

EEG TIME SERIES DATA ANALYSIS IN FOCAL CEREBRAL ISCHEMIC RAT MODEL

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ABSTRACT

The mammalian brain exists in a number of attractors. In order to characterize these attractors we have collected the time series data from the EEG recording of rat models. The time series was obtained by recording of the frontoparietal, occipital and temporal regions of the rat brain. Significant changes have been observed in the dimensionalities of these brain attractors between the normal state, focal ischemic state and the drug induced state. Thus, these three states were characterized by unique lyapunov exponents, correlation dimensions and embedding dimensions. The inverse of the lyapunov exponent gave us the long term coherence of the rat brain and was found to differ for the three states. The autocorrelation function measured the mean similarity of the EEG signal with itself after a time t . The degree of decay was high indicating that there was maximum correlation in the time series. Thus, the autocorrelation functions clearly indicate the effect of focal cerebral ischemia and drugs induced on the rat brain.

KEYWORDS

EEG; Focal Cerebral Ischemia; Lyapunov Exponent; Embedding Dimension; Correlation Coefficient

1. INTRODUCTION

Brain stroke is a very common and serious neurological disorder. Every year, 15 million people worldwide suffer a stroke. Nearly six million die and another five million are left permanently disabled. A stroke is a condition in which the brain cells suddenly die because of a lack of oxygen. This can be caused by an obstruction in the blood flow, or the rupture of an artery that feeds the brain. Characterization of the brain stroke EEG plays a vital role. Electroencephalography (EEG) provides a direct and comprehensive measure of cortical activity with millisecond resolution. The EEG recordings, which are aperiodic time series, are a result of the contributions of large number neuronal potentials. We have investigated induced focal cerebral ischemia and subsequent recovery by application of the Piroxicam drug. Piroxicam drug

has been used earlier studies [1]. Ischemic model of rat brain has been extensively studied [2]. However, the EEG data of focal cerebral ischemia has not yet been analyzed in terms of inverse lyapunov exponent, correlation dimension and autocorrelation functions. In this paper, we have analyzed the focal cerebral ischemia data in terms of the above parameters and were able to classify EEG spectra in terms of inverse Lyapunov exponent and correlation dimensions. Via analysis of the time series [3-7] using MATLAB R2010a based programs useful parameters series such as lyapunov coefficients, Correlation dimension and autocorrelation function were extracted from the time series. We have used these parameters to study the effect of induced stroke and subsequent drug (Piroxicam) based recovery on the rat brain.

2. MATERIALS AND METHODS

Male Charles Foster rats (6 weeks, 270 ± 10 g) were in-bred at the Central Animal House, Banaras Hindu University were used for the experiments. Animals were kept under standard laboratory conditions maintained with animal care and housing. In our study, a total of 24 animals were divided in three groups consisting of control (n=8), induced stroke (n=8) and Piroxicam drug treated (n=8) for each group. Piroxicam and other chemicals were purchased from Sigma, USA. They were allowed free access to food and water and maintained at 12 h day/night cycle.

Focal cerebral ischemia was induced by occlusion of the middle cerebral artery (MCA) using a modification of the intraluminal technique. Animals were anesthetized with ketamine and xylazine (75 mg/kg and 10 mg/kg i.p, respectively). The neck muscles were separated further to expose external carotid artery (ECA) and internal carotid artery (ICA). A 4.0 cm length 3-0 monofilament nylon suture (Ethicon) was introduced into the ECA lumen through a small nick and gently advanced from to the ICA lumen to block the origin of MCA. The approximate length of filament inserted near the bifurcation point to the MCA blockade site was about 18-22mm. The ECA stump was tightened by thread around the intraluminal nylon suture to prevent bleeding. Reperfusion was allowed by gently removing the monofilament after 1 h of ischemia. In sham-operated animals, all the procedures except for the insertion of the nylon filament were carried out. Animals were allowed to recover from anesthesia and on regaining the righting reflex, were transferred to cages in the animal room, with temperature maintained at $26 \pm 2.5^\circ\text{C}$.

