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# EEG Analysis of Brain Dynamics in Children with Language Disorders

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***Abstract*—**Current study established for EEG signal analysis in patients with language disorder. Language disorder can be defined as meaningful delay in the use or understanding of spoken or written language. The disorder can include the content or meaning of language, its form, or its use. Here we applied Z-score, power spectrum, and coherence methods to discriminate the language disorder data from healthy ones. Power spectrum of each channel in alpha, beta, gamma, delta, and theta frequency bands was measured. In addition, intra hemispheric Z-score obtained by scoring algorithm. Obtained results showed high Z-score and power spectrum in posterior regions. Therefore, we can conclude that peoples with language disorder have high brain activity in frontal region of brain in comparison with healthy peoples.

Results showed that high coherence correlates with irregularities in the ERP and is often found during complex task, whereas low coherence is often found in pathological conditions. The results of the Z-score analysis of the brain dynamics showed higher Z-score peak frequency in delta, theta and beta sub bands of Language Disorder patients. In this analysis there were activity signs in both hemispheres and the left-dominant hemisphere was more active than the right.

***Keywords*—**EEG, electroencephalography, coherence methods, language disorder, power spectrum, z-score.

## I. Introduction

PEOPLE with language disorders have been variously referred to as language disordered, language impaired, language delayed, or as having a specific language dysfunction. A language disorder can be defined as meaningful delay in the use or understanding of spoken or written language. The disorder can include the content or meaning of language (semantics), its form (phonology, syntax, and morphology) or its use (pragmatics). Semantics is the sight of language that controls the meaning of words and word combinations. The rules that govern the distribution, structure and sequencing of speech sounds concerned as phonology, Syntax is the rule system that controls how words are gathered into larger meaningful units of phrases, clauses, and sentences. The aspect of a language that controls word structure is morphology. It includes grammatical word inflections that carry tense. The sight of language that concerned with the social use of language is pragmatics [1].

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Research in Language disordered children has a long history, going back to the Stanford Conference on Childhood Aphasia in the 1960s. For many years rehearses puzzled by failure of numerous children to master language at the normal rate, in spite of good intelligence and instruction [2]. Some researchers have proposed that low-level auditory perceptual problems caused specific language impairment (SLI) in children. The binding problem in cognitive neuroscience mostly deals with the way brain integrates signals, separated in space and time. Temporal correlation hypothesis is one of the better-known hypotheses proposing a neuronal v code for integrated information processing [3]. This hypothesis states that, under certain circumstances, neurons with same feature can discharge synchrony. Neuronal synchrony has been shown for adjacent neurons in the cats and monkey's visual, auditory, motor, somatosensory and association cortices ("local-scale synchronization") [4] and between neuronal assemblies of distant brain regions, e.g., between somatosensory, motor, visual and parietal association cortices during a visio-motoric task (''Large scale synchronization'') [5] . With respect to distributed neuronal assemblies, Large-scale synchronization seems particularly important, which should be integrated during most complexes cognitive processing [6], [7] and especially among language analysis and processing [8]. A common way that can study Large-scale neuronal synchronization and the nature of brain oscillations during cognitive information processing is EEG or MEG signal analysis techniques [9]. One approach to obtain information from frequency band between different EEG or MEG signals is the coherence computation. Coherence is a method to measure the linear dependency between two distant brain regions quantitatively as expressed by their EEG activity. Scalp recorded EEG coherence is a large-scale measure, which characterize dynamic functional interactions between electrode signals. High coherence between EEG signals is a sign of increased functional interaction between the underlying neuronal networks [10] .

Coherence calculation provides an analytical tool by which a signal content of two-recorded EEG can be monitored and quantified. Background noise may occur randomly or continuously in one or both signals, new frequency components may add up into the signals and particular frequencies may change their amplitude. Moreover, phase between components in the two-recorded signals may differ over time [11]. Therefore, coherence may also be a tool to measure stability of phase between the same frequency components of two simultaneously recorded EEG signals. High coherence between two EEG signals means high cooperation and synchronization between underlying brain regions within a certain frequency band [12].

In general, brain regions that are stimulated and activated by cognitive tasks show increased coherence within certain frequency bands, depending on the nature and difficulty of the task. It appears that each mental operation is accompanied by characteristic coherence patterns [8]. In this study, we try to determine the brain dynamics behavior in LD. Therefore, we have used varied methods such as dynamic coherences, power spectrum analysis, and Z-score analysis to determine the differences between normal and peoples with language disorder.

