Effect of Vibroacoustic Stimulation to Electroencephalogram
음향진동자극이 뇌파에 미치는 영향

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Key Words : 음향진동(Acoustic Vibration), 뇌파(EEG), 음악자극(Music Stimulation), 음향진동장치(Vibroacoustic Equipment), 음향진동자극(Vibroacoustic Stimulation), SMR파(Sensori-motor Rhythm)

Abstract : 인체에 음향진동장치에 의하여 자극을 가하였을 경우 영향을 고찰한다. 5명의 건강한 남자 대학생을 대상으로 하여, 3가지 형태의 음악을 음향과 진동자극의 신호원으로 사용해서 실험을 행하였다. 모든 피험자에 대하여, 자극 전, 음악자극, 진동자극, 자극 후로 나누어 뇌파를 측정하였다. 실험의 모든 피험자의 측정 데이터의 t-검정을 수행하여 유의성이 있는 데이터에 한하여 뇌파를 고찰하였다. 결과로서, 음악과 음향파와 진동자극이 뇌파에 미치는 영향은 음향진동장치에 따른 진동자극 형태, 피험자의 몸과 정신 상태에 따라 현저하게 달라질 수 있다는 것을 알 수 있다. 그리고 적절한 음악과 음향진동장치를 사용하여 특정의 뇌파 상태를 유도 할 수 있음을 확인하였다.

1. 서 론

Music is the art which pursuit aesthetic appreciation closely related to emotional human life. These characteristics of music having relationships may induce physiological response of the human body.

Human may have different music response when listening various music due to individual character such as age, gender, physical and mental conditions of human body, music preference, and musical inclination[1]. In addition, these responses based upon music composition elements such as music types, rhythm, harmony, tempo, dynamics, and melody may cause excite, awake, and/or settle down human body and relax strain[2].

Between music and human body, there might be several factors owing to individual character and music composition elements and there might be opposite emotional response when listening same music. However, active using of music and vibroacoustic stimulation may be the application for the disease cure and sleep inducing[3].

There are previous studies related to a sound wave and its response of the human body. Broner reported that human body absorbed 2% sound energy at 100Hz in the study of low frequency noise effect on human body[4]. Bartleet[5], Hodge[6], and Maranto[7] studied and found results related to physiological responses caused by music.

There were Skille's vibroacoustic therapy[8] as a response study on human body of acoustic vibration wave and Madsen, Standley and Gregory's response study[9-10] on the effect of vibrotactile device.

There are several studies related to human body response caused by music and vibroacoustic stimulation but there are no interdisciplinary cooperative studies and only independent studies have been done among music and sound specialists, medical professionals, and machine device professionals so far[11-12]. Consequently, there are in short of more scientific, standard, and

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detailed basis study results.

In this study, using vibroacoustic equipment with selected music, acoustic vibration signals from somewhat low set frequency area were applied to human body as stimulation by contact vibration and sound wave and then human body responses were considered using EEG experiment.

2. Experimental equipments and methods

2.1 Subjects

Subject completed questionnaires were selected and 20-25 aged university students who were healthy males.

The questionnaire used in this study included body condition on the experiment day, enough 7 hour-sleep per day, past medical history, injection or dental care experience during recent 3 days, drug dosage, other disease status, average daily sleep hours, and rising hours, to select students who did not have factors continuously affecting EEG. In addition, this study kept Helsinki declaration standard (subject should be voluntary participants and they should know they are going to participate experiment. When taking experiment agreement, there needs to be special attention that subject's agreement is naturally from one's free will under no forced condition and/or no expected relationship between subjects and researchers). Selected subjects in this study were 5 students and named as a, b, c, d, and e.

2.2 Vibroacoustic equipment

Fig. 1 shows vibroacoustic stimulation equipment and the measuring system of EEG used in this study. The upper right in Fig.1 shows equipment for executing vibration and acoustic reflector , and the lower right in Fig.1 shows CD player and Amp.

