Wavelet Coherence Analysis of Change Blindness

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RECEIVED ON 18.06.2012 ACCEPTED ON 18.09.2012

ABSTRACT

Change blindness is the incapability of the brain to detect substantial visual changes in the presence of other visual interruption. The objectives of this study are to examine the EEG (Electroencephalographic) based changes in functional connectivity of the brain due to the change blindness. The functional connectivity was estimated using the wavelet-based MSC (Magnitude Square Coherence) function of ERPs (Event Related Potentials). The ERPs of 30 subjects were used and were recorded using the visual attention experiment in which subjects were instructed to detect changes in visual stimulus presented before them through the computer monitor. The two-way ANOVA statistical test revealed significant increase in both gamma and theta band MSCs, and significant decrease in beta band MSC for change detection trials. These findings imply that change blindness might be associated to the lack of functional connectivity in gamma and theta bands and increase of functional connectivity in beta band. Since gamma, theta, and beta frequency bands reflect different functions of cognitive process such as maintenance, encoding, retrieval, and matching and work load of VSTM (Visual Short Term Memory), the change in functional connectivity might be correlated to these cognitive processes during change blindness.

Key Words: **Electroencephalography, Change Blindness, Wavelet Coherence, Event Related Potentials.**

1. INTRODUCTION

Change blindness occurs when human brain is unable to notice visual changes taking place in brief interruption of viewing. Several factors such as attention, abnormality in short term memory and limited processing capacity of the brain are considered major cause of change blindness [1]. Literature reports increase in FMRI (Functional Magnetic Resonance Imaging) technique activity in the frontal and parietal lobes during the change detection [2-3]. Since human brain processes the various information in the order of milliseconds, the FMRI techniques which offers poor temporal resolution can hide short duration variations in activated network due to change blindness. Therefore most of important information might be lost. The ERPs, which are time-locked EEG with sensory or cognitive events, provide better temporal resolution even in the order of milliseconds but at the cost of poor spatial resolution. Change detection studies based on ERP analysis have investigated the electrophysiological correlates of change detection with better temporal resolution [3-5]. Most of these studies report increase of negativity in ERPs around 200-300 ms at posterior regions of the brain for change detection stimulus

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as compared to stimulus failure to detect change. In addition to the time-domain analysis of ERPs, the frequency-domain analysis of event related potentials for the study of change blindness has also revealed important information. For example, literature reports increase in the amplitude of ERP component in gamma band of frequency in the temporal and parietal regions of the brain as well as decrease in ERP component in beta band of frequency in the parietal and occipital regions of the brain during the change detection trial as compared to the change blindness trial [6-8]. Apart from the conventional ERP analysis of change blindness, EEG literature reports few studies on change blindness using power spectral density. These studies report increase in power spectral density function computed for gamma band of frequency (30-50 Hz) in temporal and parietal regions of the brain for the change detection trail as compared to the change blindness trial [7-9].

The coherence function is another signal processing method which has been used in EEG analysis for examining the correlation between different regions of the brain. Literature reports the use of EEG-based coherence function for various cognitive and neurological disorders. For example, it is being used in the detection of the epileptogenic focus from epilepsy patients [10], identification of neuroanatomic pathways for a seizure propagation [11], alcoholic disorders [12] as well as for the detection of various cognitive disorders [13-14]. However to the best of our knowledge and literature survey, the use of EEG-based coherence function for the study of change blindness has been reported in literature only twice [15-16]. These studies report increased coherence for change detection trial as compared to the change blindness trial for different positions of the electrodes. The major disadvantage of these studies is following.

(1) Study on coherence analysis of change detection/ change blindness is limited to only one subject which results lack of statistical consistency.

(2) The results claim the increase in coherence (functional connectivity) between frontal and posterior regions of the brain. However, the role of four important regions of the brain, known as frontal, parietal, temporal, and occipital regions, in the context of coherence analysis has not been reported. Since each of these brain regions reflects particular brain functions, the results of coherence analysis in the context of these brain regions might be proved useful in understanding the relationship between change blindness and different functions of the brain. In addition to this, the current imaging techniques indicate some kind of association between frontal-parietal regions of the brain during the change detection tasks but it is not clear whether these brain regions show the activity due to change blindness or this activity is related to the visual attention.

(3) The relationship between various frequency bands and coherence analysis of change blindness is not studied in previous studies which is important because ERP activity in specific frequency band might reflect specific neurophysiological mechanisms and therefore can result in different cognitive processes.

