Chapter

Language as the Working Model of Human Mind

Amitabh Dube, Umesh Kumar, Kapil Gupta, Jitendra Gupta, Bhoopendra Patel, Sanjay Kumar Singhal, Kavita Yadav, Lubaina Jetaji and Shubha Dube

Abstract

The Human Mind, functional aspect of *Human Brain*, has been envisaged to be working on the tenets of *Chaos*, *a seeming order within a disorder*, the premise of *Universe*. The armamentarium of *Human Mind* makes use of distributed neuronal networks sub-serving *Sensorial Mechanisms, Mirror Neurone System (MNS)* and *Motor Mechanisms* etching a stochastic trajectory on the virtual phase-space of *Human Mind*, obeying the ethos of *Chaos*. The informational *sensorial mechanisms* recruit *attentional mechanisms* channelising through the window of chaotic neural dynamics onto *MNS* that providing *algorithmic image information flow along virtual phase- space coordinates* concluding onto *motor mechanisms* that generates and mirrors a *stimulus- specific and stimulus-adequate response*. The singularity of self-iterating fractal architectonics of *Event-Related Synchrony (ERS)*, a *Power Spectral Density (PSD)* precept of *electroencephalographic (EEG) time-series* denotes preferential and categorical *inhibition gateway* and an *Event-Related Desynchrony (ERD)* represents event related and locked gateway to stimulatory/excitatory neuronal architectonics leading to stimulus-locked and adequate neural response. The contextual inference in relation to *stochastic phase-space trajectory of self- iterating fractal of Off-Center* α *ERS (Central)-On-Surround* α *ERD-On Surround* θ *ERS* document efficient *neural dynamics of working memory.*, across patterned modulation and flow of the neurally coded information.

Keywords: Human Mind, Chaos, Stochastic Trajectory, Mirror Neurone System, Neural Dynamics, Electroencephalograph (EEG), Event Related Synchronisation (ERS)/Desynchronisation (ERD)

1. The multi-dimensional hierarchy of organisational levels in brain

Brains are characterised by every property that engineers and computer scientists detest and avoid. They are **chaotic, unstable, nonlinear, non-stationary, non-Gaussian, asynchronous, noisy, and unpredictable in fine grain**, yet undeniably they are among the most successful devices that a billion years of evolution has produced. **Brain systems** operate on many levels of organisation, *microscopic, mesoscopic and macroscopic*, each with its scales of time and space. **Dynamics**, the modelling of change, is applicable to every level, from the atomic to the molecular, and from macromolecular organelles to the neurones into which they are

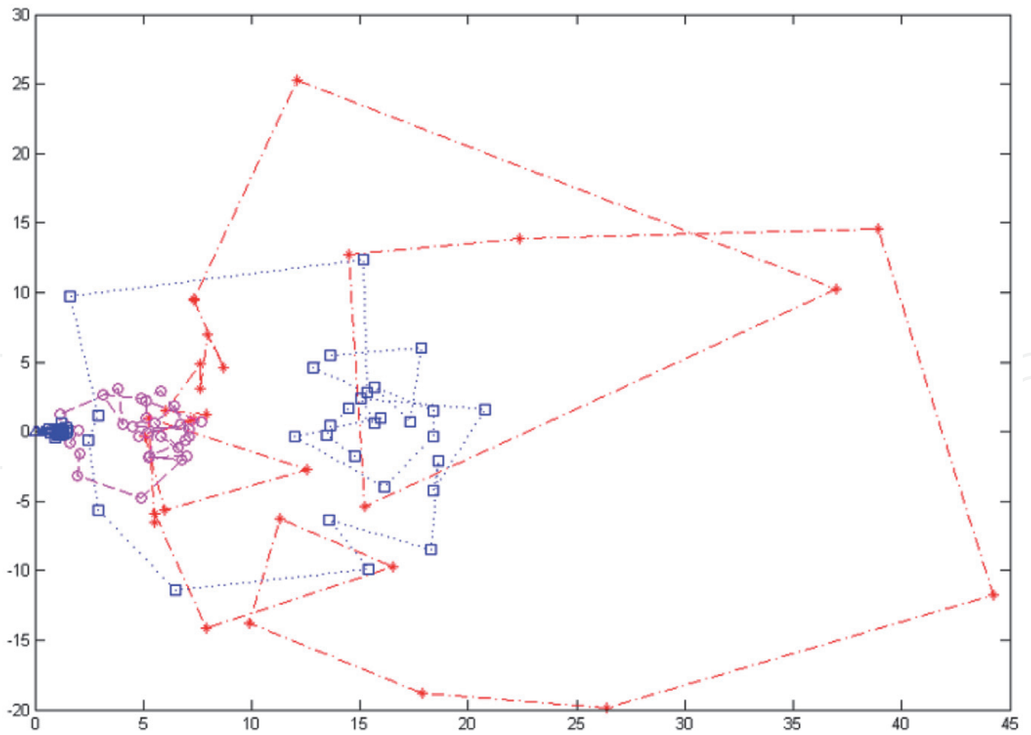

Figure 1.
Hilbert transform of EEG lead pair across EEG lead pair for EEG frequency-waveform bands of δ, θ, α, β, γ representing the stochastic trajectory of neural dynamics in real-time.

incorporated. In turn the **neurones** form populations, these form the sub-assemblies of brains, and so on up to embodied brains interacting purposively with the material, interpersonal, and politico-social environments.

Subsequently, the ***mesoscopic* level**, very aptly characterised by ***nonlinear dynamical electroencephalographic (EEG) electrical activity*** [1], seems to be the optimally suited substratum of interplay of neuronal discharge and its patterning, that seems to have been very beautifully and intelligently decrypted and decoded through the armamentarium of **digital biological signal processing across *linear (relative and absolute power spectral densities, coherence and others)* and *non-linear classifiers (entropy, fractal dimensions and others)*.**

The varied discrete and quantal features of *Human Brain* working and co-opting, in tandem and in sync, across the dimensions and coordinates of space and time evolve into the *phase-space stochastic trajectory of* abstruse and arcane domain of *the Human Mind* observing the principles of *non-linear dynamics of Chaos [2]*. The human brain provides the scaffold and framework for the functional dynamics of human mind in real time [3] following the principles of *Chaos*, further documented by our centre in 2009 [4] (**Figure** 1).

Carl Jung has very aptly outlined the schema *as "In All Chaos There is A Cosmos, In All Disorder A Secret Order"*. The *Secret Order* as has been exemplified by Carl Jung forms the nidus to explore further the realms of *Chaos*.

2. The working of the human brain

The *Human Brain* communicates and interfaces through electrical and chemical processes in a *fractal* and *self-iterating fashion*. The neurones fire at a rate of 5–50/second through *integrate-and-fire neurones and resonate and fire neurones* with a summated thought-processing time of around 329 milliseconds [5].

3. Neurotransmitters

The chemicals deployed by the *Human Brain* involve *neurotransmitters, neurohormones, neuropeptides, neuromodulators inclusive of dopamine, serotonin, acetylcholine, gamma aminobutyric acid (GABA), glutamate, glycine, adenosine triphosphate (ATP)* to name some of the chemicals. The neurotransmitters seem to be the key to functioning and influencing the neurophysiology of the *Human Brain* and are diffusely distributed with selective cerebral predominances responsible for the genesis of a select personality-trait brain waves and rhythms. The precursors to the *neurotransmitters, amino acids*, are readily available in the diet and the *diet* (and its interaction with the specific metabolic patterning of an individual) *determines the persona/qualia* of an individual.

4. The rigid versus distributed functional patterning

- **The Frontal Lobe** has a dominance of **dopamine** and is responsible for the generation of **β**, **beta-rhythm** that represents the state of alertness in an individual,

- **The Prefrontal Lobe** being the site of spiritual experience and consciousness generates the fast brain waves of **γ**, **gamma-rhythm** (with frequency of more than 30/second) through the action of **glutamate** neurotransmitter that excites the fast inhibitory synapses interconnecting inhibitory neurones [6].