Music played by CD player transported to speakers which enable subject to listen. Spontaneously, played music signals went through high frequency-pass filter of vibroacoustic equipment and low frequency of acoustic vibration signals were extracted. And then they were sent to vibration transducer located in pad above the bed. Transducer vibration applied to specific areas of the human body such as waist and thigh with contact vibration.

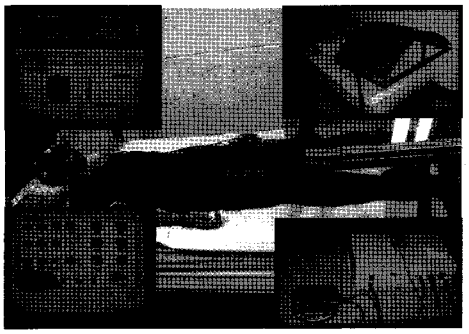


Fig. 1 Vibroacoustic equipment and measuring system of EEG.

Table 1 Specification of the vibroacoustic equipment

Amp.	Voltage; AC100V , Vibration output; 20W Audio output; 1W, Power; 40W, Input; 2P , Output; 2P
Pad	Transducer; 6P , Diaphragm; 3-layer Frequency; 20~250Hz, Impedanc; 10.7Ω
Speaker	Impedance; 8Ω , Rated power; 12W Frequency; 125~10kH

After then, vibration wave originated from transducer could softly stimulate human skin through direct or indirect reflexed waves from acoustic reflector made of acrylic.

Vibrotactile intensity was controlled by the Amp. Table 1 shows vibroacoustic equipment specification.

2.3 Measuring system of EEG and measurement regions

Like apparatus shown as the left side in Fig.1, PolyG-I equipment, multi biotic measuring machine, was used in this study which could spontaneously be used for electrocardiogram, pulse wave, breathing, skin electrical conduction. EEG from subjects were measured by 256Hz sampling frequency and 0~50Hz pass filter.

As seen in Fig. 2, measured areas were on head surface 8 sites with measuring brain waves by monopolar way. Based upon 10/20-international electrodes array method, measurement electrodes were attached on Fpl, Fp2, F3, F4, T3, T4, P3, and P4 location (Small circles in Fig. 2). Standard electrode was attached on A1 and ground connection electrodes was attached on A2 where neck behind.

2.4 Measurement methods

EEG measurement were performed by 4 stages for one subject. At the first 5 minute phase, EEG measurement was done under comfortable condition (Before stimulation) after enough resting. Then during the next 5 minutes, EEG was measured when subject was applied to music stimulation (Stimulation 1) through speakers. During the third 5 minutes, EEG was measured by applying music and vibroacoustic stimulation (Simulation 2) to human body. To examine continuing degree about those stimulations, measurement was performed under condition without any stimulation (After stimulation) during last 5 minutes.

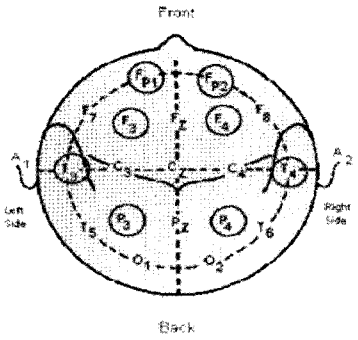


Fig. 2 Arrangement plan of electrodes.

Table 2 includes music content information used in this study. Each music also is used as symbolized one.

2.5 Characteristics of brain waves

For analyzing brain waves, classification of brain waves based on frequency are as follows. Delta wave (δ wave : 0.2 ~ 3.99 Hz) when deep sleep or newborn baby case, and seta wave (Θ wave : 4 ~ 7.99 Hz) when emotional stability or the procedure to sleep. Alpha wave (α wave : 8 ~ 12.99 Hz) is usually seen in comfortable condition such as strain relaxation and it increase the amplitude of wave in much more settled and comfortable condition. SMR wave (Sensorimotor Rhythm : 13 ~ 15 Hz) is usually seen under no strain condition and enables human to focus tasks without stress which causes easy and accurate task accomplishment. Beta wave (β wave : 13 ~ 29.99 Hz) is predominantly seen in unstable condition, strain and stress condition, and/or dealing with complicated calculation. Gamma wave (γ wave : 30 ~ 50 Hz) is shown up under very nervous emotional condition and/or greatly related to high recognition process such as inference and judgement. The frequency of artifact areas caused by eye and body movement are almost same as delta wave frequency areas. When long time EEG measurement experiment is done, eye and body movement are essentially generated, therefore, increased delta wave power is not included in analysis factors because it may be seen as increased delta wave.

