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Bicoherence Analysis Of Change Blindness

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Abstract: The electroencephalogram (EEG) are electric potentials which are produced by neurons inside the brain. Over the years, EEG has been proved a useful technique for understanding the neuro-physiological mechanisam of various cognitive and neurological disorders. The EEG analysis of change blindness, which is psychological phenomenon that occurs when brain is unable to notice substantial visual changes, has also been reported in literature. However these studies are based upon linear signal processing methods and therefore non-linear characteristics of EEG signals are lost. This study examines the non-linear characteristics of EEG using both auto and cross-bicoherence functions. The cross-bicoherence function reveals the non-linear relationship between signals in terms of their frequencies.

Keywords: Electroencephalography, change blindness, cross-bicoherence function, event related potentials

1. INTRODUCTION

Change blindness is psychological phenomenon which arises when human brain is incapable to detect substational visual changes in short intervals of viewing. Various factors such as attention, disorder in visual short term memory, and inadequate brain processing are assumed as the main causes which can produce the change blindness (Beck *et al.,* 2001). Few studies have reported increased functional magnetic resonance imaging technique (FMRI) activity over the parietal and frontal regions of the brain while the subjects were busy in detecting the change (Beck *et al.,* 2001; Pessoa *et al.,* 2005; Simons *et al.,* 2005) However these studies do not provide the evidence that change in the FMRI activity can be related to the change detection or change blindness. This is because such change in FMRI activity might be correlated to the visual attention phenomenon. In order to examine the time domain neuro-physiological mechanisam of various cognitive disorders including change blindnees, the satisfactory time resolution of very short duration is required. This is because human brain processes the information in very short duration of time even in the order of milli-seconds. As compared to the current imaging techniques which offer better spatial resolution at the cost of poor temporal resolution, the EEG offers suitable temporal resolution even in the order of milli-seconds. The event related potentials (ERPs), which are time-locked EEG with sensory or cognitive events, have been proved a useful tool in the study of change blindness and various other neurological disorders. Literature reports decrease in ERP component at different locations of the brain for change blindness trial as compared to the change detection trial (Pessoa *et al.,* 2005; Koivisto *et al.,* 2003; Elimer *et al.,* 2005). Apart from the time-domain ERP analysis, the frequency-domain analysis of ERPs for the change blindness reveals important findings. For example, decrease in gamma band ERP activity and inecrease in beta band ERP activity for change blindness trial has been reported in literature (Pesonen *et a*l., 2007 Alvaro *et al.,* 20011). The EEG-based power spectral density function, which shows the distribution of energy in frequency domain, has been found comparatively smaller in value for change blindness trail (Klimesch *et al.,* 1999; Park *et al.,* 2010). Few studies report decrease in functional connectivity between different regions of the brain during the change blindness trial (Qazi *et al.,* 2005 Markazi *et al.,* 2005). The functional connectivity in these studies was assessed using the coherence function, which is used to reveal linear correlation between signals.

Apart from the linear signal processing methods such as power spectral density function and coherence function, the nonlinear signal processing methods have also brought useful results for various neurological and cognitive disorders. The cross and auto bicoherence functions, which evaluate the quadratic phase coupling type nonlinear interaction between two different and same signals respectively, have various clinical applications. For example, auto-bicoherence function has been used to examine the effects of anesthetic drugs on EEG (Hagihira *et al.,* 2002; Morimoto *et al.,* 2006). It is also used in the Bispectral Index System, which is designed for the assessment of hypnosis depth. Both cross and auto-bicoherence functions have been used to understand the neurophysiological mechanism of visual short term memory processing (Schack *et al.,* 2002) Apart from

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these studies, the cross and auto-bicoherence functions have been used in the study of various other neurological and cognitive disorders. However the use of both cross and auto-bicoherence functions for the study of change blindness disorder has not been reported in the literature to the best of our knowledge. Therefore this study uses the EEG-based auto and cross-bicoherence functions in order to examine the non-linear EEG interactions involved in the neurophysiological mechanism of change blindness.

2. MATERIAL AND METHODS

The EEG data of event related potentials (ERPs) for change blindness study was recorded in the laboratory of the Centre for Cognition and Neuroimaging at Brunel University. The data was recorded from 15 healthy subjects who were recruited as paid volunteers. No sign of neurological and physical disorder was observed after the subjects were diagnosed from neurologist and general physician. The ERPs of change blindness were elicited by following the procedure as following. The subjects were seated on comfortable seat and they were shown visual sets of two pictures in two different ways through the computer screen. The picture sets were selected from the study of (Snodgrss and Vanderwart, 1980), and they contained either two same pictures with no changes or two same pictures with substantial visual changes. The subjects were asked to detect changes in visual pictures and press the mouse key if they were confident about those changes. The two picture sets, each of which with different visual features, were shown to the subject for one minute. The set of two pictures was called change blindness trial in case if subjects were failed to detect either changes in two pictures or no changes in two pictures. The trial was called change detection trial in case if subjects were successful in detecting either changes in two pictures or no changes in two pictures. Each trail was shown to the subjects with the time interval of 3.2 seconds and time interval between two pictures in each set was 1.6 seconds.

