

Techniques for Predicting Epileptic Seizures

D. A. Birch, Brandeis University, University of Florida

Z. Qiu, University of Florida

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Abstract

Several techniques were used with moderate success in an attempt to predict epileptic seizures based on the maximum Lyapunov exponents of the patients' electroencephalograms(EEG's). The basis of all of the techniques used is two point correlations between the Lyapunov exponents of the time-varying voltages of the electrodes used to record the EEG's. Among the calculations made were the relative distances of the electrodes from the focus of the seizures and the integrals of the correlations. These techniques enable impending seizures to be seen qualitatively an hour or two in advance in some cases, but still need to be quantified in a reliable algorithm that will predict weak seizures without giving too many false alarms. Attempts were also made to draw parallels with the two dimensional Ising model of magnetism by treating the occurrence of a seizure as a phase transition.

1 Introduction

In attempting to predict epileptic seizures many efforts have emphasized focal epilepsy. In a patient with focal epilepsy a specific area of the brain, called the focus, starts a seizure which spreads out to the rest of the brain. Besides just predicting seizures with the hope that techniques will be developed to prevent the seizures predicted, efforts have also been made to locate the focus as precisely as possible. Currently one of the treatments for focal epilepsy is to surgically remove the portion of the brain causing the seizures[4].

The data used in Dr. Iasemides' research comes from the EEG's of seriously ill patients and is gathered from subdural electrodes, that is electrodes implanted in the brain. Depending on the experiment each patient had up to 64 electrodes. The

EEG's are originally recorded on a video tape along with video of the patient taken at the same time. The EEG's are later extracted from the tape and digitized for analysis. The video of the patient can be used to compare the activity of the EEG with the state of the patient[4]. A research team from Bonn used 128 electrodes in their study[5].

Previous research in the timing of seizures has shown that their occurrence is not purely random and that the intermittance of seizures exhibits chaotic behavior[2]. Additional experiments showing that during a seizure the EEG's of the patient become more ordered are universally agreed on as correct. One measure of how chaotic a system is, the maximum Lyapunov exponent, has clearly been shown to decrease in the time leading up to a seizure. Calculations of the Lyapunov exponents for multiple subdural electrodes and noting when they drop can be used to predict seizures several minutes ahead of time[3]. Later another team was able to predict seizures up to eleven minutes ahead of time by approximating the dimension of the chaos in the EEG and noting when it decreased[5].

2 Calculations

The data used in this research was the maximum Lyapunov exponents of EEG's from two different patients calculated every 10.24 seconds by Dr. Iasemides' team. One of the data sets, called SON, was taken from a patient with 32 electrodes, the second, FUS, was taken from a patient with 30 electrodes. Most of the calculations were done on the FUS data set because it was a continuous set of data 217 hours long containing 24 different seizures as opposed to the SON set which consisted of four different data sets, each approximately 1.4 hours long and containing one seizure each.

We have tried a variety of techniques to improve the prediction time, some have offered qualitative information as to if a seizure is imminent in that a person studying one of the plots produced could see that abnormal activity was occurring and that a

seizure was coming but we were unable to quantify this intuition into a prediction algorithm. One of the problems encountered was the inability to establish a reliable baseline for ordinary activity. A baseline calculated in a region ten or more hours away from a seizure is ineffective for predicting a weak seizure or one that closely follows a previous seizure.

The definition used here for strong and weak seizures are not necessarily related to the effect of the seizure on the patient but rather the behavior of the Lyapunov exponents. Seizures where the Lyapunov exponents of many electrodes become highly correlated well before the seizure are considered strong and seizures with smaller correlations and fewer electrodes following the focus are classified as weak seizures.

One of the quantities calculated for each seizure was the distance in terms of correlation lengths of each electrode from the focal point of the seizure. It was shown that before and during most seizures the distance of each electrode decreased dramatically for brief time periods and then bounced back to their normal state. These decreasing distances provided a qualitative indicator that a seizure was upcoming; however, occasionally these distances would decrease dramatically when there was no seizure, giving a false alarm. Another problem was that preceding a weak seizure the decreases in distance were not nearly as large as the changes before a strong seizure. The range of each electrode was calculated using the following formula for two-point correlation of the i th electrode with the focus where L_i are the maximum Lyapunov exponents of the i th electrode and L_0 are the exponents of the focal electrode. The averages were taken over a thirty point (about five minutes) window:

$$C_{i0} = \langle L_i - \langle L_i \rangle \rangle \langle L_0 - \langle L_0 \rangle \rangle \quad (1)$$

The correlations are related to the range of the electrodes according to the following relation with ξ equal to the correlation length and r_{i0} as the distance between the electrodes:

$$C_{i0}^2 = A^2 \cos^2(qr_{i0}) e^{-\frac{2r_{i0}}{\xi}} \quad (2)$$

If one averages over a large enough interval the \cos^2 term can be replaced by $1/2$ and the equation rearranged to yield the following equation which is the one used to calculate the electrode ranges:

$$\frac{r_{i0}}{\xi} = -\frac{1}{2} \ln \frac{2C_{i0}^2}{C_{00}^2} \quad (3)$$

In an attempt to quantify the indicator electrodes were assigned to zones based on their distance from the focus. During a seizure all electrodes came into the nearest zone, that of electrodes within .5 correlation lengths of the seizure. However the slope of the number of the electrodes in this region as a function of time was nearly vertical, meaning that there was very little lead time for predicting seizures.

In a second attempt to quantify an alert integrals of the normalized correlations were calculated in the intervals leading up to a seizure with the idea that the increases in correlations during a pseudo-seizure would have too short a duration to contribute to the overall integral. Also, calculating an integral could add up any subtle differences between the behavior of the background and a weak seizure. However, in some cases the integrals of regions with no activity were greater than the regions preceding seizures. The expression for the normalized correlation is:

$$N_{i0} = \frac{C_{i0}}{\sqrt[2]{\sigma_i \sigma_0}} \quad (4)$$

$$\sigma_i = \sqrt[2]{\langle L_i^2 \rangle - \langle L_i \rangle^2} \quad (5)$$

In addition to attempting to predict seizures efforts were made to determine which electrodes were closest to the focus. A simple approach was to calculate the correlations between all pairs of electrodes and then find the sum of the correlations of each electrodes with all other electrodes. The idea behind this approach is being that electrodes with all other electrodes. The idea behind this approach is that the electrode with the highest total would be the focus. However, the result of this method will clearly depend on how the electrodes are distributed in the brain; if several electrodes are clustered together in one region of the brain their total correlations would

be unnaturally high. In order to determine the position of the focus accurately a more sophisticated algorithm would be required, perhaps one that considers change in correlation over time with the focus being the electrode which experiences the first significant increase in correlation with its neighbors during the onset of a seizure.

3 Discussion

The method of predicting seizures by monitoring the relative distances of the seizures is successful for strong seizures. Work still needs to be done to quantify a cutoff for the ranges which when reached indicates a seizure is probably coming. The method of integrals shows promise for the large seizures, however a method still needs to be developed for weaker seizures and a baseline value for ordinary activity needs to be found. Another calculation that should be carried out in future experiments is to attempt to reduce the number of electrodes necessary to predict seizures. Currently even if the data were digitized at real time the calculations are still executed slower than real time. If a few premium electrodes were selected for use than the time necessary for calculations would be reduced as there would be fewer Lyapunov exponents and correlations to be calculated. There was no success in drawing parallels with the Ising model of magnetism; future calculations could try to reconcile the behavior of the seizures with the behavior of the two-dimensional Ising model. Another calculation to be carried out is the correlation of the slopes of the Lyapunov exponents over time.

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