CORTICAL DYNAMICS AND COORDINATION DURING MEDITATION

P Indic
School of Engineering
Cochin University of Science and Technology
Koch 22, Kerala, India
E-mail: indic@cusat.ac.in

Abstract

An investigation on collective dynamics of brain during meditation is conducted using the methods of nonlinear dynamics and phase synchronization. The relevance of degree of co ordination of different regions of brain as well as the nonlinear dynamical parameters likes correlation dimension and Kolmogorov entropy is evaluated. It has been found that before meditation each region of the brain interacts with the nearest regions whereas during meditation strength of interaction between the regions reduces. Further, the dimension and entropy value is more during meditation compared to before meditation. This is possibly because during meditation, there is less stress to neural system and this suggests the possibility of using meditation methods for the treatment of mental stress and related psychological problems

CORTICAL DYNAMICS AND COORDINATION DURING MEDITATION

P Indic
School of Engineering
Cochin University of Science and Technology
Koch 22, Kerala, India
E- mail: indic@cusat.ac.in

Introduction

Several studies have been conducted to investigate the effect of meditation on physiological, psychological and biological changes. These investigations showed that there is a remarkable change in EEG, GSR, metabolic activity and heart rate during meditation [Benson et al., 1990; Stigsby et al., 1981]. Mc Evoy et al [1980] investigated the effect of meditation on auditory evoked potentials and concluded the possibility of interaction of brain stem auditory evoked potentials and meditation. It is quite natural that under these conditions brain function undergoes changes. However, in order to understand the dynamics of brain during meditation and investigate the possibility of using meditation methods for mental stress and other related psychological problems, it is essential to know the dynamical aspects of brain. Therefore, we here applied the recently developed methods of nonlinear dynamics and phase synchronization [Grassberger et al, 1983;Rosenblum et al, 1996], to understand the dynamics and interactions of different regions of brain during meditation.

Human brain is one of the least understood complex systems in nature. Capability of human brain to perform higher cognitive functions has been the subject matter of rigorous research in recent times. Several methods of nonlinear dynamics have been applied in EEG analysis, to unveil the underlying phenomenon of brain functioning [Pradhan et al., 1999]. One of the widely used methods in this direction is the analysis of EEG signals as time series and thereby evaluates some of the invariant parameters using the methods of deterministic chaos. However these methods can be used only for univariate time series and for understanding the interactions of different regions of brain, a multivariate time series analysis is required. Further EEG signals are nonstationary in nature and this poses difficulty in the evaluation of these parameters. Indic et al [1999] suggested that the nonstationary nature is due to the interaction of various time scales involved in the dynamical process and proper characterization of human brain dynamics is possible only if all the relevant time scales are identified. Therefore, we made an analysis to understand the collective dynamics in the functioning of human brain during meditation by looking for phase synchronization between various regions of the brain. This approach of multivariate time series analysis extracts information regarding the coordination of weakly interacting system from nonstationary data [Tass et al., 1998]. Further, the characteristic parameters have also been evaluated to understand the dynamics of brain using nonlinear dynamical approach.

In order to understand the dynamics we considered EEG from three persons before as well as during meditation. The meditation performed by these persons is in the Buddhist tradition called *Vipassana.* Vipassana is a state of mind, which characterizes the complete detachment from the outside world and obtain the deeper insight into oneself. This is a mindfulness form of meditation whereas other forms of meditation fall under the category of concentration methods [P. Novak, 1996].

Materials and Methods.

1.) Data Acquisition

EEG data is obtained from the data bank of NIMHANS, Bangalore, India. Data is acquired using an EEG machine coupled to a PC using analog to digital converter and an array processor. The electrodes are placed at 16 locations on the scalp. These locations are fixed according to International 10 - 20 systems. The electrode locations (channel number given in bracket) are Fp1 (1), Fp2 (2), F3 (3), F4 (4), F7 (5), F8 (6), C3 (7), C4 (8), T3 (9), T4 (10), P3 (11), P4 (12), T5 (13), T6 (14), O1 (15) and O2 (16). The sampling is done at the rate of 512 samples/channel/seconds. The acquired data is filtered using a FIR digital filter of order 150 with a bandwidth of 0.1 — 32 Hz. The data is visually screened to identify artifacts. The data is acquired from three volunteers before and during meditation both with eyes closed condition.

