Methodology Article

Quantitative Analysis of Inter- and Intrahemispheric Coherence on Epileptic Electroencephalography Signal

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Abstract

When an epileptic seizure occurs, the neuron's activity of the brain is dynamically changed, which affects the connectivity between brain regions. The connectivity of each brain region can be quantified by electroencephalography (EEG) coherence, which measures the statistical correlation between electrodes spatially separated on the scalp. Previous studies conducted a coherence analysis of all EEG electrodes covering all parts of the brain. However, in an epileptic condition, seizures occur in a specific region of the brain then spreading to other areas. Therefore, this study applies an energy-based channel selection process to determine the coherence analysis in the most active brain regions during the seizure. This paper presents a quantitative analysis of inter- and intrahemispheric coherence in epileptic EEG signals and the correlation with the channel activity to glean insights about brain area connectivity changes during epileptic seizures. The EEG signals are obtained from ten patients' data from the CHB-MIT dataset. Pair-wise electrode spectral coherence is calculated in the full band and five sub-bands of EEG signals. The channel activity level is determined by calculating the energy of each channel in all patients. The EEG coherence observation in the preictal (Coh_{pre}) and ictal (Coh_{ictal}) conditions showed a significant decrease of Coh_{ictal} in the most active channel, especially in the lower EEG sub-bands. This finding indicates that there is a strong correlation between the decrease of mean spectral coherence and channel activity. The decrease of coherence in epileptic conditions ($Coh_{ictal} < Coh_{pre}$) indicates low neuronal connectivity. There are some exceptions in some channel pairs, but a constant pattern is found in the high activity channel. This shows a strong correlation between the decrease of coherence and the channel activity. The finding in this study demonstrates that the neuronal connectivity of epileptic EEG signals is suitable to be analyzed in the more active brain regions.

Keywords: *Channel activity, coherence, electroencephalography, ictal, preictal, seizure*

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Introduction

Epilepsy is a brain disorder that globally affects millions of people. This disease is not contagious, but everyone has a great chance of having epilepsy. Epilepsy occurs due to a neurological disorder in the brain, producing an abnormality in the brain signal. The abnormality caused by illness or brain damage may lead to a seizure condition.[1] Moreover, the main characteristic of epilepsy is the recurring seizure condition. There are two definitions of epilepsy. The first is the conceptual definition, which states that a person with epilepsy must have at least one epileptic seizure. The operational definition defines a person to have epilepsy when two or more unprovoked seizures arise at least in 24 h[2-4]

Patients with epilepsy can experience a lot of episodes of seizures during various activities. Even though the patients already took several anti-epilepsy medications, there are still many sudden seizure activities. This uncertainty can trigger trauma, excessive mental anxiety disorder, and can lead to depression. Moreover, sufferers can experience fractures and lead to unexpected death.[5]

Epilepsy is diagnosed by observing the seizure activity of the patient. The observation is done by physical visual inspection, electroencephalography (EEG) signal observation, functional magnetic resonance imaging, and computed tomography (CT) scan. EEG is the most commonly used by the neurologist since it is the least expensive method.[6] Neurologists analyze the EEG recordings

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through a visual inspection based on their experiences. This method is very subjective and needs a lot of time to inspect hours of multichannel EEG recordings.[7,8] To quantify the observation of EEG recordings, scientists develop a computer-aided diagnosis system to help neurologists detect or predict the seizure condition in the epileptic EEG signal recordings.[9-11]

The EEG signals can provide useful information about the seizure condition. Various methodologies have been observed to detect and predict seizure conditions in the EEG signal. Seizure or ictal condition is characterized by a slower background rhythm.[12] The EEG signal is analyzed by observing the EEG in the time domain, frequency domain, and time–frequency domain.[13,14] Reviews about the advanced development of seizure detection are well explained in,[11,15,16] In recent years, the study of computational epilepsy research has shifted to a more challenging problem, the seizure prediction method.[17-19]

Most of the reviewed studies observe the EEG using multivariate time series recording. The multivariate characteristic exists because the EEG signals are recorded using many electrodes placed in the head's scalp. The recorded signals show the neuron's electrical activity, which shows the brain's vast synchronized network communication. The neuronal network's synchronized activity shows the exceptional connectivity between neurons that the brain needed to fully functional.[20] Each region of the brain is specialized in processing specific information. For example, the occipital region is mainly used for visual processing and auditory in the temporal region, while emotion is associated with the prefrontal region,[21,22] Since the EEG signal is generated from a complex system, a study to quantify the interaction between EEG channels representing each region of the brain is needed.[23]

EEG coherence is a method used to analyze the connectivity of two or more electrodes of EEG located in a specific brain region. It checks the similarity of neuronal oscillatory between the electrode pairs. This method has been used since the 1960s to assess the frequency content's similarity among EEG sensors. Recently, coherence was used to analyze the connectivity of a specific region of the brain in the neurological disorder case.[20] In other words, the coherence value indicates the strength of the functional relationship between the brain's region.[24]

Brazier uses coherence to figure out how a brain region was influencing another region during seizure.[25] The method was then improved by including more frequencies and observing the interhemispheric interactions.[26] A quantitative study of the EEG signal in Alzheimer's patients showed a neuronal connectivity decrease by analyzing the coherence of EEG signals[27-29] A similar pattern was also found in epilepsy patients,[30,31] Bowyer *et al*.[20] reviewed the decrease of coherence value in abnormal conditions compared to normal conditions on EEG and MEG signals. There were different coherence characteristics in preictal, ictal, and postictal periods for each patient.[32] Furthermore, there was evidence that the epileptic neocortex was functionally disconnected from the surrounding brain region during seizure.[33] Shriram *et al*.[34] observed the mean coherence in five EEG bands. It shows that the mean coherence of delta, theta, and alpha bands is higher than the other sub-bands in the normal condition.

