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VISUOMOTOR INTEGRATION, EXECUTIVE FUNCTIONS, AND LEXICAL ACCESS AS CANDIDATE NEUROCOGNITIVE MARKERS OF READING PERFORMANCE IN SCHOOLCHILDREN AT RISK FOR DYSLEXIA

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Abstract:
This study investigated the relationships among visuomotor integration, executive functions, lexical access, and reading performance in schoolchildren at risk for dyslexia. Twenty-five third-grade students aged 8–9 years completed measures of rapid automatized naming, naming errors, self-monitoring, reading comprehension, visuomotor performance, and visuomotor screening. Spearman correlations, age-adjusted partial correlations, false discovery rate correction, and hierarchical regression models were applied. Self-monitoring was strongly associated with rapid naming time ($\rho = -0.774$, $p < 0.001$), visuomotor performance ($\rho = -0.596$, $p = 0.002$), and reading comprehension ($\rho = 0.544$, $p = 0.005$). Rapid naming time was also associated with reading comprehension ($\rho = -0.531$, $p = 0.006$) and naming errors ($\rho = 0.524$, $p = 0.007$). Rapid naming explained 22.7% of the variance in reading comprehension, whereas the addition of self-monitoring and visuomotor performance increased R^2 without significant incremental effects. The findings suggest that executive monitoring, lexical access, and visuomotor integration form an interconnected neurocognitive organization associated with reading-related performance in children at risk for dyslexia.

Keywords: Dyslexia, executive functions, visuomotor integration

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1. Introduction

Learning to read results from the interaction between linguistic processes and domain-general cognitive mechanisms, particularly executive functions, visual attention, and the integration of sensory and motor systems. In children with dyslexia or at risk for reading difficulties, reading impairment is not limited to phonological processing but also involves alterations in inhibition, working memory, cognitive flexibility, processing speed, and visuospatial attention (Taran *et al.*, 2022; Dahhan *et al.*, 2022; Medina & Guimarães, 2021; Lee, 2023; Franceschini *et al.*, 2022; Taran *et al.*, 2023). This body of evidence supports a multifactorial view of dyslexia, in which different neurocognitive domains contribute to reading accuracy, fluency, and comprehension (Taran *et al.*, 2022; Martins *et al.*, 2025; Taran *et al.*, 2023; Horowitz-Kraus *et al.*, 2026).

Among these domains, executive functions have been shown to be particularly relevant to reading performance. Longitudinal evidence indicates that executive functioning at different stages of development predicts subsequent reading achievement (Brock *et al.*, 2018; Zuckerman *et al.*, 2023). In children with dyslexia, executive deficits are more strongly associated with reading fluency than with accuracy and are also related to reduced activation of the typical left-hemisphere reading network (Dahhan *et al.*, 2022). Consistent correlations have also been reported among reading, phonemic awareness, working memory, inhibitory control, cognitive flexibility, and orthographic verbal fluency, indicating that successful reading depends on cognitive self-regulation during text processing (Medina & Guimarães, 2021; Pereira *et al.*, 2024; Ramezani & Fawcett, 2024).

Rapid lexical access constitutes another central component of reading, particularly because of its relationship with the automatization of word recognition and reading fluency. Improvements in naming speed, lexical access speed, and processing speed have been associated with better reading performance, suggesting that slowing in these processes may hinder the consolidation of more efficient reading routes (Ramezani & Fawcett, 2024; Horowitz-Kraus *et al.*, 2025; Taran *et al.*, 2023). In addition, eye-tracking studies have shown that cognitive and oculomotor variables improve the prediction of reading difficulties, reinforcing the view that access to the orthographic lexicon depends on coordinated perceptual and attentional operations (Pereira *et al.*, 2024; Caldani *et al.*, 2020).

Visual attention and visuospatial processing also play an important role in this framework. Visuospatial attentional abilities predict reading acquisition as early as the pre-reading stage, and children with reading difficulties show clear impairments in visuospatial attention (Taran *et al.*, 2022; Franceschini *et al.*, 2022). In parallel, alterations in the visual processing of written words, particularly in the left ventral occipitotemporal region, increase with the severity of reading impairment, suggesting that deficits in visual word-form processing may constrain reading comprehension (Brem *et al.*, 2020).

Visuomotor integration emerges as an additional component of this network, although it has been less frequently examined in conjunction with reading. Longitudinal data indicate that visuomotor integration in early childhood education predicts later reading performance (Brock *et al.*, 2018), and studies in other pediatric populations suggest that it may act as an independent predictor of reading achievement (Yang *et al.*, 2025). Recent evidence also indicates that executive processes, such as working memory and inhibitory control, may exert part of their academic effects through visuomotor integration, strengthening the plausibility of functional relationships among these domains (Dong *et al.*, 2026).

At the neurobiological level, fluent reading appears to depend on synchronization among executive, attentional, and sensory networks. Children with dyslexia show reduced functional connectivity between attentional networks and regions associated with reading, whereas gains in fluency have been linked to stronger connections among executive, sensory, and audiovisual integration networks (Taran *et al.*, 2022; Farah *et al.*, 2024; Horowitz-Kraus *et al.*, 2025; Taran *et al.*, 2023; Horowitz-Kraus *et al.*, 2026). Taken together, these findings indicate that dyslexia and risk for specific learning difficulties should be understood in terms of an integrated neurocognitive network rather than a single isolated deficit (Martins *et al.*, 2025; Horowitz-Kraus, 2023; Horowitz-Kraus *et al.*, 2026).