- **The Parietal Lobe** has a dominance of **acetylcholine** that engenders the **α**, **alpha-waves**,

- **The Occipital Lobe** with the dominance of the neurotransmitter **serotonin** induces **δ**, **delta-waves** of sleep and memory consolidation and

- **The Temporal Lobe** does the overall function of a tranquilliser and/or analgesic through the help of **GABA** inducing **θ**, **theta wave** pattern along the human mental phase-space.

However, the modular aspect of the *Human Brain* with rigid configurations (as proposed by *Cajal* way back in 1913) has given way to the model of distributed neuronal networks that has resilience and the capacity to adjust and be flexible to the demands of internal and external milieu, wherein the mind-set with positivity influences and modulates the distributed neuronal pools and networks evolving the cognitive abilities of an individual.

A subtle and perceptible paradigm shift has been witnessed across the frontiers of *Neurosciences and Neurology* wherein **the *Human Mind*, once thought to be working along the framework of modular architectonics**, is now envisaged to be traversing the alleyway along the distributed neuronal pools conjuring onto **dedicated and apportioned networks** that have the ability and the interface to **crosstalk**.

The building block scaffold of the respective dedicated neuronal pools is the archetypal *neurone* that has the endowed potential to respond in a ***space and time coordinate-locked precept of action potential, the espoused all-or-none phenomenon*** that incidentally happens to be the singular canonical principle of functional neurones. The armamentarium of neuronal language evolved through the presence and/or absence of *action potential all-or-none phenomena* along with **differential**

neuronal architectonics processing inclusive of serial, parallel, divergent, convergent, reverberating along with inter-neuronal reverberations [7].

The unitary and singular neuronal tenet got segregated through the remarkable neurophysiological characteristic of ***learning*** **into dedicated neuronal pools** that became functionally conspicuous and perceptible as ***sensory, mirror, motor and interneurones***. Such dedicated neuronal pools then evolved the distinctive patterned waveforms as evinced through electroencephalographic (EEG) signals [8] of *theta (**θ**), delta (**δ**), alpha (**α**), beta (**β**) and gamma (**α**) waves* and **such distributed neuronal pools** then evolved discrete neurodynamical phenomena of

- *Event-Related Desynchrony (ERD) [evinced as decrease in Power Spectral Density (PSD)]* and
- *Event-Related Synchrony (ERS) [an increase in PSD]* in respective wave-forms bands.

5. The human mind

The *Human Mind* is the neurophysiological precept that tends to amalgamate the ***Triune Brain Complex*** through the distributed electro-chemical neural circuitry that follow the non-linear chaotic neural dynamics simulating the principles of Chaos in Nature [9]. ***The primacy and singularity of chaos and chaotic systems (Complex Dynamic Systems)*** *depict* ***behaviours of determinism, paradox, self – generation, self – iteration, self – organisation, intrinsic unpredictability within the confines of the defined geometry across space – time*** *that is sustained by the complex feedback loops. The qualia of chaotic systems include the* ***sensitivity to initial conditions*** *with* ***disproportionate responsiveness to stimuli****, the translatability from micro-through mesoscopic and macroscopic proportions, and the* ***attractor-centring that is shuffled across space – time*** *and is apparently a – causal (enfolded; implicate/explicate), global singularity and is flexible and amenable to creation.* ***The Strange Attractor-Centred Stochastic Trajectory*** *so evolved through the* ***neuronal oscillations*** [4, 10] that sublimes the awe and grandeur of *Human Mind* seems to be the gateway and/or portal to flow of information that is legible, reproducible and stands the vagaries and vicissitudes of the flow of space and time.

In this backdrop and the chance brush and close encounter with *Chaotic Nonlinear Neural Dynamics of Human Mind* [4], our centre came across the novel finding of ***Dysfunctional Mirror Neurone System*** *['Broken Mirrors' of Professor V. S. Ramachandran and Oberman [11]]* in children with *Attention Deficit Hyperactivity Disorder (ADHD)*, a disorder of social intelligence, an antecedent sequel to '*Broken Mirrors*', that was neurodynamically represented as the phenomenon of *Event-Related Synchrony (ERS) of mu rhythm (alpha waveform along somatosensory EEG lead pairs)* [12]) when the ADHD participant children aped and imitated the action protocol of hyperventilation, while an *Event-Related Desynchrony (ERD)* was observed in the similar rhythm of *mu waveform* in EEG lead pairs of normal control children.

The *Human Mind* replicates the transmutation and metamorphosis of the non-linear dynamics of chaos wherein a fine interplay between matter and energy takes place, i.e., the abstruse versus the intangible with quantum shift being appreciated through the perturbations of space–time synthesising *sensory–mirror–motor neurones–cognition* tangible precepts plunging along the ethos and tenor of chaos, journeying to the most fundamental or primal state of consciousness – Chaos, when

shift in primal image of self becomes possible through its de-structured nature in entirety. In this qualified state of Chaos, the Human Mind evolves onto a rhythm/pattern that seems to be reverberating with Cosmic Consciousness.

It is conceivable that the sensorial stimulus evinces a characteristic ***event/stimulus-related synchrony (ERS)* of *theta (θ) wave-form*** reflective of an antecedent and incidental entrainment of ***attentional neuronal mechanistic resources*** that seemingly feeds onto and opens the portal of the algorithmic flow of *mirror neurone system arsenal through means of* ***event/stimulus-related desynchrony (ERD) of alpha (α) wave-form*** *that seems to feed onto the* ***motor neuronal system*** *responding through ERD to effect a cogent, logical and stimulus/event-locked response.* Such a model of intricate dance of ***event/stimulus-related synchrony (ERS)* of *theta (θ) waveform*** *and* ***event/stimulus-related desynchrony (ERD) of alpha (α) wave-form*** [13, 14] has been hypothesised to be the mainstay of the working *Human Mind*.

The *Human Mind* is conceived as an entity forming the functional singularity of *Human Brain* that evolves through the integration of *quantum mechanics of wave-particle espousing the inter-convertibility of mass into energy waveform and vice versa, the Higgs Boson being the interface and the amalgamating particle.*

A set of neuronal pools, *referred to as fractals with the inherent capability of self-organising and self-iterating,* are recruited to sub-serve a distinct selected function limited by the coordinates of space–time with a time decay of 2–3 seconds recouped and retrieved by another set of neuronal pools observing similar fractal neurodynamical dimensions of synced *ERD* and *ERS*. The set of neuronal pools that evolve during the course of time rhyme and oscillate with a specific wave-pattern that is construed and translated onto the *stochastic phase-space trajectory with the strange attractor* specific for the function being attended to silhouetting and profiling the *Human Mind*.

Taking the analogy further, *Cosmic Consciousness* seem to be the predicate of *mass-energy wave-form interface* as exemplified by the *God particle, Higgs Boson*. The effervescent and evolving Human Mind works on the same principle of Cosmos with a tendency to cohere and sync with the flow of Cosmic Consciousness.

6. The working model of language

The working of *Human Mind along with its functional and morphological correlates* has been an arena that has overwhelmed and beguiled mankind since times immemorial.

The Neurophysiologists and Cognitive Neuroscientists have resorted varied procedures, both non – invasive and invasive, to gain an insight and to reveal the mystics of *working human mind*, wherein *Electroencephalography (EEG)* and *Event Related Potentials (ERPs)* [15–17] provide the desired armamentarium to record underlying neural dynamics of human mind in real – time, through precepts of flow of space and time namely, amplitude and latency, respectively, that are time-locked to specific sensory, motor and/or cognitive modalities of stimuli [18].

EEG and ERPs seem to be the tools with temporal precision but poor spatial localisation for appreciation of underlying neuronal dedicated networks and their dynamics for various higher mental and cognitive functions to identify, isolate and register across space – time, the physical qualia of the stimulus (features detection, the so-called feature-detectors). The neural dynamics of working memory have been envisaged to be funnelled onto the 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 [19–22].

