Spectral Analysis Of EEG Signals During Hypnosis

S. Deivanayagi
Biomedical Engineering Group
Department of Applied Mechanics
Indian Institute of Technology Madras
Chennai India 600036

M. Manivannan
Biomedical Engineering Group
Department of Applied Mechanics
Indian Institute of Technology Madras
Chennai India 600036
mani@iitm.ac.in

Peter Fernandez
Psycholab, Porur
Chennai, India

Abstract

Although Hypnotherapy is a powerful alternative for an array of neurological disorders, patients should be willing to be hypnotized and convinced that hypnosis works. For the successful treatment, it is absolutely essential for the hypnotherapists to ascertain that the patient is properly hypnotized, and therefore require a reliable method to find the mental state of the patient. Even among the hypnotic researchers, there is no consensus on what the reliable metric to use for tracking the mental status of the patients. In this paper we present a reliable method we developed. We designed a portable EEG amplifier to acquire the brain signal with high gain, and high accuracy. The response of the EEG signal before, during, and after hypnosis is studied for 10 subjects. The spectral analysis of EEG during hypnosis shows the frequency bands in theta and alpha range. During hypnosis all the subject's frequencies consistently fall in the higher theta2 and smaller alpha1 band of frequencies.

Keywords: Hypnotherapy, EEG Amplifier Design, Spectral Analysis. Alternative Medicine.

1. Introduction

Hypnotherapy is becoming a respectable alternative for an array of clinical and social conditions. In modern clinical practice hypnotherapy gives solutions to the neurological disorders like Schizophrenia, Stroke, Cerebral Palsy, Parkinson's diseases, Epilepsy, Meningitis, Paralysis, headaches and many other psycho-physiological diseases. Hypnotherapy is considered to be safe for anyone. However, the treatment is effective only when the patient is willing to be hypnotized and convinced that hypnosis works. It is absolutely essential for the hypnotherapists to ascertain whether the patient is properly hypnotized or not during the treatment. Although the hypnotherapists know, in many instances, the mental state of their patients during hypnosis using many visible cues that the patients exhibit, we require a reliable method to find the mental state. Among the hypnotic researchers, there is no consensus on what the reliable metric to use for tracking the mental status of the patients. In this paper we present a spectral analysis technique based on EEG signals to monitor the mental status of the patients during hypnosis.

Paper Identification Number: OCT07-11
This peer-reviewed journal paper has been published by the Pentagram Research Centre (P) Limited. Responsibility of contents of this paper rests upon the authors and not upon Pentagram Research Centre (P) Limited. Copies can be obtained from the company for a cost.

In section two, the detail of the typical hypnotic procedure is given along with the theory of hypnosis. In section three we elaborate on the related works in finding a reliable method of tracking mental status. In section four we present our experiments and our technique to analyze the EEG data. In section five, we present our results and conclude that the theta power is a reliable method for our purpose.

2. Review of Metrics of Hypnotic State

Among the hypnotic researchers, there is no consensus on what the reliable metric to track the mental status of the patients. In a very recent work in 1998 by De Pascalis et.a.l, EEG activity and heart rate during recall of emotional events in hypnosis were investigated [2]. Recordings were also obtained during three eyes-open and eyes-closed baseline periods: (1) waking rest; (2) early-rest in hypnosis (just after the hypnotic induction); (3) late-rest hypnosis (at the end of hypnotic condition). EEG was recorded at frontal (F3, F4), central (C3, C4), and posterior sites (middle of O1-P3-T5 and O2-P4-T6 triangles). Using log transform of mean spectral amplitude, eight EEG frequency bands (4-44 Hz) were evaluated. High hypnotizable subjects, as compared to the lows, produced higher theta1 amplitude (4-6 Hz) across both left- and right-frontal and right-posterior areas. These subjects also produced smaller alpha1 amplitude (8.25-10 Hz) over both left and right frontal recording sites [2]. EEG evaluations were done by Fast-Fourier spectral analyses during the following conditions: waking-rest in eyes-open and eyes-closed condition; early, middle, and late phases of hypnotic induction; rest-hypnosis in eyes closed condition; hypnotic dream and age regression were discussed in De Pascalis.V (1993). With posterior scalp recordings, during hypnotic dream and age regression, high hypnotizables displayed, as compared with the rest-hypnosis condition, a decrease in alpha 1 and alpha 2 amplitudes. According to De Pascalis theta power was never a predictor of hypnotic susceptibility. But he itself disproved it in 1998 paper [2]. The comparison has been done between the low and highly hypnotizable subjects [1].

