AUTOMATIC DETECTION AND LOCALIZATION OF EPILEPSY IN THE ELECTROENCEPHALOGRAM

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1 Introduction

Electroencephalography (EEG) is a non-invasive tool which measures the electrical activity of the brain at the scalp. EEG is routinely used in the diagnosis of patients with epilepsy. A neurologist looks for transients (spikes) in the EEG which are related to epilepsy. When these transients are found in the EEG it is likely that the patient has epilepsy. Manual detection of these spikes is laboursome. So an automatic detection algorithm may save al lot of time.

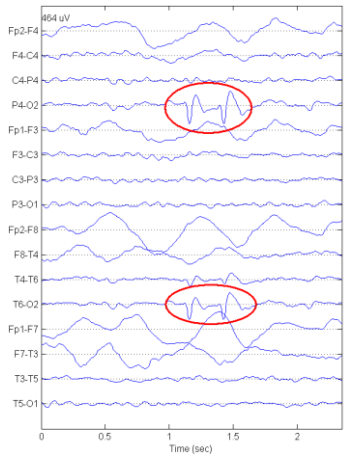


Figure 1: EEG with epileptiform spikes.

The background of the EEG also contains focal activity arising of the same area as the epileptiform activity [1]. This may provide a new perspective on extracting clinical useful information from the EEG of patients with epilepsy.

In this paper we propose an algorithm based on Independent Component Analysis (ICA) [2,3,4] and dipole source localization [5] to automatically detect and localize epileptiform spikes and focal activity in the EEG.

2 Materials and Methods

2.1 Detection and localization of epileptiform spikes.

As a preprocessing step, the Teager energy operator was applied to the raw EEG.

$$T[x_n] = x^2_n - x_{n-1}.x_{n+1}$$

with x_n, x_{n-1}, x_{n+1} respectively the current, previous and next sample. This operator has a quadratic relationship with the immediate amplitude and frequency (figure 2).

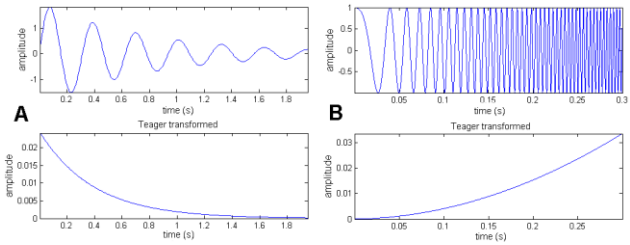


Figure 2: A: Signal with constant frequency and linear decaying amplitude (upper) and corresponding Teager transformed signal (below). B: Signal with constant amplitude and linear increasing frequency (upper) and corresponding Teager transformed signal (below).

The Teager operator amplifies the epileptiform spikes in the EEG, which facilitates the detection (figure 3).

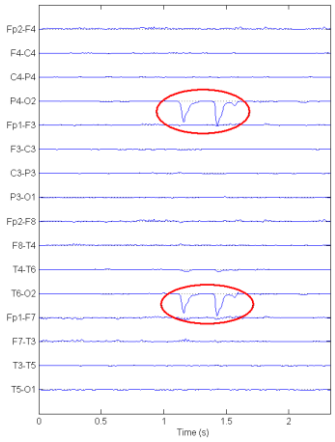


Figure 3: Teager transform of EEG in figure 1.

Comparison of figure 1 and its Teager transform in figure 3 shows that this operator amplifies the epileptiform spikes. If the transformed EEG exceeds a certain threshold an ICA-decomposition is calculated. ICA is a technique which extracts statistically independent components (S) from a set of measured signals (X) [2,3,4].

$$X = A.S$$

The goal of Independent Component Analysis is to estimate the mixing matrix A and/or the source vector S given only the measured signals X.

The ICA components are calculated from a 2s epoch centered on the detection. Only the component with the highest energy at the time of detection is selected for further analysis. This is the component responsible for the high energy in the measured EEG.

Some artifacts like eye blinks and muscle activity also have a high energy and are also detected by this method. In order to reduce these false positives a wavelet analysis (db1 wavelet) is performed on the selected ICA-component. Epileptiform spikes have a high contribution in different wavelet scales (figure 4) [6]. This property is used to discriminate between spikes and artifacts. This is done by calculating the kurtosis of each component and defining a threshold.

