

# Neuropsychological

## Trends

34

November 2023

---

- Minal Kachhawa - Umesh Kumar - Bhoopendra Patel -  
Ramesh Chand Choudhary - Dashrath Ganwani - Amitabh Dube*  
The event related potential profiling of consonants and vowels  
across rule learning task through auditory stimuli 7
- Alicia M. Trbovich - Patrick J. Sparto - Theodore J. Huppert -  
R.J. Elbin - Alicia M. Kissinger-Knox - Daniel Charek -  
Michael W. Collins - Anthony P. Kontos*  
Changes in brain activation measured by functional Near-Infrared  
Spectroscopy associated with continuing to play following  
sport-related concussion among adolescent athletes 39
- Martina Sansone - Michela Balconi*  
Did it work? Effective decisions in the workplace 59
- Gargi Shukla*  
Review study on neuropsychological impact of ecotherapy  
on urbanization 85
-



# The event related potential profiling of consonants and vowels across rule learning task through auditory stimuli

**Minal Kachhawa<sup>1</sup> - Umesh Kumar<sup>2</sup> - Bhoopendra Patel<sup>3</sup> - Ramesh Chand Choudhary<sup>4</sup> - Dashrath Ganwani<sup>1</sup> - Amitabh Dube<sup>1</sup>**

<sup>1</sup> Department of Physiology, SMS Medical College, Jaipur, Rajasthan, India

<sup>2</sup> Department of Physiology, GMC, Kota, Rajasthan, India

<sup>3</sup> Department of Physiology, AIIMS, Bilaspur, Himachal Pradesh, India

<sup>4</sup> Department of Physiology, GMC, Chittorgarh, Rajasthan, India

DOI: <https://doi.org/10.7358/neur-2023-034-kach>

[drminalkachhawa@gmail.com](mailto:drminalkachhawa@gmail.com)

---

## ABSTRACT

*The present study was aimed to investigate the hypothesis of differential use of consonants and vowels in rule learning tasks by analysing patterned Event-Related Potentials (ERPs) in response to trisyllabic auditory non-sense word stimuli in an oddball paradigm. The study included standard stimuli of ABB rule, applicable to vowels in vowel conditions and consonants in consonant conditions, and two deviant stimulus types consisting of novel phonemes. The results showed that both phoneme and rule deviants exhibited significant changes in ERP profiling in amplitude and latency compared to standard stimuli in consonant conditions and only with rule deviant in vowel conditions. These findings suggest that vowels and consonants play a fundamental role in neurolinguistics, whereas, vowels are important for understanding the rules of language, while consonants commencing the process of lexicon access. Overall, the study provides important insights into the neural dynamics underlying the differential processing of consonants and vowels.*

*Keywords: Event Related Potential; vowels; consonants; language processing; rule abstraction*

## 1. INTRODUCTION

Language intrinsically has seemingly evolved in human through quantal genesis of phonemes and syllables across the use of unitary building blocks of vowels and consonants. Syllables are smallest unit of spoken language and vowels act as a nucleus/nidus/seeding stimulus with or without the presence of a consonant and are primarily responsible for generation of a meaningful word (De Jong & Van der Leij, 2003). Phonemes represent range of sounds, abstracted from continuous stream of speech that are characteristically distinct from one another with the distinctive role of distinguishing and singularizing one word from the other word (De Jong & Van der Leij, 2003). The ontogenetic evolution of language characterises appearance of vowels on the human mind landscape with their vocalization early in infancy followed by the developmental facade of consonants, since more complex neural mechanisms (inclusive of sensorial, mirror neuronal system and motor neuronal system) are employed for production of consonants sounds as compared to that of vowels (Stark, 1980).

Consonants and vowels are two different phonological categories with separate articulation and neurophysiological properties. Perception of consonants are shorter and more categorical while vowels are often harmonized within words. There are also neuropsychological (Caramazza et al., 2000; Ferreres et al., 2003) and neurophysiological evidence for involvement of different brain loci in neurological processing of consonants and vowels (Carreiras & Price, 2008; Carreiras et al., 2009; Vergara-Martínez et al., 2011).

Several speech processing theories posit the presence and involvement of multiple areas that subserve the neurophysiological precept of speech and language comprehension, inclusive of both the frontal and temporal lobes of both cerebral hemispheres. The two primary areas involved in language processing and speech production are Wernicke's area, responsible for language comprehension through audition, and Broca's area, responsible for the neural algorithm of language production through the motor mechanisms of the vocal apparatus. This process receives input from the interfacial mirror neuron system (MNS), which is responsible for the mirror neural image of the motor response (Hickok & Poeppel, 2007). The left hemisphere region of the brain is predominantly involved in speech perception and production, with the right auditory area primarily processing linguistic accents in right-handed individuals, while the left auditory area processes syllable differences involving vowels and consonants. This lateralization is known as "functional hemispheric lateralization". Other cortical structures involved in speech perception include the penumbra areas surrounding the primary area of the auditory cortex. The anterior and lateral parts of the superior temporal gyrus (STG) and superior temporal sulcus (STS) are activated more rigorously by meaningful speech

sounds than by non-speech noise or pseudo-speech of similar acoustic complexity (Binder et al., 2000; Scott et al., 2000; Davis & Johnsrude 2003; Liebenthal et al., 2005), suggesting the presence of a primate filtering fine-tuned neural mechanism. The specific cerebral area of these neural representations needs further evaluation, with some proposing that neuronal pools subservient primarily to posterior STG/STS represent phonetic-phonological processing, while others propose a distributed network of neuronal pools that crosstalk across space and time (the network theory), while working along the framework of modular neural architectonics. Such a model of distributed dynamically evolving neuronal network seemingly is robust facilitating cognitive abilities of an individual (Dube et al., 2021).

The Mirror Neuron System (MNS) and synaptic neuroplasticity are known to have a significant impact on the development of spoken and written languages within the distributed neuronal pools model. The MNS serves as a bridge between the sensorium's qualitative experience and the motor system, facilitating the formation of neural images through memory based on the baseline reverberating chaotic neural dynamics (Dube et al., 2021). Research has shown that a dysfunctional Mirror Neuron System can hinder social intelligence and language acquisition (Oberman & Ramachandran, 2007). Additionally, Obleser & Kotz (2010) proposed that local activation patterns that separate acoustic-phonetic features are most commonly found in higher areas of the auditory cortex (Tian et al., 2001). With the emergence of advanced neuroimaging methods, our understanding of brain function has shifted from traditional localizationist models of Wernicke and Broca to more complex, widely distributed neural networks. This has led to new insights into cortical neural dynamics and the white matter anatomy of human language (Middlebrooks et al., 2017). Brain stimulation studies have also challenged the modular view of language processing, proposing instead parallel, interconnected neural networks that are responsible for semantic, phonological, and syntactic language processing. These distinct neural sub-circuitries are constrained by anatomic boundaries and can lead to double dissociation during processing of different aspects of language (Duffau, Moritz-Gasser & Mandonnet, 2014). Examining intraoperative direct electrostimulation mapping and real-time behavioral monitoring, as well as neuropsychological and neuroimaging techniques, has revealed the interplay between neural network circuitry and highlighted the importance of subcortical connectivity in neuroplasticity. This meta-networking model involving heteromodal cortices and white matter connectivity provides a better understanding of the complex cognitive functions of the human brain (Duffau et al., 2014).

Various neuropsychological studies utilizing functional magnetic resonance imaging have suggested that processing of consonants and vowels,

the fundamental units and building blocks in any language, involves differential functional involvement of various distributed neuronal systems that are spread across space and time. This neural processing is conceptually distinct in that damage to the representation of one unit does not necessarily affect the other (Caramazza et al., 2000; Cotelli et al., 2003). Additionally, behavioral and electrophysiological studies have investigated whether the processing of vowels and consonants differs in terms of neuronal activation patterns and whether this difference is modulated by task demands. Such studies have exemplified the presence of double dissociation between consonants and vowels.

The examination of various languages of diverse origins indicates that consonants are generally more numerous than vowels, making them more crucial at the lexical level, particularly because vowels often lose their distinctiveness in unstressed positions and through phenomena like harmony. Consequently, consonants are primarily distinguished by their quantity, while vowels are distinguished mainly by their quality, as they carry much of the prosody and rhythm that differentiate languages around the world, resulting in their segregation into different rhythmic groups based on the percentage of vowels in the speech stream and the regularity of vocalic intervals (Ramus et al., 1999). The roots of words in any language consist exclusively of consonants, whereas insertion of vowels defines and categorises morphological patterns (McCarthy & Wood, 1985; Bonatti et al., 2005, 2007).

Although previous neuropsychological, electrophysiological and behavioural studies have provided various considerable evidences of the presence of an inherent double, dissociative and distinctive neural processing requirements of and for consonants and vowels, wherein consonantal information are relatively important for lexical processing and vowels are involved in abstraction principles of rule learning processes, most of the studies have focused on visual paradigms and lack precise structure-function relationship correlates from current neuropsychological and electrophysiological investigative tools. Furthermore, although the initial proposal of Cutler et al. (2000) and Nespor et al. (2003) are concerned with speech, the evidence from the auditory modality in adult experiments is so far mostly indirect. To better appreciate the differential consonant and vowel neural processing, researchers should employ paradigms that differentially weight lexico-semantic and phonological/prosodic processing during speech perception and production tasks. Both tasks of speech perception and production seem to proceed along similar time correlates, making this approach more likely to provide insights into the neural mechanisms involved in speech processing.