EEG electrodes were implanted and placed to the skull at positions that were optimized following stereotactic coordinates (Paxinos) in pilot experiments. A bipolar electrode montage system was used for recording the rat brain EEG signal. Electrodes were placed bilaterally in the skull over the frontoparietal, occipital and temporal regions of the rat brain. A reference electrode was placed posterior to lambda over the transverse sinus.

2.1. Lyapunov exponents

The dynamics of complex systems (such as the mammalian brain) is constrained to certain paths or flows. Flows may be analyzed in terms of Gauss's theorem: time rate of flow into a volume must equal the flow out of the volume. Consider a volume element of radius \mathcal{E} . Grassberger and Procaccia [5-6] have shown that as result of the flow the number of points in the volume element is given by the power law as

$$C(r) \approx \varepsilon^d \quad (1)$$

Where, d is the correlation dimension given by the slope of the $\log C(r)$ versus $\log(\varepsilon)$ (Fig. 1-9). Thus distances between trajectories grow exponentially:

$$\|\delta(t)\| \approx \|\delta_0\| e^{\lambda t} \quad (2)$$

The plot of $\ln(\|\delta(t)\|)$ versus t gives a straight line with slope λ (Fig. 1-3) where λ is the Lyapunov exponent. The existence of the linear plots confirms that equations (1) and (3) are associated with attractors of the rat brain (Fig. 1-3). In general the mammalian brain exists in a number of attractors [8].

2.2. Correlation dimension:

Consider the time series: $\{V(t_i), V(t_i + \tau), \dots, V(t_i + (n-1)\tau)\}$. The integral correlation coefficient is obtained via the method outlined in [1]. Here one starts with a reference point V_i and its distance to the rest of the points is computed. Then one computes how many points lie within a given distance r from V . Repeating this process for all i one arrives at $C(r)$, the integral correlation coefficient of the attractor. For small r , $C(r) \sim r^\nu$ where ν is the correlation dimension and is given by the slope of the plot of $\log(C(r))$ versus $\log(r)$. The slope was computed directly in the Matlab program for various embedding dimension. The plot of the correlation dimension ν versus embedding dimension m was obtained (Fig. 4).

2.3. Autocorrelation functions:

The autocorrelation function of a time series is a measure of how the values of the time series separated by a time τ behave. The autocorrelation coefficient for the time series defined above is given by [3]

$$\psi(\tau) = \frac{\frac{1}{N} \sum_{i=1}^N [V(t_i) - \bar{V}][V(t_i + \tau) - \bar{V}]}{\frac{1}{N} \sum_{i=1}^N [V(t_i) - \bar{V}]^2} \quad (3)$$

where,

$$\bar{V} = \frac{1}{N} \sum_{i=1}^N V(t_i) \quad (4)$$

A plot of the autocorrelation function for the control, stroke induced and drug based recovery is shown in (Fig.5-7).