Medical research done by Song *et al*.[32] processed 256 channels to study the coherence between the brain's hemisphere. Shriram *et al*.[34] and Mammone *et al*.[23] also process all recorded channels directly to analyze the coherence pattern. However, this requires a significant resource to be implemented in the fast and real-time seizure detection and prediction system. Since the future development of epileptic EEG analysis is to create real-time processing, optimal computation is needed. Thus, the channel selection method is considered a suitable method to reduce the computational complexity. In this study, the channel selection method is applied to optimize the analysis of coherence.

The study by Aggarwal *et al*.[31] reduces the processed channels from 153 to 24 channels. The selected electrodes are chosen by matching the location in each hemisphere. Selecting channels by considering the similarity between neighboring electrodes is done by Cotic *et al*.[35] Ravish *et al*.[30] observed 16 channels from the CHB-MIT dataset, which then selected four channels in the frontal and temporal cortex. The selected channel was chosen because it was considered sufficient to cover the seizure and infer the general or partial seizure. Zhang *et al*.[36] observed 23 channels from the same dataset in the nonictal condition. The channel reduction or channel selection plays an important role in the coherence analysis. However, the unspecific channel selection process will create ambiguity when applied in different data or cases. Therefore, to quantify the channel selection process, this study proposes the use of energy-based channel selection to optimize the coherence analysis in epileptic EEG signals.

Numerous studies have shown that the EEG connectivity between brain regions can provide valuable information about the dynamics of neurons' activity. However, further exploration of how the brain regions' connectivity changed in a moment before the seizure occurs or in the preictal condition is needed. This study aims to obtain additional information about brain region connectivity in epileptic EEG recording, specifically in the preictal and ictal conditions. A comprehensive analysis of five sub-bands EEG in inter- and intrahemispheric electrode pairs is presented. Furthermore, the relationship between coherence and high activity of the specific brains' region during the seizure is discussed.

The rest of the paper is arranged as follows. The second section described the dataset used in this study, explanation about EEG coherence, and energy calculation for selecting the appropriate EEG channels. The third section presents the result of energy calculation, inter- and intrahemispheric EEG coherence, including the local and distal coherence. The discussion is presented in the fourth section, including the comparison with other previous studies. The last section presents the conclusion and future work of this study.

Materials and Methods

Dataset

The dataset used in this study is taken from open access data at physionet.org, known as the CHB-MIT EEG dataset. This dataset is a long-term EEG recording from 24 patients collected at the Children's Hospital in Boston in collaboration with the Massachusetts Institute of Technology. The data are recorded from pediatric subjects who undergo assessment for surgical intervention. These data contain 987.85 h of EEG recording with 170 seizure occurrences. The EEGs were recorded using a multichannel bipolar EEG montage (18–24 channels per patient), following the 10–20 system of EEG electrode placement, at a rate of 256 Hz.[37] This study observes the brain region connectivity from 10 patients of the dataset (CHB01-CHB10). A summary of the data used in this study is presented in Table 1.

This study uses 16 bipolar montage channels available in all ten patients, representing the brain's left and right hemispheres. They are "FP1-F7," "FP2-F8," "F7-T7," "F8-T8," "T7-P7," "T8-P8v "P7-O1," "P8-O2," "FP1-F3," "FP2-F4," "F3-C3," "F4-C4," "C3-P3," "C4-P4," ""P3-O1," and "P4-O2." The channel mapping is shown in Figure 1. This study used 55 EEG recordings from patients CHB01–CHB10 that have seizure conditions. The seizure periods are varied from 9 up to 264 s with an average of 74 s. This study used the seizure (ictal) period from the long EEG recording based on the dataset's information. Meanwhile, the preictal period's sample is taken from the exact time before the ictal period, and it has the same length as the ictal sample for each patient. The same duration is chosen because of the need for functional connectivity patterns at the same time window. The red highlight in Figure 2a showed the acquiring process of ictal and preictal signals from the third session of patient CHB01. The preictal and ictal signals are shown in Figure 2b and c, respectively.

Table 1: Summary of the dataset used in this study

Patients	Sex	Age	Number of session	Recording time (h)	Number of seizure	Number of channel
CHB01	P	11	42	40.55	7	23
CHB02	L	11	36	35.3	3	23
CHB03	P	14	38	38	7	23
CHB04	L	22	42	155.9	4	23-24
CHB05	P	7	39	39	5	23
CHB06	P	1.5	18	66.7	10	23
CHB07	P	14.5	19	68.1	3	23
CHB08	L	3.5	20	20	5	23
CHB09	P	10	19	67.8	4	23-24
CHB10	L	3	24	50	7	23

Electroencephalography coherence

EEG coherence is a method to quantify the cortical connectivity between the brain's spatially distributed points.[38] It shows the spectral correlation between two different montages of EEG signals. The study about coherence may assess the neuron's loss connections in the brain.[39] Since there is a slower background rhythm in ictal conditions,[12] neurons' connections are getting lower.[33] The coherence function is a common frequency domain analysis. When it is used in a biomedical signal such as EEG, it allows us to find the similarity of two signals.[40] Thus coherence is considered a perfect analytical tool to assess the connection between brain regions.