Therefore, the aim of this study is to investigate the distinct roles of vowels and consonants in adult phonological processing with auditory stimuli and the effect of rules abstraction on different classes of phonemes. The study

examines the event-related potential (ERP) profiles elicited by consonants and vowels in an auditory pattern implementation task, using specific EEG electrodes. The auditory stimuli consisted of trisyllabic nonsense words following the consonant-vowel-consonant-vowel-consonant-vowel (CVCVCV) rule and were presented using the oddball paradigm. The ERPs so generated were assessed and compared with respect to amplitude and latency of early waveforms P50, MMN and N400 on presentation of different stimuli over vowels and consonants conditions separately. The study aims to gain insights into the differential roles of vowels and consonants in phonological processing. The amplitude and latency measures of the early waveforms provide information about how the brain processes and distinguishes between different phonemes and phonetic patterns. Further providing a better understanding of underlying neural mechanisms for phonological processing in adults.

## 2. EXPERIMENTAL PROCEDURE

### *2.1 Sample*

The present cross sectional observational comparative study was conducted after obtaining the desired clearance from Institutional Research Review Board and Ethics Committee. Sixty apparently healthy individuals aged 18 to 35 from our institute's population were included in the study. The selected participants met our inclusion and exclusion criteria for the study task, and were bilinguals who spoke both Hindi and English, with Hindi being their mother tongue. The participants were divided equally into two groups: 30 individuals in the vowel condition (22 males and 8 females, with a mean age of  $23.5 \pm 4.47$  years) and 30 individuals in the consonant condition (21 males and 9 females with a mean age of  $22.96 \pm 3.48$  years). All methods followed relevant guidelines and regulations, and participants were fully informed about the test and provided with informed consent. Participants with any form of neurological impairment, chronic or acute illness, chronic alcoholism or smoking habits, or those taking psychoactive medications were excluded from the study.

### *2.2 Stimuli*

The target syllable “ke”, “ku”, “fa”, “fi”, “fe”, “fu”, “la”, “lo”, “li”, “lu”, “ma”, “mo”, “mi”, “mu”, “ra”, “ro” and “ri” were recorded in female voice that is produced with a neutral intonation following the stress syllable “pa”. Moreover, it has been documented by Edworthy et al., 2003 and supported recently by

Song et al., 2022, that female voice, with inherent advantage of portraying urgency and exigency, is more effective in resolution of sentence recognition and segregation as compared to that of male voice, the distributed amygdaloid-hypothalamic-hippocampal neuronal circuitry (the esoteric limbic system) spicing and flavoring additionally the neural inputs, fine-tuning for the observed better precision and resolution. The target syllables are extracted and normalized to equate for duration and intensity. Each target syllable is of 330ms duration, and each phoneme of the syllable has a fundamental frequency of 240Hz. These target syllables are then combined to construct trisyllabic CVCVCV non-sense words according to the two conditions “Vowel Condition” and “Consonant Condition”, respectively.

### *2.2.1 Stimuli of vowel condition*

For the vowel condition, 16 nonsense words were used as standard stimuli that were created by combining the phonemes /k/, /f/, /e/, /u/. The standard stimuli had an ABB rule implemented over the vowels and implementation of such a rule across vowels in the present experimental set-up mandated that the second vowel was repeated while the first one was different, though consonants were ordered randomly. The Deviant Stimuli (324 nonsense words in total) were created by combining phonemes that were not used in standard words namely, /l/, /m/, /r/, /a/, /o/, /i/. Half of the words used as deviant stimuli were Phoneme Deviants and other half were Rule Deviants. The Phoneme Deviants differed from standard stimuli only in their phonemes. As in standard stimuli, vowels were organized following the same rule of ABB in phoneme deviants, while consonants varied randomly placed. Rule deviants differed from standard stimuli in both their phonemes as well as the rule used to organize the vowels. Vowels in the rule deviant stimuli were combined using an ABA rule, such that the first and third vowels were the same, while the vowels in the middle were different and consonants varied randomly.

### *2.2.2 Stimuli of consonant condition*

In the Consonant condition, 16 nonsense words were used as standards that were composed by the phonemes /k/, /f/, /e/, /u/ (the same as in the vowel condition). In contrast to the vowel condition, the ABB rule was implemented over the consonants, so the second and third consonants were the same and the first consonant was different, while vowels varied randomly. As in the vowel condition, two types of deviant stimuli were created using the new phonemes /l/, /m/, /r/, /a/, /o/, /i/. Half of the deviant stimuli were Phoneme Deviants that had consonants organized in the same ABB rule as standard stimuli. The other



half of deviant stimuli were organized such that they followed an ABA rule constituting Rule Deviants applied on consonants in consonant condition.

### *2.2.3 Stimuli of behavioural test*

For the behavioural test, 16 test stimuli were created with phonemes /f/, /l/, /m/, /a/, /u/, /i/. Consonants in half of the test stimuli followed the standard ABB rule while in the other half the consonants were not repeated within a word and thus followed an ABC rule that was never presented during the recording phase. None of the test words was used as standard or deviant stimuli during the experiment and test pairs were chosen such that the only difference between the two items was in their consonants.

## *2.3 Procedure*

### *2.3.1 The stimulus protocol*

All eligible participant subjects sat comfortably on a wooden chair in a soundproof and a dimly light room as the recording protocol started, while nonsense words were presented through a pair of loudspeakers. The participants were instructed to keep their eyes open with minimal eye blinks and all other motor movement throughout the presentation of stimulus blocks. In both conditions (Consonant and Vowel condition), stimuli were presented in two blocks with a 2-minute break between the first and second block. A total of 1616 nonsense words were presented to each subject that is, 808 nonsense words in each block. Out of which 608 were standard words and 100 words each belonging to two different classes of deviants that were the Rule Deviant and the Phoneme Deviant respectively. All the 16 standard words of both the conditions were randomly repeated 38 times avoiding immediate repetitions. The deviant probability was set at 0.12 and a deviant stimulus was presented after a minimum of five standard stimuli with duration for each word being 990 ms and the following word was presented after a time-gap of 510 ms. The order of presentation of the words was balanced with stimulus onset asynchrony (SOA) set at 1500ms. Each block had a stimulation time of approximately 21 minutes. The whole experimental session inclusive of electrode mounting and removal extended to around 55 minutes.

### *2.4 EEG recording, analysis and quantification*

The ERP data was recorded using BESS (Brain Electro Scan System) software version 4.0 (Axxonet Systems Technologies Ltd, India). Ag/AgCl surface

electrodes soaked in saline water 24 hours prior to the experiment were used to record data. The electrodes were secured on the scalp of participants using a silicon bracket scalp cap according to known anatomical landmarks. 24 Electrodes channels were placed on F3, F1, FC3, FC1, F4, F2, FC4, FC2, C3, C1, CP3, CP1, C4, C2, CP4, CP2, P5, P3, P1, PO3, P4, P2, P6, and PO4 regions of the scalp according to the International 10/20 System. The reference electrode was applied on the left earlobe and ground electrode was placed at the forehead.

The electrode impedances were fixed at 10 k $\Omega$  for reliable and valid reduction of Ocular Artifacts and electrical activities were amplified using an amplifier. By using higher impedance possible noise and interference due to eye movement were minimized which could otherwise affect the accuracy of ERP analysis. A band pass filter of 0.1 to 30 Hz & 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 EEG recordings were digitized at a sampling rate of 500 Hz. All the EEG recordings were preceded with running a baseline EEG for few minutes to ensure clean data acquisition. Once the EEG waves stabilized, the stimulus protocol was loaded, and the data acquisition was started using the predefined stimulus protocol. Eye blink and other artefacts were manually removed based on visual inspection.

The ERP data was analysed with BESS (Brain Electro Scan System) software version 4.0 (Axxonet Systems Technologies Ltd, India). Epochs of 800 milliseconds duration were extracted from the continuous EEG record for ERP analysis. The trigger points for the epochs were selected in a manner that the trigger point, set to the start of the coded event, triggers marked the onset of each stimulus (i.e., 100 ms before the start of the syllable stimuli). The epochs were baselined by means of voltage averaging of the period amongst the syllable start and the prior 100 milliseconds. Visual artefacts in the ERP epochs were manually removed. The ERPs were then averaged across both conditions namely the Vowel and the Consonant conditions conferring to the predefined bins, differently for the standard stimuli, the phoneme deviant stimuli and the rule deviant stimuli respectively for both the conditions. Group averages were then created by averaging across the participants.

Head maps of both conditions were generated with BESS (Brain Electro Scan System) software version 4.0 (Axxonet Systems Technologies Ltd, India) using the grand average of the ERP recording of vowel and consonant condition for all three types of stimuli (Standard, Phoneme Deviant and Rule deviant stimuli) separately for each condition.