Similar problem has been addressed by Sabourin et. al. But they claimed that mean alpha power was never a predictor of hypnotic susceptibility instead of theta power as concluded by De Pascalis et al. They screened 12 high and 12 low hypnotizable subjects. He has quoted the same as De Pascalis et.al. that during hypnosis the frequency band falls in the theta band. But there is no main effect for or interactions between waking/hypnosis and hypnotic level were found for coherence between derivations or maximum spectral power within theta, alpha and beta EEG bands. Hypnotizable subjects generated theta power at all occipital, central and frontal locations in conditions of waking and hypnosis [9].

Joel F. Lubar1 et al (1991) studied that if there were differences between high and low hypnotic susceptible subjects based upon fast Fourier power spectral analysis of the EEG recorded both before and during hypnotic tasks from frontal-temporal and occipital-parietal locations. They obtained some significant differences based upon EEG recording electrode location, EEG frequency within six different frequency domains, and hypnotic tasks. However, no main effect differences were obtained based upon hypnotic susceptibility. They conclude that placement of electrode is very important while acquiring the signal [4].

In a paper by Nancy et al, the EEG measures described high- and low-hypnotizable participants in 1) initial baseline period 2) baselines preceding and following a standard hypnotic induction and 3) during the induction. During the actual hypnotic induction, theta power significantly increased in the more posterior areas of the cortex, whereas alpha activity increased across all sites (frontal, central and posterior) [6].

De Pascalis (1998) et al and Toshiaki et al (2001) they discussed the emotional states induced by hypnosis-based suggestions. Toshiaki et al analyzed nineteen channel eyes-closed EEG (Source localization) using FFT approximation and LORETA (low resolution electromagnetic tomography) and global test were taken during two emotional states after induction of light hypnosis, anxiety and then relaxation was suggested using a standardized text. The beta2 has been analyzed in the emotional states. Whereas De Pascalis discussed the emotional states (induced both happiness and sadness), concluded that 40 Hz frequency occurs during the emotional induction [12].

Tebecis (1975) studied the EEG during the transcendental meditation and he compared with the stage of hypnosis. There is no consistent difference between meditation and hypnosis group, although trends towards increased theta and decreased beta activity during meditation were apparent. The biggest differences in mean EEG parameters were between subject groups. The group of meditators exhibited significantly more theta activity. The EEG characteristics of the group of meditators were similar to those of a group of subjects experienced in self-hypnosis. He concluded that EEG gradually decreases over weeks and months [11].

3. Methodology

To acquire the brain signal, a high gain, accurate and ease-of-use (portable) biopotential amplifier is carefully designed using high precision instrumentation amplifier.

In this section, the specifications of the set up are given. The gain of the preamplifier is set to 14. The gain of main amplifier and the low pass filter is set to 200 and 6 respectively. The total gain of the bio-amplifier circuit is 20000. The cut-off frequency of the LPF is 55Hz and that of HPF is 0.16 Hz.

An off the shelf 2 stage IA, INA114 is used as preamplifier. The gain of this preamplifier is kept low to prevent saturation from DC potentials from electrodes and skin potentials. Noise performance is crucial in our design because scalp electrodes couple brain waves of only a few microvolts to the amplifier. Noise specification over our bandwidth (0.1 – 100 Hz) and source resistance range (10.0-100KΩ) of the amplifier is superior. The common mode rejection of the amplifier is typically 100 dB. The gain of preamplifier G for the values of resistors RG1 = RG2 = 1.8KΩ is approximately 15.

A first order high pass filter with cut off frequency (0.15 Hz) in cascade with the preamplifier ensures the removal of DC potentials. The frequency of the interested signal lies between 0.1 and 55Hz.

