

Brain Music System :Brain Music Therapy Based on Real-Time Sonified Brain Signals

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Abstract

The paper discusses a standardized therapeutic treatment using the Brain Music System, a system that uses Sonified Neurofeedback accurately and cost effectively to convert brainwaves into musical sound using Digital Signal Processing algorithms. A standard course of sonified neurofeedback therapy (for example 15 sessions), tailored specifically to individual patients suffering from a number of neurological conditions such as Autism Spectrum Disorder is a realistic possibility due to the inexpensive and portable nature of the system, and could be used both inside or even outside of a traditional clinical setting for subjects suffering from a wide array of mental and neurological conditions including Autism Spectrum Disorder. In a pilot study to test the algorithms and output of the Brain Music System, the distribution of the Alpha, Beta and Theta waves in normal subjects corresponds closely to that in published studies using standard high-end equipment (confined to expensive clinical setups). These results allows the Brain Music System to align its protocol to practice standards, and to better associate standard algorithmic tasks to each of the three mentioned brainwave types.

1 Introduction

Listening to music is a personal experience which is influenced by a variety of factors. Music and other mental activities share the same cognitive functions as well as operations. These other mental activities include among others language as a means of expression and communication. However, listening to music for the majority of people is mostly of a receptive nature. The arousing feeling by music and the appreciation of music are essentially the interaction of the musical piece with the emotional and mental status of the listener. Without the expression of this receptive process, exploration of its neuroanatomical substrate is difficult. Nevertheless, the interaction of music with the brain may be reflected in alterations in brain electrical activity, recorded by the electroencephalogram (EEG) as demonstrated by Satoshi et al. A brief exposure to music can lead to an instant improvement in spatial duty performance, correlating with alterations in the EEG power spectrum.

1.1 EEG Waves and Sound Waves

We know that “Sound is a regular mechanical vibration that travels through matter as a waveform” which exhibits all characteristics of longitudinal waves. (Kurtus). Sound waves with specific characteristics can be viewed as music. Alterations of ordinary sound in tone, note, time durations etc. create melody or music. The words of N’Diaye “a distributed network of brain areas has been repeatedly evidenced in timing tasks” identify musical touch of brain waves and activities. (N’Diaye, Garnero and Pouthas). Each state of brain is represented by certain waves called brain waves of which Gamma, Beta, Alpha, Theta and Delta are the recognized brain waves. Gamma waves (30 to 70 Hz) are produced while processing of various attended stimuli.... From an EEG point of view, they will be present mostly while a subject is awake, but they will always be supported by other waves in the beta, alpha, theta, or delta ranges. Usual considerations are given to main brain waves excluding supporting gamma waves. Brainwave activity tends to fall into four groups: beta, alpha, theta and delta. These categories are associated with the rapidity of oscillation (frequency) of brainwaves. It may be asked why usage of sound waves itself are adopted, rather than light or visual rays. This can be resolved by understanding that EEG signals can be easily represented by sound waves due to similarity of both in many of their characteristics. The selection of sound waves instead of light or visual rays is due to the properties of light itself. “Light is composed of transverse waves in an electromagnetic field....The denser the medium, the greater the speed of sound. The opposite is true of light.... Sound travels through all substances, but light cannot pass through opaque materials.” (Comparison of Light Waves with Sound Waves). The stated properties of light makes it inappropriate to be compared with EEG signals which are more alike sound waves.

1.2 Brain Structure and Music

It was important to identify the part of brain responsible for creating music. The two hemispheres make up major portion of brain , the right hemisphere is associated with creativity and the left hemisphere is associated with

logic abilities (Brain Structures and Their Functions). The functions of right and left hemispheres make it clear that both are involved while the brain creates music. “Accepted neurological theories suggest that the right hemisphere deals with special elements like pitch whereas the left is responsible for the structure and progress of the melody (Heslet, 2).” Studies of relations between neural regions and music (Levitin, 2006) illustrate the involvement of both hemispheres in creating music.

