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A SSVEP Based EEG Signal Analysis to Discriminate the Effects of Music Levels on Executional Attention

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Abstract: In this work the electrical activity in brain or known as electroencephalogram (EEG) signal is being analyzed to study the various effects of sound on the human brain activity. The effect is in the form of variation in either frequency or in the power of different EEG bands. A biological EEG signal stimulated by Music listening reflects the state of mind, impacts the analytical brain and the subjective-artistic brain. A two channel EEG acquisition unit is being used to extract brain signal with high transfer rate as well as good SNR. This paper focused on three types of brain waves which are theta (4-7 Hz), alpha (8-12 Hz) and beta wave (13-30 Hz). The analysis is carried out using Power Spectral density (PSD), Correlation co-efficient analysis. The outcome of this research depicted that high amplitude Alpha and low amplitude Beta wave and low amplitude Alpha and high amplitude Beta wave is associated with melody and rock music respectively meanwhile theta has no effect. High power of alpha waves and low power of beta waves that obtained during low levels of sound (Melody) indicate that subjects were in relaxed state. When subjects exposed to high level of sound (Rock), beta waves power increased indicating subjects in disturbed state. Meanwhile, the decrease of alpha wave magnitude showed that subjects in tense. Thus the subject's executional attention level is determined by analyzing the different components of EEG signal.

Keywords: Electroencephalogram (EEG), Steady-State Visual Evoked Potential (SSVEP), Non-Invasive Signal Recording, Power Spectral Density (PSD), Correlation Coefficient, Brain Wave, Eeg Bands

1. Introduction

In recent years, Biomedical Engineering (BME) has played an important role in the application of engineering technology to design advanced Medicare system for the improvement of healthcare which include diagnosis, monitoring, and therapy. The applications of Biomedical Engineering include the development of biocompatible prostheses, various diagnostic and therapeutic medical devices ranging from clinical equipment to micro-implants and also analysis of MRIs, EEGs, EOGs, EMGs signals for monitoring and diagnosis.

EEG measures brain wave activity over longer epochs and activity of certain waves can be averaged over the duration of the recording [1]. EEG measures voltage fluctuations resulting from ionic current flows within the neurons of the brain as shown in Fig.1. The greater the numbers of neurons in the brain that fire at the same time, the stronger the EEG signal [2]. In clinical contexts, EEG refers to the recording of the brain's spontaneous electrical activity over a short period of time, usually 20–40 minutes, as recorded from multiple electrodes placed on the scalp.

EEG is most often used to diagnose sleep disorders, coma, encephalopathy and brain death which can be used for diagnosis of tumors, stroke and other focal brain disorders. Although high-resolution anatomical imaging techniques such as MRI (Magnetic Resonance Imaging) and CT (Computed Tomography) are more commonly used techniques, EEG offers better accuracy and efficiency with relatively low cost.

In the central nervous system, when a neuron is activated by other neurons through afferent action potentials, excitatory post-synaptic potentials (EPSPs) are triggered at its apical dendrites. Thus the membrane of the apical dendrites becomes depolarized and electronegative compared to the cell soma. As a consequence of this transient potential difference, current flows from the non-excited soma to the excited apical dendritic tree, and a negative polarity emerges at the surface [3]. This is shown in Fig.1.

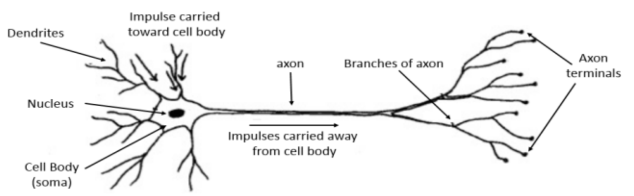


Figure 1. *Neuron general structure and generation of electrical signal (EEG Signal) due to external stimulation.*

EEG measures mostly the currents that flow during synaptic excitations of the dendrites of many pyramidal neurons in the cerebral cortex. EEG signal consists of a wave that varies in time, much like a sound signal, or a vibration [2]. The useful information contained in the raw EEG signal cannot be visualized with just bare eyes. Raw EEG signals usually contain artifacts that will complicate the analysis of EEG signal. These interference waveforms, the artifacts, are any recorded electrical potentials not originated in brain [4]. The main sources of artifacts are:

1. EEG equipment.
2. Interfacing noise from subject and recording system.
3. The leads and the electrodes.

EEG signals, as one of the biological signals, are μV range (0.5 to ~ 100μV) at low frequency (0.5 to 30 ~ 40Hz). They are usually referred to as rhythms and are classified into five frequency bands [5] shown in Table 1.