The recoded EEG data was converted into digital signal using the sampling rate of 256 Hz. The EEG data was recorded into sound attenuated radio frequency shielded room for avoiding the EEG artifacts caused due to the electromagnetic radiation. In order to minimize the EEG artifacts caused due to the body movement of subjects, the subjects were asked not to perform any unnessaccery movement. The band pass filter of frequency range 0.02-50 Hz was used for minimizing the EEG artifacts caused due to electrogalvanic and electromyographic signals.

Estimation of auto and cross-bicoherence functions

The cross-bicoherence function reveals the non-linear characteristics of two different signals in terms of quadratic phase coupling (QPC). The cross-bicoherence function for two time series $x(t)$ and $y(t)$ was estimated using the following relation .

$$\Upsilon_{xy}(\omega_1,\omega_2) = \frac{\sum_{n=1}^{n=m} B_n^{xy}(\omega_1,\omega_2)}{\sqrt{P_n^x(\omega_1),P_n^y(\omega_2)P_n^y(\omega_1+\omega_2)}} \quad (1)$$

Equation 1 outlines the method for computing the cross-bicoherence function as following.

Assume for the electrode position X, $x_{\mathrm{n}}(t_1)$, $x_{\mathrm{n}}(t_2)$ and $x_{\mathrm{n}}(t_3)$ be the set of single repeated trials at time t_1 , t_2 , and t_3 whose Fourier transforms are $X_{\mathrm{n}}(\omega_1)$ and $X_{\mathrm{n}}(\omega_2)$ and $X_{\mathrm{n}}(\omega_3)$ respectivley. Where $t_3 = t_1 + t_2$ and n stands for sample value of corresponding time series. Similarly, for the electrode position Y, $y_{\mathrm{n}}(t_1)$, $\mathrm{y}(t_2)$ and $y_{\mathrm{n}}(t_3)$ be the set of single repeated trials at time t_1 , t_2 , and t_3 whose Fourier transforms are $Y_{\mathrm{n}}(\omega_1)$ and $Y_{\mathrm{n}}(\omega_2)$ and $Y_{\mathrm{n}}(\omega_3)$ respectivley. The cross-bispectrum for single repeated trial was estimated using the relation $B_n^{xy}(\omega_1,\omega_2) = X_n(\omega_1)Y_n(\omega_2)Y_n^*(\omega_1+\omega_2)$. The power spectra for electrode positions X and Y was estimated using the relations
$P_n^x(\omega_1) = X_n(\omega_1)X_n^*(\omega_1), P_n^y(\omega_2) = Y_n(\omega_2)Y_n^*(\omega_2)$, and $P_n^y(\omega_1+\omega_2) = Y_n(\omega_2)Y_n^*(\omega_2)$.

Then the averages of cross-bispectra and power spectra across all repeated trials were obtained and then used in equation (1) to obtain the value of cross-bicoherence. Finally the magnitude square cross-bicoherence (abbreviated as MSCB) was calculated by estimating the square of the absolute value of equation (1) The auto-bicoherence function was estimated using the same procedure described for cross-bicoherence function and by measuring it for two similar time series.

Statistical Analysis

Since cross-bicoherence and auto-bicoherence functions may involve the contribution of complex numbers, the results in this study are analyzed using the magnitude square of these functions. Both cross and auto bicoherence functions may involve a bias and variance, their statistical significance was assessed by using the following method (Shils *et al.*, 1996)

$$\phi(\omega_1,\omega_2) > \frac{2e}{\sqrt{r}} \quad (2)$$

where r shows the number of repeated trails, and magnitude square of both cross and auto-bicoherence functions are denoted by $\phi(\omega_1,\omega_2)$. The error e can be estimated by the relation:

$$\epsilon[\phi(\omega_1,\omega_2)] = \left(\frac{\phi(\omega_1,\omega_2)}{\omega_1^{max}\omega_2^{max}(\omega_1^{max}+\omega_2^{max})r}\right)^{1/2} \quad (3)$$

The 95% level of statistical significance was set and any estimate of both functions less than $\frac{2e}{\sqrt{r}}$ was discarded.

3. RESULTS AND DISCUSSION

The magnitude square of auto-bicoherence (MSAB function) for change detection trials was compared to the magnitude square of cross-bicoherence (MSCB function) for change blindness trials for various positions of electrodes on the brain.The pre-frontal positions of electrodes FP1 and FP2 showed significant increase in MSAB activity for change detection trial as compared to the change blindness trials for majority of subjects. The difference was found more prominent when two frequencies $\omega_1$and ω_2 were in the range of gamma frequency band [30-40] Hz. The another important result was increase in MSAB function at FP1, FP2, FPZ for change blindness trial as compared to the change detection trials. However the increase in the MSAB function for change blindness trial was observed when both frequencies ω_1 and ω_2 were in the same frequency region of beta band (15-20 Hz). This result is in contrast to previously discussed result in which MSAB function exhibited the larger value for change detection trial across the two same frequency regions of gamma band.

