Original Article

Electroencephalography Changes during Change Blindness Disorder

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ABSTRACT

BACKGROUND/OBJECTIVE: The electroencephalogram (EEG) is the process of recording electrical potentials produced by neurons in the brain. For understanding the neuro-physiological mechanism of various cognitive and neurological disorders, EEG has been proved a vital technique for many years. The change blindness which is incapability of brain to notice substantial visual changes is among such disorders. This study investigates the complexity in information process of EEG signals during the change blindness disorder using the two different measures called entropy and correlation dimension functions.

METHODS: The EEG data of change blindness disorder was recorded from 22 subjects while they were performing change detection and change blindness trials for two types of stimuli. These were (1) single stimulus followed by another matching stimulus, (2) single stimulus followed by another non-matching stimulus. The measure of complexity in recorded EEG was estimated using both correlation dimension and approximate entropy functions.

RESULTS: The results have shown significant decrease in values of approximate entropy and correlation dimension at frontal position of electrodes for change blindness trials.

CONCLUSION: The neurophysiological implication of these results provide the possibility that the increase of brain complexity, which can be interpreted as increase of information process and integration, was not sustained in frontal position of brain during the change blindness disorder.

KEY WORDS: Electroencephalography, approximate entropy, correlation dimension, event related potentials, change blindness.

INTRODUCTION

The incapability of the brain to detect substantial visual changes taking place in short interval of time is called change blindness disorder. The disorder in short term memory and insufficient processing of brain can be the main cause of change blindness disorder[1]. Literature reports increase in functional magnetic resonance imaging technique (FMRI) activity over the frontal and parietal brain locations during the experiment in which subjects were failed to detect changes in visual stimulus[1-3]. However these studies failed to provide time-domain information of neuro-physiological mechanism involved in change blindness. This limitation arises due to the poor time-domain resolution offered by FMRI and other imaging techniques. However current imaging techniques provide better spatial resolution as compared to EEG whereas EEG provides better time-domain resolution as compared to the current imaging techniques. EEG-based studies on change blindness are based upon the event related potentials (ERPs) which are time-locked EEG signals with sensory or cognitive events. Most of these studies are based upon the experiment in which subjects have been asked to detect the changes in two types of stimuli. These are single stimulus followed by another matching stimulus and single stimulus followed by another non-matching stimulus. The trial is called change detection trial (CD) in case if subject is successful in detecting the change otherwise it is called change blindness trial (CB). Following the similar methodology, increase in ERP amplitude in time domain for change blindness trial as compared to the change detection trial has been reported in different studies.[3,-,5]The other studies, which are based on the frequency domain analysis of ERPs, have reported decreased ERP amplitude in gamma band of frequency as well as increased ERP amplitude in beta band of frequency for change blindness trials.[6,-8]Over the years few signal processing techniques have been developed which provide more useful information about EEG than those based on amplitude analysis of ERPs.

Literature reports a use of power spectral density and coherence function for the study of EEG signals in change blindness. The power spectral density, which reveals the distribution of energy of signal in frequency domain, has been found low in value for change blindness trails.[7-9]The another signal processing method is coherence function which is being used in EEG analysis to detect a functional connectivity

between different regions of the brain. Various studies have reported decrease in coherence function for change blindness trials over the parietal and frontal regions of the brain, [10, 11] thus showing the relationship between lack of functional connectivity and change blindness.

Apart from the coherence and power spectral density functions, EEG is useful for nonlinear signal processing techniques for various neurological disorders. These methods provide information not obtainable from the linear signal processing methods such as power spectrum and coherence function. The use of the nonlinear signal processing methods has provided important clinical results for various neurological disorders. For example, mutual information analysis and synchronization like-hood techniques have been used to examine the process of information process between different cortical regions of the brain in Alzheimer's disease.[12-14] The correlation dimension and entropy, which are the measures of complexity of information process, have been used in EEG analysis for various neurological disorders. One of the important clinical applications observed for these nonlinear measures is the seizure predication system. Various EEG-based studies have shown changes in correlation dimension and entropy 10-20 minutes ago before and after the onset of seizure activity.[15-18]The Lyapunov exponent which is another nonlinear measure has been used to investigate the relationship between various stages of sleep and underlying brain activity.[19-21]In addition to this, literature reports its use to study heart signals.[22]

The clinical applications of nonlinear signal processing techniques discussed above suggest the possibility that nonlinear dynamics of the brain might be involved in change blindness disorder and can provide further insight into the neuro-physiological mechanism of change blindness. Therefore this study is performed to examine the nonlinear mechanism of brain for change blindness disorder using the approximate entropy (ApEn) and correlation dimension (CDM) analysis of ERPs. Both functions provide the measure of complexity involved in information process of underlying brain process.