In view of the above mentioned limitations in the previous studies based on coherence analysis of change blindness, the main objectives of this study were to examine the functional connectivity between various regions of the brain for three frequency bands: gamma, beta and theta. The ERP data of 30 subjects were used which was recorded during the visual attention experiment in which subjects were instructed to detect changes in picture stimulus presented before them through the computer monitor. The MSC function was used in order to compute the functional connectivity between various regions of the brain and it was computed using the wavelet transform. The advantage of using wavelet transform is that it allows time-frequency

analysis at optimal time-frequency resolution. Unlike the previous studies on the coherence analysis of change blindness in which VCUS effects have not been taken into account, this study has examined the coherence function keeping in account the volume conduction effects.

2. METHODS

2.1 Data

This study EEG data set of ERPs which was recorded using the visual oddball experiment. The data set was obtained from the laboratory of the Centre for Cognition and Neuroimaging at Brunel University West London. For further details on this data set, see [15-16] where ERP analysis using this data set has been published. The brief introduction of this data set is following.

15 male subjects were recruited as paid volunteers for the recording of the data set. The subjects were in the age range of between 18 and 26 years. Artefacts due to the various body parts of subjects were minimized by keeping the subjects in relax position and without the unnecessary movement of their body parts including their eyes. In addition to this, band pass filter between 1-100 Hz was used in order to filter out the low and high frequency artefacts caused by the subjects. The sampling rate of 1000Hz was used in order to digitize the ERP data. International 10-20 system of electrode's position based on 32 electrodes was used for recording the ERP data at the sampling rate of 1000Hz. Subjects were shown two types of pictures: (1) Pictures of human faces and (2) Pictures of natural scenes taken from the study of [17]. Any picture out of these pictures was shown to the subject as the stimulus. Each trial started from 500ms duration of stimulus followed by blank display of 500ms. After this blank display, another stimulus of 500ms appears followed by another blank display of 500ms. Therefore duration of each trial was 2 seconds. The task of the subject was to decide whether two picture stimulus shown to him was same or different. The subjects were asked to show their respond by pressing the mouse key. In case if subject was successful to recognize change or no change trial, it was called change detection trial and in case if subject was not successful in detecting change or no change trial, it was called change blindness trial. The similar procedure was repeated for the pictures of natural scenes. The total of 310 such trials were recorded.

3. EEG SIGNAL PROCESSING

3.1 Wavelet-Based Coherence

For discrete time series x(n), the wavelet transform is:

$$X_n^x(a,b) = \frac{1}{\sqrt{a}} \sum_{n=1}^{N} x(n) \psi_{a,b}^*(n) \quad (1)$$

where *a* is called the scaling parameter, *b* is called the position parameter and * denotes the conjugate operation. The wavelet function $\psi_{(a,b)}(n)$ is called mother wavelet for a=1 and b=0. As scaling parameter *a* changes, the mother wavelet is stretched or expended for covering different ranges of frequency ranges and change in parameter *b* brings the change in the position of mother wavelet. Therefore time-frequency analysis of signal is achieved by changing the values of parameters a and b.

For two time series *x(n)* and *y(n)* whose wavelet transforms are $X^n_x(a,b)$ and $Y^n_y(a,b)$, the wavelet cross-spectrum $W^{nx}_y(a,b)$ and the wavelet auto-spectra $W^{nx}_x(a,b)$ and $W^{ny}_y(a,b)$ are:

$$W_n^x(a,b) = X_n^x(a,b) * Y_n^{*x}(a,b) \quad (2)$$

$$W_n^{xx}(a,b) = X_n^x(a,b) * X_n^{*x}(a,b) \quad (3)$$

$$W_n^{yy}(a,b) = X_n^y(a,b) * Y_n^{*y}(a,b) \quad (4)$$

The wavelet coherence is given by:

$$W_n^{xy}(a,b) = \frac{W_n^{xy}(a.b)}{\sqrt{W_n^{xx}(a,b) * W_n^{yy}(a,b)}} \quad (5)$$

For time-frequency coherence analysis, the cross and auto spectra appearing in Equation (6) represent the average of cross and auto spectra estimated for each trial respectively.

4. STATISTICAL CONSIDERATIONS

4.1 The Group Difference

Fisher's Z transformation was applied to normalize the MSC values and then the two-way ANOVA test was used on the normal distribution of MSCs for assessing a statistical significance of MSC difference between change detection and change blindness trial.

4.2 Confidential Interval of MSC

The statistical significance of time-frequency MSC was assessed using the method of [18] which is based on the following relation

$$P_t = 1-(1-t)^{R-1} \quad (6)$$

where $0 \leq t \leq 1$

where t is the detection threshold, R is the number of repeated trials, and P_t is the desired level of confidence. For a 95% confidence interval:

$$1 - (1-t)^{R-1} = 0.95 \quad (7)$$

or

$$t_{95\%} = 1 - 0.05^{\frac{1}{R}-1} \quad (8)$$

Any value of MSC less than the $t_{95\%}$ was not considered as the significant value.

