Performance Evaluation of SWT and ICA Techniques for Automatic Separation between Oscillations and Epileptic Spikes by SWT and ICA Techniques

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Abstract

In this work, we studied two approaches for separating the signal mixtures observed by FO electrodes, which are filtered techniques, independent component analysis (ICA) and transformed into wavelets. Precisely, we will study two methods to solve the problem of overlap between the spikes and the oscillation. To do this, we must first study the technique of analysis in independent components and implement it for the separation between these two biomarkers of epilepsy. Next, we will evaluate the performance of the ICA method and the Stationary Wavelet Transform (SWT) filtering method.

Key Words: Spikes, SWT, ICA, Epilepsy, FO.

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Introduction

Clinical research mainly focuses on the application of new technologies for diagnosis, treatment and therapy, while basic research is interested in understanding the mechanisms underlying the development of epilepsy, its causes, its different manifestations and its impact on brain function.

The field of neuroscience takes a big leap in time because of the development of brain activity recording techniques (EEG, MRI, MEG) that allow us to diagnose and detect neurological diseases ([3],[8],[10]). Therefore, the electroencephalogram (EEG) illustrates the electrical activity of the brain recorded using the electrodes that put on the scalp. EEG data is characterized by its complexity and its sensitivity to various artefacts, for example: cardiac, ocular, muscular etc.

From the recording of the EEG we find that the spikes (is defined as a triangular transient clearly distinguished from the background activity, that is to say, having an amplitude of at least twice that of l activity (which are the most classic marker of epilepsy) overlap with the oscillations.

Transients usually appear in epilepsy during paroxysmal discharges (epileptic spikes). However, the oscillations can appear in both cases: pathological and healthy. In cognition, some rhythms are considered markers of the processes of concentration. The interpretation of these forms requires a clear characterization in the time-frequency domain. We can meet at the level of this characterization a complexity due to an overlap between the points (transient) and oscillations on the same traces of the EEG. In reality, false ripples generally come from simple filtering of transients in a frequency interval can cause false ripples ('false ripples' [1]).

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The choice of the technique for separating the shapes is more or less difficult and in particular, when there is a total overlap between the spikes and the oscillations.

In this work, we will study the techniques, ensuring the separation of the mixture of the transient and oscillatory signals observed in the plot of the EEG FO, we will be interested in two main methods, which are the method of analysis of the independent components, and the technique of filtering based on the stationary wavelets transform SWT.

Furthermore, we will want to extract the transients, which are characterized by a small temporal spread, and the oscillations, which can be recorded even in a healthy state. Thus, in the time-frequency domain, these forms require very precise characterization and the separation between them is a fairly difficult and delicate task due to their frequency overlap. To do this, we will use in the last chapter two techniques, which are SWT stationary wavelet filtering and the independent component analysis method in order to carefully detect and reconstruct the pre-ictal oscillations.

In this article, we will first describe our database, then we will apply our separation approaches on real epileptic data, then on simulated data in order to find separate oscillations at the spikes, then we evaluate the performance of the two methods for extracting oscillations from EEG FO data.

These two techniques will be applied, tested and validated and evaluated first on a simulated then real database: EEG FO.

Materials and Methods

Materials

We used two simulated and real pharmaco-resistant epilepsy databases. The execution of these signals is done using the "Matlab" Mathwork, Natick, MA with the assistance of EEGlab toolbox, which allows us to visualize the traces of the FO electrodes.

Simulated data. We exploited simulated data, which are inspired by real data from the EEG Foramen Ovale. This data contains six channels admitting two periods and which are sampled with a sampling frequency equal to 1000Hz.

The first period represents the oscillations (the pre-ictal state) and the second shows the crisis of large amplitude transients. Then we add a white noise characterized by an infinite average power. This noise has a spectrum of (1/f) which is similar to the real noise contaminating the recordings of real brain activities.

Using the inverse SWT function, we obtain pre-ictal oscillations (gamma) and spikes using masks [12]. Then the use of the inverse SWT (iswt) allows to reconstruct the desired part of the signal (in our case the pure pre-ictal gamma oscillations and the uncontaminated transients).

