Detection of epileptic seizures in EEG signals during long-term monitoring of patients after traumatic brain injury

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Abstract. Long-term (several days) monitoring of epileptiform activity in scalp EEG of posttraumatic brain injury patients is an important task. EEG signals contain epileptiform seizures and similar signals of myographic activity associated with chewing. Both epileptiform activity and chewing artifacts appear in the same frequency range, which complicates their differentiation. To distinguish epileptiform activity from chewing artifacts, a method based on the wavelet spectrogram analysis of EEG is proposed. EEG wavelet spectrogram contains broadband peaks at times corresponding to peak-wave epileptiform activity on the one hand, and peaks of myographic activity at chewing on the other hand. The periodicity of these peaks is investigated. The difference in the period dispersion of epileptiform peaks and chewing peaks are found.

1. Introduction

One of the most frequent consequences of traumatic brain injury is the development of post-traumatic epilepsy. Up to 25% of all patients with traumatic brain damage are at high risk of developing post-traumatic epilepsy [1]. The occurrence of post-traumatic epilepsy severely limits the working capacity of patients, reduces the quality of life, often leads to recurrent brain injury, often due to epileptic seizures [2,3]. The rapid response of medical staff to the appearance of epileptic seizures helps to avoid negative consequences.

Patients are located in the clinic in intensive care units or ordinary wards. One of the most common ways to observe a patient's condition is EEG monitoring. An electroencephalogram contains many artifacts associated with movement. The problem of detecting artifacts has existed for a long time. Many techniques have been proposed for detecting and classification of motion artifacts [4-14] and epileptic seizures [15-39]. Despite the abundance of existing methods, the most difficult and unresolved problem is the detection of chewing artifacts.

This article describes the method of differentiation of epileptiform activity from chewing artifacts, based on the analysis of wavelet spectrograms of EEG. EEG wavelet spectrograms contain broadband peaks at times, corresponding to peak-wave epileptiform activity, on the one hand, and peaks of myographic activity when chewing, on the other hand. The periodicity of these peaks is investigated.
The difference in the spread of the periods of these peaks was found to be a differentiating feature of these two types of signals.

2. Experimental data
EEG records with an epileptic seizure and chewing artifact, recorded at a sampling rate of 500 Hz, obtained at the Department of Neurosurgery & Neuro ICU of Scientific Institute Medicine named after N.V. Sklifosovsky. All records were filtered before processing. Notch filters at frequencies that are multiples of 50 Hz were used to suppress power-line noise and 2nd order bandpass Butterworth filter with a passband of 0.5–22 Hz was used. Figure 1 shows fragments of EEG signals with (a) chewing and (b) epileptic seizure.

![Fragment of EEG with chewing](image1)

![Fragment of EEG with epileptic seizure](image2)

**Figure 1.** a) Fragment of EEG with chewing; b) Fragment of EEG with an epileptic seizure.

3. The method of differentiation of epileptic discharges from motion artifacts
The approach is based on wavelet spectrogram analysis [40-42]. The complex Morlet wavelet was used because it is understandable for neurophysiologists. Also for this wavelet, it was shown in [43] that the points of the ridge are the points of the stationary phase.

\[
W(\tau, f) = \sqrt{f} \int x(t) \psi((t - \tau)f) dt
\]  

(1)

The Morlet mother function is given by the following formula (2):

\[
\psi(\eta) = \frac{1}{\sqrt{\pi * F_b}} * \exp\left(2\pi i F_c \eta\right) * \exp\left(-\frac{\eta^2}{F_b}\right)
\]  

(2)

Coefficients \( F_b = F_c = 1 \). Power spectral density is calculated to build spectrograms:

\[
S(\tau, f) = |W(\tau, f)|^2
\]  

(3)
Figure 2. Fragment of the EEG wavelet spectrogram: (a) with chewing; (b) with an epileptic seizure.

Figure 3. Fourier spectra of wavelet EEG spectrogram slices during chewing at (a) - frequencies from 1 Hz to 3 Hz; (b) - frequencies from 3.5 Hz to 6 Hz.
Figure 2 (a, b) shows 30-second fragments of EEG wavelet spectrograms with chewing artifacts and with an epileptic seizure, respectively.

