Disturbance of patterns in EEG spatial correlations [*]

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Abstract

In the study of epileptic seizure or epileptic attack , a strategy receiving increased attention is the use of nonlinear methods in detecting the earliest dynamical changes preceding seizures. The methods usually consider continuous EEG measurements from epileptic patients to predict and ultimately control seizures. As part of the inquiry into the structure of the dynamics of the brain activity we investigate changes amongst the EEG signals being recorded at different locations on the scalp. Patterns emerging from the correlation coefficients between the EEG channels seem to be disturbed with the approach of a crisis. Results show that those patterns are often disturbed 10 to 15 minutes before the beginning of crises, helping to detect the earliest dynamical changes preceding seizures.

Keywords: EEG spatial correlations, epileptic seizures

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1 Introduction

Using a metric related to the correlation coefficients between activities of pairs of EEG channels, a method is proposed to reconstruct characteristic patterns of correlation from the EEG data. The method was applied to seizure and normal activity recorded from scalp electrodes in epileptic patients. Patterns of characteristic time delays were identified from the observation of synchronous behavior between EEG channels, assembled in mono or bipolar derivations. Those patterns, which can be observed along both epileptic seizure and normal epochs, allowed for the classification of the pairs of channels into either weakly or strongly correlated ones. Few minutes before the EEG seizure initiation the characteristic time delays remain almost unchanged for the strongly correlated channels, while some weakly correlated pairs of channels display interesting changes in their typical time delays. Disturbance of the behavior of the characteristic time delays for weakly correlated channels was observed in 20 out of 22 patients. Our results do suggest the existence of a well defined structure in the space defined by the correlation coefficients between EEG channels and their typical time delays. Moreover, results also show that disturbance in that correlation structure is empirically related to the beginning of a seizure; suggesting that, some weakly correlated pairs of channels may display a different pattern of synchronous coupling when a seizure approaches.

2 Data collection

EEG signals were recorded in epileptic patients with diverse forms of epilepsy and epileptic seizures, mainly pharmacorresistent epilepsy under polytherapy, during routine EEG videomonitoring sessions for seizures assessment (seizures qualification and quantification). EEG was digitally recorded (124 Hz sampling) and refformated in monopolar (common reference averaging or Cz) or bipolar linkages. Each documented seizure (by Video and Technician observation) was marked and the signals, up to one hour before seizure initiation, during seizure and after seizure termination and EEG normalization. This data was stored for latter processing.

3 Method

Consider EEG signals recorded at 16 different locations on the scalp over some time interval as Fig.1 shows.