Table 2 Music contents used in experiment

Symbol	Music title
Music A	Adagio-tempo d'andante -allegro vivace(cello)
Music B	The Ludlow (piano, a string orchestra)
Music C	Sonata for cello & piano No. 3 in A major, Op. 69:

2.6 Tests of experimental data

To verify test of significance, all subject EEG measurement data were analyzed by dependent sample t-test.

Dependent sample t-test is the way to compare simple sample group average difference between two groups and it tests if the average difference between two factors would be 0 or not.

In this study, all subjects were under same experimental condition and changes in measured

brain waves by musics or vibroacoustic stimulus were measured. With measured data, dependent sample t-test was performed among before stimulation and stimulation 1, before stimulation and stimulation 2, stimulation 1 and stimulation 2.

Test statistic, t_0 is as below;

$$t_0 = \frac{(\overline{X_1} - \overline{X_2}) - (\mu_1 - \mu_2)}{S_{\overline{X_1} - \overline{X_2}} / \sqrt[2]{n}} \quad (1)$$

where, $\overline{X_1}, \overline{X_2}$: mean of experiment 1 result and experiment 2 result

$\mu_1 - \mu_2$: mean difference between two experiment results hypothesized in this study

n : sampling size

$S_{\overline{X_1} - \overline{X_2}}$: Expected standard error

Comparing critical value from t-distribution and t_0, measurement data were done for the test of significance.

3. Results and Discussions

Applying musical and vibroacoustic stimulation to human body, EEG equipment measured brain waves. Measured data were analyzed by TeleScan(software) exclusively used for EEG analysis. The analyzed results of brain waves were shown as the power value(μV^2) versus frequency.

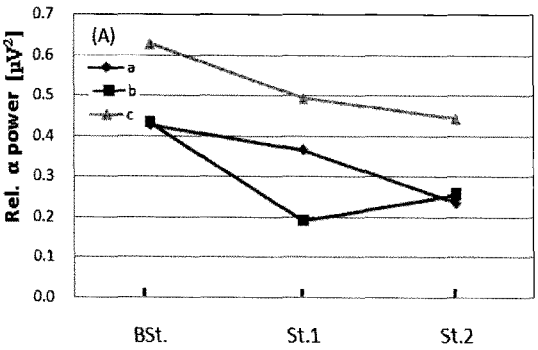
Table 3 shows subject a, b, and c's results. It shows t-test results(Probability P values) between measurement data. And it indicates values averaged and analyzed brain wave data value measured from 8 areas of the head under before stimulation (Bst.), stimulation 1(st.1: music stimulation), and stimulation 2 (st.2: vibroacoustic stimulation) using music A, a cello music. Each subject's α, β, and SMR wave absolute value and relative value is shown in Table 3. Also, measured data from subject were used for test of significance and performed by dependent sample t-test among Bst. and st.1, Bst. and st. 2, st.1 and st.2. Most of the results were statistically significant with two-side test, $P < 0.05$. Only subject a and b's SMR wave data among Bst. and st.1 was not statistically significant. However, a and b's SMR wave data had significance in st.1 and st.2 t-test, which did not totally affect stimulation effect on brain waves and did not have problem to evaluate study results.

