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Prediction of epileptic seizures using accumulated energy in a multiresolution framework

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Abstract

Records of brain electrical activity from intracranial EEG of four patients with different types of epilepsy are analyzed to predict the epileptic seizure onset. A method based on the evolution of the accumulated energy using wavelet analysis is introduced. This is an efficient method to predict epileptic seizures: from 13 preseizure signals, the seizure onset in 12 of those are predicted.

Keywords: Intracranial EEG; Wavelet analysis; Prediction; Epileptic seizure

1. Introduction

One of the most devastating features of epilepsy is the apparently random nature of seizures. In most patients, seizures occur suddenly, without external, previously detected, precipitants. A system able to predict seizures would allow some preventive measures to keep the risk of seizure to a minimum. These measures could improve the quality of life of patients with epilepsy.

Intracranial recordings of patients who are candidates for surgical treatment offers the most precise access to the emergence of a seizure, and will be used in this paper. As it was recently pointed out (Le Van Quyen et al., 2001), changes in scalp electrical activity are similar to those detected from intracranial recordings. Then, the analysis of EEGs from depth electrodes give important information about the onset of seizures that could be applied to scalp records.

In previous papers (Lehnertz and Elger, 1998; Le Van Quyen et al., 2000; Martinerie et al., 1998) was shown that the evolution towards a seizure involves not just two states—interictal and ictal—but also a preictal transitional phase of several minutes that could be the basis to anticipate seizures in clinical applications. This idea is used in this paper.

The first works on forecasting epileptic seizures began in 1975 (Viglione and Walsh, 1975; Viglione et al., 1973). From that times other mathematical techniques were introduced, and different approaches to the problem were intended (Chillemi et al., 2001, 2002; Lehnertz and Elger, 1998; Litt and Echauz, 2002; Litt et al., 1999, 2001; Martinerie et al., 1998).

It was recently described an algorithm for predicting epileptic seizures based on accumulation of energy function calculated from the EEG signal (Litt et al., 1999, 2001). We introduce in this paper a prediction algorithm based on the accumulated energy function but in a multiresolution framework. A multiresolution analysis (Mallat, 1998) split the EEG signal in several frequency bands using a bank of digital filters with decimation. Thus, a detailed analysis of the EEG is obtained, and information hidden in the accumulated energy function proposed in the cited papers is explicited. The results obtained in the study of 13 seizures are shown.

2. Materials and methods

The method of prediction introduced in this paper is based on comparisons between the accumulated energy in epochs

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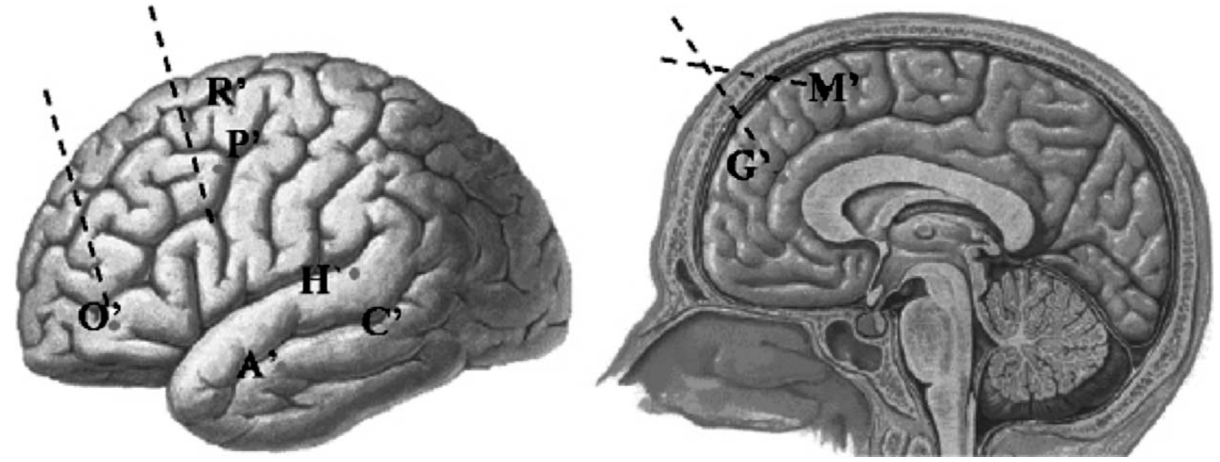