The main amplifier gets the signal from the high pass filter and amplifies with the desired gain. It is implemented with TL084 Quad JFET General-Purpose Operational Amplifier. The amplifier is used as a non-inverting amplifier, because this configuration has input impedance compared to the inverting amplifier, beside the obvious reason of not providing a 180˚ phase shift. The gain can be varied from 15 to 330 provides the major portion of the gain.

Isolation amplifier is used to break ground loops or to eliminate source ground and to provide an interface between PC and the biopotential amplifier, which is in physical contact with the patient. A Texas Instruments, ISO124 isolation amplifier with very low barrier capacitance (2pf) and isolation between the amplifier common and PC ground is used. The amplifier is powered by batteries.

A third-order anti-alias filter with cut-off frequency of 97 Hz and a gain of 6, band limits the signal and provides the final amplification. It is designed to have linear phase. The linear phase is important, since such a filter provides constant group delay to the signals in the pass band. The filter used has a response, which is a compromise between Bessel, and Butterworth filters.

3.1. EEG Signal Acquisition

In this work, we choose 8 right-handed subjects between 27 to 35 years of age, among the 8 subjects three are female and 5 are male subjects. The subjects were all volunteers. The EEG data is acquired while the subject is undergoing Hypnosis, who is hypnotized by a psychotherapist for 5 minutes. Shielded electrodes of standard size disc type Ag-AgCl electrodes are used to acquire the EEG signal. Following 10 -20 convention for electrode placement the first channel electrodes are placed on frontal cortex (F3) and other is on left earlobe (A1). The second channel electrodes are placed on the central cortex (C3) and on the right ear lobe (A2). The third pair of electrodes is placed over the centre of P3, O1 and T5 and the reference at forehead (FPZ).

An analog-to-digital converter PMD-1208FS DAQ card was used to acquire the signal at a sampling rate of 256 Hz. So, we obtain 76800 samples per channel. The PMD DAQ card does not perform simultaneous A/d conversion on the five channels. Instead, the 5 channels are multiplexed to a single A/D converter internally. Hence, there is a time lag between different channels in the (pseudo) simultaneous sampling. The voltage range of the A/D converter is ± 5V. The digitized data stored in the computer memory for later processing.

The necessary software for acquiring the EEG signal using 12 bit ADC (PMD-1208FS) is developed in Visual C++ and the signals are recorded at frontal (F3), Central (C3) and posterior site (middle of O1-P3-T5 triangle). EEG recording was obtained during three baseline periods: (1) waking rest (before hypnosis) (2) During hypnosis (3) early-rest in hypnosis (just after hypnosis).

3.2. EEG Signal Analysis

The data is continuously acquired for 300s at 1000 samples per second. The epochs are windowed using rectangular window and then passed through a filter, a band pass filter (0.5 to 40 Hz). A 2048-point FFT is performed on the filtered signal to get the frequency spectrum. A resolution of nearly 0.256 Hz is used in the present analysis. Higher resolutions can be obtained by changing the epoch length. [10]. Data analysis involves digital low pass filtering and spectral estimation using Fast Fourier Transform (FFT). The data are filtered with a digital FIR band pass filter. The upper and lower cutoff frequencies are 0.5 Hz and 40 Hz respectively. The order of the filter is 4. FIR filter is preferred over IIR filter for the following reasons. First, FIR filter offers constant group delay (i.e. linear phase) throughout the frequency spectrum. Second, it gives complete stability at all frequencies regardless of the size of the filter. Filter algorithm is implemented in MATLAB programming environment. The data is stored in computer memory. To get the filtered output, the data are convolved with the filter coefficients. The filtered data are stored in computer memory for further processing. The aim of signal processing is to extract the frequency component of the EEG signal. When a person (subject) is undergoing hypnosis, the frequency should fall in the higher theta (6-8Hz) and lower alpha (8-10Hz) waves. To extract the particular frequency feature, based on the maximum amplitude, the data points are transformed to frequency domain. This is done by performing Fast Fourier Transform (FFT) of the filtered data. A 1024 point FFT (n-FFT) is performed for each frame of the filtered data. The output of the FFT gives the power spectral values. The frequency resolution (FR) is given by [8]

$$FR = \frac{f_s}{LU}$$

where f_s is the sampling frequency, L is the recording length and U is a factor dependent on the type of the window used.
As seen from the above equation, resolution is inversely proportional to L; hence, high resolution is obtained at the cost of lengthy recording times.