3. RESULTS

3.1. Lyapunov exponents:

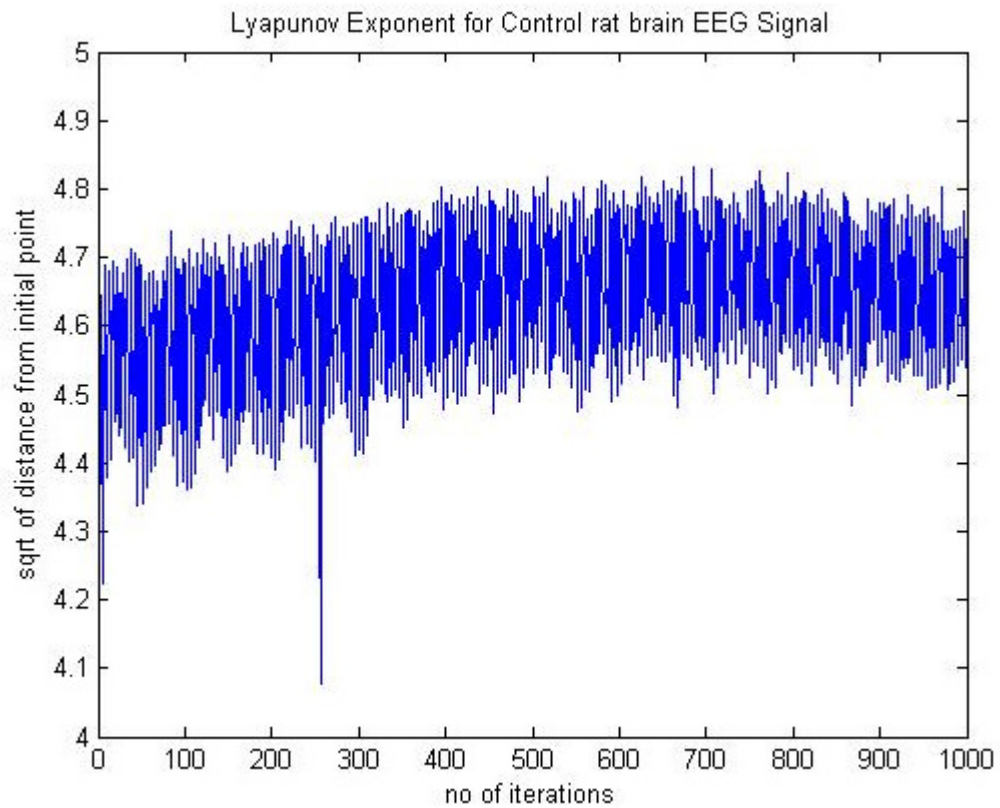


Figure 1. Lyapunov Exponent for Control rat brain EEG Signal

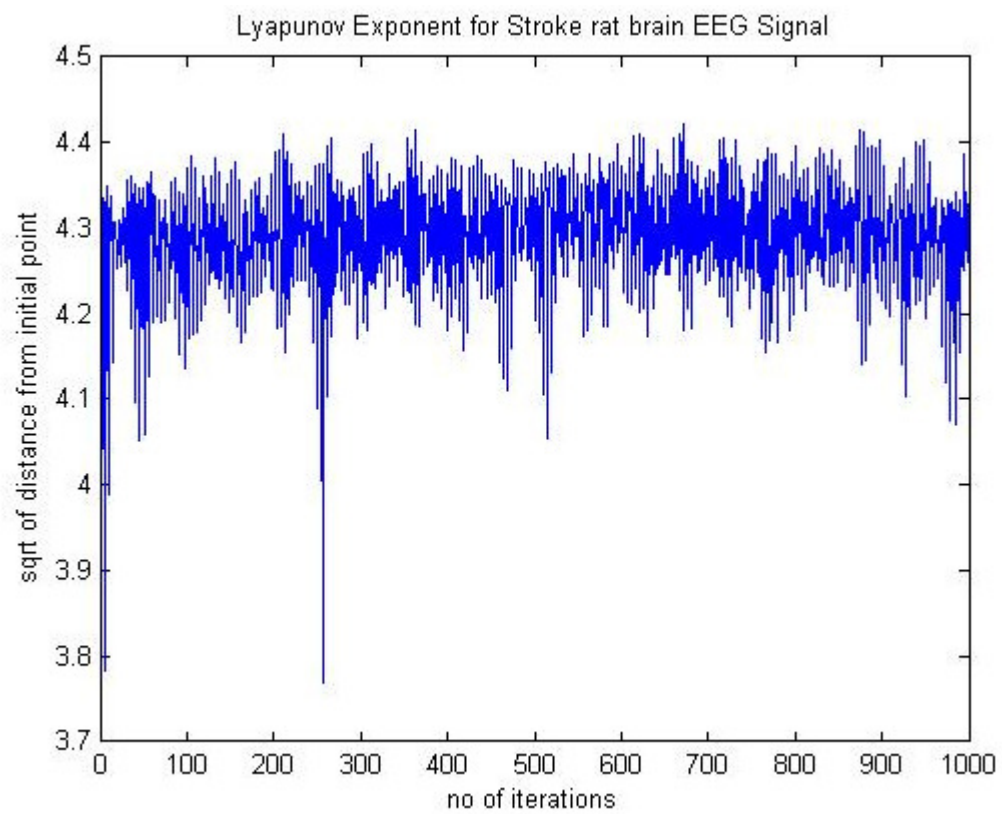


Figure 2. Lyapunov Exponent for Stroke rat brain EEG Signal

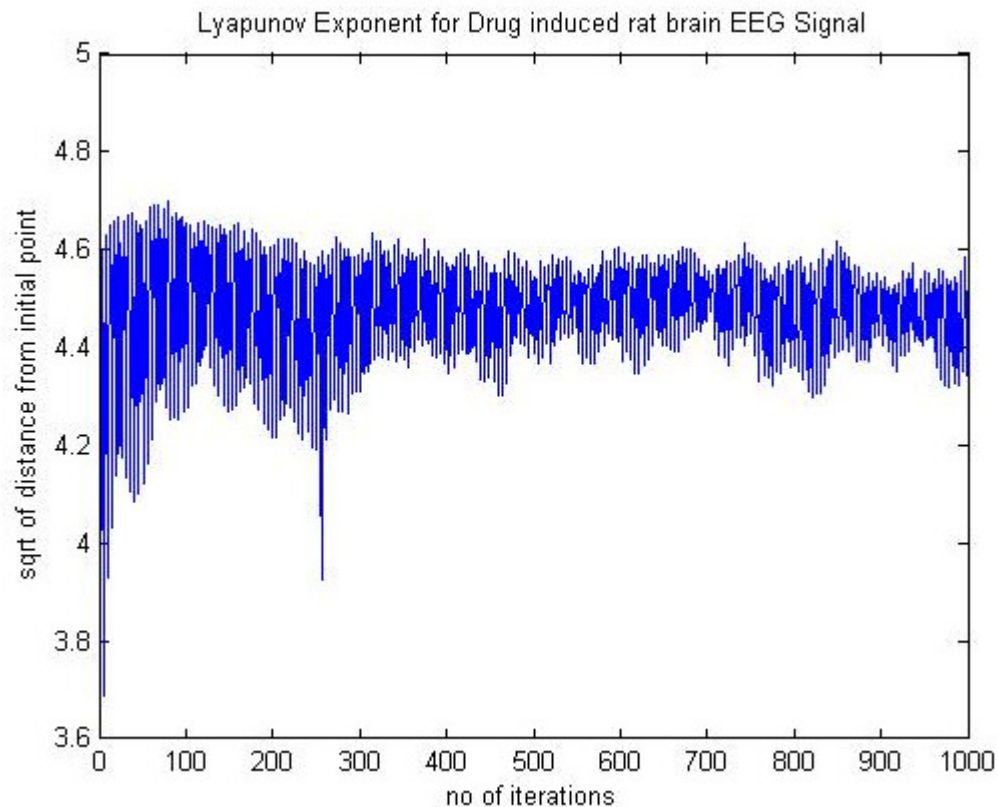


Figure 3. Lyapunov Exponent for Drug induced rat brain EEG Signal

Lyapunov exponents for the control data were negative, implying that the neurons in the rat brain were in the stable state (Fig. 1-3). The Lyapunov exponents for the entire stroke data were positive indicating that there was some instability had been induced in the system. After application of drug, in some cases the Lyapunov exponents were in some cases positive and in some cases were negative. The negative Lyapunov exponents indicated the neurons of the brain have reached the stable state. On the other hand, when the Lyapunov exponents were positive it meant that the neurons were in the unstable state.

