Power spectral densities of electroencephalographic theta and alpha frequency waves during information processing of language comprehension

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ABSTRACT

A cross sectional study was conducted to assess electroencephalograph (EEG) Power Spectral Densities (PSD) of alpha and theta frequency bands for an integrative functional role of working memory (WM) in the architectonics of a synthesized and coordinated communication system as exemplified by the observable phenomenon of the evolved structured Language of Human Mind by using Visuo-Spatial Delayed Match to Sample (DMTS) task. The analysis exhibited significant Event Related Synchronization (ERS) along theta wave-form at temporal region along with Lateral Asymmetry Index (LAI) of Alpha Event Related Desynchronization (ERD) at parietal region suggestive of the phenomenal singularity of ERS of theta along temporal regions that seems to be intricately interwoven onto the spectacle of LAI of alpha ERD, presumably evolving a synthesized enveloped working memory, along the virtual phase-space of Human Mind and eventually translating into the comprehensible means of communication of Humans, i.e., Language.

Keywords: EEG; theta; alpha; working memory; event related synchronization/desynchronization

1. INTRODUCTION

Neurolinguistics, an interdisciplinary domain that draws in inputs from application disciplines of neurosciences, linguistics, cognitive sciences, computers electronics and communications, neuropsychology and neurophysiology and basic sciences of mathematics and physics, explores underlying neural mechanisms of human brain and its correlation with the phenomenon of means of communication, i.e., Language.

Neural oscillations across coordinates of time (brainwaves), within individual neurons or through interactions amongst neurons (neuronal pools), are rhythmic patterns of neural activity of central nervous system and such patterned neural dynamics signify respective neurophysiological functional characteristics. It has been singular constant efforts of techniques of Biological Signal Processing (BSP) to categorise electroencephalographic (EEG) signals through varied armamentarium of linear domain of Power Spectral Densities (PSDs), linear discriminant analysis (LDA) and non – linear domains of neural networks. Memory is a tangible precept of the human mind, evolving along realms of functional human mind in real-time, by which information is encoded, stored and retrieved across coordinates of time which may or may not be stereotyped (Melton, 1963). It is a dynamical information processing system with explicit and implicit functioning mode of constituent parts of sensory processor, Short-Term Memory (Working Memory), and Long-Term Memory (inclusive of episodic and semantic memory) and interaction between these systems involve the precept of intention of memory retrieval and storage (Baddeley, 2007; Baddeley & Hitch, 2010).

Working memory seems to be prerequisite premise needed for information processing and information storage needed for higher cognitive processing, such as language comprehension, learning and reasoning (Baddeley, 2003). Semantic memory and information processing establish sequential flow of events through logical algorithmically flow that is concrete, viable and neurally dynamical pliable concept, where flow of information is a continuous and gradual process, flowing with tides of space and time, evolving into genesis of legible, meaningful, comprehensible words and syntactically coherent sentence. Encoding of episodic memory is a context based process. It involves identifying and isolating specified space and time coordinates of the particular event utilizing neural bursts of the human mind. Working memory (WM) is an attempt of the human mind to hold onto the flow of space and time in a bid to hold information coordinates within a specified time span specific to dedicated neuronal pools that could be laying down the foundation for comprehension, thinking and planning (Baddley, 2003; 2012).

Memory models proposed by Baddeley and Hitch (1974), Cowan (1997), Ruchkin et al. (2003) and Fuster et al. (2003; 2009; 2012) posit that memory is not confined along one particular area in human Brain but is distributed across a vast network primarily being sub-served by prefrontal cortex, temporal and posterior parietal areas (D'Esposito, 2007; Postle, 2006). The Neurophysiologists and Cognitive Neuroscientists such as Richard Caton (1842-1946), Hans Berger (1873-1941), Fisher and Lowenback (1934), Gibbs and Jasper (1936), from its armamentarium of varied procedures, both non-invasive and invasive, have employed such tools to gain an insight to unravel the mystics of working of human mind. It has been observed that Electroencephalography (EEG), a non-invasive recording of underlying neural dynamics of the human mind in real-time and its dynamics for myriad mental and cognitive functions to identify, isolate and register across space-time, physical qualia of the stimulus (features detection) (Beres, 2017), seems to be a tool with temporal precision but poor spatial localization. EEG is capable of measuring electrical potential changes generated from the various neuronal transmission processes in human brain (Schomer et al., 2012). These voltage fluctuations are present across different frequency bands such as delta, theta, alpha, beta and gamma wave-forms or band-forms. EEG offers a higher temporal resolution and is a neurophysiological correlate of neurological relevant time-scales (Burns & Rajan, 2015).