Table 3 Probability of reliability of the measuring data of brain wave for music A

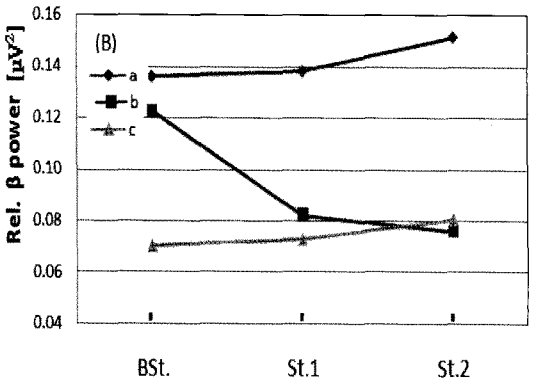
Brain wave	Subjects	Stimulus	Absolute mean values of 8-ch	Relative mean values of 8-ch	P values	
α	a	Bst.	25.127	0.429	Bst.-st.1	0.0008
		st.1	14.464	0.368	Bst.-st.2	0.0008
		st.2	7.778	0.237	st.1-st.2	0.0009
	b	Bst.	31.923	0.434	Bst..st.1	0.0014
		st.1	10.047	0.192	Bst.-st.2	0.0089
		st.2	14.989	0.258	st.1-st.2	0.0001
	c	Bst.	84.322	0.629	Bst..st.1	0.0174
		st.1	44.445	0.493	Bst.-st.2	0.0142
		st.2	39.518	0.443	st.1-st.2	0.0106
β	a	Bst.	8.654	0.136	Bst..st.1	2.51E-05
		st.1	6.555	0.138	Bst.-st.2	5.97E-05
		st.2	6.052	0.151	st.1-st.2	0.0015
	b	Bst.	10.279	0.122	Bst..st.1	4.63E-06
		st.1	5.914	0.082	Bst.-st.2	0.0007
		st.2	6.880	0.076	st.1-st.2	0.0083
	c	Bst.	9.943	0.071	Bst..st.1	0.0074
		st.1	7.318	0.073	Bst.-st.2	0.0222
		st.2	7.833	0.081	st.1-st.2	0.0056
SMR	a	Bst.	1.248	0.023	Bst..st.1	0.7560
		st.1	1.228	0.024	Bst.-st.2	0.0052
		st.2	1.031	0.025	st.1-st.2	2.61E-05
	b	Bst.	1.512	0.015	Bst..st.1	0.2155
		st.1	1.652	0.021	Bst.-st.2	0.0061
		st.2	2.471	0.022	st.1-st.2	0.0009
	c	Bst.	1.776	0.018	Bst..st.1	0.0150
		st.1	1.379	0.021	Bst.-st.2	0.0069
		st.2	1.312	0.036	st.1-st.2	0.0404

* Bst. : Before stimulation, st.1 : stimulation 1, st.2 : stimulation 2

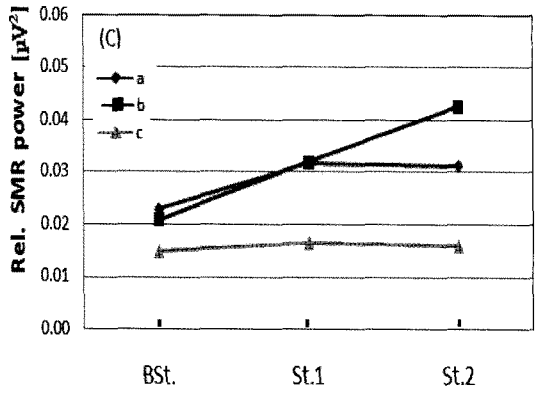
Therefore, the results are also shown in Fig. 3. In Fig. 3(B), β wave power values of subject a and c were little bit increased during st.1, comparing to before stimulaton(Bst.) phase. However, subject b's β wave power value was dramatically decreased. During st.2 phase, β wave power values of subject a and c kept slowly increased and subject b's β wave power value was somewhat decreased.



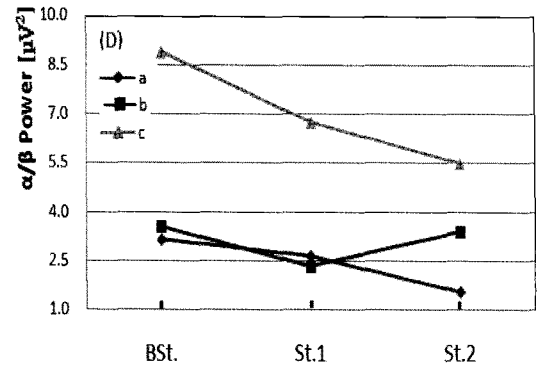
(A) Relative α wave



(B) Relative β wave



(C) Relative SMR wave



(D) α wave / β wave

Fig. 3 Relative powers of brain wave on music A

In Fig. 3(C), SMR wave power values, one of slow β power value, subject c's was little bit increased but subject a and b's were suddenly much increased in st.1 case comparing than Bst.. In st.2 case, subject a and c's relative power values were mostly unchanged but only subject b's was greatly increased.