The ERPs of change blindness disorder were obtained by recording these signals from the subjects who were performing the change detection tasks. Both ApEn and CDM functions have shown significant changes during the change blindness trials. Therefore results of this study might prove useful in understanding the relationship between information process in brain and change blindness disorder. As no study so far had been done to investigate the nonlinear EEG analysis of change blindness, the results of this study might be useful in improving the further understanding about neurophysiological mechanism of change blindness.

METHODOLOGY

Data

The ERPs have been proved as useful technique in obtaining the EEG features of underlying brain process. These signals are EEG signals which are recorded from the subjects who are busy in performing given task.The EEG signals of change blindness disorder are usually obtained by recording the ERPs from subjects who are asked to perform change detection task by the visual stimulus.

The EEG data was recorded from 22 physically fit subjects whose ages ranged between 18-25 years. These subjects were recruited as paid volunteers and these subjects did not show any sign of neurological disorder while they were examined by neurologist**.** The ERP data recorded using the 32 electrodes which were positioned on scalp according to international 10 -20 system of electrode's position. The subjects were seated on seats before the computer monitor and their task was to detect changes in visual pictures shown to them through the computer screen.

There were two categories of pictures; the first one category includes pictures of human faces and the other one category pictures of historical places. The change detection or change blindness trial was obtained as following. The subjects were shown frame of two pictures of human faces followed by the blank display of duration 500ms. Then another frame of two pictures of human faces was shown to the subjects again followed by the blank display of duration 500ms. The duration of each frame consisting of human faces was set to 500ms. Therefore the total duration of trial was 2000ms. The subjects were asked to press the mouse button in case if they were confident in either detecting or not detecting the visual changes in two frames. Such trial was called change blindness trial in case if response of subjects was wrong otherwise it was called change detection trial. The same procedure was repeated with two pictures of historical places. The recorded data was converted into digital format at the sampling rate of 256 Hz.

Even though EEG is used for recording the brain activity, the electrical signals producing from regions other than the brain are also recorded during the recording. The recorded EEG activity which is not recorded from the brain is referred as EEG artifact. The EEG artifacts caused by the movement of subject's body parts were carefully minimized during the recording of EEG data. Subjects were seated in reclining chairs with comfortable position and were instructed to relax jaw muscles, avoid unnecessary movement of their body and eyes. In addition to this,

the band pass filter of frequency range 0.02-50 Hz was used for rejecting the low and high frequency artifacts called electrogalvanic and electromyographic signals respectively. Radio electromagnetic waves are emitted by electronic devices such as microwave, hospital paging system, cordless phones and wireless routers. The EEG artifacts caused due to such radio waves were rejected by recording the EEG data into the sound attenuated radio frequency shielded room. The data evaluated in statistical program SPSS version 16.0. Numerical data was presented as Mean ± Standard Deviation. Kolmogorov-Smirnov statistical test was used to examine if the data were normally distributed.

RESULTS

The position of the electrodes on the brain is represented as following. The frontal, temporal, parietal, and occipital region of the brain were organized as [FZ, F3, F4, FP1, FP2, FC1, FC2, FC5], [T7, T8],[PZ, P3, P4, P7, P8], and [OZ, O1, O2] respectively. For both change detection and change blindness trials, the Kolmogorov-Smirnov test revealed that the data was not normally distributed. Therefore the non-parametric statistical analysisbased Mann–Whitney U test was used in order to compare the ERPs of change blindness and change detection trials. First we examined the ApEn difference between ERPs of change detection and change blindness trials. The Table I summarize the results of change blindness and change detection as mean ±SD and compared with Mann–Whitney U test. As shown in Table I that change blindness trails show significantly lower values of ApEn function than those corresponding to change detection trials. In addition to this, the pre-frontal positions of electrodes (FP1, FP2) show comparatively larger significant level and this significant level decreases as frontal position of electrodes moves towards the post-frontal position of electrodes.