## II. Method

### A. Participants

Number of 60 children between 4-14 years old, including 30 language disorder and 30 healthy subjects, was selected to participate in this study. The healthy participants were Tehran citizens who were informed about the study by posters, and the language-disordered volunteers participants were selected from the rehabilitation centers in Tehran. The healthy participants that entered in the study had no history of neurological psychological disease, brain injuries, or seizures. The all participant's parents signed a written testimonial prior to participation. Nonverbal intelligence quotient (IQ) and handedness of all participants were scored by the Raven Progressive Matrices and the Edinburgh Handedness Questionnaire (ranging from 0 to 100 for right-handedness), respectively. Birth weight was asked and the head circumference determined by an examiner.

TABLE I
Statistical Description of the Participants' Characteristics (Age, Nonverbal IQ, Handedness, Birth Weight, and Head Circumference)

| | Mean | SD | F | P-value |
|---|---|---|---|---|
| **Age (years)** | | | | |
| **Normal** | 9.5962 | 2.50607 | 3.271 | 0.078 |
| **LD** | 8.1053 | 3.01652 | | |
| **Nonverbal IQ** | | | | |
| **Normal** | 110.8889 | 16.69762 | 218.41 | 0.000 |
| **LD** | 55.25 | 5.75 | | |
| **Handedness** | | | | |
| **Normal** | 94.1789 | 12.38851 | 4.153 | 0.050 |
| **LD** | 62.8472 | 65.84826 | | |
| **Birth weight (g)** | | | | |
| **Normal** | 3,186.1111 | 532.69723 | 1.266 | 0.269 |
| **LD** | 2,925.2941 | 816.89288 | | |
| | **Head circumference (cm)** | | | |
| **Normal** | 53.8947 | 1.67148 | 71.937 | 0.000 |
| **LD** | 49.1778 | 1.71106 | | |

### B. EEG Recording

Neuro-psychophysiological EEG signals were recorded using a standard 19-channel PC-based system. Using an electro-cap that Ag–AgCL electrodes were located at 19 scalp regions (Fp1, Fp2, F3, F4, C3, C4, P3, P4, O1, O2, F7, F8, T3, T4, T5, T6, $F_z$, $C_z$, and $P_z$) according to the international standard 10–20 system, referenced against averaged earlobes with the ground electrode on $Fp_z$ (Fig. 1). The electrode-scalp resistance was kept below 10 KΩ. The vertical-horizontal EOG was registered on the right eye.

With the subjects in a relaxed state and eyes closed, sitting on a comfortable fixed chair in a quiet room, continuous EEGs were recorded for 240 s with a sampling rate of 250 Hz. The obtained EEG signal filtered by a band-pass filter with cut off frequency of 0.1–100 Hz, and digitized in 16 digits. 60 second of each participant's EEG signals, judged to be free of eye blinking and Electro-oculographic artifacts, where the absolute amplitude of EOG was <70μv and free of movement artifacts, was selected from each EEG to be studied, based on visual inspection. Fig. 2 shows EEG power spectrum at representative frontal, central, and parietal midline electrodes ($F_z$,$C_z$, and $P_z$) for the normal group (represented in a, c, and e, respectively, at the left side, depicted by black lines) and the LD group (represented in b, d, and f, respectively).

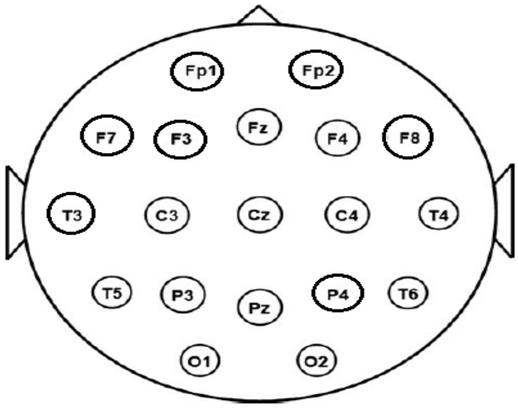


Fig. 1 The international standard 10–20 system

### C. EEG Analysis

Three regions of brain that studied here were: the anterior (F1, F2, F$p_z$, F3, F4, F7, and F8), central ($C_z$, C3, and C4), and posterior ($P_z$, P3, P4, T5, T6, O1, and O2) lobes. By low and high pass Butterworth filter the EEGs were restricted to 1–30 Hz. Then the linear and nonlinear analyses were applied to the remaining EEGs with the following descriptions and details.

#### 1. Power Spectrum Analysis

The relative powers of the EEG sub-bands beta (12–30 Hz), alpha (8–12 Hz), theta (4–8 Hz) and delta (1–4 Hz) were computed based on Welsh's method and using Hamming widows with fifty percent overlaps. The average powers of the EEG bands of different loci were determined for each of the three brain regions (according to the brain topography considered) and hereby the regional powers were obtained at each band.

