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An epileptic focus location method based on ECoG[1]

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Abstract. Epilepsy is a neurological disorder characterized by the sudden abnormal discharging of brain neurons that can lead to encephalographic (EEG) abnormalities. In this study, data was obtained from epileptic patients with intracranial depth electrodes and analyzed using wavelet entropy algorithms in order to locate the epileptic foci. Significant increases in the wavelet entropy of the epileptic signals were identified during multiple episodes of clinical seizures. The results indicated that the algorithm was capable of identifying entropy changes in the epileptic sources. Furthermore, the correlations among the electrocorticogram (ECoG) signals of different channels determined using the amplitude-amplitude coupling method verified that the epileptic foci exhibited significantly higher coupling strengths. Thus, cross frequency coupling (CFC) could be an inspiration to energy and signal transitive mode of seizure and, thereby, improve diagnostic processes.

Keywords: Epilepsy, ECoG, wavelet entropy, correlation, CFC

1. Introduction

Epilepsy is a common chronic neurological categorized by abnormal and excessive discharging of neurons resulting from the ultra-snchronization of neuronal activity. Due to its complexity and repetitious nature, epilepsy severely affects the lives of afflicted patients. The diagnosis of epilepsy is a highly important aspect of modern medicine [1].

Currently, EEG testing is used to diagnose and identify epilepsy [2, 3]. EEG testing, an empirical method, involves the detection of peaks and sharp waves in patients using real-time surveillance videos [4, 5]. However, the time-domain characteristics of EEG signals are not obvious and are usually accompanied by strong artifacts. In addition, enormous amounts of data must be analyzed in order to accurately identify epileptic activity. Frequency domain analysis is another method used in the clinical application of EEG. According to the Welch spectrum estimating method [6], epileptic seizures should result in the occurrence of high frequency EEG signals and the broadening of the main frequency spectrum. However, the results obtained using this method are generally vague. Moreover, HMM is a common unsupervised method of EEG classification. However, this model must be fitted to training data, in which all states are known to occur, before testing other data, and initial models are

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not always available. One method, which involves the use of HMMs without trained classifiers, has been proposed [7]. Recently, a quasi-supervised classifier that models observations in an unsupervised manner, but mimics human responses whenever training scores are available has also been proposed [8]. Programmable computer-controlled devices have also been employed to automatically analyze EEG results [9]. Although these methods all have clinical applications, a new method is needed to effectively locate epileptic foci and, thereby, diagnose and treat epilepsy.

In this paper, an automatic detection algorithm for epileptic foci based on wavelet entropy was proposed [10]. The wavelet entropy of EEG signals collected from patients with epilepsy were calculated and compared using a specific intracranial electrode for each channel [11]. The changes that occurred in the wavelet entropy during epileptic activity were observed in order to determine their epileptic foci. The epileptic prediction results were compared to actual surgical results, and the correlations among the different channels during epileptic activity were observed using the CFC algorithm [12, 13]. The relationships among all of the channels during epileptic activity were presented. Since CFC algorithm is well known, the combination of CFC and wavelet entropy is of help to improve the performance of current wavelet entropy based method. This method effectively identified the foci of the seizures and, due to its simplicity and convenience, could have significant clinical applications.

2. Methods

2.1. EEG signal acquisition

One of the epileptic patients' EEGs was supplied by the People's Hospital of Peking University, China. The EEG signals were extracted using intracranial depth electrodes and acquired using the "NicoletOne Monitor" (Gregory company production, USA) recording system at a sampling rate of 1024Hz. Six of the electrodes were placed in the right prefrontal cortex, and four of the intracranial electrodes were placed in the right temporal lobe, comprising a total of ten channels, of which channels 7-10 were the epileptic foci determined by clinical doctors using magnetic resonance imaging (MRI). Doctors roughly estimated the epileptic areas based on the EEGs obtained from scalp electrodes and used these areas to determine the burial positions of the intracranial electrodes. An ECG channel was also inserted in order to record the sampling rate. For this patient, the clinical experts used ten cortex electrodes and two skin electrodes (calibration electrodes).

2.2. Wavelet entropy algorithm

The wavelet method [14, 15] has predominantly been used to analyze epileptic EEG results. Entropy is one of the most important features of epileptic states [16]. The energy distribution of a set of wavelet decomposition layers could be described as a probability sequence, the entropy of which reflects the ordering characteristics of a signal. During seizures, the sudden discharging of large numbers of neurons results in a greater degree of neurological chaos than under normal circumstances. Thus, wavelet entropy could be used to effectively identify the occurrence of epileptic activity according to discharge characteristics.

In order to determine in which channels an epileptic seizure occurred, the wavelet entropy of each ECoG signal was calculated. By calculating wavelet entropy, the automatic detection of epilepsy could be realized. Sliding window technology, which is sensitive to changes in wavelet entropy, was used to calculate the wavelet entropy values at different periods of time. During the analysis, the window length was equal to1.5 times that of the sample rate, and the signals were decomposed into five-layer db3 wavelets. Then, the wavelet decomposition and wavelet entropy values were used to calculate the ECoG signal of each channel.