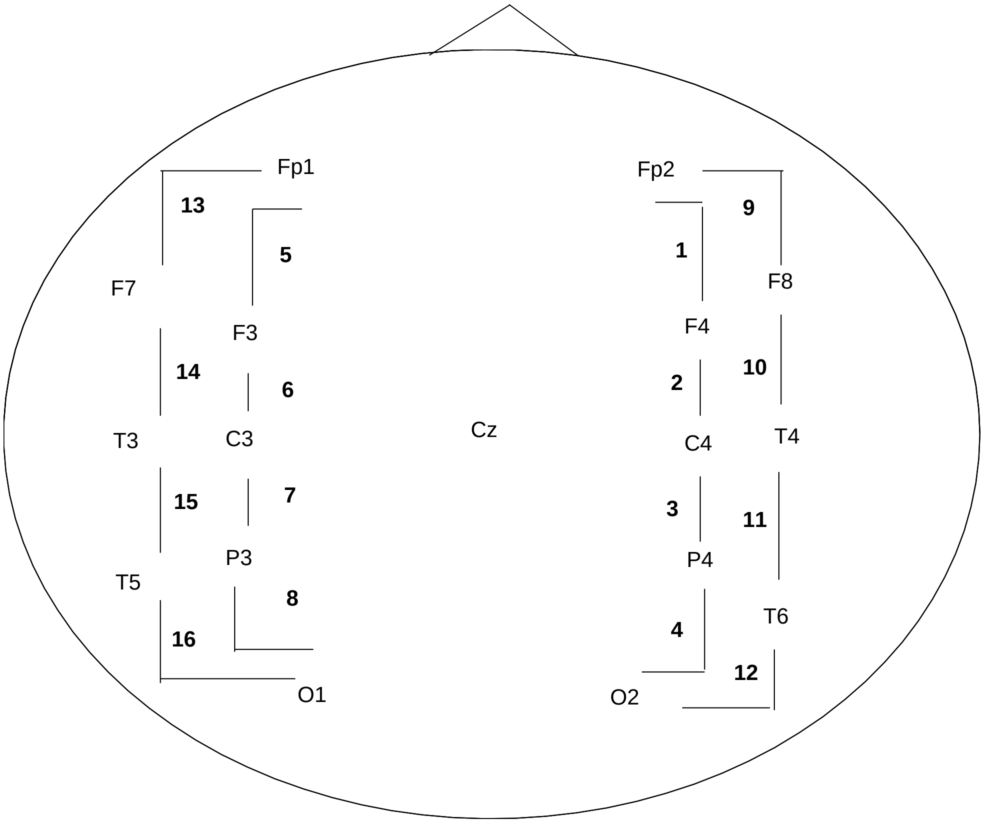

Figure 1: Monopolar Montage and Channel Numeration

The idea is simply stated in the following terms:

1. Plot the individual signals recorded at the 16 EEG channels.
2. Classify the set of EEG signals accordingly to the synchronization pattern being observed from the plots.

   Typical sets are those displaying apparent synchronous behavior between channels whose order numbers differ from a multiple of k, $k \in N$.

In those cases, the EEG patient is referred to as being a module-k patient, since when the signals in his EEG channels of order i and j display a similar behavior then $|i - j| = m.k \quad m, k \in N$.

Twenty-two patients/seizures have been studied. From the application of the method, we could verify that for 13 patients $k = 3$ and for 9 patients $k = 4$. Fig.2 shows an example of the 16 EEG plots of a module-4 patient.

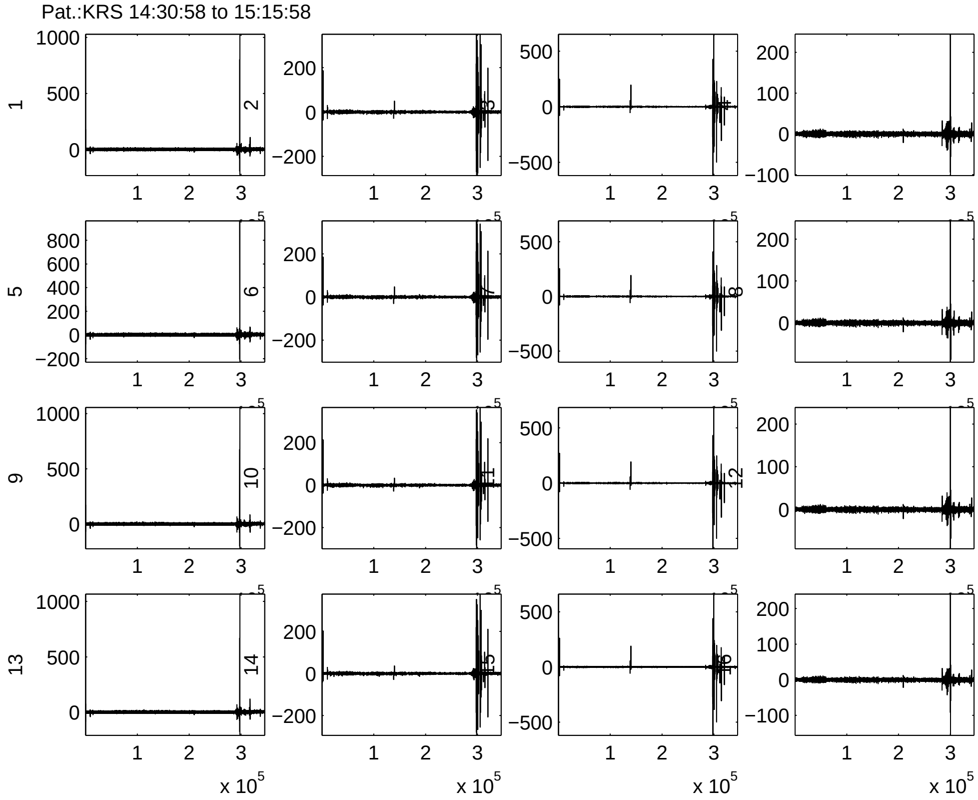

Figure 2: EEG plots of module-4 patient ($k = 4$)