#### 2. Statistical Analysis

The first use of T-tests and Z-scores to compare an individual means and standard deviations with the normative database means and standard deviations proposed by Matousek and Petersen [13]. The T-test is defined as the ratio of the difference between values divided by the standard deviation as (1).

$$t = \frac{\overline{x} - \mu}{s / \sqrt{n}} \quad (1)$$

where $\overline{x}$ is the sample mean, μ = 0 (or m) is the hypothesized population mean, s is the sample standard deviation, and n is the sample size.

The Z statistic is defined as the difference between the value from an individual and the mean of the population that divided by the standard deviation of the population as (2)

$$Z = \frac{x_i - \overline{X}}{SD} \quad (2)$$

John and colleague expanded the use of the Z-score for clinical evaluation including the use of multivariate measures such as the Mahalanobis distance metric. A direct normalization of the Gaussian distribution using Z-scores is useful in comparing individuals to a QEEG normative database [14], [15].

3. Coherence Analysis

The coherence analysis during language processing is powerful tool for investigating rhythmic, large-scale properties of EEG signals accompanying linguistic function. In general EEG coherence studies can be divided into clinical studies and studies with healthy subjects. In this study we concern with coherence studies on patients with language disorders as the main pathological symptom. To the best of our knowledge, apart from the extensive studies on dyslexic patients there are no studies on EEG coherence and specific language disorders. Coherence of an EEG signal computed as:

$$C_{xy} = \frac{|G_{xy}|^2}{G_{xx} G_{yy}} \quad (3)$$

where $G_{xy}$ is the cross-spectral density between x and y, and $G_{xx}$ and $G_{yy}$ are the auto-spectral density of x and y respectively.

TABLE II
RESULTS OBTAINED FROM MEASUREMENT IN BRAIN REGIONS

| | | Normal | | | | LD | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean power | Std | Mean coherence | Std | Mean power | Std | Mean coherence | Std |
| Delta | Anterior | 13.77 | 4.35 | 0.48 | 0.33 | 52.30 | 13.29 | 0.56 | 0.24 |
| | Medial | 17.65 | 7.35 | 0.19 | 0.26 | 45.47 | 13.37 | 0.23 | 0.12 |
| | Posterior | 206.26 | 9.93 | 0.038 | 0.005 | 113.90 | 40.92 | 0.06 | 0.00 |
| Theta | Anterior | 11.80 | 7.75 | .057 | 0.30 | 23.82 | 9.57 | 0.65 | 0.21 |
| | Medial | 19.63 | 7.72 | 0.26 | 0.28 | 33.09 | 10.73 | 0.33 | 0.17 |
| | Posterior | 33.33 | 11.06 | 0.038 | 0.006 | 62.50 | 16.69 | 0.035 | 0.00 |
| Alpha | Anterior | 18.55 | 1.35 | 0.59 | 0.31 | 26.67 | 10.26 | 0.66 | 0.20 |
| | Medial | 33.80 | 26.71 | 0.29 | 0.26 | 37.06 | 12.23 | 0.41 | 0.20 |
| | Posterior | 93.70 | 55.31 | 0.17 | .02 | 86.166 | 24.88 | 0.11 | 0.01 |
| Beta | Anterior | 0.98 | 0.47 | 0.47 | 0.31 | 1.92 | 0.85 | 0.45 | 0.25 |
| | Medial | 1.35 | 0.53 | 0.20 | 0.26 | 3.00 | 1.10 | 0.13 | 0.13 |
| | Posterior | 2.94 | 0.79 | 0.02 | 0.002 | 4.10 | 0.60 | 0.06 | 0.00 |
| Gamma | Anterior | 0.071 | .048 | 0.47 | 0.30 | 0.30 | 0 | 0.30 | 0.28 |
| | Medial | 0.31 | 0.064 | 0.22 | 0.26 | 0.29 | 0.03 | 0.13 | 0.08 |
| | Posterior | 0.60 | 0.20 | 0.05 | 0.007 | 0.33 | 0.05 | 0.05 | 0.00 |