Digital evaluation of EEG examines association(s) amongst varied EEG frequency band zones and antecedent information processing of the human mind, wherein EEG wave-form is digitised, quantified and segregated through Fast Fourier Transform (FFT) in order to assess changes in pattern in strength in terms of microvolts of electrical energy of dedicated neuronal pools. Among the various frequency bands, delta waves (0.5–4 Hz) have the lowest frequency and have been demonstrated during deep and unconscious sleep. A higher frequency band than delta is theta waves (4–8 Hz) that is observed during sleep and quiet focus. During a state of relaxed mind alpha band (8-14Hz) dominates and even in closed eye condition. In the fully conscious state beta waves appear (14–30 Hz). Finally, Gamma waves (over 30 Hz) are known to have stronger electrical signals in response to visual stimulation (Abo-Zahhad et al., 2015). Among these, theta activity has been found to play an important role during memory and information processing (Addante et al., 2011) primarily during episodic memory retrieval (Lega et al., 2012). This is achieved by activation of memory traces especially in the frontal brain areas (Khader et al., 2010). Theta wave changes over frontal region also represent access to stored information (Klimesch et al., 2001) and recognition processes (Klimesch et al., 2004).

EEG power spectral densities (PSDs through FFT) of alpha and theta frequency bands during a WM task in terms of amplitudes of these frequency bands, follow separate trajectories in their nativity, that could hold relevant information and act as gateway to give an insight into underlying neurophysiological precepts and neural dynamics responsible for evolution and progression of evolved phenomena of written and spoken language that make use of varied edifices of memory systems (Beres, 2017). Cortical activity (10 – 14 Hz) has been associated with semantic processing (Doppelmayr et al., 2002). Theta activity (4 – 7 Hz) has been found to be associated with Working Memory performance (Kahana et al., 1999; Klimesch, 1998; Röhm et al., 2001) and sensorimotor rhythm (SMR) activity (12 – 15 Hz) has been associated with attentional processing (Egner & Gruzelier, 2001). It could be inferred that feature detection seems to be purview of theta band forms of EEG signals and concept formation that involves abstraction of flow of neuronal processes seems to be the domain of alpha band form (Klimesch et al., 1994; 1996; 1997; 2007; 2011).

Rhythmic theta activity is usually not observed in EEG signals of normal, awake adults. Physiologically, theta frequency emerging from hippocampus (seat of formation of episodic memory) is difficult to record through scalp electrodes. However, it is presumed that theta frequency could travel through longitudinal pathways into neocortex making it possible to record such evoked theta frequencies through scalp electrodes (Zhang & Jacobs, 2015). Evoked theta activity has been observed as amplified frequency, synchronised and phase locked in response to increased WM demands (Kahana et al., 1999; Klimesch, 1998; Röhm et al., 2001). EEG oscillatory responses recorded from human scalp at different frequencies can be related to myriad aspects of cognitive functioning ranging from stimulus processing, attention machanisms {Ko et al., 2017 (monitored EEG spectra by Visual attention task)}, Working memory (Dai et al., 2017) to Long-Term Memory (Friedrich et al., 2015; Klimesch, 1998). Increased PSD of theta frequency (~3–8 Hz) has been noted in alliance with working memory functions (Klimesch, 1996; Rizzuto et al., 2003), responding memory load (Jensen & Tesche, 2002), and task demands (Raghavachari et al., 2001). Event-related responses of alpha frequency (~8–12 Hz) has been linked to attention, alertness (Klimesch, 1998) and incidental memory processes (Klimesch, 1998; Krause et al., 1999) with decrease in alpha power being associated with increasing in cognitive load (Krause et al., 2000; Stipacek et al., 2003).

Event-related oscillatory EEG activities can be quantified by means of the Event Related Desynchronization (ERD) method (Pfurtscheller & Aranibar, 1977; Pfurtscheller & Lopes da Silva, 1999), wherein a relative decrease in PSDs of a certain frequency band during stimulus processing (as compared to a no-stimulation reference/control condition) is called ERD, whereas the opposite, a relative increase in the power is called Event Related

Synchronization (ERS) (Pfurtscheller & Lopes da Silva, 1999). The ERD/ERS values are within-subject measures of relative changes in the EEG (Pfurtscheller & Aranibar, 1977; Krause, 2003). The ERD/ ERS technique in EEG analysis seem to be providing comparatively better temporal resolution and is suited for assessing dynamic brain oscillatory responses during cognitive processing. EEG also offers sensitivity towards tangential and radial neuronal activities.

The EEG actictivity in theta, alpha and gamma frequency bands could be holding important clues to decipher the role of working memory in encoding, register and retrieval of memory inputs (Lisman & Buzsáki, 2008; Lisman & Idiart, 1995). This is evident by the ERS in theta frequency band that represented encoding and retrieval of episodic or new information, and ERD in alpha frequency band that represented encoding and processing of semantic information (Klimesch et al., 1994; 1998; 2001; 2007). Additionally, role of alpha frequency band of EEG was also reported (Wianda & Ross, 2019) in processing of WM in encoding and retention through local and long-range neural networks.