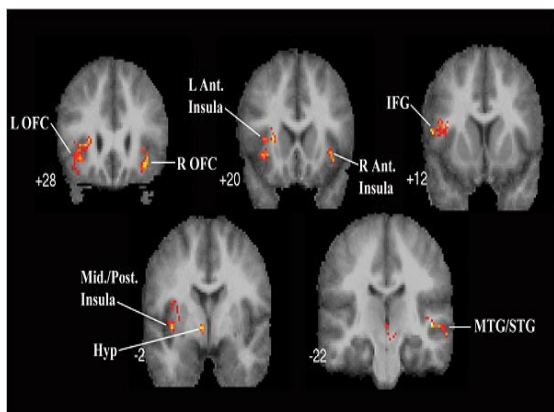


Figure 1.0 (Levitin, 2006)

“Images from an experiment to locate the neural regions of the brain involved in listening to music. Dr Levitin scanned the brains of 13 people as they listened to scrambled and unscrambled versions of a tune.” (Levitin, 2006)

Several studies have sought out the points on the brain linked to meditation or music. This research has shown the scope of meditating music for neurological treatment. “Activity in the left prefrontal cortex (the seat of positive emotions such as happiness) swamped activity in the right prefrontal (site of negative emotions and anxiety), something never before seen from purely mental activity.” (Meditation Alters Brain Structures). The linking of brain structuring to meditational music experienced is a realistic success for neurology.

1.3 Sonification of Neural Signals

There are various distinct processes involved in converting neural signals to sound signals or sonification of neural signals. It is a fact that “analyzing multichannel EEG signals using sounds seems a natural method: using a sonification of EEG signals... perceive simultaneously every channel, and analyze more tractably the time dynamics of the signals – hoping to gain new insights about the brain signals.” (Vialatte and Cichocki). The sonification of neural signals is done in various steps having separate set of procedures. This process will consist of the following stages:

1. Data acquisition
2. Data pre-processing
3. The creation of visual and

sonic map

4. Visualization and sonification

Usually, Data acquisition process is defined as the phase of data handling that begins with the sensing of variables and ends with a magnetic recording or other record of raw data.

The data recorded then undergoes preprocessing during data preprocessing stage. Data preprocessing describes any type of processing performed on raw data to prepare it for another processing procedure. In sonification activity, data preprocessing is done to get relevant input to represent data before creating the actual visual and sonification output. Visualization can be defined as a tool or method for interpreting image data fed into a computer and for generating images from complex multi-dimensional data sets which is responsible for representing recorded data into visual patterns. Visualization is accompanied by sonification which “is the transformation of data relations into perceived relations in an acoustic signal for the purposes of facilitating communication or interpretation” where in our application music is produced at the end. (Hermann).

Various experiments were carried out for deducing some efficient approach for sonification process. Researchers from Georgia Institute of Technology in Atlanta were among those. They were in search of “aesthetically satisfying and educationally useful representation of complex datasets of neural activity through hands-on interaction” sonification procedures. They succeeded in it by their reach to introduce the triumph project on “framework of the “Fish and Chips” project (in collaboration with the Symbiotic Research Group, Perth, Australia), where they sonified low resolution audio signal from an in-vitro culture of fish neural cells.” (Weinberg and Thatcher 246).

3 Impacts of Neuro feedback Music

“Neuro feedback training is brainwave biofeedback.” (Hammond). The brain waves are fed back to brain cells so that it helps in attaining a pleasant frequency of brain activity. This method can be viewed as “exercising or doing physical therapy with the brain, enhancing cognitive flexibility and control.” (Hammond). By doing this, variations to brain waves can be achieved. But, it is a fact that brain waves are responsible for various activities and moods of an individual. So, through keen analysis and investigation, it becomes possible to change a mood to another by employing neuro feedback. There is extensive experimentation carried out to analyse impacts of Neuro feedback Music. Department of Cognitive Neuroscience and Behaviour within the Faculty of Medicine at Imperial College in London, is an association that explored on the matter through their experiments. They mainly relied on two separate experiments they conducted. “In experiment 1, a group of students was trained on the SMR, Beta1, and a/t protocols and performance changes were compared to a no-training control group and a group receiving additional interventions.” (Egner and Gruzeliar 1221). The variations in performance brought about by three

different neuro feedback protocols were evaluated. “In experiment 2, different neuro feedback protocols were trained in separate groups and performance changes were contrasted with comparison groups undergoing alternative interventions.” (Egner and Gruzelier 1221-1222). Both the experiments dug out the positive impacts of neuro feedback.

4 Brain Music System

The Brain Music System delivers electroencephalographic data as modulated MIDI. It is similar to the brain-computer interface (BCI) system created and amply documented by Professor Eduardo Miranda, but runs optimally even on a 2 channel EEG since it does not depend on the collecting end for the processing functions but uses computational methods which can be supported by regular modern office computers (making its uses different and more accessible due to its cheaper running costs).