Fig. 1. Placement of electrodes in patient 2.

of preictal activity and background activity. Records of brain electrical activity from intracranial electrodes corresponding to 13 seizures and 7 background epochs were analyzed. They correspond to four patients, two males and two females, candidates to surgery. For each one a clinic history, complete neurological exam, neurophysiological evaluation, brain magnetic resonance and video electroencephalography were realized. The patients were evaluated with stereoelectroencephalography technique (Binnie et al., 1994; Munari et al., 1994). Depth electrodes with 5–15 contacts were implanted in different zones of the brain using the Talairach method (Talairach et al., 1974) (see Fig. 1).

The regions explored with depth electrodes were defined as epileptic zones from conclusions obtained from non-invasive analysis. The number of electrodes ranges from three to six according to the complexity of the epileptic zone, and their position verified by magnetic resonance. The EEG signals were recorded using 200 Hz as sample frequency. Expert neurologists analyzed these records in visual form using Vector EEE32, BioScience, with EEG Harmonie Stellate software. The epileptic types are shown in Table 1.

The wavelet used in the signal analysis was the Daubechies-4 (Daubechies, 1992). It is an orthonormal wavelet, and then, the signal energy in each level j of the multiresolution analysis is:

$$E_j = \sum_{i=1}^{N_j} d_j^2(i),$$

where $d_j(i)$ $(i = 1, \ldots, N_j)$ are the wavelet coefficients in the level j, and N_j the amount of wavelet coefficients in the level j.

The accumulated energy in each level was calculated using the following formula:

$$\mathrm{AE}_j(k) = \sum_{i=a(k+1)+1}^{a(k+1)+b} d_j^2(i) + \mathrm{AE}_j(k-1), \qquad (1)$$

where b is the width of the window and $b - a$ the overlap. Levels $j = 1, \ldots, 8$ are used, because there is no relevant information in the levels corresponding to low frequencies (<0.5 Hz). The algorithm of prediction is based on the two following steps:

(1) the computation of the slope of the least square straight line to $\mathrm{AE}_j(k)$ function;
(2) the evaluation of the ratio between the slopes of the preseizure signal and the background signal in each level of the multiresolution analysis.

3. Results

The results presented in this section correspond to signals recorded from electrode contacts placed in or very close to zones generating the seizures, previously described. The epochs corresponding to the background signal used as reference in the prediction algorithm were chosen several hours before the seizure onset. Fig. 2 shows the behavior of the

Table 1
Epilepsy types corresponding to analyzed patients 13 preseizure and 7 background signals of 90 min each one were analyzed

Patient	Epilepsy types	Epileptic focus
1	Lateral (or neocortical) temporal lobe seizures	Left gyrus temporal superior cortex
2	Lateral (or neocortical) temporal lobe seizures	Left gyrus temporal superior cortex
3	Medial–lateral temporal lobe seizures	Right amygdala and hippocampus
4	Neocortical occipito-parietal lobe seizures	Right lateral occipito-parietal cortex

The preseizure signals contain 70 min before the onset of the seizure.

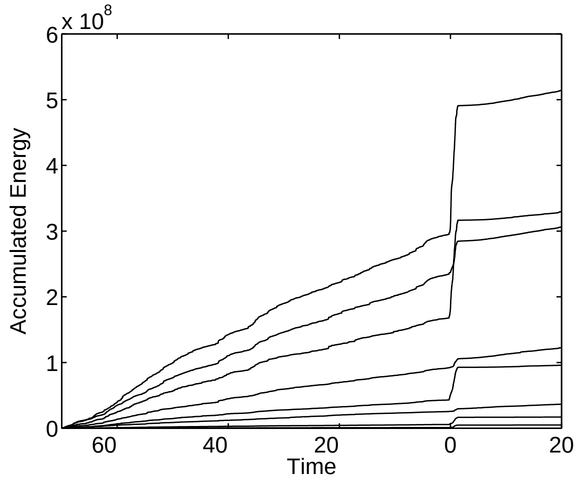

Fig. 2. Accumulated energy in each level of the multiresolution considered, for a preseizure epoch.

eight levels of the accumulated energy as function of time, corresponding to patient 1.

