International Journal of Engineering Sciences & Emerging Technologies, Apr. 2013.
ISSN: 2231 – 6604 Volume 5, Issue 1, pp: 59-67 ©IJESET

STUDY OF THE EFFECT OF MUSIC ON CENTRAL NERVOUS SYSTEM THROUGH LONG TERM ANALYSIS OF EEG SIGNAL IN TIME DOMAIN

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ABSTRACT

The paper studies the effect of music signal on central nervous system (CNS) through EEG signal analysis of normal healthy subjects. The subjects are all engineering students, ages ranging between 20 and30. The data are taken in two stages- one when they listen to a special type of music selected and the other, when they are in normal stage and not listening to any music. The experiments are done on eight leads, frontal leads being five in number and rest three being central. On the collected signals Independent Component Analysis (ICA) is applied to assist the process for isolating noise components and for providing cues to explain the functions of different brain areas from the view point of neurology. The results obtained through ICA were subjected to the study of long-term dynamics giving rise to three dimensional chaotic attractors. Next the chaotic attractors are subjected to the quantification analysis of three dimensional attractor by 'ellipsoid fit'. It is found that the effect is most prominent in the frontal leads. However, the central leads also show some changes, but not as significant as frontal leads. Thus the present study also compares the results on the effect of music in the two types of leads separately. To validate the result, topographical scalp maps are constructed with the observed data. Interestingly the results of the scalp map support the results of quantification.

KEYWORDS*: Electroencephalographic (EEG) signal, phase space construction, Independent component analysis (ICA), topographical scalp map.*

I. INTRODUCTION

Music has a strong impact on human body and mind, because we believe that music has a direct connection with human feeling and mood. Music is remarkable for its ability to manipulate emotions and stress in listeners. However, the exact way in which the brain processes music is still a very important area of research. In this context, an essential question that may arise is to know how music affects human central nervous system. Moreover it is also necessary to identify the exact portions of the brain, which responds to music significantly.

In recent years, a lot of research is focused on the physiological effect of music. The electroencephalographic (EEG) is often used to verify the influence of music on human brain activity. In [1], the authors used frequency distribution analysis and the independent component analysis (ICA) to discover the EEG responses of subjects with different musical signal stimuli. Some features on EEG were expected to demonstrate the different musical signal stimuli. [2-4] Musical signal stimuli were metal music, sonata music and the favourite music selected by subjects. 19 point channel EEG was considered for the purpose of experiment. Spectra analysis based on Fourier transform was applied to obtain the $\alpha, \beta, \gamma, \theta$ band power of EEG signal under different music stimuli. The power at each band of each channel was taken as the feature of EEG. The correlation of the features between different situations and subjects was used to show which channel display the difference of EEG signals. Besides, ICA [5] was applied to assist in the process of isolating noise components and to provide cues to explain the functions of different brain areas in point of neurology. The result showed that some independent components obtained from ICA can demonstrate more significant difference for different music. The features composed of spectral power of each band were very similar in listening to metal music, but showed less similarity in listening to sonata music. Hence, the response of EEG to sonata was found to be more meaningful and metal music may induce same effect for different subjects. T3 and Pz were the channels with relatively lower correlation under different music stimuli. Therefore, it was concluded that the locations of T3 and Pz of brain may play an important role in feeling music.

In [6] the author's aim was to confirm the character of EEG and the location in brain, when a person was enjoying different rhythm music. The rhythms were generated by Skating Waltz, Radetzy-March and Disco Music. These made the subjects excited. In all cases the character of EEG was found to be different. Moreover the region of the location in brain when a person was excited was focused in the area of the middle abdomen in the pons'side. This analysis was also based on frequency domain.

In [7] the authors used some nonlinear techniques to study the effect of music on brain. The effect of two types of music on the electroencephalogram (EEG) activity is examined, namely Indian Carnatic classical and rock music. About 300 seconds worth of EEG data is used to study the effect of each type of music. The analysis is carried out using two different methods based on nonlinear theory. The scaling properties of the EEG are studied using the Detrended fluctuation analysis (DFA) algorithm [8-10], and the complexity of the electroencephalogram signal is quantified by the multi-scale entropy (MSE) method. It is found that both methods show significant difference in the values of the estimated parameters for the electroencephalogram with and without music. The MSE method shows higher values of entropy for both types of music, indicating that the complexity of the electroencephalogram increases when the brain processes music.

