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Characteristic Analysis of Auditory Stimuli Utilizing the Sound Source of Ultrasonic Band and the Audible Frequency Band and Cerebral Activation State Changes

Jeonghoon Shin[1], Minji Kim[1] and Sojeong Lee[2]

[1]Dept. of Information Technology Engineering, Catholic University of Daegu, Hayang-ro 13-13, Hayang-eup, Gyeongsan-si, Gyeongbuk 712-702, Korea
{only4you, sky11123}@cu.ac.kr
[2]Bugil Academy GLP
61 Dandae-ro Shinbu-dong, Dongnam-gu, Cheonan-si, Chungnam-do, 330-941 Bugil Academy, Korea
ain0912@gmail.com

Abstract

Neurofeedback, which is considered an alternative medicine, is a training that changes the cerebral activation state by a patient's own efforts. New Neurofeedback users often have a hard time learning to control their own brain waves. For this reason, many users give up on Neurofeedback therapy prematurely. Neurofeedback advocates have been studying a variety of brain activation state control methods to develop easier Neurofeedback therapies to overcome this defect. Humans receive a variety of external information with the help of various sensory organs such as the eyes and ears. This information is recognized by the cerebrum, and as a result it induces changes in the activation state of the brain. Auditory stimulation of external stimuli is perceived as sound by stimulating the brain through air conduction. In general, the auditory stimulus bandwidth from 20Hz to 20KHz is used. Auditory stimulus of ultrasound higher than 22KHz is not used as an external stimulus to induce the brain activation state change, since humans cannot hear beyond this bandwidth. It is known that auditory stimulus of ultrasound bandwidth directly stimulates the cochlea of the inner ear and can induce changes in the brain activation state. However, no specific research results that compare the difference between the audible and the ultrasound stimulus has been presented, so there are limitations utilizing the ultrasound bandwidths in practical applications. For this reason, this study has analyzed changes in brain activation utilizing the auditory stimulation in audible and in ultrasound frequency. The research result of this study can be applied in a variety of applications, which uses ultrasound auditory stimulus.

Keywords: *Neurofeedback, Auditory Stimulus, Ultrasound Bandwidth*

1. Introduction

The need for controlling diseases using modern medical scientific methods is a very important matter. New treatments for various diseases are continuously being suggested. However, the vast majority of treatments currently being proposed require the use of drugs and surgery. These treatments are often subject to numerous side effects, while at the same time offering relief for many patients. To deal with these issues, a variety of alternative medicines have been, over the years, utilized for the treatment of these diseases and conditions. [1-2]

As an example, in the field of psychiatry, Neurofeedback is being used as a therapeutic technique to minimize the side effects of treatment using drugs and surgery, and various clinical results have been suggested for this treatment. In these trials, patients attempt to

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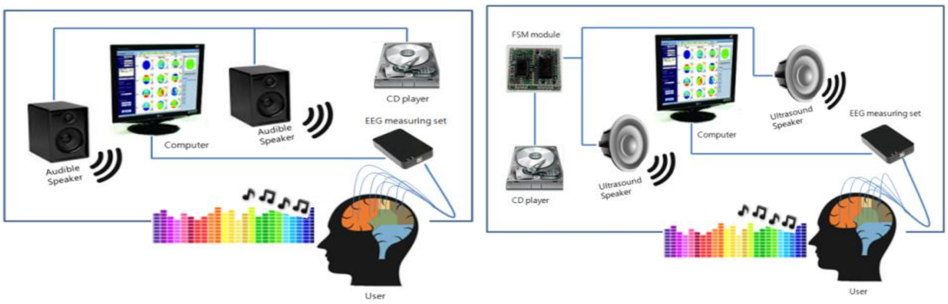
treat themselves by attempting to learn how to bring their brain activity back to a "normal" state using their own efforts. However, people who use Neurofeedback for the first time tend to have trouble mastering the way to control the activation state of their brains and the treatment tends not to go smoothly, thus, the need to find a solution to this problem is evident [3-8]. In this regard, various studies are underway to find improved therapeutic methods like Neurofeedback therapy techniques that utilize external stimuli, such as audio-visual stimulation. External stimuli, such as light and sound, are recognized in the brain through the sensory organs and induce a change in the activation state of the brain. If the changes in the brain after having been activated by light and sound can be analyzed accurately, they could be used systematically as a method to change and control the brain activation states in many other fields, not only Neurofeedback. The external stimulus approach utilizing light and sound has two problems. First, light and sound might not only be exposed to the patient in need of treatment, but also to others nearby who do not welcome this stimuli. Second, since light and sound passes through the sense organs before being recognized in the cerebrum, the same stimulation can induce various forms of brain activation states in response to the patient. The sensory organ characteristics of each person are different, and when these properties are in conjunction with external stimuli, there are bound to be variations. In addition to the limitations of application fields and available places, it is difficult to select the external stimulus to draw results with uniform algorithms due to these problems. These elements inhibit practical applications like commercialization. In this paper, in order to solve these problems fundamentally, we have conducted experiments and analyzed utilizing stimuli in the ultrasound bandwidth that can minimize the effect of human sensory organs, and can induce changes in the brain activation state directly. There has been research that has shown auditory stimulation of the ultrasound bandwidth directly stimulates the inner ear and affects the activation state changes to the cerebrum, but there are no specific research results that have been compared and analyzed with auditory stimulus in the audible frequency [9-13]. If comparative study and analysis of the specific characteristics associated with auditory stimuli of ultrasonic and audible frequency bands is conducted successfully, the research could suggest auditory stimuli that could replace audible auditory stimuli and could solve various problems caused by using the audible auditory stimuli. In this paper, in order to fundamentally solve changes in cerebral activation state due to differences in sound sources, we have converted sound sources, recorded in audio and ultrasound frequencies and provided to the subjects, and analyzed the similarity and differentiation of the changes in the activation state of the user's brain. We have thoroughly designed this research to ensure that the results can be practically used in a variety of different fields.