Table 1. *Frequency bands of EEG signal.*

SL #	Brain Waves	Frequency Band (Hz)
01	Delta (δ)	1-4
02	Theta (θ)	4-8
03	Alpha(α)	8-13
04	Beta(β)	13-30
05	Gamma(γ)	36-44

The Delta band having a frequency range of 1-4Hz and amplitude of 10mV is mostly active in the first few years of infancy. It is also active during healing, regeneration and rejuvenation. Delta brainwave invokes an anesthetic pseudo-drug effect and helps the release of growth hormone in deep sleep state.

The Theta band having a frequency range of 4-7Hz and an amplitude of 50μV for kids and 10μV for adults is sometimes said to have the same anesthetic pseudo-drug effect as the Delta band but is mostly active during drowsiness at lowest frequency e.g. 4Hz.

The Alpha band having a frequency range of 8-12Hz and an amplitude of 75μV for kids and 50μV for adults on the contrary is usually associated with relaxed, alert state of consciousness. The Alpha state is activated during a calm and relax condition. During this state, the human brain can easily interpret data and absorb most of the data because of the relax-but-aware brain mode. This wave can be interpreted as a measure of executional attention .For this reason, Alpha wave is the main area of attention in the research on the effects of music on brains executional attention.

The Beta band is the normal state of mind as experienced on a day-to-day basis.it is associated with the state of alertness, problem solving and anxiousness. These waves range in frequencies between 13 to 30 Hz with an amplitude of 10-20 μV.

The Gamma band with its highest frequency (35-44 Hz) and negligibly small amplitude relate to neural consciousness via the mechanism for conscious attention. These are, according to some studies mainly associated with people who are exhibiting a 'higher consciousness' of thinking [6].

For many people across cultures, music is a common form of entertainment. Music is an integral form of human communication used to relay emotion, group identity, and even political information [7]-[8]. Listening to music and appreciating it is a complex process that involves memory, learning, and emotions. Music is remarkable for its ability to manipulate emotions in listeners. A lot of research studies have shown that music has physiological as well as psychological effects which are quantifiable. Studies show that listening to classical music boosts understanding while listening to rock music distracts the mind, results in increased heart rate and faster breathing [9]. Electroencephalogram (EEG) can indicate changes in brain activity when processing music [10].

2. EEG Acquisition

Three channel EEG signals were recorded using BIOPAC MP 36 as shown in Fig. 2(a). Electrode placement for EEG data acquisition using BIOPAC MP36 unit with right ear lobe reference is shown in Fig. 2(b). Same fixed positions of the three electrodes avoid the difficulty of position calibration for every other user and provide universality of application [3].

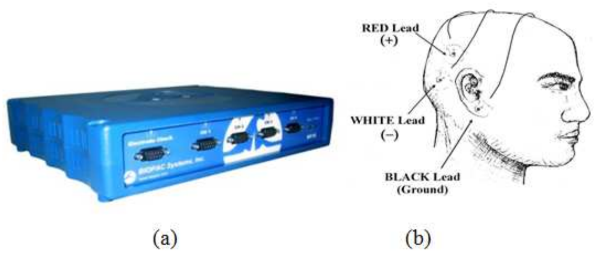


Figure 2. *(a) Three channel EEG signals recording BIOPAC MP36 unit. (b) Electrode placement for EEG data acquisition using BIOPAC MP36.*

3. Proposed Methodology

The proposed methodology is briefly described in three blocks as follows:

3.1. Block 1- Signal Extraction

The raw EEG signal is extracted from the healthy subjects under visual and acoustic stimulations condition which is amplified in the instrumentation amplifier. The amplified EEG signal is then filtered to remove the high frequency noise components. The EEG acquisition system is shown in

Fig. 3.

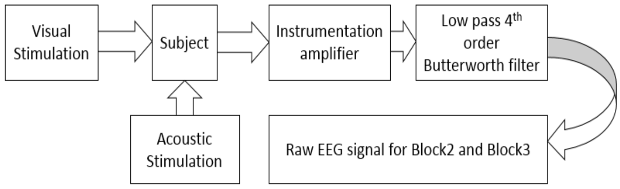


Figure 3. *Signal extraction from brain due to visual and acoustic stimulation.*

3.2. Block 2- Band Seperation and Necessary Calculations

Extracted raw EEG signal from block-1 is then filterized with low pass and band pass filters to separate out the four EEG bands namely delta, theta, alpha, beta to find out the ennergy and power. Information Transfer rate (ITR) is calculated from FFT of the signal as shown in Fig. 4.