The objective of the present study was to evaluate the changes in EEG power spectral density in theta frequency wave-form during episodic information processing and to evaluate the EEG power spectral density changes in alpha frequency wave-form during semantic memory and information processing, for which verbal Delayed Match To Sample Working Memory task was selected (Griesmayr et al., 2010). In addition, in the current study the response-frame of EEG alpha and theta frequency band as a function of time (~0-1140 s) was also assessed.

2. Methods

2.1 Sample

The present study (cross sectional, descriptive observational research protocol) was conducted in the Department of Physiology at S.M.S. Medical College and Attached Hospitals, Jaipur, Rajasthan (India), after getting requisite approval from Institution Research Review Board, Institutional Ethics Committee of the College and informed written consent from participants.

It was initiated on 80 (Males= 44, Females=36) apparently healthy (to the best of our knowledge and survey, considering the inclusion and exclusion criterias, chosen subjects were fit to perform the task) undergraduate students of Jaipur city, age-range of 18-25 years with mean age of 21.92 years (SD of 2.20), wherein Delayed Match To Sample task (DMTS) was run along with a concomitant EEG time-series. The participants included in the study were right-handed (Handedness was assessed by a questionnaire in which subjects were asked about the hand they use in different tasks such as handwriting, throwing a ball, etc. A subject was considered right-handed if he/she indicated to use the right hand in all of these different tasks) , cooperative with normal or corrected to normal vision. Subjects with any type of neurological impairment, any chronic or acute illness, left-handed, colour-blind and those on psychoactive medications were excluded from the present study.

2.2 Procedure

The subjects were advised to wash their scalp with shampoo, the night before the EEG recording and abstain from use of hair creams/oils and/or sprays and avoid caffeinated drinks at least 2 hours before the initiation of test procedure. The subjects were seated on an ergonomic wooden chair in a sound attenuated dimly lit air conditioned room with an ambient temperature of 25°C and EEG was recorded using making use of saline soaked Ag/AgCl surface electrodes that were secured using a silicon bracket cap positioned on subject's head accordingly. The EEG electrodes were placed on FP1, FP2, F7, F3, AFz, Fz, F4, F8, T3, C3, Cz, C4, T4, P7, P3, Pz, P4, P8, O1, O2 regions of scalp as per International 10-20 system (Jasper, 1958). The subjects so selected satisfied the above mentioned inclusion and exclusion criteria. The procedure of the experiment was thoroughly explained before including the participants in the proposed research plan. The raw EEG was recorded using Brain Electro Scan System (BESS) version 4.0 (Axxonet Systems Technologies Ltd., India). The electrode impedance was kept below 5 Ω and electrical activities were amplified using an amplifier. Notch filters of 50 Hz and 60 Hz were applied in order to remove the electrical line noise and for smoothening of the waveform respectively. The raw EEG recordings were digitised at a sampling rate of 512 Hz. The data (recording) was displayed on a computer screen and all the recordings proceeded with running a baseline EEG for five minute to ensure clean data acquisition. Once the EEG waves stabilised, the stimulus protocol was loaded and the data acquisition was started. The EEG using the predefined stimulus protocol which consisted of the presentation of Standardised Visuo-Spatial Delayed Match To Sample (DMTS) task.

2.2.1 The Stimulus Protocol

The stimulus protocol of DMTS was designed to assess conditions of retention, semantic manipulation of forward processing (appreciation of place and unit value) and backward processing/manipulation. The tasks consisted of presentation of consonant letter strings (target letter strings) with four letters each, shown simultaneously for a period of 1000 ms against a black background centrally on the computer screen with font, Arial and font size of 80. The letters were either coloured in grey, red or blue with the colour categorised to respective three conditions that were to be carried out as per instructions (Berger et al., 2014).

2.2.2 The Task Conditions

The retention condition consisted of consonant letter strings, in grey colour, being flashed on computer screen and the participants had to only retain the letters in their exact order during the subsequent retention interval of 2000 ms before comparing them to a probe letter sting. The semantic forward processing condition included consonant letter strings, in blue colour, so flashed that had to be arranged in alphabetic ascending order and in the third backward processing condition of consonant letter strings being flashed in red colour had to arranged in a descending anti-alphabetic order. On flow of retention interval of 2000 ms, a probe consonant letter string appeared on the computer screen for 1000 ms and the participants had to decide and indicate by 'Y' or 'N' key on the keyboard as 'Y' assigned for Yes response and 'N' assigned for No response, whether it matched their representation of the target letter string (either retained or manipulated, depending on instruction) or not. The inter-trial interval was restricted to 2000 ms (Figure 1).