From the above literature survey it is observed that the long term dynamics of EEG signal was not studied earlier. But the true picture is not expected to come only from the local analysis. This is the motivation behind considering such a global analysis. In this article, the long term dynamics of the EEG signals of healthy subjects in pre-music and on-music states have been studied and proper quantifications have been made to distinguish the pre-music and on-music state. The mostly affected regions of the brain have also been identified. Interestingly, it is found that our results tally with the results of topographical scalp map constructed from the same EEG signals.

The article is presented sequentially. Section 2 deals with the methodology that includes Acquisition of EEG signal, phase space plots and its quantification technique and the calculation of suitable time-delay for phase space plots by the method of Average Mutual Information (AMI). In section 3, results are presented, which includes two sample results of ICA, two sample phase space plots with suitable time-delay, one for a subject in pre-music state and the other for a subject in on-music state, the results of quantifications for each of the four subjects in pre-music and on-music states and two sample topographical maps, one for a subject in pre-music state and the other for a subject in on-music state. The core findings are highlighted in the Conclusion section.

II. METHODS

2.1. Acquisition of EEG signal

At first EEG data are collected from different subjects recorded by Neuro-win machine at School of BioScience and Engineering, Jadavpur University. All subjects are basically students, age between 20-30 years. All signals are taken at School of BioScience and Engineering, Jadavpur University under normal room temperature and least noisy environment. Signals have been collected in two stages. In the first stage EEG are taken at normal condition. Then in the second stage EEG signals are taken when subjects are listening to instrumental music. All signals are taken in ten minutes duration. For collection of EEG signals we had chosen eight electrodes (FP1, FP2, F3, Fz, F4, C3, Cz, and C4) because our main objective is to emphasize on Frontal Lobe [11] and mid portion of the brain. Then recorded signals are processed by MATLABR2010a software for quantification of signals. ICA algorithm [12, 13] was adopted to remove the artifacts of EEG signals and these independent components were actually compared for normal condition and when subjects listening to music.

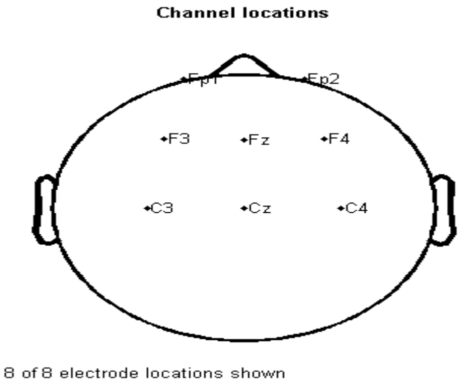

Figure 1: location of 8 leads of electrode on scalp standard 10/20 system.

2.2. Phase Space plot and quantification [14, 17]

Let the time series of the experimental data is given by $\{x(k), k = 1, 2, ..., N\}$. Also let the embedding dimension and the delay time for reconstruction of the attractor are m and τ respectively. Then we have the reconstructed phase space:
$X(k) = \left(x(k), x(k+\tau), x(k+2\tau), ..., x(k+(m-1)\tau)\right), k = 1, 2, ..., M$, where $\{X(k)\}$ is the phase point in m-dimensional phase space and $M = N - (m - 1)\tau$ is the number of phase points, describes the evaluative trajectory of the system in the phase space.
To find the suitable delay, the method of Average mutual information (AMI) [15] is generally used. Embedding dimension is normally calculated by using the false nearest neighbor (FNN) [16] method. As in the present discussion, we have reconstructed only the three dimensional phase spaces; we have not discussed FNN method in detail.
Clustering of points of the reconstructed phase space in three dimensions is a quantification technique [17], which is used to distinguish two different phase spaces in three dimensions.