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 the underlying neural mechanisms of human brain and its correlation with the *phenomenon of the means of communication, that is* **Language**.

7. The ontogeny of language: The piggyback ride of working memory

At birth young infants exhibit a universal capacity to detect differences between phonetic contrasts used in world's language [23]. The mother (or father) has to entrain the attentional mechanisms of the child through *Social Gaze* with subsequent motherese (or fatherse or parentese), a form of language that involves lot of changes in pitch, is melodious and repetitive. *Social Gaze or Eye Contact* with the mother forms the essence or pre-requisite of genesis of language, wherein the *vowels* (and that too the *extremes of vowels, i.e., 'a' and 'o' 'u'*) precede *consonants* for the mere fact that lips movements is maximal for vowels and due to the simplified mechanism(s) that underlie the *neurolinguistics* of vowel. The language development or transition of the human mind onto the axes of language has been hypothesised to take place along two neural phases, namely *Phase I* and *Phase II.*

7.1 Phase I (neurodynamical phase)

The neurodynamical phase also known as the ***general open-system*** is uncommitted and open to change and plasticity and is the phase where priming of the human mind takes place. The universal capacity of the human mind is dramatically altered by the language experience starting as early as 6 months for *vowels (a, e, i, o, u)* and by 10 months for *consonants*. The *extremes of vowels, namely 'a', 'o' and 'u'* involve maximal movements of the lips that the child gets enamoured through the mental landscape so formed by the stochastic trajectory initiated in the *Phase-Space of Human Mind* by the system of *Mirror Neurones.*

7.2 Phase II (linguistic phase)

It represents the language specific phase wherein the human mind becomes committed to the specific language that is being acquired and usually starts from end of the first year of life. Neural oscillations across the coordinates of time (brainwaves), within individual neurones or through interactions among neurones, *are rhythmic or repetitive patterns of neural activity of the central nervous system* and *such patterned neural dynamics signify and describes the respective neurophysiological functional characteristics*. The techniques of *Biological Signal Processing (BSP)* have been employed to classify and categorise EEG signals through linear domain of power spectral density (PSD), linear discriminant analysis (LDA) and varied non – linear domains of neural networks.

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 neurone system (MNS) and *synaptic neuroplasticity*. *MNS* plays a pivotal role and is considered to be an interface between the qualia of sensorium and motor system of the intricately woven *Human Mind*, wherein activation of *Mirror Neurone System* initiates the process of image formation in the virtual phase-space trajectory of 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 (WM)*, *the primacy of emergent Human Mind* [24], for *Encoding, Registration and Retrieval of Memory* [25, 26] inputs has been postulated to be served by *three EEG Wave-Forms Complex of Theta* [27, 28], *Alpha and Gamma frequency bands* [10] with a bootstrapping blueprint wherein the ***gamma wave-forms or bursts hitchhike or piggy back rides the theta wave responsible for feature detection*** **along with *alpha-theta wave-form*** *that coincidentally allocates* ***attentional resources*** *onto the evolved dedicated neuronal circuitry that are stimulus-specific* [29, 30]. 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** [31]. 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* [32].

It has been envisioned that,

- ERS in θ, theta frequency waveform is related to encoding and retrieval of episodic or new information, and

- ERD in α, alpha frequency waveform is related to encoding and processing of semantic information [29, 30, 33–37].

Pfurtscheller and Klimesch [38], Pfurtscheller and Aranibar [39] and Pfurtscheller and Lopes da Silva [40] had reported that during visual stimulation **alpha wave-form desynchronises** giving rise to ***ERD*** **over occipital recording sites** whereas **over motor cortex synchrony in form of *ERS*** could be observed. Sauseng et al. [41], [42] put forward the observation of **change in *PSD of alpha wave-form*** **that is observed at the occipital and pre-frontal areas during *top-down processing*** *in a working memory task*, wherein a ***decrease in alpha PSD power at occipital site*** with a **consequential *increased alpha PSD power is observed at prefrontal EEG electrode site*. The *ERD quantum*** **of alpha frequency wave-form during encoding** in a visual working memory task has been correlated with the memory load ([29, 30, 33–36]).

However, [43] reported that the processing of working memory of **encoding and retention involves the oscillatory activities along multiple frequency bands of EEG wave forms inclusive of *alpha frequency*** *as well* through local and long-range neural networks proposing the existence of **multiple parallel functional mechanisms of alpha oscillations** [44]. In this context of equivocal representation of alpha oscillations, it would be interesting to examine changes in alpha oscillations pattern that could be sensitive and characteristic to working memory task.

The observation documented from our laboratory of ***theta wave form band synchrony*****, known as *Event-Related Synchrony (ERS)*** **mirroring increased *PSD,*** across distributed range of task relevant areas of brain namely,

- ***The Retention Function*** being primarily centred along select frontal and temporal areas,

- ***The Semantic Manipulation*** *along select frontal, temporal and parietal* with

- ***The Backward Manipulation*** involving frontal, central and temporal areas [*Neuropsychological Trends* in print] during working memory task of

registration, retention and retrieval processing is reflective of dynamical linking, an observation that had been documented by EEG studies of [41, 42, 45] as well, though [46–48] could not appreciate such breakthrough linkage (**Figure 2**).

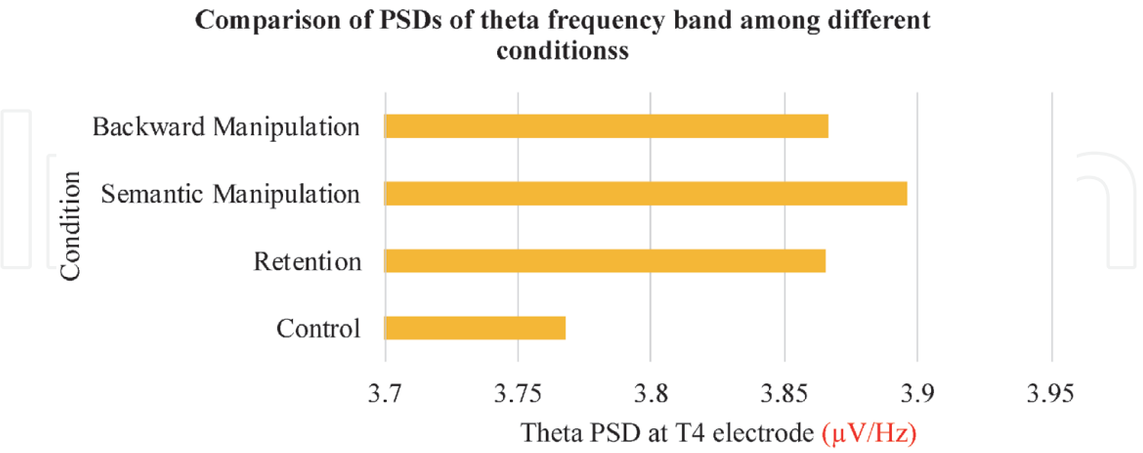

Figure 2.
Power spectral densities (PSDs) of theta frequency wave form in three memory conditions of retention, semantic manipulation and backward manipulation with raw EEG data being processed through BESS software where epochs (epoch length = 1000 ms) were separated for each trial [54 trials being part of delayed-match-to-sample (DMTS) task] and data was averaged separately respectively for each electrode for each condition (FP1, FP2, F7, F3, AFz, Fz, F4, F8, T3, C3, Cz, C4, T4, P7, P3, Pz, P4, P8, O1, O2 electrodes were selected). 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.

