KMAN PUBLISHING INSTITUTE
Journal Website

Article history:
Received 05 September 2025
Revised 26 January 2026
Accepted 16 February 2026
Initial Publication 30 May 2026
Final Publication 01 June 2026

Psychological Research in Individuals with Exceptional Needs

Volume 4, Issue 2, pp 1-13

E-ISSN: 3060-6713

Machine Learning–Based Prediction of Reading Comprehension Deficits from Attention Control, Processing Speed, Phonological Awareness, and Academic Anxiety in Children with Dyslexia

Kamran. Ganji[1], Mandana. Roostaee Hosein Abade[1*]

1. Department of Educational Psychology, Mal.C., Islamic Azad University, Malayer, Iran

*** Corresponding author email address**: mandanaroostaee5@gmail.com

A r t i c l e I n f o

Article type:
Original Research

How to cite this article:
Ganji, K. & Roostaee Hosein Abade, M. (2026). Machine Learning–Based Prediction of Reading Comprehension Deficits from Attention Control, Processing Speed, Phonological Awareness, and Academic Anxiety in Children with Dyslexia. *Psychological Research in Individuals with Exceptional Needs*, *4*(2), 1-13.
https://doi.org/10.61838/kman.prien.5551

A B S T R A C T

The present study aimed to predict reading comprehension deficits based on attention control, processing speed, phonological awareness, and academic anxiety using machine learning models in children with dyslexia. This study employed a correlational design with a machine learning predictive approach. The statistical population included children with dyslexia enrolled in elementary schools and learning disability centers in Tehran during the 2025–2026 academic year. A total of 240 children aged 8–12 years were selected using multistage cluster sampling and purposive screening procedures. Data collection instruments included the Reading Comprehension Subtest of the Gray Oral Reading Tests, the Attention Control Scale, the Processing Speed Index of the Wechsler Intelligence Scale for Children–Fifth Edition, the Comprehensive Test of Phonological Processing, and the Academic Anxiety Scale. Data were analyzed using SPSS-27 and Python machine learning libraries. Several algorithms including Random Forest, Support Vector Machine, Gradient Boosting, and Artificial Neural Network models were implemented. Model evaluation was conducted using accuracy, precision, recall, F1-score, root mean square error, and area under the receiver operating characteristic curve indices. The findings revealed significant relationships among all study variables. Reading comprehension deficits demonstrated significant negative correlations with attention control, processing speed, and phonological awareness, while academic anxiety showed a significant positive association with reading comprehension deficits. Among predictor variables, phonological awareness had the strongest relationship with reading comprehension deficits. The Gradient Boosting model demonstrated the highest predictive performance with 93% accuracy, 91% precision, 92% recall, an F1-score of 91%, and an area under the curve value of 0.96. The Random Forest model also showed high predictive performance with 91% accuracy and an area under the curve value of 0.94. Feature importance analysis indicated that phonological awareness was the strongest predictor, followed by attention control, academic anxiety, and processing speed.

The findings support multifactorial neurocognitive models of dyslexia suggesting that reading comprehension deficits are influenced by integrated cognitive, executive, phonological, and emotional processes. Machine learning algorithms, particularly ensemble learning models, demonstrated high effectiveness in predicting reading comprehension deficits among children with dyslexia. These findings highlight the potential utility of machine learning approaches for early screening, individualized assessment, and targeted intervention planning in educational and clinical settings.

Keywords: *Dyslexia, Reading Comprehension Deficits, Machine Learning, Attention Control, Processing Speed, Phonological Awareness, Academic Anxiety, Predictive Modeling, Executive Functions, Learning Disabilities*

1. Introduction

Developmental dyslexia is one of the most prevalent neurodevelopmental learning disorders and is primarily characterized by persistent difficulties in word recognition, decoding, reading fluency, and reading comprehension despite adequate intelligence, educational opportunity, and sensory functioning. In recent decades, dyslexia has increasingly been conceptualized as a multidimensional neurocognitive disorder involving complex interactions among linguistic, cognitive, attentional, emotional, and executive processes rather than a singular phonological deficit. Contemporary theoretical models emphasize that reading comprehension difficulties in children with dyslexia emerge from a combination of impairments in phonological processing, executive functioning, working memory, processing speed, language comprehension, and emotional regulation (Snowling & Hulme, 2020; Wolf et al., 2024). This broader conceptualization has substantially transformed approaches to assessment, intervention, and prediction of reading-related impairments in educational and clinical contexts.

Reading comprehension represents one of the most critical academic skills during childhood because it directly influences educational achievement, classroom participation, academic self-concept, and later occupational functioning. Children with dyslexia often experience significant difficulties in extracting meaning from written text, integrating linguistic information, and sustaining comprehension across increasingly complex reading materials. These comprehension deficits frequently persist into adolescence and adulthood, affecting educational trajectories and psychosocial adjustment (Knight et al., 2024; Saunders et al., 2025). Research has demonstrated that reading comprehension impairments are not solely attributable to decoding difficulties but are also associated with deficits in executive functioning, attentional regulation, cognitive flexibility, working memory, and linguistic integration (Kizilaslan & TunagÜR, 2021; Medina & Guimarães, 2021). Consequently, understanding the cognitive and emotional mechanisms underlying reading comprehension deficits has become a major focus in dyslexia research.

Among the most influential predictors of reading performance in children with dyslexia is phonological awareness, which refers to the ability to identify, manipulate, segment, and integrate speech sounds within language structures. Phonological processing deficits are widely recognized as a central feature of dyslexia and are consistently associated with impairments in decoding, fluency, and comprehension (Pasqualotto & Venuti, 2020; Snowling & Hulme, 2020). Children with weak phonological awareness often struggle to establish stable grapheme–phoneme correspondences, resulting in slower and less accurate reading processes that compromise comprehension efficiency. Neuropsychological and meta-analytic evidence further suggests that phonological deficits interact with broader executive and attentional systems to influence reading outcomes (Peng et al., 2022; Valenzuela & Martín-Ruiz, 2022). In this regard, recent comparative investigations have shown that children with dyslexia exhibit substantially weaker linguistic and phonological skills compared to typically developing peers, particularly in phonemic manipulation and verbal processing tasks (López-Zamora et al., 2025).