Real data. We used the actual data, which are the recordings of the Foramen Electrodes of a person with drug-resistant epilepsy. The acquisition and treatment phases have generally been set by the Clinical Neurophysiology department of La Timon Hospital in Marseille and validated by an expert neurologist; in addition, these data are recorded on the system called a Deltamed system. The FO electrodes are invasive.

These data are characterized by a sampling frequency, which is equal to 1000 Hz. The recording of the EEG FO was chosen for the analysis of the gamma wave polymorphisms and the epileptic vibrations, which represented it.

The eight deeply implanted electrodes with multi-contacts and a diameter of 0.8 mm. They are positioned in the right hemisphere. Each electrode has between 10 and 15 contacts spaced 2 mm in length, at a contact distance equal to 1.5 mm. These electrodes are implanted according to the stereotaxic method of Talairach [9].

Methods

In this part, we will explain our approach on the two spikes separation approaches (SWT and ICA).

SWT and overlap separation. In this part, we will use the SWT method (Stationary Wavelet Transform) for the extraction of epileptic oscillations. Indeed, there are several epileptic oscillations at different frequency intervals obtained by recording the FO electrodes (gamma band, theta and beta) ([2], [11]). These oscillations always appear in people suffering from pharmaco-resistant focal epilepsy.

The stationary wavelet transform (SWT) is based on a time-frequency analysis ([4], [5]). This technique is generally invariant and invertible while employing masks for the selection of specific parts in the time-frequency plane.

The general principle of the stationary wavelet transform is divided into two stages; first, represent the signal in the timescale domain by approximation and detail coefficients, then reconstruct the pure transient part again using the selected coefficients [12].

The components were chosen from the oscillatory components. In reality, the SWT is based on the application of a thresholding phase. The latter comprises first, the application of a rectangular mask in order to reconstruct the oscillations, after the decomposition step, the oscillatory components were selected from among oscillatory components. Indeed, SWT consists in applying a thresholding step which is firstly based on a rectangular mask to reconstruct the oscillations.
The final phase of the separation is the reconstruction of the detail coefficients and the approximation coefficients after thresholding. We can obtain these two coefficients through the Matlab command "iswt".
Separation between oscillations and spikes by ICA. We look for components which are statistically independent and not Gaussian, while maximizing the temporal independence of the sources. The ICA method is based on a data chain, which mainly comprises two matrices, which are the mixing matrix and the separation matrix. The usefulness of the ICA in terms of epileptic data is to separate transient activities and pure pre-ictal oscillations for preparation for the onset of a crisis.
First, we will launch the ICA test using the EEGlab toolbox on the Matlab software, once the test is finished, we get statically independent components. The ICA will be applied to the simulated data and then to the actual data.
The simulated databases consist of six channels, which are inspired by the actual data.
The EEGLAB toolbox allows us to apply several ICA decomposition algorithms like 'Jade', Fast-ICA. In our memory, we will apply the informax ('runica') algorithm to our database.
The informax algorithm is applied to Gaussian data in most cases in order to extract the independent components.
The ICA is used in the case of artefacts because they are independent of each other. The ICA allows separation of brain sources [6] such as data recorded from the EEG and the MEG.

Results and Discussion

The purpose of this work is to evaluate qualitatively the performances of two separation methods (SWT and ICA) on our data either simulated or real. To show the performances of two techniques to use we visualized the results of simulations on our simulated and real data.

SWT Detection of Pre-ictal Oscillations for Simulated Data

We will apply at the level of this section the filtering technique by SWT on simulated data. This data is composed of six channels.
In Fig. 1, we present, the signals simulated through these channels.