## *2.5 Statistical analysis*

The statistical analysis on the group average data for amplitude and latency of

the different stimuli (standard, phoneme deviant, and rule deviant) was performed using SPSS software version 25. For amplitude analysis, the mean and standard deviation in  $\mu\text{V}$  were determined for the early component, MMN component, and N400 using a paired t-test. A significance level of  $p < 0.05$  was considered to determine statistical significance. The amplitude of standard stimuli was separately compared with both rule deviant stimuli and phoneme deviant stimuli for early component P50, MMN and N400 wave components. Similarly, for latency analysis, the mean and standard deviation in ms were calculated for the early component, MMN component, and N400 using a paired t-test. A p-value of  $p < 0.05$  was considered statistically significant. The latency of standard stimuli was compared with both rule deviant stimuli and phoneme deviant stimuli for early component P50, MMN and N400 wave components. In this study, a student's paired t-test was chosen as the statistical analysis method because the amplitude and latency measures were compared within the same participants across different conditions. By calculating the mean and standard deviation of the amplitude and latency, the assumption of normal distribution can be assessed. Setting a significance level of  $p < 0.05$ , the paired t-test helped determine whether the observed differences in the measures were statistically significant and likely attributable to the effects of the stimuli conditions rather than random chance.

### 3. RESULTS

The study involved 60 participants, who were evenly divided into two groups: 30 participants in the Vowel condition and 30 in the Consonant condition. The data collected was analyzed and showed that the mean age in the Vowel condition was 23.5 years (with a standard deviation of 4.47), and the male to female ratio was 2.75:1. In the Consonant condition, the mean age was 22.96 years (with a standard deviation of 3.48), and the male to female ratio was 2.34:1. The audio stimulus used in the Consonant condition consisted of CVCVCV trisyllabic non-words.

#### *3.1 Behavioural test*

After conducting independent t-test, there was no significant difference found between the performance of participants in the vowel and consonant conditions on the behavioural test. Specifically, the percentage of correct responses in the vowel condition was  $61.250 \pm 11.536$ , while it was  $60.416 \pm 12.319$  in the consonant condition (t value = 0.273, p value = 0.787) (refer Table 1).

Table 1. Comparing the percentage of correct response across Vowel and Consonant conditions

Condition	Percentage correct response	Standard deviation
Vowel condition	61.250%	11.536
Consonant condition	60.416%	12.319

Note: The table represents the percentage of correct response and standard deviation for the Vowel and Consonant conditions.  $p < 0.05$  was taken as statistically significant.

### 3.2 In vowel condition

The results showed that presenting rule deviant stimuli in an oddball paradigm in a continuous stream of standard stimuli led to a significant increase in waveform amplitude, as determined by independent t-tests.

Specifically, significant differences were observed at multiple electrodes during the early component (around 45 milliseconds), MMN, and N400 time windows. These included F1, F3, FC1, FC3, F4, FC2, FC4, C1, CP1, C2, C4, CP2, CP4, P1, P3, P5, P03, P4, P6, and P04 for the early component; FC3, CP1, CP3, P5, and P6 for the MMN component; and F1, F3, FC1, FC3, F2, F4, FC2, FC4, C1, C3, CP1, CP3, C2, C4, CP2, CP4, P1, P3, P5, P03, P2, P4, P6, and P04 for the N400 waveform.

The increase in amplitude of the three observed waveforms on presentation of rule deviant stimuli was seen globally across anterior, central, and posterior EEG leads, as shown in Table 2.

The significant differences in the early component occurred at F1 ( $p = 0.001$ ), F3 ( $p = 0.039$ ), FC1 ( $p = 0.021$ ), FC3 ( $p = 0.049$ ), F4 ( $p = 0.016$ ), FC2 ( $p = 0.045$ ), FC4 ( $p = 0.027$ ), C1 ( $p = 0.002$ ), CP1 ( $p = 0.037$ ), C2 ( $p = 0.044$ ), C4 ( $p = 0.035$ ), CP2 ( $p = 0.038$ ), CP4 ( $p = 0.026$ ), P1 ( $p = 0.027$ ), P3 ( $p = 0.003$ ), P5 ( $p = 0.023$ ), P03 ( $p = 0.028$ ), P4 ( $p = 0.038$ ), P6 ( $p = 0.030$ ), and P04 ( $p = 0.023$ ). Similarly, significant differences in the MMN component were observed at FC3 ( $p = 0.013$ ), CP1 ( $p = 0.049$ ), CP3 ( $p = 0.004$ ), P5 ( $p = 0.004$ ), and P6 ( $p = 0.005$ ). Lastly, the significant differences in the N400 waveform were found at F1 ( $p = 0.049$ ), F3 ( $p = 0.014$ ), FC1 ( $p = 0.007$ ), FC3 ( $p = 0.011$ ), F2 ( $p = 0.015$ ), F4 ( $p = 0.031$ ), FC2 ( $p < 0.001$ ), FC4 ( $p = 0.005$ ), C1 ( $p < 0.001$ ), C3 ( $p = 0.001$ ), CP1 ( $p = 0.005$ ), CP3 ( $p = 0.004$ ), C2 ( $p = 0.002$ ), C4 ( $p = 0.007$ ), CP2 ( $p = 0.009$ ), CP4 ( $p = 0.021$ ), P1 ( $p = 0.049$ ), P3 ( $p = 0.004$ ), P5 ( $p = 0.012$ ), P03 ( $p = 0.003$ ), P2 ( $p = 0.024$ ), P4 ( $p = 0.013$ ), P6 ( $p = 0.040$ ), and P04 ( $p = 0.001$ ).

No significant increase in amplitude was observed when comparing

standard and phoneme deviant stimuli with the  $p$  value  $> 0.05$  at all electrode sites.

The study suggests that violating a rule implemented on non-word stimuli elicits different neural responses compared to phoneme deviants in the vowel condition.

A significant difference was observed when comparing the ERP profiles of early components (around 45 milliseconds), MMN, and N400 in terms of latency, while presenting the rule deviant stimuli in an oddball paradigm in a continuous stream of standard stimuli while no such effect was observed on presentation of phoneme deviant stimuli. Specifically, a decrease in the latency of the waveform in the timeline of the early component of ERP and MMN, and an increase in the latency of the N400 waveform was observed when presenting rule deviant stimuli. Table 3 shows that when a rule implemented on non-word stimuli is violated with respect to standard stimuli, the latency for the standard stimuli was between 47ms to 50ms, whereas the latency of rule deviant stimuli was about 43ms to 46ms in the early component, and a significant difference was observed at FC3 ( $p = 0.013$ ), CP1 ( $p = 0.049$ ), CP3 ( $p = 0.004$ ), P5 ( $p = 0.004$ ), and P6 ( $p = 0.005$ ).

For the MMN component, the observed average latency for standard stimuli was 150ms to 158ms, while the latency of rule deviant stimuli was about 135ms to 148ms, and a significant difference was observed at FC2 ( $p = 0.044$ ), FC4 ( $p = 0.029$ ), C1 ( $p = 0.039$ ), C3 ( $p = 0.042$ ), P3 ( $p = 0.028$ ), and PO3 ( $p = 0.011$ ). The latency of the N400 component of ERP at different electrode sites was observed to be 375ms to 396ms for standard stimuli, whereas it was 400ms to 415ms for rule deviant stimuli, and a significant difference was observed at F1 ( $p < 0.001$ ), F3 ( $p = 0.004$ ), FC1 ( $p = 0.040$ ), FC3 ( $p = 0.027$ ), F2 ( $p = 0.005$ ), F4 ( $p = 0.025$ ), FC2 ( $p = 0.034$ ), FC4 ( $p = 0.021$ ), C1 ( $p = 0.040$ ), C3 ( $p = 0.008$ ), CP1 ( $p = 0.001$ ), CP3 ( $p = 0.005$ ), C2 ( $p = 0.014$ ), C4 ( $p = 0.023$ ), CP2 ( $p = 0.031$ ), CP4 ( $p = 0.026$ ), P1 ( $p = 0.048$ ), P5 ( $p = 0.017$ ), P03 ( $p = 0.025$ ), P2 ( $p = 0.036$ ), P6 ( $p = 0.027$ ), and P04 ( $p = 0.026$ ).

Table 2. The EEG leads exhibiting significant changes in amplitude of respective ERP waveforms when compared across different stimuli in vowel

Comparison	ERP waveform	Significant change in amplitude of ERP waveform in EEG leads ( $p < 0.05$ )		
		Anterior	Central	Posterior
Standard vs Phoneme Deviant	Early component	-	-	-
Standard vs Rule Deviant	Early component	F1, F3, FC1, FC3, F4, FC2, FC4	C1, CP1, C2, C4, CP2, CP4	P1, P3, P5, PO3, P4, P6, PO4
Standard vs Phoneme Deviant	MMN	-	-	-
Standard vs Rule Deviant	MMN	F1, F3, FC1, FC3, F2, F4, FC2, FC4	C1, C3, CP1, CP3, C2, C4, CP2, CP4	P1, P3, P5, PO3, P2, P4, P6, PO4
Standard vs Phoneme Deviant	N400	-	-	-
Standard vs Rule Deviant	N400	F1, F3, FC1, FC3, F2, F4, FC2, FC4	C1, C3, CP1, CP3, C2, C4, CP2, CP4	P1, P3, P5, PO3, P2, P4, P6, PO4

Note. This table presents significant changes in the amplitude of ERP waveforms when comparing different stimuli (Standard vs Phoneme Deviant and Standard vs Rule Deviant) within the Vowel Condition. The EEG leads demonstrating Significant amplitude changes are indicated for each ERP waveform (Early Component, MMN, and N400) across the anterior, central, and posterior regions. A hyphen (“-”) signifies the absence of significant amplitude changes. Significance was determined at  $p < 0.05$ .