3. Classifying a patient/seizure as module-k allows for formally defining *linked* channels.
    - channels i and j are *linked* $\Leftrightarrow |i - j| = m.k \quad m, k \in N$

For a patient module-4 the following pairs of channels are examples of *linked* channels: $[2, 6], [2, 10], [2, 14]$ and $[1, 5], [5, 9], [1, 13]$.

Although *linked* channels seem to display synchronous behavior, when the correlation coefficients C_{ij} between pairs of *linked* channels are compute, the resulting values do not show the existence of any stronger correlation, being the values of C_{ij} close to those obtained for the correlation between any other pair.

However, when a time-delay is introduced between the *linked* channels, the similarity that is observed in their corresponding plots can be formally recognized. To this end, we proceed through the following steps.

4. For each pair of *linked* channels s_i and s_j compute the correlation coefficient $C_\theta(i, j)$ at multiple time delays (θ).

$$C_\theta(i,j) = \frac{\langle s_i . s_{j\theta}\rangle - \langle s_i\rangle . \langle s_{j\theta}\rangle}{\langle \sigma_i . \sigma_{j\theta}\rangle} \tag{1}$$

$$\theta = \frac{\Delta_t}{128} \quad \Delta_t = 0, 1, 2, 3, 4 \tag{2}$$

5. It was empirically observed that, for each pair of *linked* channels s_i and s_j, there is a typical value of θ that maximizes the correlation coefficient $C_\theta(i, j)$

6. The typical values of θ can be computed from the difference between the order numbers of the *linked* channels s_i and s_j, as below (eq.3).

$$\theta(i,j)_{max} = (\frac{\Delta_t}{128})\frac{i-j}{k} \quad \Delta_t = 0, 1, 2, 3, 4 \tag{3}$$

The first plot in Fig.3 shows the histograms of the values of θ that maximizes the correlation coefficients between three pairs of *linked* channels. The second plot shows the same results obtained for three pairs of *unlinked* channels.

Meanwhile, the patterns emerging from the correlation coefficients between the EEG channels seem to be disturbed with the approach of a crisis. The disturbance of the behavior of the characteristic time delays for *unlinked* pairs is observed in 20 out of 22 patients.