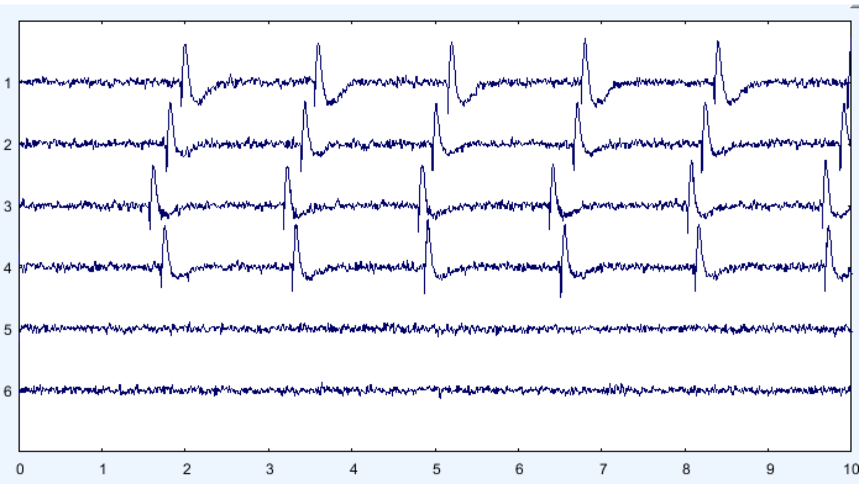

Fig. 1. Presentation of simulated data composed of six channels

We obtain a model of the pre-ictal spikes from the first to the fourth channel as illustrated in Fig. 1, this was followed by a discharge in the third and fourth channel.
We apply SWT on the second channel (with a decimation level equal to 6) and we obtain the results of the coefficients of approximation and details presented in Fig. 2 (a and b).
Then we applied a thresholding step on these two coefficients, we obtain the masks shown in Fig. 2 (c and d).

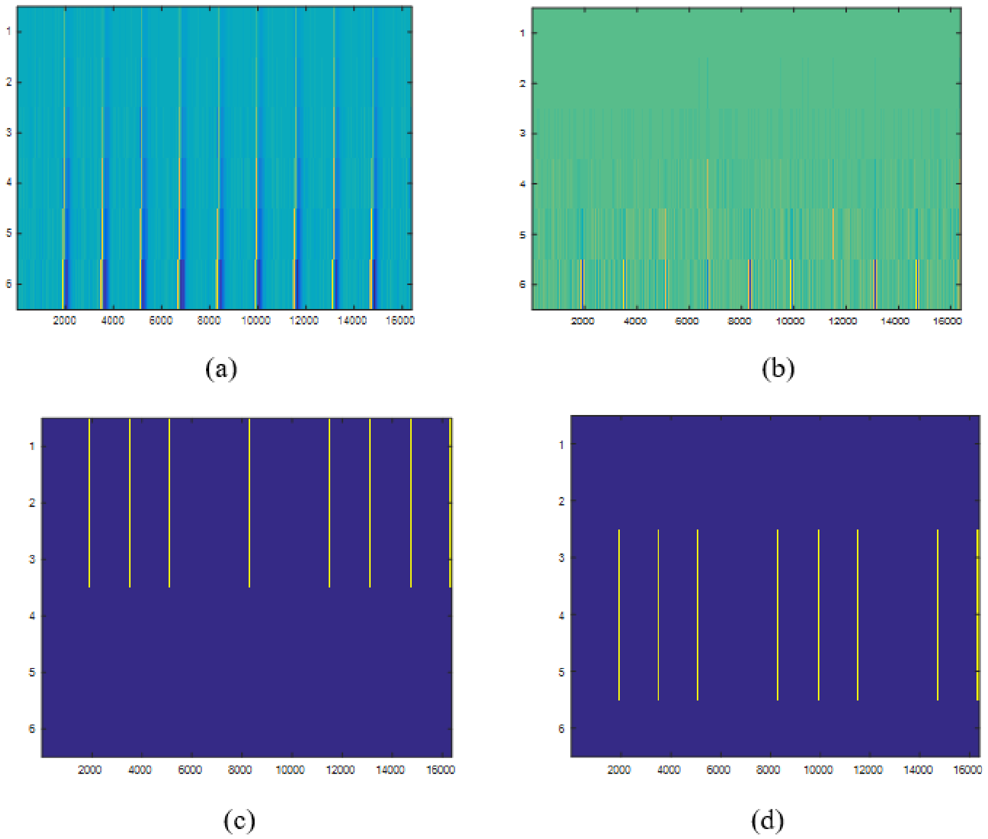

Fig. 2. Pre-ictal spikes model simulation, (a). Coefficients of approximation, (b) details, (c) Mask of coefficients of approximation and (d) of details

After having estimated the products of convolution between the coefficients and the rectangular masks, we calculated the SWT to obtain pure reconstructed pre-ictal oscillations. Fig. 3. is a superposition of the oscillations reconstructed by the SWT (in blue color) with the original signal of the simulated EEG FO (in red color)?

