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A Comparative Analysis of Brain Wave Patterns in Children With and Without Dyslexia

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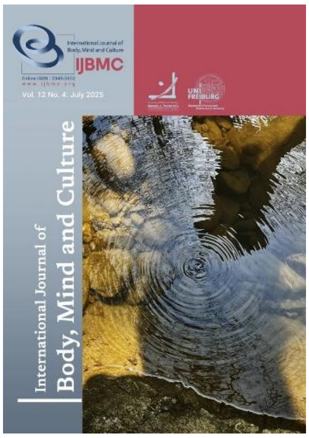

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ABSTRACT

Objective: Dyslexia, a neurodevelopmental disorder, disrupts reading and learning abilities in children. Early diagnosis is critical for mitigating its long-term effects. While prior research has examined the neurological underpinnings of dyslexia, the role of specific brain wave abnormalities in the occipital region remains underexplored. This study investigates occipital brain wave patterns in children with and without dyslexia to evaluate their potential as diagnostic markers.

Methods and Materials: This study involved 30 students referred to a specialized learning disabilities center in Karaj, Iran. Participants were screened using the Wechsler Intelligence Scale (4th Edition) and the NEMATest for dyslexia. Based on the screening, 15 students with severe dyslexia were matched with 15 neurotypical peers. Brain wave activity was recorded using EEG during reading tasks, focusing on the occipital region. Statistical analyses, including bi-serial correlation and logistic regression, were used to assess differences between the groups.

Findings: Dyslexic children exhibited significantly higher frequencies of sharp peaks and temporal phase differences in occipital brain waves compared to neurotypical peers (odds ratio 1.4, $p<0.05$). These abnormalities were more pronounced during reading tasks, suggesting a strong association between occipital brain wave patterns and dyslexia.

Conclusion: The findings highlight occipital brain wave abnormalities as potential diagnostic markers for dyslexia. Future research should validate these results in larger and more diverse populations and explore their integration into clinical diagnostic frameworks to enhance early detection and intervention strategies.

Keywords: Dyslexia, Brain Waves, Occipital Region, EEG, Learning Disorders

Introduction

Specific learning disabilities, categorized under neurodevelopmental disorders, significantly impact the proper development of the brain or central nervous system during childhood. Dyslexia, as one of the most common and impactful learning disabilities, disrupts the ability to read and comprehend written texts. This condition is characterized by difficulties in recognizing words, decoding written language, and understanding the meaning of text. These challenges often persist throughout life, affecting academic, social, and professional performance (Zorzi et al., 2012). Dyslexia is estimated to affect 5–10% of the global population, with variability in its prevalence depending on language, cultural, and diagnostic factors. Given its widespread impact, early detection and intervention are critical to mitigating its adverse effects (Richlan et al., 2010).

Reading difficulties are among the most pronounced challenges faced by individuals with dyslexia. Reading is a multifaceted cognitive activity that requires the integration of several processes, including attention, memory, phonological processing, and comprehension. Dyslexic children often struggle with decoding words, recognizing letters, and processing the spatial and temporal characteristics of written language (Fernández et al., 2014). This disorder is further complicated by co-occurring conditions such as attention deficit hyperactivity disorder (ADHD) and autism, which share overlapping symptoms, including difficulties in language processing and executive function. Although dyslexia is distinct from these conditions, genetic studies suggest potential shared mechanisms, emphasizing the complexity of its etiology (Huettig & Brouwer, 2015).

From a neurological perspective, dyslexia has been extensively studied in recent decades. Research has revealed structural and functional abnormalities in several brain regions, including the temporal, parietal, and occipital lobes, which are critical for reading and language processing (Richlan et al., 2010). Becker's reading balance model provides a theoretical framework for understanding dyslexia. This model posits that dyslexia arises from disruptions in the balance of activity between the brain's hemispheres. According to Becker, the right hemisphere primarily supports early stages of reading by processing the spatial structure of words. As reading skills develop, tasks transition to the left hemisphere, which is more specialized for language processing. Dyslexia is hypothesized to result from either delayed or incomplete transitions between these stages, leading to persistent difficulties in reading fluency and comprehension (Bakker, 2016). These findings underscore the importance of examining both structural and functional brain activity in understanding the underlying mechanisms of dyslexia.