2.) Methods

The data obtained from each channel is divided into different nonoverlapping sliding windows of length 1024 data points, as the data is nonstationary in nature. The correlation dimension, D2and Kolmogorov entropy, K2 (Grassberger et al, 1983) is evaluated using the modified method of Grassberger and Procassia algorithm (Havstad et al, 1988). In this method, the obtained time series is reconstructed in a phase space using the famous time delay embedding. The time lag required to construct is determined from the Average mutual information criteria. The embedding dimension required for embedding the obtained time series is determined using False Nearest Neighbor approach (Abarbanel et al, 1993). This algorithm has been checked using the time series generated from Henon map and logistic equation with standard values.

To understand the co ordination of different regions of brain, instantaneous phase of each observed signal is calculated by means of Hilbert transform. To search for phase locking, a histogram of relative phase distribution is drawn and a peak in the histogram ensures phase locking. To characterize the strength of interaction, deviation of actual distribution of relative phase from a uniform one is determined by finding an index ρ based on Shannon entropy [Tass et al., 1998]. This index gives the degree of coordination of different brain areas. The index ρ can take values between 0 and 1. $\rho = 0$ corresponds to absence of synchronization while $\rho=1$ corresponds to perfect synchronization. The present work is restricted to 1:1 locking ratio.

The average value of strength of synchronization index determined before meditation as well as during meditation is presented in Figure3. The average value of D2 and K2 presented in Table I. The result presented here is that of one of the volunteers however a consistent result has been obtained for all the three cases.

Results and Discussions

It has been found that before meditation each brain region is interacting with neighboring regions with varying degree of synchronization index. One can interpret this as the capacity of weighing various aspects of information processing. However during meditation, interactions are weakened as indicated by the reduction in value of synchronization index (Figure 3). This is because prior to meditation, interaction with the external world stimulate phase synchronization of oscillators in different locations of brain leading to associative process generating new patterns of distribution of neuronal firing. This results in the awareness of the external world and brain generates a number of independent input / output commands in response to such awareness. Such cooperative effects lead to "thinking", "cognitive" and "decision" process.

Figure 1(a & b) gives the histogram of relative phase distribution for a window length of 10 seconds duration between pre frontal and frontal region in the left hemisphere of the brain. Before meditation, one can observe a peak in the relative phase distribution whereas during meditation, the distribution is broadened indicating that the coordination between the two regions is reduced. Figure 1(c) gives the histogram of relative phase distribution of prefrontal and temporal region again in the left hemisphere before meditation. There is no sharp peak and the distribution is very much broadened indicating a very little interaction. Similar observation is also obtained during meditation in these regions. This indicates that there is not much influence between farther regions before as well as during meditation. A closer look at the Figure3 reveal that before meditation interactions are present in front and back regions of brain as compared to mid region. Figure. 2 gives the strength of interaction calculated for running windows of duration 2 seconds between right prefrontal region and the left frontal region. The observed interaction between left and right hemisphere is an indication of information flow between the two lobes of brain.

The results of D2 and K2 are given in Table I. the values of D2 and K2 for each channel characterize the nature of the attractor in the phase space corresponding to a particular location. The most significant result is that the average value of D2 and K2 increases in all the channels during meditation. This observation strongly tempts one to consider the brain as a system of collection of different classes of attractors and before meditation, they interact to form structures with reduced complexity or degrees of freedom. During meditation many interactions are reduced, which are reflected in the values of synchronization index, the attractors have more degree of freedom, which results in a comparatively larger value of D2 and K2.

The results presented here should be seen only as a preliminary study. The data set is from three persons and recorded from 16 locations on skull space. However, this gives an insight into the collective dynamics of brain in general.