Let $\{x(k)\}_{k=1}^{N}$ be a continuous signal obtained from any system. Also let that the three dimensional phase space is reconstructed by sub-dividing this signal into three groups as x^+, x^-, x^{--} with same delay τ, where $x^+ = \{x(k)\}_{k=1}^{N-2\tau}$, $x^- = \{x(k)\}_{k=1+\tau}^{N-\tau}$, $x^{--} = \{x(k)\}_{k=1+2\tau}^{N}$,

$$1 \le \tau \le \frac{N}{2}, \text{ if } N \text{ is even and } 1 \le \tau \le \frac{N-1}{2}, \text{ if } N \text{ is odd.}$$

This co-ordinate system is transformed by a three dimensional rotation with same angle $\frac{\pi}{4}$ (as the distribution of the points of maximum density on the attractor is along roughly lying with inclination $\frac{\pi}{4}$, so we consider the principal axis of the ellipsoid along that line) with respect to X Y and Z axis, which is given by .

$$x_m = \frac{1}{2}\cdot x^+ + (\frac{1}{2\sqrt{2}} - \frac{1}{2})\cdot x^- + \left(\frac{1}{2\sqrt{2}} + \frac{1}{2}\right)\cdot x^{--} = \frac{2\sqrt{2}\cdot x^+ - \left(\sqrt{2}-1\right)\cdot x^- + \left(\sqrt{2}+1\right)\cdot x^{--}}{2\sqrt{2}};$$
$$x_n = \frac{1}{2}\cdot x^+ + \left(\frac{1}{2\sqrt{2}} + \frac{1}{2}\right)\cdot x^- + \left(\frac{1}{2\sqrt{2}} - \frac{1}{2}\right)\cdot x^{--} = \frac{2\sqrt{2}\cdot x^+ + \left(\sqrt{2}+1\right)\cdot x^- - \left(\sqrt{2}-1\right)\cdot x^{--}}{2\sqrt{2}};$$
$$x_p = \left(-\frac{1}{\sqrt{2}}\right)\cdot x^+ + \frac{1}{2}\cdot x^- + \frac{1}{2}\cdot x^{--} = \frac{-2\cdot x^+ + \sqrt{2}\cdot x^- + \sqrt{2}\cdot x^{--}}{2\sqrt{2}}.$$

Thus a new co-ordinate system (x_m, x_n, x_p) is formed.

Let $\overline{x_m} = Mean(x_m), \overline{x_n} = Mean(x_n), \overline{x_p} = Mean(x_p)$ and $SD_1 = \sqrt{Var(x_m)}$,

$SD_2 = \sqrt{Var(x_n)}$, $SD_3 = \sqrt{Var(x_p)}$.

Finally, an ellipsoid centered at $(\overline{x_m}, \overline{x_n}, \overline{x_p})$ with three axes of length SD_1, SD_2 and SD_3 is fitted to the existing reconstructed phase space.

2.3. Average Mutual information [15]

Mutual information function can be used to determine the "optimal" value of the time delay for the state space reconstruction.

Suppose $\{x(t)\}_{t=1}^{N}$ is the given time series. The idea is that a good choice for the delay τ is one that, given the state of the system $x(t)$, provides maximum new information with measurement at $x(t+\tau)$. Average Mutual information, denoted by $I(\tau)$ is defined as

$$I(\tau) = \sum_{t=1}^{N-\tau} P\left[x(t), x(t+\tau)\right] \log\left(\frac{P\left[x(t), x(t+\tau)\right]}{P\left[x(t)\right] P\left[x(t+\tau)\right]}\right)$$

$[\tau = 1, 2, ..., N-1]$, where $P[\square]$ denotes the probability.

It was suggested in [15] that the value of time-delay, where $I(\tau)$ reaches its first minimum be used for the state space reconstruction.

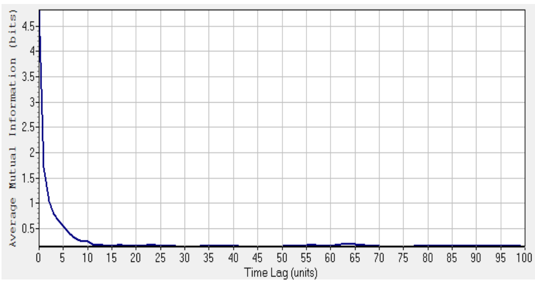

Figure 2: The plot of AMI versus time-delay that gives the suitable time-delay for the reconstruction of the phase space plot.