2.3. Cross-frequency coupling algorithm

Each frequency subband was analyzed during seizure activity in order to reveal their epileptic features. CFC could also be used to examine the characteristics of seizures based on the features of large amplitude EEGs. In order to select channels for further cross-frequency studies, the relationships among all of the thirteen channels were calculated using the correlation algorithm. The best-coupled and worst-coupled channels were selected for cross-frequency research.

The most common method used to study the relationships among the signals of different channels is the cross-correlation function. The cross-frequency amplitude-amplitude coupling algorithm is based on the correlation function. The amplitude-amplitude coupling among the thirteen channels was analyzed in order to obtain the coupling coefficient vector and calculate the mean, or coupling index value, of any two channels.

The signals of each channel were filtered into ten frequency zones. Then, the following five CFC experiments were conducted: (1) Cross-coupling among the ten frequency segments of the two electrodes that coupled best (channels 7 and 8), (2)cross-coupling among the ten frequency segments of the two electrodes that coupled worst (channels 1 and 6), (3)cross-coupling among the ten frequency segments of two electrodes that coupled best and worst (channels 7 and 1), (4) cross-coupling among the ten frequency segments of an electrode located in an epileptic foci (channel 9), and (5)cross-coupling among the ten frequency segments of an electrode that was not located in an epileptic foci (channel 13).

3. Results and discussion

The wavelet entropy results of ten channels are shown in Table 1. In Table 1, “+” was used to indicate an increase in wavelet entropy, while “-” was used to indicate a decrease or no change in wavelet entropy.

As shown by the results, wavelet entropy only indicated seizure activity in some of the channels. However, the channels in which the epileptic activity was detected consisted of lesions verified by clinical diagnoses and surgical procedures. Thus, wavelet entropy could be an effective means of identifying seizure activity at epileptic sources.

Table 1

Wavelet entropy results of each channel. “+” was used to indicate an increase in wavelet entropy, while “-”was used to indicate a decrease or no change in wavelet entropy

Channel number	1	2	3	4	5	6	7	8	9	10
Wavelet entropy	-	-	-	-	-	-	+	+	+	+

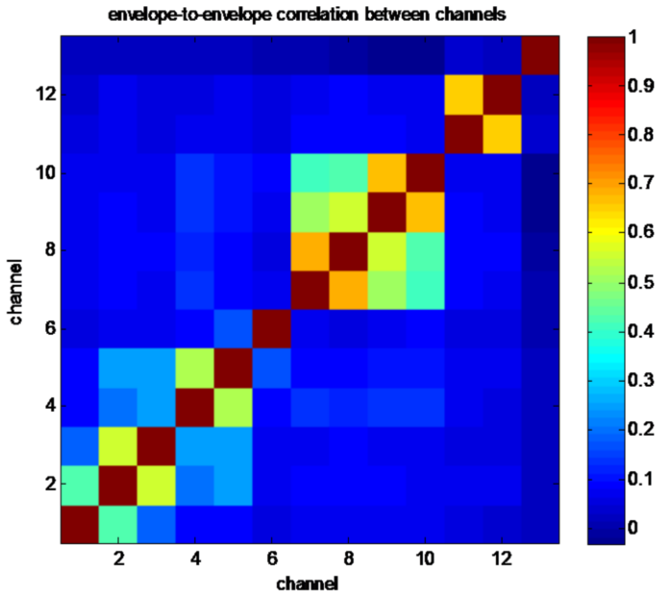

Fig. 1. Channel-channel coupling results. The coupling coefficients of thirteen channels were calculated. Other than the coupling between the two reference electrodes, the coupling between channels 8 and 7 and 9 and 10 was significantly higher than the coupling between any of the other electrodes. Thus, channels 7-10 exhibited high levels of energy.

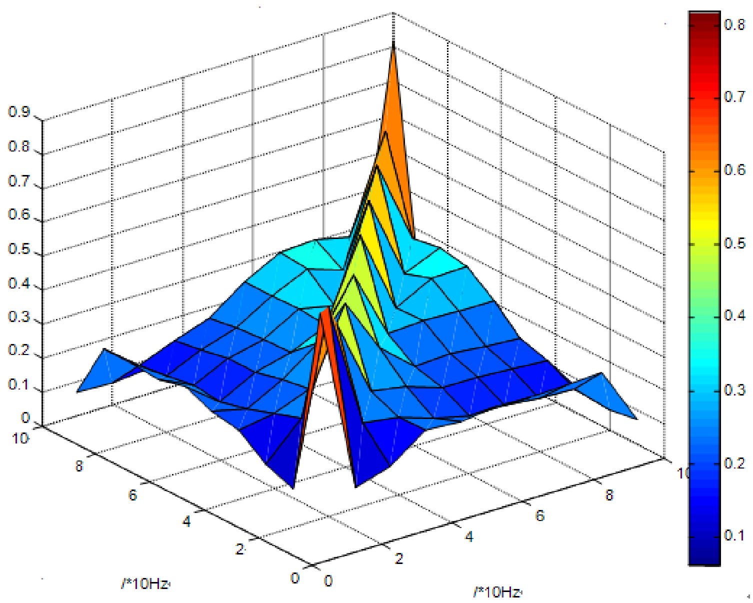

Fig. 2. Dual-channel CFC analysis results. The amplitude-amplitude coupling of channels 7 and 8 yielded good results. Cross-coupling among the ten frequencies of the two channels.