Despite this evidence, studies that jointly investigate the relationships among visuomotor integration, executive functions, lexical access, and reading performance in schoolchildren at risk for dyslexia remain scarce (Zuckerman *et al.*, 2023; Marks *et al.*, 2023; Horowitz-Kraus *et al.*, 2026). Therefore, the present study aimed to investigate the relationships among visuomotor integration, executive functions, lexical access, and reading performance in schoolchildren at risk for dyslexia, seeking to understand how these domains are organized as interdependent components of a neurocognitive network associated with reading automatization and comprehension.

2. Materials and Methods

This was an observational, analytical, cross-sectional study involving 25 students enrolled in the third grade of elementary school who had previously been identified as being at risk for dyslexia. The sample comprised 12 girls and 13 boys, including 10 students aged 8 years and 15 aged 9 years. The mean age of the participants was 9.04 ± 0.05 years.

Data collection was conducted in two stages. First, the research team individually interviewed the teachers responsible for the classes to obtain information regarding the students' reading, writing, and visuomotor integration abilities. During this stage, the Reading and Writing Screening Scale (*Escala de Rastreio para Leitura e Escrita* – ERLE) and the Visuomotor Screening Scale for Schoolchildren (*Escala de Triagem Visuomotora para Escolares* – ETVE) were administered. Subsequently, the students were directly assessed for visuomotor integration, self-monitoring, rapid automatized naming, reading fluency and comprehension, and word and pseudoword recognition competence.

In the version of the ERLE used in the present study, the instrument comprised 15 items completed by teachers according to the frequency of behaviors observed during the 45 days preceding the interview. The items investigated aspects such as slowness, inaccuracy, and insecurity during reading; comprehension difficulties; letter substitutions, omissions, or additions; handwriting problems; and difficulties organizing and expressing ideas in writing. Each item was scored on a four-point Likert scale: "never," one point; "rarely," two points; "sometimes," three points; and "frequently/always," four points. Total scores ranged from 15 to 60 points, with higher scores indicating a greater frequency of reading and writing difficulties perceived by the teacher. The scale was used as a screening instrument and not to establish a diagnosis of dyslexia. The original instrument was developed and validated to screen for the risk of developmental dyslexia in elementary school students (Bassôa *et al.*, 2021).

The ETVE was used to identify risk factors related to the development of visuomotor abilities based on teachers' perceptions of students' performance in everyday activities. The instrument comprises 15 statements scored on a five-point scale, ranging from one point, corresponding to "not at all like the child," to five points, corresponding to "very much like the child." Total scores range from 15 to 75 points. Because of the direction of the statements, higher scores indicate a greater frequency of difficulties and, consequently, poorer visuomotor performance as perceived by the teacher. Age-specific parameters were considered when interpreting the results: scores of up to 29 points for children aged between 7 years and 8 years and 11 months, and scores of up to 25 points for children aged between 9 years and 10 years and 11 months. Scores above the respective cutoff values were considered indicative of risk in visuomotor abilities.

During the second stage, the Nine-Hole Peg Test, the Self-Monitoring Test, and the reading comprehension assessment were administered individually in a spacious, adequately illuminated room within the school environment.

Visuomotor integration was assessed using the Nine-Hole Peg Test (9HPT), which consists of a board containing nine holes and nine pegs. The task required participants to place the pegs individually into the holes and then immediately remove them and return them to the container as quickly as possible. In the present study, the 9HPT was performed exclusively with the child's preferred hand. Performance was recorded as the total time required to complete the task, expressed in seconds. As a time-based measure, the test does not have a predetermined maximum score; shorter completion times indicate better visuomotor integration, greater manual dexterity, and faster task execution.

Self-monitoring was assessed using a test consisting of four sheets, each containing 10 items. A target stimulus was presented at the upper central portion of each sheet, and the child was required to locate and mark the items that matched the target. The sheets remained face down until the examiner gave the instruction to begin, and the child was not permitted to view them or start the task before authorization. After the instruction, the child had 30 seconds to complete each sheet.

The Self-Monitoring Test score was calculated by summing the correctly marked items and subtracting one point for each incorrectly marked item. The final score ranged from 0 to 40 points, with higher scores indicating better performance. Completing the task requires the integrated involvement of different executive function components. The child must maintain the target stimulus in working memory, inhibit impulsive responses to distracting stimuli, and adjust the search and selection strategy throughout the task. Therefore, the score was interpreted as a global indicator of self-monitoring involving working memory, inhibitory control, and cognitive flexibility, rather than as an independent measure of each of these functions.

Sequential naming speed was assessed using the Rapid Automatized Naming (RAN) test, which measures how quickly participants can verbally identify series of familiar stimuli. The instrument includes subtests for naming colors, digits, letters, and objects. In the present study, only the color-naming subtest was used (Peng *et al.*, 2017). This subtest comprised the colors green, red, yellow, black, and blue, presented in a randomized sequence. Before the assessment, the examiner verified that each participant could correctly recognize and name all colors used in the task.

The RAN test was administered individually in a quiet, adequately illuminated room within the school environment. Participants were seated comfortably with their feet supported on the floor; when necessary, a footrest was provided. The children were instructed to name the colors from left to right as quickly and accurately as possible. They were permitted to point to the stimuli while naming them, but the test sheet was required to remain on the table throughout the task. Performance was analyzed according to the total completion time, recorded in seconds, and the number of errors. The minimum possible number of errors was zero, whereas the maximum corresponded to the total number of stimuli presented. There was no predetermined maximum completion time. Shorter completion times and fewer errors indicated better rapid automatized naming performance.