Table 3. The EEG leads exhibiting significant changes in latency of respective ERP waveforms when compared across different stimuli in vowel condition

Comparison	ERP waveform	Significant change in latency of ERP waveform in EEG leads ( $p < 0.05$ )		
		Anterior	Central	Posterior
Standard vs Phoneme Deviant	Early component	-	-	-
Standard vs Rule Deviant	Early component	FC3	CP1, CP3	P5, P6
Standard vs Phoneme Deviant	MMN	-	-	-
Standard vs Rule Deviant	MMN	FC2, FC4	C1, C3,	P3, PO3,
Standard vs Phoneme Deviant	N400	-	-	-
Standard vs Rule Deviant	N400	F1, F3, FC1, FC3, F2, F4, FC2, FC4	C1, C3, CP1, CP3, C2, C4, CP2, CP4	P1, P5, PO3, P2, P6, PO4

Note. This table presents significant changes in the latency of ERP waveforms when comparing different stimuli (Standard vs Phoneme Deviant and Standard vs Rule Deviant) within the Vowel Condition. The EEG leads demonstrating Significant Latency changes are indicated for each ERP waveform (Early Component, MMN, and N400) across the anterior, central, and posterior regions. A hyphen (“-”) signifies the absence of significant latency changes. significance was determined at  $p < 0.05$ .

### 3.3 In consonant condition

When comparing the amplitudes of early component (around 45 milliseconds), MMN, and N400 in ERP profiles using independent t-tests, significant increases in waveform amplitude were observed with the oddball presentation of both types of deviant stimuli in a continuous stream of standard stimuli. These increases in waveform amplitude in response to phoneme deviant stimuli were globally observed in anterior, central, and posterior EEG leads, while presenting rule deviant stimuli showed such effects mostly in selected central

and posterior EEG leads (refer Table 4).

When comparing the amplitude in the time frame of the early component between standard stimuli and phoneme deviant stimuli, significant increases were observed at F1 ( $p = 0.004$ ), F3 ( $p = 0.036$ ), FC1 ( $p = 0.001$ ), FC1 ( $p = 0.001$ ), FC3 ( $p < 0.001$ ), F2 ( $p = 0.032$ ), F4 ( $p = 0.006$ ), FC2 ( $p = 0.005$ ), FC4 ( $p = 0.002$ ), C1 ( $p = 0.042$ ), CP1 ( $p = 0.004$ ), CP2 ( $p = 0.004$ ), CP4 ( $p = 0.036$ ), P1 ( $p = 0.005$ ), P3 ( $p = 0.019$ ), PO3 ( $p = 0.019$ ), P2 ( $p = 0.009$ ), P4 ( $p = 0.007$ ), P6 ( $p = 0.022$ ), and PO4 ( $p = 0.006$ ). Significant differences ( $P < 0.05$ ) were also observed at P1 ( $p = 0.014$ ) when comparing the amplitude of standard stimuli with that of rule deviant stimuli.

When considering the MMN component of the ERP waveform, significant increases in amplitude were observed when comparing the standard stimuli with phoneme deviant stimuli at F1 ( $p = 0.035$ ), F3 ( $p = 0.021$ ), FC1 ( $p = 0.014$ ), FC3 ( $p < 0.001$ ), F2 ( $p = 0.015$ ), F4 ( $p = 0.002$ ), FC2 ( $p = 0.020$ ), FC4 ( $p = 0.002$ ), C1 ( $p = 0.038$ ), C3 ( $p = 0.008$ ), CP1 ( $p < 0.001$ ), CP3 ( $p < 0.001$ ), C2 ( $p = 0.018$ ), C4 ( $p = 0.033$ ), CP2 ( $p = 0.001$ ), CP4 ( $p = 0.003$ ), P1 ( $p = 0.006$ ), P3 ( $p < 0.001$ ), P5 ( $p = 0.001$ ), PO3 ( $p < 0.001$ ), P2 ( $p = 0.001$ ), P4 ( $p = 0.020$ ), P6 ( $p = 0.017$ ), and at PO4 ( $p = 0.027$ ). Significant increases in amplitude were also observed at F4 ( $p = 0.030$ ), CP1 ( $p = 0.008$ ), CP2 ( $p = 0.018$ ), P3 ( $p = 0.008$ ), P5 ( $p = 0.049$ ), PO3 ( $p = 0.043$ ), and P2 ( $p = 0.022$ ) when comparing the amplitude of standard stimuli with rule deviant stimuli.

Significant increase in the amplitude of N400 waveform was observed at all twenty-four electrode sites while comparing the amplitude of N400 waveform between standard stimuli and phoneme deviant stimuli. The  $p$  values were significant at F1 ( $p = 0.040$ ), F3 ( $p = 0.028$ ), FC1 ( $p = 0.007$ ), FC3 ( $p < 0.007$ ), F2 ( $p = 0.008$ ), F4 ( $p < 0.001$ ), FC2 ( $p = 0.006$ ), FC4 ( $p = 0.006$ ), C1 ( $p = 0.003$ ), C3 ( $p < 0.001$ ), CP1 ( $p < 0.001$ ), CP3 ( $p = 0.001$ ), C2 ( $p = 0.001$ ), C4 ( $p = 0.002$ ), CP2 ( $p < 0.001$ ), CP4 ( $p < 0.001$ ), P1 ( $p < 0.001$ ), P3 ( $p < 0.001$ ), P5 ( $p = 0.004$ ), PO3 ( $p < 0.001$ ), P2 ( $p = 0.001$ ), P4 ( $p = 0.012$ ), P6 ( $p < 0.001$ ), and at PO4 ( $p = 0.032$ ). On the other hand, when comparing between standard stimuli and rule deviant stimuli, significant difference was observed only at selected electrode sites. The electrode sites and  $p$  values were F2 ( $p = 0.043$ ), FC2 ( $p = 0.019$ ), C3 ( $p = 0.005$ ), CP1 ( $p = 0.023$ ), CP3 ( $p = 0.013$ ), C2 ( $p = 0.020$ ), CP2 ( $p = 0.033$ ), CP4 ( $p = 0.017$ ), P1 ( $p = 0.007$ ), P6 ( $p = 0.026$ ), and at PO4 ( $p = 0.034$ ).



Table 4. The EEG leads exhibiting significant changes in amplitude of respective ERP waveforms when compared across different stimuli in consonant condition

Comparison	ERP waveform	Significant change in amplitude of ERP waveform in EEG leads ( $p < 0.05$ )		
		Anterior	Central	Posterior
Standard vs Phoneme Deviant	Early component	F1, F3, FC1, FC3, F2, F4, FC2, FC4	C1, CP1, CP2, CP4	P1, P3, PO3, P2, P4, P6, PO4
Standard vs Rule Deviant	Early component	-	-	P1
Standard vs Phoneme Deviant	MMN	F1, F3, FC1, FC3, F2, F4, FC2, FC4	C1, C3, CP1, CP3, C2, C4, CP2, CP4	P1, P3, P5, PO3, P2, P4, P6, PO4
Standard vs Rule Deviant	MMN	F4	CP1, CP2	P3, P5, PO3, P2
Standard vs Phoneme Deviant	N400	F2, FC2	C3, CP1, CP3, C2, CP2, CP4	P1, P6, PO4
Standard vs Rule Deviant	N400	-	CP3, C2, C4, CP2, CP4	P3, PO3, P6

Note: This table presents significant changes in the amplitude of ERP waveforms when comparing different stimuli (Standard vs Phoneme Deviant and Standard vs Rule Deviant) within the Consonant Condition. The EEG leads demonstrating Significant amplitude changes are indicated for each ERP waveform (Early Component, MMN, and N400) across the anterior, central, and posterior regions. A hyphen (“-”) signifies the absence of significant amplitude changes. Significance was determined at  $p < 0.05$ .

In the consonant condition, significant differences were observed in the latency of the early component, MMN, and N400 of ERP components when comparing standard stimuli with phoneme deviant stimuli and rule deviant stimuli, but only at selected electrodes. The effect was mostly centrally and posteriorly localized, indicating the involvement of these brain regions in processing phonemic information and lexical access of a particular language (refer Table 5).

In the early component of ERP, the latency of standard stimuli was in the range of 53ms to 62ms, while the latency of phoneme deviant stimuli ranged

from 47ms to 55ms at different electrode sites. Significant differences were observed at FC2 ( $p = 0.016$ ), FC4 ( $p = 0.012$ ), C3 ( $p = 0.024$ ), CP3 ( $p = 0.039$ ), C2 ( $p = 0.027$ ), P5 ( $p = 0.014$ ), PO3 ( $p = 0.007$ ), and P2 ( $p = 0.029$ ). When comparing the latency of standard stimuli with rule deviant stimuli, which ranged from 51ms to 60ms, no significant difference was observed in the early waveform component.

In the MMN component window, the latency of standard stimuli was in the range of 180ms to 198ms, while the latency of phoneme deviant stimuli was 175ms to 184ms at different electrode sites. Significant differences were observed at FC2 ( $p = 0.016$ ), FC4 ( $p = 0.012$ ), C3 ( $p = 0.024$ ), CP3 ( $p = 0.039$ ), C2 ( $p = 0.027$ ), P5 ( $p = 0.014$ ), PO3 ( $p = 0.007$ ), and P2 ( $p = 0.029$ ). When comparing the latency of MMN with respect to standard and rule deviant stimuli, which had a latency of 178ms to 187ms, significant differences were observed at F1 ( $p = 0.005$ ) and P2 ( $p = 0.029$ ) only.