There were α/β power value rates about identical subjects in Fig. 3(D). In spite of decreasing subject b's β wave power values, all α/βpower value rates of subject a, b, and c were decreased under st.1 phase. And then subject b's α wave power value showed big drop. Subject b's vibroacoustic stimulation effects were much more clear so subject b's α/β power value rate was increased because of great increse in α wave and SMR wave power value even though subject a and c's α/β power value rates were continuously decreased.

Table 4 Probability of reliability of the measuring data of brain wave for music B

Brain wave	Subjects	Stimulus	Absolute mean values of 8-ch	Relative mean values of 8-ch	P values	
α	c	Bst.	70.775	0.697	Bst.-st.1	0.0017
		st.1	43.843	0.652	Bst.-st.2	0.0003
		st.2	17.203	0.427	st.1-st.2	4.27E-05
	d	Bst.	57.398	0.607	Bst.-st.1	0.0027
		st.1	44.587	0.612	Bst.-st.2	0.0022
		st.2	30.406	0.562	st.1-st.2	0.0022
	e	Bst.	10.473	0.254	Bst.-st.1	0.0656
		st.1	14.563	0.399	Bst.-st.2	0.0769
		st.2	14.752	0.368	st.1-st.2	0.4458
β	c	Bst.	10.050	0.085	Bst.-st.1	0.0013
		st.1	7.453	0.094	Bst.-st.2	0.0003
		st.2	6.637	0.132	st.1-st.2	7.16E-06
	d	Bst.	9.184	0.091	Bst.-st.1	0.1066
		st.1	8.720	0.110	Bst.-st.2	2.04E-05
		st.2	6.799	0.111	st.1-st.2	0.0005
	e	Bst.	5.102	0.101	Bst.-st.1	0.0526
		st.1	4.927	0.122	Bst.-st.2	0.0677
		st.2	6.241	0.138	st.1-st.2	0.0435
SMR	c	Bst.	1.806	0.018	Bst.-st.1	0.0280
		st.1	1.353	0.021	Bst.-st.2	0.0302
		st.2	1.435	0.036	st.1-st.2	0.0474
	d	Bst.	1.353	0.015	Bst.-st.1	0.2155
		st.1	1.412	0.021	Bst.-st.2	0.0023
		st.2	1.153	0.022	st.1-st.2	0.0051
	e	Bst.	0.943	0.023	Bst.-st.1	0.0016
		st.1	0.814	0.024	Bst.-st.2	0.8587
		st.2	0.953	0.025	st.1-st.2	0.0255

In other words, vibroacoustic stimulation effect of music A caused subject a and c's α wave power values drop. Although their β wave were somewhat increased, subject b's α wave and SMR wave power values were greatly increased. Therefore it was ascertained that a stimulation of vibroacoustic equipment would be more effective to induce the SMR wave of EEG of subject b than another subjects.

Table 4 shows α, β, and SMR wave's absolute and relative power values of subject c, d, and e. And it indicates values analyzed and averaged 8 channel measured data, using with music B, piano and string orchestra music, under Bst., st.1, and st. 2 cases. Also Table 4 shows the results of t-test like Table 3.

T-test results of subject c and d mostly were statistically significant with two-side test, $P< 0.05$. T-test results of subject e, as seen in Table 4, there were no significant in measured α, β, and SMR wave. Therefore, subject e's data was excluded and only subject c and d's analysis results were shown in Fig. 4.