The coherence function is defined as the calculation of signals' cross-power spectrum (P_{xy} (ω)) over the power spectra (P_{xx} (ω) and P_{yy} (ω)) of the compared signal, as shown in Eq. 1.[41]

$$C_{xy}(w) = \frac{P_{xy}(w)}{\sqrt{P_{xx}(w)P_{yy}(w)}} \tag{1}$$

The power spectrum and the cross-power spectrum are calculated using Eq. 2 and 3·

$$P_{xx}(w) = \hat{x}(w)\overline{\hat{x}(w)} \tag{2}$$

$$P_{xy}(w) = \hat{x}(w)\overline{\hat{y}(w)} \tag{3}$$

Here, $\hat{x}$ the is the Fourier transform of x, which calculated using Eq. 4, while the $\overline{x}$ is the complex conjugate of x.

$$\hat{x}(w) = \int_{-\infty}^{\infty} x(t)\, e^{-iwt}\, dt \tag{4}$$

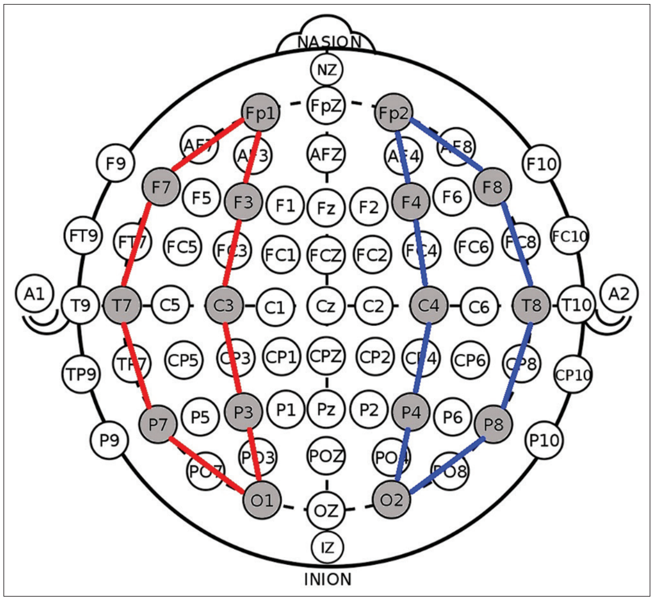

Figure 1: The selected bipolar montage

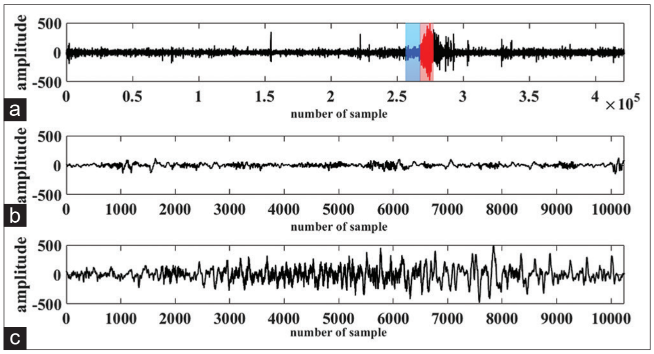

Figure 2: Example of normal and seizure electroencephalography signal, (a) electroencephalography signal recording from patient CHB01, the ictal and preictal periods are highlighted with red and blue colors, respectively, (b) preictal signal, (c) ictal signal

This study measures the coherences based on the electrodes' location representing a specific region of the brain. There are two scenarios used to measure coherence, interhemispheric and intrahemispheric coherence. Both the scenarios use a combination of 16 bipolar channel montages that covered the left and right hemispheres of the brain. Interhemispheric coherence is the measurement between the left and right hemispheres of the brain, while intrahemispheric coherence measures the brain's hemispheres within the same region. Distal pairs of electrodes are added to broaden the intrahemispheric coherence measurement, which measures the connection between channels that are separated by one or more electrodes. The electrode pairs of the inter- and intrahemispheric coherence are shown in Table 2.

The coherence of each electrode pair is calculated over the five EEG frequency bands. The coherence values are then compared between the preictal and ictal conditions. The difference between the compared values is analyzed using the independent *t*-test, where the significance value is set at $P < 0.05$.

Energy calculation

A slowing background rhythm, high spike waves, and lower frequency characterize the ictal period in the EEG signal.[42] Based on these characteristics, this study observes the correlation of the high energy with the coherence value during the transition of the preictal period to the ictal period. The energy measurement is done for each channel available in the dataset using Eq. 5.[43]

$$E = \sum_{n=0}^{\infty} \left| x(n) \right|^2 \tag{5}$$

Here, $x(n)$ is the input signal. The process is started by shorting the energy of each channel in descending order. Then, the channel that has greater energy than the total average energy for each patient is selected. Higher energy means there is a significant activity that occurs in a specific brain region.[44] The example of the energy calculation for each session is shown in Figure 3.

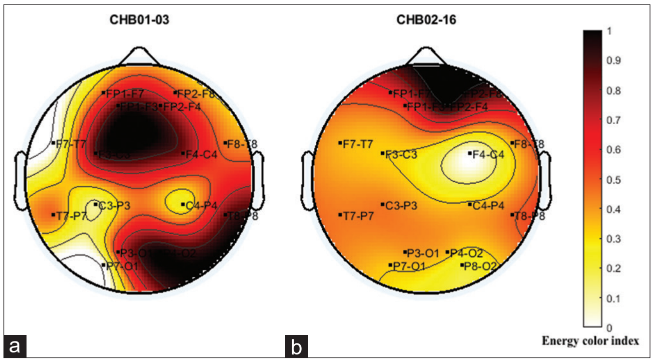

Figure 3: Example of energy measurement of patient ID (a) CHB01_03 and (b) CHB02_16

Results

The CHB-MIT dataset is filtered with a low-pass filter to remove high-frequency artifacts. The data are then segmented into ictal and preictal conditions based on the information given by the dataset. The coherence is then calculated in the 16 selected channels following the pairs shown in Table 2. In general, the result shows that the ictal period's coherence value is lower than the preictal period in the full band EEG. This condition occurs on all electrode pairs in the interhemispheric coherence. However, in the intrahemispheric coherence, the ictal s lower coherence values only occur on several electrode pairs. Detailed information on the inter- and intrahemispheric coherence values is discussed in the next subsection.