In the present study 54 trials per condition were taken, resulting in a total number of 162 trials with 50% of them being a match and 50% being a non-match between target and probe (Luck, 2005). The sequence of stimuli presentation singularly adhered to with first presentation being of grey consonant letter strings followed by blue consonant letter strings that was concluded by third protocol of red consonant letter strings. In each trial, an initial 500 ms for fixation ('+') was allocated, followed in tandem by sequence of stimuli presentation and inter trial interval of 2000 ms for a black blank display. The raw EEG data thus obtained for the task consisting of three conditions for 54 trials were then subjected to further analysis by the BESS software, where epochs were separated out for each trial and an epoch length of 1000 ms (first half i.e., 1000 ms being relegated to retention interval).The data was then selectively averaged separately for each electrode site, for each condition, for 80 subjects. The stimulus presentation and EEG acquisition were synchronised, and coded event triggers marked the onset of each stimulus, response screen and the participants' responses in the EEG signal recorded with BESS software.

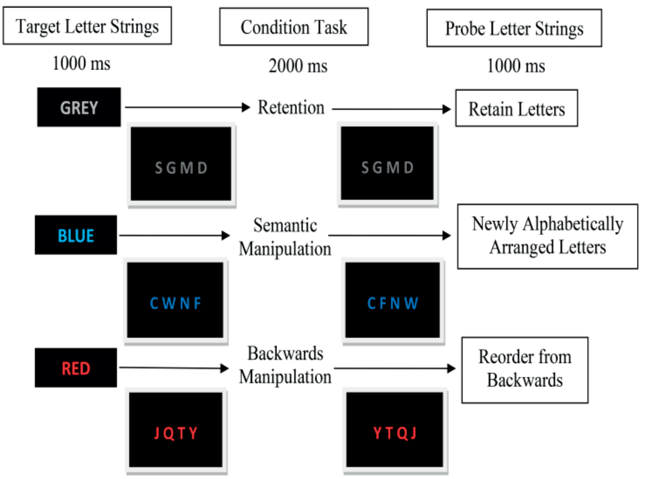

Figure 1. Schematic diagram of stimulus protocol. It shows the schematic diagram of stimulus protocol used during EEG recording in different task conditions (Retention, Semantic Manipulation & Backwards Manipulation). The tasks consisted of presentation of target letter strings with four letters (grey, red or blue in colour) each, shown simultaneously for a period of 1000 ms against a black background centrally on the computer screen

2.3 EEG recording Analysis and Quantification

The means of PSDs of each condition were calculated and compared with control condition using one-way ANOVA (analysis of variance). The means of absolute power (of 80 subjects) in each condition were calculated and statistically compared using two-way repeated-measures ANOVA {with the factor 1 being specific condition of retention, forward semantic and backward manipulations factor 2 being Region of Interest {ROI or Channels; Frontal (FP1, FP2, F3, F4), Central (C3, C4), Parietal (P3, P4, P7, P8), Temporal (T3, T4), Occipital (O1, O2)}. The test of sphericity was done through Greenhouse-Geisser corrections that were applied when demanded and significance level was set to $p < 0.05$. Paired sample t-tests were used for post-hoc comparisons of conditions for each time interval and region of interest separately for theta and alpha frequency band.

The lateral asymmetry index (LAI) was calculated and compared with that of control condition in both theta and alpha frequency bands using paired sample t-tests. Statistical analysis was performed to compare power estimates for theta and alpha frequency band for the time window of the retention interval. For EEG signals match and non-match, correct and incorrect responses of all trials were considered in statistical analysis. Incorrect trials were considered in the statistical analysis due to the fact that their number was few; and secondly, incorrect responses might also be because of erroneous encoding or retrieval processes, whereas the current analysis solely focused on processes during the delay interval. For statistical analysis of amplitude estimations, the EEG data recorded, for each trial control condition (t0) is the time period before the presentation of the target stimulus and t2 is the retention interval of each trial were then segmented into epochs of 1000 ms each, resulting in two time intervals per retention period (ta: from stimulus offset until 1000 ms later and tb: from 1000 ms after stimulus offset until probe onset at 2000 ms after stimulus offset) and after interpreting the epoch range per trial, resultant epochs of every trial are averaged for the mean absolute power for the conditions (Figure 2).

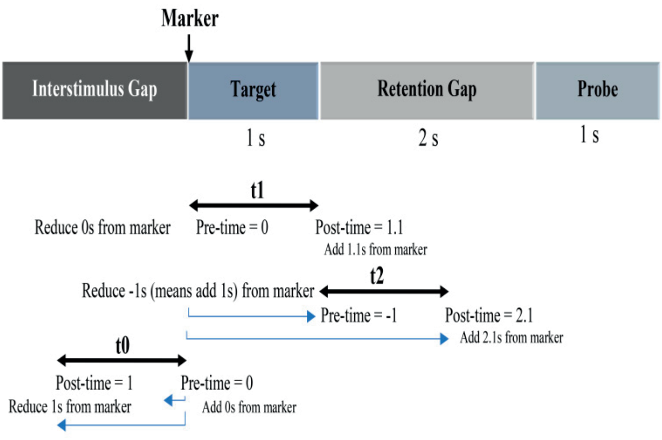

Figure 2. Epoch ranges for the trials. It shows the scheme of epoch ranges used for the trial during EGG acquisition and analysis. Target was presented for 1 second (t1) and there was a retention gap of 1 second (t2). Time before presentation of stimuli was marked as control

3. Results

The EEG was run on 80 {Males= 44 (54%), Females=36 (46%)} apparently young healthy undergraduate students of Jaipur city, Rajasthan, age between 18-25 years with mean age=21.92 years (SD=2.20) with DMTS task.

