Sindh Univ. Res. Jour. (Sci. Ser.) Vol.44 (3) 457-462 (2012)

SINDH UNIVERSITY RESEARCH JOURNAL (SCIENCE SERIES)

Volume Conduction Effects On The Wavelet Coherence Analysis Of EEG Recorded From Subjects With Extreme Low Birth Weight, Change Blindness And Epilepsy

I.A. MEMON, I. A. ISMAILI*, M.S. KALHORO

Institute of Physics, University of Sindh, Jamshoro

Received 19th May 2012 and Revised 23rd August 2012

Abstract: The magnitude square coherence (MSC) function is a useful measure to detect the linear correlation between two signals. However estimation of true MSC function is a major issue in EEG signal processing. Apart from the statistical problems, the volume conduction effects from various uncorrelated sources (VCUS) present in the brain introduce the biased estimates into its true value. Based on the assumption that VCUS effects are additive and therefore can be ignored while comparing two or more different EEG activities, various EEG-based studies have ignored the issue of VCUS effects. MSC analysis of epilepsy, MSC analysis of change blindness, and MSC analysis for extreme low birth weight effects on brain are among such studies which have been frequently reported in literature without keeping in account the issue of VCUS effects. This study using EEG and scalp Laplacian-based wavelet MSC functions has provided the substantial evidence that VCUS effects are not additive and they produce significant effects on the results of these studies. Since scalp Laplacian is a useful measure under some conditions for minimizing the VCUS effects, the difference in SL-based MSC function between control and non-control subjects was compared to the same study but based on conventional EEG based MSC function. And then the results of statistical analysis obtained from both studies were compared to each other in order to examine the effects of VCUS effects. This study was repeated for above three mentioned neurological disorders.

Keywords: Wavelet coherence, volume conduction, seizure, EEG

1. INTRODUCTION

EEG based MSC function is used to measure the functional relation between difference regions of the brain. However estimation of true MSC function is major issue in EEG signal processing. The most challenging issue while measuring the true MSC function is contribution of unwanted signals which is produced due to uncorrelated sources present in the brain. EEG literature provides various techniques in order to minimize these unwanted signals henceforth called volume conduction effects (VCUS ((Nunez *et al.,* 1997). Majority of these techniques are based on scalp Laplacian (SL) which is a useful approximation of radial current density flowing from the brain towards the scalp. The literature provides significant amount of evidence that SL has the ability to minimize nearby electrical activity from the nearby sources. Nunez and Srinivasan, (2005) have reported that SL-based MSC function provides minimum VCUS effects as compared to the conventional EEG-based MSC function. In another study by same author, the characteristics of VCUS effects on MSC function have been studied using four shell model of head (Nunez *et al.,* 1997). It was reported in this study that VCUS effects on EEG-based MSC function are independent of frequency and they depends upon the inter-electrode distance and they decreases as the inter-electrode distance increases. One of major disadvantage of SL-based MSC function is that it is not robust measure for large dipole layers because it filers most of coherence from large dipole layers. Therefore the use of both MSC methods can provide better understanding of coherence study. EEG literature on very occasions reports MSC studies of various neurological and cognitive disorders without keeping in account the issue of VCUS effects. The change blindness, effects of extreme low birth weight, and epilepsy are among the such disorders whose EEG-based MSC studies have been reported in literature without keeping in account the issue of VCUS. Following is the brief review of these disorders in the context of EEG-based MSC analysis.

Change Blindness

The change blindness is the inability of brain to notice visual changes taking place in brief intervals of viewing. The study of change blindness in the context of MSC function has been reported in literature twice to the best of our knowledge, but both the studies have not taken into account the issue of VCUS effects (Markazi *et al.,* 2005; Qazi *et al.,* 2005).

Extreme low birth weight effects

The another neurological disorder which has been studied using EEG-based MSC function without

++ Corresponding author: email: Email: memon904@btinternet.com Cell. No +92-3368510917

*Institute of Information and Communication Technology, University of Sindh, Jamshoro

keeping in account the issue of VCUS effects is related to the effects of extreme low birth weight on human brain. Extreme low birth weight (ELBW) might affect the growth of human brain. Few studies have been reported on the effects of ELBW on EEG-based MSC function and moreover these studies have not resolved the issue of VCUS effects (Als *et al.,* 2004; Grieve *et al.,* 2008 Miskovic *et al.,* 2009 Gonzalez *et al.,* 2011).