Energy calculation result

Energy calculation is performed on all channel montages of EEG recording sessions that have seizure conditions. The purpose of this calculation is to assess the most active channels based on their energy level. The energy of all channel montages is then sorted in descending order. The threshold value is set based on the mean value. Thus, the channel montages having the energy above the threshold are labeled as the "selected channel." This is the first iteration of the channel selection process. The first iteration is carried out in all sessions of all patients. To generalize the most active channel montage, we count how many times each channel montage is labeled as the "selected channel." The more a channel montage is labeled as "selected channel," the more active it is compared to other channel montages. Figure 4 shows the activity level of each channel montage represented in a color form. This activity leveling is needed to assist the coherence's analysis, which is discussed in the next section.

The most active channel montage is shown in red color. It indicates that the channel montage is found as an active channel in all patients more than ten times. The prefrontal cortex region (FP1–F7, FP1–F3, FP2–F4, and FP2–F8) is categorized as the most active area.

Table 2: Inter- and intrahemisphere coherence electrode pairs

Interhemispheric	Left intrahemispheric		Right intrahemispheric	
	Left local	Distal	Right local	Distal
(FP1-F7)-(FP2-F8); (F7-T7)-(F8-T8); (T7-P7)-(T8-P8); (P7-O1)-(P8-O2); (FP1-F3)-(FP2-F4); (F3-C3)-(F4-C4); (C3-P3)-(C4-P4); (P3-O1)-(P4-O2)	(FP1-F7)-(F7-T7); (FP1-F7)-(FP1-F3); (FP1-F7)-(F3-C3); (F7-T7)-(FP1-F3); (F7-T7)-(F3-C3); (FP1-F3)-(F3-C3); (T7-P7)-(P7-O1); (T7-P7)-(C3-P3); (T7-P7)-(P3-O1); (P7-O1)-(C3-P3); (P7-O1)-(P3-O1); (C3-P3)-(P3-O1).	(FP1-F7)-(P3-O1); (FP1-F7)-(P7-O1); (P7-O1)-(FP1-F3); (FP1-F3)-(P3-O1).	(FP2-F8)-(F8-T8); (FP2-F8)-(FP2-F4); (FP2-F8)- (F4-C4); (F8-T8)- (FP2-F4); (F8-T8)-(F4-C4); (FP2-F4)- (F4-C4); (T8-P8)- (P8-O2); (T8-P8)-(C4-P4); (T8-P8)- (P4-O2); (P8-O2)- (C4-P4); (P8-O2)-(P4-O2); (C4-P4)- (P4-O2).	(FP2-F8)-(P4-O2); (FP2-F8)-(P8-O2); (P8-O2)-(FP2-F4); (FP2-F4)-(P4-O2);

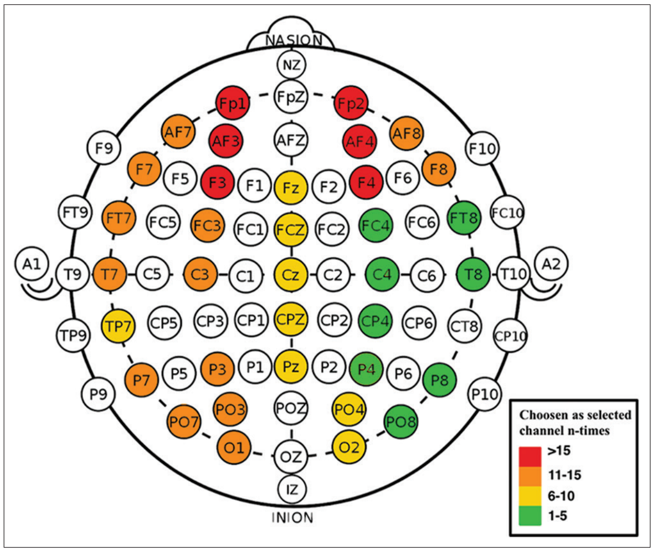

Figure 4: Color representation of the 16-most active channels based on the energy calculation

Interhemispheric coherence

Figure 5 shows the interhemispheric coherence between the left and right hemisphere electrode pairs. This study calculates the mean spectral coherence for all subjects in all five frequency bands. The mean spectral coherence results of the ictal period on the delta, theta, and alpha bands are mostly lower than the preictal period. However, in the beta and gamma bands, the pattern is biased. The condition occurs because the seizure or ictal condition has a slower background rhythm, which is indicated by lower signals' frequency. The highest reduction of coherence is found in the "(FP1-F3)-(FP2-F4)" pair ($P = 0.0049$). Furthermore, the *t*-test shows that in the delta, theta, and alpha bands, there is a significant difference in the "(FP1-F3)-(FP2-F4)" and "(P3O1-P4O2)" pairs ($P < 0.05$).

Intrahemispheric coherence

Further investigation is performed in the intrahemispheric electrode pairs, which calculate the coherence between the brains same cortical hemisphere. There are two types of intrahemispheric electrode pairs, the left or right intrahemispheric coherence and the distal coherence. The left or right intrahemispheric coherence measures nearby electrodes, with the distance between electrodes being set to one. The system uses it as the distal coherence measurement if the electrode's range is more than one electrode. The details of each pair are shown in Table 2.