In addition to phonological processing, attention control has emerged as a significant predictor of reading achievement and academic functioning in dyslexia. Attention control refers to the capacity to sustain focus, shift attentional resources appropriately, inhibit irrelevant stimuli, and regulate cognitive engagement during goal-directed tasks. Reading comprehension requires continuous attentional monitoring, integration of semantic information, and suppression of distracting environmental or internal stimuli. Consequently, deficits in attention regulation may substantially impair reading efficiency and text

E-ISSN: 3060-6713

comprehension (Gharaibeh, 2025; Khan & Lal, 2023). Executive dysfunctions involving attentional control are particularly common among children with learning disabilities and often co-occur with dyslexia and attention-deficit/hyperactivity symptoms (Conant & Miller, 2024; Landínez-Martínez et al., 2025). Studies examining executive functioning in children with dyslexia have consistently reported impairments in selective attention, inhibitory control, and working memory updating, all of which contribute to reading comprehension difficulties (Basharpoor et al., 2024; Ferreira et al., 2023).

Processing speed constitutes another critical cognitive factor associated with reading proficiency and comprehension. Efficient reading requires rapid visual recognition, fast lexical access, quick integration of semantic information, and timely coordination of cognitive operations. Children with dyslexia frequently demonstrate reduced processing speed, which negatively affects decoding automaticity and reading fluency (Li et al., 2022; Peng et al., 2022). Slower processing speed may increase cognitive load during reading tasks, thereby reducing the attentional resources available for higher-order comprehension processes. Empirical findings indicate that deficits in processing speed are strongly associated with difficulties in reading accuracy, comprehension, and academic achievement across different linguistic and educational contexts (Misciagna, 2022; Vágvölgyi et al., 2024). Moreover, neuropsychological investigations have demonstrated that processing speed interacts with working memory and executive functions in determining reading performance among children with developmental dyslexia (Kizilaslan & TunagÜR, 2021; Medina & Guimarães, 2021).

Beyond cognitive and linguistic impairments, emotional factors such as academic anxiety have also received increasing attention in dyslexia research. Children with persistent reading difficulties often experience repeated academic failure, negative classroom experiences, reduced self-confidence, and heightened performance anxiety. Academic anxiety can interfere with attentional regulation, working memory efficiency, and cognitive flexibility, thereby exacerbating reading comprehension deficits (Chung et al., 2023; Kormos, 2025). Research has shown that students with dyslexia frequently exhibit elevated levels of reading anxiety, school-related stress, and emotional distress compared to their peers without learning disabilities (Alves et al., 2024; Chung et al., 2023). Anxiety-related cognitive interference may impair the ability to process written information effectively, sustain concentration during reading tasks, and retrieve linguistic information from memory. Consequently, academic anxiety is increasingly viewed as an important emotional mechanism contributing to the maintenance and severity of reading difficulties.

Current neurocognitive models of dyslexia emphasize that reading comprehension deficits emerge from interactions among multiple systems rather than isolated impairments. Multifactorial frameworks propose that phonological deficits coexist with weaknesses in executive functioning, attentional regulation, processing efficiency, and emotional adjustment (Pasqualotto & Venuti, 2020; Wolf et al., 2024). Similarly, developmental and neuropsychological perspectives suggest that dyslexia reflects atypical connectivity among neural networks responsible for language processing, cognitive control, and memory integration (Flores-Gallegos et al., 2024; Pellegrino et al., 2023). Functional neuroimaging studies have demonstrated altered activation patterns in frontotemporal and parietal brain regions associated with reading and executive functioning in children with dyslexia (Flores-Gallegos et al., 2024). These findings support the assumption that dyslexia involves broad disruptions in cognitive coordination and information processing rather than solely phonological impairments.

The growing complexity of dyslexia research has generated increased interest in advanced computational approaches capable of integrating multidimensional cognitive, emotional, and behavioral data. Traditional statistical methods often face limitations in modeling nonlinear relationships and high-dimensional interactions among predictors. Machine learning approaches provide an innovative framework for identifying complex predictive patterns and generating accurate classification models for learning disorders (Alrubaian, 2025; Pinheiro-Chagas, 2025). Machine learning algorithms can analyze large sets of interconnected variables, identify hidden patterns, and produce predictive models with high sensitivity and specificity. In educational and neuropsychological research, machine learning has increasingly been employed to predict dyslexia risk, classify cognitive profiles, and identify children requiring early intervention (Cardoso-Pereira et al., 2024; Renata Pires Sena de Assumpção & Germano, 2025).

Recent advances in machine learning applications to dyslexia research have shown promising results. Predictive algorithms based on neuropsychological, linguistic, attentional, and behavioral variables have demonstrated substantial accuracy in identifying children at risk for reading disorders (Alrubaian, 2025). Data-driven cognitive

E-ISSN: 3060-6713

clustering approaches have also revealed heterogeneous neurocognitive profiles among children with persistent developmental dyslexia, indicating that different combinations of deficits may underlie reading difficulties (Pinheiro-Chagas, 2025). Similarly, studies incorporating eye-tracking measures, executive functioning indices, and neuropsycholinguistic variables have demonstrated the capacity of machine learning models to distinguish dyslexic readers from typical readers with considerable precision (Cardoso-Pereira et al., 2024). These findings suggest that machine learning approaches may facilitate earlier screening, individualized educational planning, and targeted intervention development.

Despite substantial progress in dyslexia research, several gaps remain within the literature. First, many previous studies have focused primarily on phonological deficits while underestimating the combined contributions of executive functions, processing speed, and emotional variables to reading comprehension impairments (Khan & Lal, 2023; Pasqualotto & Venuti, 2020). Second, relatively few investigations have simultaneously examined attention control, phonological awareness, processing speed, and academic anxiety within an integrated predictive framework. Third, although machine learning approaches have demonstrated considerable potential in educational prediction models, their application to reading comprehension deficits among children with dyslexia remains relatively limited, particularly in non-Western educational contexts (Alrubaian, 2025; Schneider & Mather, 2025). Furthermore, the heterogeneity of dyslexia profiles suggests that multidimensional and data-driven approaches may be more effective than traditional linear models for understanding individual differences in reading difficulties (Kranz et al., 2024; Wolf et al., 2024).

Another important consideration involves the developmental and comorbid nature of dyslexia. Research has indicated substantial overlap between dyslexia, developmental language disorder, attentional impairments, and broader learning disabilities (Bonti et al., 2021; Larissa Mariane et al., 2022). Children with dyslexia often exhibit deficits extending beyond reading itself, including impairments in executive functioning, mathematical reasoning, verbal fluency, and emotional regulation (Li et al., 2022; Nicolson & Fawcett, 2021). These overlapping difficulties may further complicate the identification and prediction of reading comprehension impairments. Consequently, comprehensive predictive models must account for multiple interacting domains of functioning rather than focusing exclusively on isolated reading skills.