The assessment of power-spectral density of EEG signals from our laboratory paved the way for appreciation of closely intertwined intricate dance of *ERS/ERD along the coordinates of space and time that probably seems to be the flip-flop switch for the flow of corporeal and legible information* (**Figure 3**) [49]. The ERS of theta wave-form with significantly appreciable change in Power Spectral Density (PSD) at EEG electrode pair of T4 (**Figure 1**) along with concomitant ERD of alpha wave form skewing onto left hemisphere lateralisation of neurophysiological processes [as exemplified by Oblique Lateral Asymmetry Index (LAI)] during the select conditions of retention, semantic manipulation and backward manipulation (**Figure 2**) is yet another example of concomitant stimulatory and inhibitory dedicated neuronal pools that evolve during and are responsible for the stimulus-specific adequate response. More likely, the looped fractals of neuronal pools (modules) of on-centre ERS theta wave form, on-centre ERD alpha and offsurround ERS alpha or off-centre ERS alpha and onsurround ERD alpha have a tendency to self-iterate that tends to etch the stochastic trajectory along the Human Mind Phase-Space.

The characteristic of temporal distribution of *ERS/ERD PSD* along the run of EEG time-series was evaluated in our laboratory and during the **DMTS task**, **the temporal distribution across *two frequency bands of theta and alpha*** was accessed to assess neuronal oscillatory activities during **WM tasks** across select cortical regions [50–52] and to assess modular memory facets and processes that entrain dedicated self-iterating fractals of neuronal pools in human brain resulting in memory consolidation processes concluding into **language acquisition, manipulation and comprehension processes.**

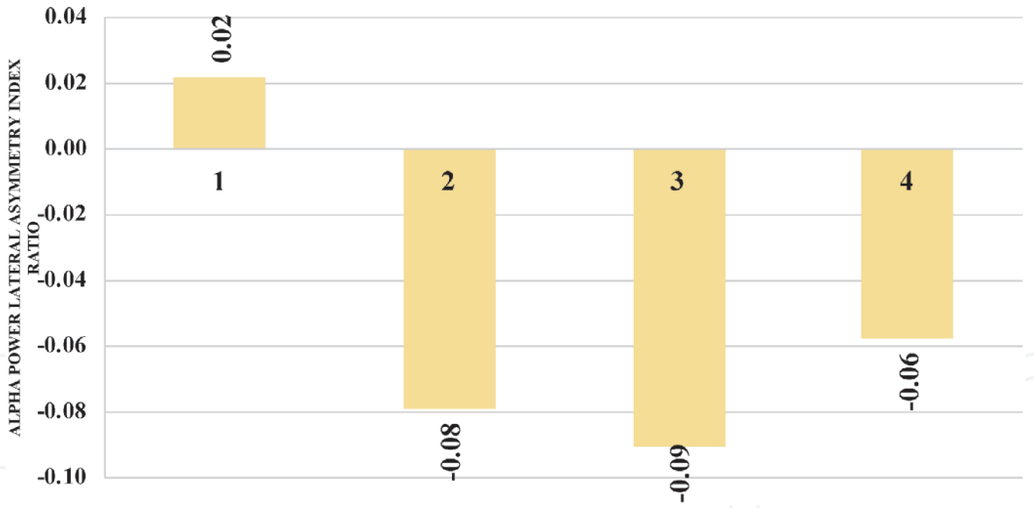

Figure 3.
Portrays Lateral Asymmetry Index (LAI) ratio of different conditions of Alpha Frequency Band at P3-P4 EEG electrode site. Significant difference could be appreciated at parietal region of P3-P4 EEG electrode pair along alpha frequency band using T-test with p = 0.004, p=0.002 (p < 0.05) at 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 lateralisation. 1 = Control Condition, 2 = RetentionCondition, 3 = Semantic Condition, 4 = Backward Condition. LAI = [P (left) - P (right)]/[P (left) + p (right)].

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.

Figures 4 and **5** depicts *ERD/ERS percentage change {ERD% = (Actual Power-Reference Power)/Reference Power × 100} of Power Spectral Densities of Alpha frequency wave form* when compared among male and females in *Retention Condition* where significant difference could be seen at CZ, P8, T4 electrode sites and **Figure** 5 displays results of *ERD/ERS alpha activity in Semantic Condition*, exhibiting significant differences along CZ, P4, T4 EEG electrode sites. The common denominator appreciates the intricate interwoven ***Off-Centre α ERS (Central)-On-Surround α ERD Neural Dynamics*** as could be deduced and envisioned from observations of **Figures 4** and **5** that seem to be intertwined and interlocked through observations of findings of **Figures 2** and **3**, with the self-iterating trajectorial pathways of the

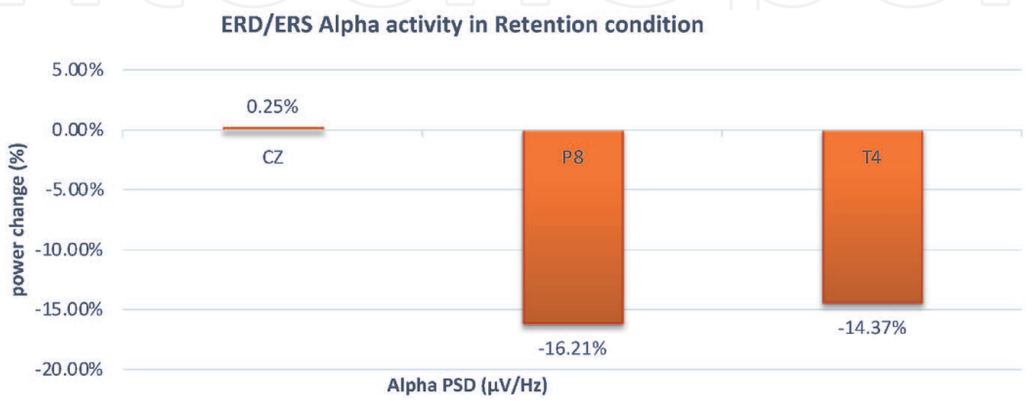

Figure 4.
Depicts ERD/ERS percentage change [ERD% = (Actual Power-Reference Power)/Reference Power × 100] of Power Spectral Densities of Alpha frequency wave form when compared among males and females in Retention Condition where significant difference could be observed at CZ, P8 and T4 EEG electrode sites.

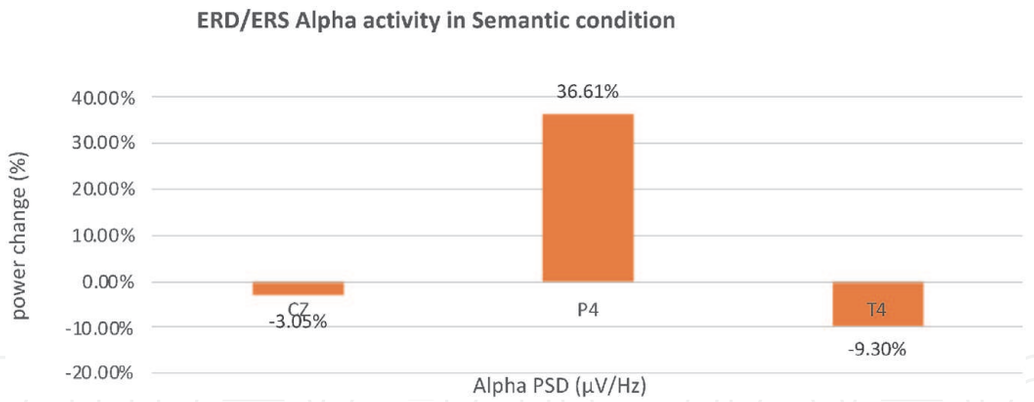

Figure 5.
Illustrates ERD/ERS percentage change {ERD% = (Actual Power-Reference Power)/Reference Power × 100} of Power Spectral Densities of Alpha frequency wave form when compared among male and females in Retention Condition where significant difference could be seen along CZ, P4, T4 EEG electrode sites.

looped alpha and theta wave forms through respective precepts of Event-Related Synchrony (ERS) and Event-Related Desynchrony (ERD).

In this context and with the characteristically patterned observations data from the present study [*Neuropsychological Trends* in print] the precepts of *Neural Dynamics of Working Memory Model* has been conceptualised as:

- **The Retention** Precept singularly involves Theta ERS along temporal regions with antecedent etched LAI (Lateral Asymmetry Index) Alpha ERD along fractal neuronal networks of parietal region.