2. Experimental Design

2.1. Experimental Environments

In this study, in order to analyze the changes of cerebral activation states using a sound source of an audio frequency band and the ultrasonic bandwidth, we have conFigured an experimental environment as shown in Figure 1 below. The ultrasound sources which were used in the experiment were prepared by converting audible sound sources into 3 ranges (20, 30, and 40KHz) and were sequentially presented to the subjects who participated in the experiment described in Figure 1 below.



(a) Auditory Stimulation in the Audio Frequency Band (b) Auditory Stimulation in the Ultrasonic Band

Figure 1. Experimental Environment

In order to analyze the effect of auditory stimulation on the changes in the brain activity of subjects, this study has selected healthy men and women in their 20's as subject groups. The experiment was conducted with a total of 150 subjects, so that statistical reliability was ensured. First, we analyzed changes in the cerebrum activation condition after participants (there were 45 men and 46 women used in this particular experiment) listened to sounds in the audio frequency band. Sixty subjects (evenly divided between male and female) were recruited and participated in the experiment to analyze the changes in the cerebrum activation condition, and they listened to the same sound, but which had been converted into the ultrasonic bandwidth. This group was further divided into three groups based on bandwidth (20, 30, and 40KHz) (10 men and 10 women for each group).

2.2. Stimulus Sound Source Selection and Electroencephalogram Extraction

The type of auditory stimulus that was used in the experiment is popular. To prevent losses owing to lyrics damaged during tempo conversion, the selected music was played with a single instrument. In order to analyze the stable state in the relaxed state, Beethoven's Pathetique 2nd Movement was selected, since it was composed in a major key, and has a tempo similar to that of a human heartbeat. The original music which was used in this experiment has been converted from a major key to a minor key to induce changes in the emotions of the listeners, and a comparative analysis has also been carried out. In order to analyze the effect of tension through tempo change, we had the subjects listen to music 20% faster than normal, and 20% slower than normal.

We used the same sound source in the audible frequency bandwidth for ultrasound bandwidth in order to minimize the variables of the changes in emotion emanating from changes in stimuli. In addition, in order to induce mood swings, nervousness, and other emotions, conversion between major and minor keys, and tempo changes, were performed in the same manner as the sound source of the audio frequency band. Table 1 indicates the auditory stimulation sources used in this experiment.

Table 1. Sound Source of Audible Frequency Band and Ultrasound Band

Sound Source of Audible Frequency Band			Sound Source of Ultrasound Band
Music (Sound)	Conversion Pattern	Tempo (BPM)	Ultrasound frequency
Beethoven's Pathetique 2nd movement	Major	70 to 90 (Maintain the speed of the original song)	20KHz 30KHz 40KHz
	Minor		
	Major	110 to 130 (20% faster than the original song)	20KHz 30KHz 40KHz
	Minor		
	Major	30 to 50	20KHz

	Minor	(20% slower than the original song)	30KHz 40KHz

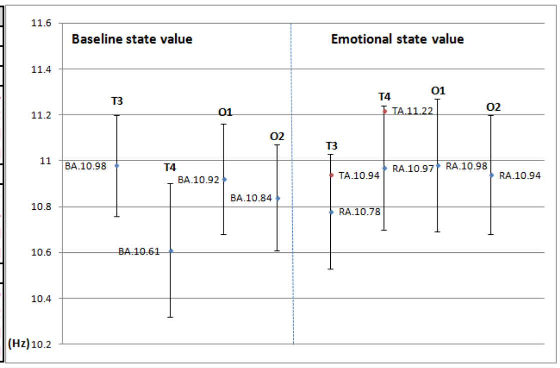
When converting the original sound source into the ultrasonic band, we used a sound generator and an oscilloscope to ensure accuracy. After converting the 100hz signal output from the sound generator to the ultrasonic bandwidth, the conversion to the output value of the oscilloscope 20khz, 30khz, and 40khz sharp was performed to the stimulation source of the audible frequency band.

Electrode arrangement for the electroencephalogram extraction follows the 10-20 international electrode placement. In this experiment, the electroencephalogram signal was extracted from 8 points (F7, F8, T3, T4, T5, T6, O1, O2) at a sampling of 256Hz and brain waves from 4 points (T3, T4, O1, O2) in a close correlation with audio-visual stimulus were analyzed.