In the N400 component, the latency of standard stimuli was in the range of 385ms to 407ms, while the latency of phoneme deviant stimuli was 393ms to 420ms at different electrode sites. Significant differences were observed at CP3 ( $p = 0.017$ ), C2 ( $p = 0.002$ ), C4 ( $p = 0.003$ ), CP2 ( $p = 0.021$ ), CP4 ( $p = 0.003$ ), P3 ( $p = 0.049$ ), PO3 ( $p = 0.013$ ), and P6 ( $p = 0.015$ ). When comparing the latency of standard stimuli with rule deviant stimuli, which ranged from 385ms to 412ms, a significant difference was observed only at F1 ( $p = 0.022$ ).

Table 5. The EEG leads exhibiting significant changes in latency of respective ERP waveforms when compared across different stimuli in consonant condition

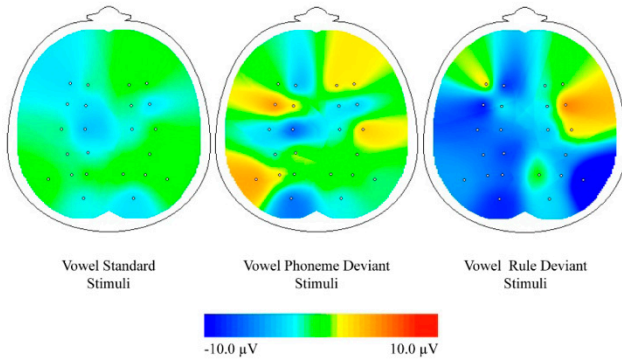
Comparison	ERP waveform	Significant Change in Latency of ERP waveform in EEG Leads ( $p < 0.05$ )		
		Anterior	Central	Posterior
Standard vs Phoneme Deviant	Early component	FC2, FC4	C3, CP3, C2	P5, PO3, P2
Standard vs Rule Deviant	Early component	-	-	-
Standard vs Phoneme Deviant	MMN	F1, FC1, F3, F4, FC2, FC4	C2, CP4,	PO3, P2, P4, PO4
Standard vs Rule Deviant	MMN	F1	-	P2
Standard vs Phoneme Deviant	N400	-	CP3, C2, C4, CP2, CP4	P3, PO3, P6
Standard vs Rule Deviant	N400	F1	-	-

Note: This table presents significant changes in the latency of ERP waveforms when comparing different stimuli (Standard vs Phoneme Deviant and Standard vs Rule Deviant) within the Consonant Condition. The EEG leads demonstrating Significant Latency changes are indicated for each ERP waveform (Early Component, MMN, and N400) across the anterior, central, and posterior regions. A hyphen (“-”) signifies the absence of significant latency changes. significance was determined at  $p < 0.05$ .

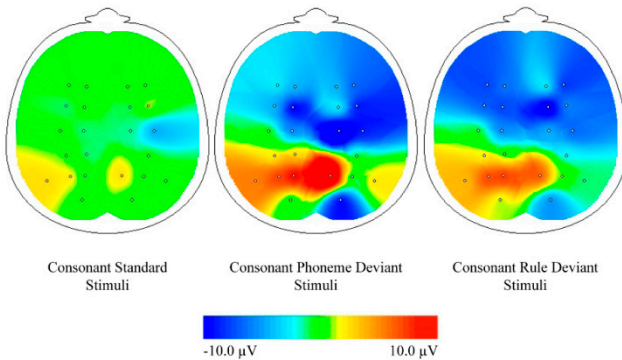
Such a selective and differential neural dynamical response of ERPs namely, P50 and MMN and N400 in vowel condition while presenting rule deviant paradigm only (and not in phoneme deviant epitome) across the linguistic coordinates of vowels, the primal representative edifice of neural language, implicates a neural dynamical sensorial and associative response suggestive of associative (syntactic) learning wherein vowels seemingly initiates the rule learning task of abstraction. In contrast to these significant changes in ERP profiles while comparing the standard stimuli with phoneme deviant globally across anterior, central and posterior EEG leads as well as with presentation of rule deviant stimuli across selected EEG leads only underscores the salience of

consonants in datamining of lexicon access and recognition, admixed with associative abstraction as well, from the pre-formed neural linguistic forest in a rule learning task across select distributed neuronal pools. While comparing the amplitude across both conditions, significant results were obtained only in MMN window with respect to standard stimuli, although while comparing the phoneme deviant and rule deviant stimuli respectively across both the condition significant difference was observed across various electrode sites. Whereas while comparing the latencies of different ERP profiles across both conditions vowel and consonant, the latency in vowel condition where rule was applied to the vowels and consonants are randomly placed in a trisyllabic non word stimuli, the observed latency was less than that of respective stimuli of consonant condition. Hence suggesting a better use of vowels in rule abstraction task than consonants though it was evinced by behavioural test as well that participants learn the rule independently of whether it was implemented over consonants or vowels in a rule learning task.

Figure 1 and 2 show the head maps of the two conditions, the vowel condition, and the consonant condition, respectively, when different stimuli e.g., standard, Phoneme deviant and rule deviant stimuli are presented. The brain topographic maps of the grand average are depicting the neural responses elicited by different types of stimuli in an oddball paradigm, providing a spatial representation of the neural activity across the scalp. By averaging the brain response across all participants, the grand average maps highlight the common pattern of activation (increased neural activation), or inhibition (decreased neural activation) observed in the brain. These spatial patterns provide insights into the neural processing and cognitive mechanism involved in discriminating between the standard and deviant stimuli. In the vowel condition, maps depict an increased activation with rule deviant stimuli whereas such a response was observed with both phoneme and rule deviant in the consonant condition.



*Figure 1. The head maps in Consonant Condition with different stimuli; Standard Stimuli, Phoneme Deviant Stimuli and Rule Deviant Stimuli, showing increased activation with only Rule Deviant Stimuli when compared with Standard Stimuli not with Phoneme Deviant Stimuli*



*Figure 2. The head maps in Consonant Condition with different stimuli; Standard Stimuli, Phoneme Deviant Stimuli and Rule Deviant Stimuli, showing increased activation with both Phoneme and Rule Deviant Stimuli when compared with Standard Stimuli*

## 4. DISCUSSION

### *4.1 Differential role of vowels and consonants in a rule learning task*

The present study was an attempt to evaluate the hypothesis that states Consonants incidentally happen to be the triggering fulcrum of lexicon access entities i.e., word mining, word hunting and retrieval from the lowland marshmallow of words so acquired and learnt and Vowels are harbinger elements that augur the abstraction principle (principle/rule of abstraction), the basic dictum that tends to reduce redundancy and duplication, forming the qualia of language. The underlying neural dynamics of lexicon access through consonants (quanta) and abstraction principle through vowels (qualia), were acquired and digitally processed and evaluated to appreciate the primal neural mechanism responsible for salience of learning of a means of communication that is alien and structured, language, across the landscape of electroencephalographic (EEG) and event-related potentials (ERPs) waveform patterning.

The Event-Related Potentials (ERPs) correlates of early waveforms, MMN and N400 entities namely, amplitude and latency, were analysed at scalp areas of left anterior region (F1, F3, FC1, FC3), right anterior region (F2, F4, FC2, FC4), left central region (C1, C3, CP1, CP3), right central region (C2, C4, CP2, CP4), left posterior region (P1, P3, P5, PO3) and right posterior region (P2, P4, P6, PO4). These regions were chosen in order to assess and explore the effect of rule abstraction task of the Working Human Mind in real-time at the said targeted area as the underlying specific areas of human brain have been proposed to be the nidus seeding zones responsible for neural dynamical processing antecedent to abstract regularities that incidentally happens to the singular and primal neurophysiological event, quintessential to learning of the so-called structured means of communication known as language. In the present study, the patterning of amplitude and latency components of ERP early waveforms, MMN, N400 in response to different events/stimuli of standard stimuli, phoneme deviant stimuli and rule deviant stimuli were comparatively assessed across proviso of both consonant and vowel condition, i.e., when the rules were applied and run-on on vowels in a three syllabic CVCVCV non-word and on the three-syllabic consonants non-word. The comparison was made within the condition amongst different stimuli classes and also across the vowel and consonant conditions.

In the vowel condition, the presentation of standard auditory stimuli with infrequent deviant stimuli (either the rule deviant or phoneme deviant) did not show any significant difference in the component during the presentation of phoneme deviant stimuli. However, when rule deviant stimuli were presented in the vowel condition, a significant increase in amplitude (i.e., heightened

ERP amplitude) was observed globally across the anterior, central, and posterior EEG leads. The ABA rule deviant stimuli, compared to the ABB rule prototype, evoked a significant increase in P50 early component, MMN, and N400 waveforms along the vowel axis, representing the inherent neural dynamical response to novel stimuli of ABA rule deviant phenomenology amidst sequential ABB prototypes. This response exemplifies the distinctive featured response of distributed neuronal pools to a novel stimulus, known as Event-Related Synchrony (ERS), which characterizes the rule/principle abstraction qualia of vowels, setting in motion the “abstraction principle”, the distinguishing neurophysiological feature (feature detector) of vowels.