3.1 The cortical distribution of theta frequency wave-form

The two-way repeated measures ANOVA comparing the EEG responses between the three conditions, a main effect of condition, could not differ significantly in theta frequency band, thereby upholding the premise that the three neurophysiological cognitive manoeuvres of retention, semantic and backward manipulation are being processed through neural mechanisms that appear to be statistically similar [F(4.9, 387.3) = 1.91, p=0.09]. ERS as evinced through enhanced PSD (increase in mean amplitude power in sq. microvolts), was observed in theta wave-form in all three conditions/manoeuvres of retention (FZ, F3, F4, F7, T3, T4) semantic forward information processing (FP1, FP2, AFZ, FZ, F3, F4, F7, F8, C3, P7, T3, T4) and backward information processing (FP1, FP2, AFZ, FZ, F3, F4, F7, F8, C3, T3, T4) of EEG electrode pairs and on comparative evaluation with basal EEG time-series run along said EEG electrode pairs, significant difference in PSD could be appreciated only along T4 EEG electrode pair in conditions of retention (p = 0.05), semantic manipulation (p = 0.05) and backward manipulation (p = 0.01) by using one way ANOVA at 5% level of significance (Figure 3).

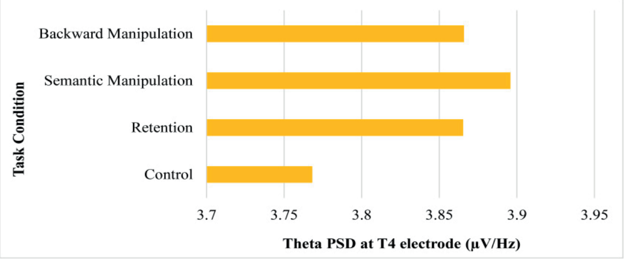

Figure 3. Comparison of T4 EEG channel in different task conditions in Theta frequency band. It shows the comparison of T4 EEG channel activity among different task conditions in theta frequency bands. Significant difference in PSD was observed in T4 EEG electrode pair in conditions of retention (p = 0.05), semantic manipulation (p = 0.05) and backward manipulation (p = 0.01) by using one way ANOVA at 5% level of significance

ERD as evinced as decreased PSD (in sq. microvolts) in EEG electrode pairs in all three conditions/manoeuvres of retention (FP1, FP2, AFZ, CZ, C3, C4, PZ, P3, P4, P7, P8, 01, 02), semantic forward information processing (CZ, C4, PZ, P3, P4, P7, P8, O1, O2) and backward information processing (CZ, C4, PZ, P3, P4, P7, P8, O1, O2) and on comparative evaluation with basal EEG time-series (control condition) along said EEG electrode pairs, significant difference in PSD (in sq. microvolts) could be appreciated in conditions of retention [Cz ($p = 0.02$), C3 ($p = 0.03$), P7 ($p = 0.00$), P8 ($p = 0.02$)], semantic forward information processing [P7 ($p = 0.00$), P8 ($p = 0.007$)] and backward information processing [Cz ($p = 0.04$), P7 ($p = 0.00$)] by using one way ANOVA at 5% level of significance.

The comparison of means and SDs of LAI of mean PSD (in sq. micro Volts) between control and retention, semantic forward information processing and backward information processing neural mechanism in theta frequency band was analysed, wherein values of LAI range from 1 (when right hemisphere exhibits zero activity) to –1 (when hemisphere exhibits zero activity). The LAI is calculated as {LAI= P (Left) – P (Right) / P (Left) + P (Right)} for each electrode pairs could not differ significantly where p value is not significant in any of the pair (Thut et al., 2006).

3.2 The cortical distribution of Alpha frequency wave-form

The interaction among three conditions of retention, semantic information forward processing and backward information processing based on performance in different tasks were compared across Regions of Interest in alpha frequency band showed significant difference ($p < 0.001$) using two way repeated measure ANOVA at 5% level of confidence [$F (5.54, 437.97) = 4.45$, $p < 0.001$], though the comparison among conditions across same EEG channel did not differ significantly. ERD in terms of decreased mean PSD (in sq. micro Volts) of alpha wave form band, though not significant, was observed across all regions during retention, semantic forward information processing and backward information processing conditions was observed when compared to that of control condition, though the change was not significant [using one way ANOVA at 5% level of significance]. However, significant difference could be appreciated at parietal region of P3-P4 EEG electrode pair along alpha frequency band using T-test with $p = 0.004$, $p=0.002$ ($p < 0.05$) at 5% level of significance with left hemisphere lateralisation (skewed neurophysiological processes) during retention condition and semantic manipulation condition, respectively. In backward manipulation condition, significant difference could be appreciated at additional parietal EEG lead pairs of P7-P8 besides P3-P4 with $p = 0.02$ in both electrode pairs ($p < 0.05$) at 5% level of significance with left hemisphere lateralization (Figure 4).