Epilepsy

Literature reports various EEG-based MSC studies for epilepsy without keeping in account the issue of VCUS. (Tsai *et al.,* 1995; Sherman *et al.,* 1997) reported the increased EEG based coherence during the clonic seizure. These studies were performed without minimizing the VCUS effects for various inter-electrode distances including the shortest inter-electrode distance of 3.2cm where VCUS effects might be maximum. (Mormann *et al.,* 2000 Bahcivan *et al.,* 2001) recorded the EEG activity of epileptic rats using the maximum inter-electrode distance 2.8 cm. They reported increased MSC function during the ictal period of seizure. There is a strong possibility that increased MSC function in EEG signals of rats might be due to the contribution of artificial MSC function produced by VCUS effects. This is because literature reports strong contribution of VCUS for inter-electrode distance of at-most 3.2cm (Nunez and Srinivasan., 2005) whereas maximum inter-electrode distance of 2.8cm was used in recording the ictal EEG activity of rats.

Major aim of study

The brief literature review discussed above provides the evidence that issue of VCUS effects have been ignored in large number of studies, which are based on the MSC analysis of epilepsy, change blindness, and effects of ELBW. Therefore the major aim of this study is to examine the VCUS effects on the MSC analysis of these three neurological disorders. The MSC analysis was performed separately for each of these neurological disorders by examining the MSC difference between control and non-control EEG activities. Since most of EEG signals encounter in nature contain important information in both time and frequency domain, the wavelet based MSC function was used which allows time-frequency analysis of signals at optimal time-frequency resolution.

2. METHODS

Change Blindness Data

This data was obtained form the Centre for Cognition and Neuroimaging at Brunel University West London. This data set has been used in previous studies (Markazi *et al.,* 2005; Qazi *et al.,* 2005) where further detail about the data set is given. The brief introduction of change blindness date is following. 15 male healthy subjects whose ages ranged between 18-26 years were used for obtaining the ERP data of change blindness and change detection as following. The ERPs were elicited using the visual oddball experiment in which subjects were asked to detect the changes. In case if subject was failed to detect correct change, it was called the change blindness trial otherwise it was called change detection trial. All the standard precautions to avoid artefacts caused by the subject's body movement and external sources were taken.

Epilepsy Data

The EEG data of Epilepsy was obtained from the online sources of Freiburg Epilepsy Center at the University Hospital of Freiburg Germany using the following website **Error! Hyperlink reference not valid.**. The data set was used in previous studies (Aschenbrenner-Scheibe *et al.,* 2003; Winterhalder *et al.,* 2003; Schelter *et al.,* 2006) where detail about this data set is given, however the brief introduction of this data set is following. The EEG data was recorded from 21 subjects suffering from medically focal epilepsy. All the standard precautions to avoid artefacts caused by the subject's body movement and external sources were taken during the recoding of data set.

ELBW Data

This ERP data set was recorded by us for our previous study based on the effects of ELBW on MSC function (Memon and Kalhoro, 2012). The detailed introduction of data can be obtained from our previous studies based on this data set. However the brief introduction of this data set is following. The 79 young adults who were born with ELBW less than 1000g were selected for the group of ELBW. The normal birth weight (NBW) group of 79 subjects were also selected. The subjects in each group were males, having same race and their ages ranged between 22-25 years at the time of experiment. The ERPs were elicited using the the visual oddball experiment in which subjects were instructed to detect the changes. In case if subject was failed to detect correct change, it was called the change blindness trial otherwise it was called change detection trial.

