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Left-Right Information flow in the Brain during EEG arousals

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***Abstract*—In disorders such as sleep apnea, sleep is fragmented with frequent EEG-arousal (EEGA) as determined via changes in the sleep-electroencephalogram. EEGA is a poorly understood, complicated phenomenon which is critically important in studying the mysteries of sleep. In this paper we study the information flow between the left and right hemispheres of the brain during the EEGA as manifested through Inter-Hemispheric Asynchrony (IHA) of the surface EEG. EEG data (using electrodes A1/C4 and A2/C3 of international 10-20 system) was collected from 5 subjects undergoing routine Polysomnography (PSG). Spectral correlation coefficient (R) was computed between EEG data from two hemispheres for delta-δ(0.5-4Hz), theta-θ(4.1-8Hz), alpha-α(8.1-12Hz) & beta-β(12.1-25Hz) frequency bands, during EEGA events. EEGA were graded in 3 levels as (i) micro arousals (3–6s), (ii) short arousals (6.1-10s), & (iii) long arousals (10.1-15s). Our results revealed that in β band, IHA increases above the baseline after the onset of EEGA and returns to the baseline after the conclusion of event. Results indicated that the duration of EEGA events has a direct influence on the onset of IHA. The latency (L) between the onset of arousals and IHA were found to be L = 2 ± 0.5s (for micro arousals), 4 ± 2.2s (short arousals) and 6.5 ± 3.6s (long arousals).**

***Keyword*—Electroencephalographic arousals, Inter-hemispheric asynchrony, spectral correlation.**

I. INTRODUCTION

Electroenchephelographic arousals (EEGA) are considered to be one of the main cause of day time sleepiness. EEGA in sleep is defined as an abrupt shift in EEG frequency, lasting for ≥3s, which may include theta, alpha and frequency greater than 16Hz but not spindles [4].

EEGA are the elementary components of the physiological sleep, and all individuals appear to have a certain number of spontaneous arousals. The line which distinguishes between disturbed and undisturbed sleep using EEGA as standard criteria, is yet remains to be established. In sleep medicine, the term EEGA carries a more general meaning than 'waking up'. It is widely recognized that the arousals play a significant role in determining the pathophysiology of sleep disorders. According to the criteria developed by the ASDA, arousals are the marker of sleep disruption and such should be treated as detrimental. The consequences of reoccurring EEGA are fragmented sleep leading to such complications as day time sleepiness, morning headache, memory difficulties and lethargy [2].

The characteristics, origin and affects of arousals are currently under active investigations by sleep clinicians and basic researchers alike. Researchers have developed various hypotheses and experimental methods to investigate the changes in EEG during OSA related EEGA [9-11]. In spite of EEGA scientific and clinical value, due to poor understanding of its phenomenon, studies have not considered the hemispherical difference of EEGA. The issue of asymmetry of brain has been investigated by group of researchers [3] [7] [8]. *None of theses studies, however, considered the significance of EEGA on the hemispheric correlation.* **In our previous studies on EEGA, we showed the general variation in IHA during the EEGA affected periods of sleep [2]. In this paper, we present novel insights into, how the information flows between the left and right hemispheres of the brain in EEGA, as manifested through Inter-hemispheric Asynchrony (IHA) of the surface EEG.**

II. METHODOLOGY

A. Clinical Data Acquisition & EEGA scoring

The clinical data acquisition environment for this work is the Sleep Diagnostic Laboratory of the Prince Alexandra Hospital [1] Australia. Patients suspected of suffering from sleep disordered breathing are referred to the hospital for routine overnight diagnostic test Polysomnography (PSG). In a typical PSG test, signals such as ECG, EEG, EMG, EOG, nasal airflow, respiratory effort, body positions, leg movements and the blood oxygen saturation are carefully monitored as shown in Fig.1. Altogether, a PSG test involves over 15 channels of measurements. Routine PSG data were recorded using Clinical PSG equipment, Siesta, Compumedics®, Sydney, Australia. Patient's preparation, placement of electrodes and instrumental setup was done by expert sleep technician. EEG data were recorded from the cortical regions of both hemispheres using electrode position C4, C3, A1, and A2 based on the standard international 10-20 system for electrode placement, with sampling frequency of 256 Hz. As part of analysis PSG data is manually scored by a sleep technician according to standard R&K [5] criteria for determining sleep stages. The ASDA criterion was used for the scoring of EEGA, formally defined in Appendix.