4.1 Brain Waves Conversion

A number of methods are available to be employed in analysing the various factors involved in transforming brain waves to music. Power spectrum analysis (PSA) and Discrete Fourier Transform (DFT) techniques are suitable in our context. “The Fourier Transform of the Auto correlation Function is the Power Spectrum.” (Nyack). Power spectrum is used in analysing various images which finds application in this investigation as well. The first step in PSA is to Fourier transform the image $I(x, y)$ and calculates the square modulus of the FT to generate the power spectrum, $p(u, v)$.

$$p(u,v) = |FT[I(x, y)]|^2$$

In order for us to obtain the active PSA, the FT array is rearranged according to frequencies in a way that the zero frequency is in the centre of the array, the 1st quadrant is in the upper right, the second in the upper left, etc. .

The resulting array was later converted to get values from 1.0 to 10.0 whose logarithm to base 10 is obtained. The array obtained was then used to obtain the required equivalent; here brain waves underwent power spectrum analysis to get music equivalent for them. Discrete Fourier Transform (DFT) is another procedure carried out. “The Discrete Fourier Transform (DFT) allows the computation of spectra from discrete-time data... in discrete-time we can exactly calculate spectra.” (Johnson). This definition itself explains the relevance of this method in our analysis of brain waves. Accurate computation is significant for conversion of brain waves to music waves so that least redundancies result.

4.2 System Design

The system used in the current project is built on the basis of the LORETA algorithm discussed about by Filatriau et al. (2007, p. 2). In more detail, the system design includes three major stages, i. e. EEG collection, digital signal processing, and MIDI representation. Graphically, the system design progress is identified in figure 2.0

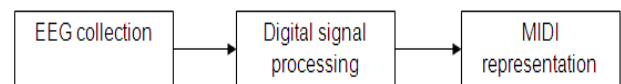


Figure 4.0

This system design permits collection of the EEG waves of the participants’ brains with the help of electrodes placed on their both hemispheres. Next, the data collected is processed with the help of the LORETA algorithm (Filatriau et al., 2007, p. 2), and after this the system produces MIDI files on the basis of analogies between the qualities of EEG waves and specific musical notes. As seen from the above statement (Filatriau et al., 2007, p. 2), the LORETA algorithm plays a crucial role in the operation of the system design. This algorithm is based on four major criteria defined and calculated as first, it is necessary to measure the potential of EEG wave occurrence, Φ . Second, the value of the sources producing those EEG waves, ϕ , is measured. The third and the fourth criteria that help in estimating the second point are the lead field matrix, G , and the rate of additional noise, η (Filatriau et al., 2007, p. 2):

$$\Phi = G \phi + \eta$$

At the same time, Ito et al. (2006, p. 1153) propose a slightly different formula that includes the role of mental change in sound stimulation, S , and the additional noise, N , for the calculation of Y , the time series data:

$$Y = S + N$$

In any case, both formulae require additional calculations, and Filatriau et al. (2007, p. 2) provide rationale for them, arguing that the bayesian formalism fits the goal of defining the value of the sources producing those EEG waves from the above formula. So, the design system discussed here uses the following formula to obtain the final data that are later sent to the sound synthesis module (Filatriau et al., 2007, p. 2)

$$P(\phi/\Phi) = P(\Phi/\phi)P(\phi) / P(\Phi)$$

The data obtained through the above formula are ready for processing with the help of the LORETA algorithm

that includes four stages:

1. Sending the data to the sound synthesis module;
2. Associating the brain zones with cognition, visualization, and movements;
3. Creation of dipoles from the calculated data;
4. Computing the dipoles and using them as features for creating the respective MIDI files

Thus, the use of the LORETA algorithm is the basis on which the performance of the discussed system design is founded and the scheme described in figure 4.1 becomes possible with the use of this cheaper technology :

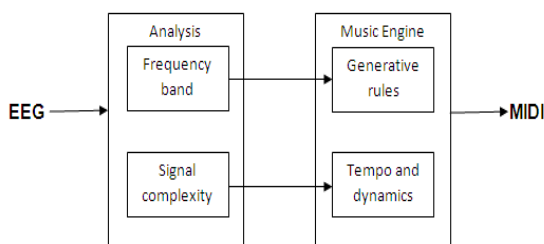


Figure 4.1(Filatrou et al., 2007)

At this point, the system's design performance follows this scheme and uses the LORETA algorithm to enable the researchers to convert the EEG waves into MIDI music files.