Reading performance was assessed individually in a quiet, well-lit room. Each child was seated comfortably, with both feet flat on the floor, at a table whose height was positioned between the level of the umbilicus and the lower thorax. The assessment sheet remained flat on the table throughout the procedure, and the child was instructed not to lift or remove it from the surface.

Real-word reading was assessed using a list of 120 words presented in randomized order, including high-, medium-, and low-frequency words. The child was instructed to read each word aloud, while the examiner recorded the words read correctly. Scores ranged from 0 to 120 points, with higher scores indicating better real-word reading accuracy.

Nonword reading was assessed using a list of 10 nonwords. The child was instructed to read each item aloud, while the examiner recorded the number of correctly read nonwords. Scores ranged from 0 to 10 points, with higher scores indicating greater accuracy in phonological decoding.

Oral reading fluency was determined during the real-word reading task. Using a stopwatch, the examiner recorded the number of real words read correctly within 60 seconds. Reading fluency was therefore expressed as the number of correctly read words per minute, with higher values indicating better oral reading fluency.

Descriptive analyses were initially performed for all variables. Associations among visuomotor measures, rapid automatized naming, self-monitoring, reading fluency, and reading comprehension were examined using Spearman's correlation coefficient. To control the false discovery rate resulting from multiple comparisons, the Benjamini–Hochberg correction was applied. Partial correlations controlling for age and sex were also calculated, and linear regression models were conducted to investigate the contributions of visuomotor and executive variables to reading performance. The significance level was set at 5%, and the corresponding 95% confidence intervals were reported.

The study protocol was approved by the Research Ethics Committee through Plataforma Brasil under Certificate of Presentation for Ethical Consideration number 07163119.1.0000.5244.

3. Results

The sample comprised 25 third-grade elementary school students who had previously been identified as being at risk for dyslexia, including 10 children (40%) aged 8 years and 15 (60%) aged 9 years. All participants were enrolled in the same grade level, thereby reducing potential effects of curricular differences on performance in the cognitive tasks investigated. Descriptive statistics for the neurocognitive variables are presented in Table 1.

Table 1: Sample characteristics and descriptive statistics of the neurocognitive measures

Measure	n	Mean ± SD	Median (Q1–Q3)	Min–Max	CV (%)	Shapiro–Wilk W	p
RAN Time	25	54.97 ± 14.13	49.97 (45.03–63.02)	34.07–87.00	25.71	0.919	0.049
RAN Errors	25	2.24 ± 2.49	1.00 (0.00–4.00)	0.00–8.00	111.07	0.823	< 0.001
Self-monitoring	25	23.36 ± 9.46	25.00 (17.00–30.00)	2.00–39.00	40.52	0.947	0.213
Reading Comprehension	25	45.44 ± 23.50	48.00 (25.00–64.00)	4.00–89.00	51.71	0.974	0.758
NHPT	25	24.48 ± 3.82	24.78 (21.62–27.36)	17.74–31.65	15.62	0.977	0.817
ETVE	25	40.04 ± 19.14	37.00 (23.00–57.00)	15.00–69.00	47.81	0.899	0.017

Note: SD = standard deviation, Q1 and Q3 = first and third quartiles, CV = coefficient of variation. The sample comprised 25 participants: 10 children aged 8 years (40%) and 15 aged 9 years (60%), all enrolled in the third grade of elementary school. Shapiro–Wilk p-values below 0.05 indicate a significant departure from normality.

For each variable, the mean, standard deviation, median, interquartile range, minimum and maximum values, coefficient of variation, and results of the Shapiro–Wilk normality test were reported.

Rapid Automatized Naming completion time had a mean of 54.97 ± 14.13 seconds, indicating substantial individual variability in lexical access speed. The mean number of naming errors was 2.24 ± 2.49, reflecting an asymmetric distribution characterized by a predominance of participants with few errors and a smaller subgroup with substantially poorer performance.

Performance on the Nine-Hole Peg Test (NHPT) had a mean of 24.48 ± 3.82 seconds, suggesting moderate variability in visuomotor integration. Self-monitoring had a mean score of 23.36 ± 9.46 points and was among the variables showing the greatest heterogeneity within the sample. Reading comprehension had a mean score of 45.44 ± 23.50 points, with wide dispersion across participants, indicating considerable variability in functional reading-related performance. The ETVE had a mean score of 40.04 ± 19.14 points and was also characterized by substantial dispersion.

Assessment of the data distributions indicated approximate normality for NHPT, self-monitoring, and reading comprehension, whereas Rapid Automatized Naming completion time, number of naming errors, and ETVE scores showed non-normal distributions. Therefore, subsequent correlational analyses were conducted using Spearman's correlation coefficient (ρ). Figure 1 presents the distribution of the assessed variables to facilitate visual inspection of the scores, medians, ranges, and extreme values.