One of the most promising areas of dyslexia research involves studying brain wave activity. Electroencephalography (EEG) has emerged as a valuable tool for examining the neural correlates of reading and language processing. Abnormalities in specific frequency bands, such as theta (4–8 Hz) and alpha (8–12 Hz), have been consistently observed in individuals with dyslexia. Theta activity is often associated with working memory and cognitive control, while alpha activity is linked to attention and information processing. Studies have shown that children with dyslexia exhibit increased theta activity and reduced alpha power compared to their typically developing peers (Chabot et al., 1999; Walker & Norman, 2006). These findings suggest that dyslexia may involve disruptions in the neural networks responsible for coordinating cognitive and linguistic functions.

Despite these advancements, there is limited research specifically focusing on the role of the occipital region in dyslexia. The occipital lobe, located at the back of the brain, is primarily responsible for visual processing and plays a crucial role in reading by facilitating letter and word recognition. Functional imaging studies have shown that dyslexic individuals often exhibit reduced activity in the left occipital and occipitotemporal regions during reading tasks. These deficits are thought to contribute to difficulties in visual word recognition and reading fluency (Richlan et al., 2010). Moreover, abnormalities in occipital brain wave patterns, such as increased theta activity and disrupted alpha oscillations, have been reported during tasks involving visual attention and reading (Nasir et al., 2022). These findings suggest that the occipital lobe may play a critical role in understanding the neural mechanisms underlying dyslexia.

Several studies have highlighted the potential of EEG as a diagnostic tool for dyslexia. For instance, research by Nasir et al. (2022) demonstrated that dyslexic children exhibit distinctive patterns of brain wave activity in the occipital region during cognitive tasks, particularly an increased frequency of sharp peaks and temporal phase differences (Nasir et al., 2022). Similarly, studies by Huettig and Brouwer (2015) emphasized the role of phonological and auditory processing deficits in dyslexia, linking them to abnormal EEG activity (Huettig & Brouwer, 2015). These findings support the hypothesis that dyslexia involves disruptions in the neural circuits underlying reading and language processing.

However, existing research on brain wave activity in dyslexia has primarily focused on the theta and alpha bands in general, with limited attention to their specific manifestations in the occipital region. Given the critical role of the occipital lobe in visual processing and its connections to other brain regions involved in reading, a deeper exploration of its activity patterns is warranted. Understanding these patterns could provide valuable insights into the neural basis of dyslexia and inform the development of more effective diagnostic and therapeutic approaches.

In addition to advancing our understanding of the neural mechanisms of dyslexia, studying occipital brain wave activity holds significant practical implications. Early detection of dyslexia remains a major challenge, particularly in resource-limited settings where access to specialized diagnostic tools is limited. EEG-based assessments offer a non-invasive and cost-effective alternative for identifying dyslexia at an early stage. By identifying specific brain wave abnormalities associated with dyslexia, such as those in the occipital region, clinicians could develop targeted interventions to improve reading skills and mitigate the long-term effects of the disorder.

Given the critical role of the occipital lobe in reading and the limited research on its involvement in dyslexia, this study aims to address this gap by examining occipital brain wave activity in children with and without dyslexia. Specifically, the study seeks to identify patterns of brain wave abnormalities that differentiate dyslexic children from their neurotypical peers. By utilizing EEG, this research provides a detailed analysis of brain wave activity during reading tasks, with a particular focus on the occipital region. The findings of this study could contribute to the development of neuroscience-based diagnostic frameworks for dyslexia, facilitating early detection and intervention.

Methods and Materials

Study Design and Participants

This study employed a causal-comparative research design to investigate differences in occipital brain wave patterns between children with and without dyslexia. The design aimed to identify specific brain wave abnormalities associated with dyslexia, with a focus on the occipital region during cognitive reading tasks. The causal-comparative method was chosen because it allows for the study of naturally occurring differences between groups without manipulating the independent variable, thereby ensuring both ethical and practical feasibility.