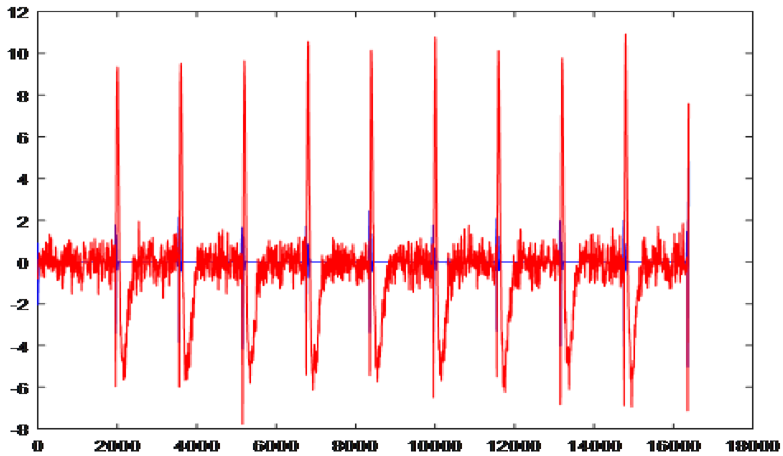

Fig. 3. A figure caption is always placed below the illustration. Short captions are centered, while long ones are justified. The macro button chooses the correct format automatically

Extraction of Pre-ictal Oscillations by Applying SWT to Real Data

For our real data, we have applied the SWT filtering approach on real signals having 31 channels. In Fig. 4, we present the detection of real pre-ictal oscillations of the 5th channel by SWT methods.

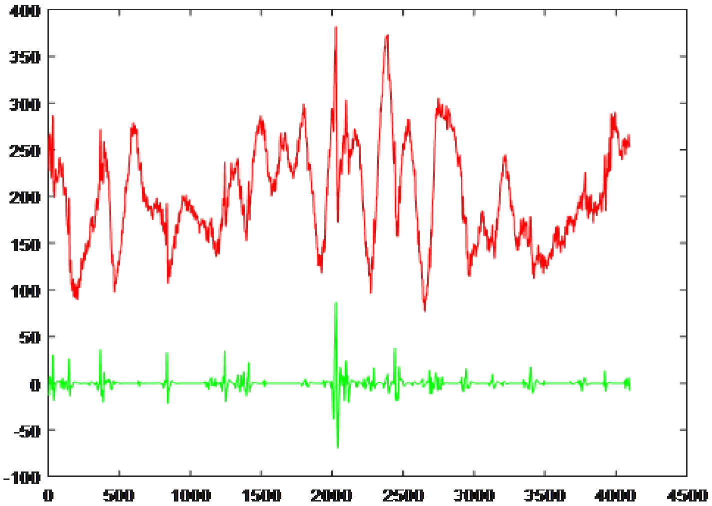

Fig. 4. Detection of real pre-ictal oscillations of the 5th channel by SWT

Fig. 4 shows the reconstruction of the pre-ictal oscillations shown in green. The parameters used are identical to those used in the case of simulated data. We kept the same wavelet "Symlets", also the number of points (4902) and the level of decomposition (equal to 6).

ICA Method for Separating Oscillations and Spikes Using Simulated and Real Data

In this section we will use another source separation approach which is independent component analysis to perform the separation between oscillations and epileptic spikes. This method is based on blind source separation (BSS) approaches. The principle of ICA is to look for components that are statistically independent and not Gaussian while maximizing the temporal independence of the sources.

The ICA method is based on a data chain that consists primarily of two matrices, which are the mixture matrix and the separation matrix. The usefulness of ICA at the level of epileptic data is to separate transient activities and pure pre ictal oscillations for the preparation for the occurrence of a seizure.

The results obtained during the application of the ICA on the simulated data versus the actual data are presented in Fig. 5.

In Fig. 5, we show the result after applying the ICA on simulated and real data. We get oscillations that are separated at the spikes.