- **The Semantic (Forward) Processing** appreciating the relevance of ascendance (increasing quantal framework) observes a similar patterned and looped Theta ERS (temporal region) with LAI Alpha ERD along parietal regional precept of fractal neuronal networks.

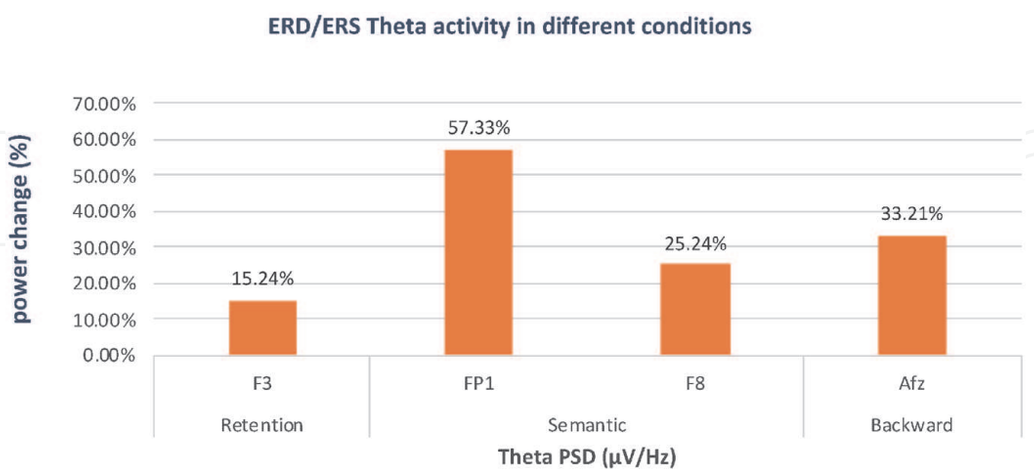

Figure 6.
ERD/ERS percentage change of Power Spectral Densities (PSDs)of Theta frequency wave form when compared among male and females in all the three conditions where significant difference could be appreciated at F3 in Retention condition; at FP1,F8 in Semantic manipulation condition and at AFz in Backward manipulation condition and results could reflect same as Alpha frequency wave form that females outperformed in the visuo-spatial DMTS task compared to males using T-test at 5% confidence level. The contextual inference from the present study in relation to the above stochastic phase-space trajectory of ***Off-Centre α ERS (Central)-On-Surround α ERD-On Surround θ ERS*** *document a significantly enhanced PSD values of said trajectorial path in females as compared to that observed in males, endowing the female gender with neurophysiologically efficient neural dynamics of working memory.*

- **The *Backward Processing*** *in Memory warrants a similar Theta ERS-LAI Alpha ERD looping along temporal and parietal region (with additional inputs from parietal areas).*

The hypothesis posited is that the concept of *Neural Dynamics of Working Memory Model* reflects as under:

- *The Theta Frequency Wave-Form ERS along temporal region* with concomitant and antecedent *LAI Alpha Frequency wave-form ERD along parietal terrain* characterise the ***Retention and Semantic Forward Information Processing*** *Precepts* and

- ***The Backward Information Processing Precept*** exemplified through *Theta Frequency Waveform ERS along temporal area* with concomitant and antecedent *LAI of Alpha Frequency Waveform ERD along extended parietal region* (**Figure 6**). The contextual inference from the present study (refer **Figures 1–6**) in relation to the above stochastic phase-space trajectory of ***Off-Center α ERS (Central)-On-Surround α ERD-On Surround θ ERS*** *document* a significantly enhanced PSD values of said trajectorial path in females as compared to that observed in males, endowing the female gender with neurophysiologically efficient *neural dynamics* of working memory.

It seems that there are two aspects of processing of LTM in terms of mean PSD and LAI along theta and alpha frequency waveforms.

- ***The Skewed Theta frequency waveform ERS along right temporal region*** **during** ***retention, semantic forward information processing and backward information processing conditions*** along with

- The Alpha frequency waveform ERD with Lateral Asymmetry Index spreading through parietal region during retention and semantic forward information processing conditionis suggestive of *laterality restricted looping of ERS-ERD console within the left hemisphere*.

The precept of ***Hemispheric Encoding/Retrieval Asymmetry (HERA)*** so documented had been first hypothesised by Tulving et al. [53] supported by Nyberg et al. [54] as well that advocates the premise of **preferential and skewed involvement of left hemisphere in semantic (algorithmic non-linear neural information flow) retrieval and encoding** whereas **right hemisphere seems to be more involved with the episodic retrieval.**

The visual sensory inputs/information so perceived in the form of varied protocols of ***Delayed Matched to Sample Task (DMTS)*** is essentially relayed to primary visual cortex underlying EEG occipital region electrode pairs where information is processed. Primary visual cortex (V17) [55] subserves the qualia of perception and visual association areas (V18, 19) [56]. [57] concluded **the process of recognition through *patterned-matching of the gamma-burst, alpha-theta waveforms looping or the bootstrapping (piggy-back riding) of gamma burst onto alpha-theta combine waveforms*.** The visual inputs as a part of visuo-spatial *DMTS* are perceived by occipital region and it has been modelled [58] that such visual impulses are then translated and transmogrified into auditory impulses in the differently-abled angular gyrus (anterolateral region of parietal lobe, near the superior edge of temporal lobe and immediately posterior to the supramarginal gyrus), a feature that could be observed as *increase in the 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 the semantics of visuo-auditory interface impulse perceived as symbols, letters, words and matching sounds accordingly [59].

ERS of Theta Waveform so evolved by interacting stimulus-locked dedicated neuronal pools *with* ***ERD of Alpha waveform functionally and neurophysiologically representing the dedicated reverberating mirror neuronal pool*** *system seems to be representing* ***the working model of Human Memory-Language****.* It seems that the generation of language shapes into the virtual stochastic phase-space of human mind through the help of **reverberating Lateral Asymmetry of *Alpha wave-form ERD, representative of Mirror Neurone System (MNS)***. Previous studies have reported that *Alpha ERD during motor response in a WM task has been interpreted as the preparation of a movement-specific motor task* but does not reflect processing for the specific task itself [43, 60]. 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 [61], 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 the Mirror Neurone System (MNS) creating and evolving an image (an alter-image in the stochastic phase-space of Human Mind)* during the ensuing encoding interval.

The findings of ***ERS in theta wave-form*** *with a significant change in PSD along select EEG electrode pairs a recent study from our laboratory* have also been reported by [62, 63], though Burke et al. [21] and [46, 47] could not observe such a patterned and locked differential EEG theta wave-form PSD during the manoeuvres of retention, semantic and backward manipulation and hypothesised a possibility of contextual overlapping between encoding and retrieval tasks.

The above documentation of ***ERS Theta Frequency waveform bootstrapping*** *with concomitant* ***ERD of Alpha Frequency waveform*** *seem to evolve an envelope of Working Memory that translates into a comprehensible means of communication, Language.* The interplay between these frequency wave-form forms the ground of working memory which is thought to be an important constituent component instrumental in language acquisition, comprehension and manipulation. The amount of information/memory inputs restricted by day-to-day working memory might be useful and can be considered as the focus for processing and acquisition of language e.g., semantics of letters and words (positioning and placement), syntactics of words (reproducible neurodynamically grammatically cogent disposition/sequence), word frequency, plausibility, discourse context, intonational information, etc.

The processing of letters or words in the form of memory inputs give an insight into the underlying neuro-physiological processing and neural dynamics responsible for the 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 *the* ***PSDs of theta frequency band during episodic memory and information processing*** that follow separate paths in their nativity could be responsible for holding relevant information across coordinates of space and time (freezing the flow of space and time in the process) providing a gateway for synthesis of a structured and evolved system of communication, 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 Human Mind.*

8. The 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 if 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 ERP studies that the response profile of *Human Mind* 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 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 waveforms* with the available resources, the interplay between these frequency waveforms, initiate the ground of working memory which seemingly is hitched-hiked onto **language acquisition, comprehension and manipulation**. The dynamical power spectral interplay of *theta and alpha frequency waveforms* along the coordinates of space and time during the *Working Memory* tasks of *retention, semantic (forward processing) and backward processing* seem to form the *gateway of primacy* opening the portal of algorithmic flow of neural information so needed for the neurocognitive primacy of language. 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.