Estimation of SL and EEG-based MSC functions

The SL was estimated using the Hjorth method (Hjorth, 1975). Then the two EEG time series $x(n)$ and $y(n)$ and their corresponding SLs $l_x(n)\ and\ l_y(n)$ were transformed into the wavelets using the Morlet as mother wavelet. The wavelet cross-spectrum $Z_n^{xy}(a,b)$ and wavelet auto-spectrum $Z_n^{xx}(a,b)$ for EEG and SL were calculated using the following relations.

$$Z_n^{xy}(a,b) = X_n^x(a,b) \cdot Y_n^{*x}(a,b) \quad (1)$$

$$Z_n^{xx}(a,b) = X_n^x(a,b) \cdot X_n^{*x}(a,b) \quad (2)$$

$$Z_n^{yy}(a,b) = Y_n^y(a,b) \cdot Y_n^{*y}(a,b) \quad (3)$$

The wavelet coherence is given by

$$\gamma_n^{xy}(a,b) = \frac{Z_n^{xy}(a,b)}{\sqrt{Z_n^{xx}(a,b) \cdot Z_n^{yy}(a,b)}} \quad (4)$$

The square of absolute value of Equation (7) is called the MSC function. The wavelet MSC function was estimated by taking the averages of cross and auto spectra across the repeated trials.

3. <u>RESULTS AND DISCUSSION</u>

This study uses the two-way ANOVA test to examine the MSC difference between EEG activities using both SL and EEG-based MSC functions. Therefore Both SL and EEG-based MSC functions were normalized using the Fisher's Z transformation in order to fulfill the requirement required for the ANOVA test.

Change blindness study for healthy subjects.

Effects of maximum 3.2 cm short inter-electrode distance.

The VCUS effects on MSC function, corresponding to the maximum inter-electrode distance of 3.2 cm inter-electrode distance, were found large. This is because most of the MSC spectra were frequency independent and therefore showing large artificial MSC due to VCUS. The EEG-based MSC function ranging between 100-200ms from the onset of second stimulus was separated and average of EEG-based MSC function across that sample length was taken for further analysis. The sample of length around 100-200ms was selected because it revealed the difference between change detection and change blindness trials more efficiently than the other sample lengths. The average EEG-based MSC function was found larger for change detection trial as compared to the change blindness trials for position of electrodes. As shown in **(Table 1)** that ANOVA test revealed significance difference in average EEG-based MSCs between change detection and change blindness trials for various position of electrodes. This study was again repeated using the SL-based MSC analysis. Most of SL-based MSCs as compared to the corresponding EEG-based MSCs were frequency independent and were comparatively smaller in values. This result provides the significant evidence that SL-based MSC function has the ability to reveal coherence with minimum VCUS.

Table 1: The EEG-based and SL-based MSCs and ANOVA score for short inter-electrode distances of at most 10cm.

Disorder	Method	FC1-FC2	F3-FC5	CP1-CP2	CP2-CP6	P4-PZ	ANOVA F	ANOVA P-value
Healthy	SL-MSC	1.57±0.10	1.40±0.11	1.52±0.08	1.68±0.09	1.59±0.08	2.952	0.094
subjects	CD	1.23±0.09	1.25±0.12	1.25±0.11	1.24±0.11	1.22±0.10		
	CB							
	EEG-MSC						17.415	0.04*
	CD	1.82±0.11	1.13±0.09	1.72±0.07	1.82±0.08	1.96±0.09		
	CB	0.36±0.05	0.45±0.08	0.57±0.08	1.05±0.07	1.14±0.07		
ELBW	SL-MSC						2.536	0.45
	CD	1.44±0.09	1.75±0.26	1.48±0.27	1.57±0.25	1.29±0.08		
	CB	1.23±0.09	1.43±0.28	1.37±0.20	1.35±0.22	1.08±0.06		
	EEG-MSC							
	CD						0.783	0.12
	CB	0.67±0.29	1.47±0.08	1.55±0.08	1.54±0.08	0.43±0.28		
		0.41±0.28	1.24±0.12	1.21±0.10	1.20±0.11	0.39±0.22		
Epilepsy	SL-MSC							
	Non-control							
	Control	1.83±0.08	1.95±0.08	1.23±0.06	1.93±0.07	0.99±0.07	4.545	0.04*
	EEG-MSC	1.17±0.09	1.42±0.12	0.49±0.10	1.47±0.10	0.50±0.10		
	Non-control							
	Conttol							
		1.97±0.10	1.53±0.08	1.74±0.05	1.83±0.07	1.61±0.07	17.221	0.02*
		1.00±0.03	0.30 ±0.07	0.54 ±0.07	0.31±0.05	0.54±0.05		