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B. Artefact Removal

EEG in sleep PSG data may contain several artefacts.

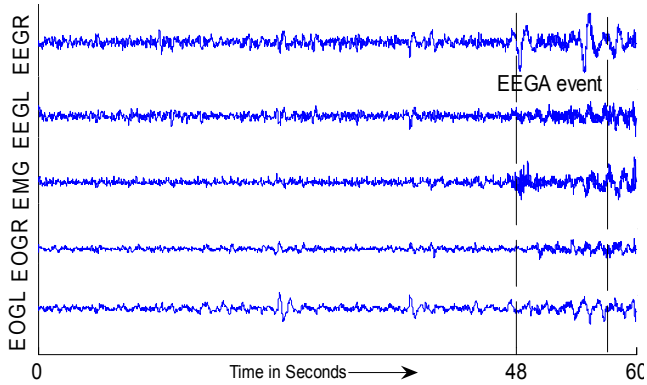

Fig.1. Sixty seconds of PSG data showing some of the main physiological signals. (a)-(b) EEGR & EEGL right & left hemisphere EEG, (c) Chin EMG, (d)-(e) EOGR & EOGL measuring right & left eye movement. Y-axis is in mV. It also shows EEGA event of 9.8s duration.

The two major artefacts usually present in EEG are (i) EMG interference & (ii) EOG activity.

1) EMG artefacts/Electrical interference/Movement artefacts– These kinds of artefacts are induced either due to muscle activity, by local power line interference or due to head movement of the subject. For this paper we were interested in frequency band (0.5 – 25Hz), so we used a 10th order digital Butterworth filter with lower and higher cut-off frequency f_l=0.5Hz and f_h=25Hz respectively Fig.2. Filtering will remove the low frequency artefacts such as movement artefacts & also deals effectively with high frequency artefacts such as muscle noise and power

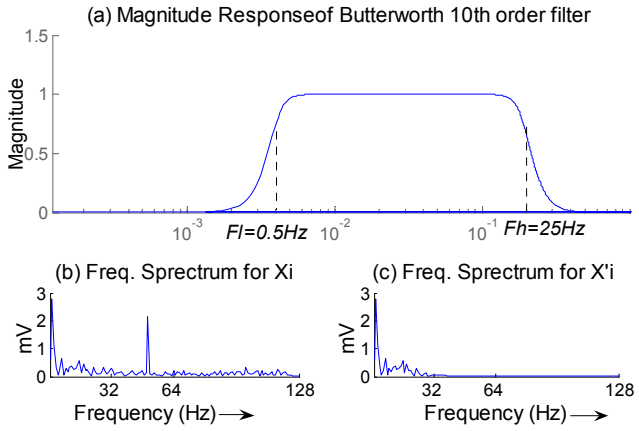

Fig.2. a) Butterworth Filter magnitude response. F_l=0.5Hz & F_h=25Hz are the lower and upper cutoff frequency respectively. b) Frequency response of observed noisy signal, $X_i(n)$. c) Frequency spectrum of filtered signal X'^j_i, free of 50Hz electrical interference and other higher frequencies.

line interference at 50Hz.

2) EOG artefacts – These are of two kinds, blink artefacts & eye ball movement artefacts. Since our data is from sleep EEG data so blink artefacts is less cause of concern. Eye ball movement artefacts causes' problem in the EEG analysis, since they overlap with frequency of EEG. There are several algorithms in the literature to remove eye ball movement artefacts [11-12]. But none of these are widely accepted [11]. The main reason for this is that none of these algorithms can reliably eliminate EOG artefacts from EEG data. The method we propose in this paper depends in computing the correlation between EEG measured in multiple electrodes. As such, EOG artefacts can interfere with the results. In order to eliminate the affect of EOG in our method we followed the following procedure.