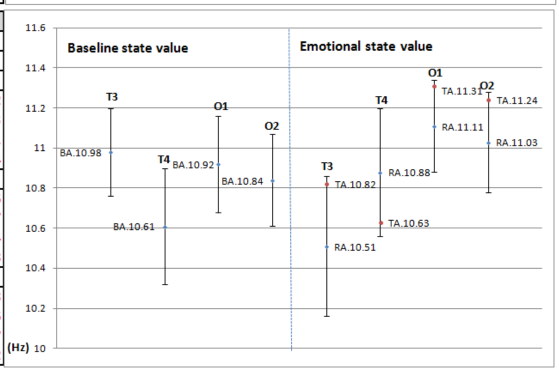
3. Experiments and Results

In this study, we have suggested a new analysis method based on frequency characteristics of EEG spectra in the emotions, which analyzed the four emotional states of humans, by M. B. Kostyunina and M. A. Kulikov [14-15] to analyze the impact of auditory stimulation sources in the audible frequency band and the ultrasound band on the cerebrum activation state. According to the reference, to classify the four emotional states (Joy, Anger, Fear, Sorrow) in humans, the frequency bandwidth value with the peak energy value among the EEG spectrum, belonging to the alpha band, and the distribution of the baseline state were analyzed and the results show that frequency bandwidth where peak energy is placed changes depending on the changes of emotional state. For the classification of emotional states, the reference measured the brain waves at 10 points of F3, F4, C3, C4, T3, T4, P3, P4, O1, O2 and was utilized in the analysis. In this study, we have utilized frequency bandwidth location, which has peak energy in the alpha band, at 4-points of T3, T4, O1, and O2 strongly correlated with audio-visual stimulus, and energy value in baseline. Figure 2 shows the classification criteria of the emotional state which is newly proposed in this study.

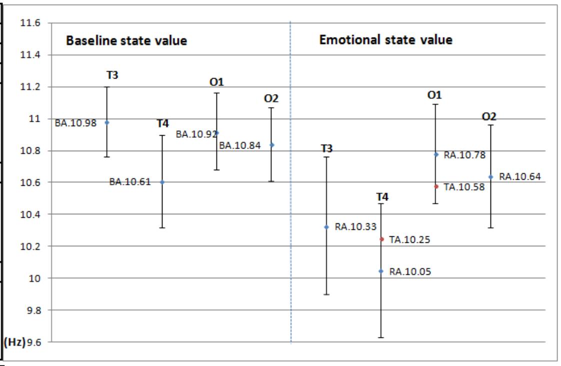
Joy				
	Reference paper		This paper	
	Baseline	Emotion	Baseline	Emotion
Average value				
T3	10.98	10.78	10.98	10.94
T4	10.61	10.97	10.61	11.22
O1	10.92	10.98	10.92	Not used
O2	10.84	10.94	10.84	Not used
Maximun value				
T3	11.2	11.03	11.2	11.03
T4	10.9	11.24	10.9	11.24
O1	11.16	11.27	11.16	Not used
O2	11.07	11.2	11.07	Not used
Minimum value				
T3	10.76	10.53	10.76	10.86
T4	10.32	10.7	10.32	11.2
O1	10.68	10.69	10.68	Not used
O2	10.61	10.68	10.61	Not used



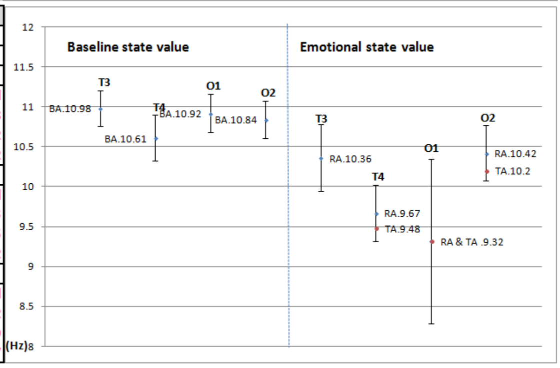
Anger				
	Reference paper		This paper	
	Baseline	Emotion	Baseline	Emotion
Average value				
T3	10.98	10.51	10.98	10.82
T4	10.61	10.88	10.61	10.63
O1	10.92	11.11	10.92	11.31
O2	10.84	11.03	10.84	11.24
Maximun value				
T3	11.2	10.86	11.2	10.86
T4	10.9	11.2	10.9	10.7
O1	11.16	11.34	11.16	11.34
O2	11.07	11.28	11.07	11.28
Minimum value				
T3	10.76	10.16	10.76	10.78
T4	10.32	10.56	10.32	10.56
O1	10.68	10.88	10.68	11.27
O2	10.61	10.78	10.61	11.2



Fear				
	Reference paper		This paper	
	Baseline	Emotion	Baseline	Emotion
Average value				
T3	10.98	10.33	10.98	Not used
T4	10.61	10.05	10.61	10.25
O1	10.92	10.78	10.92	10.58
O2	10.84	10.64	10.84	Not used
Maximun value				
T3	11.2	10.76	11.2	Not used
T4	10.9	10.47	10.9	10.47
O1	11.16	11.09	11.16	10.69
O2	11.07	10.96	11.07	Not used
Minimum value				
T3	10.76	9.9	10.76	Not used
T4	10.32	9.63	10.32	10.02
O1	10.68	10.47	10.68	10.47
O2	10.61	10.32	10.61	Not used