This study examined various subjects who exhibited the larger SL-based MSC for change detection trials as compared to the change blindness trials. Therefore the results were consistent to the EEG-based MSC analysis. The two-way ANOVA test was applied to examine how significance was the difference between change detection trial as compared to the change blindness trial for SL-based MSC analysis. As shown in (**Table 1**) that EEG-based MSC difference between change blindness (CB) and change detection (CD) trials is statistically significant as the corresponding p-value is 0.04. Hence there is a 96% probability for the difference in EEG-based MSC difference between change detection and change blindness trials which is quite a significant value. As shown in (**Table 1**) that contrary to the EEG-based MSC, the SL-based MSC analysis for same study revealed comparatively larger p-value i.e., 0.09 thus indicating the 91% probability for the difference in SL-based MSC function between change detection and change blindness trials. The p-value = 0.09 for the SL-based MSC analysis is not the statistically significant when the significant level is set to 0.05. The SL-based MSC study was performed for more real coherences and it is claimed for two main reasons. (1) the SL-based MSC spectra were found without the effects of VCUS as most of its part compared to the EEG-based MSC spectra were frequency dependant. (2) As shown in (**Table 1**) that The SL-based MSCs for both change blindness and change detection trials were reflecting the overall contribution of underlying EEG dipole layer sources because they were comparable in magnitude to the EEG-based MSCs and even in some cases they were larger in magnitude. Therefore p-value obtained using the SL-based MSC analysis in change blindness study reflects the real value of statistical significance as compared to the one based on EEG-based MSC analysis. Keeping in view the difference in p-values between EEG-based MSC and SL-based MSC p-values, it can be concluded that VCUS effects can introduce significant biased estimates into the results of EEG-based MSC difference if the inter-electrode distance is at most of 3.2cm.

Effects of inter-electrode distance larger than 10cm

As shown in (**Table 2**) that Both SL and EEG-based MSC functions are larger in value for change detection trial as compared to the change blindness trial for inter-electrode distance of larger than 10cm. The minor contribution of VCUS effects on MSC was examined for such inter-electrode distance. The absence of VCUS effects was due to the large inter-electrode distance used in the estimation of EEG-based MSC function. As shown in **(Table 2)** that there is a slight reduce in the significant level in MSC difference as p-value based on SL-based MSC function is larger as compared to the one based on EEG-based MSC function. However, two-way ANOVA revealed significant difference in both EEG and SL-based MSC analysis.

Table 2:The EEG-based and SL-based MSCs and ANOVA score for inter-electrode distances of larger than 10cm.

Disorder	Method		F4-CP1	F3-CP2	FC5-PZ	FC6-PZ	FZ-CP6	ANOVA	
								F	P-value
Healthy subjects	SL-MSC	CD	0.77±0.10	0.80±0.11	0.88±0.08	0.78±0.09	1.02±0.08	3.841	0.05*
		CB	0.23±0.09	0.35±0.12	0.45±0.11	0.23±0.11	0.42±0.10		
	EEG-MSC	CD	0.92±0.21	0.93±0.19	0.92±0.17	0.91±0.18	1.26±0.19	19.211	0.04*
		CB	0.21±0.15	0.37±0.18	0.31±0.18	0.15±0.17	0.51±0.17		
ELBW	SL-MSC	CD	0.84±0.09	1.05±0.26	0.88±0.27	0.97±0.25	0.69±0.08	2.536	0.38
		CB	0.63±0.09	0.93±0.28	0.77±0.20	0.85±0.22	0.48±0.06		
	EEG-MSC	CD	1.27±0.29	1.32±0.08	1.15±0.08	1.24±0.08	1.83±0.28	0.983	0.35
		CB	1.01±0.28	0.84±0.12	0.81±0.10	0.90±0.11	1.51±0.22		
Epilepsy	SL-MSC	Non-control	0.53±0.08	0.85±0.08	0.88±0.06	0.83±0.07	0.99±0.07	7.665	0.04*
		Control	0.17±0.09	0.42±0.12	0.41±0.10	0.37±0.10	0.40±0.10		
	EEG-MSC	Non-control	1.89±0.10	1.23±0.08	0.84±0.05	0.97±0.07	1.21±0.07	35.221	0.03*
		Control	1.00±0.03	0.40 ±0.07	0.21 ±0.07	0.31±0.05	0.54±0.05		