Recent intervention-oriented studies have also emphasized the importance of identifying cognitive and emotional predictors of reading difficulties to improve treatment outcomes. Executive function training programs, virtual reality interventions, and neurocognitive rehabilitation approaches have demonstrated positive effects on reading performance among children with dyslexia (Basharpoor et al., 2024; Maresca et al., 2024; Maresca et al., 2022). Similarly, integrative neurobiological perspectives suggest that reading interventions should simultaneously target phonological processing, executive functioning, attentional regulation, and emotional adjustment (Pellegrino et al., 2023; Wilcox et al., 2020). Effective implementation of individualized interventions therefore requires accurate identification of the most influential predictors of reading comprehension deficits.

The increasing prevalence of data-driven educational assessment further underscores the need for predictive models capable of supporting evidence-based decision-making in schools and clinical settings. Machine learning techniques may provide clinicians, psychologists, and educators with efficient tools for identifying children at risk for severe reading difficulties and tailoring interventions according to specific cognitive profiles (Saunders et al., 2025; Schneider & Mather, 2025). Such approaches are particularly valuable in contexts where early diagnosis and intervention resources remain limited. Furthermore, predictive modeling may contribute to more comprehensive conceptualizations of dyslexia by clarifying the relative contributions of cognitive, linguistic, and emotional factors to reading comprehension impairments.

Accordingly, the present study aimed to predict reading comprehension deficits based on attention control, processing speed, phonological awareness, and academic anxiety using machine learning models in children with dyslexia.

2. Methods and Materials

2.1. Study Design and Participants

This study was conducted using a correlational design with a predictive modeling approach based on machine learning algorithms. The statistical population consisted of children with dyslexia who were enrolled in learning disability centers and elementary schools in Tehran during the 2025–2026 academic year. A total of 240 children aged

E-ISSN: 3060-6713

between 8 and 12 years were selected using multistage cluster sampling and purposive screening procedures. Initially, several educational districts in Tehran were randomly selected, and then specialized learning disorder centers and elementary schools affiliated with these districts were identified. Children who had previously received a formal diagnosis of dyslexia from educational psychologists or clinical specialists were screened for eligibility. Inclusion criteria included a confirmed diagnosis of dyslexia, normal intellectual functioning based on school psychological records, enrollment in elementary school, absence of severe neurological or psychiatric disorders, and parental consent for participation. Exclusion criteria included comorbid intellectual disability, severe sensory impairments, uncorrected visual or auditory deficits, and incomplete questionnaire responses. After obtaining informed consent from parents and school authorities, participants completed the research instruments individually in quiet educational settings under the supervision of trained psychology graduate students.

2.2. Measures

Reading comprehension deficits were assessed using the Reading Comprehension Subtest of the Gray Oral Reading Tests developed by Wiederholt and Bryant in 2012. This standardized instrument evaluates reading comprehension ability through passages followed by comprehension questions designed to assess literal and inferential understanding of written text. The test includes age-appropriate reading passages with increasing levels of difficulty and provides standardized scores based on normative data. Scoring is conducted according to the manual guidelines, with higher scores indicating better reading comprehension performance and lower scores reflecting greater comprehension deficits. Previous studies have demonstrated satisfactory psychometric properties for the instrument, including high internal consistency, test–retest reliability, and construct validity in populations with learning disabilities.

Attention control was measured using the Attention Control Scale developed by Derryberry and Reed in 2002. This self-report instrument evaluates the individual's ability to focus attention, shift attention when necessary, and maintain cognitive control in distracting situations. The scale consists of 20 items scored on a four-point Likert continuum ranging from almost never to always. Higher scores indicate stronger attentional control and cognitive regulation abilities. The scale contains subcomponents related to focusing and shifting attention and has been widely used in cognitive and educational psychology research. Previous studies have confirmed the scale's convergent validity, factorial validity, and acceptable Cronbach's alpha coefficients across child and adolescent populations.

Processing speed was assessed using the Processing Speed Index of the Wechsler Intelligence Scale for Children–Fifth Edition developed by Wechsler in 2014. This index includes timed subtests that evaluate rapid visual scanning, visual discrimination, symbol coding, and cognitive efficiency. Participants are required to perform simple visual-cognitive tasks under time constraints, allowing the assessment of mental speed and efficiency in processing information. Scores are standardized according to age-based norms, with lower scores indicating reduced processing speed. Extensive psychometric evaluations have demonstrated strong reliability and validity for the Processing Speed Index in both clinical and educational contexts, particularly among children with learning disorders and dyslexia.

Phonological awareness was measured using the Comprehensive Test of Phonological Processing developed by Wagner, Torgesen, Rashotte, and Pearson in 2013. This instrument assesses phonological processing abilities including phoneme blending, phoneme segmentation, sound matching, rapid naming, and phonological memory. The test includes multiple subtests that evaluate the child's awareness and manipulation of speech sounds, which are considered essential predictors of reading development and decoding ability. Responses are scored according to standardized administration procedures, and higher scores indicate stronger phonological processing skills. Previous studies have reported excellent reliability indices and strong predictive validity for identifying reading difficulties and dyslexia-related impairments.

Academic anxiety was assessed using the Academic Anxiety Scale developed by Alpert and Haber in 1960. This questionnaire measures anxiety associated with academic performance, classroom participation, examinations, and school-related cognitive concerns. The instrument consists of 19 items rated on a five-point Likert scale ranging from strongly disagree to strongly agree. Higher scores reflect greater levels of academic anxiety and emotional distress related to educational performance. The scale has demonstrated acceptable internal consistency, criterion validity, and stability across educational settings and has

E-ISSN: 3060-6713

been extensively used in studies examining emotional predictors of academic functioning.

2.3. Data Analysis

Data analysis was conducted using SPSS version 27 and Python programming libraries for machine learning analysis. Initially, descriptive statistics including means, standard deviations, skewness, and kurtosis values were calculated for all variables. Pearson correlation coefficients were computed to examine the relationships among attention control, processing speed, phonological awareness, academic anxiety, and reading comprehension deficits. Prior to predictive modeling, data preprocessing procedures including normalization, missing data treatment, and feature standardization were performed. Several machine learning algorithms including Random Forest, Support Vector Machine, Gradient Boosting, and Artificial Neural Network models were implemented to predict reading comprehension deficits based on the predictor variables. The dataset was divided into training and testing subsets using an 80/20 split approach, and model performance was evaluated through cross-validation procedures. Evaluation metrics included accuracy, precision, recall, F1-score, mean squared error, and area under the receiver operating characteristic curve. Feature importance analysis was also conducted to identify the relative contribution of each predictor variable in the prediction of reading comprehension deficits among children with dyslexia.