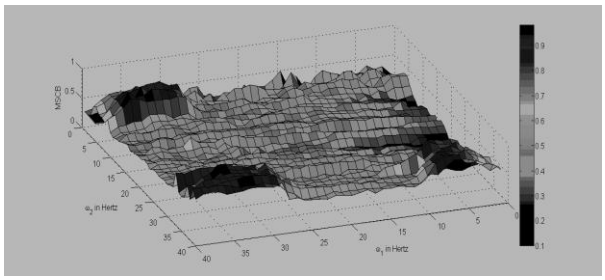

Fig. 1: EEG-based MSCB function for change detection trial

The cross-bicoherence function for change blindness trials was compared to the cross-bicoherence function for change detection trials. The frontal positions of electrodes, as shown in **(Table 1)**, showed significant increase in gamma band. The difference was more significant in all cases when two frequencies were in the frequencies range of [33-40][4-8] and [33-40][33-40] Hz. The frequency regions [33-40] and [4-8] corresponds to gamma and beta frequency bands respectively. Contrary to the gamma and theta bands of frequency, the beta band of frequency showed increase in MSCB function for change blindness trials as compared to the MSCB function change blindness trials. This result is illustrated in Figure 1 where MSCB function for change detection trial is plotted for two frequencies $\omega_1$and ω_2 in Hertz. It is clearly shown that MSCB function shows larger peaks when both frequencies are in range of [33-40] [33-40], and [33-40][4-8] Hz.

The statistical significance for the difference in both MSAB and MSCB functions between change detection and change blindness trials was assessed by using the non-parametric Wilcoxon rank-sum test. The test was performed for the frequency regions of [beta, beta], [gamma, theta] and [gamma, gamma] and therefore the average MSAB and MSCB functions across these frequency regions were used.

As shown in **(Table 1)** Wilcoxon rank-sum test test revealed significantly large MSAB activity at Frontal position of electrodes for change detection trial in gamma band of frequency. However no significant difference in other bands of frequencies were oberved between change detection and change blindness trials. The MSCB activity, as shown in **(Table 2),** at frontal

Table 1:The MSAB function and score of Wilcoxon rank-sum (WRS) test

Electrode positions for three combinations	WRS test results across gamma and theta bands for MSAB function. P = 0.023		WRS test results across both gamma bands for MSAB function. P=0.035	
	CB	CD	CB	CD
[FP1] [FP1][FP1]	0.42+0.02	0.56+0.01	0.45+0.05	0.65+0.04
[FZ] [FZ][FZ]	0.43+0.03	0.73+0.05	0.52+0.03	0.73+0.02
[FP2] [FP2][FP2]	0.90+0.03	0.94+0.02	0.54+0.07	0.51+0.04
[F3] [F3][F3]	0.34+0.05	0.47+1.03	0.92+0.02	0.96+0.05
[F4] [F4][F4]	0.52+0.02	0.65+0.04	0.26+1.03	0.14+1.03
[F1] [F1][F1]	0.83+1.01	0.94+0.03	0.93+1.02	1.18+1.01
[F2] [F2][F2]	0.33+0.05	0.46+0.08	1.24+0.08	1.38+1.01

The *asterisk symbol indicates the significant value of P for the 0.05 level of significance*

Table 2:The MSCB function and score of Wilcoxon rank-sum (WRS) test

Electrode positions for three combinations	WRS test results across gamma and theta bands for MSCB function. P=0.022		WRS test results across both gamma bands for MSCB function. P=0.037	
	CB	CD	CB	CD
[FP1] [FP2][FP2]	0.22+0.01	0.36+0.02	0.31+0.06	0.49+0.04
[FP2] [FP1][FP1]	0.23+0.04	0.73+0.03	0.42+1.01	0.57+0.09
[FZ] [FP1][FP1]	0.61+0.04	0.94+0.01	0.53+0.03	1.39+0.08
[F2] [F4][F4]	0.64+0.04	0.77+1.01	1.15+0.09	1.99+0.04
[F1] [F2][F2]	0.42+1.03	0.95+1.02	0.96+0.06	1.43+0.09

electrode positions shows statistically significant increase in change detection trial in pair of frequency bands [gamma, gamma] and [gamma, theta]. However in contrast to significant increase in MSCB activity for change detection trials, the MSCB activity shows significant decrease for change detection trials across the pair of frequency regions corresponding to both beta band of frequencies. This difference in results for MSCB activity might be due to the fact that standard frequency bands gamma, beta, and theta reflect different neurophysiological mechanism and therefore beta band MSCB function have shown the different result as compared to the results obtained using gamma and theta band MSCB functions.

4. CONCLUSIONS

Statistically significant high auto-bicoherence and cross-bicoherence between fast frequencies and slow frequencies were observed at frontal position of electrodes for change detection trials as compared to the change blindness trials. The presence of high auto and cross-bicoherence at frontal position of electrodes indicates the presence of quadratic phase coupling (QPC) between fast and slow frequencies. This important finding leads to the conclusion that phenomenon of QPC might be the key factor in understanding the neurophysiological mechanism of change blindness.

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