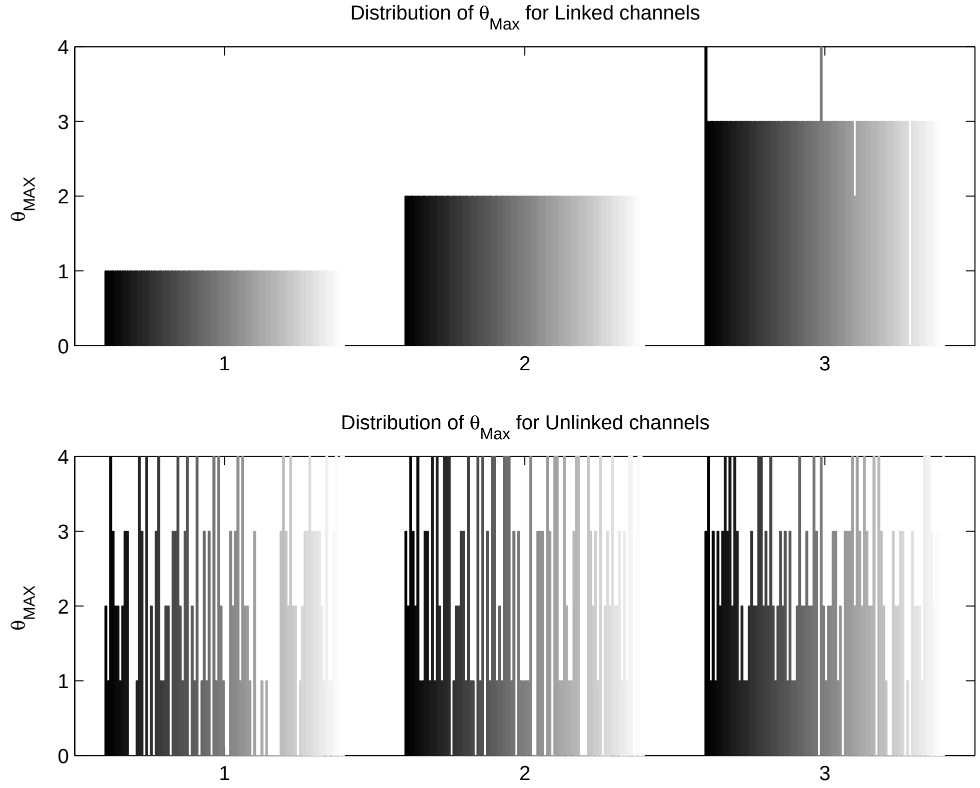

Figure 3: Histograms of the values of θ_{max} for 3 pairs of *linked* and for 3 pairs of *unlinked* channels (bottom)

Few minutes before the EEG seizure initiation the characteristic time delays remain almost unchanged for the*linked* pairs, while some *unlinked* pairs display interesting changes in their typical time delays.

The plots in Fig.4 show the values of θ_{max} varying in time for a pair of *linked* channels (top) and for *unlinked* pairs (bottom). The vertical lines at time 12:28:48 indicate the occurrence of a seizure.

Although *unlinked* pairs display a much less uniform behavior in what concerns the values of θ_{max}, they seem to be those where the disturbance of the (weak) regular pattern is more frequently observed. This fact is illustrated in the plots presented in Fig.4. The two plots show the behavior of θ_{max} for two *unlinked* pairs ($[2,7] and [13,9]$) being disturbed

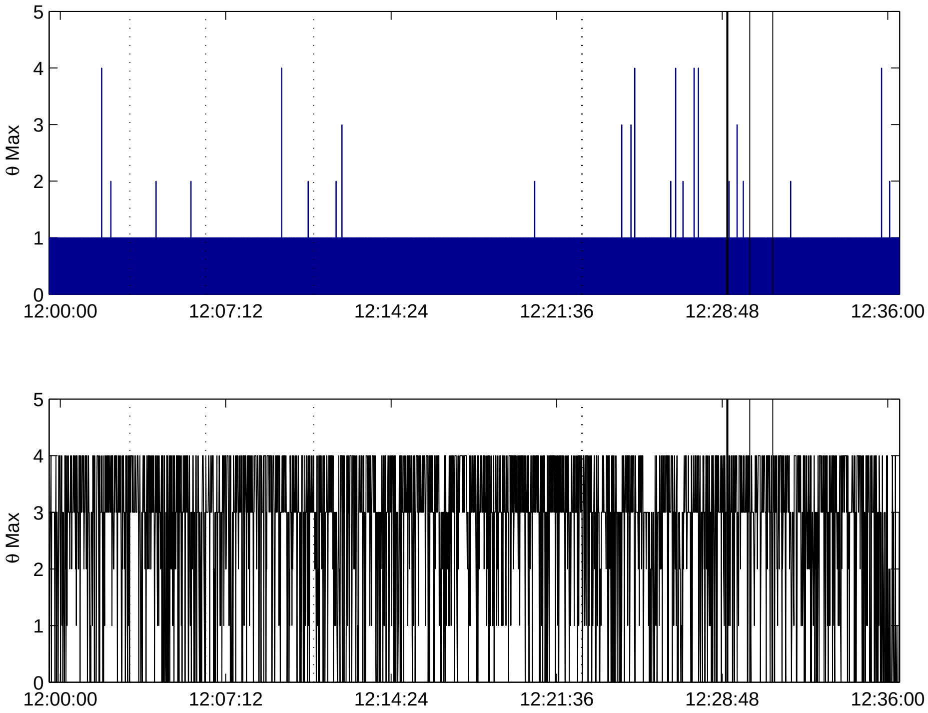

Figure 4: Values of θ_{max} varying in time for *linked* and *unlinked* channels (bottom)

as a crisis approaches. The dashed vertical lines indicate the occurrence of a seizure.