Change blindness study for subjects born with ELBW

Effects of maximum 3.2 cm short inter-electrode distance

This study was performed following the same methodology which was used in this study for MSC analysis of change detection on healthy subjects. Most of EEG-based MSC spectra were found affected by the VCUS effects as compared to the SL-based MSC spectra. (Table 1) shows the non-significant EEG-based and SL-based MSC differences between change detection and change blindness trials for ELBW subjects. As shown in (Table 1) that there is a significant drop in the statistical significance of EEG-based MSC difference. This is because p-value obtained using genuine SL-based MSC functions is larger in value as compared to the one obtained using EEG-based MSC function. Therefore larger difference in p-values between EEG and SL-based MSC studies again leads to the conclusion that VCUS effects can significantly introduce the biased estimates into the results of MSC difference if inter-electrode is at most of 3.2cm.

Effects of inter-electrode distance larger than 10cm

The EEG-based MSC spectra for both change blindness and change detection were found qualitatively similar to the corresponding SL-based MSC spectra and therefore it was not affected by the VCUS effects. Due to the effects of larger inter-electrode distance, the values of both SL and EEG-based MSCs were found smaller in values. However the results of this study were consistent to the same study performed using the comparatively short inter-electrode of maximum 3.2cm. As shown in (**Table 1** and **Table 2**) that results of both SL and EEG-based MSC studies show larger value of coherence for change detection trials as compared to those obtained for change blindness trials. However difference in MSCs based on both coherence methods is not statistically significant and difference in p-values based on both MSC methods is minor. Because the difference in p-values based on both coherence methods is not large, it can be concluded that effects of VCUS for larger inter-electrode distance such as 10cm is not large enough to introduce the biased estimates into the results of study based on the MSC difference of change blindness for the ELBW subjects.

Study of ictal EEG activity

Effects of maximum 3.2 cm short inter-electrode distance.

As shown in (Table 1) that EEG-based MSC functions for ictal EEG is larger in value as compared to MSC functions for non-ictal EEG and there is a significant change in MSC difference between these EEG activities. Both studies based on SL and EEG-based MSC functions showed statistically significant difference in MSCs. The larger p-value was examined using the SL-based MSC analysis as compared to the one obtained using the EEG-based MSC analysis. Thus it might be concluded that VCUS effects can introduce the biased estimates into the results of study based on MSC difference between ictal and non-ictal EEG provided inter-electrode distance is at most of 3.2cm.

Effects of inter-electrode distance larger than 10cm

Due to the large inter-electrode distance, MSC spectra were comparatively found very less affected by the VCUS effects. As shown in (**Table 2**) that there is a small difference in p-values between the one based on EEG-based MSC analysis and the one based on SL-based MSC analysis. Therefore it might be concluded that due to the inter-electrode distance of larger than 10 cm, the effects of VCUS on difference of MSC function was not large enough to introduce the biased estimates into the statistical analysis of results.

4. CONCLUSION

This study examines the VCUS effects on the statistical analysis of MSC difference study between control and non-control subjects for three different neurological disorders which included change blindness disorder in healthy subjects, change blindness disorder in ELBW subjects and epilepsy disorder. The results showed that biased estimates due to the VCUS effects depend upon the inter-electrode distance used in the estimation of corresponding MSC function. The VCUS sources produced significant effects on results of the study corresponding to the short inter-electrode distance of at most 3.2cm. However VCUS sources, corresponding to the inter-electrode distance of larger than 10cm, produced minor effects on the results. The results of this study put a question marks on several EEG-based MSC studies which have not taken into account the effects of VCUS especially for those studies when inter-electrode distance is around the 3.2cm.

REFERENCES:

Aschenbrenner-Scheibe, R., M. Winterhalder, H.U. Voss, J. Timmer., and A. Schulze-Bonhage (2003) How well can epileptic seizures be predicted? an evaluation of a nonlinear method. Brain : A Journal of Neurology 126 **(12):** 2616-2626.