Next we examined the difference of CDM function between ERPs of change detection and change blindness trials. The CDM function was estimated using the Equation 4. Table I summarizes the CDMvalues (mean ± SD) for the change blindness and change detection trials and the p-values of the Mann–Whitney U test. As shown in Table I that change blindness trials reveal significantly lower values of CDMfunction as compared to those obtained using the change detection trials at frontal position of electrodes. This result is in agreement to the results of ApEn analysis which

Table I: ApEn and CD functions

ERP activity scores for change blindness (CB) and change detection (CD) trials

Position of electrodes	Values of ApEn function (mean (SD)			Values of CD function (mean (SD)		
	CB trial	CD trial	P-value*	CB trial	CD trial	P-value*
FZ	1.44±0.26	1.61±0.14	0.021	1.08±0.21	1.22±0.21	0.022
F3	1.49± 0.24	1.62±0.15	0.037	0.81±0.24	0.95± 0.18	0.034
F4	1.53± 0.24	1.60±0.22	0.031	0.72±0.16	0.86±0.24	0.028
FP1	1.55± 0.24	1.73±0.19	0.008	0.71±0.21	0.86±0.13	0.007
FP2	1.46± 0.16	1.62±0.21	0.007	0.97±0.20	1.12±0.14	0.006
FC1	1.51± 0.18	1.63±0.24	0.068	0.53±0.21	0.64±0.18	0.069
FC2	1.61± 0.19	1.74±0.25	0.059	1.21±0.26	1.34±0.31	0.078
FC5	1.52± 0.18	1.63±0.21	0.062	1.21±0.33	1.34±0.27	0.053
CP1	1.33± 0.34	1.39±0.20	0.483	0.95±0.24	0.98±0.21	0.792
CP2	1.38± 0.20	1.39±0.27	0.976	0.95±0.25	0.98 ±.22	0.731
CP5	1.80±0.27	1.83±0.35	0.816	1.00±0.22	1.12 ±.18	0.865
PZ	0.89±0.15	0.99±0.11	0.079	0.95±1.14	1.04±0.13	0.621
P3	1.54±0.26	1.59±0.21	0.420	0.91±0.13	0.99±0.20	0.412
P4	1.53±0.27	1.58±0.22	0.491	0.95±0.16	0.97±0.23	0.834
P7	1.57±0.24	1.59±0.17	0.822	1.00±0.18	1.05±0.23	0.637
P8	1.62±0.25	1.63±0.14	0.832	1.00±0.18	1.06±0.20	0.432
T7	0.94±0.04	0.98±0.10	0.504	0.92±0.07	0.98 ±0.13	0.368
T8	1.10±0.09	0.97±0.09	0.586	0.95±0.13	0.90 ±0.15	0.923
0Z	1.01± 0.12	1.01±0.12	0.993	1.09±0.14	1.09± 0.13	0.987
01	1.01± 0.13	1.03±0.12	0.830	0.96±0.13	1.03±0.13	0.219
02	1.80±0.34	1.81±0.29	0.960	1.31±0.24	1.33± 0.15	0.861

* Mann–Whitney U test

Results are presented as Mean± Standard Deviation

showed significant decrease in values of ApEn function for change blindness trials.

DISCUSSION

This study examines the difference in ERPs between change blindness and change detection trials using two different measures called ApEn and CDM functions. The change blindness trials showed significant decrease in the values of both ApEn and CDM functions. To correctly interpret the results of this study, the neurophysiologic meanings of approximate entropy (ApEn) and CDM functions require further attention. As mentioned before that both EEG-based ApEn and CDM functions are the measure of complexity of information process as well as they reflects the integration of various brain processes.This includes the integration of incoming stimulus and the integration of brain activity due to functionally segregated neurons with underlying brain process.[24] In this point of view, the results of this study imply that increase in information processing and integration that was observed during change detection trials was not sustained in subjects who were performing the change blindness disorder.

Both ApEn and CDM functions showed significant changes only at the frontal position of electrodes only. In addition to this the prefrontal position of electrodes showed very large statistical significance as compared to the post-frontal positions of the electrodes. Even though pathophysiological implications of this result is not possible here, but it leads to the possibility that deficits in information process and integration during the change blindness trials were stronger in the working memory tasks. This is because prefrontal areas of the brain are strongly involved in working memory tasks.[25]

The previous EEG-based studies on change blindness order are not adequate and moreover these studies are based on only linear characteristics of EEG correlates such as coherence.[10, 11] and power spectral density functions.[8, 9] In addition to this, literature report few studies on change blindness disorder using visual analysis of ERPs.[3-5] This is first study where the nonlinear characteristics of EEG during the change blindness disorder have been discussed. The results presented in this study will provide more insight into the neurophysiological mechanism of change blindness disorder.

CONCLUSION

The change blindness disorder exhibited the decrease in the values of EEG-based approximate entropy and correlation dimension functions at frontal positions of brain. Moreover comparatively stronger significance level was observed at prefrontal position of electrodes. Keeping in view the neurophysiologic meanings of both these functions, these findings lead to the conclusion that during change blindness disorder the deficit in theintegratation of different brain process at frontal side of the brain arises. Since this change was more significant at prefrontal positions of electrodes where working memory process are strongly involved, it might be concluded that such deficit might arise in the working memory process.