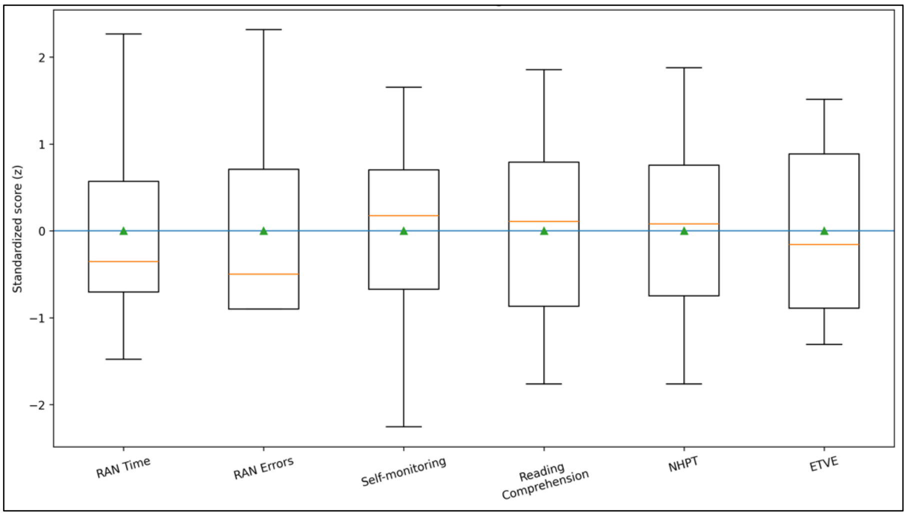

Figure 1: Distribution of assessed neurocognitive measures (standardized boxplots)

3.1 Bivariate Organization of Reading-Related Neurocognitive Processes

The complete correlation matrix is presented in Table 2, while the overall pattern of these associations is graphically displayed in Figure 2.

Table 2: Spearman correlations among the neurocognitive measures

Variable 1	Variable 2	Spearman ϱ	95% CI	p	FDR-adjusted p	Significant after FDR
RAN Time	**RAN Errors**	**0.524**	**[0.134, 0.808]**	**0.007**	**0.022**	**Yes**
RAN Time	**Self-monitoring**	**-0.774**	**[-0.927, -0.489]**	**< 0.001**	**< 0.001**	**Yes**
RAN Time	**Reading Comprehension**	**-0.531**	**[-0.744, -0.209]**	**0.006**	**0.022**	**Yes**
RAN Time	NHPT	0.385	[-0.028, 0.705]	0.057	0.107	No
RAN Time	ETVE	0.307	[-0.141, 0.661]	0.136	0.186	No
RAN Errors	Self-monitoring	-0.451	[-0.777, -0.024]	0.024	0.058	No
RAN Errors	Reading Comprehension	-0.342	[-0.658, 0.062]	0.094	0.157	No
RAN Errors	NHPT	0.220	[-0.250, 0.642]	0.290	0.335	No
RAN Errors	ETVE	0.100	[-0.294, 0.467]	0.636	0.636	No
Self-monitoring	**Reading Comprehension**	**0.544**	**[0.226, 0.757]**	**0.005**	**0.022**	**Yes**
Self-monitoring	**NHPT**	**-0.596**	**[-0.803, -0.257]**	**0.002**	**0.012**	**Yes**
Self-monitoring	ETVE	-0.168	[-0.594, 0.279]	0.423	0.453	No
Reading Comprehension	NHPT	-0.442	[-0.741, -0.039]	0.027	0.058	No
Reading Comprehension	ETVE	-0.262	[-0.566, 0.118]	0.207	0.258	No
NHPT	ETVE	0.329	[-0.054, 0.620]	0.109	0.163	No

Note: The 95% CIs were estimated using 3.000 bootstrap resamples. The false discovery rate was controlled using the Benjamini–Hochberg procedure across the 15 comparisons. Bold rows remained significant after FDR correction.

The correlational analysis revealed a highly organized pattern of associations among executive functions, visuomotor integration, lexical access, and reading comprehension. Self-monitoring showed the greatest number of statistically significant connections, constituting the main functional axis of the identified network.

The strongest association was observed between self-monitoring and rapid automatized naming time ($\varrho = -0.774$, $p < 0.001$), indicating that participants with a greater ability to monitor and regulate their own behavior demonstrated more efficient lexical access.

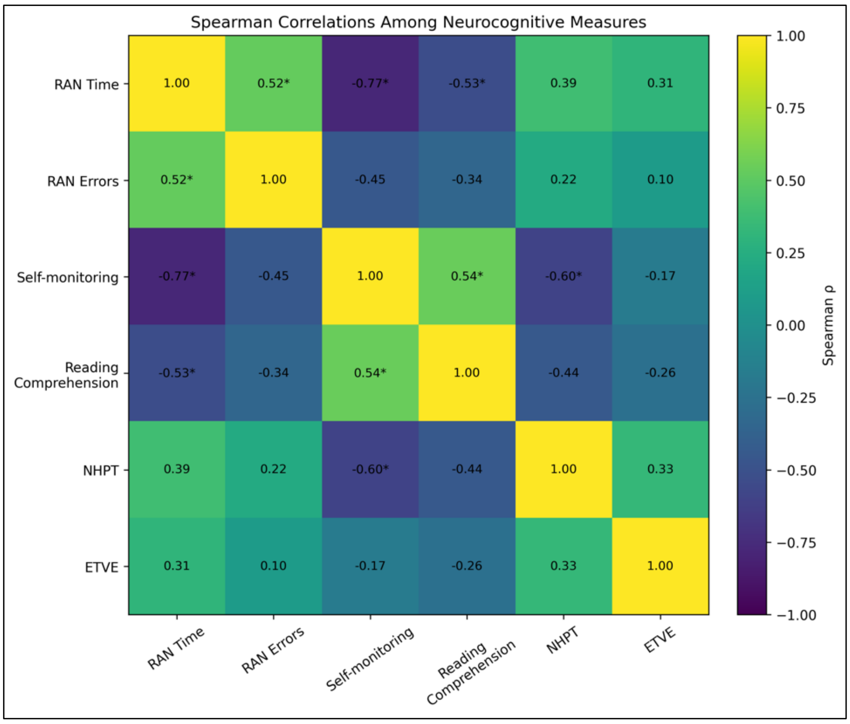

Figure 2: Heatmap of Correlations Among Neurocognitive Domains

In addition, self-monitoring was significantly correlated with NHPT performance ($\varrho = -0.596$, $p = 0.002$) and reading comprehension ($\varrho = 0.544$, $p = 0.005$), highlighting the integration among executive, motor, and linguistic mechanisms.