4. Results and Discussion

The response of the EEG signal before, during and after hypnosis is studied for 10 subjects. Among 10 subjects, the responses of 8 subjects were good which is tabulated in the Table 1. There is a peak, which falls in higher theta2 frequency of EEG signal frequency band. The response is very clear and the frequency falls in the expected range. There is a peak at 9.0 Hz of subject 6, which falls in smaller alpha1 frequency shows that the expected response is obtained. Subject 5 is not hypnotized since his frequency does not fall in the expected frequency range. From the table 1 we can conclude that during hypnosis all the subject's (except subject 5) frequencies fall in the higher theta2 and smaller alpha1 band of frequencies. Before hypnosis (waking rest state) almost all subject's frequencies falls in the band of alpha range. After hypnosis (early-rest in hypnosis) the frequencies of subjects 1, 2, 4, 5, 6, 7 falls in alpha2 range which concludes that they are bit drowsy not in hypnosis state as discussed earlier.

Table 1: Offline analysis of EEG signals before, during and after hypnosis (Waking rest, during and early-rest in hypnosis states)

Subjects	Before			During			After		
	F	C	P	F	C	P	F	C	P
1	10	10.2	10.2	7.7	7.7	10	10.7	10.7	8.5
2	8.0	34.2	12	7.7	7.5	7.7	11.2	11.2	11.0
3	8.2	8.25	8.25	7.7	8.7	8.7	7.75	7.7	7.7
4	8.5	9.0	8	7.7	7.7	9.2	9.0	9.5	7.5
5	10.7	38.2	10.7	11	11	9.0	10.7	10.7	8.7
6	7.7	8.0	10.0	6.7	6.7	9.0	8.7	8.2	8.5
7	8.2	9.75	9.75	7.7	9.2	9.5	9.0	9.5	7.5
8	10	10.2	9.5	8.7	8.7	9.5	2.2	2.0	1.2

But subject 3 does not come out of the hypnotic state is confirmed from the frequencies that was obtained after hypnosis. One more peculiar case from the above discussed subjects was subject 8 whose frequencies after hypnosis falls in delta, which shows that the subject has gone to deep, sleep state. The tabular column gives all the details about the response of 8 subjects before, during and after hypnosis. Figure 1 shows the bar chart of the response that is discussed in table 1. The power spectrum of some subjects is shown in figure 2 to 9.

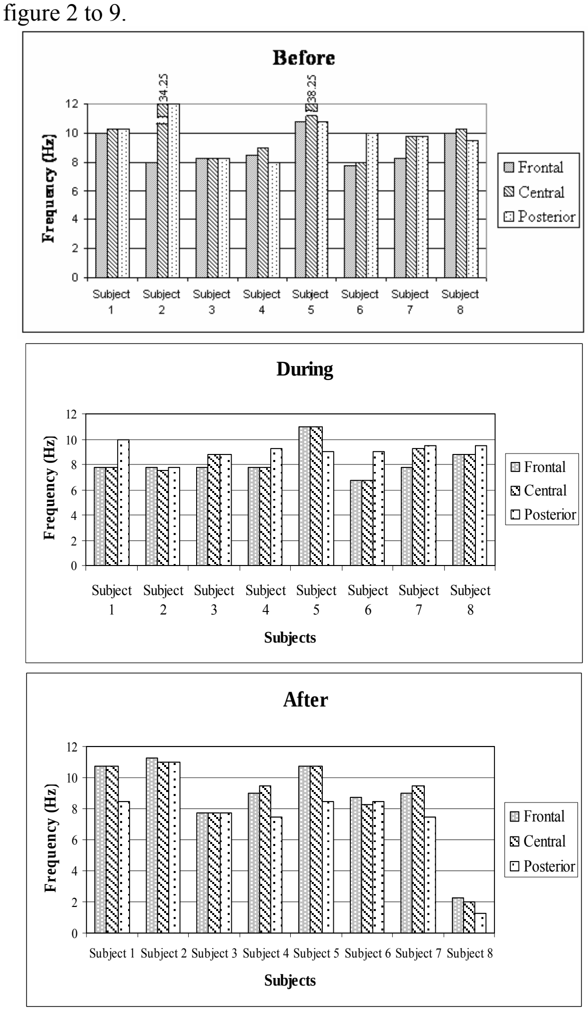


Figure 1: Frequency Response of each region of 8 subjects a) before hypnosis b) during hypnosis c) after hypnosis

The frequency response of each region (frontal, central, and posterior) of subject 3 before, during and after hypnosis is shown in Figure 2. It confirms that during hypnosis the frequency falls in the range of higher theta2 and lower alpha1.