3. Findings and Results

The final sample consisted of 240 children with dyslexia from elementary schools and learning disability centers in Tehran. Among the participants, 134 children (55.8%) were boys and 106 children (44.2%) were girls. The mean age of the participants was 10.14 years (SD = 1.27), with an age range of 8 to 12 years. Regarding educational level, 52 participants (21.7%) were enrolled in second grade, 61 participants (25.4%) in third grade, 67 participants (27.9%) in fourth grade, and 60 participants (25.0%) in fifth grade. The majority of participants came from middle socioeconomic backgrounds according to school counseling records. Screening records further indicated that all participants had previously received a formal diagnosis of dyslexia by educational specialists and demonstrated persistent reading comprehension difficulties despite receiving educational support services. Preliminary examination of the dataset showed no missing values exceeding 5%, and assumptions of normality were considered acceptable based on skewness and kurtosis indices.

Table 1

Descriptive Statistics and Correlations among Study Variables

Variables	Mean	SD	1	2	3	4	5
1. Reading Comprehension Deficits	31.84	8.15	1				
2. Attention Control	42.71	7.26	-0.61**	1			
3. Processing Speed	87.93	12.48	-0.58**	0.46**	1		
4. Phonological Awareness	79.56	10.37	-0.72**	0.52**	0.63**	1	
5. Academic Anxiety	58.22	9.41	0.55**	-0.48**	-0.39**	-0.44**	1

**p < 0.01

The descriptive findings presented in Table 1 demonstrated that children with dyslexia exhibited relatively high levels of reading comprehension deficits and academic anxiety, while average scores for attention control, processing speed, and phonological awareness were below normative expectations for their age group. Correlational analyses revealed statistically significant associations among all study variables. Reading comprehension deficits showed significant negative correlations with attention control ($r = -0.61$, $p < 0.01$), processing speed ($r = -0.58$, $p < 0.01$), and phonological awareness ($r = -0.72$, $p < 0.01$), indicating that higher cognitive and phonological functioning were associated with fewer comprehension problems. In contrast, academic anxiety demonstrated a positive and significant correlation with reading comprehension deficits ($r = 0.55$, $p < 0.01$), suggesting that elevated anxiety levels were associated with more severe reading comprehension difficulties. Among predictor variables, phonological awareness displayed the strongest correlation with reading comprehension deficits, highlighting its central role in reading performance among children with dyslexia. Additionally, attention control and processing speed were positively associated with phonological awareness, indicating substantial overlap

E-ISSN: 3060-6713

between executive functioning and phonological processing abilities in this population.

Table 2

Performance Metrics of Machine Learning Models in Predicting Reading Comprehension Deficits

Model	Accuracy	Precision	Recall	F1-Score	RMSE	AUC
Random Forest	0.91	0.89	0.90	0.89	4.11	0.94
Support Vector Machine	0.87	0.85	0.86	0.85	5.02	0.90
Gradient Boosting	0.93	0.91	0.92	0.91	3.78	0.96
Artificial Neural Network	0.89	0.88	0.87	0.87	4.54	0.92

The comparative findings of the machine learning analyses are presented in Table 2. Among the evaluated predictive models, the Gradient Boosting algorithm demonstrated the highest predictive performance for identifying reading comprehension deficits in children with dyslexia. Specifically, this model achieved an accuracy of 93%, precision of 91%, recall of 92%, and an F1-score of 91%, while also producing the lowest root mean square error (RMSE = 3.78) and the highest area under the curve value (AUC = 0.96). These findings indicate excellent classification capability and high predictive stability. The Random Forest model also demonstrated strong predictive performance with an accuracy rate of 91% and AUC value of 0.94, suggesting that ensemble-based algorithms were particularly effective in modeling the multidimensional relationships among cognitive, emotional, and phonological variables. Although the Artificial Neural Network model showed satisfactory performance indices, its predictive accuracy was slightly lower than that of the ensemble methods. The Support Vector Machine model demonstrated comparatively weaker performance, though its classification indices remained within acceptable ranges. Overall, the findings suggest that machine learning algorithms, particularly ensemble learning approaches, are highly effective in predicting reading comprehension deficits based on attention control, processing speed, phonological awareness, and academic anxiety among children with dyslexia.

Table 3

Feature Importance Analysis for Predicting Reading Comprehension Deficits

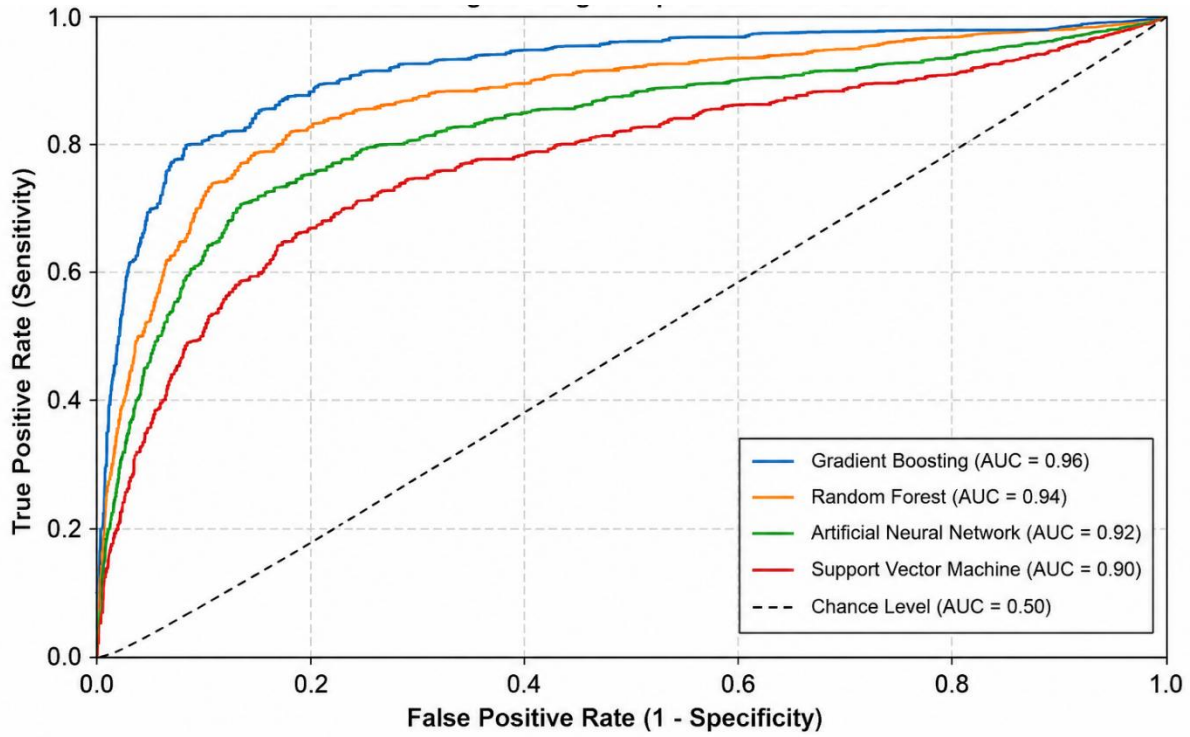
Predictor Variable	Importance Score
Phonological Awareness	0.38
Attention Control	0.27
Academic Anxiety	0.21
Processing Speed	0.14