Rapid automatized naming time was negatively associated with reading comprehension ($\varrho = -0.531$, $p = 0.006$) and positively associated with the number of naming errors ($\varrho = 0.524$, $p = 0.007$), suggesting that less efficient lexical access was simultaneously associated with slower naming, reduced accuracy, and poorer reading performance.

After correction for multiple comparisons using the Benjamini–Hochberg procedure, all of these associations remained statistically significant.

The correlations between naming errors and self-monitoring ($\varrho = -0.451$, $p = 0.024$) and between NHPT performance and reading comprehension ($\varrho = -0.442$, $p = 0.027$) were of moderate magnitude but did not remain statistically significant after false discovery rate correction ($p_{FDR} = 0.058$). Therefore, these findings were interpreted as exploratory evidence.

3.2 Robustness of the Correlation Structure

To assess the stability of the observed associations, partial correlations controlling for age and sex were performed (Table 3).

Table 3: Age-adjusted partial Spearman correlations

Variable 1	Variable 2	Partial ρ	95% CI	p	FDR-adjusted p	Significant after FDR
RAN Time	**RAN Errors**	**0.500**	**[0.121, 0.752]**	**0.013**	**0.039**	**Yes**
RAN Time	**Self-monitoring**	**-0.784**	**[-0.902, -0.557]**	**< 0.001**	**< 0.001**	**Yes**
RAN Time	**Reading Comprehension**	**-0.583**	**[-0.799, -0.235]**	**0.003**	**0.014**	**Yes**
RAN Time	NHPT	0.425	[0.026, 0.707]	0.039	0.072	No
RAN Time	ETVE	0.304	[-0.114, 0.630]	0.149	0.203	No
RAN Errors	Self-monitoring	-0.461	[-0.729, -0.070]	0.023	0.059	No
RAN Errors	Reading Comprehension	-0.406	[-0.696, -0.004]	0.049	0.081	No
RAN Errors	NHPT	0.269	[-0.151, 0.607]	0.204	0.235	No
RAN Errors	ETVE	0.091	[-0.324, 0.477]	0.672	0.672	No
Self-monitoring	Reading Comprehension	0.556	[0.196, 0.783]	0.005	0.018	Yes
Self-monitoring	NHPT	-0.606	[-0.811, -0.268]	0.002	0.013	Yes
Self-monitoring	ETVE	-0.167	[-0.534, 0.253]	0.435	0.466	No
Reading Comprehension	NHPT	-0.428	[-0.709, -0.030]	0.037	0.072	No
Reading Comprehension	ETVE	-0.274	[-0.610, 0.146]	0.196	0.235	No
NHPT	ETVE	0.339	[-0.075, 0.653]	0.105	0.158	No

Note: Partial correlations were adjusted for age only because sex was not available in the dataset. Confidence intervals were obtained using the Fisher z approximation. Bold rows remained significant after FDR correction.

The preservation of the magnitude and direction of the main correlations after controlling for demographic variables reinforces that the observed functional organization cannot be attributed solely to maturational processes, indicating that these relationships reflect intrinsic interactions among the cognitive domains investigated.

3.3 Hierarchical Multiple Regression Models

The incremental contribution of the different neurocognitive domains to reading comprehension was investigated using hierarchical linear regression (Table 4).

Table 4: Hierarchical linear regression models predicting reading comprehension

Model	Predictor-level estimates						Overall model fit					
	Predictor	B (HC3 SE)	95% CI	β	p	VIF / Tol.	R	R^2	Adj. R^2	ΔR^2	ΔF (p)	Robust F (p)
1	RAN Time	-0.792 (0.335)	[-1.484, -0.099]	-0.476	0.027	1.00 / 1.00	0.476	0.227	0.193	0.227	6.741 (0.016)	5.590 (0.027)
2	RAN Time	-0.343 (0.563)	[-1.511, 0.824]	-0.207	0.548	2.22 / 0.45	0.535	0.286	0.221	0.059	1.828 (0.190)	5.539 (0.011)
	Self-monitoring	0.902 (0.731)	[-0.613, 2.417]	0.363	0.230	2.22 / 0.45						
3	RAN Time	-0.381 (0.702)	[-1.841, 1.080]	-0.229	0.593	2.24 / 0.45	0.560	0.313	0.215	0.027	0.834 (0.371)	3.207 (0.044)
	Self-monitoring	0.563 (0.884)	[-1.275, 2.402]	0.227	0.531	2.91 / 0.34						
	NHPT	-1.257 (1.780)	[-4.959, 2.445]	-0.205	0.488	1.53 / 0.65						

Note: Outcome: reading comprehension. B = unstandardized coefficient; β = standardized coefficient; HC3 SE = heteroscedasticity-consistent robust standard error; CI = confidence interval; VIF = variance inflation factor; Tol. = tolerance. Overall model statistics are presented once for each model and apply to all predictors entered at that step. Model 1 included RAN Time; Model 2 added Self-monitoring; Model 3 added NHPT. The increments in explained variance were not statistically significant for Model 2 (ΔR^2 = 0.059, p = 0.190) or Model 3 (ΔR^2 = 0.027, p = 0.371). Residual normality and homoscedasticity assumptions were not violated; HC3 estimates are reported because influence diagnostics identified Cook's D values above the heuristic threshold of 4/n.