We used EOG rejection method for eliminating EOG contaminated EEGA events. A threshold $\in$ was set. If the amplitude of EOG during any epoch containing EEGA event crossed $\in$ for more than 10% of the epoch duration, then that epoch was removed from further analysis. The logic used is given in equation (1).

$$\max\{abs[EOGR_j(t)]>\in], abs[EOGL_j(t)]>\in\} \quad (1)$$

Where, t is the 10% of the total duration time of epoch, EOGR and EOGL represent the ocular signal from right and left eye respectively and j gives the jth EEGA event

C. Calculation of 'spectral correlation'

The EEG data analyzed were centered on the EEGA, as identified using ASDA definition. To access the IHA changes, we calculated the spectral correlation coefficient **R,** every t seconds containing 'l' samples for frequency bands of interest. The procedure is as follows,

S1) Let the digitized EEG data during any arousal event, recorded from hemisphere 'i' of the brain during PSG test be X_i^j, where i=L and i=R for left and right hemisphere of the brain, j represents the jth arousal event.

S2) Pass X_i^j through digital Butterworth filter, Fig.2 to get X'^j_i. Reject or accept X'^j_i using equation eq.(1) and logic described in section 2.B. Let resulting filtered signal be X''^j_i.

S3) To normalize the time difference in the duration of the EEGA event, we defined a normalizing factor which breaks X''^j_i, into m blocks of size 'l' samples. This normalizing factor will be equal to m. We called this normalized time as 'normalized time unit'.

S4) Estimate the Fourier Transform of $X''^j_i(m)$ and obtain amplitude spectrum defined by $Y_i^j(m)$. Separate $Y_i^j(m)$ into k frequency band. Here k= Delta-δ(0.5-4Hz), Theta-θ(4.1-8Hz), Alpha-α(8.1-12Hz) & Beta-β(12.1-25Hz). Let resulting spectral magnitude be denoted by $Y_L^{jk}(m)$ and $Y_R^{jk}(m)$, where 'L' and 'R' signifies the left and right hemisphere respectively.

S5) Calculate the spectral correlation coefficient using (2) for m blocks as given by:

$$R^{jk}(m)=\frac{\sum[(Y_R^j(m,l)-\bar{Y}_R^j(m,l))\times(Y_L^j(m,l)-\bar{Y}_L^j(n,l))]}{\sqrt{\sum[Y_R^j(m,l)-\bar{Y}_R^j(m,l)]^2\times\sum[Y_L^j(m,l)-\bar{Y}_L^j(n,l)]^2}} \quad (2)$$

S6) Average out $R^{jk}(m)$ to get $\bar{R}^k$.

III. Result and Discussion

PSG data from five subjects was analyzed. Two of the subjects were diagnosed with apnea syndrome after PSG test. Other 3 were found to be normal. Altogether 475 EEGA events were analyzed from 5 subjects. In all 103 EEGA events were rejected from further analysis due to artefacts, according to the criteria established in section 2B. The EEGA events from each subjects were divided into 3 groups according to the duration of event as follows, (i) micro-arousal 3-6s, (ii) short arousals 6.1-10s, (iii) long arousals 10.1-15s. EEGA events longer than 15s are considered as awake periods according to ASDA and R&K scoring criteria, hence were excluded from this study.

To investigate the variation of R with occurrences of EEGA, we centered our attention on periods around the EEGA events. Change in R represents a corresponding inverse variation in the IHA of the brain. We studied the IHA behavior for all 4 frequency bands, Delta-δ (0.5-4Hz), Theta-θ (4.1-8Hz), Alpha-α (8.1-12Hz) & Beta-β (12.1-25Hz) during EEGA events. All the bands exhibited different pattern of IHA changes. Most systematic and remarkable variation in IHA was seen in β frequency band. Figure 3 shows the variation of IHA during EEGA events with different length groups for 2 subjects in β band. Each group displayed a uniform pattern of IHA changes. According to Fig.3 IHA between the left and right hemispheres of brain increased after the onset of EEGA event. Somewhere during the event it acquires maximum value, creating a ditch before the end of event. Towards the end of the EEGA events, the IHA started returning towards its baseline value. Figure 4 shows corresponding average R for all 5 patients analyzed. Figure 5 presents the average IHA pattern calculated over 5 subjects in different EEGA groups for δ band. From the Fig.5 it can be observed that δ band have inconsistent and insignificant variation in IHA. In other frequency bands too i.e. θ and α behavior of IHA was similar to δ.