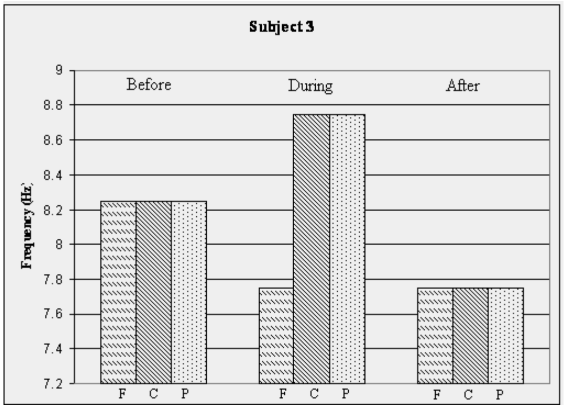
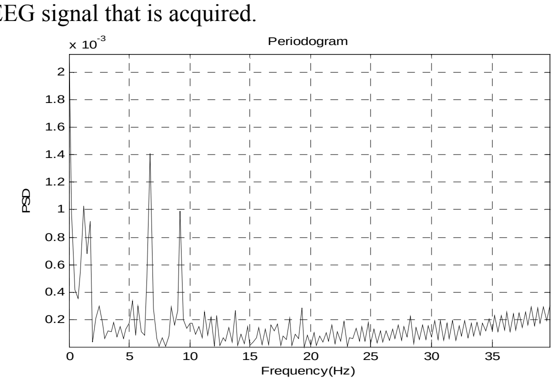
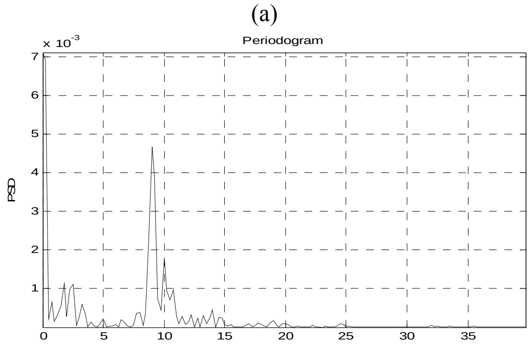


Figure 2 Frequency response of each region of subject 3 before, during and after hypnosis

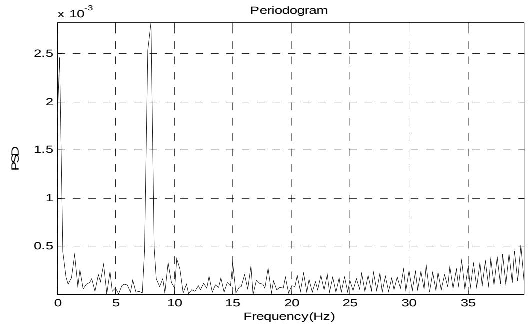
Figure 3 a and b shows the power spectrum of the EEG signal that is acquired during hypnosis from the frontal and central region of the left hemisphere respectively. The peak occurs at 6.75 Hz that falls in the higher theta2 (6 -8 Hz) in frontal and at 6.75 Hz and 9.25 Hz, which falls in both higher theta2 (6 -8 Hz) and smaller alpha1 (8-10 Hz) in the central respectively. Figure 5 shows the power spectrum of the EEG signal that is acquired.