Model 1 showed that rapid automatized naming time explained 22.7% of the variance in reading comprehension (R^2 = 0.227), supporting the relevance of lexical access efficiency to reading performance (figure 3). The inclusion of self-monitoring increased the explained variance to 28.6% (ΔR^2 = 0.059). However, this increment was not statistically significant, suggesting that the contribution of executive functioning may partially overlap with that of rapid naming speed rather than represent a clearly independent effect.

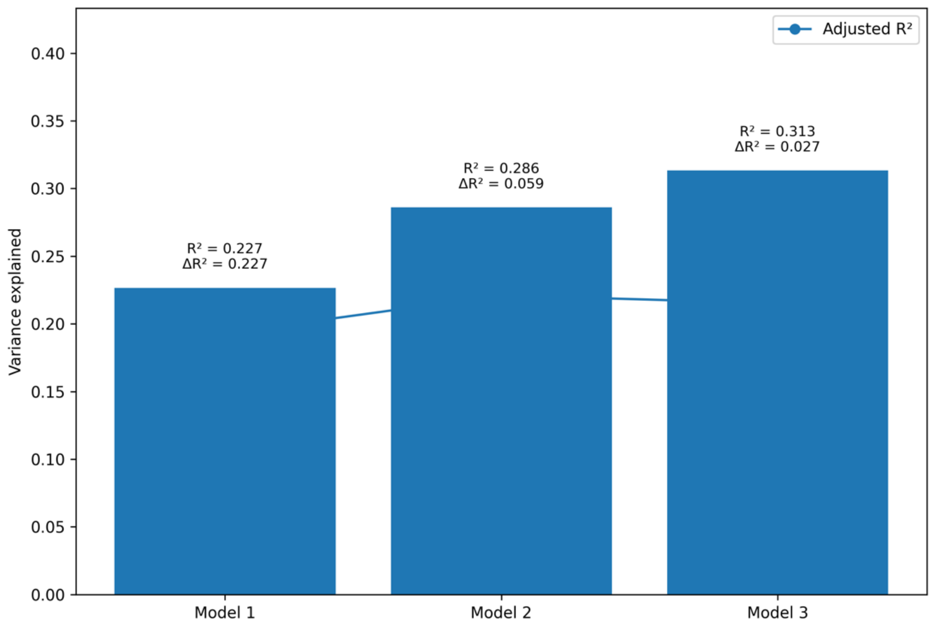

Figure 3: Incremental Variance Explained by the Hierarchical Regression Models

In Model 3, the inclusion of NHPT performance increased the total explained variance to 31.3% (ΔR^2 = 0.027). Nevertheless, this additional increment was also not statistically significant, indicating that visuomotor performance did not provide a robust independent contribution to reading comprehension after accounting for lexical and executive components.

The absence of high variance inflation factor values and the maintenance of tolerance indices above critical thresholds indicated no relevant multicollinearity among the predictors, supporting the statistical stability of the fitted models.

3.4 Proposed Neurocognitive Model

The synthesis of the correlational analyses, partial correlations, and regression models made it possible to propose an integrated model of the organization of reading-related processes (Figure 4).

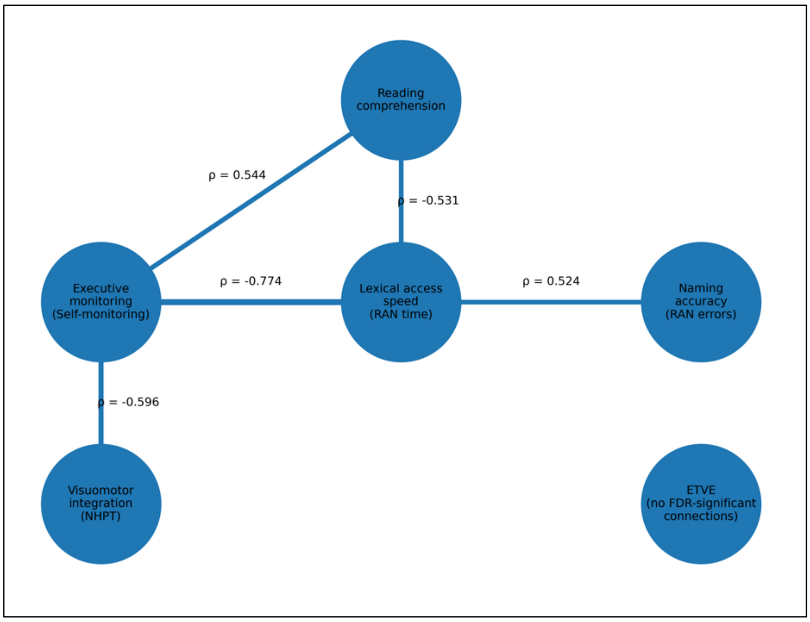

Figure 4: Proposed Neurocognitive Model of the Organization of Reading-Related Processes in Children at Risk for Dyslexia. Only associations that remained statistically significant after Benjamini–Hochberg false discovery rate correction are displayed. Values shown next to the connections represent Spearman's correlation coefficients (ϱ), and line thickness is proportional to the absolute magnitude of each association. Negative coefficients indicate that higher scores in one measure were associated with lower scores or shorter completion times in the other measure, whereas positive coefficients indicate that both measures varied in the same direction. The figure represents an associative neurocognitive organization and should not be interpreted as evidence of causal or directional relationships. RAN = Rapid Automatized Naming; NHPT = Nine-Hole Peg Test; ETVE = *Escala de Triagem Visuomotora para Escolares* (Visuomotor Screening Scale for Schoolchildren).