Conclusions

In this work, the dynamics of human brain during meditation has been compared with that during nonmeditating (eyes closed condition) state using the methods of nonlinear dynamics. Studies involving phase synchronization technique show that the different parts of the brain interact during nonmeditating state as compared to meditating state. During eyes, closed condition different regions of the brain interact with each other through thought process to get a coherent state. Interaction between different regions of brain, as stated earlier, generates associative memory. During meditation, one is trained to control thought processes, which will lead to decoupling of different regions of the brain. This is clear from the lowering of values of synchronization index. This suggests that during meditation the brain is free from external stimuli causing less stress to neural system. This observation is helpful in the study of effect of meditation on mental stress and other related psychological problem.

Acknowledgement.

The author expresses his sincere gratitude to Prof. R Pratap, Prof. V P N Nampoori, Prof. N Pradhan and Dr. R. Sreenivasan for their support and guidance.

References

1. Abarbanel, H.D.I., Brown, R., Sidorwich, J.J., and Tsimring, L.S. (1993). The analysis of observed chaotic data in physical systems, *Reviews of Modern Physics,* **65**, 1331
2. Benson, H., Malhotara, M.S., Goldman, R.F., Jacobs, G.D. and Hopkins, P.J. Three case reports of the metabolic and electroencephalographic changes during advanced Buddhist meditation technique. *Behavioural Medicine*, **90**, 1990, 90-95.
3. Grassberger, P. and Procaccia, I. (1983). Measuring the strangeness of strange attractors. *Physica D*, **9**, 189.
4. Indic, P., Pratap, R., Nampoori, V.P.N. and Pradhan, N. Significance of time scales in nonlinear dynamical analysis of Electroencephalogram signals. *International J. Neuroscience*, **99**, 1999, 181- 194.
5. Mc Evoy, T.M., Frumkin L.R and Harkins,S.W., Effect of meditation on brainstem auditory evoked potentials.*International J. Neuroscience*, **10**, 1980, 165-170
6. Novak P., Buddhist Meditation and Consciousness of time. *Journal of Consciousness Studies*, **3**, 1996, 267-277
7. Parlitz, U., Junge, L., Lauterborn, W. and Kockarev, L. Experimental observation of phase synchronization. *Physical Review E*, **54,** (2), 1996, 2115 - 2117
8. Pradhan, N., Rapp, P.E., and Sreenivasan, R. (Ed), Proceedings of International conference on nonlinear dynamics and brain functioning, Nova, 1999.
9. Rosenblum, M.G., Pikovsky, A.S., and Kurths, J. Phase synchronization of Chaotic Oscillators. *Physical Rev. Letters*, 76 (11), 1996, 1804-1807.

10. Shafer, C., Rosenblum, M.G., Kurths, J. and Abel, H .H, Heartbeat synchronized with ventilation. *Nature,* **392**, 1998, 239-240

11. Stigsby, B., Rodenberg, J.C and Moth, H.B. Electroencephalographic findings during mantra meditation (Transcendental meditation). A controlled, quantitative study of experienced meditators. *Electroencephalography & Clinical Neurophysiology*, **51**,1981, 434-442.

12. Tass P, Rosenblum, Weule, J., Pikovsky, A., Volkmann, J., Schnitzler, A., and Freund, H.J. Detection of n: m phase locking from noisy data: Application to Magnetoencephalography. *Physical Rev. Letter*, **81**, 1998, 3291-3294