The relationships among the channels in which epilepsy has been detected were analyzed. The coupling coefficients of the thirteen channels were calculated in order to obtain the two-dimensional ichnography shown in Figure 1. Figure 1 exhibits the characteristics of diagonal symmetry since the orders of the signals were not considered during the coupling coefficient calculations. Other than the two reference electrodes, the degree of coupling between channels 8 and 7 and 9 and 10 was higher than between any of the other electrodes. Thus, channels 7-10 exhibited high levels of energy. These lesions are characterized by the abnormal discharging of nerve cells at high amplitudes.

This abnormal discharging is transmitted to other nerve cells, resulting in widespread effects. In epilepsy, in order to influence the discharge of other neurons, the amount of energy must be high enough to compensate for lost energy. Thus, the energy values could have been affected by the stimulation, modulation, and aggravation of the epileptic foci. Thus, the epileptic focus of this patient could have been located at electrodes 7-10.

Further studies concerning the relationships among the specific modulated characteristics of the signals should be conducted. The results of the five CFC experiments were as Figures 2-4. Thus, the energy values of the epileptic foci in the dual-channel analysis were significantly higher than those of the non-epileptic foci, indicating strong coupling among the epileptic foci. However, the results of the single-channel CFC algorithm were different. The amount of coupling in the epileptic foci was slightly less than that in the non-epileptic foci.

4. Conclusions

In this paper, an epilepsy detection algorithm based on wavelet entropy was proposed. The results indicated that the channels that detected epilepsy were the epileptic foci surgically identified by clinical doctors. The CFC algorithm combined with wavelet entropy was proposed for the detection of epilepsy. The epileptic foci exhibited significantly higher coupling strengths than non-epileptic foci between different channels. Furthermore, according to results of the cross-frequency analysis, the epileptic foci exhibit apparent effects on the cross-frequency despite non-epileptic foci not exhibiting obvious effects. Thus, the wavelet entropy and CFC algorithms could be used to identify epileptic foci.

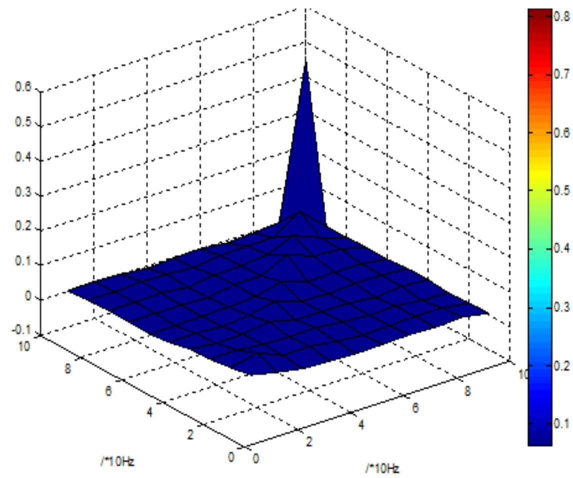

Fig. 3. Dual-channel CFC analysis results. The amplitude-amplitude coupling of channels 1 and 6 yielded bad results. Cross-coupling among the ten frequencies of the two channels.

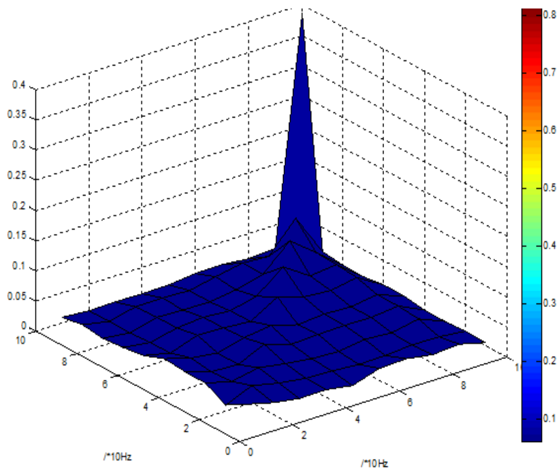

Fig. 4. Dual-channel CFC analysis results. The amplitude-amplitude coupling of channels 7 and 8 yielded good results. The amplitude-amplitude coupling of channels 1 and 6 yielded bad results. An electrode was selected from each group, including channels 7 and 1. Cross-coupling among the ten frequencies of the two channels.

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