In all cases, the least square line that approximates the accumulated energy function (AE) in the preseizures epoch in each multiresolution level has a slope S_S different to that of the least square line that approximates the accumulated energy function in the background epoch, S_B. The ratio $r = S_S/S_B$ is proposed as parameter in order to predict the seizure onset. Fig. 3a–d show representative examples of values of r corresponding to two channels in four seizures, one for each patient.

Table 2 summarizes the results obtained. When $r = 1$, there is no difference between the epochs analyzed. A threshold should be defined for deciding if there is a difference between the behavior of the AE in the preseizure epoch and in the background epoch. In the case of awake patients, the ratio r becomes greater than 1, but in asleep patients, the ratio r is smaller that 1. Taking into account this fact, two thresholds defined, $\varepsilon_1 > 0$ and $\varepsilon_2 > 0$. Values $r > 1 + \varepsilon_1$ (awake cases) or $r < 1 - \varepsilon_2$ (asleep cases), indicate that the seizure onset is near. The smaller ε_1 and ε_2, the greater the possibility of false alarms. For the group of patients studied, we choose $\varepsilon_1 = 0.3$ for awake state and $\varepsilon_2 = 0.35$ for asleep state. The seizure is predicted when $r > 1.3$ in the first case, and $r < 0.65$ in the second case, in the three first levels of the multiresolution accumulated energy. The results are shown in Table 2. In the first column named “Pred”, the results corresponding to the multiresolution analysis are presented: Y means yes, i.e., the seizure is predicted using the parameter r, and N means no. As can be seen, only in one case the method fails. Using the accumulated energy function without the multiresolution analysis, the results are