Local and distal coherence right

Figure 6 shows that in the full band EEG, some of the coherence's mean values of the ictal condition are lower than the preictal condition. Thus, the values for the other sub-bands are observed. Seven pairs in the delta bands show a lower value of the ictal conditions, while there are 10 pairs in theta, 13 in alpha, twelve in beta, and 9 pairs in gamma. The most significant reduction of the mean values coherence is shown in the "(FP2-F8)-(FP2-F4)" electrode pairs for delta, theta, and alpha bands ($P < 0.05$). The highest reduction of the mean spectral coherence is found in the delta band ($P = 0.0004$).

Local and distal coherence left

Similar to the right hemispheric coherence result, some electrode pairs show that the ictal condition has a lower mean spectral coherence value than the preictal condition. The highest reduction in the full band EEG is found in the "(FP1-F7)-(FP1-F3)" electrode pair ($P < 0.0008$). The same electrode pairs in the delta, theta, and alpha bands show a similar significance result ($P < 0.05$). The details are shown in Figure 7.

Discussion

Table 3 shows the use of coherence to analyze the neuronal connectivity in the brain areas. It can be seen that the coherence analysis can be done to observe the abnormalities that occur in the epileptic condition. Most of the studies shown in Table 3 were conducting the coherence analysis using all EEG electrodes covering all brain regions. Since the seizure condition mostly occurs in a specific brain region, it is important to focus the EEG signal analysis on the most appropriate brain area. The aforementioned results show that significant decreases were found in the most active parts of the brain. However, it should be noted that each patient has a different ictogenic/epileptogenic zone. Thus the neuronal coherence was observed based on the most active brain area during the seizure, which differs for each patient. This study is able to quantify the most active brain region during the seizure by applying energy-based

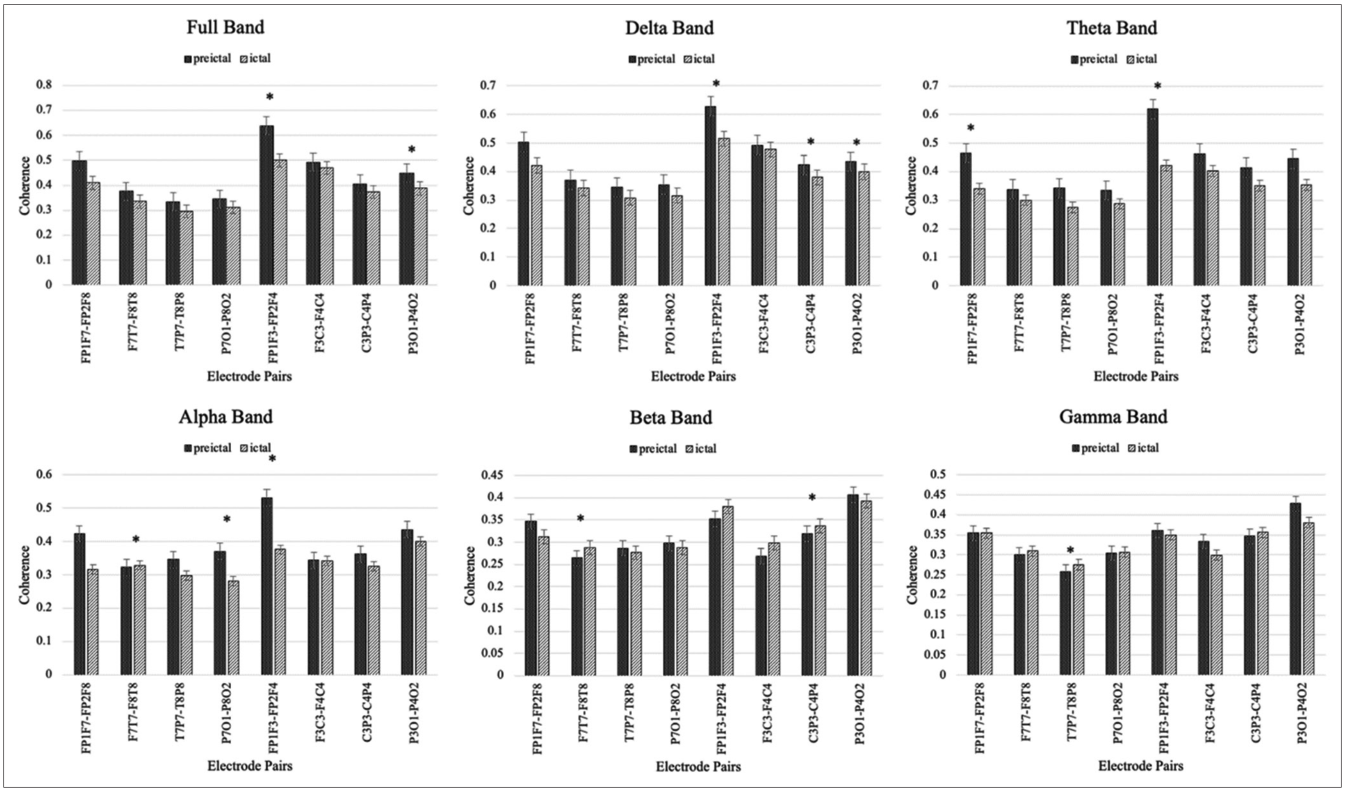

Figure 5: Interhemispheric mean spectral coherence values in the full band and five bands of electroencephalography signals, the electrode pairs with a significant difference ($P < 0.05$) between the preictal and ictal are denoted with an asterisk (*) above the graph