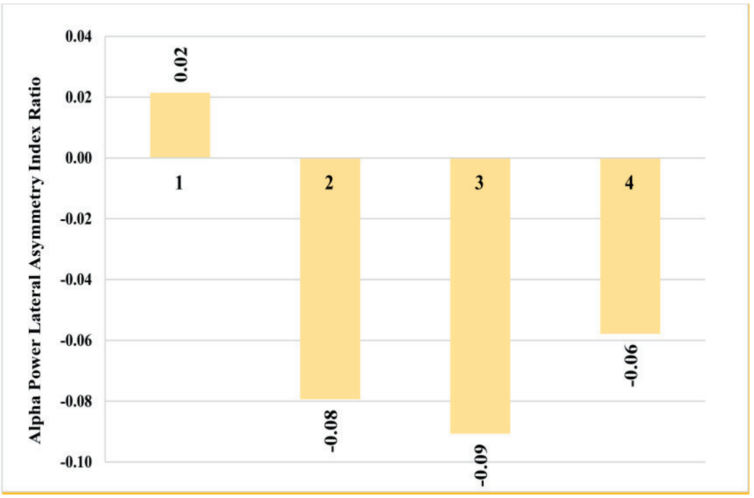

Figure 4. Lateral Asymmetry Index of different conditions of alpha frequency band at for P3-P4 electrode area. It shows the Lateral Asymmetry Index during different task conditions for alpha frequency band at P3-P4 electrode area. Task conditions are denoted as 1 (Control Condition), 2 (Retention Condition), 3 (Semantic Manipulation), 4 (Backward Manipulation). Alpha frequency wave-form showed significant difference in Lateral Asymmetry Index at parietal region with P3-P4 EEG electrode pairs in retention and semantic forward information processing condition ($p=0.004$, $p=0.002$ respectively)

4. Discussion

4.1 Human Mind: Neural Dynamics of Language

The arena of working of the Human Mind along with its functional and morphological correlates has overwhelmed and beguiled mankind since times immemorial. The neural dynamics of working memory have been envisaged to be funnelled onto language acquisition processes and the interplay between multiple frequency wave-forms in the cortical neural networks play an elementary deciding role in such an intricately woven process. The concept of human mind in acquisition of language or general learning mechanism(s) contribute to such an evolved mechanism of spoken and written language that imprisons the mechanistic of mirror neuron system (MNS) and synaptic neuroplasticity. MNS plays a pivotal role and is considered to be an interface between the qualia or sensorium and motor system of the intricately woven Human Mind, wherein activation of Mirror Neuron System initiates the process of image formation in the virtual phase-space trajectory of the human mind so evolved by the baseline reverberating chaotic neural dynamics, a phenomenon learnt and hard-wired through the neurophysiological process of memory .

The neural signature of Working Memory for Encoding, Registration and Retrieval of Memory inputs has been postulated to be served by three EEG Wave-Forms Complex of Theta, Alpha and Gamma frequency bands with a bootstrapping blueprint wherein gamma wave-forms or bursts hitchhike or piggy back rides the theta wave responsible for feature detection (Singer, 1993), along with alpha-theta wave-form that coincidentally allocates attentional resources onto the evolved dedicated neuronal circuitry that are stimulus-specific (Köster et al., 2018; Roux & Uhlhaas, 2014). These frequency oscillations have been observed to modulate neuronal excitability by controlling neuronal firing, and could be responsible for holding of stimulus-specific information in space and time along the coordinates of working memory neuronal pool (Haegens et al., 2011; Hakim & Vogel, 2018). Such a neural synchronisation proposal may provide a solution to underlying mechanism(s) of synthesis and amalgamation of features of an object through coordinated firing patterns that in essence underlie the feature detector mechanism(s) of neuronal process (Lisman & Idiart, 1995; Belluscio et al., 2012; Colgin et al., 2009). It has been envisioned that ERS in theta frequency wave-form is related to encoding and retrieval of episodic or new information, and ERD in alpha frequency wave-form is related to encoding and processing of semantic information (Klimesch et al., 1994; 1996; 1997; 1998; 2007; 2011; Babiloni et al., 2004). The observation documented in the present study of theta wave form band synchrony, known as ERS, mirroring increased PSD, across distributed range of task relevant areas of brain [retention (FZ, F3, F4, F7, T3, T4) semantic manipulation (FP1, FP2, AFZ, FZ, F3, F4, F7, F8, C3, P7, T3, T4) and backward manipulation (FP1, FP2, AFZ, FZ, F3, F4, F7, F8, C3, T3, T4)] during working memory task of registration, retention and retrieval processing is reflective of dynamical linking, an observation seconded by previous EEG studies of Sarnthein et al. (1998) and Sauseng et al. (2008) , though the same has been disputed by Hanslmayr et al. (2008) and Nigbur et al. (2012).