Table I: Average value and Standard deviation in bracket of D2 and K2

Channels	Before Meditation		During meditation	
	D2	K2	D2	K2
Fp1	6.46 (0.35)	7.70 (0.85)	8.03 (1.33)	8.33 (1.23)
Fp2	6.61 (0.61)	7.3 (1.34)	8.28 (0.91)	8.51 (0.39)
F3	6.42 (0.66)	7.05 (0.93)	7.61 (0.92)	7.71 (1.96)
F4	6.67 (0.91)	8.01 (1.42)	8.31 (1.25)	8.02 (1.56)
F7	5.91 (0.64)	6.85 (1.5)	7.33 (0.76)	8.52 (1.25)
F8	6.85 (0.65)	7.42 (1.81)	8.51 (0.69)	10.24 (3.38)
C3	6.68 (0.84)	8.11 (1.98)	7.71 (0.87)	7.95 (1.82)
C4	6.86 (1.18)	6.62 (1.19)	6.15 (3.04)	8.08 (1.28)
T3	6.45 (0.28)	7.99 (1.02)	8.06 (0.83)	10.45 (4.59)
T4	6.96 (0.87)	7.27 (1.95)	8.99 (0.61)	10.00 (1.13)
P3	6.50 (0.51)	7.36 (0.93)	8.56 (1.1)	10.35 (2.50)
P4	6.02 (0.65)	6.99 (0.87)	8.60 (0.78)	9.21 (2.83)
T5	6.74 (0.74)	9.2 (2.88)	8.65 (0.69)	10.64 (1.84)
T6	5.97 (0.74)	6.79 (0.73)	8.61 (0.81)	9.98 (2.66)
O1	6.85 (0.35)	8.74 (1.13)	8.76 (0.92)	10.12 (0.88)
O2	6.67 (0.65)	7.79 (1.64)	8.44 (0.87)	10.18 (3.37)

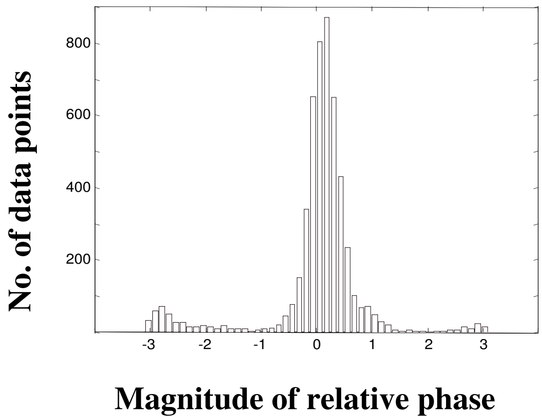


Figure 1 (a) Histogram of relative phase prior to meditation between Fp1 and F3 for a particular window (ρ = 0.308)

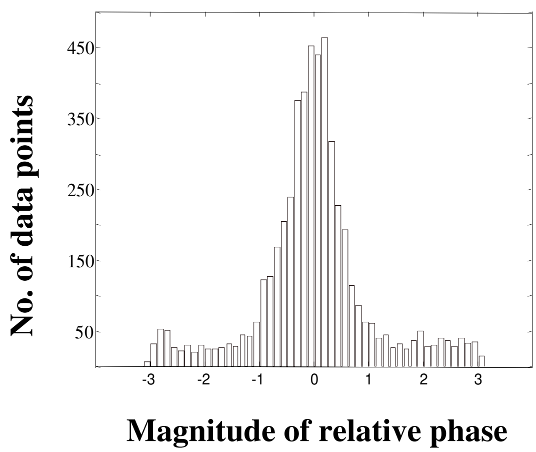


Figure 1(b) Histogram of relative phase during meditation between Fp1 and F3 for a particular window (ρ= 0.1454)