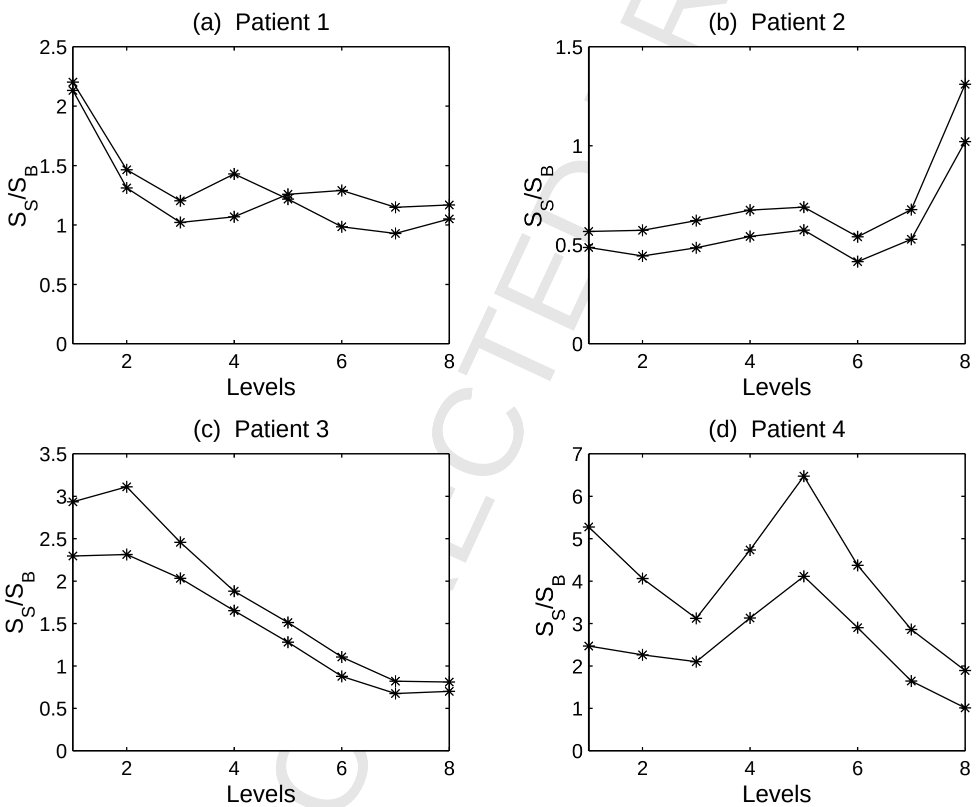

Fig. 3. The r values in two channels placed in or near the seizure foci, in each level of the multiresolution. In (a–d), the patients were awake and in (b), the patient was asleep.

Table 2
Ratio between the slopes in each level of the multiresolution analysis and the total accumulated energy

Seizure	State	Patient	AEp_j/AEb_j levels									AEp/AEb	
			1	2	3	4	5	6	7	8	Pred	Total	Pred
1	Awake	1	1.3	1.5	1.8	2.0	2.6	2.9	3.0	4.1	Y	2.65	Y
2	Awake	1	2.1	1.3	1.0	1.1	1.3	1.3	1.1	1.2	Y	1.21	N
3	Awake	1	1.9	2.0	1.7	1.8	1.9	2.0	2.6	3.1	Y	2.01	Y
4	Awake	2	1.1	1.3	1.4	1.4	1.3	1.1	0.9	1.0	N	1.18	N
5	Awake	2	1.4	1.4	1.4	1.5	1.4	1.2	1.2	1.2	Y	1.21	N
6	Awake	3	2.9	3.1	2.5	1.9	1.5	1.1	0.8	0.8	Y	1.27	N
7	Awake	3	2.3	2.7	2.4	2.1	1.8	1.6	1.2	1.0	Y	1.62	Y
8	Awake	4	5.2	3.3	1.3	1.3	1.2	0.8	0.8	0.8	Y	1.04	N
9	Awake	4	2.5	2.2	1.6	1.8	1.6	0.8	0.6	0.5	Y	1.16	N
10	Asleep	1	0.5	0.4	0.4	0.6	0.8	0.8	0.6	0.6	Y	0.68	Y
11	Asleep	1	0.1	0.2	0.4	0.5	0.6	0.6	0.3	0.3	Y	0.49	Y
12	Asleep	1	0.3	0.4	0.6	0.9	1.3	1.6	0.9	0.7	Y	1.11	N
13	Asleep	2	0.5	0.4	0.5	0.5	0.6	0.4	0.5	1.0	Y	0.51	Y

The seizure forecast is more effective in the first case.

shown in the last column of Table 2. With the same values of the thresholds, only 6 out of the 13 cases are predicted. In order to improve this performance, the value of the threshold should be smaller, but then the possibility of false alarms is greater. This fact shows the advantage of the use of the accumulated energy function in the framework of multiresolution analysis.

Some remarks about the prediction algorithm introduced in this paper:

(1) In order to get a fast algorithm, the lifting method (Daubechies and Sweldens, 1998) for calculating the wavelet coefficient is used. This method leads to a speed-up of around two times when compared to the standard implementation and allows for an in-place implementation of the fast wavelet transform.
(2) The results obtained do not depend neither the width nor the overlapping in Eq. (1); and, as a consequence, the choice is made taking the computational burden into account.
(3) The value of ε_1 and ε_2 can change for different patients.

4. Conclusions

Through the results obtained we conclude that the wavelet-based method applied to the accumulated energy would contribute for predicting epileptic seizure onset from EEGs signals. Using the accumulated energy in a wavelet framework, we could forecast the onset of epileptic seizures 70 min before in the cases analyzed. This analysis can supply complementary information potentially useful from a clinical point of view.

Uncited reference

Viglione et al. (1970).

Acknowledgements

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