5. RESULTS AND DISCUSSION

5.1 Volume Conduction Effects on Coherence Analysis

Following is the alphabetical representation of electrodes for various positions of the electrodes on the brain. The electrodes on the frontal region of the brain was represented by FZ, F3, F4, F7, F8, FC1, FC2, FC5, the electrodes on the parietal region of the brain was represented by PZ, P3, P4, P7, P8, the electrodes on the temporal region of the brain was represented by T7, T8, and the electrodes on the occipital region of the brain was represented by OZ, O1, O2. Because of the time-frequency analysis of MSC using wavelet transform, it was found that MSC which was independent of time was also independent of frequency. Since EEG literature provides significant evidence that volume conduction effects due to VCUS (Various Uncorrelated Sources) present in the brain are independent of frequency, it might be concluded that MSC due to VCUS effects is independent of both time and frequency. The MSCs affected by VCUS effects were identified using this result and were not included in the analysis of results. Therefore, MSC of 25 subjects out of 50 subjects for each pair of electrode was selected in such a way that no VCUS effects on corresponding MSCs were observed during the analysis of results. The issue of VCUS effects was important in this study because VCUS effects introduce the artificial coherence into the true value of coherence function and hence produce the biased estimates. For reviews on VCUS effects e.g. [19-21].

5.2 Coherence Analysis

The wavelet MSC for each trial corresponding to pair of electrodes X and Y was estimated using the square of the absolute value of Equation (5) and the Morlet mother wavelet.

$$\psi(n) = \frac{1}{n} e^{\frac{t^2}{2}} e^{i\omega_0(t)} \quad (9)$$

The nondimensional frequency $\omega_0=6$ for the Morlet mother wavelet was used, because it provides a scaling parameter of the wavelet nearly equivalent to Fourier period [22], thus providing an optimum definition in the frequency

domain. The average of all estimated wavelet MSCs for each trial across all repeated trial was estimated. Furthermore in order to assess the effects of frequency bands and type of stimulus using the two-way ANOVA test, the mean band MSC was obtained by taking the average of that MSC across the time-frequency region of $[t_1\text{-}t_2]$ $[f_1\text{-}f_2]$ where $t_1\text{-}t_2$ corresponds to the time durations of 500-1000ms from the offsets of first and second stimulus and $f_1\text{-}f_2$ corresponds to the frequency regions of gamma [30-50], beta [15-26], and, theta[4-7] Hz bands. The mean band MSCs corresponding to the gamma, beta and theta frequency bands are called in this study gamma band, beta band and theta band MSCs respectively.

Tables 1-2 represents average of these mean band MSCs obtained by taking the average of mean band MSCs estimated for each subject. The mean band MSCs shown in these tables correspond to the time region of second stimulus. As shown in Tables 1-2 that, ANOVA test significantly revealed increased gamma band MSC between parietal and frontal regions and between frontal and occipital regions of the brain for change detection trials as compared to the change blindness trials during the interval of 500-1000ms from the offset of second stimulus.

During the time interval of first stimulus, no significant difference in gamma band MSCs between change detection and change blindness trials was examined which might be due to the reason that during this time interval subjects have to activate a template of the target in visual short term memory and decision making process regarding change detection takes place during the time interval of second stimulus. Even though no statistically significant difference in gamma band MSCs between the two trials was examined during the time-interval of first stimulus, there were various subjects who exhibited large gamma band MSCs during this time interval. This effect might be due to the rehearsal of objects in visual short term memory.

As shown in Tables 1-2 that the ANOVA test revealed significantly large theta band MSC between frontal and parietal and between frontal and occipital regions of the brain for change detection trials as compared to the change blindness trials during the interval of 500-1000ms from the offset of second stimulus. However no significant difference in theta band MSC between change detection and change blind trials was examined during the time-interval of first stimulus. The significant decrease in beta band MSC between frontal and parietal and between frontal and occipital regions of the brain for change detection trial as compared to the change blindness trial was observed from the offset of second stimulus. This result is in contrast to gamma and theta band MSCs which exhibited statistically significant increase in MSC for change detection trial as compared to change blindness trial for similar position of electrodes. The standard frequency bands gamma, beta, and theta reflect different neurophysiological mechanism and therefore beta band MSC have shown the different result as compared to the results obtained using gamma and theta band MSCs.