The latency (L) between the onset of arousals and induced IHA were found to be different in various arousals groups in β band. L = 2 ± 0.5s (for micro arousals), 4 ± 2.2s (short arousals) and 6.5 ± 3.6s (long arousals). In order to minimize the error introduced due to the subjective nature of the EEG scoring procedure, we used a single expert medical technologist in marking of EEGA events.

Fig.3, Fig.4 and Fig.5 lead to the following observations:

- EEGA events are associated with increase in IHA of the brain, in the beta frequency band, as indicated by a lowering of correlation coefficients.
- Induced IHA depends on the duration of EEGA.
- IHA assumes its largest value, on average, in middle of

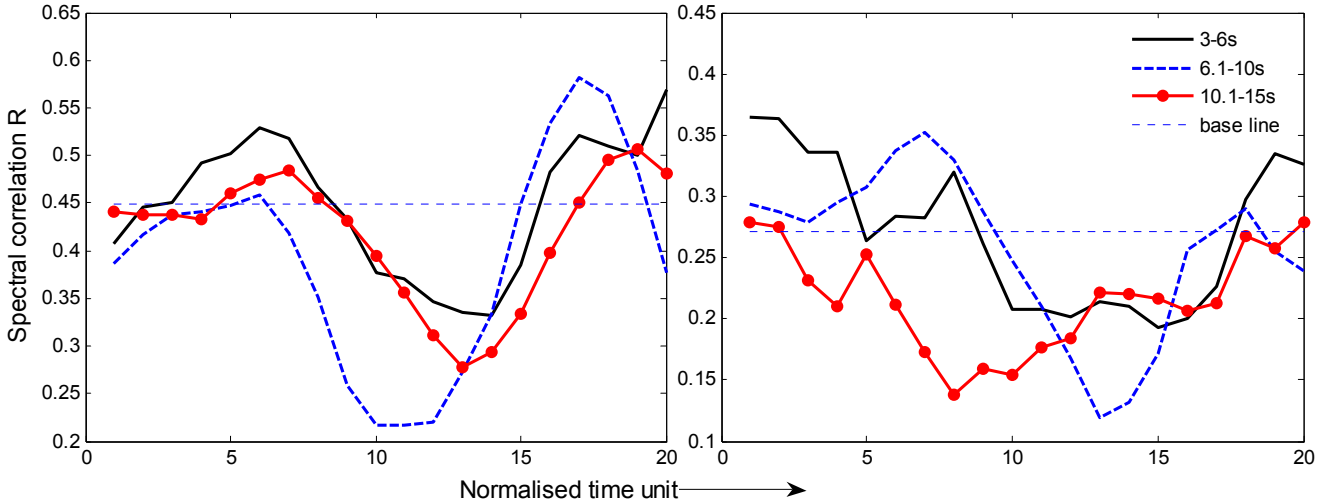

Fig.3. Variation in IHA during different EEGA group, for two subjects in β band. Y-axis represents the spectral correlation coefficient calculated between left and right hemispheres of brain. X-axis is normalized time unit (see section 2b C. S4). Each EEGA event was segmented into 'm' blocks of length 'l' sample, section 2 C. Here m=20.