CASE 1: According to our experimental result, we can say 5 out of 8 sets in fronto-parietal region; 6 out of 8 sets in occipital region and, 4 out of 8 sets in temporal region the inverse Lyapunov exponent of the stroke value was less than the corresponding control value. That signifies the induced stroke in the neurons of the rat brain. The different regions of the brain are affected differently by the induced stroke; Occipital region of the rat brain suffers the most damage while the temporal region suffers the least. The reason for the differential effect of the stroke on the different region of the rat brain is not known.

CASE 2: After the drug was administered in our experiment, we got 4 out of 8 sets in fronto-parietal region; 3 out of 8 sets in occipital region and, 3 out of 8 sets in temporal region the inverse Lyapunov exponent of the drug induced value is more than the corresponding induced stroke value and its effect the different region differently. In these cases the inverse lyapunov exponents indicative the higher coherence length implying that the recovery from stroke due to the drug have been more. The degree of recovery was also different.

3.2. Correlation Dimensions:

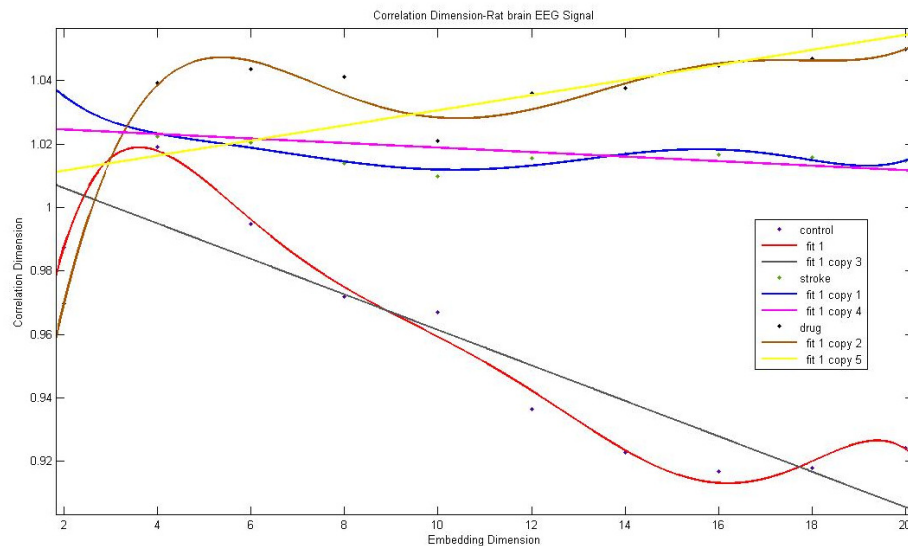


Figure 4. Correlation dimensions of rat brain: Control, Stroke and Drug

Correlation Dimension decreases due to the induced stroke with respect to the control value and increases when drug was administered (Fig. 4).

Case 1: According to our experimental result, we can say that 3 out of 8 sets in fronto-parietal region; 5 out of 8 cases in occipital region and, 6 out of 8 cases in temporal region, the correlation dimension of the stroke value was less than the corresponding control value. According to the correlation dimension, temporal region of the rat brain suffers the most damage while the Frontoparietal region suffers the least. The reason for the differential effect of the stroke on the different region of the rat brain is not known.

CASE 2: After the drug was administered in our experiment, we got 4 out of 8 sets in fronto-parietal region; 3 out of 8 sets in occipital region and, 4 out of 8 sets in temporal region the correlation dimension of the drug induced value is more than the corresponding induced stroke value and its effect the different region differently. Further in those cases where correlation dimension in the drug induced data were less compared with the stroke value, the recovery was not optimum.

