Correlation Dimension Maps of EEG from Epileptic Absences

Carla Silva*, Iveta R. Pimentel+, Alexandre Andrade*, John P. Foreid*, and Eduardo Ducla-Soares*

Summary: Purpose: The understanding of brain activity, and in particular events such as epileptic seizures, lies on the characterisation of the dynamics of the neural networks. The theory of non-linear dynamics provides signal analysis techniques which may give new information on the behaviour of such networks. Methods: We calculated correlation dimension maps for 19-channel EEG data from 3 patients with a total of 7 absence seizures. The signals were analysed before, during and after the seizures. Phase randomised surrogate data was used to test chaos. Results: In the seizures of two patients we could distinguish two dynamical regions on the cerebral cortex, one that seemed to exhibit chaos whereas the other seemed to exhibit noise. The pattern shown is essentially the same for seizures triggered by hyperventilation, but differ for seizures triggered by light flashes. The chaotic dynamics that one seems to observe is determined by a small number of variables and has low complexity. On the other hand, in the seizures of another patient no chaotic region was found. Before and during the seizures no chaos was found either, in all cases. Conclusions: The application of non-linear signal analysis revealed the existence of differences in the spatial dynamics associated to absence seizures. This may contribute to the understanding of those seizures and be of assistance in clinical diagnosis.

Introduction

Over the last few years there has been an increasing interest in the application of non-linear dynamics theory, commonly referred as chaos theory, to brain activity. Those studies have mostly been concerned with EEG signals from intracranial or scalp recordings, in animals or human subjects, and considered in particular epilepsy, sleep, cognitive and evoked responses (see e.g., Elbert et al. 1994; Pritchards and Duke 1995).

Chaos theory (Schuster 1984; Bassingthwaighte et al. 1994; Elbert et al. 1994) allows a characterisation of the dynamics of complex systems from the analysis of a signal generated by the system, which consists of a series of measurements in time of a pertinent and easily accessible variable. In brain studies one uses EEG data to investigate the dynamics of the neuronal networks.

EEG signals show in general great irregularity that may have different origins, i.e., it may be simply due to noise or otherwise may reflect the presence of chaos. Chaos is irregular behaviour that occurs in deterministic systems with a small number of independent variables that are non-linear. Noise is simply produced by random fluctuation of many variables. Chaos theory allows a distinction on whether the irregularities in the EEG signal are due to chaos or noise. Such approach may therefore provide a new insight into the dynamics of brain activity since the two situations involve different underlying mechanisms. In the presence of chaos, the complexity of the dynamics can be quantified in terms of the properties of the attractor in phase-space, e.g., its correlation dimension D. Dimensional analysis may therefore provide a classification of brain activity in terms of its complexity. However a careful discussion is necessary to distinguish chaos from noise because finding a correlation dimension D₂ is a necessary but not a sufficient condition for chaos. Even though the presence of chaos cannot be assured, the correlation dimension analysis may provide valuable information as a tool to detect differences in the dynamic behaviour associated with different degrees of determinism.

There are different types of epilepsy (Lopes da Silva and Niedermeyer 1993), of a focal or generalised nature. Epileptic seizures may occur spontaneously or may be induced by various means. Well-controlled intracranial EEG recordings were performed in rats with focal epilepsy.
and the data was analysed using chaos theory (Pijn et al.
1991), in order to test the ability of this tool to detect the
epileptogenic focus and the spread of the seizure activity.
A decrease of the correlation dimension $D_2$ was observed
at the seizure onset. Later, chaos analysis was applied to
intracranial EEG recordings from a group of patients with
unilateral temporal lobe epilepsy (Lehnerty and Elger
1995). A low value of $D_2$ was found during the seizure,
again especially at the zone of ictal onset. Recently, Pijn
et al. (1997) carried out a very thorough analysis of chaos in
intracranial EEG recorded signals, during interictal and
ictal states, of temporal lobe epileptic patients. Although
they were not able to ascribe a value of $D_2$ to the signals
showing seizure activity, they found significant evidence
of the existence of a considerable degree of determinism in
the system generating those signals. On the contrary, they
found that signals from areas that did not show seizure
activity were almost indistinguishable from the same sig-
nal with randomised phases, regardless of whether they
were recorded during interictal or ictal states. They then
concluded that, in the particular case studied, chaos analy-
sis yields good results in terms of locating the epileptogenic
region and following the ictal spread throughout the brain.
Looking at a generalised type of epilepsy, Babloyanz and
Destexhe (1986), who were the first to apply chaos theory
to epileptic activity, analysed EEG signals from an absence
seizure recorded at two different sites on the brain. They
found chaos in the signals, with a low value of $D_2$ which
implies low complexity. Chaotic behaviour with a higher
value of $D_2$ was also reported (Frank et al. 1990) for epilep-
tic activity but, in this case, the seizures were a generalised
state with both absence and grand mal events.