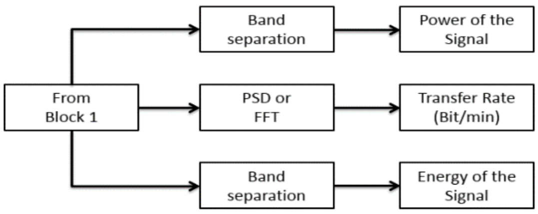


Figure 4. *Block diagram for ITR, power and energy calculation.*

3.3. Block 3-Determination of Correlation Coefficients for Different Stimuli

In block-3 low pass and band pass filters are again used to separate out the four EEG bands namely delta, theta, alpha, beta for different acoustic stimuli conditions to find out correlation coefficient with that at normal visual condition keeping subjects in relax state.

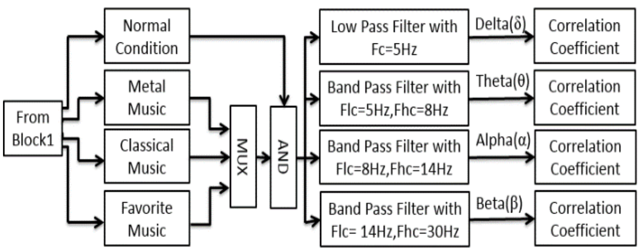


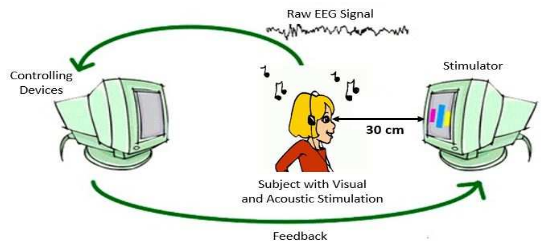
Figure 5. *Block diagram of filtering and determination of correlation coefficient.*

4. Subject and Experimental Conditions

Total 3 persons aged 25+/-2 years act as a subject for signal extraction. EEG data was recorded at the Biomedical Engineering Laboratory (under BME Dept.) in Khulna University of Engineering and Technology (KUET), Khulna-9203, Bangladesh as shown in Fig. 6. The statistical information of the subject used in experiment is given in a Table 2.

Table 2. *Subject's specifications.*

SL. No.	Subject Index	Age	Height	Weight	Sex
1	S1	27	5'5"	69 kg	Male
2	S2	25	5'7"	64 kg	Male
3	S3	23	5'3"	66 kg	Male



(a)

(b)

Figure 6. *Pictorial View of EEG signal Extraction a) proposed set-up b) actual signal extraction.*

During the signal extraction subjects were asked to keep concentration on a visual stimulator and listen to different music for 3 minutes.

EEG recordings can be divided into four steps: -

1. When no music is provided.
2. When listening to melody (Rabindra sangeet).
3. When listening to music of subjects preference.
4. When listening Rock (Metal).

During the extraction of EEG signals, the experiment was performed in controlled environment free from external sound (noise) [11].

5. Mathematical Backgrounds

5.1. Power Spectral Density (PSD)

The Power Spectral Density (PSD) analysis is performed for finding out the power of the signal over a particular frequency band [12]-[13]. PSD of the signal is a measure of the contributions of different frequency components to the power or variance of the wave. It is actually the rate of variance of the data distributed over the frequency components into which it may be decomposed.

If the total power of a signal *x(t)* in a finite time interval T is given by

$$P = \lim_{T\to\infty} \frac{1}{2T} \int_{-T}^{T} x(t)^2 dt$$

And Fourier Transform of *x(t)* over a finite time interval

[0~T] is given by

$$\hat{x}_T(\omega) = \frac{1}{\sqrt{T}} \int_0^T x(t) e^{-j\omega t} dt$$

Then the power spectral density of *x(t)* is given by:

$$S_{xx}(\omega) = \lim_{T \to \infty} E[|\hat{x}_T(\omega)|^2]$$

Where *E* is the expected value.

