Is There a Relationship between Consciousness and Epilepsy?

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Abstract

The aim of this article is to describe the relationship between consciousness and epilepsy. Epilepsy is a neurological disorder which can be seen all over the world. It can be diagnosed by the brain's electrical activity (EEG). The determination of epileptic attacks by EEG signals is quite common in both clinical and research fields. During epileptic seizures, the brain dynamics that make up the graph consist of abnormalities in EEG signals. In this study, the relation between epilepsy and consciousness will be investigated by using wavelet entropy and artificial neural networks.

Keywords: Consciousness, brain, EEG, chaos, epilepsy, wavelet entropy.

1. Introduction

Epilepsy is one of the most complex and wide-ranging brain disorders involving diverse etiologies with a common symptom of spontaneous recurrent seizures characterized by intermittent paroxysmal and highly organized rhythmic neuronal discharges in the cerebral cortex (Chaovalitwongse et al., 2003). Epileptic seizures are caused by a large collection of neurons synchronous and abnormally discharged. The synchronous discharge stereotype involuntary and suddenly appeared and these changes have caused transient epileptic seizure behaviour, deeply negatively affecting the patient's life. Abnormal cell discharge may occur for reasons such as trauma, oxygen insufficiency, tumours, infections and metabolic disorders. However, it is not possible to find any cause in half of the epileptic patients (McNamara, 1999). Despite the fact that epilepsy is referred to as "seizure disease", it is not correct to call seizures "epilepsy". Seizures are symptoms, but epilepsy is a disease characterized by recurrent seizure (Shneker & Fountain, 2003).

Nonlinearity and a sensitive dependence on initial conditions are the requirements of the chaos. What is meant by sensitive dependence is that even the slightest change in the initial conditions may result in a significant change in the output. As chaos requires dependence on the initial conditions and it is unpredictable in the long run. Even though the system is deterministic, it does not allow long term guesses. Yet, for deterministic systems, long term guesses can be made, but for random systems the later steps cannot be estimated. As the initial conditions may grow exponentially in this process, large errors may occur in the output. This situation is the cause of sensitive dependence, and sensitive dependence veils the long term estimations. That is because the longer the period, the larger the error.

In the most general sense, consciousness is awareness, or the state of being aware. It is the state when the person is both aware of himself/herself and the surroundings. The brain is considered to be the central decision making organ of the human body. It consists of two lobes which are right and left lobes. Anatomically, the human brain consists of approximately 100 billion neural cells that are called neurons. Neurons are actually connected to each other with dendrites. The complexity of the neural circuit of the brain can be understood when we keep thinking that each neuron makes about thousands of contacts with other neurons. The complexity of the neural circuit will be different for each brain and these differences may result in different brain capacities. The brain capacity may differ not only with the neural links, but also with the activity of the circuit components. When this event is physiologically investigated, we see that the information flow is the result of the electrical and chemical communication between the neurons. The connection pattern of the trillions of connections between neurons in the brain and the activity rate of these connections are the two main factors that determine the brain capacity. The activity is related to the electrical and chemical events on the neurons. Electrical transmission is done via ions (Na, K, Cl, etc.) while the chemical transmission is done between synapsis via biomolecules that are called neurotransmitters (serotonin, acetylcholine, epinephrine, etc.).

The studies which state that the consciousness is adversely affected during epilepsy seizures have a broad spectrum. The adverse effects generally manifest as cloudy consciousness and/or decrease in the consciousness levels. Johanson et al. (2003) stated that the order or the state of consciousness is distorted during epileptic seizures. Blumenfeld and Taylor (2003), discuss that the patient will become unconscious during generalized seizures and may also become unconscious during partial complex seizures. Monaco et al. (2005) suggested that both the level of consciousness and the state of it will be adversely affected during seizures. Cavanna et al. (2008), tried to measure and statistically evaluate the consciousness levels and the consciousness states of the epileptic patients with a test of 20 questions called Ictal Consciousness Inventory. Hughes (2008) discussed that information is transmitted to the brain cortex via the gamma oscillations (30-100Hz). He reported that the gamma oscillations may be formed as alternatives to the epileptic foci in the pre-ictal period and that the amplitude of the gamma oscillations increases when going from pre-ictal to ictal periods. Danielson et al. (2011) used MRS (Magnetic Resonance Spectroscopy) and PET (Positron Emission Tomography) scans to examine the state of consciousness during epilepsy seizures. Foley et al. (2014) investigated the distortion of consciousness during epilepsy seizures using MEG device.

2. Material and Methods

We will provide information on the materials (epileptic EEG data) and evaluation of epileptic EEG data with wavelet entropy and artificial neural networks.