The decrease in P-value value (increase in significant level) based on ANOVA test was observed for change in MSCs between change detection and change blindness trial as the inter-electrode distance increased from frontal position to towards occipital region of the brain and vice versa. The ANOVA test revealed significant difference in MSC between change detection and change blindness trial for pair of electrodes corresponding to the frontal and parietal regions as well as for frontal and occipital regions of the brain. However, except for few cases, no significant difference in MSCs between change detection and change blindness trials was observed for MSCs corresponding to the brain regions of inter-frontal, inter-parietal, and inter-occipital.

TABLE 1. THE DIFFERENCE IN MSCS BETWEEN CD (CHANGE DETECTION) AND CB (CHANGE BLINDNESS) TRIALS (AVERAGE OF MEAN BAND MSCS+ STANDARD DEVIATION) FOR DIFFERENT FREQUENCY BANDS AND CORRESPONDING SCORES OF ANOVA STATISTICAL TEST

Electrode Positions	ANOVA Results for Gamma Band		ANOVA Results for Beta Band		ANOVA Results for Theta Band	
	F 6	P-value 0.022	F 5.06	P-value 0.034	F 4.88	P-value 0.037
	CB	CD	CB	CD	CB	CD
FZ-PZ	0.43+0.03	0.57+0.04	0.66+0.03	0.43+0.06	0.41+0.06	0.59+0.04
FZ-P3	0.72+0.04	0.45+0.06	0.74+0.04	0.70+0.03	0.32+1.01	0.47+0.09
FZ-P4	0.90+0.04	0.95+0.03	0.45+0.06	0.53+0.06	1.73+0.03	1.29+0.08
FZ-P7	0.33+0.06	0.48+1.01	0.97+0.06	0.90+0.04	1.25+0.09	1.29+0.04
FZ-P8	0.81+0.03	0.66+0.06	0.14+1.02	0.24+1.02	0.86+0.06	1.33+0.09
F3-PZ	0.92+1.01	0.95+0.04	1.18+1.01	0.92+1.01	0.61+0.08	0.82+1.01
F3-P3	0.33+0.06	0.47+0.09	1.37+1.02	1.22+0.08	1.33+0.03	0.90+1.02
F3-P4	0.66+0.03	0.77+1.02	0.95+0.08	0.74+0.03	1.83+0.03	0.84+0.06
F3-P7	0.38+1.01	0.41+0.03	0.29+0.09	0.34+1.02	0.51+0.08	0.52+0.06
F3-P8	0.48+0.04	0.61+0.06	0.32+0.03	0.29+0.03	0.18+1.02	1.02+1.02
F4-PZ	0.99+1.02	1.12+1.02	0.67+0.03	0.11+0.09	0.19+0.08	1.37+0.07
F4-P3	0.33+0.06	0.52+0.06	0.75+0.09	0.49+0.04	0.16+0.09	0.28+0.07
F4-P4	0.40+0.08	0.61 +0.08	1.25+0.06	0.90+1.01	0.56+1.02	1.65+0.03
F4-P7	0.28 +0.03	0.51+0.09	1.07+0.05	0.95+0.09	0.70+0.06	1.07+0.05
F4-P8	0.97+1.02	1.12+0.04	1.65+1.02	1.12+0.04	0.44+1.01	0.52+0.06
F7-PZ	0.79+0.06	1.04+0.03	0.88+0.05	0.74+0.08	0.18+1.01	0.29+0.05
F7-P3	1.12+0.08	1.65+0.09	1.29+0.04	1.07+0.09	0.22+0.07	0.41+1.01
F7-P4	0.28+0.06	2.09+1.01	0.61+0.04	0.18+0.04	0.33+0.09	0.56+0.09
F7-P7	0.90+0.04	1.15+1.02	0.45+0.09	0.44+0.09	0.41+0.07	0.44+0.04
F7-P8	0.79+0.09	1.12+0.09	0.19+0.06	0.61+0.06	1.02+1.02	1.07+1.02
F8-PZ	0.41+1.02	0.56+0.03	0.49+1.01	1.12+1.01	0.75+0.09	1.02+0.03
F8-P3	0.36+0.06	0.43+0.02	0.92+0.09	0.77+1.02	0.61+0.07	0.74+0.06
F8-P4	1.12+0.09	0.79+1.01	0.82+0.03	0.67+0.03	1.18+0.06	1.42+1.01
F8-P7	1.65+1.01	1.83+0.06	0.47+0.04	0.41+0.06	0.70+0.03	1.73+0.03
F8-P8	1.58+0.03	1.73+0.04	1.04+1.01	0.82+0.06	1.07+0.03	1.12+1.02
The Asterisk Symbol Indicates the Significant Value of P-value for the 0.05 Level of Significance						

6. CONCLUSION

The functional connectivity between frontal and parietal and between frontal and occipital regions of the brain was found larger for change detection trial as compared to the change blindness trial in gamma and theta bands of frequency. However in contrast to gamma and theta bands of frequency, the beta band showed larger functional connectivity between frontal and parietal and between frontal and occipital regions of the brain for change blindness trial. Since gamma, theta, and beta band oscillations are correlated with different neurophysiological mechanisms resulting in different cognitive process, the change in functional connectivity in these frequency bands might be the key factor in understanding the relationship between lack or increase of functional connectivity during change blindness.