In this work we present a chaos analysis of 19-chan-
nel EEG data normally recorded in a clinical setting, from
patients with absence seizures. This type of generalised
epilepsy usually invades the entire cerebral cortex and
shows, in general, a bilateral symmetry between the two
hemispheres. Our purpose on analysing such a set of
channels is to detect possible spatial variations in the
cerebral dynamics. We present maps of the correlation
dimension $D_2$ over the brain, for a total of 7 seizures from
3 patients, stimulated either by hyperventilation or light
flashes. Those seizures were selected from a more ex-
tended set of data (18 seizures from 9 patients) as they are
representative of the different dynamical behaviours that
we found and that will be presented in this work. We
analyse the EEG signals before, during and after the
epileptic seizures, in order to look at differences in the
dynamics of the neuronal networks at the various states.
This may allow a characterisation of the epileptic activity.
In order to have a stronger test to distinguish chaos from
noise we compare our original EEG signals with surro-
gate data obtained through phase randomisation of their
Fourier components (Pijn et al. 1991).

Materials and Methods

Data acquisition

Electroencephalographic recordings of 19 channels
in a standard 10/20 referential configuration, were taken
from patients with absences. The signals were recorded
before, during and after the epileptic seizures. These
were triggered by hyperventilation or light flashes. The
reference potential was given by the average of the sig-
nals at electrodes located on each side of the chin. A
Bio-Logic recording system was used with an acquisition
rate of 100Hz or 200Hz, and the signals were filtered
high-pass 1Hz, and for the sampling rate of 200Hz also
with a low-pass 70Hz (the highest value available for
spontaneous activity recording, in the system used).

Data analysis

We start by presenting the most traditional forms of
data analysis, direct inspection of the time series, power
spectrum and auto-correlation, and then evolve into tech-
niques of chaos theory, which will allow a distinction on
whether the irregularities in the EEG signals are noise or
possibly chaos; in the latter case a quantitative charac-
terisation of the complexity of the dynamics is provided
in terms of the correlation dimension $D_2$.

EEG signal

Signals associated to a triggered epileptic seizure
were observed over the entire scalp. Figure 1 shows
EEG recordings at two different channels on a patient.
During the seizure the electrical potential of the brain
$V(t)$ suddenly increases by typically a factor of ten,
switching into a series of spike - slow wave complexes
with a dominant frequency of $\approx 3$Hz, which shows some
irregularity. All the signals observed, at the different
channels on each patient, seem to exhibit the same
structure, though with differences in amplitude de-
pending on the site. The measured seizures had dur-
ations from about 7 to 15s.

Power spectrum

The power spectrum gives information on the fre-
cuency values present in the signal and their weights.
Although the power spectrum has played a major role in
data analysis, it misses crucial information on the phase
contents of the signals. Figure 2 shows the power spec-
trum of the signals in figure 1. One can see a large peak
at $\approx 3$Hz (and the harmonic at $\approx 6$Hz), and a broad band
around that value extending from lower to higher fre-
cuencies. This band is associated to the irregularities in
the EEG signal. The power spectrum for all the signals,
at the different channels on a patient, seem to exhibit the