The feature importance analysis revealed that phonological awareness was the strongest predictor of reading comprehension deficits, with an importance score of 0.38. This finding suggests that deficits in phonological processing abilities play the most substantial role in predicting reading comprehension problems among children with dyslexia. Attention control emerged as the second most influential predictor with an importance score of 0.27, indicating that executive attentional processes significantly contribute to reading comprehension performance. Academic anxiety also demonstrated a meaningful predictive contribution (0.21), emphasizing the importance of emotional and motivational factors in reading-related functioning. Processing speed showed the lowest importance score among the predictors (0.14), although its contribution remained statistically and practically meaningful within the predictive models. Collectively, these findings demonstrate that reading comprehension deficits in dyslexia are influenced by a multidimensional interaction of cognitive, phonological, and emotional processes rather than a single isolated factor. The results further support the theoretical assumption that successful reading comprehension requires the integration of executive attention regulation, rapid information processing, phonological decoding abilities, and emotional stability within academic contexts.

E-ISSN: 3060-6713

Figure 1

Comparative ROC Curves of Machine Learning Models for Predicting Reading Comprehension Deficits



The receiver operating characteristic curves demonstrated that the Gradient Boosting and Random Forest models achieved the highest discriminative capacity among all evaluated algorithms. The Gradient Boosting model showed the largest area under the curve, reflecting superior sensitivity and specificity in identifying children with severe reading comprehension deficits. The Random Forest model similarly demonstrated strong classification performance with stable predictive boundaries across different probability thresholds. In contrast, the Support Vector Machine model displayed comparatively lower sensitivity in distinguishing high-risk cases, while the Artificial Neural Network model exhibited moderate but acceptable classification efficiency. The ROC analysis overall confirmed that ensemble-based machine learning methods provided the most robust and clinically useful predictive models for identifying reading comprehension deficits in children with dyslexia. These findings indicate that machine learning approaches may serve as valuable tools for early educational screening, individualized intervention planning, and data-driven assessment of cognitive and emotional risk factors associated with dyslexia-related reading difficulties.

4. Discussion

The present study aimed to predict reading comprehension deficits based on attention control, processing speed, phonological awareness, and academic anxiety using machine learning models in children with dyslexia. The findings demonstrated that all predictor variables were significantly associated with reading comprehension deficits and that machine learning algorithms, particularly Gradient Boosting and Random Forest models, achieved high predictive accuracy in identifying children with severe reading comprehension impairments. Among the predictor variables, phonological awareness emerged as the strongest predictor, followed by attention control, academic anxiety, and processing speed. Overall, the findings support multidimensional and neurocognitive models of dyslexia suggesting that reading comprehension difficulties result from complex interactions among cognitive, linguistic, executive, and emotional factors rather than a single isolated deficit.

One of the most important findings of the present study was the strong predictive role of phonological awareness in reading comprehension deficits among children with dyslexia. This finding is highly consistent with classical and

E-ISSN: 3060-6713

contemporary theories of dyslexia emphasizing the central importance of phonological processing in reading development (Snowling & Hulme, 2020; Wolf et al., 2024). Children with weak phonological awareness experience difficulties in segmenting, manipulating, and integrating speech sounds, which directly impairs decoding automaticity and reading fluency. Inefficient decoding subsequently increases cognitive load during reading tasks and reduces the availability of attentional and working memory resources necessary for comprehension processes. The present findings are aligned with previous investigations demonstrating that phonological awareness constitutes one of the strongest predictors of reading performance and literacy acquisition in children with dyslexia (López-Zamora et al., 2025; Medina & Guimarães, 2021). Similarly, Peng et al. reported that phonological processing deficits significantly contribute to individual differences in reading difficulties across linguistic systems and developmental stages (Peng et al., 2022). The current findings further support integrative neuropsychological perspectives proposing that phonological processing deficits remain a core mechanism underlying dyslexia even when other executive and attentional impairments are present (Misciagna, 2022; Valenzuela & Martín-Ruiz, 2022).

The findings also demonstrated that attention control significantly predicted reading comprehension deficits. Children with lower attentional regulation exhibited more severe reading comprehension impairments, indicating the important role of executive attentional processes in successful reading performance. Reading comprehension requires sustained concentration, selective attention, inhibitory control, and cognitive flexibility to integrate textual information and suppress irrelevant stimuli. Children with dyslexia often exhibit impairments in executive functioning and attentional regulation, which may compromise their ability to maintain cognitive engagement during reading tasks (Gharaibeh, 2025; Khan & Lal, 2023). The present results are consistent with previous research demonstrating significant associations between executive dysfunctions and reading impairments among children with learning disabilities (Basharpoor et al., 2024; Ferreira et al., 2023). Basharpoor et al. found that computerized executive function training significantly improved reading performance in children with dyslexia, suggesting that attentional and executive mechanisms contribute directly to reading efficiency (Basharpoor et al., 2024). Furthermore, the findings correspond with neurocognitive frameworks proposing that dyslexia involves broader impairments in attentional coordination and executive regulation rather than solely phonological dysfunctions (Pasqualotto & Venuti, 2020; Pellegrino et al., 2023).