Power Spectral Density can also be calculated from the Fourier Transform of the autocorrelation function of a signal. To obtain correct features of the EEG signal power spectral density estimation is used. The power spectral density of the signal is computed as the frequency response of an autoregressive model of the signal, based on previous values of the signal [14]. The order of this model is very important to obtain an accurate estimation of the spectrum [15].

5.2. Correlation Coefficient, r

Correlation coefficient, also known as r, R, or Pearson's r, is a measure that determines the degree to which two variables movements are linearly associated. Correlation coefficient is also a measure of the strength and direction of the linear relationship between two variables x and y that is defined as the (sample) covariance of the variables divided by the product of their (sample) standard deviations given by the equation below:

$$r = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \overline{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \overline{y})^2}}$$

5.3. Power and Energy of Signal

The energy E of a signal *x(t)* is given by the integral of the squares of the signal or in other words the auto-correlation of the signal.

$$E = \int_{-\infty}^{\infty} |x(t)|^2 dt$$

The power of a frequency band is computed from the complex-valued Fourier coefficients obtained from the Fourier transform as follows:

$$f_k = \int_{-\infty}^{\infty} x(t) e^{-j2\pi tk} dt$$

Where t is time, k is the desired frequency in Hz, i is the imaginary number, and $x(t)$ is the value of the continuous signal at time t. But since the EEG signal is digitalized discrete version of Fourier transform, the fast Fourier transform (FFT) is generally used. Given a Fourier coefficient $a + bi$, the power is calculated as $\frac{|a+bi|^2}{F_s}$ where F_s is the sampling rate.

6. Results Analysis

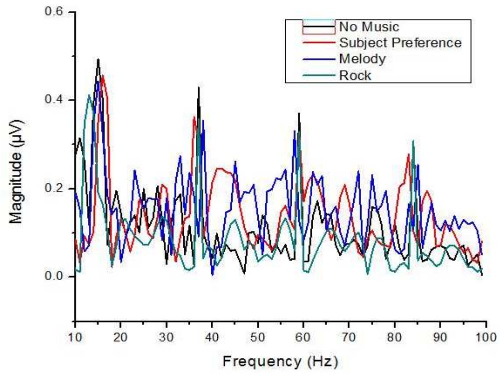
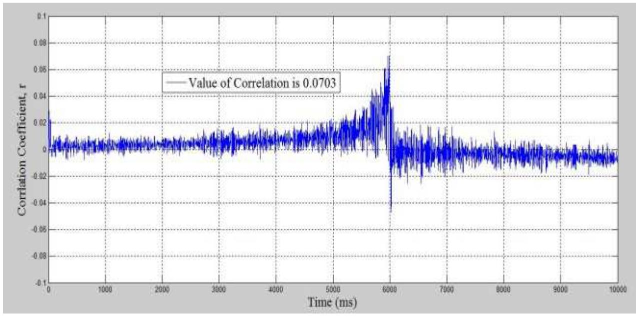


Figure 7. *Frequency Spectrum of SSVEP in response to 15 Hz stimulation for four different stimulus conditions with RED color circle of diameter 3 inch.*



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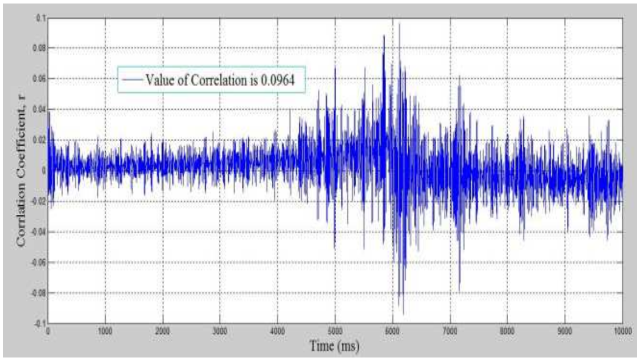