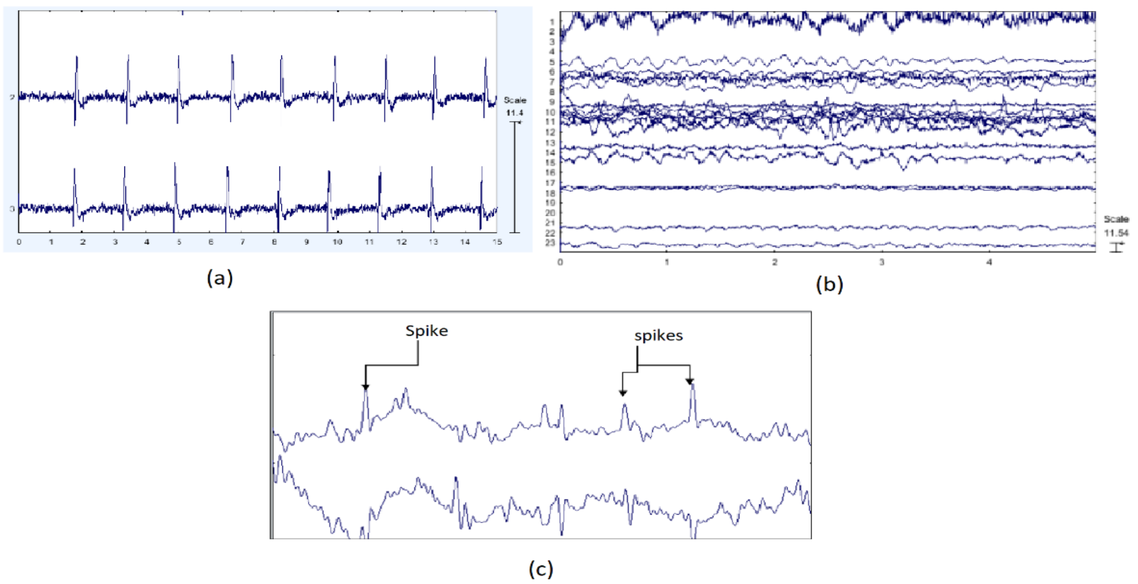

Fig. 5. The application of the ICA on the simulated and real data. (a). Spike detection using the ICA technique on simulated data. (b). Representation of independent components after application of ICA with a scale of 11.54. (c). Two components of the ICA indicating a separation between oscillations and spikes

To make this simulation clearer we have chosen two channels and we have increased the size of this channel as already shown in Fig. 5 to show the good separation between the different channels, this result is simulated with a scale of 11.4. We will apply the ICA separation approach (analysis on independent components) on the real data, as we did for the simulated data. In some cases, we can launder the actual data using the PCA and we can reduce the dimensionality at the same time.
In Fig. 5 (b), we present the first 24 components obtained after the ICA. The last seven remaining components have different artifacts (noise).
We note that the last components are also noisy signals, so there are Components that show muscle activity, and others that show eye movement.
To show this result is clearer we chose two components (13 and 14) then we zoomed the simulation result of these two components. (The arrows indicate a clear separation between oscillations and spikes, showing Fig. 5.(c)).

Topographies

By definition Topography is considered as a representation of the potential via the channels on the scalp.
The values of the points of the scalp located between the electrodes are calculated by interpolation, which allows a visualization of the field lines. A dipole topography (very characteristic shape at the level of the sensors) suggests a cerebral origin of the measurements (unlike the artefacts, which have more complicated structures).
Using the EEGLAB interface, we will trace the corresponding 2D components of two resting epileptic transients.
In *Fig. 6*, we present the topographic maps of the 23 independent components.