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REFERENCES

1. Beck DM, Rees G, Frith CD, et al. Neural correlates of change detection and change blindness. Nat Neurosci. 2001; 4: 645-50.
2. Simons DJ, Rensink RA. Change blindness: Past, present, and future. Trends Cogn Sci. 2005; 9: 16-20.
3. Pessoa L, Ungerleider LG. Neural correlates of change detection and change blindness in a working memory task. Cereb Cortex. 2004; 14: 511-20.
4. Koivisto M, Revonsuo A. An ERP study of change detection, change blindness, and visual awareness.Psychophysiology.2003;40:423-29.
5. Eimer M, Mazza V. Electrophysiological correlates of change detection. Psychophysiology.2005; 42: 328-42.
6. Pesonen M, Hamalainen H, Krause CM. Brain oscillatory 4-30 Hz responses during a visual n-back memory task with varying memory load. Brain Res. 2007; 1138: 171-7.
7. Park HD, Min BK, Lee KM. EEG oscillations reflect visual short-term memory processes for the change detection in human faces. Neuroimage.2010; 53: 629-37.
8. Darriba A, Pazo-Alvarez P, Capilla A, et al. Oscillatory brain activity in the time frequency domain associated to change blindness and change detection awareness. J Cogn[Neurosci. 2012; 24: 337-50.
9. Klimesch W. EEG alpha and theta oscillations reflect cognitive and memory performance: A review and analysis. Brain Res Brain Res Rev. 1999;29:169-95.
10. Qazi S,Markazi S,Stergioulas L.K. Time-frequency and time-frequency coherence of change blindness usingwigner distributions. Transactions on biology and biomedicine.2005; 2:1109-9518.
11. Markazi S, Qazi S, StergioulasL. K. Study of change blindness eegsynchronisation using wavelet coherence analysis. Proceedings of the 2005

IEEE engineering in medicine and biology 27th annual conference Shanghai, China, 2005;1-4.
12. Jeong J, Gore JC, Peterson BS. Mutual information analysis of the EEG in patients with alzheimer's disease. ClinNeurophysiol. 2001; 112: 827-35.
13. Stam CJ, van der Made Y, Pijnenburg YA, et al. EEG synchronization in mild cognitive impairment and alzheimer's disease. ActaNeurol Scand. 2003; 108: 90-6.
14. Pijnenburg YA, v d Made Y, van Cappellen van Walsum AM, et al. EG synchronization likelihood in mild cognitive impairment and Alzheimer's disease during aworking memory task**.** ClinNeurophysiol. 2004;115:1332-9.
15. Raiesdana S, Golpayegani SM, Firoozabadi SM, et al. On the discrimination of patho-physiological states in epilepsy by means of dynamical measures.ComputBiol Med. 2009; 39: 1073-82.
16. vanDrongelen W, Nayak S, Frim DM, et al. Seizure anticipation in pediatric epilepsy: Use of kolmogorov entropy. Pediatr Neurol. 2003;29:207-13.
17. Xu M, Long K, Jian Z,et al. Nonlinear analysis on the EEG information of rat epileptic model. Sheng Wu Yi Xue Gong Cheng XueZaZhi.2003; 20: 511-14.
18. Aarabi A, He B.A rule-based seizure prediction method for focal neocortical epilepsy. ClinNeurophysiol. 2012; 123: 1111-22.
19. Fell J, Roschke J, Beckmann P. Deterministic chaos and the first positive lyapunov exponent: A nonlinear analysis of the human electroencephalogram during sleep. BiolCybern. 1993; 69: 139-46.
20. Roschke J, Fell J, Beckmann P. The calculation of the first positive lyapunov exponent in sleep EEG data.ElectroencephalogrClinNeurophysiol. 1993; 86:.348-52
21. Fell J, Roschke J. Nonlinear dynamical aspects of the human sleep EEG. Int J Neurosci. 1994; 76: 109-29.
22. Sammer G. Heart period variability and respiratory changes associated with physical and mental load: Non-linear analysis. Ergonomics.1998; 41: 746-55.
23. Andreas G. Topics in Nonlinear Time Series Analysis: With Implications for EEG Analysis published by world scientific publishing Singapore May 2000.
24. Tononi G, Edelman GM. Consciousness and the integration of information in the brain. AdvNeurol1998;77:245-79.
25. Isseroff A, Rosvold HE, Galkin TW, et al. Spatial memory impairments following damage to the mediodorsal nucleus of the thalamus in rhesus monkeys. Brain Res. 1982; 232: 97-113.

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