TABLE III
INTRA-HEMISPHERIC LEFT Z-SCORE PEAK FREQUENCY

| | Delta | Theta | Alpha | Beta | High Beta | Beta 1 | Beta 2 | Beta 3 |
|---|---|---|---|---|---|---|---|---|
| FP1 – LE | -1.45 | 1.05 | -1.03 | -0.32 | 0.50 | 0.93 | -1.8 | -0.10 |
| F3 – LE | -0.50 | 0.82 | -0.02 | -0.49 | 0.91 | 0.55 | -1.26 | -0.53 |
| C3 – LE | -0.25 | 0.18 | 0.29 | -0.07 | 0.90 | 1.25 | -1.35 | -0.45 |
| P3 – LE | 0.04 | -0.47 | -0.39 | 0.10 | 1.40 | 1.50 | -0.07 | -0.60 |
| O1 – LE | 0.39 | 2.32 | -1.89 | -.12 | 1.55 | 1.77 | -2.56 | 0.50 |
| F7 – LE | -.1.01 | 1.08 | -1.14 | 0.10. | 1.00 | 0.87 | -0.84 | 0.40 |
| T3 – LE | -0.40 | 1.24 | -1.20 | -1.54 | 0.50 | 0.37 | -2.01 | -1.01 |
| T5 – LE | 0.20 | 0.70 | -0.40 | -1.13 | 1.01 | 1.61 | -2.26 | -1.12 |

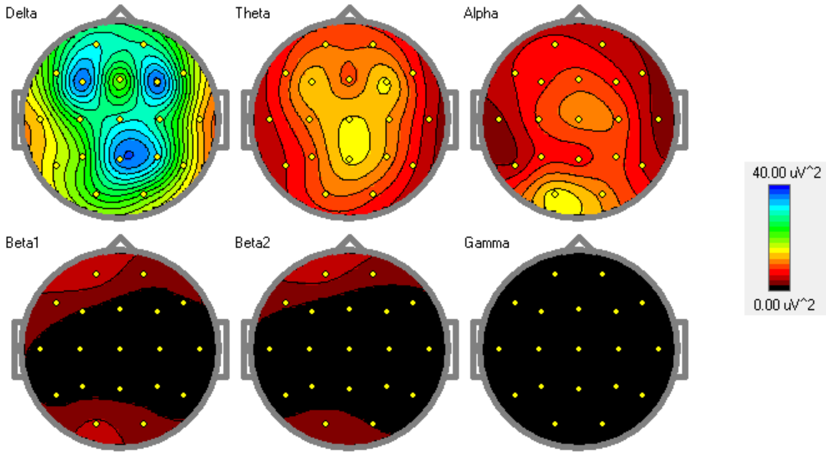


Fig. 2 Normal eeg power spectra map

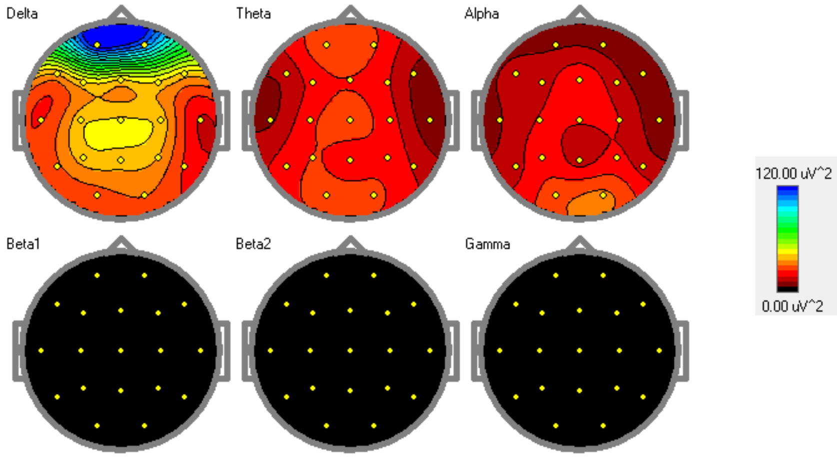


Fig. 3 Abnormal eeg power spectra

TABLE IV
INTRA-HEMISPHERIC RIGHT Z-SCORE PEAK FREQUENCY

| | Delta | Theta | Alpha | Beta | High Beta | Beta 1 | Beta 2 | Beta 3 |
|---|---|---|---|---|---|---|---|---|
| FP2 – LE | -1.03 | 1.45 | -0.43 | 0.75 | 1.00 | 0.85 | -0.15 | 0.73 |
| F4 – LE | -0.97 | 0.72 | -0.73 | -0.47 | 0.35 | 0.89 | -1.55 | -0.60 |
| C4 – LE | -0.80 | 0.15 | -0.39 | 0.08 | 0.56 | 1.37 | -1.07 | -0.09 |
| P4 – LE | 0.10 | -0.44 | -0.42 | 0.14 | -0.37 | 1.16 | -0.33 | -0.48 |
| O2 – LE | -1.49 | 2.50 | -1.94 | -0.17 | 0.64 | 1.24 | -2.12 | 0.29 |
| F8 – LE | -2.14 | 1.32 | -0.99 | 0.22 | 2.32 | 1.25 | -0.70 | 0.72 |
| T4 – LE | 0.95 | 0.83 | -0.70 | -1.00 | 0.31 | 0.54 | -2.12 | -0.80 |
| T6 – LE | -0.43 | 1.25 | -0.75 | -0.46 | 0.65 | 0.20 | -1.00 | -1.00 |