(a)

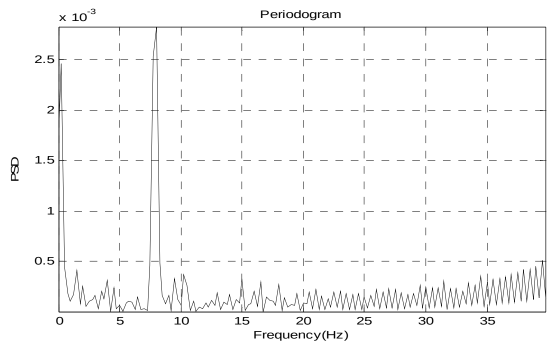


(b)

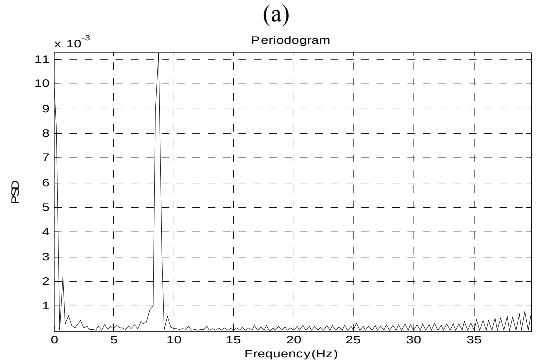


(c)

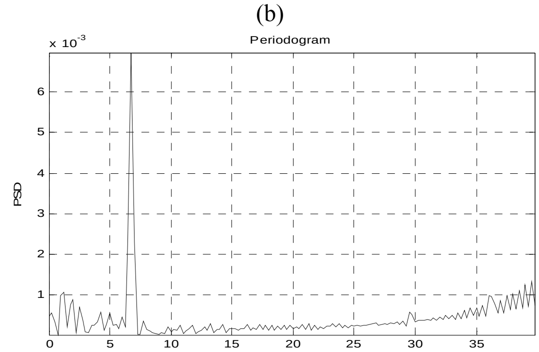
Figure 3: Power spectrum of EEG signal during hypnosis from a) central (C3) b) posterior c) frontal regions



(a)

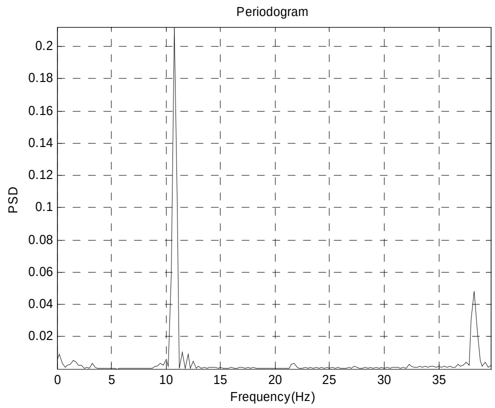


(b)

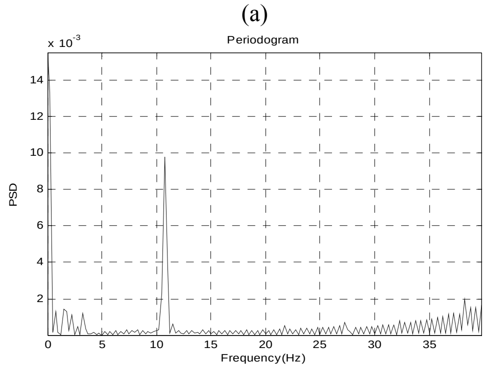


(c)

Figure 4: Power spectrum of EEG signal before hypnosis from a) central (C3) b) posterior c) frontal regions



(a)



(b)

Figure 5 Power spectrum of EEG signal after hypnosis from a) frontal (F3) b) central regions

The peak occurs at 9.0 Hz that falls in smaller alpha1 (8-10 Hz). Figure 4 a and b shows the power spectrum of the EEG signal that is acquired before hypnosis from the frontal and central region of the left hemisphere respectively. The peak occurs at 7.75 Hz that falls in higher theta2 (6 -8 Hz) and at 8.0 Hz that falls in higher theta2 (6 -8 Hz). Figure 4.c shows the power spectrum of the EEG signal that is acquired before hypnosis from the posterior region of the left hemisphere. The peak occurs at 8.25 Hz that falls in higher theta2 (6 -8 Hz). Figure 5.a spectrum shows that the subject 5 has two peaks at 10.75 and 38.2. This subject's response is peculiar. In the frontal region during the waking rest, the response has the gamma frequency also which conclude that the subject is emotional (happy) and highly suggestible to the doctor's suggestion in that period. Figure 5.c shows the power spectrum of the EEG signal that is acquired before hypnosis from the posterior region of the left hemisphere. The peak occurs at 10.75 Hz that falls in higher alpha2 (10 -12 Hz). We expected a greater theta activity in high hypnotizable subjects. In particular, high hypnotizable subjects during waking and hypnosis conditions had greater theta in the left hemisphere at frontal regions. In the hypnosis condition there was an increased activity for both theta1 and alpha1 over left hemispherical regions.