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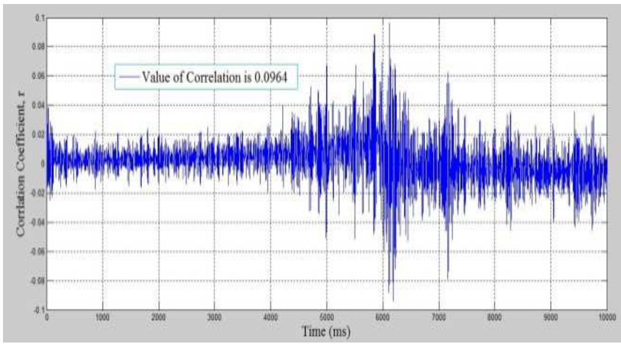
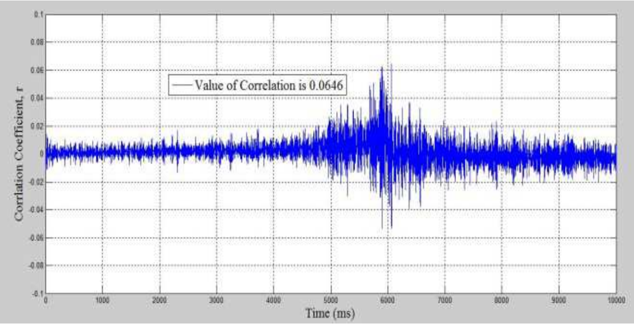


(c)

Figure 8. *Graphical representation of correlation coefficient for alpha band with normal condition (no music) and (a) subject preference (b) Melody (c) Rock.*

In Fig.7 it is seen that under normal condition (without music), a peak is found at the exactly the stimulation frequency (15 Hz) but different acoustic stimulation results in the shift of peak position from the exact frequency of stimulation. Fig.8 and 9 are graphical representation of correlation coefficient for different number of samples.



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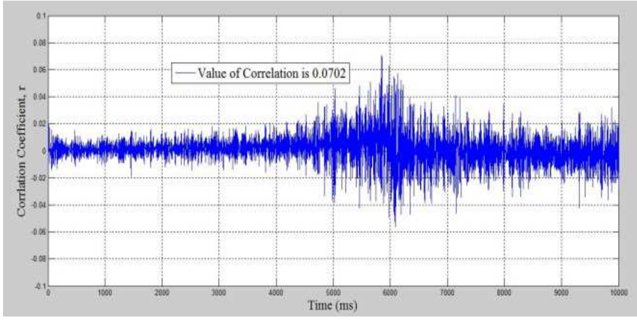

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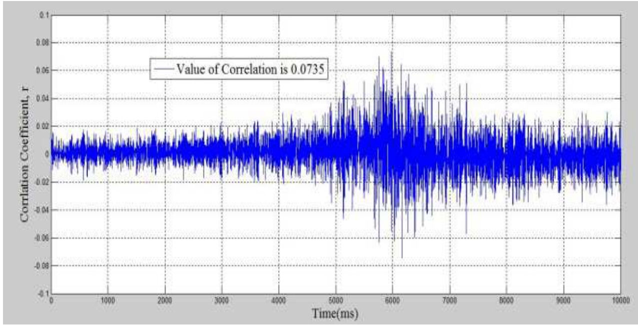

(c)

Figure 9. *Graphical representation of correlation coefficient for beta band with normal condition (no music) and (a) subject preference (b) Melody (c) Rock.*

Table 3. *ITR Calculation for three sample trials of Each Subject For First Task Where Each Subject Were Asked To Gaze At Visual Stimulator For 10 Seconds For Each Trial For Red Color Circle Of Dia 3 Inch (#=15hz, *=16hz ,$=17hz).*

Subject	Target	Duration (Second)	Detection Pattern	False Positives	Number of correct detections	Speed Bit/min	Avg. Speed Bit/min
	A	10.00	############	No	12	72.00	
KHS	B	10.00	*****_****	No	11	66.00	68.00
	$	10.00	$$$$$#$$$$	1	11	66.00	

Table 4. *Summary of ITR for different stimuli conditions.*

Subject	Music type	Average ITR (Bit/min)
S1	No music	68.00
	Subjects preference	65.00
	Melody (Rabindra Sangeet)	66.00
	Rock (Metal)	67.00
S2	No music	69.00
	Subjects preference	64.00
	Melody (Rabindra Sangeet)	68.00
	Rock (Metal)	67.00
S3	No music	68.00
	Subjects preference	65.00
	Melody (Rabindra Sangeet)	66.00
	Rock (Metal)	66.00

Table 5. *Correlation coefficient of different frequency band with normal (no music) and three other music.*