TABLE V
INTRA-HEMISPHERIC CENTER Z-SCORE PEAK FREQUENCY

| | Delta | Theta | Alpha | Beta | High Beta | Beta 1 | Beta 2 | Beta 3 |
|---|---|---|---|---|---|---|---|---|
| $F_z$ – LE | 0.21 | -0.24 | -0.95 | 0.71 | 1.00 | 1.39 | -1.00 | 0.37 |
| $C_z$ – LE | -0.33 | 0.16 | -0.16 | 0.93 | 1.33 | 1.57 | -0.88 | 0.24 |
| $P_z$ – LE | -0.57 | -0.13 | 0.33 | 1.39 | 1.37 | 1.29 | -0.28 | 0.64 |

Table V shows Relationships of brain dynamics and severity of disabilities. The intra-hemispheric Z-score peak frequency of the EEG has evaluated in 3 distinctive regions (left, center and right). Results show that the posterior of the left and right hemispheres have more activities in beta frequency band. In addition, we detect activity in delta and theta bands of right and left intra- hemisphere respectively. Power spectra analysis of the EEG data shows the significant correlation of the LD and increasing power spectra. As Z-score power spectrum analysis shows that posterior of brain has high power than anterior especially in delta band in comparison of normal and abnormal persons.

## III. Discussion and Conclusion

Electro-neurophysiological abnormalities of the cortex in LD have investigated in few studies, in current study the authors tried to reveal the deficits of brain dynamics in the group of patients. Both linear and nonlinear characteristics of the brain dynamics were investigated (using power spectrum Z-score analyses of the resting EEGs) in order to detect the deficits as much as possible. The results of the linear analysis showed a slow brain activity (delta, theta and beta waves) in LD. These finding has significant correlation with this fact that the language processing area have located in occipital lobe. The primary areas most relevant for language processing are located in the posterior occipital lobes (Brodmann area 17). Since the person with language, disorder has more effort during speech, so it is obvious that EEG signal in occipital region of these patients has high power.

The results of the Z-score analysis of the brain dynamics showed higher Z-score peak frequency in delta, theta and beta sub bands of LD patients. In this analysis, there were activity signs in both hemispheres and the left-dominant hemisphere was more active than the right. This is consistent with the view that the neuronal populations involved in language processing are distributed over both hemispheres, but that the majority of the relevant neurons are located in the left hemisphere.

Findings in literature and our own findings shows that high coherence correlates with irregularities in the ERP and is often found during complex task, whereas low coherence is often found in pathological conditions. Furthermore, coherence is a frequency-dependent measure, and patterns of coherence networks tend to differ between frequencies. The meaning of coherence networks maybe interpreted differently depending on the frequency band investigated, since different components of a cognitive task are presumably processed via different frequencies. High coherence apparently correlates with the increasingly multimodal features of certain word types. In addition, phase relations during word processing indicated direction of information and propagation speed of information transfer, which proved an important new parameter for studying cognitive processes. Coherence can also reflect operations during sentence processing and shows specific behavior to various aspects of sentence processing in different frequency ranges. At high frequencies coherence, maybe correlate with semantic integration and parsing processes. These results argue that EEG-coherence analysis is an important tool for studying high-level cognitive processes, such as language processing. This method supports a somewhat different view on brain function during language processing in so far as the actual process of language comprehension and production is not correlated with location but with interaction. Particularly, coherence between distant electrodes challenges the common view that language function can be mostly attributed to definite circumscribed ‘‘language centers’’. Results of EEG coherence studies demonstrate ‘‘transient functional language networks’’, which sometimes are of a very short duration (200ms). The typical appearance of these ‘‘transient functional language networks’’ depends on the kind of verbal stimuli, the task and on the individual experience of persons performing the task. Large-scale information transfer via frequency coding is possibly one of the mechanisms, which facilitate parallel processing within the brain, since a single signal may contain different aspects of information within various frequency ranges. This may be one reason for the high speed of information processing. Furthermore, the assumption that ‘‘transient functional language centers’’ exist may partly explain the spontaneous recovery from acquired aphasic disturbances. Among many other successfully applied neurophysiological methods, the description of functional networks during language processes using coherence analysis provides a small but important piece of the mosaic on our way to understanding the neurophysiological basis of language processing.

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