Another significant finding of the study involved the predictive contribution of processing speed to reading comprehension deficits. Although processing speed demonstrated a lower feature importance score compared to phonological awareness and attention control, it remained a meaningful predictor within the machine learning models. Reduced processing speed may interfere with rapid visual recognition, lexical retrieval, semantic integration, and fluency development, thereby impairing reading comprehension. Children with slower cognitive processing often require greater mental effort to decode and interpret written information, resulting in reduced efficiency during complex reading tasks (Li et al., 2022; Vágvölgyi et al., 2024). The current findings are consistent with previous studies demonstrating that processing speed deficits are strongly associated with reading difficulties and lower academic achievement among children with dyslexia (Kizilaslan & TunagÜR, 2021; Peng et al., 2022). In addition, neuropsychological investigations have suggested that processing speed limitations may negatively affect working memory efficiency and executive functioning during reading activities (Nicolson & Fawcett, 2021; Valenzuela & Martín-Ruiz, 2022). Therefore, the present results support the assumption that cognitive efficiency and rapid information processing constitute essential components of successful reading comprehension.

The present study also demonstrated that academic anxiety significantly predicted reading comprehension deficits among children with dyslexia. Children with higher levels of school-related anxiety exhibited more severe reading comprehension problems, suggesting that emotional distress may substantially interfere with cognitive and linguistic functioning during academic tasks. This finding supports cognitive-interference theories proposing that anxiety consumes attentional and working memory resources necessary for efficient information processing (Kormos, 2025). Children with dyslexia frequently encounter repeated academic failure, social comparison, and negative classroom experiences, which may contribute to heightened anxiety and reduced self-confidence. Anxiety-related cognitive interference may impair concentration, disrupt attentional control, and reduce comprehension efficiency during reading activities. The findings are highly consistent with studies demonstrating significant relationships between academic anxiety, reading anxiety,

E-ISSN: 3060-6713

and reading performance among students with dyslexia (Alves et al., 2024; Chung et al., 2023). Chung et al. specifically reported that reading anxiety and negative reading self-concept were associated with weaker reading skills in adolescents with dyslexia (Chung et al., 2023). These findings collectively emphasize the importance of considering emotional and motivational factors in the assessment and intervention of reading disorders.

An important contribution of the present study involves the successful application of machine learning approaches to predict reading comprehension deficits in children with dyslexia. The Gradient Boosting and Random Forest algorithms demonstrated the highest predictive performance, indicating that ensemble-based machine learning methods are particularly effective in modeling multidimensional educational and neuropsychological data. These findings support recent research emphasizing the value of data-driven computational approaches in dyslexia screening and assessment (Alrubaian, 2025; Pinheiro-Chagas, 2025). Machine learning models possess the ability to identify nonlinear interactions and hidden relationships among variables that may not be adequately captured through traditional statistical analyses. The current findings are consistent with studies showing that machine learning algorithms can accurately classify dyslexia risk and cognitive profiles based on neuropsychological, linguistic, and behavioral indicators (Cardoso-Pereira et al., 2024; Renata Pires Sena de Assumpção & Germano, 2025). Alrubaian demonstrated that advanced machine learning algorithms achieved substantial predictive accuracy in identifying dyslexia-related risk factors across screening and diagnostic stages (Alrubaian, 2025). Similarly, Pinheiro-Chagas identified distinct cognitive clusters among individuals with developmental dyslexia using data-driven analytical techniques (Pinheiro-Chagas, 2025). Therefore, the present study extends previous findings by demonstrating the applicability of machine learning models specifically for predicting reading comprehension deficits based on integrated cognitive and emotional variables.

The multidimensional pattern of findings observed in the present study strongly supports contemporary multifactorial models of dyslexia. According to these models, reading comprehension deficits emerge from interactions among linguistic impairments, executive dysfunctions, attentional weaknesses, cognitive inefficiencies, and emotional difficulties (Pasqualotto & Venuti, 2020; Wolf et al., 2024). The coexistence of phonological deficits, executive dysfunctions, attentional impairments, and anxiety-related difficulties suggests that dyslexia should not be conceptualized as a purely language-based disorder. Instead, reading impairments appear to reflect disruptions in broader neurocognitive systems responsible for information processing, self-regulation, and cognitive coordination. These findings also correspond with integrative neurodevelopmental perspectives emphasizing overlapping vulnerabilities across learning disabilities, attentional disorders, and developmental language impairments (Conant & Miller, 2024; Larissa Mariane et al., 2022). The heterogeneity of cognitive and emotional profiles among children with dyslexia further supports the necessity of individualized assessment and intervention approaches.

The findings additionally have important educational and clinical implications. The high predictive accuracy of machine learning models suggests that data-driven screening approaches may facilitate earlier identification of children at risk for severe reading comprehension deficits. Early detection is particularly important because delayed intervention may contribute to cumulative academic failure, reduced self-esteem, and persistent educational disadvantages (Saunders et al., 2025; Schneider & Mather, 2025). Moreover, identifying the relative contribution of cognitive and emotional predictors may assist clinicians and educators in developing targeted intervention programs tailored to individual profiles. For example, children demonstrating severe phonological deficits may benefit primarily from phonological awareness training, whereas children with pronounced attentional or anxiety-related difficulties may require executive functioning interventions or emotional support strategies. Recent intervention-oriented studies have shown that executive function training, neurocognitive rehabilitation, and virtual reality-based interventions may improve reading performance among children with dyslexia (Basharpoor et al., 2024; Maresca et al., 2024; Maresca et al., 2022). Consequently, the present findings reinforce the importance of multidimensional and individualized approaches to dyslexia intervention.

5. Conclusion

An important aspect of the findings involves the broader theoretical understanding of reading comprehension deficits. The strong predictive contribution of executive and emotional variables suggests that successful reading comprehension extends beyond decoding and linguistic processing. Reading comprehension requires sustained attention, efficient information processing, emotional

E-ISSN: 3060-6713

regulation, semantic integration, and working memory coordination. Therefore, interventions focusing exclusively on phonological remediation may fail to address broader neurocognitive and emotional mechanisms contributing to reading difficulties. This interpretation is supported by previous studies emphasizing the interconnected nature of language processing, executive functioning, and emotional regulation in dyslexia (Kormos, 2025; Pellegrino et al., 2023). Furthermore, neurofunctional investigations have demonstrated altered connectivity among brain regions responsible for executive functioning, language processing, and working memory in children with reading disabilities (Flores-Gallegos et al., 2024). The current findings therefore contribute to increasingly dynamic and comprehensive conceptualizations of dyslexia emphasizing systemic cognitive interactions (Wolf et al., 2024).