4.3 Musical Engine

The transformation of Brainwaves into Sound (Sonification of Neural Signals) is the major task to be tackled by the Brain Music System . The topic itself is arguable and literature does leave a lot of open ended questions as to which methodology to adopt and the success that such algorithmic solutions might have ,

There are various distinct processes involved in converting neural signals to sound signals . It is a fact that "analyzing multichannel EEG signals using sounds seems a natural method: using a sonification of EEG signals.... perceive simultaneously every channel, and analyze more tractably the time dynamics of the signals - hoping to gain new insights about the brain signals." (Vialatte and Cichocki)..

This topic is mainly discussed by 2 peers of neuroscientists that both focus on their distinct interests .1) The Engineering neuroscientists ,2) The Biological neuroscientists . The first peer is more interested in obtaining a functional system that functions in a way that is functional but not necessarily compliant perfectly to what happens during the Brainwave

formation , whilst the 2nd peer is more focused on to representing all the processes that occur during the brainwave formation , in most cases the problem with latter ground being that the designed systems "lack stability " (Miranda 2003)

Miranda and Hofstadter argues that the biological representation of music needs to be linked to 3 important features , these being the timbre , pitch and tempo (Miranda 2003). We managed to build our system basing ourselves on this concept and keeping in mind the power limitation that our low-end system got (including the fact that the collected EEG data are only collected from limited parts of the scalp and then augmented)

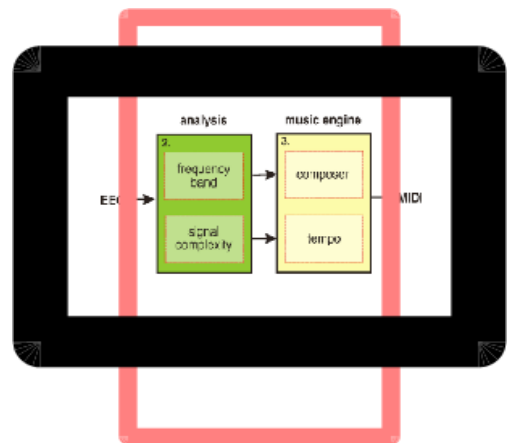


Figure 4.2 illustrates the adapted musical engine and the analysis section adopted by the BMS

The Brain Music System's musical engine is built on the theoretical works by Hofstadter (Hofstadter, K , 2009) and Miranda (Miranda 2003) and adapted and simplified in order to work with a 2 channel EEG , allowing the frequency bands emitted by the different brainwave types to control a purpose built Generative System with the signal complexity controlling the music interpretation .The mathematical formula adopted in this case is

$$\text{Difference in Signal} = \text{Difference in tempo} + \text{Musical Grammar}$$

4.4 Musical Generative Rules

With the system being an "online" one it is difficult to be able to gather the initial musical representation (as the brain signals will need to be stimulated in order to start reacting and sending synchronized signals for processing) . The BMS musical engine does generate computer generated music (not biological music) for the first 2.0 seconds . During this short time frame the music generated by the system does not hold any biological importance and just after that time frame. After that , the system will use the N100 rule (a standard

EEG collection rule that enables a particular collecting algorithm), with a data collection sample being taken every 80-120 milliseconds as a result of the previous musical representation. Each representation will serve as an auditory stimulus triggering the response used for the next data collection point.

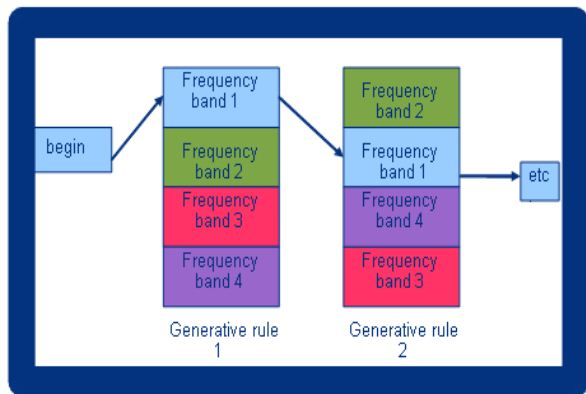


Figure 4.3 illustrates the generative system's sample collection and processing (Miranda, 2003)