Thus, results from the present study demonstrate that there are distinctive EEG patterns among resting baselines that characterize high and low hypnotizable subjects we expected emotionality to be experienced more strongly by high hypnotizable as compared to low hypnotizable subjects. High hypnotizable individuals did report greater levels of emotional experiences than low susceptible individuals. Moreover, looking at the Galbraith et al. (1970) findings, the highest correlated theta frequency with hypnotizability was at 5 Hz which is corresponding to the center frequency of our theta1 band. Finally, the alpha1 trend observed across waking and hypnosis conditions over frontal and temporo-parieto-occipital regions of the left hemisphere in the happiness emotion condition left-hemisphere prevalence over frontal and central scalp sites. Across emotional conditions highly hypnotizable individuals had greater alpha2 amplitude. The second effect indicated that alpha2 was greater over the left frontal.

5. Conclusion

The spectral analysis of EEG during hypnosis shows the frequency bands in theta and alpha range as we expected. From the analysis, we conclude that during hypnosis, the frequency bands acquired from the scalp falls in the higher theta and smaller alpha waves. For 2 subjects it is observed that, due to low suggestibility, the response is not very good.

The analysis can be extended to the frequencies other than those discussed in this work like beta and gamma frequencies. Better signal processing algorithms can be implemented using other spectral estimation methods like parametric method and non-parametric methods (Modified periodogram, Welch, Multitaper methods) and wavelet transforms. Real time analysis will be implemented in the future.

Six channel EEG amplifier instead of four channel amplifier will be helpful to acquire the data over both right and left hemisphere and compare the responses that can be acquired from frontal (F3, F4), central (C3, C4) and posterior (middle of O1-P3-T5, middle of O2-P4-T4).

6. References

[1] De Pascalis .V EEG spectral analysis during hypnotic induction, hypnotic dream and age regression, *International Journal of Psychophysiology,* (Sep 1993) Vol 15, Issue 2, 153-166.

[2] De Pascalisa .V, W.J. Rayb, I. Tranquilloa, D. D'Amicoa EEG activity and heart rate during recall of emotional events in hypnosis: relationships with hypnotizability and suggestibility, *International Journal of Psychophysiology* (1998) 29, .255-275.

[3] Hilgard, E.R., Dissociation and theories of hypnosis. In: Fromm, E., Nash, M.R. Eds.., Contemporary Hypnosis Research. Guilford Press, New York, (1992) 69-101.

[4] Joel F. Lubar1, Daniel M. Gordon1, R. Steven Harrist1, Michael R. Nash1, Christopher A. Mann1 and Julia E. Lacy1 EEG correlates of hypnotic susceptibility based upon fast Fourier power spectral analysis, Vol 16, No 1, (March 1991) 75 – 85.

[5] Kihlstrom, J., Convergence in understanding hypnosis? Perhaps, but perhaps not so fast. Int. J. Clin. Exp. Hypn. 45, (1997) 324 - 332.

[6] Nancy F. Graffin, William J. Ray, and Richard Lundy EEG Concomitants of Hypnosis and Hypnotic Susceptibility *Journal of Abnormal Psychology* Vol. 104, No. 1, (1995) 123-131.

[7] Pierre Rainville1, Robert K. Hofbauer2, M. Catherine Bushnell2, Gary H. Duncan1, and Donald D. Price Hypnosis Modulates Activity in Brain Structures Involved in the Regulation of Consciousness, *Journal of Cognitive Neuroscience* (2001) 14:6, 887–901.

[8] Proakis G J and Manolakis G D Digital Signal Processing: Principles, Algorithms and Applications (London: Macmillan) (1996).