The study population consisted of students referred to the 12 Bahman Learning Disability Center in Zone 2 of Karaj, Iran, during the 2023–2024 academic year. A two-stage sampling process was implemented to ensure a representative and diagnostically relevant sample. Students suspected of having learning disabilities were identified through initial evaluations conducted by the center's specialists. The ease of access to these students was facilitated by the researcher's role as a specialist and manager of the center. From the initial pool, 30 students were selected using a simple random sampling method to ensure unbiased group selection. This group included: Dyslexic Group (n=15): Students identified with severe dyslexia based on their performance on the NEMA Reading and Dyslexia Test. Control Group (n=15): Neurotypical students matched with the dyslexic group based on age (9–12 years) and gender.

Inclusion criteria were age range between 9–12 years, Diagnosis of dyslexia confirmed using the NEMA test, Normal intelligence as determined by the Wechsler Intelligence Scale for Children (4th Edition), and willingness to participate in the study, with informed consent provided by parents/guardians. Exclusion Criteria were the presence of comorbid neurological or sensory disorders (e.g., severe ADHD or autism), non-cooperation during testing or EEG sessions, and history of uncorrected visual or auditory impairments.

Initial screening was conducted using the Wechsler Intelligence Scale to exclude students with intellectual disabilities. The NEMA test was administered to identify students with dyslexia and classify them into either the dyslexic or neurotypical groups. Scores were standardized for comparability. EEG recordings were conducted in a controlled, quiet environment to minimize external distractions. Each participant underwent two conditions: Participants were instructed to relax with their eyes closed for 60 seconds to establish a baseline measurement of resting brain wave activity. Participants were shown age-appropriate reading materials (displayed at 10-second intervals) on a computer monitor. Each reading segment was flanked by 5-second rest periods to allow neural recovery. The materials were selected to match participants' reading levels and avoid frustration. EEG signals were recorded from occipital channels using the 10-20 system (O1 and

O2 placements). Preprocessing included artifact removal, such as filtering out eye blinks and motion-related noise. A band-pass filter (0.5–50 Hz) was applied to isolate theta (4–8 Hz) and alpha (8–12 Hz) frequency bands. Metrics recorded included: Frequency of sharp peaks in theta and alpha bands, temporal phase differences between left and right occipital regions.

Instruments

Wechsler Intelligence Scale for Children (4th Edition): In the initial phase, students attending regular elementary schools in Zone 2 of Karaj and visiting the 12 Bahman Learning Disability Center were evaluated using the Wechsler Intelligence Scale for Children (4th Edition). This widely used tool assesses verbal comprehension, perceptual reasoning, working memory, and processing speed through its standardized subtests. These domains collectively determine general intellectual ability and cognitive proficiency. The scale includes a total of 15 cognitive subtests, making it a reliable screening instrument for identifying children with suspected learning disabilities in Special Education contexts. Reliability coefficients for this scale have been reported as statistically significant, with a split-half reliability of 0.98 for children aged 6–11 years (Aminloo et al., 2013). In this study, 15 students without learning disabilities and 30 students with learning disabilities were selected based on the results of this assessment.

Reading and Dyslexia Test (NEMA): The NEMA Reading and Dyslexia Test, developed by Karami Noori and Moradi (2016), was employed to diagnose reading disabilities after the initial screening with the Wechsler Scale. This test is designed explicitly for Persian-speaking children. It includes ten subtests: word reading (three 40-word lists with a Cronbach's alpha of 0.98), reading nonsense words (0.85), naming pictures (0.75), phoneme deletion (0.78), letter identification (0.66), word identification (0.75), and rhyme recognition (0.88). These subtests offer a comprehensive assessment of reading and language processing abilities. The reliability of the test, verified through internal consistency measures, ensures its effectiveness as a diagnostic tool for dyslexia (Moradi et al., 2016).

BioLine Device for Electroencephalography (EEG): For recording brain waves during the reading task, the BioLine twelve-channel device with the BioSes software will be used. The EEG signals will be captured during the reading task. The standard 10-20 system will be employed for signal recording. Each participant will undergo three 20-second periods: 5 seconds of rest, 10 seconds of visual stimulus (displaying reading material), and 5 seconds of rest again. The EEG signals will be recorded from the left and right occipital regions of the skull (Nasir et al., 2022; Richlan et al., 2010).

Data Analysis

This method was used to examine the relationship between brain wave abnormalities and dyslexia. The bi-serial correlation is particularly suitable for assessing relationships between continuous and binary variables, such as brain wave frequency and group classification. Logistic regression was used to evaluate the predictive value of brain wave abnormalities in classifying participants into dyslexic and neurotypical groups. Key assumptions, including linearity of independent variables and absence of multicollinearity, were tested and met. The odds ratios derived from the model provided insights into the strength of association between EEG metrics and dyslexia.