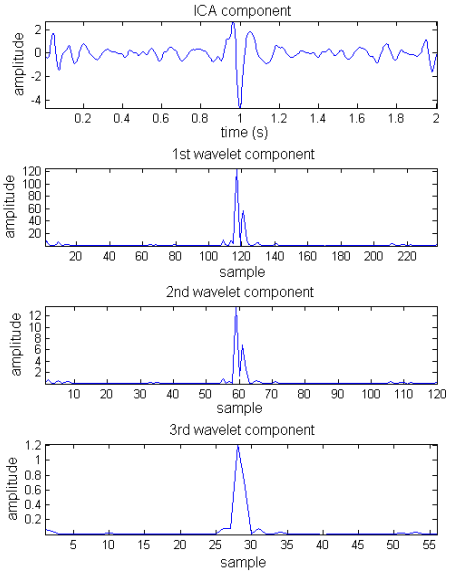


Figure 4: Three wavelet components of a selected ICA component which corresponds to an epileptiform spike.

After removal of the artifact components, the remaining components are localized by using dipole source localization. This technique uses a 3-layer spherical head model in which a dipole is calculated that minimizes the relative residual error (RRE) between the measured potential distribution (V_{MEAS}) and the generated potential distribution by the dipole (V_{DIP}) [5]:

$$RRE = \frac{|V_{DIP} - V_{MEAS}|^2}{|V_{MEAS}|^2}$$

The RRE is the fraction of energy which can not be explained by the dipole model.

2.2 Detection and localization of focal activity in the background EEG.

Vanrumste et al [1] has proven how Singular Value Decomposition (SVD) can be used to detect focal activity in the background EEG. This method has the disadvantage that there may be only one dominant generator in the selected epoch. We investigated the use of ICA instead of SVD. This results in a method which is not dependent on the number of generators in the EEG.

The EEG is divided into overlapping epochs with length of 2s and a step of 200ms. Each epoch is decomposed by ICA into independent components. Now we want to select an ICA-component which corresponds to background activity. This is done by reconstructing the EEG based on each ICA-component separately (figure 5).

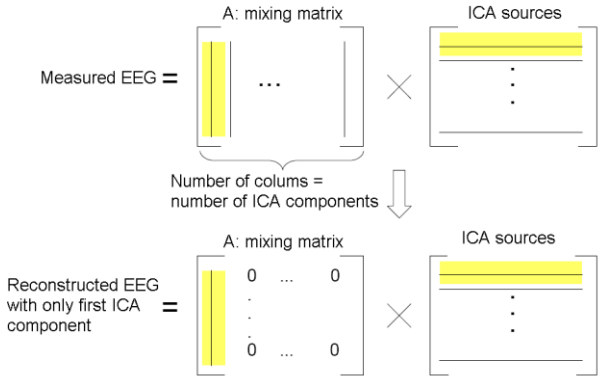


Figure 5: Reconstruction of EEG based on one ICA-component.

The component with the highest summed amplitude (absolute value) in the recombination is then selected. In this way we have selected a component which has a high contribution during the whole epoch of 2s and not short activity like epileptic spikes (±30ms). The selected component is then localized by using dipole source localization.

2.3 EEG data

We analyzed 9 19-channel scalp EEGs from epileptic patients with a total recording time of 155min. The recordings contained both epileptic spikes and large artifacts (due to movement, eye blinks).

3 Results

3.1 Spike detection

The proposed spikedetector has a sensitivity of 86% and a selectivity of 51% in average for the 9 patients. The low selectivity is due to artifacts (mainly muscle artifacts). This can be improved by artifact reduction before the analysis. The localization of the detected

spikes corresponded in 7/9 patients very well with the diagnosis of the neurologist (table 1). In 2 patients there was no clear focal spot. Figures 6 and 7 show some detected spikes and the corresponding localization (only localizations with RRE<4% are shown). The dipole locations are visualized inside the 3 shell model. The left figure is a frontal view of the head, the middle a top view and the one on the right a side view.

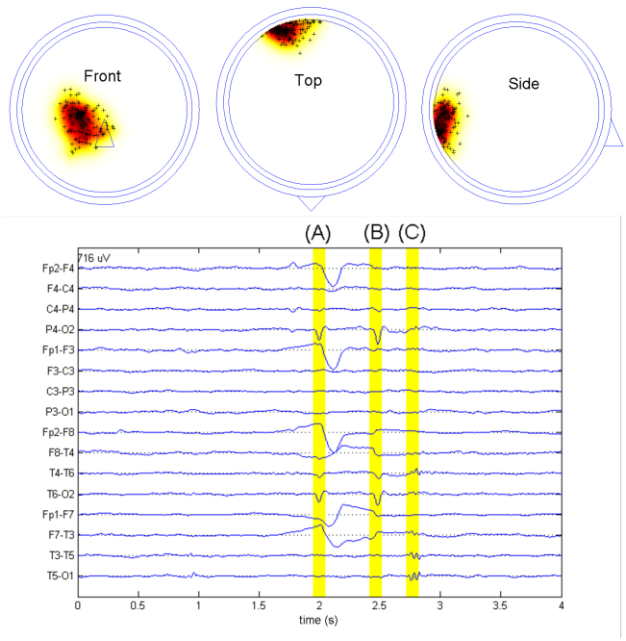


Figure 6: Result of the localization of epileptic spikes and the corresponding EEG of a patient with right lobe occipital epilepsy. (A) and (B) are detected epileptiform spikes, (C) is a false positive (artifact).