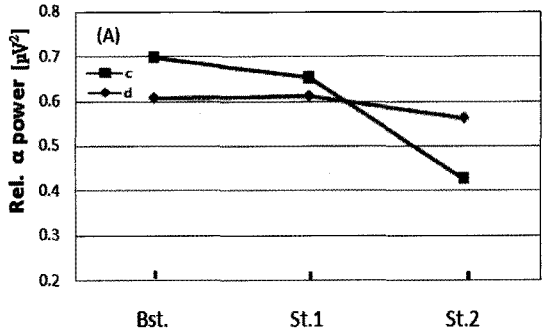
According to Fig. 4(A), subject c and d's relative α wave power values related to music B were decreased with narrow limits or no more changes in st.1 phase than Bst. phase. During st.2 phase, subject c's α wave were greatly decreased comparing to subject d's.

In Fig. 4(B), relative β wave power values about identical subjects were increased during st.1 than Bst.. Under st.2 phase, subject c's power value was suddenly increased but subject d's was mostly unchanged.

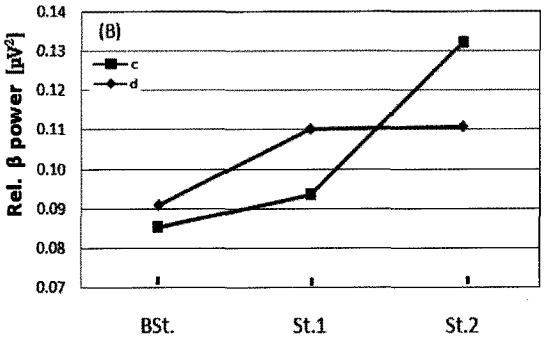
SMR wave in Fig. 4(C) shows same tendency as Fig. 4(B) but subject c's power value was suddenly also increased under st.2 condition.

In Fig. 4(D), α/β power value rates were decreased under st.1 and st.2 phase comparing to Bst.. Especially in subject c's case, power value rate was dramatically decreased during st.2 phase.

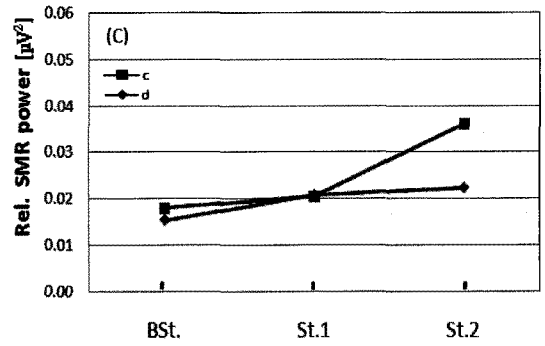
Fig. 5 shows α, β, and SMR wave power values, and α/β power rates of subject c with stimulation using music A, music B,and music C(sonata for the cello and the piano).