Subsequently, it is conceived that self-iterating fractal of interacting *ERD* and *ERS* through respective frequency waveforms *theta (θ)* and *alpha (**α**) waveforms* is construed with θ*waveform band singularity of ERS* across frontal and midline regions with antecedent **α***ERD* across respective mirror neurone system domain along with**α***ERS* at central region. The singularity of *ERS* denotes a preferential and categorical *inhibition gateway* and an *ERD* represents an event related and locked gateway to stimulatory/excitatory neuronal architectonics presumably responsible for *stimulus-locked and adequate neural response*. The fine and intricate interplay of θ *ERS (frontal and midline areas fine-tuned excitation)*, **α** *ERD (parietal and temporal floral activation) and* **α** *ERS (central selective inhibition)* evolves the self-evolving florid landscape of an **ERD on-centre and ERS off-surround loci along with an ERS off-centre and ERD on-surround**. The evolution of *frontal and midline excitatory* θ *ERS* along stochastic phase-space trajectory is a reflection of an evolving *fractal self-iterating excitatory gateway with antecedent fine-tuned channelisation of attentional mechanisms onto the stimulus/event restricting extraneous interfering neural mechanisms in the process*. The florid **α** *ERD* is representative of an evolving *excitatory stochastic phase-space trajectory dynamically mirroring the functional Mirror Neurone System (MNS)* responsible for algorithmic information flow onto subsequent *MNS* along with antecedent *central selective inhibition through* **α** *ERS inhibiting interfering contrivances (an example of* **α** *ERS Off-Centre with* **α** *ERD on-surround with*

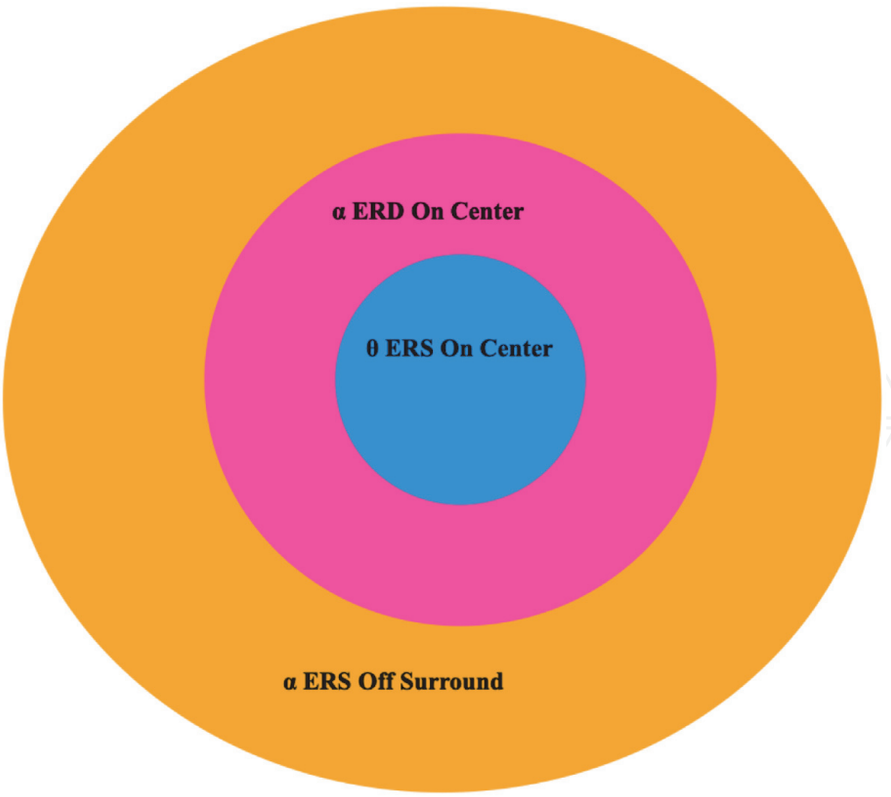

Figure 7.
The theta (θ) ERD on centre, alpha (α) ERD on centre and alpha (α) ERS off surround model.

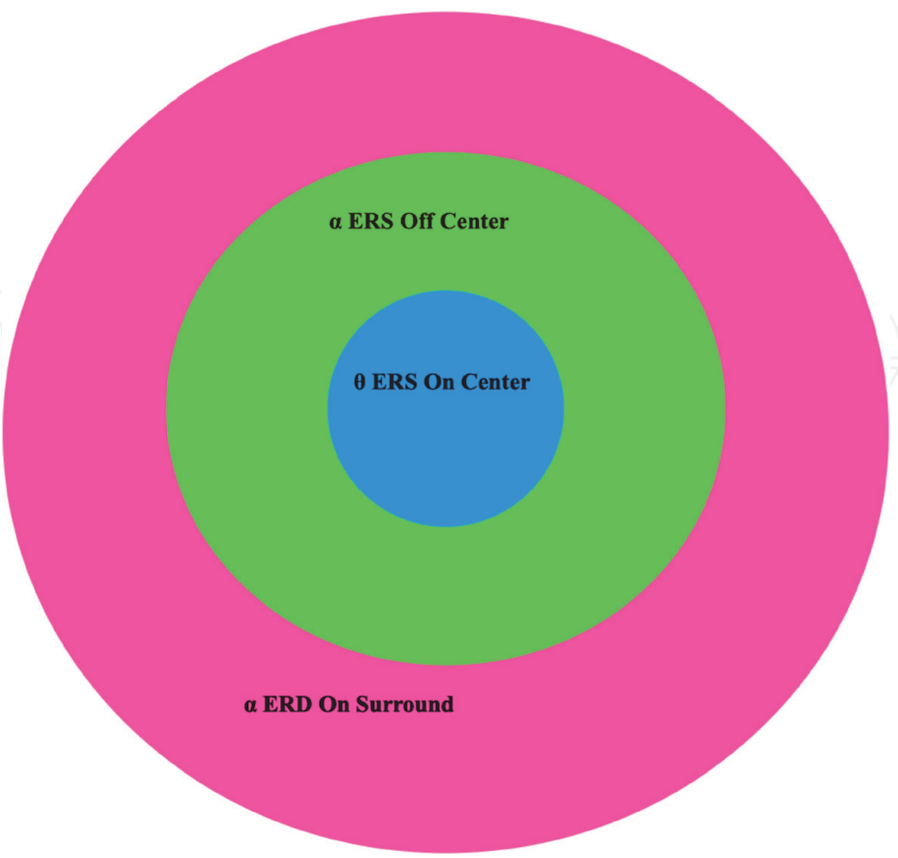

Figure 8.
The theta (θ) ERS on centre, alpha (α) ERS off centre and alpha (α) ERD on surround model.

θ *ERS on-surround).* These self-iterating fractal architectonics of *central inhibitory, Off-Centre* **α** *ERS, surround excitatory on-surround* **α** *ERD and on surround* θ *ERS,* representative of *interwoven PSD singular* ***Off-Centre α ERS (Central)-On-Surround α ERD-On Surround θ ERS*** *phenomenology* seem to define the qualia and quanta of underlying neural mechanisms of *working memory* (**Figure 7**).

The contextual inference in relation to *stochastic phase-space trajectory of* ***Off-Centre α ERS (Central)-On-Surround α ERD-On Surround θ ERS*** document a neurophysiologically efficient *neural dynamics of working memory* (**Figure 8**) [49].