5 Brain Music Therapy

Neurological studies show that temporary co-ordination between different and often distant neural assemblies play a vital role in higher cognitive phenomena. Multiple cortical regions may become co-active during cognitive tasks and also functionally interdependent. For instance, most of information processing most likely takes place in the rear brain regions containing the visual cortex when eyes are open, whereas the principal processing occurs in the frontal brain when eyes are closed (Bhattacharya et al.). It has been shown that listening to music helps to arrange the cortical patterns so that they may not wash out at the expense of other pattern development functions, and particularly, the right hemisphere processes, music is important for excitation and priming of the common repertoire and orderly flow of the cortical patterns responsible for higher brain functions, and helps in the enhancement and facilitation of the cortical symmetry operations among the inherent patterns. "The cortex's response to music can be thought as the 'Rosetta Stone' for the 'code' or internal language of higher brain function". (Rauscher et al)

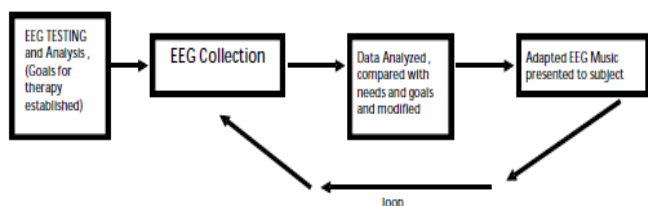


Figure 1. Brain Music Therapy Diagram

By analyzing the components of an EEG output; namely alpha, Beta, Delta, and Theta waves, a system can be developed to convert these waves into music by a number of computational methods (modified LORETA in the case of Brain Music System). Various studies show that alteration of this process and presenting to an altered musical representation to the subject in a loop form can help in leveling the brainwaves as a structured type of therapy as shown in "Brain Music Therapy diagram". This type of therapeutic adaptation can be successfully applied to a range of clinical conditions such as epilepsy, attention deficit hyperactivity disorder and the locked-in syndrome, and to optimise performance in healthy subjects. "In healthy individuals, neurofeedback has been shown to improve artistry in music students and dance performance". (Egner et al.)

6 Pilot Study

The results for ten subjects undergoing a regular recording of 15 second active blocks using the Brain Music System (as described by Attard Trevisan and Jones) with a Pendent EEG collecting device were collected and presented in the table below. The four different brain waves i.e., Alpha, Beta, Delta, and Theta were color-coded as green, red, yellow, and blue respectively. The table below presents the average values of the four forms of EEG waves for ten subjects undergoing 15 seconds of useful recording blocks.

Objectives of the Study

1. Check if there are common patterns and levels of Brainwave activity in EEG outputs which can be optimally used in the musical process of the Brain Music System
2. Compare Output Brainwave levels by the "modified LORETA" with published literature studies

6 Results

EEG	subject 1	subject 2	subject 3	subject 4	subject 5	subject 6	subject 7	subject 8	subject 9	subject 10
Alpha	3.37	3.36	3.29	3.06	3.23	2.88	2.95	2.13	3.52	3.22
Beta	5	4.91	5.21	4.64	4.95	5.03	5.09	5.09	5.02	4.97
Delta	2.89	2.83	2.61	2.42	2.41	2.45	2.93	2.61	2.23	2.88
Theta	3.76	3.34	3.45	3.94	3.59	3.34	3.83	3.97	3.83	4.07