The observation of the significant difference in amplitude across the anterior, central and posterior EEG leads during the presentation of rule deviant stimuli over vowel condition supports the role of vowels in rule abstraction in language processing (Key et al., 2005). This phenomenon, characterized by the early component at 45 ms, reflects the arousal level of the participant subjects listening to speech sequences (Morris et al., 2016). Similar findings have been documented in P50 dynamics after subtle variations in synthesized diphthongs (Monte-Ordoño & Toro, 2017). The MMN ERP waveform is observed after the presentation of deviant and novel auditory stimuli, including speech (Escera et al., 2000; Pulvermüller & Shtyrov, 2003). Although the N400 component has traditionally been associated with lexical processes, some studies have observed its involvement in abstract structure processing in a rule learning task (Mueller et al., 2012), abstract grammar processing (Choudhary et al., 2009), and non-members in a categorization task (Núñez Peña & Honrubia-Serrano, 2005). Furthermore, the enhanced amplitude across rule deviant stimuli represents the neural conception of a novel stimulus that needs to be learned and consolidated as memory across the interfacial neuronal system of the Mirror Neuron System (MNS) through self-iterating neural mechanisms transforming the singularity of Event-Related Synchrony (ERS) into open neural gates of Event-Related Desynchrony (ERD), facilitating the flow of information that is tangible, reproducible, and learned (Muthukumaraswamy & Singh, 2008).

The latency of early component, MMN, and N400 of ERP variables did not show a significant change across the standard stimuli and phoneme deviant stimuli conditions. However, a significant difference in latency of these ERP waveforms was observed across the anterior, central, and posterior EEG leads when compared between the standard stimuli and rule deviant conditions. The difference in latency was more pronounced in the N400 component of the ERP waveform in both the right and left hemispheres. The early component and MMN variable of the ERP waveform showed a quantal decrease in latency, which was more profound in the left hemispheric EEG lead compared to the

right hemispheric EEG lead. Morris et al. (2016) observed a longer latency in early components with attention condition compared to divert condition. While a significant difference was only found with rule deviant in the present study, Pakarinen et al. (2013) observed a decrease in latency when deviating the phonemic category, duration, and loudness in semi-synthetic vowel stimuli presented in an oddball paradigm.

It is intriguing to note that vowels, which are fundamental to language, trigger an inherent rule/principle abstraction process during neuronal processing. This process is reflected in a patterned response of statistically significant increased amplitude in ERP waveforms of the early component, MMN, and N400 when the vowel violates the rule. The latency of the early component and MMN waveforms is decreased, while the timeline for the appearance of the N400 waveform is enhanced. The exotic gate of ERS, manifested in the form of an enhanced amplitude and decreased latency in the exogenous component, along with an increased endogenous N400 latency, serves as the basic neuronal effect observed in this study. This event contributes to the underlying parametric principle of language, which is superimposed with time constraints.

In the context of consonant condition, it was observed that the amplitude of early component, P50, showed a significant increase (around 53 ms) on presentation of phoneme deviant stimuli globally across anterior, central, and posterior electrode sites. However, for rule deviant stimuli, a similar comparative increase in amplitude was observed locally and singularly across the posterior parietal EEG electrode site of P50 only, as compared to the averaged amplitude graphic on standard stimuli presentation. This comprehensive and unqualified ERP waveform amplitude peaking across phoneme deviant stimuli indicates the discriminatory lexicon access function of consonants, which has been reported in previous studies as well (Cutler et al., 2000; Pons & Toro, 2010).

However, the amplitude variability pattern across MMN and N400 ERP waveforms across varied EEG electrode sites was different. A significant increase in ERP waveforms amplitude in the phoneme deviant stimuli (*vis-à-vis* standard stimuli in MMN waveform at around 180 ms) could be appreciated globally across all EEG electrode sites, though the rule deviant stimuli paradigm could also elicit significant increase in amplitude of the waveform across select frontal, central and posterior EEG electrode sites of F4, C1, C2, P3, P5, PO3 and P2. A similar observation could also be appreciated across N400 ERP waveform response to the paradigmatic research protocol wherein a global amplitude increase on presentation of phoneme deviant stimuli (*vis-à-vis* standard stimuli) could be appreciated, though a localized amplitude increase could be appreciated on presentation of rule deviant stimuli (*vis-à-vis* standard



stimuli) across select central and posterior EEG electrode sites namely CP3, C2, C4, CP2, CP4 and P3, PO3, P6, respectively. This is an interesting observation in across the premise that consonants, in their pristine edifice, are primarily involved in lexicon access and such a dual divergent profiling across both phoneme and rule deviants gives an ambivalent spectrum and flavour to the entity of consonants, underscoring the fact that consonants (so conscripted in the present research design) on voicing essentially need the spousal support and patronage of vowels. Moreover, as highlighted earlier, the primacy and novelty of a stimulus are singularly etched on the stochastic trajectorial phase-space of human mind as ERS (Event-Related Synchrony), the distributed neuronal pools firing in phase and synchrony in response to a perceivable and legitimate neural stimulus that with the timeline and time frame of neurophysiological cellular and molecular correlates of memory and learning is morphed and transformed into ERD (Event-Related Desynchrony; Krause 2006; Gomarus et al., 2006; Pesonen et al., 2006).

It would be worthwhile to mention that such a patterned reinforced neural dynamical global response to the trisyllabic syllable of CVCVCV being manipulated experimentally across phoneme axis in consonant condition underscores the fact that presentation of novel consonant phoneme acoustic (through phoneme deviant stimuli) recruits dedicated neuronal pools across the cortical hemispheres to evolve the archetypal peaking neural response of an unlearned behaviour (metamorphosed into blunting decreased amplitude response of a learned behaviour) (Dong et al., 2015; Gomarus et al., 2006). These heightened ERP waveforms represent neural dynamical closed system gates at the mesoscopic level, which are transformed and translated through the molecular neurophysiological synaptic mechanism of memory into neural dynamical open system gates of Event-Related Desynchrony (ERD; Pfurtscheller & Da Silva, 1999).

The neural dynamical response at the mesoscopic level reflects the appearance of a learned memory of the event on the horizon of the human mind's stochastic trajectorial phase-space, which is reflective of the underlying ongoing cellular neurophysiological process of successful flow of neural information. ERS (Event-Related Synchrony), on the other hand, represents the neural dynamical response to a novel event with closed neural gates, wherein the flow of neural information takes place only upon the successful acquisition of learned memory neural molecular synaptic correlates (Rossi et al., 2006; Marblestone et al., 2016). These events are represented mesoscopically through open neural gates of ERD.

The response of the ERP character in the consonant condition to the two deviant stimuli of phoneme and rule precept is ambivalent, as distinct from the singular response observed in rule deviant stimuli when executed through vowel

preceptorial landscape, highlighting the salience of vowels in the abstraction principle. This corroborates the admixed qualia of consonants in assessing the lexicon from the available and learnt lexical repertoire through their specific neural signature pool and the associative abstraction role of consonant, which essentially requires admixture with vowels for voicing from the pre-formed neural linguistic plasma/sea in a rule learning task across select distributed neuronal pools (Crowther & Mann, 1994). The increased amplitude of the early component of ERP suggests the processing of novel syllable transitions present within the deviant stimuli. Such processing likely involves online updating of the incongruent information present in the deviant stimuli (compared to the standard stimuli) (Monte-Ordoño & Toro, 2017). The increased amplitude with respect to the MMN component after presentation of both phoneme and rule deviant stimuli is typically due to local, physical changes in the auditory input (Bekinschtein et al., 2009). The association of the N400 ERP waveform with the lexical search needs further elaboration (Kutas & Federmeier, 2000; Lau et al., 2008), and the observations of the present research protocol that exemplify a significant dual response in both deviant stimuli conditions (rule and phoneme) further substantiate the reliance of consonants on vowels, which have a logical and mutual betrothal for making their appearance on the horizon of the neurolinguistic plane (Sandoval & Gomez, 2013). In the consonant condition, a significant difference in the latency of novel phoneme deviant stimuli (compared to standard stimuli) can be appreciated in the early component of ERP and MMN, P50 globally in anterior, central, and posterior electrode sites. However, with rule deviant stimuli, a localized response in the latency of MMN was appreciated in select anterior and posterior EEG electrode sites. On the other hand, the latency correlates of the N400 endogenous (representing associative cognitive neural processing) ERP waveform increased in both phoneme and rule deviant stimuli protocols. This response with the phoneme deviant stimuli profiled a more generalized response across central and posterior EEG electrode sites, while rule deviant stimuli registered a significant response only at select anterior EEG electrode sites (F1 EEG lead).

These findings demonstrate the distinct neural electrophysiological responses to violating abstract rules across different phonetic categories of vowels and consonants in a task involving pattern generalization and lexical decision-making. The distinctive characteristic across the neural feature detectors of vowels and consonants appears early in the stochastic phase-space of the human mind and can be observed along both exogenous and endogenous ERP waveforms. The changing patterning of consonants initiates neural processes involved in lexicon access and semantic learning, resulting in enhanced MMN and N400 ERP waveform responses to phonemic variation

and deviation. In contrast, the variable vowel abstraction rule patterning initiates neural dynamics that give rise to the singularity of syntactic learning.