Despite the strengths of the present study, several limitations should be acknowledged. First, the cross-sectional design limits causal interpretation regarding the relationships among cognitive variables, anxiety, and reading comprehension deficits. Second, the study sample was limited to children with dyslexia in Tehran, which may restrict the generalizability of the findings to other cultural, linguistic, or educational contexts. Third, some measures relied on self-report or behavioral assessment methods that may be influenced by response biases or situational factors. Fourth, although machine learning models demonstrated high predictive accuracy, external validation using independent datasets was not conducted. Finally, additional variables such as socioeconomic status, parental educational background, teacher support, and motivational factors were not included in the predictive models.

Future research should employ longitudinal designs to examine developmental changes in cognitive and emotional predictors of reading comprehension deficits over time. Additional studies should investigate larger and more culturally diverse samples to improve the generalizability of predictive models. Researchers are also encouraged to incorporate neuroimaging, eye-tracking, and physiological assessment techniques to better understand the neural and biological mechanisms underlying dyslexia-related reading impairments. Future machine learning investigations may benefit from combining multimodal datasets including linguistic, neuropsychological, emotional, and neurofunctional variables to improve predictive precision. Furthermore, comparative studies evaluating different intervention approaches based on individualized cognitive profiles may contribute to more effective educational and therapeutic practices.

The findings of the present study suggest several practical implications for educators, clinicians, school psychologists, and policymakers. Early screening programs should incorporate multidimensional assessment approaches evaluating phonological awareness, attentional control, processing speed, and emotional functioning rather than relying exclusively on traditional reading tests. Schools may benefit from implementing data-driven screening systems capable of identifying students at elevated risk for reading comprehension difficulties before severe academic failure occurs. Educational interventions should be individualized according to each child's cognitive and emotional profile and should integrate phonological training, executive functioning exercises, attentional regulation strategies, and anxiety-reduction techniques. In addition, teachers and parents should receive training regarding the multifactorial nature of dyslexia to promote more supportive and psychologically informed educational environments for children experiencing reading difficulties.

Authors' Contributions

Authors equally contributed to this article.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

Acknowledgments

We would like to express our gratitude to all individuals helped us to do the project.

Declaration of Interest

The authors report no conflict of interest.

Funding

According to the authors, this article has no financial support.

E-ISSN: 3060-6713

Ethics Considerations

The study protocol adhered to the principles outlined in the Helsinki Declaration, which provides guidelines for ethical research involving human participants.

References

Alrubaian, A. (2025). Exploring and Identifying Key Factors in Predicting Dyslexia in Children: Advanced Machine Learning Algorithms From Screening to Diagnosis. *Clinical Psychology & Psychotherapy*, *32*(3). https://doi.org/10.1002/cpp.70077

Alves, R. J. R., Victória, R. d. A. G., Fonseca, B. G., Gabrielle, M. C. d. A., Duarte, J. L., & Crenitte, P. A. P. (2024). The Big Five Personality Traits in Dyslexic Adults: An Exploratory Study. *Actas Esp Psiquiatr*, *52*(4), 428-436. https://doi.org/10.62641/aep.v52i4.1661

Basharpoor, S., Seif, E., & Daneshvar, S. (2024). Computerized Executive Functions Training: The Efficacy on Reading Performance of Children With Dyslexia. *Dyslexia*, *30*(2). https://doi.org/10.1002/dys.1762

Bonti, E., Kamari, A., Sofologi, M., Giannoglou, S., Porfyri, G.-N., Tatsiopoulou, P., Kougioumtzis, G. A., Efstratopoulou, M., & Diakogiannis, I. (2021). Similarities and Differences in the Learning Profiles of Adolescents With SLD and SLI in Mathematics. https://doi.org/10.20944/preprints202103.0606.v1

Cardoso-Pereira, N., Costa, A., & Guerreiro, M. (2024). Predictive Models of Reading Difficulties Considering Neuropsycholinguistic Profiles of Atypical and ADHD-inattentive Type Readers, and Eye-Tracking Measures. *Journal of Eye Movement Research*, *16*(4). https://doi.org/10.16910/jemr.16.4.6

Chung, K. K. H., Lam, C. B., Chan, K. S., Lee, A., Liu, C., & Wang, L. C. (2023). Are General Anxiety, Reading Anxiety, and Reading Self-Concept Linked to Reading Skills Among Chinese Adolescents With and Without Dyslexia? *Journal of Learning Disabilities*, *57*(2), 106-119. https://doi.org/10.1177/00222194231181914

Conant, L. L., & Miller, L. E. (2024). Intellectual Developmental Disorder, Autism Spectrum Disorder, Attention-Deficit/Hyperactivity Disorder, and Specific Learning Disorders Across the Lifespan. 587-617. https://doi.org/10.1037/0000383-022

Ferreira, T. F. L., Janaína Aparecida de Oliveira, A., Stella, P. R. F., Rita de Cássia Coutinho Vieira, F., Arduin, R. G., & Ciasca, S. M. (2023). Cognitive and Behavioral Profile in Dyslexia: Challenges in Interdisciplinary Assessment. *Psychology*, *14*(06), 1038-1052. https://doi.org/10.4236/psych.2023.146056

Flores-Gallegos, R., Fernández, T. a., Alcauter, S., Pasaye, E. H., Albarrán-Cárdenas, L., Barrera-Díaz, B. E., & Rodríguez-Leis, P. (2024). Functional Connectivity Is Linked to Working Memory Differences in Children With Reading Learning Disability. *BMC pediatrics*, *24*(1). https://doi.org/10.1186/s12887-024-04791-2

Gharaibeh, M. (2025). Examining the Level of Executive Functions in the Arabic Language Among Third-Grade Students With Typical Literacy Development and Dyslexia. https://doi.org/10.21203/rs.3.rs-7786621/v1

Khan, K., & Lal, P. (2023). Executive Dysfunctions in Different Learning Disabilities: A Review. *Journal of Indian Association for Child and Adolescent Mental Health*, *19*(2), 126-142. https://doi.org/10.1177/09731342231179614

Kizilaslan, A., & TunagÜR, M. (2021). Dyslexia and Working Memory: Understanding Reading Comprehension and High Level Language Skills in Students With Dyslexia. *Kastamonu Eğitim Dergisi*, *29*(5), 941-952. https://doi.org/10.24106/kefdergi.741028

Knight, R. E., Ritter, M. J., & Loeb, D. F. (2024). Strategies Used by University Students With Dyslexia: A Narrative Review. *Communication Disorders Quarterly*, *46*(2), 103-117. https://doi.org/10.1177/15257401241275900

Kormos, J. (2025). The Role of First Language Skills, Working Memory, and Anxiety in Second Language Reading. *Studies in Second Language Acquisition*, 1-23. https://doi.org/10.1017/s0272263125101010