3.3. Autocorrelation functions:

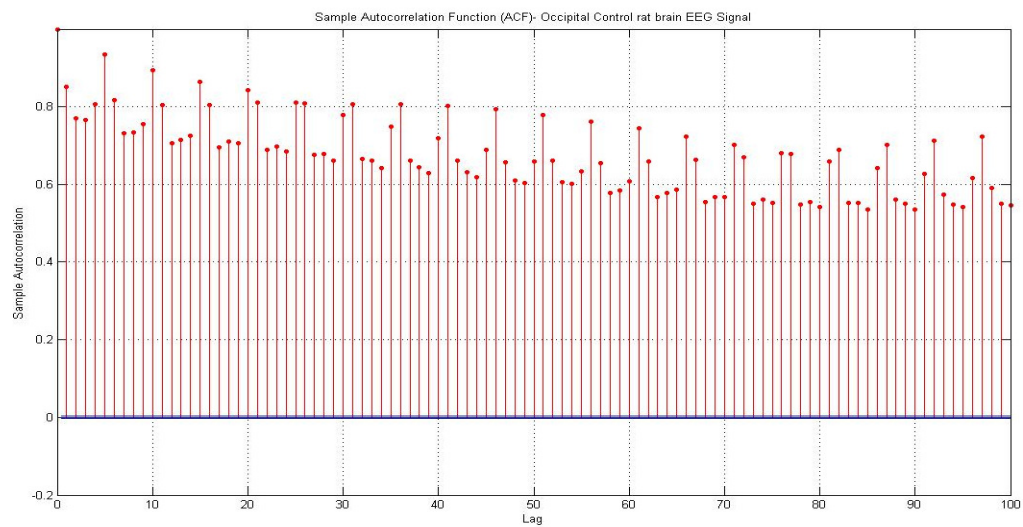


Figure 5. Autocorrelation Function- Control rat brain EEG Signal

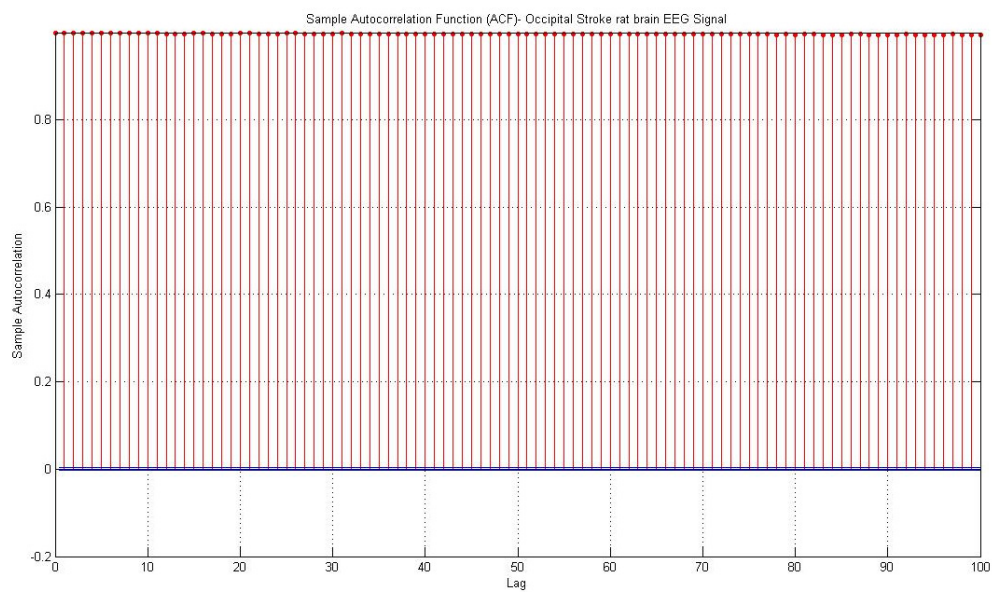


Figure 6. Autocorrelation Function- Stroke rat brain EEG Signal

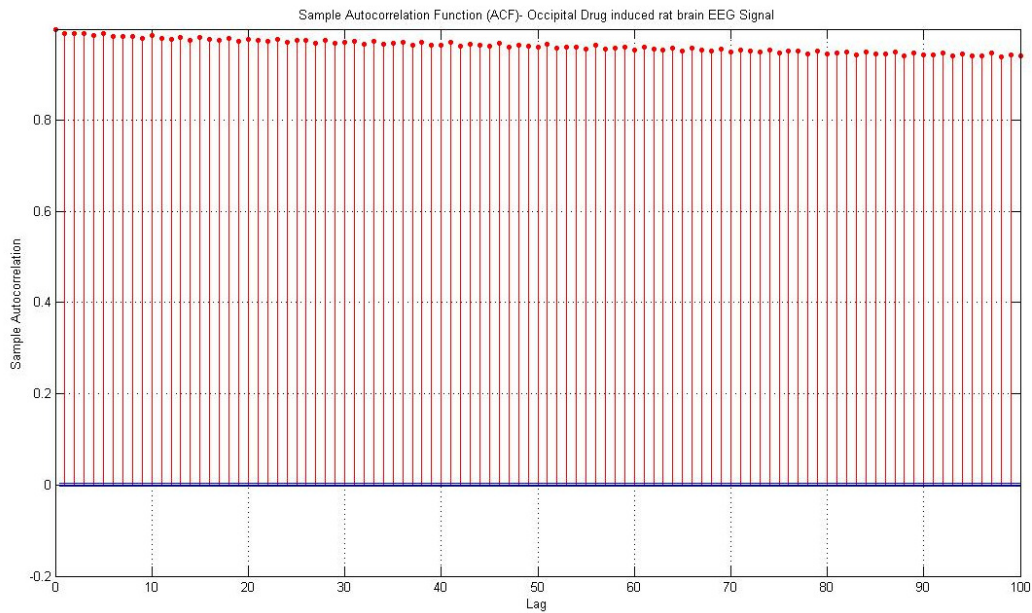


Figure 7. Autocorrelation Function- Drug induced rat brain EEG Signal

In the frontoparietal, occipital and temporal lobe of the rat brain the auto correlation function of the control signal was decaying. The degree of decay was high indicating that there was maximum correlation in the time series. However in the case of focal cerebral ischemia, the decay was inhibited considerably. On the application of the drug the decay in the auto correlation function was somewhat restored, indicating that the drug had restored the initial neuronal connectivity. (Fig. 5-7)

4. DISCUSSION

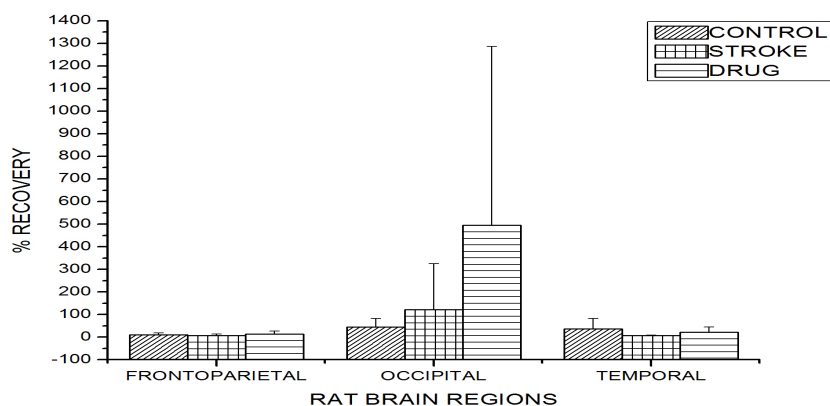


Figure 8. Graphical representation of percentage recovery

In this study, we have found that occipital region of the rat brain suffers the most damage and after inducing the drug we can say that occipital region recovered most compared with the other regions (Fig. 8). Further in those cases where inverse lyapunov exponents and correlation dimensions in the drug induced data were less compared with the stroke value, the recovery was not optimum.

5. CONCLUSION

Significant changes have been observed between the dimensionalities of these brain attractors between the normal state, focal ischemic state and the drug induced state. We have found that there are significant changes in both inverse lyapunov exponent and correlation diminutions. They indicate both the coherence time and the number of interacting neuron are affected by the induced stroke and restored partially by the application of drug. This result is also visually seeing in the graphs of the auto correlation functions.

CONFLICT OF INTEREST

The authors declare no conflict in interests. And there are no ethical issues associated with this work.

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