Table 1: Results Table

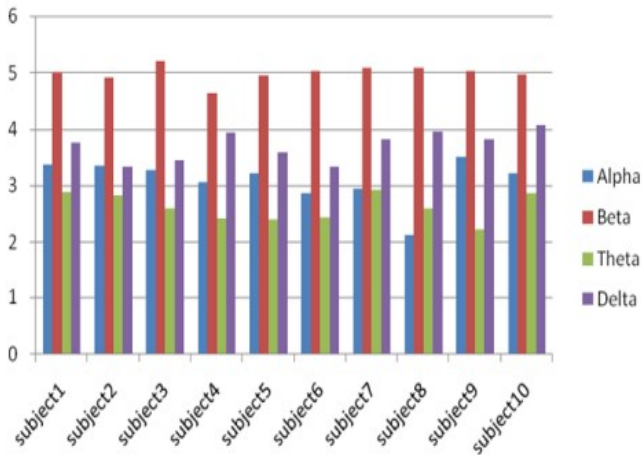


Figure 6.0 : Band Frequency Graph 1

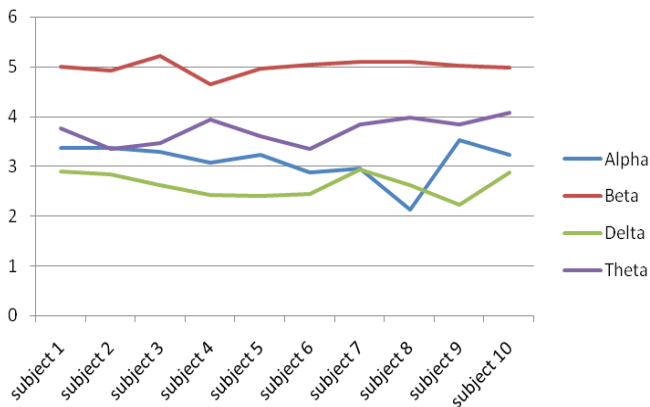


Figure 6.1: Band Frequency Graph 2

The linear Band Frequency Graph 2 shows that throughout the analysis of brain waves, the Beta wave presented as the most significant form of brain with the highest mean wave followed by Theta and Alpha waves respectively. The least form of brain

wave was the Delta wave which had consistently lower figures in most of the subjects.

According to the linear graph, Delta is statistically insignificant in this study in awake subjects and is thus deemed not relevant to include it. The means of the relevant bands recorded in the table above were analyzed and the results presented as Band Frequency Graph 1 and Band Frequency Graph 2. They clearly indicate which of the bands had the most stable output, in order to further confirm which bands should be given priority for its role in the system. The results show that the Beta waves have the most stable output, followed by the Alpha and the Theta waves.

Throughout the analysis of brain waves, the Beta wave presented as the most significant form of wave with the highest mean wave followed by Theta and Alpha waves respectively. The least form of brain wave was the Delta

wave which since the experiment needed subjects to remain assertive had consistently lower figures in each of the ten subjects .

In this study, the Beta wave provides the best avenue for the study of the interaction between a musical piece and the brain. The results indicate that the left frontal regions of the brain are more involved in processing as shown by the higher mean of the Beta range. The right hemisphere may also be increasingly engaged with higher frequencies of the Beta wave. The Beta range can be used to indicate the part of brain that is involved in processing a particular kind of music. The Theta band showed coherence in pattern in the ten subjects and that coherence increased symmetrically, except in just few cases. The Alpha band was characterized by more coherence decreases and extending over longer distances than other bands.

The interpretation of increases in coherence advances the theory of increasing cooperation between two regions of the brain. Decreases on the other hand indicate that mental process under investigation requires lower collaboration between the two regions in order to perform optimally.

Changes in gravity centers of coherence clearly indicate particular significance of the regions involved for processing information and how other cortical regions are involved. In the case of decreases, the region concerned may decouple from other cortical regions. Visual data processing studies have substantiated this view and can be applied to the alpha band as is the case in this study. In other words, attentive listening needs increased attention and suspends the freely floating thinking that could be assumed to take place upon EEG at rest; the two processes lead to parcellation of the cortex in that frequency band that is concerned in general attention processes. Moreover, it could also be that cortical coherence is reduced for an increased information exchange with subcortical sites. “As far as the behaviour in the Theta band is concerned, it was found to be fairly characteristic in processes where memory takes a momentous part (in this case, the violoncellist knew the piece by heart and thus, mentally anticipated every single phrase)” (Hellmuth et al.). Conversely, emotion is also reflected by coherence. Machleidt et al shows that different bands may be adjacent to different domains of sensory signal processing. It is worthy noting that the extensive twisting of the cortex and the electrical conductivities of tissue layers may cause the electric features of the surface EEG not to be displayed fully. However, characteristic coherence patterns can be found.

7 Conclusion

From this study, common patterns and levels of Brainwave activity in EEG outputs can be optimally used in the musical process of the Brain Music System. The stratification of the different elements of the EEG can help to find out which band is most significant in the musical process of the Brain Music System . The ability of having a standard protocol for a “Brain Music Therapy” program developed on the patient’s

individual needs while rehabilitating from a number of Neurological conditions has been eased and is now possible without incurring excessive clinical expenses. Another area of utilization of such a structured therapy is rehabilitation. People suffering from paralysis and diseases of the degenerative nervous system and who cannot effectively communicate with the outside world without the help of prosthetic devices can benefit from these findings.

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