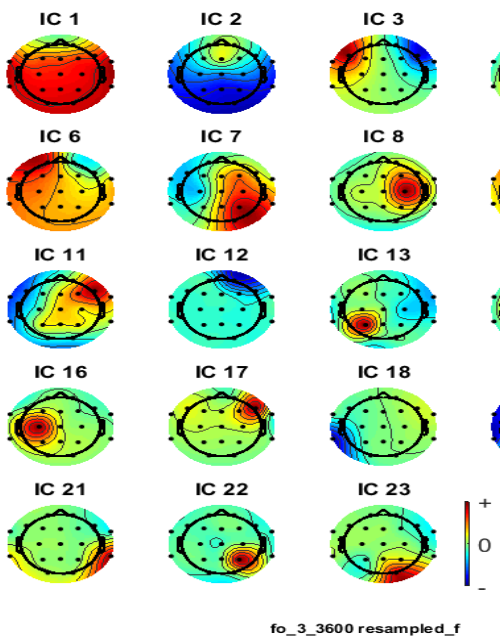

Fig. 6. A topographic map of the 23 independent components

We note from Fig. 6 the existence of two types of topography:
Topographies show the average brain activity of a transient in a state of epileptic rest, many regions of which are involved in excessive neural discharges (like the components IC13, IC19, IC22, and IC23), but there is activity of propagated dipole, confirms the existence of the gamma band so it is a diseased brain activity.
Resting topographies, they are dipolar topographies and which are characterized by a neuronal charge and discharge that means that the average transient activity is a normal cerebral activity at rest.
We focused on the components that contain the gamma bands, that is to say, higher frequencies because they allow us to validate the existence of epilepsy or not and subsequently predict the crisis.

Spectra and component maps. In Fig. 7 (a), we obtained the spectral shape of each component; each colored curve describes a spectrum of the activity of a data channel. One approach used is to graph the data signal plus the activity of the component and the power compared to the original signal on a channel.

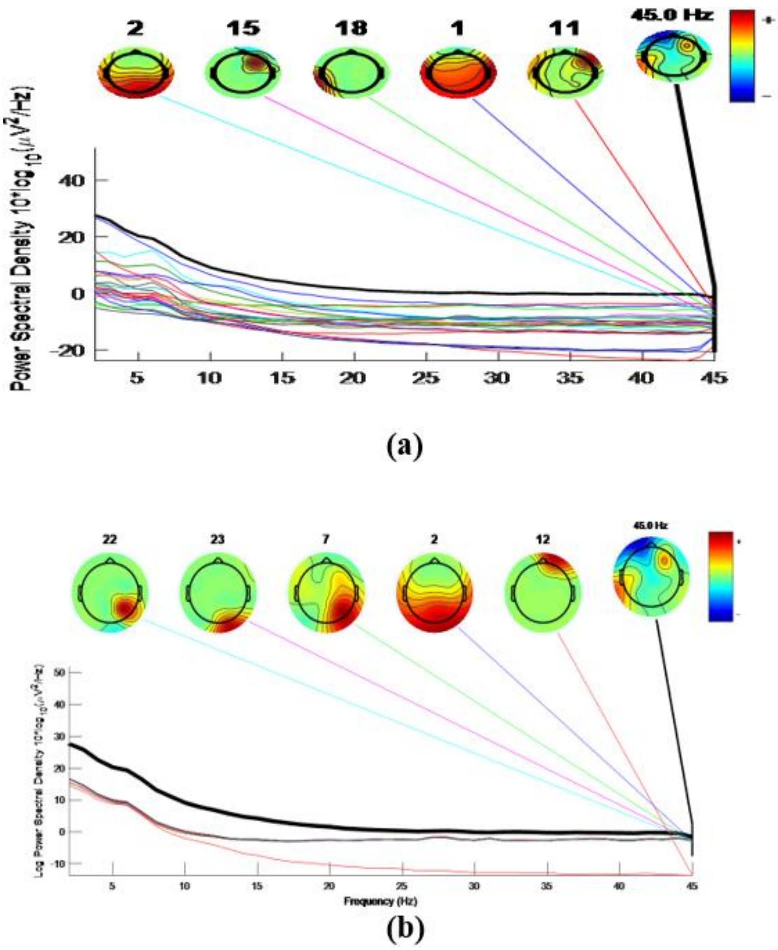

Fig. 7. The spectral shape component. (a). A real data channel spectrum representation. (b). Spectrum representation of selected components

This EEGLAB trace illustrates the components, which represent the major part of the 45 Hz activity at the POz electrode (map of the middle of the scalp). In Fig.7 (a), the power spectrum of the selected channel (which is colored in black), the spectra of brain activity in this channel of each of the 23 components (which are the lower traces) and the scalp power maps of the four components. More prominent (2, 15, 18, 11, 1).

We can also apply this method to all the components, but that requires determining the spectrum of the projection of each component on each channel, which is greedy in computation time.

Starting from tracing of the topographic map represented in Fig.7 (b), we noted that the components IC12, IC2, IC22, IC23 and IC7, are characterized by high frequencies close to 45 Hz from where their correspondences to oscillations in the gamma band.