The above model envisages a self-iterating fractal of *θ ERS On-Centre along with α ERD On-Centre and α ERS Off-Surround* mirrored along *θ ERS On-Centre, α ERS Off-Centre and α ERSD On-Surround, the so-called EEG micro states that tend to oscillate through the execution of the respective cognitive manoeuvre and these self-iterating fractals of lateral asymmetry index (LAI) of alpha (α) ERD and ERS along with theta (θ) ERS tend to open the gateway/portal of effective cognitive network.*

In this connectome, the *Human Mind* is envisaged as an esoteric concept that probably represents a logical synthesis of functional *mass* and *energy*, so represented by the characteristically patterned modulation and flow of the neurally coded information.

The Model of Algorithmic Flow of Neural Information

θ (Theta) ERS Phenomenology Underscore Underlying Attentional Recruitment Mechanisms

↓↓

Funnelling of Neural Dynamics and Reverberating θ (Theta) ERS Phenomenology Initiates/Opens Gateway/Portal to

↓↓

- Start of α (Alpha)/μ (Mu) Rhythm Neural Dynamics: Mirror Neurone System (MNS) Activation
- Start of α ERS Neural Dynamics: Inhibitory Background Noise

↓↓

Activated MNS with Fine-Tuned Background Milieu/Comrasting Dynamical Firing

↓↓

Algorithmic Flow of Neural Information through Muscle Effector System Inclusive Of Its Constituent Paired Variables Responsible For Stimulus Adequate Response i.e., Flexors/Extensors, Abductors/Adductors, Rotators (Internal and External

↓↓

- Respective Muscle Types Involved and Their Contribution
- Mirror Involvement of Agonist/Antagonist Paired Muscles

In conclusion, the neural architectonics subserving *language* seem to evolve across the self-iterating fractal features of phenomenology of *on-centre/off surround and off centre/off surround of ERD and ERS represented through electroencephalographic frequency waveforms of* θ*ERS,* α*ERD and* α*ERS* that synthesise and evolve the fine-tuned cognate neural mechanisms that evolve into the structured means of communication, *language.*

Contributors

Amitabh Dube, M.D., Umesh Kumar, M.D., Bhoopendra Patel, M.D., Lubaina Jetaji, M.Sc., Kapil Gupta, M.D., Jitendra Gupta, M.D., Sanjay Kumar Singhal, M.D., Kavita Yadav, M.Sc., Ph.D., Shubha Dube, Ph.D

Acknowledgements

The authors are greatly indebted to **Late Professor (Dr.) Ashok Panagariya**, a *Neuroscientist of International acclaim*, whose piercing insight and vision had been and will remain *The Fountainhead* of the ongoing work on *Modelling of Human Mind*.

Author details

Amitabh Dube[1*], Umesh Kumar[2], Kapil Gupta[1], Jitendra Gupta[1], Bhoopendra Patel[3], Sanjay Kumar Singhal[1], Kavita Yadav[1], Lubaina Jetaji[1] and Shubha Dube[4]

1 Physiology, S.M.S. Medical College and Attached Hospitals, Jaipur, Rajasthan, India

2 Physiology, Government Medical College, Kota, Rajasthan, India

3 Physiology, AIIMS, Bilaspur, Himachal Pradesh, India

4 Human Development, University of Rajasthan, Jaipur, Rajasthan, India

*Address all correspondence to: amitabhdube786@gmail.com

References

[1] Fingelkurts A and Fingelkurts A. 2004. Making complexity simpler: multi variability and metastability in the brain. International Journal of Neuroscience, 114 (7), 843-862.

[2] Abraham, F.D. (1995). Dynamics, bifurcations, self- organization, chaos, and mind. In R. Robertson and A. Combs (Eds.). Proceedings of The Society for Chaos Theory and the Life Sciences. Lawrence Erlbaum

[3] Freeman, W.J. (1991). The physiology of perception. Scientific America, *264, 78-85*.

[4] Dube A, Kumar A, Gupta K, Vyas P, Boolchandani D and Sonania R. 2009. Chaotic Neural Dynamics as evinced from scalp electroencephalography (EEG). 13th Congress of the European Federation of Neurological Societies (EFNS), September 12 to 15, 2009. European Journal of Neurology, Volume 16, Supplement 3, September 2009, pg 451

[5] Kampis, G. (1991). Self-modifying systems in biology and cognitive science. New York: Pergamon.

[6] Krause, C.M. (2003). Brain electric oscillations and cognitive processes. In: Hugdahl, K. (Ed.), Experimental Methods in Neuropsychology. Neuropsychology and Cognition. Kluwer Academic Publishers, Boston, pp. 111–130.

[7] Buzsáki, G.; Draguhn, A. (2004). Neuronal oscillations in cortical networks. Science, 304, 1926–1929.

[8] Jasper, H.H. (1958) The Ten-Twenty Electrode System of the International Federation. Electroencephalography and Clinical Neurophysiology, 10, 371-375.

[9] Skarda, C.A. and Freeman, W.J. (1987). How brains make chaos in order to make sense of the world. Behavioral and Brain Sciences*, 10 (2), 161-195.*

[10] Basar, E., Basar-Eroglu, C., Karakas, S., Schurmann, M. (1999). Are cognitive processes manifested in event-related gamma, alpha, theta and delta oscillations in the EEG? Neurosci. Lett. 259, 165–168.

[11] Ramachandran VS and Oberman LM. 2007. "*Broken Mirrors: A special theory of Autism*". Scientific American, 17 (2s), 63-69.

[12] Dube A, Yadav K, Gupta A and Yadav Y. 2012. Neurophysiological perspectives of electroencephalography in children with attention deficit hyperactivity disorder (ADHD). Neurophysiologie Clinique Clinical Neurophysiology, 42 (1–2), 68.

[13] Krause, C.M., Åström, T., Karrasch, M., Laine, M., Sillanmäki, L. (1999). Cortical activation related to auditory semantic matching of concrete versus abstract words. Clin. Neurophysiol., 110, 1371–1377.

[14] Krause, C.M., Sillanmäki, L., Koivisto, M., Saarela, C., Häggqvist, A., Laine, M., Hämäläinen, H., (2000). The effects of memory load on event-related EEG desynchronization and synchronization. Clin. Neurophysiol. 111, 2071–2078.

[15] Bloom, J. L., & Anneveld, M. (1982). An electrode cap tested. Electroencephalography and Clinical Neurophysiology, 54, 591–594.

[16] Egner, T., & Gruzelier, J. H. (2001). Learned self-regulation of EEG frequency components affects attention and event-related brain potentials in humans. NeuroReport: For Rapid Communication of Neuroscience Research, 12(18), 4155–4159.

[17] Luck, S. J. (2014). An Introduction to the Event-Related Potential Technique, Second Edition. Cambridge, MA: MIT Press.

[18] Beres. (2017).Time is of the Essence: A Review of Electroencephalography (EEG) and Event-Related Brain Potentials (ERPs) in Language Research. Applied Pyschophysiology and Biofeedback Volume 42, Issue 4, pp. 247–255.

[19] Berger, B.; Omer, S.; Minarik, T.; Sterr, A.; Sauseng, P. (2015) Interacting Memory Systems—Does EEG Alpha Activity Respond to Semantic Long-Term Memory Access in a Working Memory Task? Biology, *4*, 1-16.

[20] Burke JF, Long NM, Zaghloul KA, Sharan AD, Sperling MR, Kahana MJ. (2014) Human intracranial high-frequency activity maps episodic memory formation in space and time. NeuroImage., 2, 834–843.

[21] Burke JF, Zaghloul KA, Jacobs J, Williams RB, Sperling MR, Sharan AD, Kahana MJ. (2013) Synchronous and asynchronous theta and gamma activity during episodic memory formation. Journal of Neuroscience, 1, 292–304.

[22] Doppelmayr, M., Klimesch, W., Stadler, W., Pöllhuber, D., & Heine, C. (2002). EEG alpha power and intelligence. Intelligence, 30, 289–302.

[23] Kuhl PK. (2010). Brain mechanisms in early language acquisition. Neuron, 67 (5), 713-727.

[24] Postle, B.R. (2006). Working memory as an emergent property of the mind and brain. Neuroscience, 139, 23–38.

