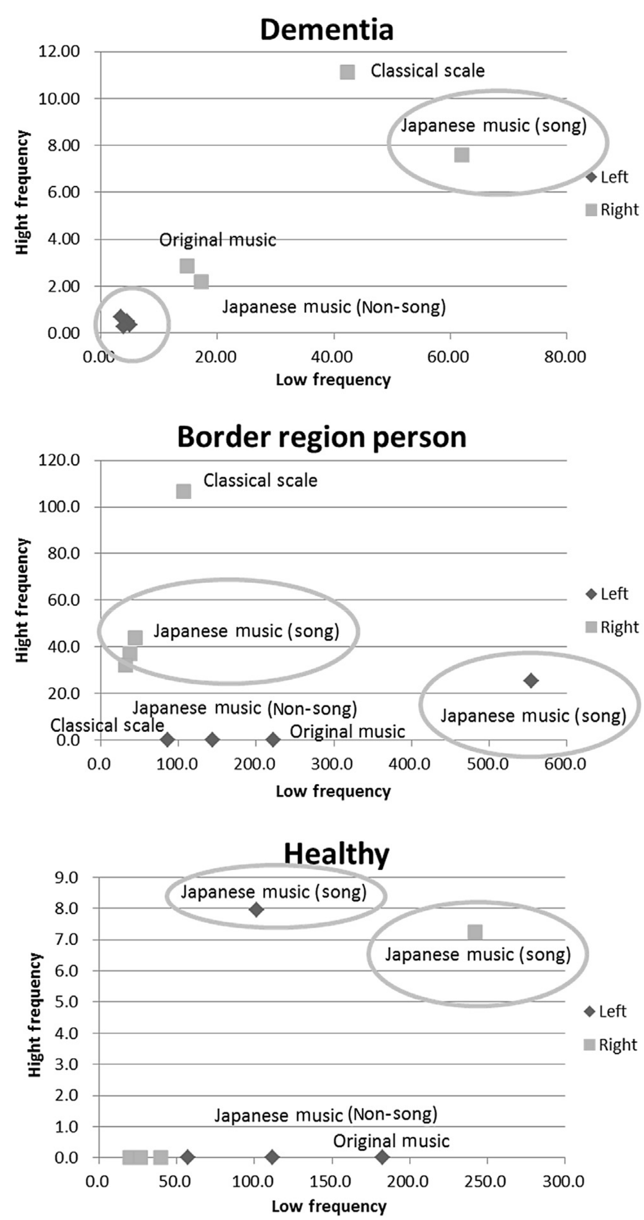

Fig. 4. Results of the questionnaires for (A) "known", (B) “like”, (C) “think”, (D) “feel”, and (E) classical scale. The dementia patients consistently rated the Japanese melodies as positive. However, in the classical scale, patients were able to identify the key. The positive rate was close to 100% in the two groups requiring care (RC), a pattern that also carried over to the original music pieces.