Kranz, A. E., Serry, T., & Snow, P. (2024). Twice-exceptionality Unmasked: A Systematic Narrative Review of the Literature on Identifying Dyslexia in the Gifted Child. *Dyslexia*, *30*(1). https://doi.org/10.1002/dys.1763

Landínez-Martínez, D., Londoño, D. M. M., Aldana, L. A., Lubert, C. D., Robledo-Castro, C., & Gutierrez, A. P. (2025). Neuropsychological and Academic Performance in Colombian Children With Attention-Deficit Hyperactivity Disorder: A Comparative Study With a Control Group. *Children*, *12*(5), 561. https://doi.org/10.3390/children12050561

Larissa Mariane, M. A. M., Anna Irenne de Lima, A., Messias, B. L. C., Maria Elizabeth Job de, V., & Azoni, C. A. S. (2022). Are Dyslexia and Developmental Language Disorder Isolated or Comorbid Conditions? An Integrative Review. *Revista Cefac*, *24*(3). https://doi.org/10.1590/1982-0216/202224312021

Li, Z., Al-Qadri, A. H., & Zhao, W. (2022). The Cognitive Ability of Chinese Students With Dyslexia and Mathematical Learning Disabilities. *Children*, *9*(12), 1949. https://doi.org/10.3390/children9121949

López-Zamora, M., Porcar-Gozalbo, N., López-Chicheri, I., & Cano-Villagrasa, A. (2025). Linguistic and Cognitive Abilities in Children With Dyslexia: A Comparative Analysis. *European Journal of Investigation in Health Psychology and Education*, *15*(3), 37. https://doi.org/10.3390/ejihpe15030037

Maresca, G., Corallo, F., Cola, M. C. D., Formica, C., Giliberto, S., Rao, G., Crupi, M. F., Quartarone, A., & Pidalà, A. (2024). Effectiveness of the Use of Virtual Reality Rehabilitation in Children With Dyslexia: Follow-Up After One Year. *Brain Sciences*, *14*(7), 655. https://doi.org/10.3390/brainsci14070655

Maresca, G., Leonardi, S., Cola, M. C. D., Giliberto, S., Cara, M. D., Corallo, F., Quartarone, A., & Pidalà, A. (2022). Use of Virtual Reality in Children With Dyslexia. *Children*, *9*(11), 1621. https://doi.org/10.3390/children9111621

Medina, G. B. K., & Guimarães, S. R. K. (2021). Reading in Developmental Dyslexia: The Role of Phonemic Awareness and Executive Functions. *Estudos De Psicologia (Campinas)*, *38*. https://doi.org/10.1590/1982-0275202138e180178

Misciagna, S. (2022). Neuropsychological Assessment of Children With Learning Disabilities. https://doi.org/10.5772/intechopen.102565

Nicolson, R. I., & Fawcett, A. J. (2021). Mathematics Disability vs. Learning Disability: A 360 Degree Analysis. *Frontiers in psychology*, *12*. https://doi.org/10.3389/fpsyg.2021.725694

Pasqualotto, A., & Venuti, P. (2020). A Multifactorial Model of Dyslexia: Evidence From Executive Functions and Phonological-based Treatments. *Learning Disabilities Research and Practice*, *35*(3), 150-164. https://doi.org/10.1111/ldrp.12228

E-ISSN: 3060-6713

Pellegrino, M., Ben-Soussan, T. D., & Paoletti, P. (2023). A Scoping Review on Movement, Neurobiology and Functional Deficits in Dyslexia: Suggestions for a Three-Fold Integrated Perspective. *International journal of environmental research and public health*, *20*(4), 3315. https://doi.org/10.3390/ijerph20043315

Peng, P., Zhang, Z., Wang, W., Lee, K., Wang, T., Wang, C., Luo, J., & Lin, J. (2022). A Meta-Analytic Review of Cognition and Reading Difficulties: Individual Differences, Moderation, and Language Mediation Mechanisms. *Psychological bulletin*, *148*(3-4), 227-272. https://doi.org/10.1037/bul0000361

Pinheiro-Chagas, P. (2025). Data-Driven Cognitive Clusters in Persistent Developmental Dyslexia. https://doi.org/10.1101/2025.11.24.690327

Renata Pires Sena de Assumpção, V., & Germano, G. D. (2025). Characterization of Reading Processes in Brazilian Adolescents: Development of Criteria for Identifying Students at Risk for Dyslexia. *Frontiers in psychology*, *16*. https://doi.org/10.3389/fpsyg.2025.1477896

Saunders, K. V., Sun, S., Tibi, S., Dawson, K., & Lombardino, L. J. (2025). Staples of Screening for Dyslexia in University Students. *Dyslexia*, *31*(4). https://doi.org/10.1002/dys.70011

Schneider, D., & Mather, N. (2025). A Postsecondary Case Study: Use of the WJ v Dyslexia Test Set and Other Tests to Inform Recommendations for Accommodations in Higher Education. *Journal of Psychoeducational Assessment*. https://doi.org/10.1177/07342829251355504

Snowling, M. J., & Hulme, C. (2020). Annual Research Review: Reading Disorders Revisited – The Critical Importance of Oral Language. *Journal of Child Psychology and Psychiatry*, *62*(5), 635-653. https://doi.org/10.1111/jcpp.13324

Vágvölgyi, R., Sahlender, M., Schröter, H., Nagengast, B., Dresler, T., Schrader, J., & Nuerk, H. C. (2024). Low Literacy Skills in Adults Can Be Largely Explained by Basic Linguistic and Domain-General Predictors. *Frontiers in psychology*, *15*. https://doi.org/10.3389/fpsyg.2024.1422896

Valenzuela, M. J. G., & Martín-Ruiz, I. (2022). Neuropsychological Perspective on Dyslexia. https://doi.org/10.5772/intechopen.99386

Wilcox, G., Galilee, A., Stamp, J., Makarenko, E., & MacMaster, F. P. (2020). The Importance of Research on Integrating Transcranial Direct Current Stimulation (TDCS) With Evidence-Based Reading Interventions. *Journal of Pediatric Neuropsychology*, *6*(4), 218-228. https://doi.org/10.1007/s40817-020-00090-7

Wolf, M., Gotlieb, R., Kim, S. A., Pedroza, V., Rhinehart, L., Gorno-Tempini, M. L., & Sears, S. (2024). Towards a Dynamic, Comprehensive Conceptualization of Dyslexia. *Annals of Dyslexia*, *74*(3), 303-324. https://doi.org/10.1007/s11881-023-00297-1

E-ISSN: 3060-6713