Findings and Results

The findings of this study focus on the differences in occipital brain wave patterns between children with and without dyslexia under two experimental conditions: eyes closed (baseline) and eyes open (reading task). The results were analyzed using logistic regression and bi-serial correlation, focusing on sharp peaks and temporal phase differences in the theta and alpha frequency bands.

Eyes-Closed Condition

In the baseline (eyes-closed) condition, dyslexic children exhibited a higher frequency of sharp peaks in the theta band compared to neurotypical children. This result indicates a significant association between theta band abnormalities and dyslexia during resting states. Dyslexic children also demonstrated significant temporal phase differences between the left and right occipital regions, suggesting impaired interhemispheric synchronization.

Eyes-Open (Reading Task) Condition

During the reading task (eyes-open condition), the abnormalities in the occipital brain wave patterns became more pronounced. Dyslexic children showed a significantly higher frequency of sharp peaks in the alpha band compared to neurotypical children. Temporal phase differences in the occipital region were also more prominent, indicating greater challenges in interhemispheric communication under cognitive load.

The logistic regression results for the two conditions (eyes open and eyes closed) are presented in the following tables.

Table 1

Logistic Regression with Eyes Closed

Expected Value	P-value	df	Wald	Standard Error	B Coefficient
1.198	0.301	1	1.070	0.175	-1.181
0.967	0.006	1	0.422	0.34	-1.772
0.462	0.322	1	0.982	0.779	-1.130

Confidence Interval (Upper/Lower): 1.689/1.851 for severe fluctuations, 2.210/1.423 for phase changes, and for the constant coefficient.

Table 2

Logistic Regression with Eyes Open

Expected Value	P-value	df	Wald	Standard Error	B Coefficient
1.360	0.099	1	2.715	0.186	-3.307
0.699	0.486	1	0.514	0.356	-1.130
0.323	0.170	1	1.879	0.824	-1.130

Confidence Interval (Upper/Lower): 1.689/1.851 for severe fluctuations, 2.210/1.423 for phase changes, and for the constant coefficient.

The results of this analysis can be simplified as follows: In the eyes closed condition, the odds ratio for the correlation between spikes and sharp peaks in the occipital brain wave channels and dyslexia is approximately 1.2. This means that in the case of severe wave abnormalities, the likelihood of dyslexia is 1.2 times higher. In the eyes open condition (while reading words), this value increases to about 1.4. Thus, the risk of dyslexia rises by 0.2 to 0.4 units for each increase in the sharp peak variable. For the phase difference variable between the dual occipital waves (i.e., the difference between the left and right occipital), the odds ratio in the eyes closed condition is approximately 1. In the open-eyed condition, it is 0.7. There is a strong and significant correlation between abnormalities in the sharp peaks and spikes in the occipital brain region and dyslexia in both the eyes closed and eyes open conditions. This correlation is particularly evident in the eyes-open condition.

More specifically, the odds of dyslexia occurring with severe abnormalities in brain waves range from 1.2 to 1.4, indicating an increased risk for each unit increase in the variable. In other words, for every unit increase in this variable, the likelihood of dyslexia rises by 0.2 to 0.4. The same analysis applies to the phase difference. The values 1 and 0.7 for the expected values of these variables suggest that the correlation with dyslexia is weaker than for sharp peaks. For each unit increase in this variable, the probability of dyslexia increases by the same proportion in the eyes closed condition. In contrast, in the eyes open condition, there is a 70% increase in the probability. Finally, it should be noted that the lower odds ratio in the phase difference variable in the eyes open condition compared to the eyes closed condition may be due to the visual processing process and interactions between different brain regions. However, since this research does not delve deeply into neuroscientific and brain activity topics, we will refrain from further speculation and hypotheses.