Subject	Music type	Correlation Coefficient (r) with normal stimuli condition			
		Delta(δ)	Theta(θ)	Alpha(α)	Beta(β)
S1	Subjects preference	0.046713	-0.016259	0.039388	0.038726
	Melody (Rabindra Sangeet)	0.227454	0.060568	0.018894	0.029260
	Rock (Metal)	0.047742	-0.023987	-0.027338	-0.009919
S2	Subjects preference	0.045733	-0.013959	0.040318	0.039726
	Melody (Rabindra Sangeet)	0.247714	0.066598	0.027874	0.010260
	Rock (Metal)	0.046792	-0.030937	-0.019398	-0.010919
S3	Subjects preference	0.047723	-0.020559	0.038378	0.037724

Subject	**Music type**	**Correlation Coefficient (r) with normal stimuli condition**			
		Delta(δ)	**Theta(θ)**	**Alpha(α)**	**Beta(β)**
	Melody (Rabindra Sangeet)	0.229484	0.061569	0.019894	0.027261
	Rock (Metal)	0.047940	-0.023388	-0.029339	-0.010918

Table 6. *Power and energy of different frequency band of normal (no music) and three other music.*

Subject	**Music type**	**Power of different bands**				**Energy of different bands (x10^5)**			
		Delta(δ)	**Theta(θ)**	**Alpha(α)**	**Beta(β)**	**Delta(δ)**	**Theta(θ)**	**Alpha(α)**	**Beta (β)**
S1	No music	50.2345	6.1021	9.5125	6.4512	14.5610	2.4510	3.9240	2.1562
	Subjects preference	48.5911	5.6156	9.4687	6.9010	15.6150	1.8046	3.0429	2.8853
	Melody (Rabindra Sangeet)	60.3345	5.3916	9.1121	8.9786	24.4990	2.1893	3.7001	3.8391
	Rock (Metal)	46.3481	4.7481	7.8061	9.4546	15.8940	1.6283	2.6769	2.3666
S2	No music	51.1245	6.1332	9.5639	5.9651	15.6310	2.3226	4.3201	2.3619
	Subjects preference	48.2943	5.4567	9.3920	7.2138	15.9360	1.7401	3.5619	3.0145
	Melody (Rabindra Sangeet)	59.1209	5.2189	8.9630	9.3102	23.8730	2.3157	3.9342	4.1821
	Rock (Metal)	47.5812	4.7093	7.8290	9.5646	16.0170	1.7261	2.8937	2.9338
S3	No music	50.0315	6.2174	9.7138	6.6720	14.1230	2.5320	3.7903	2.3712
	Subjects preference	49.5961	5.7641	9.5312	6.7821	16.3250	1.7689	2.9712	2.6928
	Melody (Rabindra Sangeet)	61.0345	5.1047	9.3372	8.8838	25.1090	2.2151	4.0234	2.4582
	Rock (Metal)	47.3785	4.5940	6.9361	10.1032	15.5610	1.7124	2.5681	2.1227

Table 3 shows the results of three sample trials of first task where each subject was asked to gaze at the RED color circle of dia 3 inch for 10 seconds for each trial. Since we are using a 0.83 FFT so the time periods are taken multiples of 0.83s for ease of analysis. In Table 4 the avg. ITR for each subject and for each musical condition with same visual stimulator are shown. Table 5 and 6 shows correlation coefficient of different frequency band with normal (no music) and three other music and power and energy of different frequency band of normal (no music) and three other music respectively.

7. Discussion

The experimental data suggest that during the listening to music of subject preference corresponds to greater power alpha wave and less power of beta wave than listening to an un-preferred music. More power of alpha wave and less power of beta wave indicates that subjects are in more relax state. When subjects are asked to listen to their preferred music, they are more likely to be relaxed and can't pay attention to the visual stimulator. As a consequence results in reduction of average ITR. On the other hand, when subjects are asked to listen to melody and rock music, they are less relaxed and can pay more attention to the visual stimulator which results in increased average ITR. Listening to melody provides more power of alpha wave (less power of beta wave) and less ITR than that of Rock music. From table V it is seen that for each subject (S1, S2 and S3) the bands are more closely correlated for preference music with normal condition (no music). From analysis it is observed that there is 22.45% and 31.18% reduction in power of alpha wave and beta wave respectively for subject preference music whereas there is 33.81% and 9.76% reduction in power of alpha wave and beta wave respectively for rock music.

8. Conclusion

Human brain reacts differently with changes in acoustic level. This is verified by analyzing different parameters viz power, energy, ITR etc. of EEG bands under normal condition without music, subject preference, melody and rock music as acoustic stimulus. Finally, it conclude that subjects are more relaxed in listening of music of their preference than listening to rock music.

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