In the present study, the characteristic of temporal distribution of ERS/ERD PSD along the run of EEG time-series was assessed. During the

Delayed Match To Sample (DMTS) task, temporal distribution was accessed across two frequency bands of theta and alpha to assess neuronal oscillatory activities during WM tasks across select cortical regions and to assess modular memory facets and processes that entrain dedicated neuronal pools in human brain resulting in memory consolidation processes concluding into language acquisition, manipulation and comprehension processes. These chunks of information or memory codes might generate a particular patterned rhythm which later during retrieval of information from dedicated neural networks might follow the phenomena of pattern matching during its response for same memory inputs.

In this context and with characteristic patterned observations data from the present study the precepts of Neural Dynamics of Working Memory Model could be conceptualised as: (1) Retention Precept:Event Related Synchronization (ERS) of Theta frequency Band at T3-T4 electrode sites, Lateral Asymmetry Index (LAI) of Event Related Desynchronization (ERD) in Alpha Frequency Band at P3-P4 electrode sites, (2) Semantic (Forward) Processing: Theta Event Related Synchronization at T3-T4 electrode sites, Lateral Asymmetry Index of Alpha Event Related Desynchronization at P3-P4 electrode sites, (3) Backward Processing: Theta Event Related Synchronization at T3-T4 electrode sites, Lateral Asymmetry Index of Alpha Event Related Desychronization at P3-P4 electrode sites and P7-P8 electrode sites.

The concept postulated of Neural Dynamics of Working Memory Model reflects as under:

- Theta Frequency Wave-Form ERS at T3-T4 EEG electrode pair with concomitant and antecedent LAI Alpha Frequency wave-form ERD at P3-P4 EEG electrode pair characterising Retention and Semantic Forward Information Processing Precepts.
- Backward Information Processing Precept is inclusive of Theta Frequency Wave-Form ERS at T3-T4 EEG electrode pair with concomitant and antecedent LAI of Alpha Frequency Wave Form ERD at P3-P4 EEG electrode pair along with additional recruitment of region of P7-P8 EEG electrode pair.

The present study subsequently suggests that there has been observed two aspects of processing of Long-Term Memory in terms of mean PSD and LAI in theta and alpha frequency wave-forms. Theta frequency wave-form exhibited significant difference in T4 EEG electrode pair (right temporal region) in retention, semantic forward information processing and backward information processing conditions when compared with that of control/basal condition ($p=0.05$, $p=0.05$, $p=0.01$ respectively) and Alpha frequency wave-form showed significant difference in Lateral Asymmetry Index at parietal region with P3-P4 EEG electrode pairs in retention and semantic forward information processing condition (p=0.004, p=0.002 respectively) and P3-P4 and P7- P8 EEG electrode pairs in backward information processing condition (p=0.02) when compared to that of control/basal condition suggestive of left hemisphere lateralisation. The observations of present study agree with the concept of hemispheric encoding/retrieval asymmetry (HERA) postulated and put forward by Tulving et al. (1994) supported by other review article (Nyberg et al., 1996; Schacter et al., 1995; Squire, 1989) as well that advocates the premise of preferential and skewed involvement of left hemisphere in semantic retrieval and encoding whereas right hemisphere seem to be more involved with episodic retrieval.

The visual sensory inputs/information so perceived in form of varied protocols of Delayed Match To Sample task is essentially relayed to primary visual cortex underlying EEG occipital region electrode pairs where information is processed. Primary visual cortex (V17) (Brodmann, 1909) subserves the qualia of perception and visual association areas (V18, 19) (Sherman & Guillery, 2000). Lisman and Jensen (2013) concluded the process of recognition through patterned-matching of gamma burst alpha-theta wave-forms looping (Lisman & Idiart, 1995). The visual inputs as a part of visuo-spatial DMTS are perceived by occipital region and it has been modelled (Desmond et al., 1997; Vanlierde et al., 2003; Babiloni et al., 2005) that such visual impulses are then translated and transmogrified into auditory impulses in differently-abled angular gyrus (anterolateral region of parietal lobe, lies near the superior edge of temporal lobe and immediately posterior to the supramarginal gyrus), a feature that could be observed as increase in amplitude (ERS) of Theta Frequency wave-form in EEG. The visual-auditory interface impulse is then transferred onto Wernicke's area/auditory neural codes (Brodmann area 22, superior temporal gyrus) in order to appreciate and decode semantics of visuo-auditory interface impulse perceived symbols, letters, words and matching sounds accordingly (Bogen & Bogen, 1976; Johns, 2014).