Discussion and Conclusion

This analysis aims to provide evidence of potential differences in cognitive and processing brain functions between children with dyslexia and normal children. The results obtained from electroencephalography (EEG) data allow us to gain a deeper understanding of the impact of dyslexia on brain activity. The results of analyzing the EEG recordings of the brain waves of children aged 9 to 12, from two groups with and without dyslexia, during resting with eyes closed and also during reading tasks, with an odds ratio greater than one (precisely, the odds ratio between 1.2 and 1.4), showed that the number of sharp peaks in the brain waves of children with dyslexia in the occipital region is much higher than in normal children. Therefore, the increase in the number of these peaks significantly raises the likelihood of being affected by this disorder.

The findings of this study demonstrate significant abnormalities in occipital brain wave patterns in dyslexic children, particularly under cognitive load during reading tasks. The presence of sharp peaks in the theta and alpha bands and temporal phase differences between the left and right occipital regions were identified as strong predictors of dyslexia. These results align with previous research (Nasir et al., 2022; Richlan et al., 2010), which has highlighted the role of disrupted neural activity in visual and cognitive processing in individuals with dyslexia. The findings provide robust evidence that task-induced cognitive load amplifies neural differences, particularly in the occipital region, which plays a critical role in visual word recognition and reading comprehension.

The observed sharp peaks in the theta and alpha bands may reflect underlying neural inefficiencies or compensatory mechanisms in children with dyslexia. Theta activity is often associated with working memory and attention, while alpha activity is linked to inhibitory control and cognitive processing. Increased sharp peaks in these frequency bands may indicate disruptions in the neural networks responsible for integrating visual and linguistic information. Similarly, the temporal phase differences observed between the left and right occipital regions suggest impaired interhemispheric communication, which could hinder the coordination of visual and phonological processes necessary for fluent reading.

While these findings underscore the diagnostic potential of EEG metrics, their clinical application requires further validation. The small sample size in this study limits the generalizability of the results, and additional research with larger, more diverse populations is needed to confirm these patterns. Future studies should also incorporate advanced EEG analyses, such as coherence or source localization, to gain a deeper understanding of the neural mechanisms underlying dyslexia.

The implications of these findings extend beyond diagnostic applications. By identifying specific neural markers of dyslexia, this research contributes to the development of neuroscience-informed interventions for addressing the condition. For example, targeted neurofeedback training or cognitive rehabilitation programs could be designed to enhance occipital lobe function and improve reading outcomes. Additionally, these findings highlight the importance of early screening for dyslexia, particularly in educational settings where undiagnosed learning difficulties can have long-term consequences.

Therefore, it is suggested that a scientific and experimental platform be established, focusing on extraction, purification, statistical calculations, and automation. This platform should prioritize the development of the Python programming language and specialized libraries for analyzing brain signal data, to assess opportunities for large-scale commercialization. Given the widespread use of communication tools equipped with cameras and visual media, this platform will make commercialization more accessible, paving the way for the construction of large health data databases and the development of big data in the future. Additionally, it is suggested to establish a measurable database related to brain waves based on composite variables, taking into account in-depth studies of dyslexia and brain wave disorders in the country. This database could serve as a valuable resource for planners in special education, educators, and experts in centers for special needs. The experience of using EEG devices on a scientific scale for research purposes to examine other children with developmental neurological disorders is also recommended. This can help expand knowledge and applications of these technologies in various fields. It is recommended that further research be conducted in diagnostic and therapeutic areas using EEG recordings to enhance methods of diagnosis and treatment for related disorders.

In conclusion, this study reveals significant abnormalities in occipital brain wave patterns in children with dyslexia, particularly under task-induced cognitive load. Sharp peaks and temporal phase differences in the theta and alpha bands emerge as reliable neural markers of dyslexia. These results have the potential to inform early diagnostic strategies and targeted interventions, paving the way for more effective support for children with dyslexia. However, further research is needed to validate these findings and explore their integration into clinical and educational frameworks. By advancing our understanding of the neural basis of dyslexia, this research contributes to the broader goal of improving outcomes for individuals with learning disabilities.

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Declaration of Interest

The authors of this article declared no conflict of interest.

Ethical Considerations

The study protocol adhered to the principles outlined in the Declaration of Helsinki, which provides guidelines for ethical research involving human participants. Ethical considerations in this study were that participation was entirely optional. Ethical approval for the study was obtained from the Central Tehran Branch, Islamic Azad University's Ethics Committee.

Transparency of Data

By the principles of transparency and open research, we declare that all data and materials used in this study are available upon request.

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Authors' Contributions

All authors equally contribute to this study.

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