Sorrow				
	Reference paper		This paper	
	Baseline	Emotion	Baseline	Emotion
Average value				
T3	10.98	10.36	10.98	Not used
T4	10.61	9.67	10.61	9.48
O1	10.92	9.32	10.92	9.32
O2	10.84	10.42	10.84	10.2
Maximun value				
T3	11.2	10.78	11.2	Not used
T4	10.9	10.02	10.9	9.63
O1	11.16	10.35	11.16	10.35
O2	11.07	10.77	11.07	10.32
Minimum value				
T3	10.76	9.94	10.76	Not used
T4	10.32	9.32	10.32	9.32
O1	10.68	8.29	10.68	8.29
O2	10.61	10.07	10.61	10.07



TA: Electrode Value (This Paper), RA: Electrode Average Value (Freference Paper), BA: Baseline Average

Figure 2. Classification Criteria of Emotional State in Accordance with the Frequency Bandwidth Where the Peak Energy of the Alpha band Is Located

Figure 2 shows the frequency band where the alpha-band peak energy is located and frequency band in the steady-state for classifying emotional state proposed in this paper. As shown in Figure 2, in this study, if the frequency bandwidths where the baseline peak energy is located, they are included from 10.76 to 11.2 for T3, from 10.32 to 10.9 for T4, from 10.68 to 11.16 for O1, from 10.61 to 11.07 for O2, classification of the four emotional states is carried out. If the frequency band of the baseline peak energy does not exist in the range, the classification of the emotional state is not carried out. Taking as an example joy, among the four emotions from Figure 3, after the frequency band of the baseline peak energy has satisfied the condition, if the alpha-band peak energy of the subject at T3 point has been included from 10.86 to 11.03Hz and that of T4 point has also been included from 11.2 to 11.24Hz, the emotion of the subject will be classified as joy in this study. Similarly, in the case of anger, after the frequency band of the baseline peak energy has satisfied the condition, if the alpha-band peak energy of the subject at four points has been included in the right range, the emotion of the subject will be classified as anger ($10.78 \leq T3 \leq 10.86$, $10.56 \leq T4 \leq 10.7$, $11.27 \leq O1 \leq 11.34$, $11.2 \leq O2 \leq 11.28$). For fear, T4 and O1 points are used for the classification. The alpha-band peak energy of the subject at T4 point should be included from 10.02 to 10.47Hz and that of O1 should be included from 10.47 to 10.69Hz. For sorrow, 3 points, except T3, are used ($9.32 \leq T4 \leq 9.63$, $8.29 \leq O1 \leq 10.35$, $10.07 \leq O2 \leq 10.32$) For both fear and sorrow, the frequency band location of the baseline peak energy must satisfy the condition.

The analysis results of the brain waves, which were collected using the above algorithm proposed in this study shows that some distributions of the alpha-band peak energy in the baseline condition have not satisfied the conditions. In order to compensate for this condition, correction values corresponding to the deviation have been used. For the correction value, the reciprocal of the distance value between the alpha-band peak distribution in the baseline condition and the alpha-band peak distribution of the subjects who participated in this study was used. The reciprocal of the distance value of a logarithmic scale, known as suitable for characteristics of the human sense organs has been used and the analysis has been performed simultaneously. Through the comparative analysis of the classification using common distance values and a log scale, this study has tried to present an auditory stimulation technique that can lead to changes in the cerebral activation state by minimizing the deviation of the human senses.

Table 2. Emotional State Classification Results of Subjects According to the Stimulus Sound Source in Audible Frequency Bandwidth (Scale Applies to Major-Minor Conversion, Tempo Conversion, and Reciprocal of the Distance Value)

Major				Minor			
slower	joy	2	4.44%	**slower**	joy	0	0.00%
45 people	anger	5	11.11%	45 people	anger	2	4.44%
	fear	10	22.22%		fear	12	26.67%
	sorrow	28	62.22%		sorrow	31	68.89%
Original	joy	2	4.44%	**Original**	joy	0	0.00%
45 people	anger	3	6.67%	45 people	anger	2	4.44%
	fear	20	44.44%		fear	9	20.00%
	sorrow	20	44.44%		sorrow	34	75.56%
faster	joy	2	4.44%	**faster**	joy	1	2.22%
45 people	anger	2	4.44%	45 people	anger	1	2.22%
	fear	9	20.00%		fear	19	42.22%
	sorrow	32	71.11%		sorrow	24	53.33%

(a) Emotional state classification of male subject according to the stimulus sound source in audible frequency bandwidth (Scale applies to major-minor conversion, tempo conversion, and reciprocal of the distance value)