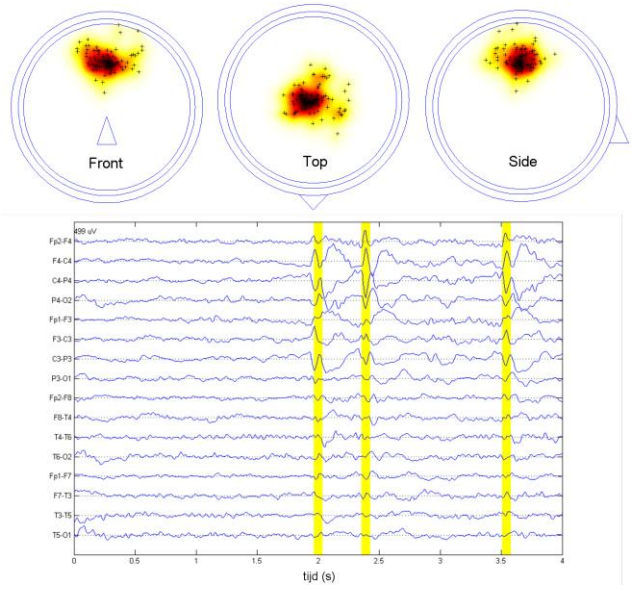


Figure 7: Result of the localization of epileptic spikes and the corresponding EEG of a patient with central lobe epilepsy.

3.2 Background analysis

The proposed background analysis clearly indicates in 7/9 patients the same focal spot as the diagnosis of the neurologist (table 1). So clearly a lot of focal activity can be found in the background EEG. There is no difference in localization between the SVD based method and the new ICA method. But the ICA-method finds much more focal activity. On average 2339 detections per patient compared to 719. This is illustrated in figure 8. The color bars indicate the density of the detections.

Table 1: Results of the localization of the epileptiform activity. R: right, L: left, O: occipital, C: central, T: temporal, P: parietal, ++: very similar, +: similar, -: large spread.

Patient	Spikedetection	Neurologist	ICA-analysis	SVD-analysis
1	LC	C (+)	C (+)	C (+)
2	O	RO (+)	RO (+)	RO (+)
3	LO	LOP (+)	LOP (+)	LOP (+)
4	RF	RF (++)	RF (++)	RF (++)
5	RC-T	RC-T (++)	RC-T (++)	RC-T (++)
6	LP-T	LP-O (+)	LP-O (+)	LP-O (+)
7	RF-T	RC-T (+)	RC-T (+)	RC-T (+)
8	RC-T + LC	RT (-)	C (-)	C (-)
9	RT-LT	C (-)	C (-)	C (-)

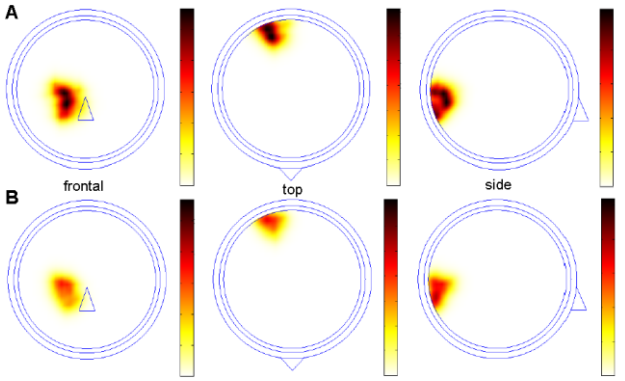


Figure 8: Comparison of the density of detections by the SVD based method (bottom) with these of the ICA-based method (top). The ICA-based method clearly detects more activity arising from the epileptiform region of the brain. Both methods find a similar location.

The results shown in figure 8 are calculated for the same patient as those shown in figure 6. Comparison of the results shows that the location found by localizing the detected spikes (figure 6) is the same as the localization of the selected background activity (figure 8). This was the case in 7/9 patients.

4 Discussion

These results show that dipole localization of epileptiform spikes may be a valuable tool for the

neurologist to localize the epileptiform region. It is also striking that the same region can be found by analysis of the background activity. The SVD and ICA method showed similar results although the ICA method is able to extract more activity arising from the epileptiform region.

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