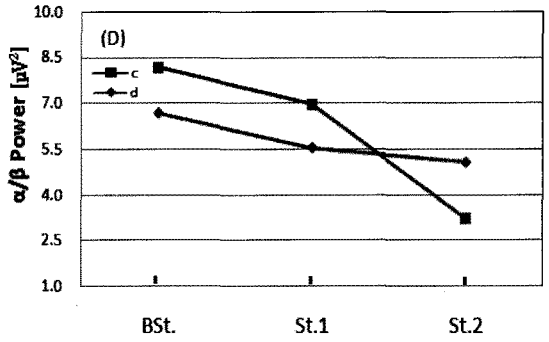
(A) Relative α wave



(B) Relative β wave

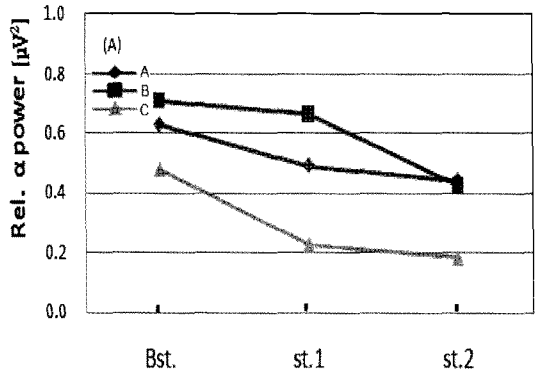


(C) Relative SMR wave

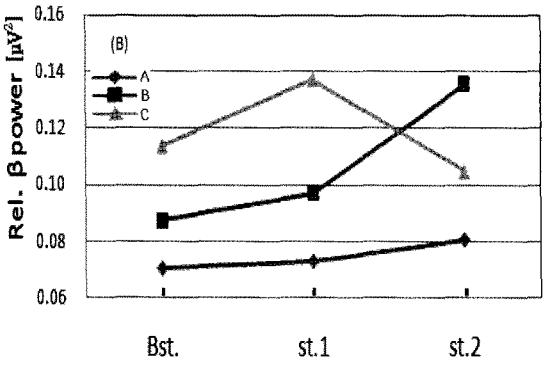


(D) α wave / β wave

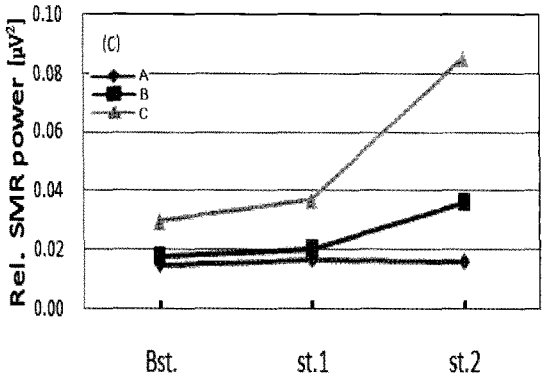
Fig. 4 Relative powers of brain wave on music B



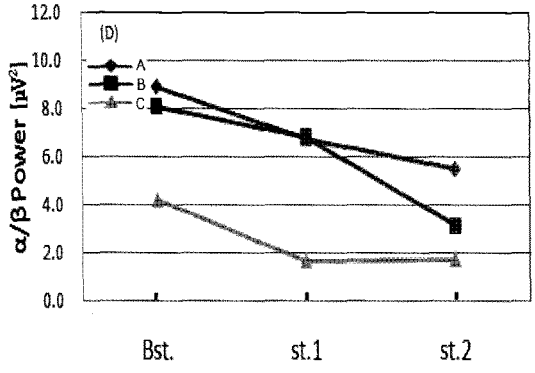
(A) Relative α wave



(B) Relative β wave



(C) Relative SMR wave.



(D) α wave / β wave

Fig. 5 Relative powers of brain wave of subject c on music A, B and C

All α wave power values were decreased, β wave power values were increased, and SMR wave power value were also increased slightly during st.1 even though there were little differences in music A, B, and C. On the other hand, the effect of music A and B had similar to each stimulation but music C had very different tendency during st.2 ; even though α wave power value was decreased like as music A and B, β wave power value was also increased, and SMR wave power value was same tendency in increasing but much more greatly increased. Both music A and B with effective use of vibroacoustic equipment may induce SMR wave but music C seems to have more effects. In other words, st.2 with applying the signals of music C may greatly induce SMR wave originated from meditation condition which is able to concentrate under the relaxed body and mind condition.

Summary

This study was performed with 5 subjects and used three kinds of music and vibroacoustic stimuli wave based upon each kinds of music. Executing music stimulation, vibro tactile and acoustic wave stimulation to human body were performed. Then measured brain waves were analyzed under each condition including before stimulation, stimulation 1, and stimulation 2. Effects by stimulation results could be studied with experiments and summarized results are followings.

1. It may be concluded that effects on brain waves by music and vibroacoustic stimulation might differ under different situations such as stimulation types with vibroacoustic equipment, human body and mental conditions when measuring, etc..

2. During stimuli by using music A, B, and C, the effect of α wave, β wave, and SMR wave power values show same tendency to the subject c but music C had very different tendency during

vibroacoustic stimuli.

3. During vibroacoustic stimuli by applying the signals of music C, because SMR wave power value was continually increased with consistency comparing to Bst.,.this can be estimated that an application of inducing mind concentration condition would be possible under relaxed body and mind conditions.

4. To secure data significance, all measured data need to be tested statistically whether data would be interrelated or not.

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