Major				Minor			
slower	Joy	4	8.70%	**slower**	joy	1	2.17%
46 people	Anger	4	8.70%	46 people	anger	3	6.52%
	Fear	24	52.17%		fear	22	47.83%
	sorrow	14	30.43%		sorrow	20	43.48%
Original	Joy	1	2.17%	**Original**	joy	0	0.00%
46 people	anger	5	10.87%	46 people	anger	3	6.52%
	fear	28	60.87%		fear	22	47.83%
	sorrow	12	26.09%		sorrow	21	45.65%
faster	joy	1	2.17%	**faster**	joy	0	0.00%
46 people	anger	4	8.70%	46 people	anger	3	6.52%
	Fear	23	50.00%		fear	27	58.70%
	sorrow	18	39.13%		sorrow	16	34.78%

(b) Emotional state classification of female subject according to the stimulus sound source in audible frequency bandwidth (Scale applies to major-minor conversion, tempo conversion, and reciprocal of the distance value)

Table 2 shows the classification results of men and women subject’s emotions. The subjects listened to sound stimulation in the audible frequency bandwidth, and emotional state classification methods and the reciprocal correction of the distance values in the baseline state were used to obtain the results. According to the experimental results, the emotional states of 45 male subjects were classified into joy, anger, fear, and sorrow, respectively 2, 5, 10, and 28, when they listened to the music, which was played at a rate 20% slower than the original. When they listened to the original music, the results were classified into 2, 3, 20, and 20 respectively. After they listened to the original song 20% faster, the results were classified into 2, 3, 20, and 20 respectively. When they listened to the music, which was converted from a major key to a minor key in 3 different tempos, the results were classified as follows (20% slower: 0, 2,12, and 31, Original: 0, 2, 9, and 34, 20% faster: 1, 1, 19, and 24). In addition, the same experiment was performed on female subjects in the same way as male subjects, and the results were classified as follows (Major-20% slower: 4, 4, 24, and 14, Major-original: 1, 5, 28, and 12, Major-20% faster: 1, 4, 23, and 18). (Minor-20% slower: 1, 3, 22, and 20, Minor-original: 0, 3, 22, and 21, Minor-20% faster: 0, 3, 27, and 16).

Table 3. Emotional State Classification of Subjects According to the Stimulus Sound Source in Audible Frequency Bandwidth (Log Scale Applies to Major-Minor Conversion, Tempo Conversion, and Reciprocal of the Distance Value)

Major				Minor			
slower	joy	14	31.11%	**slower**	joy	15	33.33%
45 people	anger	7	15.56%	45 people	anger	4	8.89%
	fear	14	31.11%		fear	11	24.44%
	sorrow	10	22.22%		sorrow	15	33.33%
Original	joy	18	40.00%	**Original**	joy	13	28.89%
45 people	anger	5	11.11%	45 people	anger	5	11.11%
	fear	11	24.44%		fear	10	22.22%
	sorrow	11	24.44%		sorrow	17	37.78%
faster	joy	12	26.67%	**faster**	joy	13	28.89%
45 people	anger	4	8.89%	45 people	anger	5	11.11%
	fear	12	26.67%		fear	18	40.00%
	sorrow	17	37.78%		sorrow	9	20.00%

(a) Emotional state classification of male subject according to the stimulus sound source in audible frequency bandwidth (Log scale applies to major-minor conversion, tempo conversion, and reciprocal of the distance value)

Major				Minor			
slower	joy	10	21.74%	**slower**	joy	7	15.22%
46 people	anger	3	6.52%	46 people	anger	5	10.87%
	fear	25	54.35%		fear	18	39.13%
	sorrow	8	17.39%		sorrow	16	34.78%
Original	joy	13	28.26%	**Original**	joy	11	23.91%
46 people	anger	4	8.70%	46 people	anger	5	10.87%
	fear	21	45.65%		fear	21	45.65%
	sorrow	8	17.39%		sorrow	9	19.57%
faster	joy	10	21.74%	**faster**	joy	4	8.70%
46 people	anger	5	10.87%	46 people	anger	5	10.87%
	fear	18	39.13%		fear	23	50.00%
	sorrow	13	28.26%		sorrow	14	30.43%

(b) Emotional state classification of female subject according to the stimulus sound source in audible frequency bandwidth (Log scale applies to major-minor conversion, tempo conversion, and reciprocal of the distance value)

To exclude the effect caused by the sensory organs' characteristics, the reciprocal of the distance value of the log scale was applied to the results in Table 2. It can be seen that the classification results in Table 3 are slightly different from the results shown in Table 2.

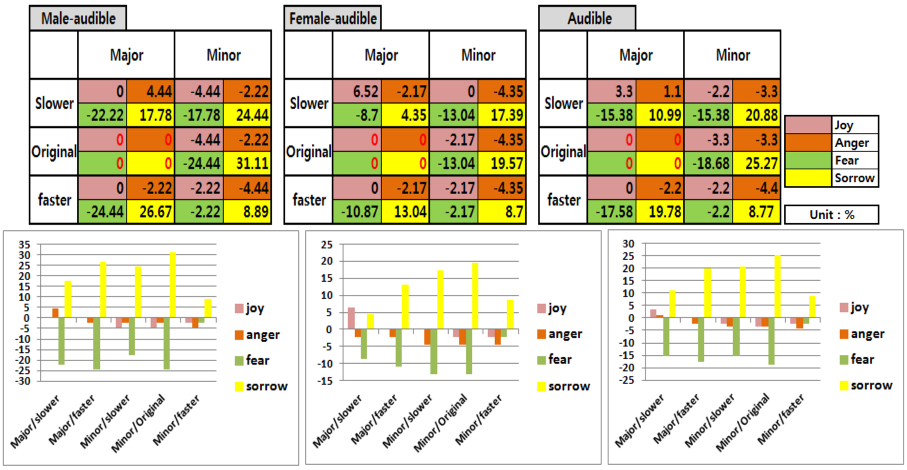


Figure 3. Rate of Changes in the Emotional State According to the Major-Minor Conversion, and Playback Speed Changes (Scale Applied to Reciprocal of the Distance Value)