III. RESULT AND DISCUSSION

3.1. Independent Component Analysis (ICA) [1]

To remove the artifacts, if present in the recorded EEG signals ICA [1] is done on all of the signals. The ICA projections of the signals in each of the eight channels for one of the normal healthy subjects before listening to any music, is presented in figure.3. The same obtained for the same subject, when listening to music of our choice is shown by figure.4.

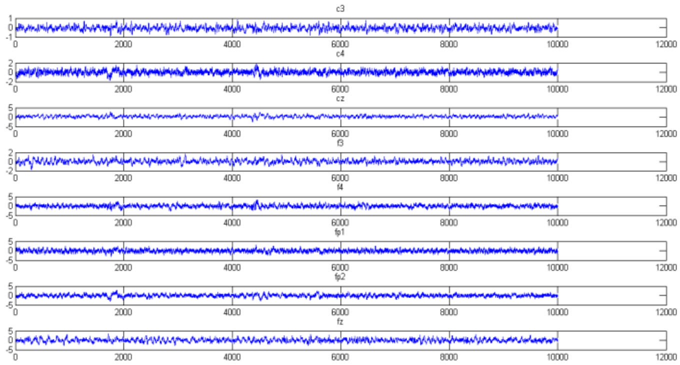

Figure 3: Eight components of the ICA projections of one of the subjects in pre-music state.

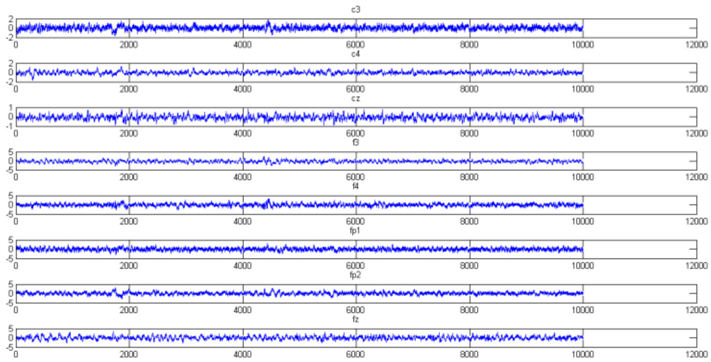

Figure 4: Eight components of the ICA projections of the subject, when listening to music.

3.2. Phase space reconstruction of EEG signals with suitable time-delay [14, 17]

The three dimensional phase space of each of the eight EEG signals recorded in eight channels for normal healthy subjects before listening to music is reconstructed with suitable time-delay obtained by the method of AMI [15]. One of them is presented in figure.5.

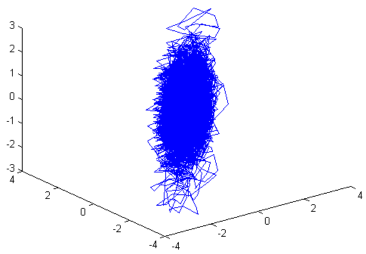

Figure 5: Reconstructed phase space of one of the eight EEG signals recorded in eight channels for normal healthy subjects before listening to music.

The reconstructed three dimensional phase space with suitable time-delay of one of the eight EEG signals recorded in eight channels for the same subject, when listening to music is given by figure.6.

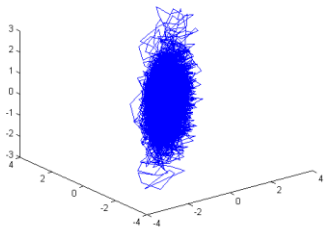

Figure 6: Reconstructed phase space of one of the eight EEG signals recorded in eight channels for the same subject, when listening to music.