2.1 Epileptic EEG Data and Patient Characteristics

The data used in this study was taken from the EEG laboratory archives of the Neurology Department at the Medicine Faculty of Dicle and İnönü Universities. There was data recorded from 7 adult patients between 2001 and 2013, during clinical studies. In the clinical records was written that these 7 patients were with partial epilepsy. It was also reported that 5 of the patients were men and the other 2 were women whose ages ranged from 25 to 45 years old, with an average of 35 years old. The patients did not have any head injuries, previous surgeries, or a family history of seizures or epilepsy. The EEG recording period varied from 3 to 48 hours. The patients did not take any medications during recordings. The records were noninvasively taken from 16 standard sites of 10-20 systems on the patients' scalp at a 200 Hz sampling rate, using a EEG digital video recording system (Grass Telefactor EEG Review and Analysis version 2.10), facilitated with 32 channels and 16 bit A/D, and Twin 2.0 software package.

2.2 Chaos Analysis

For chaos analysis, the attractors (that show all the states the system will go through in time) should be modelled in the phase space. If the time series is chaotic, the attractor formed on the phase space will create a different structure. This attractor is called the strange attractor. Strange attractors have fractional sizes. Chaotic quantities (Lyapunov exponents, entropy, etc.) are calculated after the phase space is formed. Each quantity is another attribute vector for the system. The larger the number of attribute vectors, the more we know about the system.

2.3 Phase Space

For the chaotic dynamics to be calculated, time series should be reconstructed in the phase space. As two or more functions are compared in the phase space at the same time period, at least two functions are required to construct the state space. According to Takens theorem (Takens, 1981), if there is only a single time series, using the first or further derivatives of the time series, the phase space can be constructed like in Equation 1.

$$y(n) = [x(n), x(n+\tau), x(n+2\tau), \ldots x(n+(m-1)\tau)] \quad (1)$$

The "m" used in Equation 1 is the embedding dimension and "τ" is the delay in time. The embedding dimension m is calculated using the false nearest neighbour method and the time delay τ is calculated using the first local minimum of the mutual information function. The attractor loses its properties by linearization when τ value is small, and by dispersion when τ value is large.

2.4 Wavelet Entropy

Wavelet entropy is a term that combines wavelet and entropy terms. The irregularities of the time frequency are determined with the wavelet entropy analysis.

Wavelet analysis has the utmost importance in determining the properties of the non-stationary signals. As the moments of the non-stationary signals are time dependent, Fourier analysis is not successful for such signals. Instead, wavelet analysis, which gives both time and frequency information of the signal, is used. In wavelet analysis the signal is separated into its sub-bands. The signal is fed through low-pass and high-pass filters repetitively. The sub-bands that pass through the low-pass filter constitute the "approximation coefficients" and the ones that pass through the high-pass filter constitute the detail coefficients. Here, the EEG signal is passed through five sub-bands after it is passed through the filter that selects the (0-60Hz) band. These are delta=(0-4Hz), theta=(4-8Hz), alpha=(8-12Hz), beta=(12-30Hz) and gamma=(30-60Hz) respectively.

Then the energies of the coefficients are calculated, and their normalized values are calculated as in Equation 2.

$$P_j = \frac{E_j}{E_{top}} \quad (2)$$

The normalized energies are the distributions for the different states. The comparison of these distributions is calculated with the Shannon entropy in Equation3 (Yordanova et al., 2002).

$$S = -\sum_j P_j \ln P_j \quad (3)$$

The resultant entropy value is the measure of the disorder of the system. This disorder gives general information about the system. This information makes up the attribute vector of the system.

2.5 Artificial Neural Networks (ANN)

Artificial Neural Networks (ANN) can be called the human brain model. In this study, 100 preictal and 100 ictal, a total of 200 EEG segments have been used for classification. And also, 100 segments were used for training, and 100 segments for testing the ANN. The segments have been separated into five sub-bands by wavelet analysis. Entropy was applied to the sub-bands of each segment and thus the wavelet entropy values were calculated. ANN inputs consist of these five sub-band entropies. These wavelet entropy values constitute the feature of pre-ictal and ictal segments.

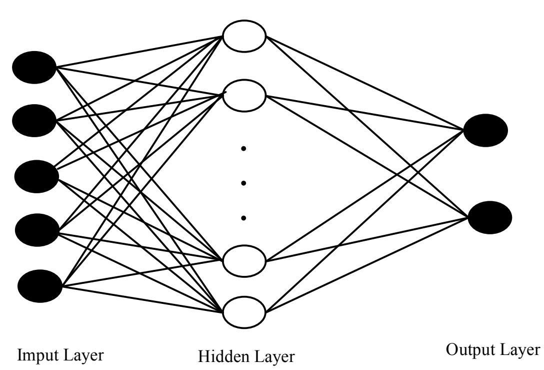

Figure 1. Multi-layer artificial neural networks model

After many tests perfomed in different situations, there has been obtained the most successful model of ANN, which is shown in Figure 1. This model has 5 input layers, one hidden layer which consists of 10 neurons, and 2 output layers. The output layer is composed of two neurons, including pre-ictal and ictal states. The log sigmoid transfer function is used for hidden and output layers. Also, the Levenberg-Marquart algorithm is used for the learning algorithm. The tuning parameters of classifiers are randomly selected, and 2-fold cross validation is used.