TABLE 2. THE DIFFERENCE IN MSCS BETWEEN CD (CHANGE DETECTION) AND CB (CHANGE BLINDNESS) TRIALS (AVERAGE OF MEAN BAND MSCS+ STANDARD DEVIATION) FOR DIFFERENT FREQUENCY BANDS AND CORRESPONDING SCORES OF ANOVA STATISTICAL TEST

Electrode Positions	ANOVA Results for Gamma Band		ANOVA Results for Beta Band		ANOVA Results for Theta Band	
	F 6.08	P-value 0.002	F 4.86	P-value 0.038	F 4.71	P-value 0.041
	CB	CD	CB	CD	CB	CD
OZ-F7	0.33+0.08	0.75+0.03	0.84 +0.08	0.57+0.04	0.35+1.05	0.48+0.08
OZ-F3	0.48+0.04	0.88+0.08	0.95+0.04	0.90+1.03	0.43+0.05	0.53+1.03
OZ-FZ	0.59+1.03	0.63+1.05	0.75+0.08	0.84+0.04	0.57+0.08	0.97+0.02
OZ-F4	0.64+0.03	0.79+0.04	1.29+0.02	1.18+1.05	0.88+0.04	1.22+0.03
OZ-F8	0.53+1.05	0.74+0.02	0.36+0.02	0.48+0.08	0.37+0.02	0.47+0.08
O1-F7	1.52+0.03	1.18+1.03	1.73+0.03	1.22+0.08	1.33+1.05	1.15+0.07
O1-F3	0.52+1.05	0.74+1.03	2.29+1.01	1.83+1.03	0.82+0.03	0.49+0.07
O1-FZ	0.53+0.08	0.66+0.08	1.25+1.03	0.95+0.02	0.53+0.04	0.97+0.04
O1-F4	0.43+0.08	0.53+1.05	0.41+1.05	0.47+1.01	0.12+0.02	0.24+0.04
O1-F8	0.56+0.04	0.60+0.02	0.44+1.01	0.41+0.04	0.37+1.03	0.24+1.05
O2-F7	0.72+1.03	1.04+0.04	0.84+0.08	0.22+1.05	1.07+1.05	1.25+0.02
O2-F3	0.15+0.04	0.51+0.04	0.97+1.05	0.64+0.05	0.48+0.03	0.52+1.03
O2-FZ	0.29+0.02	1.07+0.08	1.94+1.03	1.18+1.03	0.45+0.03	0.41+0.03
O2-F4	1.37+1.05	0.82+1.01	1.42+0.02	1.25+0.05	0.19+0.05	0.40+1.05
O2-F8	0.70+0.04	0.72+1.03	1.73+0.04	1.58+1.01	0.40+0.08	1.37+0.05
O1-FC1	0.53+0.02	0.74+1.01	1.15+0.02	0.95+0.04	0.53+1.03	0.67+1.03
O2-FC2	1.22+0.02	1.12+0.08	2.09+0.08	1.42+0.03	0.59+0.05	0.81+0.03
OZ-FC1	0.15+1.01	0.23+1.05	0.79+0.02	0.29+1.05	0.28+0.04	0.23+0.08
OZ-FC2	0.47+0.03	0.52+1.05	0.60+0.04	0.59+1.01	0.99+0.03	1.07+0.05
O1-FC5	0.72+1.01	1.37+1.01	0.29+0.02	0.79+1.01	0.41+0.02	0.21+1.05
O2-FC5	1.15+0.08	1.18+0.02	0.79+1.03	1.58+0.02	0.74+1.03	1.02+0.02
OZ-FC5	0.19+1.03	0.28+0.03	1.18+0.03	0.99+0.04	0.38+0.08	0.35+0.08
The Asterisk Symbol Indicates the Significant Value of P-value for the 0.05 Level of Significance						

ACKNOWLEDGEMENTS

The authors thank to Prof. M.J. Wright, and Dr. L. Lakha , Centre for Cognition and Neuroimaging, Brunel University, for providing the ERP data and for their guidance.

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