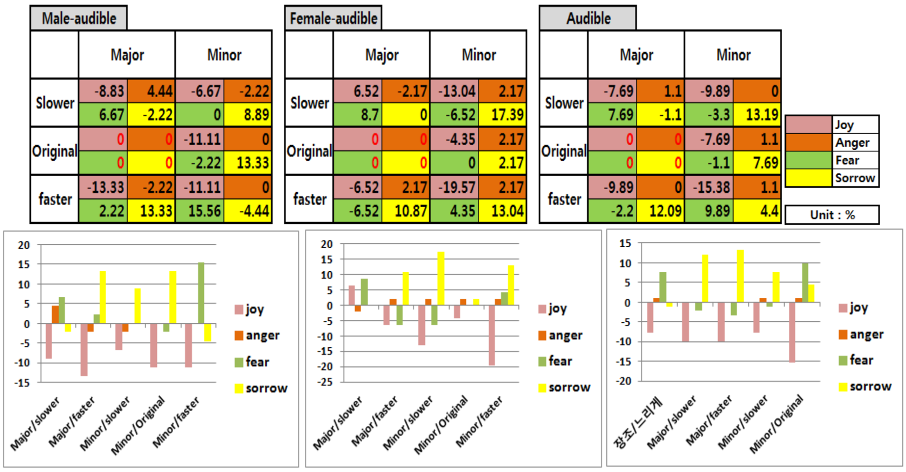


Figure 4. Rate of Changes in the Emotional State According to the Major-Minor Conversion, and Playback Speed Changes (Log Scale Applied to Reciprocal of the Distance Value)

Figures 3 and 4 show the rate of emotional state changes according to the Major/Minor conversion and playback speed changes based on the classification results for the audible stimulus of the original song. Figure 3 shows the rate of change of the correction results using the reciprocal of the distance value and Figure 4 indicates the rate of change of the correction results using the log scale for the reciprocal of the distance value.

Table 4. Emotional State Classification of Subjects According to the Stimulus Sound Source in Ultrasound Bandwidth (Scale Applies to Major-Minor Conversion, Tempo Conversion, and Reciprocal of the Distance Value)

	Major				Minor			
20KHz	**slower**	joy	0	0%	**slower**	joy	2	10%
	20people	anger	0	0%	20people	anger	0	0%
		fear	5	25%		fear	3	15%
		sorrow	15	75%		sorrow	15	75%
	Original	joy	0	0%	**Original**	joy	0	0%

	20people	anger	0	0%	20people	anger	0	0%
		fear	3	15%		fear	4	20%
		sorrow	17	85%		sorrow	16	80%
	faster	joy	0	0%	**faster**	joy	0	0%
	20people	anger	0	0%	20people	anger	0	0%
		fear	6	30%		fear	4	20%
		sorrow	14	70%		sorrow	16	80%
	Major				**Minor**			
30KHz	**slower**	joy	1	5%	**slower**	joy	0	0%
	20people	anger	1	5%	20people	anger	0	0%
		fear	3	15%		fear	7	35%
		sorrow	15	75%		sorrow	13	65%
	Original	joy	1	5%	**Original**	joy	0	0%
	20people	anger	2	10%	20people	anger	0	0%
		fear	5	25%		fear	6	30%
		sorrow	12	60%		sorrow	14	70%
	faster	joy	2	10%	faster	joy	0	0%
	20people	anger	0	0%	20people	anger	2	10%
		fear	6	30%		fear	5	25%
		sorrow	12	60%		sorrow	13	65%
	Major				**Minor**			
40KHz	**slower**	joy	0	0%	**slower**	joy	0	0%
	20people	anger	0	0%	20people	anger	0	0%
		fear	4	20%		fear	5	25%
		sorrow	16	80%		sorrow	15	75%
	Original	joy	1	5%	**Original**	joy	1	5%
	20people	anger	0	0%	20people	anger	1	5%
		fear	2	10%		fear	5	25%
		sorrow	17	85%		sorrow	13	65%
	faster	joy	0	0%	**faster**	joy	1	5%
	20people	anger	1	5%	20people	anger	1	5%
		fear	4	20%		fear	7	35%
		sorrow	15	75%		sorrow	11	55%

Table 5. Emotional State Classification of Subjects According to the Stimulus Sound Source in Ultrasound Bandwidth (Log Scale Applies to Major-Minor Conversion, Tempo Conversion, and Reciprocal of the Distance Value)