3. Results and Discussion

The fact that consciousness is a process in the brain means that the illnesses which form in the brain also affect the consciousness. As the illnesses of the brain (epilepsy, schizophrenia, Alzheimer's, etc.) have a broad spectrum, in this study we will only discuss the relationship between consciousness and epilepsy.

3.1 Feature Extraction

Firstly the Epileptic EEG data is separated into pre-ictal and ictal segments, and then the wavelet entropy values of these segments are calculated. In this study, 100 pre-ictal and 100 ictal, a total of 200 EEG segments, have been used. Here, the EEG data is passed through five sub-bands after it is passed through the filter that selects the (0-60Hz) band. These are delta=(0-4Hz), theta=(4-8Hz), alpha=(8-12Hz), beta=(12-30Hz) and gamma=(30-60Hz) respectively. Then, the Shannon entropies of the EEG sub bands are calculated; and then the feature vectors are formed by combining the values obtained with this method.

One of the feature vectors of a hundred pre-ictal and ictal segments is shown in Table1.

When the attribute vector is examined, it is observed that the gamma sub-band entropy values significantly increase from pre-ictal to ictal periods. This shows that the disorder of the gamma oscillations increases significantly during the epilepsy seizure.

Table 1. The feature vector of pre-ictal and ictal segments

Features	Pre-ictal	Ictal
Delta's Entropy	0,0071	0,0090
Theta's Entropy	0,0063	0,0099
Alpha's Entropy	0,0066	0,0103
Beta's Entropy	0,0067	0,0105
Gamma's Entropy	0,0062	0,0111

3.2 Performance Analysis

The performance analysis criterions are used to assess the performance of the system by using equations 4-8.

Sensitivity =TP/(TP+FN) (4)

Specificity =TN/(TN+FP) (5)

PPV=TP/(TP+FP) (6)

NPV=TN/(TN+FN) (7)

Accuracy=(TP+TN)/(TP+TN+FP+FN) (8)

The performance analysis criterions are known as "Sensitivity", "Specificity", "Positive Predictive Value", Negative Predictive Value" and "Accuracy". These criterions are calculated for each EEG segments.

Sensitivity is used to determine the ability of the separation ictals from actual ictals. Specificity is used to determine the ability of the separation pre-ictals from actual preictals. PPV is used to determine the possible presence of ictals when the classifier gives ictal results. NPV is used to determine the real possible presence pre-ictals when the classifier gives pre-ictal results. Accuracy is used to determine the ratio of the correctly classified samples to all samples.

Pre-ictal and Ictal Truth-Predictive Matrix is shown in Table 2.

Table 2. Preictal and Ictal Truth-Predictive Matrix

		PREDICTIVE	
		Ictal(+1)	Preictal(-1)
TRUTH	Ictal (+1)	TP (48)	FN (1)
	Preictal (-1)	FP (2)	TN (49)

The values obtained from these measurements are given in Table 2. It is coded as TP (True Positive), FP(False Positive), TN(True Negative), and FN(False Negative). These criterions are labeled (-1) for preictal and (+1) for ictal EEG segments.

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The final result of performance analysis criterions are shown in Table 3.

Table 3. Performance Analysis Criterion

	Sensitivity	Specificity	PPV	NPV	Accuracy
Performance %	98	96	96	98	97

The ANN classifier performs with an accuracy of 97%, sensitivity and specificity of 98% and 96% respectively.

In this study, the epileptic EEG signal that is separated into two segments, such as pre-ictal and ictal periods, is analysed with wavelet entropy analysis which is a Chaos analysis technique. From the analysis results, it can be seen that the entropy values of the gamma band of two segments that are pre-ictal and ictal are significantly different (Table 1). That means, during the transition between pre-ictal and ictal states, there is a recognizable change and increase in the gamma oscillations. Thus, the gamma wavelet entropy (the attribute vector) value of the ictal period is larger than the pre-ictal period.

Some authors (Summerfield et al., 2002; Balconi & Lucchiari, 2008; Roy et al., 2015) in the above mentioned publications tried to find relationships between consciousness and the gamma wave. Summerfield et al. (2002) found that the amplitude of the posterior brain electroencephalogram signal close to 40 Hz is associated with awareness-dependent processes. Balconi and Lucchiari (2008) suggested that gamma band can be represented as a marker of consciousness, as well as of the subject's evaluation of the arousing power of emotional stimuli. Thus, Balconi and Lucchiari (2008) stated that gamma frequency band analysis offers a powerful tool for studying cortical activation patterns during emotional information processing. Roy et al. (2015) stated that the time scale is associated to the 40 Hz oscillation, since that is predominant for the conscious activities of the human being.

4. Conclusions

In this study, the relationship between epilepsy and consciousness was investigated. In this context, as entropy is the measure of order or disorder in a signal or system, the increase in the attribute vector of gamma (Table 1) suggests disorder increase. The disorder increase means an increase in the clouding of consciousness. From that we can conclude that the consciousness is temporarily affected in an adverse manner during the epileptic seizure.

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