Such an inferential undermines the neural categorical connectomes of vowels and consonants in rule/principle abstraction and lexicon recognition and access that go on to form constructs for syntax and semantics, respectively. The differential neural dynamic responses as exemplified by categorical representation in form of significant decrease in latency and or increase in amplitude suggest and support the modular fractal functioning of the human mind, where the fractals of latency and amplitude iterate and self-iterate that tend to form a pattern, reproducible and validated, specific for unitary and replete language constituents of vowels and consonants. The increased amplitude of ERP waveform exemplifies Event-Related Synchrony (ERS) of neuronal pools firing in phase and archetypal of innate neural processing of information consolidation and representation of the arrival of the novel stimulus on the stochastic trajectorial horizon of Human Mind that is subsequently transformed through saturation of the self-iterative neural processing into memory and learning exemplified on the mesoscopic scale as Event-Related Desynchrony (ERD), the harbinger to open neural gate system facilitating flow of information for further processing and association. The global response along categorial comparative analysis of deviant and standard stimuli within and across consonants and vowels conditions further necessitates the presence of an interfacial neuronal system, Mirror Neuron System (MNS), that upholds the primacy of neural dynamics of ERS and ERD, the gateway for facilitation of flow of tangible, adequate and reproducible neural information essential for association and cognitive processing.

#### *4.2 Behavioural test*

In a study, participants were presented with a set of stimuli and later underwent a test where they were presented with pairs of novel non-words. One word in each pair followed the same ABB rule as the standard stimuli, while the other followed an ABC rule depending on whether it was implemented on vowels or consonants. The percentage of correct responses was compared against a chance level of 50%. Results showed that participants were able to learn the rule independently of whether it was implemented on consonants or vowels, with performance above chance in both the vowel condition (mean = 61.25%, SD of 11.536) and consonant condition (mean = 60.416%, SD of 12.319).

Previous studies (Toro et al., 2008) had found it difficult for participants to learn rules over consonants in a non-word stimulus when the exposure time was only 5 minutes. However, in the current experiment, the exposure time

was 45 minutes, which suggests that the lengthy exposure to words with an abstract pattern gave participants enough time to identify the rules over both consonants and vowels. Similar results were observed in another study where participants were presented with tokens instantiating the rule for approximately 30 minutes (Monte-Ordoño & Toro, 2017).

#### *4.3 Future perspectives*

The results of the present study add to a growing literature demonstrating that vowels and consonants trigger different neural responses, as exemplified during abstract rule learning wherein early ERP components, MMN and N400 waveforms could form potential candidates for detection of the neural signature of vowel and consonant profiles in the field of neurolinguistics, that could act as the platform for development of the hierarchical fractal algorithm needed in the domain of Brain-Computer Interface [BCI], an offshoot of Machine Learning and Artificial Intelligence. The segregation and categorisation of constituent letters of any language into vowels and consonants (during its evolution and growth through phonemic environment) on the basis of the different articulatory mechanistic seem to profile the constituent letters [vowels and consonants], phonemes, syllables, words, phrase and sentence and determine their orderly placement giving rise to a meaningful word, and hence evolving a definite means of communication which is viable in the present scenario and is tend to be valid and reproducible in the future and hence supporting the argument that the architecture of the mind is more pervasively modular.

#### *4.4 Limitations*

The present study has limitations, including the use of Ag/AgCl surface electrodes that may have caused errors in signal quality due to electrode movement on the scalp. The testing room, while sound attenuated, was not completely quiet, and the absence of Electrooculogram recordings may have missed eye blink artifacts. Head movement during recording may have also affected results. Nevertheless, the study's findings offer valuable insights into neural responses to vowels and consonants and their implications for Brain-Computer Interfaces using machine learning and artificial intelligence.

#### *Data availability*

The data that support the findings of this study are available on request from

the corresponding author, Minal Kachhawa. The data are not publicly available due to the privacy restrictions of the participants.

*Ethic Statement*

The present cross sectional observational comparative study was conducted at Department of Physiology, S.M.S. Medical College and Attached Group of Hospitals, Jaipur, India after obtaining the desired clearance from Institutional Research Review Board and Ethics Committee of the S.M.S Medical College and Hospital and is a result of self-initiated research undertaken in the domain of Biological Signal Processing and Human Mind Modelling

*Funding and Competing Interests*

No financial (intramural and/or extramural) support from any funding agency

*Author's contributions*

We attest to the fact that all Authors listed on the title page have contributed significantly to the work, have read the manuscript, attest to the validity and legitimacy of the data and its interpretation, and agree to its submission.

REFERENCES

- Bekinschtein, T. A., Dehaene, S., Rohaut, B., Tadel, F., Cohen, L., & Naccache, L. (2009). Neural signature of the conscious processing of auditory regularities. *Proceedings of the National Academy of Sciences*, *106*(5), 1672-1677. <https://doi.org/10.1073/pnas.0809667106>
- Binder, J. R., Frost, J. A., Hammeke, T. A., Bellgowan, P. S., Springer, J. A., Kaufman, J. N., & Possing, E. T. (2000). Human temporal lobe activation by speech and nonspeech sounds. *Cerebral cortex*, *10*(5), 512-528. <https://doi.org/10.1093/cercor/10.5.512>
- Bonatti, L. L., Pena, M., Nespors, M., & Mehler, J. (2005). Linguistic constraints on statistical computations: The role of consonants and vowels in continuous speech processing. *Psychological Science*, *16*(6), 451-459. <https://doi.org/10.1111/j.0956-7976.2005.01556.x>
- Bonatti, L. L., Pena, M., Nespors, M., & Mehler, J. (2007). On consonants, vowels, chickens, and eggs. *Psychological Science*, *18*(10), 924-925. <https://doi.org/10.1111/j.1467-9280.2007.02002.x>
- Caramazza, A., Chialant, D., Capasso, R., & Miceli, G. (2000). Separable processing of consonants and vowels. *Nature*, *403*(6768), 428-430. <https://doi.org/10.1038/35000206>
- Carreiras, M., & Price, C. J. (2008). Brain activation for consonants and vowels. *Cerebral Cortex*, *18*(7), 1727-1735. <https://doi.org/10.1093/cercor/bhm202>
- Carreiras, M., Vergara, M., & Perea, M. (2009). ERP correlates of transposed letter priming effects: The role of vowels versus consonants. *Psychophysiology*, *46*(1), 34-42. <https://doi.org/10.1111/j.1469-8986.2008.00725.x>
- Choudhary, K. K., Schlesewsky, M., Roehm, D., & Bornkessel-Schlesewsky, I. (2009). The N400 as a correlate of interpretively relevant linguistic rules: Evidence from Hindi. *Neuropsychologia*, *47*(13), 3012-3022. <https://doi.org/10.1016/j.neuropsychologia.2009.05.009>
- Cotelli, M., Abutalebi, J., Zorzi, M., & Cappa, S. F. (2003). Vowels in the buffer: A case study of acquired dysgraphia with selective vowel substitutions. *Cognitive Neuropsychology*, *20*(2), 99-114. <https://doi.org/10.1080/02643290244000158>
- Crowther, C. S., & Mann, V. (1994). Use of vocalic cues to consonant voicing and native language background: The influence of experimental design. *Perception & Psychophysics*, *55*, 513-525. <https://doi.org/10.3758/BF03205309>

- Cutler, A., Sebastián-Gallés, N., Soler-Vilageliu, O., & Van Ooijen, B. (2000). Constraints of vowels and consonants on lexical selection: Cross-linguistic comparisons. *Memory & cognition*, 28(5), 746-755. <https://doi.org/10.3758/BF03198409>
- Davis, M. H., & Johnsruide, I. S. (2003). Hierarchical processing in spoken language comprehension. *Journal of Neuroscience*, 23(8), 3423-3431. <https://doi.org/10.1523/JNEUROSCI.23-08-03423.2003>
- De Jong, P. F., & Van der Leij, A. (2003). Developmental changes in the manifestation of a phonological deficit in dyslexic children learning to read a regular orthography. *Journal of Educational Psychology*, 95(1), 22. <https://psycnet.apa.org/doi/10.1037/0022-0663.95.1.22>
- Dong, S., Reder, L. M., Yao, Y., Liu, Y., & Chen, F. (2015). Individual differences in working memory capacity are reflected in different ERP and EEG patterns to task difficulty. *Brain research*, 1616, 146-156. <https://doi.org/10.1016/j.brainres.2015.05.003>
- Dube, A., Kumar, U., Gupta, K., Gupta, J., Patel, B., Singhal, S. K., ... & Dube, S. (2021). Language as the Working Model of Human Mind. In *Brain-Computer Interface*. IntechOpen.
- Duffau, H., Moritz-Gasser, S., & Mandonnet, E. (2014). A re-examination of neural basis of language processing: proposal of a dynamic hodotopical model from data provided by brain stimulation mapping during picture naming. *Brain and language*, 131, 1-10 <https://doi.org/10.1016/j.bandl.2013.05.011>.
- Edworthy, J., Hellier, E., Walters, K., Clift Mathews, W., & Crowther, M. (2003). Acoustic, semantic and phonetic influences in spoken warning signal words. *Applied Cognitive Psychology: The Official Journal of the Society for Applied Research in Memory and Cognition*, 17(8), 915-933. <https://doi.org/10.1002/acp.927>
- Escera, C., Yago, E., Polo, M. D., & Grau, C. (2000). The individual replicability of mismatch negativity at short and long inter-stimulus intervals. *Clinical Neurophysiology*, 111(3), 546-551. [https://doi.org/10.1016/S1388-2457\(99\)00274-6](https://doi.org/10.1016/S1388-2457(99)00274-6)
- Ferreres, A. R., López, C. V., & China, N. N. (2003). Phonological alexia with vowel-consonant dissociation in non-word reading. *Brain and Language*, 84(3), 399-413. [https://doi.org/10.1016/S0093-934X\(02\)00559-X](https://doi.org/10.1016/S0093-934X(02)00559-X)
- Gomarus, H. K., Althaus, M., Wijers, A. A., & Minderaa, R. B. (2006). The effects of memory load and stimulus relevance on the EEG during a visual selective memory search task: an ERP and ERD/ERS study. *Clinical*