The idea of analyzing wavelet spectrograms is as follows. The wavelet spectrogram is a matrix $S(\tau, f)$ (3). Matrix values in each row corresponding to the values of frequencies $F_{\text{cur}}$ from 1 Hz to 6 Hz are selected over the entire time interval:

$$V_{\text{cur}}(\tau_k) = S(\tau_k, F_{\text{cur}}), \tau_k = 0 : T$$  \hspace{1cm} (4)

For the vectors $V_{\text{cur}}$ obtained, the Fourier spectra were calculated. Figures 3 (a, b) and 4 (a, b) show examples of the Fourier spectra of the $V_{\text{cur}}$ with $F_{\text{cur}} = 1: 0.5: 6$ Hz.

![Figure 3](image1)

![Figure 4](image2)

**Figure 4.** Fourier spectra of EEG wavelet spectrogram slices with an epileptic seizure (a) - frequencies from 1 Hz to 3 Hz; (b) - frequencies from 3.5 Hz to 6 Hz.

Table 1 presents the values of the frequency at which the main peak and the half-width of the main peak are at half-height, depending on the selected frequency-wavelet slice.

The values from Table 1 show that when the cut-off frequency of the EEG wavelet spectrogram exceeding 2.5 Hz, the peak frequency of the Fourier spectrum increases by more than 5 times for an epileptic seizure, and increases slightly for chewing. Conversely, at high cut-off frequency of the wavelet spectrogram, the half-width of the peak corresponds to epileptic seizure is less than the half-width corresponds to the chewing peak. Together, these parameters can be used as differential signs of epileptic seizures from chewing.
Table 1. Parameters of Fourier spectra of EEG wavelet spectrogram slices with chewing and an epileptic seizure.

| Frequency of wavelet spectrogram slice (Hz) | Peak frequency (chewing) | Peak frequency (epileptic seizure) | Peak half width (chewing) | Peak half width (epileptic seizure) |
|-------------------------------------------|--------------------------|-----------------------------------|---------------------------|------------------------------------|
| 1                                         | 0.35                     | 0.35                              | 0.67                      | 0.7                                |
| 1.5                                       | 0.44                     | 0.35                              | 0.78                      | 0.7                                |
| 2                                         | 0.53                     | 0.35                              | 0.79                      | 0.71                               |
| 2.5                                       | 0.62                     | 0.35                              | 0.97                      | 0.87                               |
| 3                                         | 0.62                     | 1.78                              | 1.12                      | 1.05                               |
| 3.5                                       | 0.71                     | 1.86                              | 1.06                      | 0.62                               |
| 4                                         | 0.71                     | 1.86                              | 1.2                       | 0.64                               |
| 4.5                                       | 0.71                     | 1.86                              | 1.25                      | 0.69                               |
| 5                                         | 0.71                     | 1.86                              | 1.33                      | 0.65                               |
| 5.5                                       | 0.71                     | 1.95                              | 1.51                      | 0.67                               |
| 6                                         | 0.71                     | 1.96                              | 1.91                      | 0.63                               |

4. Conclusion
The article presents the method of differentiation of epileptiform activity from chewing artifacts, based on the analysis of wavelet spectrograms of EEG. EEG wavelet spectrograms contain broadband (in frequency) peaks at time points corresponding to sharp peaks in the original signal, both at peak-wave epileptiform activity, on the one hand, and peaks of myographic activity during chewing, on the other hand. The periodicity of broadband peaks in EEG wavelet spectrograms is investigated. Fourier spectra of wavelet spectrogram slices at frequencies from 1 to 6 Hz show that with epileptic discharge, the frequency of the peak of the spectrum of slices of the wavelet spectrogram more than 5 times increases with a cut frequency of more than 2.5 Hz, and when chewing it does not change. The half-width of the spectra of the EEG wavelet spectrograms in an epileptiform seizure remains approximately the same for different cut-off frequencies. These values are signs by which an epileptic seizure can be differentiated from a chewing artifact.

5. References
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