The findings identified self-monitoring as the primary integrative component of the functional network, showing simultaneous associations with visuomotor integration, lexical access, and reading comprehension. Rapid automatized naming time represented an important link between executive processes and reading performance, whereas NHPT performance showed a more modest and complementary role in the organization of the system. In contrast, ETVE scores were not significantly associated with the other domains assessed, suggesting limited participation in the proposed model.

Taken together, the findings support the hypothesis that reading-related processes involve dynamic interactions among executive, motor, and linguistic mechanisms. The convergence of the correlational analyses and the stability of the main associations after controlling for age and sex support the existence of an integrated neurocognitive organization involving these domains in children at risk for dyslexia. Although the inclusion of self-monitoring and NHPT performance progressively increased the variance explained by the regression models, these increments were not statistically significant and should therefore be interpreted as preliminary evidence of shared rather than independent contributions.

4. Discussion

The findings of the present study indicate that self-monitoring, lexical access, and visuomotor integration are jointly associated with reading comprehension in schoolchildren at risk for dyslexia. This pattern extends explanations centered on a single cognitive deficit and is consistent with the literature conceptualizing reading as the product of interactions among executive, sensory, and linguistic processes (Farah *et al.*, 2024; Horowitz-Kraus *et al.*, 2025). However, given the correlational design of the study, these relationships should be interpreted as functional associations rather than as evidence of causality or of a mandatory hierarchical sequence among the processes assessed.

The main finding was the central position occupied by self-monitoring within the identified pattern of associations. This measure showed a strong correlation with rapid automatized naming time ($\rho = -0.774$, $p < 0.001$), as well as significant associations with NHPT performance ($\rho = -0.596$, $p = 0.002$) and reading comprehension ($\rho = 0.544$, $p = 0.005$). All of these relationships remained significant after correction for multiple comparisons. This finding converges with evidence that children with dyslexia frequently show difficulties in executive function components, including inhibitory control, working memory, cognitive flexibility, and planning, which may affect different stages of reading processing (Guerra *et al.*, 2025). It is also consistent with the findings of Ceruti *et al.* (2025), according to which profiles characterized by impaired reading comprehension may present particularly marked difficulties in working memory and planning.

The association between self-monitoring and reading comprehension is also consistent with studies attributing an important role to executive functions in the regulation of reading behavior, the maintenance of textual information, attentional control, and the continuous monitoring of coherence during text processing (Joseph & Eveleigh, 2011; Basharpoor *et al.*, 2024). Evidence from intervention studies also indicates that programs designed to strengthen executive functions may improve word reading, fluency, and text comprehension, supporting the view that this domain does not merely represent a nonspecific correlate of academic performance (Basharpoor *et al.*, 2024). In the present study, however, the inclusion of self-monitoring in the second regression model increased the explained variance in reading comprehension from 22.7% to 28.6%, but this increment did not reach statistical significance ($\Delta R^2 = 0.059$, $p = 0.190$). This result suggests that part of its contribution may overlap with rapid naming speed and should not be interpreted as a definitively demonstrated independent effect.

The second relevant axis was lexical access. Longer Rapid Automatized Naming completion time was associated with poorer reading comprehension ($\rho = -0.531$, $p = 0.006$) and a greater number of naming errors ($\rho = 0.524$, $p = 0.007$), with both associations remaining significant after false discovery rate correction. In addition, in the initial regression model, RAN time explained 22.7% of the variance in reading comprehension ($R^2 = 0.227$, adjusted $R^2 = 0.193$, $p = 0.016$). This finding is strongly consistent with the meta-analysis by McWeeny *et al.* (2022), conducted across 60 samples, which identified a longitudinal correlation of $r = -0.38$ between early RAN performance and later reading achievement, as well as a unique contribution of rapid naming beyond phonological awareness, with a semipartial correlation of $r = -0.25$.

The relevance of RAN may be understood by recognizing that this task is not restricted to a simple phonological measure. Its performance depends on the integration of visual attention, stimulus recognition, orthographic processing, phonological retrieval, sequencing, and motor planning of the verbal response (Gray & Powell-Smith, 2024; Carioti *et al.*, 2022). This multidimensional nature helps explain its simultaneous association with self-monitoring, naming accuracy, and reading comprehension. In this regard, the findings of the present study are consistent with models that conceptualize rapid automatized naming as an indicator of the efficiency with which different cognitive processes are coordinated during rapid access to linguistic representations (Norton & Wolf, 2011; Carioti *et al.*, 2022). Nevertheless, RAN should be understood as a reading-related marker rather than as a direct measure of word reading.

The contribution of visuomotor integration was more modest. NHPT performance was significantly associated with self-monitoring and showed a moderate correlation with reading comprehension (was significantly associated with self-monitoring and showed a moderate correlation with reading comprehension ($\rho = -0.442$, $p = 0.027$); however, the latter association did not remain significant after correction for multiple comparisons ($p\_FDR = 0.058$). In the hierarchical regression, the inclusion of NHPT performance added 2.7 percentage points to the explained variance in reading comprehension, increasing R^2 from 0.286 to 0.313. This increment, however, was not statistically significant ($\Delta R^2 = 0.027$, $p = 0.371$), and the adjusted R^2 showed a slight reduction. Therefore, the results do not support a robust independent contribution of NHPT performance to reading comprehension, although they suggest a possible complementary role of visuomotor efficiency.