[25] Baddeley, A. (2003). Working memory: looking back and looking forward. Nat. Rev., Neurosci. 4, 829–839

[26] Baddeley, A. (2007). Oxford psychology series: Vol. 45. Working memory, thought, and action. Oxford University Press.

[27] Jensen, O., Tesche, C.D. (2002). Frontal theta activity in humans increases with memory load in a working memory task. Eur. J. Neurosci. 15, 1395–1399.

[28] Kahana MJ, Sekuler R, Caplan JB, Kirschen M, Madsen JR. (1999). Human theta oscillations exhibit task dependence during virtual maze navigation. Nature 399:781–784.

[29] Klimesch et al. (1994). Episodic and semantic memory: an analysis in the EEG theta and alpha band. Electroencephalography and Clinical Neurophysiology, 91(6), 428-441.

[30] Klimesch et al. (1998). EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. Brain Res Brain Res Rev, 29(2–3), 169-195.

[31] Griesmayr B., Gruber W., Klimesch W. (2010). Sauseng P. Human frontal midline theta and its synchronization to gamma during a verbal delayed match to sample task. Neurobiol. Learn. Mem., 93, 208–215. doi: 10.1016/j.nlm.2009.09.013

[32] Lisman, J. E., & Idiart, M. A. P. (1995). Storage of 7 ± 2 short-term memories in oscillatory subcycles. Science, *267*(5203), 1512–1515.

[33] Klimesch et al. (1997). Brain oscillations and human memory: EEG correlates in the upper alpha and theta band. Neuroscience Letter, Nov 28;238 (1-2):9-12.

[34] Klimesch et al. (2007). EEG alpha oscillations: the inhibition-timing hypothesis. Brain Res Rev. Jan;53(1): 63-88. Epub 2006 Aug 1.

[35] Klimesch et al. (2011). Alpha oscillations and early stages of visual

encoding. Front Psychology, May 31;2: 118.

[36] Klimesch et al. (1996). Memory processes, brain oscillations and EEG synchronization. Int J Psychophysiol. 24 (1–2):61-100.

[37] Röhm D, Klimesch W, Haider H, Doppelmayr M. (2001). The role of theta and alpha oscillations for language comprehension in the human electroencephalogram. Neurosci Lett, 310(2–3), 137-140.

[38] Pfurtscheller, G., Klimesch, W. (1990) Topographical display and interpretation of event-related desynchronization during a visual-verbal task. Brain Topogr **3,** 85–93.

[39] Pfurtscheller, G., Aranibar, A. (1977). Event-related cortical desynchronization detected by power measurements of scalp EEG. Electroencephalogr. Clin. Neurophysiol. 42, 817–826.

[40] Pfurtscheller, G., Lopes da Silva, F. H. (1999). Event-related EEG/MEG synchronization and desynchronization: basic principles. Clin. Neurophysiol. 110, 1842–1857.

[41] Sauseng, Paul & Klimesch, Wolfgang & Schabus, Manuel & Doppelmayr, Michael. (2005). Fronto-parietal EEG coherence in theta and upper alpha reflect central executive functions of working memory. International journal of psychophysiology: official journal of the International Organization of Psychophysiology, 57, 97-103.

[42] Sauseng P., Klimesch W. (2008). What does phase oscillatory brain activity tell us about cognitive processes? Neurosci. Biobehav. Rev. 32, 1001–1013.

[43] Wianda, Elvis & Ross, Bernhard. (2019). The roles of alpha oscillation in working memory retention. Brain and Behavior, 9, 10.1002/brb3.1263.

[44] Stipacek, A., Grabner, R.H., Neuper, C., Fink, A., Neubauer, A.C. (2003). Sensitivity of human EEG alpha band desynchronization to different working memory components and increasing levels of memory load. Neurosci. Lett., 353, 193–196.

[45] Sarnthein J., Petsche H., Rappelsberger P., Shaw G. L., von Stein A. (1998). Synchronisation between prefrontal and posterior association cortex during human working memory. Proc. Natl. Acad. Sci. U.S.A. 95, 7092–7096. 10.1073/pnas.95.12.7092.

[46] Hanslmayr S, Staudigl T. (2013) How brain oscillations form memories-a processing based perspective on oscillatory subsequent memory effects. NeuroImage, 5, 326–334.

[47] Hanslmayr S., Pastötter B., Bäuml K. H., Gruber S., Wimber M., Klimesch W. (2008). The electrophysiological dynamics of interference during the stroop task. J. Cogn. Neurosci., 20, 215–225.

[48] Nigbur R., Cohen M. X., Ridderinkhof K. R., Stürmer B. (2012). Theta dynamics reveal domain-specific control over stimulus and response conflict. J. Cogn. Neurosci, 24 (5), 1264-1274.

[49] Lubaina, et al. (2021). Neuropsychological Trends. In print.

[50] Guillery, R.W. (2000), Brodmann's'Localisation in the Cerebral Cortex'. Translated and edited by Laurence J. Garey. (Isbn 1 86094 176 1.) London: Imperial College Press. 1999.. Journal of Anatomy, 196, 493-496.

[51] Thut G, Nietzel A, Brandt SA, Pascual-Leone A. (2006) α-Band electroencephalographic activity over

occipital cortex indexes visuospatial attention bias and predicts visual target detection. J Neurosci, 26, 9494–9502. doi:10.1523/JNEUROSCI.0875-06.2006 pmid:16971533.

[52] Van Ede F, de Lange FP, Jensen O, and Maris E (2011). Orienting attention to an upcoming tactile event involves a spatially and temporally specific modulation of sensorimotor alpha- and beta-band oscillations. Journal of Neuroscience 31, 2016-2024.

[53] Tulving, E., Kapur, S., Craik, F.I.M., Moscovitch, M. and Houle, S. (1994) Hemispheric encoding/retrieval asymmetry in episodic memory: positron emission tomography findings, Proc. Nat. Acad. Sci. USA, 91, 2008–2011.

[54] Nyberg, L., Cabeza, R. and Tulving, E. (1995) PET studies of encoding and retrieval: the HERA model, Psychol. Bull. Rev., 3, 135–148.

[55] Broadmann K. (1909) Broadmann's: Localisation in the cerebral cortex. Third edition. Springer

[56] Sherman SM and Guillery RW. (2000). Exploring the thalamus. Brain, 124 (10), 2120-2121

[57] Lisman JE and Jensen O. (2013). The θ-γ neural code. Neurone, 77 (6), 1002-1016.

[58] Desmond, J. E., Gabrieli, J. D. E., Wagner, A. D., Ginier, B. L., & Glover, G. H. (1997). Lobular patterns of cerebellar activation of verbal working-memory and finger-tapping tasks as revealed by functional MRI. The Journal of Neuroscience, *17*(24), 9675–9685.

[59] Bogen JE, Bogen GM. (1976). Wernicke's region–Where is it? Ann N Y Acad Sci., 280, 834-843. doi: 10.1111/j.1749-6632.1976.tb25546.x. PMID: 1070943.

[60] Deiber, Marie-Pierre & Sallard, Etienne & Ludwig, Catherine & Ghezzi, Catherine & Barral, Jérôme & Ibañez, Vicente. (2012). EEG alpha activity reflects motor preparation rather than the mode of action selection. Frontiers in integrative neuroscience. 6. 59. 10.3389/fnint.2012.00059.

[61] Bastiaansen MC, Böcker KB, Cluitmans PJ, Brunia CH. (1999) Event-related desynchronization related to the anticipation of a stimulus providing knowledge of results. Clin Neurophysiol., 110(2), 250-260. doi: 10.1016/s0013-4694(98)00122-9. PMID: 10210614.

[62] Kopp F., Schröger E., Lipka S. (2006). Synchronized brain activity during rehearsal and short-term memory disruption by irrelevant speech is affected by recall mode. Int. J. Psychophysiol. 61, 188–203 10.1016/j.ijpsycho.2005.10.001.

[63] Payne L., Kounios J. (2009). Coherent oscillatory networks supporting short-term memory retention. Brain Res. 1247, 126–132.