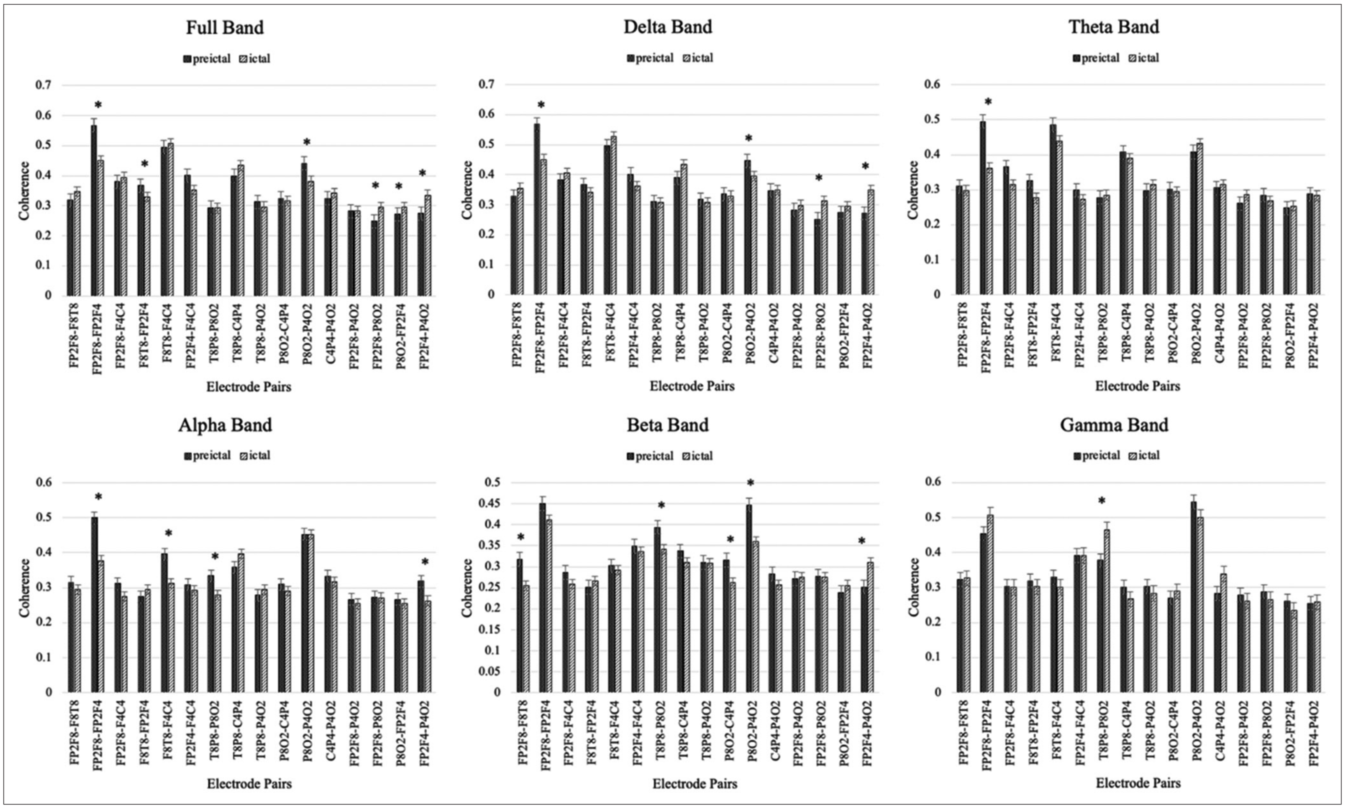

Figure 6: Right intrahemispheric coherence mean values in the full band and five bands of electroencephalography signals, the electrode pairs with a significant difference ($P < 0.05$) between the preictal and ictal are denoted with an asterisk (*) above the graph.