Als, H., F.H. Duffy, G.B. Mcanulty, M.J. Rivkin, S. Vajapeyam and R.V. Mulkern (2004) Early experience alters brain function and structure. Pediatrics **(113):** 846–857.

Bahcivan, H., N. Zhang, M.A. Mirski and D. Sherman (2001) Cross-correlation analysis of epileptiform propagation using wavelets (2001) Conference Proceedings of the 23rd Annual International Conference of the IEEE Engineering and Medicine and Biology Society, **(1):** 1804-1807.

Grieve, P.G., J. R. Isler., A. Izraelit, B.S. Peterson, W.P. Fifer and M.M. Myers (2008) EEG functional connectivity in term age extremely low birth weight infants. Clinical Neurophysiology **(119):** 2712–2720.

Gonzalez, J.J., S. Mañas, L. De Vera, L.D. Méndez, S. López., J.M. Garrido and E. Pereda (2011) Assessment of electroencephalographic functional connectivity in term and preterm neonates. Clinical Neurophysiology **(122):** 696-702.

Hjorth, B (1975) An on-online transformation of EEG scalp potential into orthogonal source derivation. Electroencephalography and Clinical Neurophysiology, (**39**): 526-530.

Memon, I.A and M.S. Kalhoro (2012) The long term effects of extreme low birth weight on visual attention memory process and functional connectivity of the brain. Sindh University Research Journal (Sci. Series) 44 **(2):** 231-236.

Klein. A., T. Sauer., A. Jedynak and W. Skrandies (2006) Conventional and wavelet coherence applied to sensory-evoked electrical brain activity. IEEE Transactions on Biomedical Engineering **(2)**:266-272.

Mormann, F., K. Lehnertz, P. David and C.E. Elger (2000) Mean phase coherence as a measure for phase synchronization and its application to the EEG of epilepsy patients. Physica D **(144):** 358-369.

Markazi, S., S. Qazi., and L.K Stergioulas (2005) Study Of Change Blindness EEG Synchronisation Using Wavelet Coherence Analysis, Proceedings of the 2005 IEEE Engineering in Medicine and Biology 27th Annual Conference Shanghai, China, September, 1-4.

Miskovic, V., L.A. Schmidt, M. Boyle and S. Saigal (2009) Regional electroencephalogram (EEG) spectral power and hemispheric coherence in young adults born at extremely low birth weight. Clinical Neurophysiology **(120):** 231-238

Nunez, P.L., R. Srinivasan., A.F. Westdorp, R.S. Wijesinghe, D.M. Tucker, R.B. Silberstein and P.J. Cadusch (1997) EEG coherency. I. Statistics, reference electrode, volume conduction, Laplacians, cortical imaging and interpretation at multiple scales. Electroencephalography and clinical neurophysiology, 103 **(5):** 499-515.

Nunez, P. L and R. Srinivasan (2005) Electric fields of the brain. Oxford university press

Qazi, S., S. Markazi., L.K Stergioulas (2005) Time-Frequency and Time-Frequency Coherence of Change Blindness-Using Wigner Distributions, WSEAS Transactions on Biology and Biomedicine **(2):** 1109-9518.

Snodgrss, J.G and M. Vanderwart (1980) A standardized set of 260 pictures: norms for the naming agreement, familiarity, and visual complexity. Journal of Experimental Psychology: Human Learning and Memory, (**6**): 174-215.

Sherman, D.L., Y.C. Tsai., L.A. Rossell., M.A. Mirski and N.V. Thakor (1997) Spectral analysis of a thalamus-to-cortex seizure pathway. IEEE Transactions on Biomedical Engineering, 44 **(8):** 657-664.

Schelter, B., M. Winterhalder, T. Maiwald, A. Brandt, A. Schad., A. Schulze-Bonhage and J. Timmer (2006) Testing statistical significance of multivariate time series analysis techniques for epileptic seizure prediction. Chaos (Woodbury, N.Y.) 4 **(8):** 657-664.

Winterhalder, M., T. Maiwald, H. U. Voss, R. Aschenbrenner-Scheibe., J. Timmer and A. Schulze-Bonhage (2003) The seizure prediction characteristic: A general framework to assess and compare seizure prediction methods. Epilepsy and Behavior 4 **(3):** 318-325.