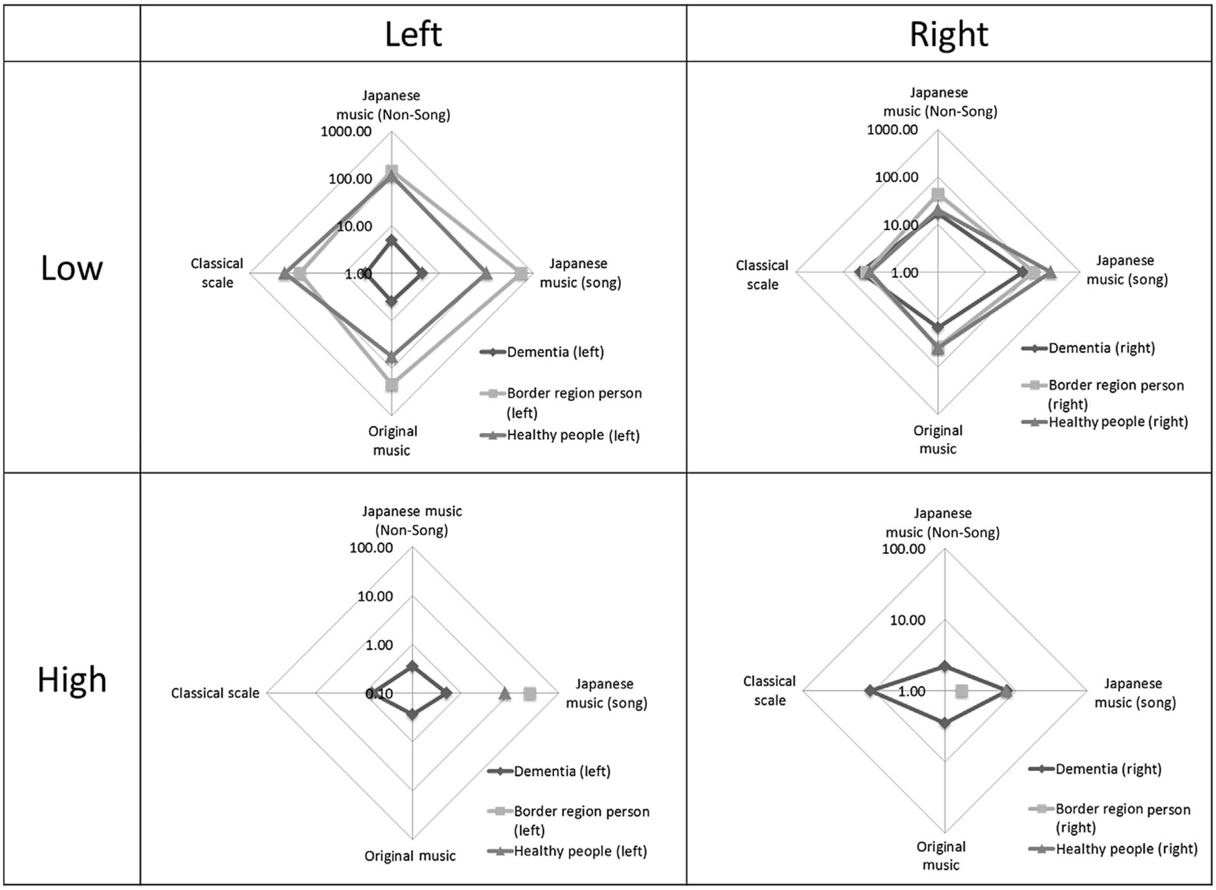

Fig. 5. Difference in the left brain and the right brain in the power spectrum. Differences between the left brain and the right brain are shown by the power spectrum.

question [2]); Fig. 4C shows the results of "think" (i.e., question [3]); Fig. 4D shows the results of "feel" (i.e., question [4]); and Fig. 4E shows the results of "think" and "feel" for the classical scales. These graphs show the vertical axis, which represents the positive rate, and the horizontal axis which represents the participants' attribute.

3.2. Experiment using NIRS

Fig. 3 shows the relationship between the total for the high frequency and the total for the low frequency. In this figure, the diamond marks indicate the left brain data, and the square marks indicate the right brain data. Fig. 5 shows the difference between the left brain and the right brain in the power spectrum.

4. Discussion

4.1. Experiment using questionnaires

Fig. 4A shows that dementia patients were able to check their own memory against a given music piece. The probability of remembering the music of Song is higher than it is for non-Song. Fig. 4B suggests that the preference of music by the dementia patients is not influenced by the lyrics (i.e., language). Fig. 4C shows the positive rate of "think" was nearly 100% limitlessly in the RC2 group in all tasks. Fig. 4D shows the positive rate of "feel" was nearly 100% limitlessly in the RC2 group in non-Song. However, the positive rate of "feel" was close to 100% limitlessly in the RC2 group, and did not just fluctuate in Song. This shows the importance of the task "sings Japanese melody". Fig. 4E shows that

Table 3
Summary of questionnaire results by the dementia patients.

	Japanese music	Classical scale
"Known"	Dementia patients were able to check their own memory against a given music piece. Remembering music for Song is easier than for non-Song.	When dementia patients answer "I know this music", they showed tendency of confusing classical scale for different music.
"Like"	Preference of the music of dementia patients is not influenced by the lyrics (i.e., language).	The patients with dementia showed preference of minor mode in Japanese music. But minor mode itself is not an influencing factor.
"Think"	The positive rate is close to 100% limitlessly in the RC2 group in all tasks.	Dementia patients were able to differentiate between major and minor keys in the classical scale.
"Feel"	The positive rate is nearly 100% limitlessly in the RC2 group in non-Song. The positive rate is nearly 100% limitlessly in the RC2 group, and does not just fluctuate in Song.	

Table 4
Tendency at each stage.

Dementia patients	The high-frequency component appears in all tasks. The power spectrum of left brain is weak.
Border region person	The power spectrum appears in every task. The high-frequency component appears in sing-a-song tasks.
Healthy people	The power spectrum of left brain is high. The high-frequency component appears in the sing-a-song tasks.

Table 5
Comparison of both brains.

	Left brain	Right brain
Low frequency	The power spectrum appears in all tasks in all people at all stages. The volume of power spectrum shows a difference in the dementia level.	The power spectrum appears in all tasks in people at all stages. The volume of the power spectrum in each stage remains at the same level.
High frequency	Power spectrum appears in all tasks in the dementia patients. Power spectrum appears in the sing-a-song task in border region people and healthy people.	

dementia patients were able to differentiate between major and minor keys in the classical scale. We summarize these results in Table 3. Based on these results, dementia patients prefer Japanese old melodies, but they do not understand and confuse the tonality of Japanese music. Their confusion is strengthened by adding songs.

4.2. Experiment using NIRS

In previous studies, an analysis method for NIRS data has not been established. We believe NIRS data shows temporal changes in cerebral blood flow, much as an electroencephalogram does, so that the analysis method of electroencephalogram is applicable to NIRS data analysis. In this study, we suggest an analysis method of NIRS data by FFT. We displayed the power spectrum of the FFT analysis of the NIRS data by two components: high frequency and low frequency. We then analyzed the characteristics of each of these two types of power spectra. Analysis for when the study participants did not sing a song showed that high frequency was included in the power spectrum of the dementia patients, but high frequency was not included in the power spectrum of the healthy participants. When the study participants sang a song, high frequency emerged in both dementia patients and in healthy participants. From these results, we guess that the dementia patient is unable to make careful control of cerebral change in blood flow. We summarize these results in Tables 4 and 5. From these results, we speculate that the dementia patient is unable to make careful control of cerebral changes in blood flow. We conversely proved that listening to a melody in Japanese music is an effective rehabilitation for dementia patients.

5. Conclusion

We summarize our results as follows: (1) dementia patients prefer Japanese old melodies, but they do not understand the tonality of Japanese music; (2) the tendency of (1) is strengthened by adding the element of Song; (3) dementia patient is poor at careful control of the blood volume change; (4) singing a song induces an out-of-control state of brain blood flow in humans at every stage; and (5) for Japanese dementia patients, Japanese music was effective in music therapy.

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