	Major				Minor			
20KHz	**slower**	joy	1	5%	**slower**	joy	2	10%
	20people	anger	6	30%	20people	anger	4	20%
		fear	7	35%		fear	5	25%
		sorrow	6	30%		sorrow	9	45%
	Original	joy	2	10%	**Original**	joy	2	10%
	20people	anger	4	20%	20people	anger	4	20%
		fear	6	30%		fear	7	35%
		sorrow	8	40%		sorrow	7	35%
	faster	joy	1	5%	**faster**	joy	1	5%
	20people	anger	4	20%	20people	anger	4	20%
		fear	7	35%		fear	7	35%
		sorrow	8	40%		sorrow	8	40%
	Major				**Minor**			

30KHz	**slower** 20people	joy	1	5%	**slower** 20people	joy	0	0%
		anger	1	5%		anger	0	0%
		fear	3	15%		fear	7	35%
		sorrow	15	75%		sorrow	13	65%
	Original 20people	joy	1	5%	**Original** 20people	joy	0	0%
		anger	2	10%		anger	0	0%
		fear	5	25%		fear	6	30%
		sorrow	12	60%		sorrow	14	70%
	faster 20people	joy	2	10%	**faster** 20people	joy	0	0%
		anger	0	0%		anger	2	10%
		fear	6	30%		fear	5	25%
		sorrow	12	60%		sorrow	13	65%
	Major				**Minor**			
40KHz	**slower** 20people	joy	0	0%	**slower** 20people	joy	0	0%
		anger	0	0%		anger	0	0%
		fear	4	20%		fear	5	25%
		sorrow	16	80%		sorrow	15	75%
	Original 20people	joy	1	5%	**Original** 20people	joy	1	5%
		anger	0	0%		anger	1	5%
		fear	2	10%		fear	5	25%
		sorrow	17	85%		sorrow	13	65%
	faster 20people	joy	0	0%	**faster** 20people	joy	1	5%
		anger	1	5%		anger	1	5%
		fear	4	20%		fear	7	35%
		sorrow	15	75%		sorrow	11	55%

Table 4 shows the emotional state classification of male and female subjects, after listening to ultrasonic stimulus sound sources, which were converted into 3 types (lowest auditory frequency band: 20 kHz, 30 kHz, and 40 kHz) by using the same stimulus sound source in the audible frequency bandwidth used in the experiment of Table 2. Table 4 shows the classification results that used the emotional state classification method, and the reciprocal correction of the distance value in the baseline state, which were suggested in this study. To exclude the effect caused by the sensory organs' characteristics, the reciprocal of the distance value of the log scale was applied to the results in Table 4 and the results are shown in Table 5.

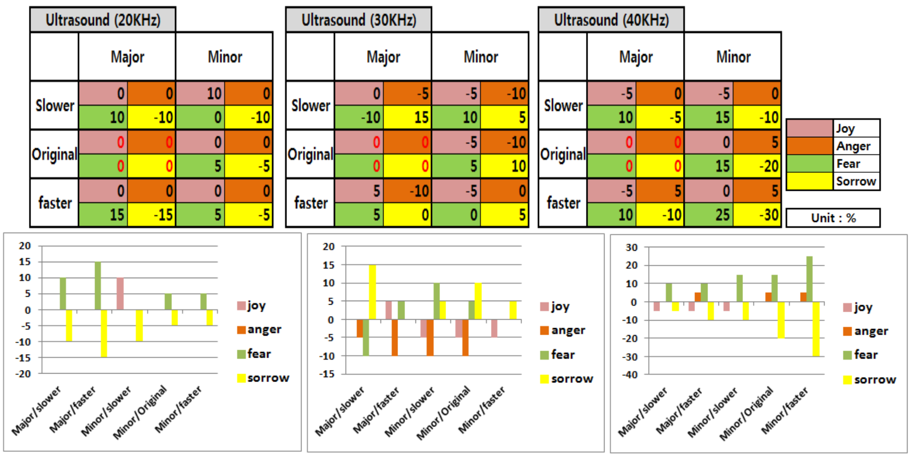


Figure 5. Rate of Changes in Emotional State According to the Major-Minor Conversion, and Playback Speed Changes of the Music Converted to the Ultrasonic Bandwidth (Scale Applied to the Reciprocal of the Distance Value)

Ultrasound (20KHz)	Major		Minor	
Slower	-5	10	0	0
	5	-10	-5	5
Original	0	0	0	0
	0	0	5	-5
faster	-5	0	-5	0
	5	0	5	0

Ultrasound (30KHz)	Major		Minor	
Slower	0	-5	-5	-10
	-10	15	10	5
Original	0	0	-5	-10
	0	0	-5	10
faster	5	-10	-5	0
	5	0	0	5

Ultrasound (40KHz)	Major		Minor	
Slower	-5	0	-5	0
	10	-5	15	-10
Original	0	0	0	5
	0	0	15	-20
faster	-5	5	0	5
	10	-10	25	-30