[9] Sabourin, M.E., Cutcomb, S.D., Crawford, H.J., Pribram, K. EEG correlates of hypnotic susceptibility and hypnotic trance: spectral analysis and coherence.. *Int. J. Psychophysiol.* (1990) 10, 125-142.

[10] Srihari mukesh .T.M, V. Jaganathan and M.Ramasubba Reddy,A novel multiple frequency stimulation method for steady state VEP based brain computer interfaces, *Physiol. Meas.* 27 (2006) 61-71.

[11] Tebecis A A controlled study of the EEG during transcendental meditation: comparison with hypnosis *Folia Psychiatr Neurol*, (1975) 29(4): 305-13.

[12] Toshiaki Isotania, b, Hideaki Tanakaa,c, Dietrich Lehmanna, Roberto D. Pascual-Marquia, Kieko Kochia, Naomi Saitob, Takami Yagyub, Toshihiko Kinoshitab, Kyohei Sasadad Source localization of EEG activity during hypnotically induced anxiety and relaxation *International Journal of Psychophysiology* (2001) 143-153.

7. About the authors

S. Deivanayagi is a graduate student of Biomedical Engineering at IIT Madras. Her main research interests include Biomedical Instrumentation and Biosignal processing.

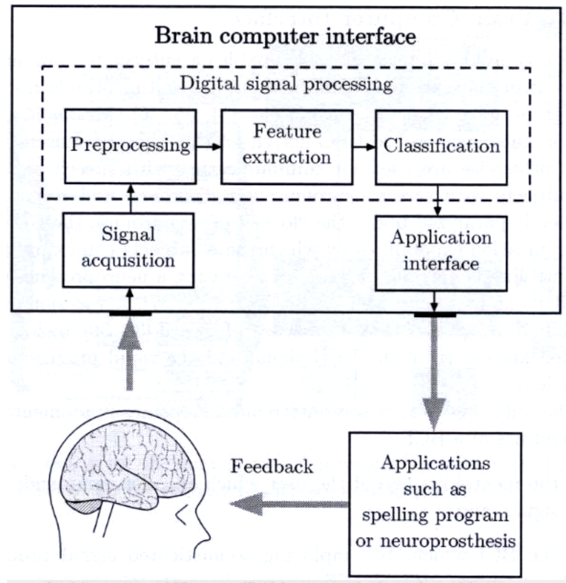
M. Manivannan is a faculty in Biomedical Engineering at IIT Madras. He is also a research affiliate/visiting scientist at the Massachusetts Institute of Technology in Cambridge USA. He received his Masters and PhD degrees in mechanical engineering from the Indian Institute of Science in 2000. His main research interests are in brain and cognition, motor and somatosensory systems, haptics, and human disease diagnosis.

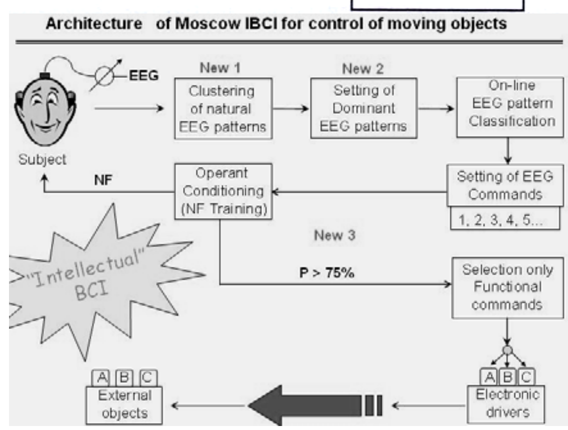
Peter Fernandez is an International Psychiatrist specializing in the dynamics of the Human Mind and Behavior. He retired as a Professor of Psychiatry and the Chief of the Institute of Mental Health in Chennai. He was a Professor and HOD of the Department of Psychiatry at Sri Ramachandra Medical College, Chennai. He is a council member of International Society of Hypnosis. He is now the Director of Psyholab for Disabled at Chennai, a model rehabilitation centre for Chronic Mental Patients.

Brain Computer Interface Architecture

Alexander Ya Kaplan
Lomonosov Moscow State University, Russia

BCI translates the EEG signal characteristics into commands which control devices. A typical BCI architecture is shown below.





Alexander Kaplan with his brain-driven car