3.3. Quantifications of the Reconstructed phase spaces [14, 17]

It is evident from figure.5 and figure.6 that both the phase spaces have a proper, dense attracting zone and the shape of the dense region is nearly elliptical. However, it is not possible to distinguish them on the basis of visual inspection. The quantification measure discussed in section IIB is thus applied and the results obtained are summarized in the following table:

Table 1: Results of quantifications by ellipsoid fit.

a1 before music					**a1 music**				
Ch.	**SD1**	**SD2**	**SD3**	**S_{avg}**	**Ch.**	**SD1**	**SD2**	**SD3**	**S_{avg}**
C3	0.3003371	0.2899594	0.2275324	0.2726097	C3	0.5057918	0.6197514	0.4265427	0.258681
C4	0.5064871	0.6202968	0.4285732	0.5184524	C4	0.3853002	0.4770878	0.2816575	0.1906743
Cz	0.319235	0.3686825	0.2908149	0.3262441	Cz	0.2854973	0.3174297	0.2484157	0.1418904
F3	0.9046974	1.0810506	0.7116867	0.8991449	F3	0.7446147	0.8993233	0.6855193	0.3882429
F4	0.5003533	0.5420484	0.4217577	0.4880531	F4	0.9036075	1.0797375	0.7106917	0.4490061
Fp1	1.1250148	1.1365194	0.547091	0.9362084	Fp1	1.1259778	1.1386213	0.5482634	0.4688104
Fp2	1.0810941	1.1080215	0.4436137	0.8775764	Fp2	1.0747818	1.101884	0.4405125	0.4361964
Fz	1.1799269	1.2243085	0.8423991	1.0822115	Fz	1.1796753	1.2277553	0.8447176	0.5420247
a2 before music					**a2 music**				
Ch.	**SD1**	**SD2**	**SD3**	**S_{avg}**	**Ch.**	**SD1**	**SD2**	**SD3**	**S_{avg}**
C3	0.5058216	0.6197949	0.4265761	0.5173975	C3	0.5058153	0.6197859	0.4265695	0.2586951
C4	0.2766866	0.3024487	0.2369855	0.2720403	C4	0.2767018	0.3024647	0.2369964	0.1360272
Cz	0.6971849	0.8044319	0.6247529	0.7087899	Cz	0.6971915	0.80444	0.6247596	0.3543985
F3	0.9042004	1.080103	0.7111197	0.8984744	F3	0.9041815	1.0801024	0.7111229	0.4492345
F4	0.5079869	0.5619238	0.4110205	0.4936437	F4	0.5079858	0.5619115	0.4110139	0.2468185
Fp1	1.1248062	1.1375177	0.5484304	0.9369181	Fp1	1.1247562	1.137485	0.5485158	0.4684595
Fp2	1.0800903	1.1066794	0.4411466	0.8759721	Fp2	1.0800827	1.1066456	0.4410094	0.4379563
Fz	1.1797715	1.2258658	0.8432892	1.0829755	Fz	1.1797564	1.2259572	0.8433402	0.541509
a3 before music					**a3 music**				
Ch.	**SD1**	**SD2**	**SD3**	**S_{avg}**	**Ch.**	**SD1**	**SD2**	**SD3**	**S_{avg}**
C3	0.5057888	0.619747	0.4265392	0.5173583	C3	0.3003268	0.2899456	0.2275216	0.136299
C4	0.2766939	0.3024561	0.2369898	0.2720466	C4	0.5064843	0.6202929	0.4285696	0.2592245
Cz	0.9036061	1.0417537	0.7035931	0.8829843	Cz	0.386685	0.4835619	0.286857	0.1928506
F3	0.9217742	1.0628801	0.7126348	0.8990964	F3	0.6600755	0.8222228	0.656106	0.3564007
F4	0.5209115	0.6481446	0.3779008	0.5156523	F4	0.7525015	0.9119866	0.6730846	0.3895955
Fp1	1.1168216	1.1334735	0.5525349	0.9342767	Fp1	1.1217485	1.1367677	0.5503292	0.4681409