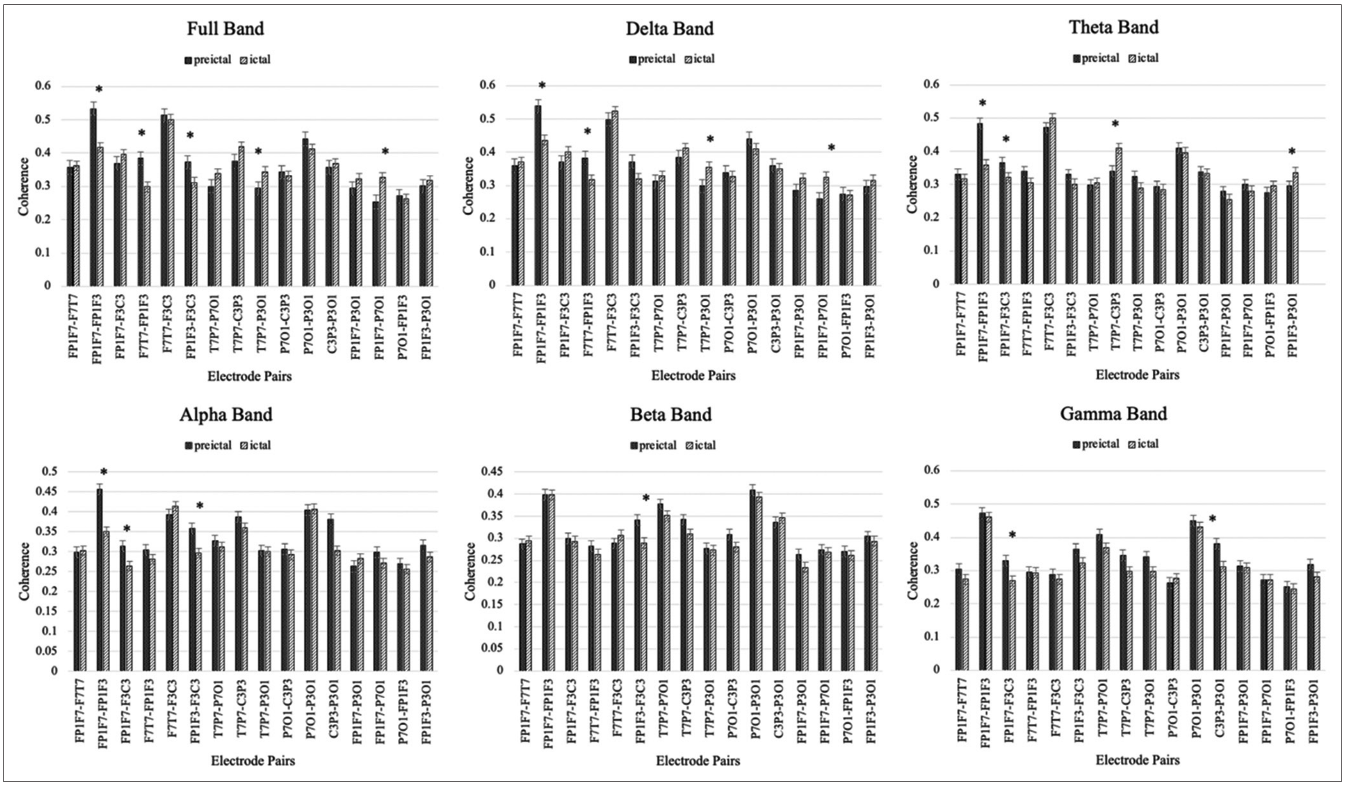

Figure 7: Left intrahemispheric coherence mean values in the full band and five bands of electroencephalography signals, the electrode pairs with a significant difference ($P < 0.05$) between the preictal and ictal are denoted with an asterisk (*) above the graph.

Table 3: Comparison with other studies

Author	Dataset	Method	Original channel	Channel selection
Julkunen *et al*.[46]	Private dataset	Global coherence	60	No
Shriram *et al*.[34]	Karunya University	Energy distribution and coherence-based changes	18	No
Busonera *et al*.[50]	Sleep disorder center of Cagliari and Parma with	Spectral coherence	19	No
Abbaszadeh *et al*.[51]	University Hospital of Freiburg, Germany	Global coherence	6	No
Narasimhan *et al*.[47]	Vanderbilt University Medical Center	Partial directed coherence	115.9±31.3	No
An *et al*.[45]	Shanghai Jiao Tong University	Partial directed coherence	128-256	Yes (1 channel)
Ravish *et al*.[30]	CHB-MIT, Meenakshi Medical College Hospital	Coherence and phase synchrony	23-26	Yes (4 channels)
This study	CHB-MIT	Spectral coherence	23-24	Yes (4-10 channels)

CHB-MIT: Children's Hospital Boston – Massachusetts Institute of Technology

channel activity. The study by Ravish *et al*.[30] selected four channels from 16 available channels. The selection is based on the assumption that the four channels were adequate to localize the seizure. Moreover, An *et al*.[45] convert the 128–256 channels into a single channel time-frequency because it may reflect the brain region's epileptogenicity. Our study used 4–10 channels based on the channel activity shown by the higher energy level.

This study evaluates the mean spectral coherence value of epileptic EEG signals in preictal and ictal conditions. The calculation is done in inter- and intrahemispheric regions of the brain. In summary, the interhemispheric mean spectral coherence values for the full band, alpha band, theta, and delta bands are lower in the ictal period than in the preictal period. A similar result is found in the study by Julkunen *et al*.,[46] Narasimhan *et al*.,[47] and Shriram *et al*.,[34] which found the decrease of coherence in the delta, theta, and alpha bands. Song *et al*.[32] mentioned that there is a specific characteristic in coherence values during the preictal, ictal, and postictal periods. Since the connection between neurons is getting lower during the brain waves' abnormality,[33] the observation in this study is done by analyzing the decrease of mean spectral coherence values between the preictal and ictal periods based on the electrode locations. Lower coherence value means less connection between electrodes.[34,48,49]

A significant decrease is mostly found in the frontal lobe of the brain. Even though some significant decreases are also found in other areas such as the temporal and parietal lobes, it is inconsistent among the five sub-bands. For example, in the delta and beta bands, the decrease happens in all channel pairs. It is found that the ictal period has a higher coherence value in the alpha bands "(F7-T7)-(F8-T8)." This showed that there are unbalanced connectivity conditions. A similar pattern can be found in the previous studies,[50] where the observation is conducted in the frontal and occipital–parietal areas. Ravish *et al*.[30] showed a rising coherence value in seizure conditions, which happened because of the decomposition method's scaling process. However, our study confirmed that the unbalanced connectivity also occurs in the frontal, occipital, temporal, and parietal areas.

The right intrahemispheric mean spectral coherence values in the full band show that there is a significant decrease in the local frontal "(FP2-F8)-(FP2-F4)" and local parietal–occipital lobe "(P8-O2)-(P4-O2)." Contrary, the distal pair, which connects the frontal and parietal–occipital lobe, shows an increase of mean spectral coherence values in the ictal period. A similar pattern occurs in the delta band. The local frontal pair is constantly decreasing in the ictal band for the full band, delta, theta, and alpha bands. Abbaszadeh *et al*.[51] mentioned that the frontal lobe could give better information from seizure conditions. This condition is confirmed by our study that the frontal lobe has a significant difference between the ictal and preictal conditions ($P < 0.05$).

The mean spectral coherence value from the left intrahemispheric electrode pairs shows a significant decrease in the local-frontal "(FP1-F7)-(FP1-F3)," "(F7-T7)-(FP1-F3)," and "(FP1-F3)-(F3-C3)." The left distal pairs have a similar pattern with the distal right hemisphere electrode pairs, which shows a higher coherence value in the ictal period.