In both cases, the changes in the values of θ_{max} occur 10 to 15 minutes before the beginning of crises. In the first plot the (null) value of θ_{max} remains unchanged for almost all the observation period and 10 minutes before the occurrence of a seizure it starts to be often greater ($\theta_{max} = 4$). In the second plot the value of θ_{max} is less uniform until 13 minutes before the approaching of the crises, when it starts to display an almost constant value ($\theta_{max} = 4$) for at least 5 minutes.

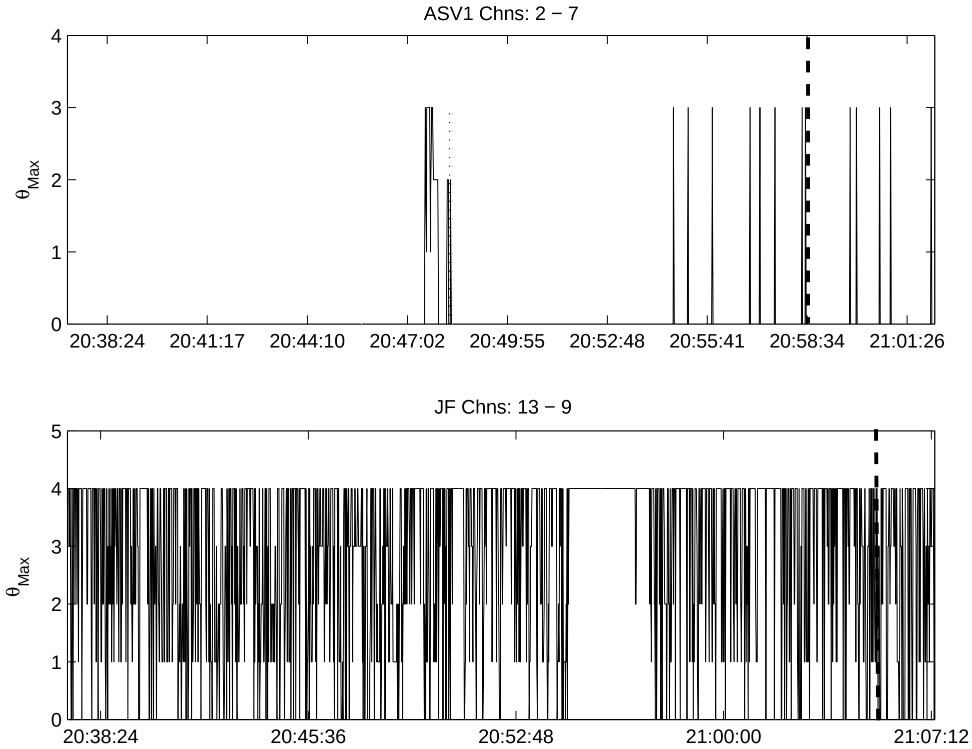

Figure 5: Values of θ_{max} varying in time for *linked* and *unlinked* channels (bottom)

4 Questions

The work presented in this working paper raised some basic questions.

1. Why are there patients module-3 and patients module-4 ?
2. Where do those patterns come from?
3. Why are they (empirically) restricted to the values three and four ?
4. Why are they persistent in both monopolar and bipolar montages?
5. Would there be other events (besides the approach of a seizure) that change the values of the characteristic delay θ_{max} ?

Future developments shall provide suitable answers to the above questions. Finally, the predictive character of our approach is also to be explored in future work.

References

[1] R. Vilela Mendes, T. Araújo and F. Louçã (2003), "Reconstructing an Economic Space from a Market Metric", Physica A, 323, 635-50.