Fp2	1.0776949	1.1079959	0.4372087	0.8742998	Fp2	1.0740159	1.1039429	0.4397323	0.4362819
Fz	1.1502997	1.2133811	0.8735436	1.0790748	Fz	1.180379	1.2290598	0.845976	0.5425691
a4 before music					**a4 music**				
Ch.	**SD1**	**SD2**	**SD3**	**S_{avg}**	**Ch.**	**SD1**	**SD2**	**SD3**	**S_{avg}**
C3	0.3003371	0.2899594	0.2275324	0.2726097	C3	0.3003366	0.2899587	0.2275319	0.1363045
C4	0.5064892	0.6202999	0.4285757	0.518455	C4	0.5064871	0.6202968	0.4285732	0.2592262
Cz	0.6977449	0.8058285	0.6258974	0.7098236	Cz	0.3866785	0.483553	0.2868595	0.1928485
F3	0.9217624	1.0628889	0.7126382	0.8990965	F3	0.5067257	0.5610988	0.4102603	0.2463475
F4	0.9035271	1.0793593	0.7104256	0.8977707	F4	0.752509	0.9119837	0.6730765	0.3895949
Fp1	1.127174	1.1389139	0.546994	0.937694	Fp1	1.1218715	1.1368444	0.5501943	0.4681517
Fp2	1.0776586	1.1047126	0.4431884	0.8751865	Fp2	1.0740114	1.1039547	0.4399247	0.4363151
Fz	1.1800135	1.2250365	0.8431212	1.0827237	Fz	1.1804099	1.2289196	0.8458938	0.5425372

It is evident from the above table that the quantifying parameter S_{avg}, which is the average of the length of the three axes of the fitted ellipsoid, can properly distinguish the two states, one before listening to music and the other listening to music. In fact, it is found that in all cases the value of S_{avg} for the subjects listening to music is less than the same for the subjects before listening to music. However, the change in S_{avg} value is prominent in case of frontal lobe channels (Fp1, Fp2, F1, Fz, F2), while it is not so significant for the mid portion of the brain (C1, C2, C3).

3.4. Topographical Scalp Map [1]

Topographical scalp maps explain the functions of different brain areas from the neurological point of view. The fixed scalp topographies give the projections of each component onto the scalp sensors. All scalp maps are shown individually scaled to increase colour contrast with polarities at their maximum projection, as indicated in the colour bar. The scalp maps obtained for the EEG signals recorded in eight channels for one of the subjects before music and when listening to music are presented in figure.7 and figure.8 respectively.

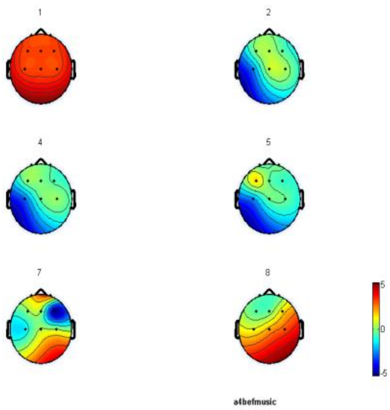

Figure 7: Eight stable components plotted in the form of topographical scalp map for a subject in pre-music condition**.**

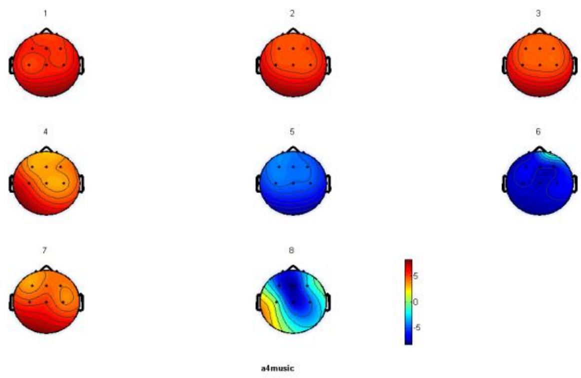

Figure 8: Eight stable components plotted in the form of topographical scalp map when the subjects listen to music.

It follows from the above two topographical scalp maps that the effect of music in CNS in positive sense is found for the EEG signals recorded in almost all of the frontal lobe channels. However, this effect is not prominent for the channels that are located at the mid portion of the brain.

IV. CONCLUSION

EEG can capture significant effect of music on mind. The mostly affected portion of the brain is its frontal lobe. The central lobe is also affected by music, but the effect is not as prominent as in the case of frontal lobe. The results of the present study tally with those obtained graphically by topographical scalp map. However, the present study is a pilot study restricted to a limited sample only. It is to be carried out on a larger sample.

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