Joy	Anger
Fear	Sorrow

Unit : %

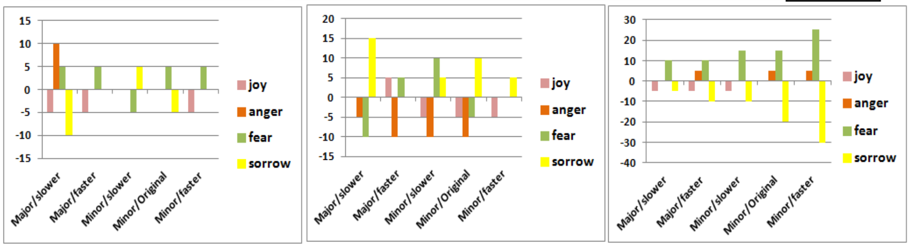


Figure 6. Rate of Changes in Emotional State According to the Major-Minor Conversion, and Playback Speed Changes on the Music Converted to Ultrasonic Bandwidth (Log Scale Applied to the Reciprocal of the Distance Value)

Figures 5 and 6 show the emotional change rate in response to the auditory stimuli in 3 types of ultrasonic bands and the stimulation source music was also converted between major and minor keys and playback speed was also changed. Figure 5 shows the rate of change of the correction results using the reciprocal of the distance value and Figure 6 shows the rate of change of the correction results using the log scale for the reciprocal of the distance value.

When comparing Figure 3 and 4 and Figure 5 and 6 respectively, there are the obvious differences between Figure 3 and 4. However, the results between Figure 5 and 6 are very similar, except the results from the 20KHz bandwidth. This means that for the auditory stimuli source of the audio frequency band, the results from general classification methods and classification methods utilizing the log scale to reflect the human sensory characteristic differences are obviously different. On the other hand, for the auditory stimuli source of the ultrasonic band, the results from those two methods are practically the same. In other words, the auditory stimuli source of the ultrasonic band does not reflect individual's unique physical characteristics and it directly affects the cerebral activation state change via direct stimulation to the inner ear.

4. Conclusion

Based on the results of this experiment, we have discovered that auditory stimuli can induce changes in cerebral activation states and emotional states. The results were somewhat different from the commonly accepted belief that music in major keys provides a bright, upbeat feeling, whereas minor keys casts a somewhat darker mood. Additionally, fast tempo music creates tension, but slow music is more depressing, and music which is similar to the heart rate gives the listener ease and comfort.

The most meaningful result from this study is that auditory stimulation sounds of the audio frequency band are reflected by the different characteristics of human sensory organs before the stimulus induces changes in brain activation states and emotional states. The auditory stimulation of the ultrasonic bandwidth reflects the minimized individual sensory characteristics, and induces changes in brain activation states and emotional states through direct stimulation to the inner ear.

In particular, for the auditory stimulation of the ultrasonic bandwidth at 20KHz, which is the boundary between the audible frequency and the ultrasonic band, it could be judged that reflecting characteristics of sensory organs and not reflecting cases are mixed at this

20KHz bandwidth. These results clearly appear through the change rate of emotional states influenced by auditory stimuli of the ultrasonic bandwidth at 20 KHz in Figures 5 and 6.

Considering the results of this study, when implementing a service to induce changes in brain activation states and emotional states by using auditory stimuli, it would be more effective to use auditory stimuli in the ultrasonic band rather than in the audio frequency band. Since the auditory stimuli in ultrasonic band can be delivered to the brain without reflecting sensory organ characteristics of each individuals, it does not require implementing the characteristic functions of a variety of forms and uniform outcomes can be achieved with consistent algorithms.

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Authors

Jeonghoon Shin, Address: Dept. of Information Technology Engineering, Catholic University of Dae-Gu, 330 Geumrak-1Ri Hauang-Eup Gyeonsan-Si Gyeongbuk, Korea. He received a B.S and M.S and ph.D.in Electronics Engineering from Sung-kyunkwan University, Korea in 1991, 1993 and 2004. From 1994 to 2002, Mr. Shin was an engineer at DACOM R&D Center, where he was involved in the design and performance analysis of wired and wireless communication network. From 2003 to 2004, he was an extraordinary professor at Induk-college, Seoul, Korea. Since March 2006, he has been a professor at Catholic University of Daegu, Kyungsan, Korea. His current research focuses on Brain Computer Interface, the five senses recognition and synthesis. He is a member of TTA, KDISS and ASK. And he is also a member of valuation committee in IITA. Tel:+82-53-850-2748 E-mail: only4you@cu.ac.kr

Minji Kim, Address: Dept. of Information Technology Engineering, Catholic University of Dae-Gu, 330 Geumrak-1Ri Hauang-Eup Gyeonsan-Si Gyeongbuk, Korea. She is at catholic university of Deagu. She is interested in Human Computer Interaction.

Tel:+82-10-4474-8566 E-mail : sky11123@cu.ac.kr

Sojeong Lee, Address: Bugil Academy GLP, 61 Dandae-ro Shinbu-dong, Dongnam-gu, Cheonan-si, Chungnam-do, 330-941 Bugil Academy, Korea

Education & Work experience: Sojeong Lee is a student at Bugil Academy GLP in Cheonan, Korea. She is interested in brain engineering.

Tel: +82-10-8571-7124 E-mail: ain0912@gmail.com