ERS of Theta Wave-Form so evolved by interacting stimulus-locked dedicated neuronal pools with ERD of Alpha wave-form functionally and neurophysiologically representing dedicated reverberating mirror neuronal pool system seems to be representing the working model of Human Memory-Language. It seems that generation of language shapes into virtual phase-space of the human mind through the help of reverberating Lateral Asymmetry of Alpha wave-form ERD, representative of Mirror Neuron System (MNS). Previous studies have reported that Alpha ERD during motor response in a WM task was interpreted as preparation of a movement for a motor task but does not reflect processing for the specific task itself (Deiber et al., 2012; Wianda & Ross, 2019). The alpha ERD in the sensorimotor system may buttress the concept of a preparatory role of alpha ERD. Alpha ERD had been also posited even during anticipation of an event (Bastiaansen et al., 1999 ; Van Ede et al., 2011), again emphasising the role of preparation for a motor response. In this background, the role of alpha ERD could be perceived as developing a preparatory schema intricately interwoven with Mirror Neuron System (MNS) creating and evolving an image (an alter-image in the phase-space of Human Mind) during the encoding ensuing interval. The findings of ERS in theta wave-form with significant change in PSD in select EEG electrode pairs in the present study have also been reported by Kopp et al. (2006) and Payne and Kounios (2009). However, Burke et al. (2013 ; 2014) and Hanslmayr and Staudigl (2014) have documented no changes in theta wave-form PSD during such maneuvers of retention, semantic and backward manipulation and hypothesized that there is contextual overlapping between encoding and retrieval tasks.

It could be concluded that the ERS Theta Frequency wave-form and ERD of Alpha Frequency wave-form seem to evolve an envelope of Working Memory that translates into a comprehensible means of communication, Language. The processing of letters or words in the form of memory inputs give an insight into underlying neuro-physiological processing and neural dynamics responsible for evolution and progression of the evolved phenomena of written and spoken language that make use of semantic and episodic memory. The EEG Power Spectral Densities (PSDs) of alpha frequency band during semantic memory and information processing and PSDs of theta frequency band during episodic memory and information processing that follow separate paths in their nativity could be responsible of holding relevant information across coordinates of space and time and could act as a gateway that forms such a structured and evolved system of communication across space and time, known as language. The above observations create the platform for an integrating function and role of principles of Working Memory in generation and evolution of a synthesised and coordinated communication system as outlined by the structured Language of the Human Mind.

4.2 Arena of Language Acquisition: Probable Neural Substrates and Signature

The major debate regarding neural substrates underlying language acquisition (inclusive of the capacity to detect phonetic distinction and develop language–specific phonetic capacity and acquire legible, valid and comprehensible words) lies in the belief whether nativist (innate rather than acquired) domain–specific dedicated neural mechanism(s) operate exclusively on linguistic data, wherein the neural architecture is decided beforehand for an individual in acquisition of language or general learning mechanism(s) contribute to such an evolved mechanism of spoken and written language. The nativist approach posits the universal capacity to detect differences in phonetic contrasts in all languages. It has further been hypothesised from event related potential (ERP) studies that response profile of human brain in terms of ERPs that are locked in space and time to varied phonetics is a significantly important component contributing to elementary building blocks of language and initial language phonetic learning is a an essential pathway to learning. Hence, it seems that the fine dance of ERS Theta Frequency wave-form observed at temporal EEG lead pair closely looped with LAI of Alpha Frequency wave-form ERD seem to evolve a synthesising envelope of Working Memory that translates into comprehensible means of communication, Language. The theta and alpha frequency wave-forms with the available resources, the interplay between these frequency wave-form, initiates the ground of working memory which is thought to be hitched-hiked onto language acquisition, comprehension and manipulation. The amount of information/memory inputs constraint by quotidian working memory might be utilitarian and can be considered as cynosure for processing and acquisition of language e.g., semantics of letters and words, syntactics of words, word frequency, plausibility, discourse context, intonational information, to name some of the intricate and fascinating nuances.

5. Limitations

The present study had the following limitations:

- The Ag/AgCl surface electrodes might have caused errors during recoding because of movement of electrodes on scalp causing poor signal quality (more noise, poor contact).
- Although efforts were made to minimize the distraction but as the room was not perfectly quiet so it might have distracted the subject during the task creating error in paying consistent attention and sufficient efforts during the performance.
- The Grey, Blue, Red color sequence of presenting the Consonant Letter strings in the DMTS task were not randomized.

6. Future perspectives

The present study provided supporting evidence in favor of use of EEG activity in understanding the language processing. The language processing is a complex phenomena and use of different EEG frequency bands, ERD/ERS and event related potentials could help in deciphering this mechanism. Further neurophysiological studies are required to understand the development and comprehension of language in human beings and the simultaneous neuronal processes engaged in memory encoding, retrieval and attentional mechanism.

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