- Neurophysiology*, 117(4), 871-884.  
<https://doi.org/10.1016/j.clinph.2005.12.008>
- Hickok, G., & Poeppel, D. (2007). The cortical organization of speech processing. *Nature reviews neuroscience*, 8(5), 393-402.  
<https://doi.org/10.1038/nrn2113>
- Key, A. P. F., Dove, G. O., & Maguire, M. J. (2005). Linking brainwaves to the brain: an ERP primer. *Developmental neuropsychology*, 27(2), 183-215.  
[https://doi.org/10.1207/s15326942dn2702\\_1](https://doi.org/10.1207/s15326942dn2702_1)
- Krause, C. M. (2006). Cognition-and memory-related ERD/ERS responses in the auditory stimulus modality. *Progress in brain research*, 159, 197-207.  
[https://doi.org/10.1016/S0079-6123\(06\)59013-2](https://doi.org/10.1016/S0079-6123(06)59013-2)
- Kutas, M., & Federmeier, K. D. (2000). Electrophysiology reveals semantic memory use in language comprehension. *Trends in cognitive sciences*, 4(12), 463-470. [https://doi.org/10.1016/S1364-6613\(00\)01560-6](https://doi.org/10.1016/S1364-6613(00)01560-6)
- Lau, E. F., Phillips, C., & Poeppel, D. (2008). A cortical network for semantics:(de) constructing the N400. *Nature reviews neuroscience*, 9(12), 920-933. <https://doi.org/10.1038/nrn2532>
- Liebenthal, E., Binder, J. R., Spitzer, S. M., Possing, E. T., & Medler, D. A. (2005). Neural substrates of phonemic perception. *Cerebral cortex*, 15(10), 1621-1631. <https://doi.org/10.1093/cercor/bhi040>
- Marblestone, A. H., Wayne, G., & Kording, K. P. (2016). Toward an integration of deep learning and neuroscience. *Frontiers in computational neuroscience*, 94. <https://doi.org/10.3389/fncom.2016.00094>
- McCarthy, G., & Wood, C. C. (1985). Scalp distributions of event-related potentials: an ambiguity associated with analysis of variance models. *Electroencephalography and Clinical Neurophysiology/Evoked Potentials Section*, 62(3), 203-208. [https://doi.org/10.1016/0168-5597\(85\)90015-2](https://doi.org/10.1016/0168-5597(85)90015-2)
- Middlebrooks, J. C., Simon, J. Z., Popper, A. N., & Fay, R. R. (Eds.). (2017). *The auditory system at the cocktail party* (Vol. 60). New York:: Springer.
- Monte-Ordoño, J., & Toro, J. M. (2017). Different ERP profiles for learning rules over consonants and vowels. *Neuropsychologia*, 97, 104-111. <https://doi.org/10.1016/j.neuropsychologia.2017.02.014>
- Morris, D. J., Steinmetzger, K., & Tøndering, J. (2016). Auditory event-related responses to diphthongs in different attention conditions. *Neuroscience letters*, 626, 158-163. <https://doi.org/10.1016/j.neulet.2016.05.002>



- Mueller, J. L., Friederici, A. D., & Männel, C. (2012). Auditory perception at the root of language learning. *Proceedings of the National Academy of Sciences*, *109*(39), 15953-15958. <https://doi.org/10.1073/pnas.1204319109>
- Muthukumaraswamy, S. D., & Singh, K. D. (2008). Modulation of the human mirror neuron system during cognitive activity. *Psychophysiology*, *45*(6), 896-905. <https://doi.org/10.1111/j.1469-8986.2008.00711.x>
- Nespor, M., Peña, M., & Mehler, J. (2003). On the different roles of vowels and consonants in speech processing and language acquisition. *Lingue e linguaggio*, *2*(2), 203-230.
- Núñez-Peña, M. I., & Honrubia-Serrano, M. L. (2005). N400 and category exemplar associative strength. *International Journal of Psychophysiology*, *56*(1), 45-54. <https://doi.org/10.1016/j.ijpsycho.2004.09.006>
- Oberman, L. M., & Ramachandran, V. S. (2007). The simulating social mind: the role of the mirror neuron system and simulation in the social and communicative deficits of autism spectrum disorders. *Psychological bulletin*, *133*(2), 310. <https://psycnet.apa.org/doi/10.1037/0033-2909.133.2.310>
- Obleser, J., & Kotz, S. A. (2010). Expectancy constraints in degraded speech modulate the language comprehension network. *Cerebral cortex*, *20*(3), 633-640. <https://doi.org/10.1093/cercor/bhp128>
- Okada, K., Rong, F., Venezia, J., Matchin, W., Hsieh, I. H., Saberi, K., ... & Hickok, G. (2010). Hierarchical organization of human auditory cortex: evidence from acoustic invariance in the response to intelligible speech. *Cerebral Cortex*, *20*(10), 2486-2495. <https://doi.org/10.1093/cercor/bhp318>
- Pakarinen, S., Teinonen, T., Shestakova, A., Kwon, M. S., Kujala, T., Hämäläinen, H., ... & Huotilainen, M. (2013). Fast parametric evaluation of central speech-sound processing with mismatch negativity (MMN). *International Journal of Psychophysiology*, *87*(1), 103-110. <https://doi.org/10.1016/j.ijpsycho.2012.11.010>
- Pesonen, M., Björnberg, C. H., Hämäläinen, H., & Krause, C. M. (2006). Brain oscillatory 1–30 Hz EEG ERD/ERS responses during the different stages of an auditory memory search task. *Neuroscience letters*, *399*(1-2), 45-50. <https://doi.org/10.1016/j.neulet.2006.01.053>
- Pfurtscheller, G., & Da Silva, F. L. (1999). Event-related EEG/MEG synchronization and desynchronization: basic principles. *Clinical neurophysiology*, *110*(11), 1842-1857. [https://doi.org/10.1016/S1388-2457\(99\)00141-8](https://doi.org/10.1016/S1388-2457(99)00141-8)

- Pons, F., & Toro, J. M. (2010). Structural generalizations over consonants and vowels in 11-month-old infants. *Cognition*, 116(3), 361-367. <https://doi.org/10.1016/j.cognition.2010.05.013>
- Pulvermüller, F., & Shtyrov, Y. (2003). Automatic processing of grammar in the human brain as revealed by the mismatch negativity. *Neuroimage*, 20(1), 159-172. [https://doi.org/10.1016/S1053-8119\(03\)00261-1](https://doi.org/10.1016/S1053-8119(03)00261-1)
- Ramus, F., Nespors, M., & Mehler, J. (1999). Correlates of linguistic rhythm in the speech signal. *Cognition*, 73(3), 265-292. [https://doi.org/10.1016/S0010-0277\(99\)00058-X](https://doi.org/10.1016/S0010-0277(99)00058-X)
- Rossi, S., Pasqualetti, P., Zito, G., Vecchio, F., Cappa, S. F., Miniussi, C., ... & Rossini, P. M. (2006). Prefrontal and parietal cortex in human episodic memory: an interference study by repetitive transcranial magnetic stimulation. *European Journal of Neuroscience*, 23(3), 793-800. <https://doi.org/10.1111/j.1460-9568.2006.04600.x>
- Sandoval, M., & Gomez, R. L. (2013). The development of nonadjacent dependency learning in natural and artificial languages. *Wiley Interdisciplinary Reviews: Cognitive Science*, 4(5), 511-522. <https://doi.org/10.1002/wcs.1244>
- Scott, S. K., Blank, C. C., Rosen, S., & Wise, R. J. (2000). Identification of a pathway for intelligible speech in the left temporal lobe. *Brain*, 123(12), 2400-2406. <https://doi.org/10.1093/brain/123.12.2400>
- Song, H., Kim, M., Park, D., Shin, Y., & Lee, J. G. (2022). Learning from noisy labels with deep neural networks: A survey. *IEEE Transactions on Neural Networks and Learning Systems*. <https://doi.org/10.1109/TNNLS.2022.3152527>
- Stark, R. E. (1980). Stages of speech development in the first year of life. In *Child phonology* (pp. 73-92). Academic Press.
- Tian, B., Reser, D., Durham, A., Kustov, A., & Rauschecker, J. P. (2001). Functional specialization in rhesus monkey auditory cortex. *Science*, 292(5515), 290-293. <https://doi.org/10.1126/science.1058911>
- Toro, J. M., Nespors, M., Mehler, J., & Bonatti, L. L. (2008). Finding words and rules in a speech stream: Functional differences between vowels and consonants. *Psychological Science*, 19(2), 137-144. <https://doi.org/10.1111/j.1467-9280.2008.02059.x>
- Vergara-Martínez, M., Perea, M., Marín, A., & Carreiras, M. (2011). The processing of consonants and vowels during letter identity and letter position assignment in visual-word recognition: An ERP study. *Brain and language*, 118(3), 105-117. <https://doi.org/10.1016/j.bandl.2010.09.006>