From our results, we observed that the SWT separation method gives a better result compared to the ICA method either at the level of real data, or to simulate data. The deference is present on everything at the point of clarity of separation of the signals for the extraction of the epileptic oscillations and at the point of detection of the points is clearer and more precise.

Conclusion

Our mission in this paper is to evaluate the techniques which are capable of effecting the separation between these two brain activities of EEG FO data.

For this, we applied two methods of separation of spikes and epileptic oscillations. These two methods are the ICA and the SWT filtering technique (stationary wavelet transformation). The purpose of these two methods is to detect the gamma oscillations of the EEG FO data.

We have shown by drawing the topography of the independent components obtained following the application of the ICA, that this separation method is considered to be an effective method which allowed us to extract pure pre-ictal oscillations. These results can also be used for future research, while continuing to improve filtering techniques for better extraction of pre-ictal gamma oscillations on other frequency bands.

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Availability of Data

The data that support the findings of this study are available from the supervised author (Nawel Jmail), upon reasonable request. Local ethical committees allow the authors to share the data.

Conflict of Interest

The authors declare that they have no conflict of interest.

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References

Bénar CG Papadopoulo T, Torrésani B, Clerc M, Consensus Matching Pursuit for multi-trial EEG signals. *J. Neurosci. Methods.,* 2009. 180: 82-170.

Hirai N Uchida S, Maehara T, Okubo Y, Shimizu H, Enhanced gamma (30-150 Hz) frequency in the human medial temporal lobe. *Neuroscience,* 1999, 90: 1149-1155.

Jarray, R., Jmail, N., Hadriche, A., & Frikha, T. (2018). A Comparison Between Modeling a Normal and an Epileptic State Using the FHN and the Epileptor Model. *Innovations in Bio-Inspired Computing and Applications,* 245–254. doi:10.1007/978-3-319-76354-5_22.

Jmail, N., Jarray, R., Hadrich, A., Frikha, T., & Benar, C. (2017). Separation between spikes and oscillation by stationary wavelet transform implemented on an embedded architecture. *Journal of the Neurological Sciences,* 381, 542. doi:10.1016/j.jns.2017.08.3735.

Jmail, N., Zaghdoud, M., Hadriche, A., Frikha, T., Ben Amar, C., & Bénar, C. (2018). Integration of stationary wavelet transform on a dynamic partial reconfiguration for recognition of pre-ictal gamma oscillations. *Heliyon,* 4(2), e00530. doi:10.1016/j.heliyon.2018.e00530

Jung, T.P., Makeig, S., McKeown, M.J., Bell, A.J., Lee, T.W., & Sejnowski, T.J. (2001). Imaging brain dynamics using independent component analysis. *Proceedings of the IEEE,* 89(7), 1107–1122. doi:10.1109/5.939827

Krieg J, Trébuchon-Da Fonseca A, Martínez-Montes E, Marquis P, Liégeois-Chauvel C, Bénar C-G (2011). A comparison of methods for assessing alpha phase resetting in electrophysiology, with application to intracerebral EEG in visual areas. *NeuroImage,* 55:67-86.

Nawel, J., Abir, H., Ichrak, B., Amal, N., & Chokri, B.A. (2019). A Comparison of Inverse Problem Methods for Source Localization of Epileptic Meg Spikes. *2019 IEEE 19th International Conference on Bioinformatics and Bioengineering (BIBE).* doi:10.1109/bibe.2019.00161

Talairach J, Bancaud J. (1973). Stereotaxic approach to epilepsy. Methodology of anatomo functional stereotaxic investigations. *Progress in Neurological Surgery,* 5: 297-354.

Tatum, William O. (2014). *Handbook of EEG interpretation.* Demos Medical Publishing, 155–190. ISBN 9781617051807. OCLC 874563370

Uchida S Maehara T, Hirai N, Okubo Y, Shimizu H, Cortical oscillations in human medial temporal lobe during wakefulness and all-night sleep. *Brain research,* 2001, 891: 7-19.

Wang XH Istephanian RSH, Member S, Song YH, Microarray Image Enhancement by Denoising Using Stationary *Wavelet Transform,* 2003, 2: 184-189.