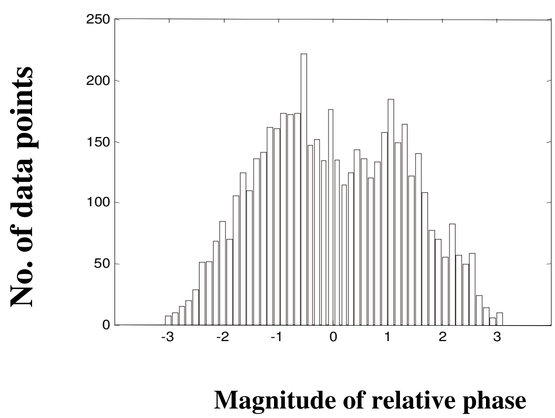
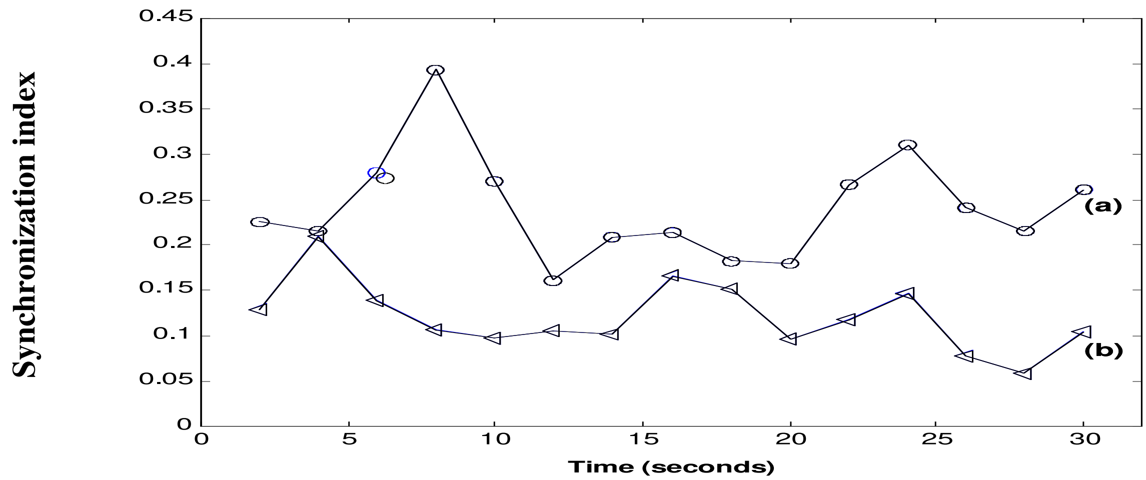


Figure 1(c) Histogram of relative phase prior to meditation between Fp1 and T5 for a particular window (ρ = 0.048)



(a) Before meditation eyes closed (b) During meditation
Figure 2. Synchronization index between F3 and Fp2

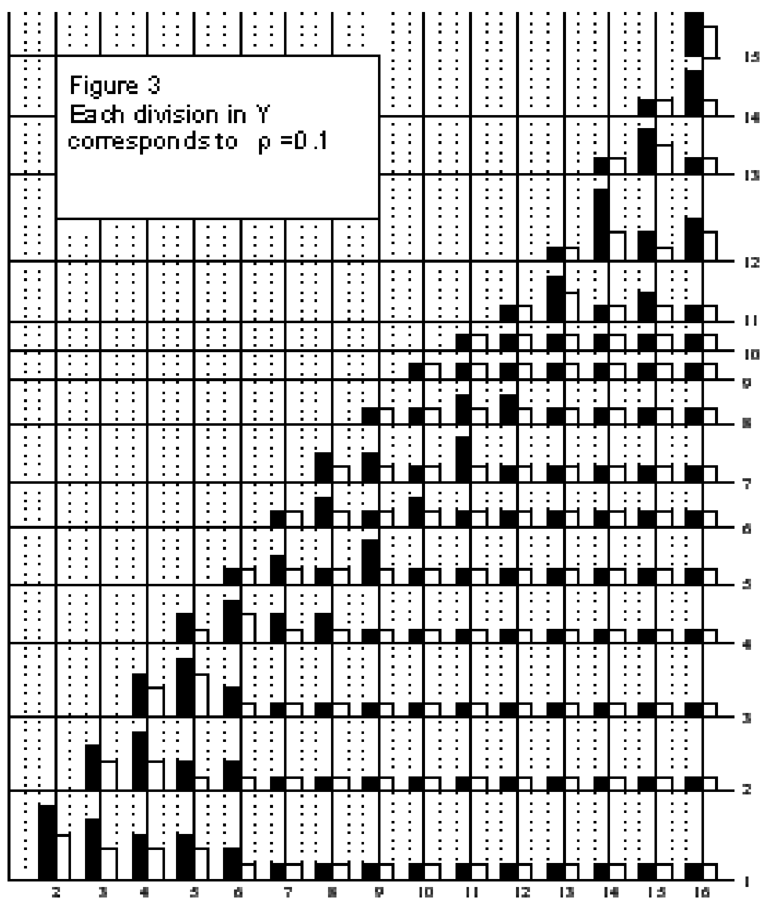


Figure 3: Average value of synchronization index. Dark shade corresponds to before meditation and white corresponds to during meditation.