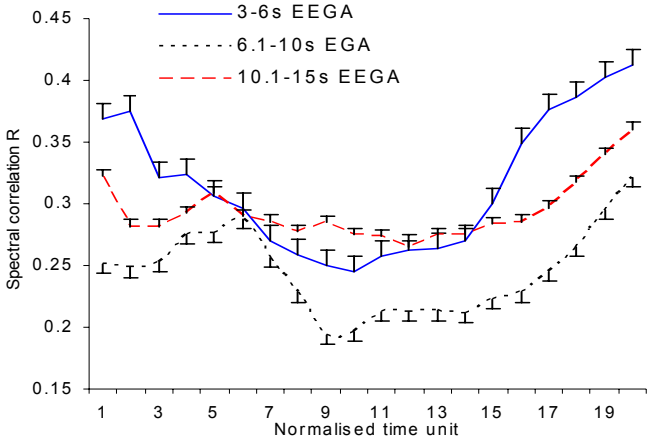

Fig.4. Average spectral correlation coefficient for all the 5 subjects studied, showing general variation in IHA, with different EEGA event duration. Y-axis represents the spectral correlation coefficient calculated between left and right hemispheres of brain. X-axis is normalized time unit (see section 2b C. S3) Error bar shows the standard deviation.

event and returns to baseline towards the end of event.

- No significant IHA pattern is recognized in δ, θ, & α band.

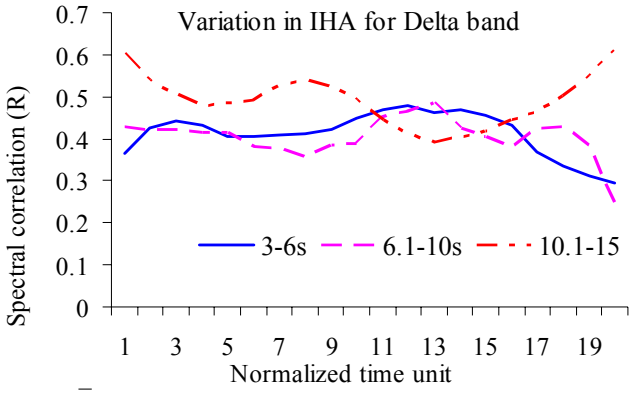

Fig.5. $\bar{R}$ for all the 5 subjects studied in δ band, showing variation in IHA, with different EEGA event duration. Y-axis represents the spectral correlation coefficient calculated between left and right hemispheres of brain. X-axis is normalized time unit. No significant pattern was identified for δ, θ, α frequency band.

The strong asymmetry in the beta frequency band during the EEGA episodes is a significant finding. These results indicate that the macro-analysis of sleep without considering the effects of EEGA is insufficient to understand how the brain behaves. We expect our result to contribute significantly towards analyzing information flow in the brain in the presence of sleep disorder such as sleep Apnea syndrome. However, at this time we are unable to offer an unequivocal explanation as to why asymmetry develops in the brain during EEGA. We are currently further investigating the behavior of IHA in other frequency bands, and trying to distinguish between individual EEGA events and those associated with apnea episodes. Our results were described by a statistical analysis of over 475 arousal events recorded from five patients. We are currently expanding the number of subjects to improve the validity of our results.

IV. CONCLUSION

We investigated the inter-hemispheric asymmetry of the brain during EEG-arousals. PSG data from five subjects referred to Sleep Diagnostic laboratory for routine Polysomnography was studied. EEG asymmetry was determined via the spectral correlation coefficient of data, which computed the correlation between EEG measured from the two hemispheres of brain. Our results revealed that in β frequency band IHA increases above the baseline after the onset of an EEGA and returns to the baseline after the conclusion of event. Results indicated that the duration of EEGA events has a direct influence on the onset of IHA. This signifies that EEG-arousals should be considered as another dimension in sleep analysis.

APPENDIX

1. Definitions of EEG Arousals [Michael B. et al 1992]

EEG Arousal is defined as abrupt shift in EEG frequency, which may include theta, alpha activity and/or frequencies greater than 16Hz (but not sleep spindles) subjected to the following scoring rules:

- The subject must be asleep for a minimum period of 10s before declaring an Arousal event,
- EEG frequency shift must be sustained for ≥ 3s, and
- EEG arousal from REM sleep requires presence of simultaneous increase in the sub-mental EMG amplitude.

2. Definition of the Arousal Index (AI)

The average number of EEGA events per hour of sleep, computed over the total sleep period, is termed as AI.

3. *Obstructive sleep apnoea-Hypopnea syndrome*

OSAHS is characterized by recurrent episodes of partial or complete upper airway obstruction during sleep. This manifest as reduction or complete cessation of airflow despite ongoing inspiration efforts.

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