It is known that preictal is the condition before a seizure occurs, while the interictal is the preictal condition located between two seizures. This study assumes that the preictal and interictal are the same condition that occurs a moment before ictal condition. Thus, this study does not discuss the coherence value between the two conditions in detail. However, to show the similarity between the two conditions, we compared the interictal with preictal and ictal coherence values, which available on chb04_28, chb06_01, chb06_04, and chb09_08. The result is presented in Figure 8.

Figure 8 shows that the interhemispheric coherence values of interictal and preictal are higher than the ictal condition. A similar condition is also found in the left and right intrahemispheric coherence. The similar coherence value of preictal and interictal conditions indicates that both conditions can be assumed as the same condition and can be used to differentiate with the ictal condition.

Since coherence is measured based on the power spectra, one of the limitations of this study's coherence method is the power spectra computation issue, especially the length of the data and non-stationarity issue. The analysis at a lower frequency can be biased at a short epoch of the EEG signal due to unreliable power spectra estimation. Furthermore, if we consider the epoch of the signal as nonstationary, the Fourier transform can not provide a reliable result. Therefore, selecting the suitable signal length that keeps the signal stationary while covering the frequency of interest is challenging.

The aforementioned results show that there is an inconsistent change of the coherence value in some montage pairs, especially in the interhemispheric coherence and in the higher frequency of EEG bands. It is noted that epilepsy occurs in the lower frequency of EEG bands such as delta, theta, and alpha bands.[12] Furthermore, this study is able to show a consistent decrease of coherence value in the lower EEG sub-bands. This study concludes that the decrease of neuronal connectivity in epileptic conditions can be easily observed in delta, theta, and alpha bands of EEG signals.

Conclusions

In this study, a coherence measurement to analyze the connectivity between two EEG electrodes representing specific brain regions is presented. This study confirms the reduction of coherence value during abnormalities, such as the ictal condition. The observation is conducted using ten patients from the CHB-MIT dataset. The combinations of inter- and intrahemispheric channel montage from 16 selected channels are performed. The mean spectral coherence from interhemispheric channels shows a significant decrease in the full band and the lower frequency sub-bands. The observation on the left and right intrahemispheric channels shows a similar pattern. However, there is an inconsistent change of the coherence value in some montage pairs. This study observes the correlation between the coherence value with the channel montage activity level to overcome the issue. It is found that there is a strong correlation between the decrease of mean spectral coherence and the high energy in the corresponding channel. For the future fork, it is important to find out the most active channel montage before applying the coherence analysis. Furthermore, the energy-based channel selection method has shown good performance in determining the most active channel montage. For future work, applying the coherence analysis in the epileptic EEG seizure detection and prediction system will better analyze the epileptic EEG signals. It is hoped that by focusing the EEG signal analysis in the appropriate brain area, the development of seizure detection and prediction system can be optimized. Moreover, by knowing the reduction of coherence values, an adaptive windowing system can be done to overcome the uncertain preictal time period problem.

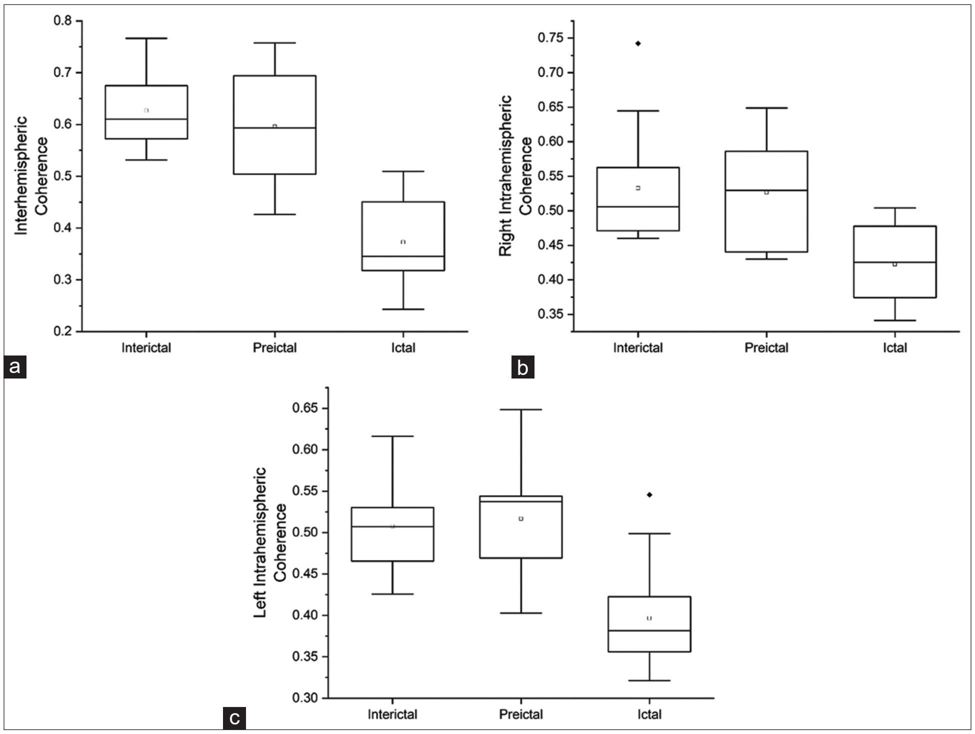

Figure 8: Comparison of interictal, preictal, and ictal coherence value from chb04_28, chb06_01, chb06_04, and chb09_08. (a) Interhemispheric coherence, (b) Right intrahemispheric coherence, (c) Left intrahemispheric coherence

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Conflicts of interest

There are no conflicts of interest.

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