This pattern shows partial convergence with the literature. Buha *et al.* (2023) observed that specific components of visuomotor coordination may contribute to academic performance but emphasized that this contribution is not uniform across all measures of the visuomotor domain. In contrast, Meng *et al.* (2018) identified more substantial unique contributions of visuomotor integration to reading, ranging from 8% to 14%. Differences among these findings may reflect sample characteristics, the instruments employed, the specific reading components used as outcomes, and distinctions among measures of manual dexterity, visuomotor integration, and visual processing.

The absence of significant associations between ETVE scores and the other domains also warrants consideration. As a Visuomotor Screening Scale for Schoolchildren, the ETVE may capture functional and behavioral manifestations observed in everyday settings, whereas the NHPT directly assesses performance on a standardized task of manual dexterity and visuomotor coordination. Therefore, the lack of convergence between these measures does not necessarily indicate that either instrument is inadequate but may instead reflect the assessment of distinct dimensions of visuomotor functioning. This interpretation is consistent with studies showing weak correlations between direct performance-based tests and observation- or report-based scales of executive functions, self-regulation, and functional performance (McCoy, 2019; Guerra *et al.*, 2025).

From an integrative perspective, the findings support a conceptualization of reading based on the coordination of multiple neurocognitive systems. Executive processes contribute to response monitoring, maintenance of task goals, and error detection; rapid naming reflects the efficiency of integration among visual recognition, lexical retrieval, and verbal production; and visuomotor mechanisms may support the perceptual and motor organization required for school-based tasks. This interpretation is consistent with studies describing reading as the product of interactions among executive, linguistic, sensory, and attentional networks (Farah *et al.*, 2024; Horowitz-Kraus *et al.*, 2025). It is also compatible with intervention studies reporting simultaneous changes in reading performance and in the functional integration of executive and sensory networks following training programs (Farah *et al.*, 2024; Horowitz-Kraus *et al.*, 2025; Dhia *et al.*, 2025).

In summary, the findings showed strong convergence with the literature regarding the relevance of executive functions and lexical access speed to reading-related processes. Self-monitoring was distinguished by the greatest number of significant associations, whereas RAN time showed a consistent relationship with reading comprehension and was the only significant predictor in the initial regression model. In contrast, findings involving NHPT performance were more modest and did not demonstrate a statistically significant incremental contribution, while ETVE scores showed no relevant associations with the remaining measures. Taken together, these results support an integrated associative organization involving executive, linguistic, and visuomotor processes, while also demonstrating that the magnitude and independence of their contributions vary across the different domains assessed.

5. Conclusion

The findings indicate that visuomotor integration, self-monitoring, and lexical access are jointly associated with reading-related processes and reading comprehension in children at risk for dyslexia. Among the domains investigated, self-monitoring occupied a central position, showing consistent associations with rapid automatized naming speed, visuomotor performance, and reading comprehension. Rapid Automatized Naming time also emerged as a relevant measure because of its relationships with naming accuracy and reading comprehension, in addition to explaining a substantial proportion of the variance in this outcome in the initial regression model.

The magnitude of the main correlations and their preservation after controlling for age support the stability of the identified associative organization. Although the inclusion of self-monitoring and NHPT performance progressively increased R^2, these increments did not reach statistical significance, indicating that part of the contribution of these domains may overlap with rapid lexical access speed. Therefore, the findings support a multidimensional understanding of reading-related processes but do not allow causal relationships or definitive independent contributions to be established among the components assessed.

From an applied perspective, the findings suggest that measures of self-monitoring, rapid automatized naming, and visuomotor performance may be considered candidate neurocognitive markers for inclusion in multidimensional screening protocols for children at risk for dyslexia. Combining these measures may contribute to a more comprehensive characterization of the difficulties presented and support the planning of early interventions integrating executive, linguistic, and visuomotor components. Future studies with larger samples, longitudinal designs, and additional direct measures of reading accuracy, fluency, and comprehension are needed to determine the predictive value of these markers and the stability of the proposed neurocognitive model.

Conflict of Interest Statement

The authors declare that they have no known financial, professional, or personal conflicts of interest that could have influenced the design, conduct, analysis, interpretation, or reporting of this study. They further confirm that no commercial or institutional relationships affected the research process or the conclusions presented in this manuscript.

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References

Al Dahhan, N. Z., Halverson, K. K., Peek, C. P., Wilmot, D., D'Mello, A. M., Romeo, R. R., Meegoda, O., Imhof, A., Wade, K., Sridhar, A., Falke, E., Centanni, T. M., Gabrieli, J. D. E., & Christodoulou, J. A. (2022). Dissociating executive function and ADHD influences on reading ability in children with dyslexia. *Cortex, 153*, 126–142. https://doi.org/10.1016/j.cortex.2022.03.025

Barghandan, R., Dadgar, H., Raji, P., & Maroufizadeh, S. (2023). The role of fine motor abilities in reading components: A cross-sectional study in children with and without dyslexia. *Iranian Journal of Child Neurology, 17*(4), 23–33. https://doi.org/10.22037/ijcn.v17i4.38710

Baron, A., Martins, A., Puggioni, G., & Harwood, V. (2026). Rapid automatized naming (RAN) and word reading fluency in early school-aged children: A pilot eye-tracking study. *Journal of Eye Movement Research, 19*(1), Article 16. https://doi.org/10.3390/jemr19010016

Basharpoor, S., Seif, E., & Daneshvar, S. (2024). Computerized executive functions training: The efficacy on reading performance of children with dyslexia. *Dyslexia, 30*(2), Article e1762. https://doi.org/10.1002/dys.1762

Brem, S., Maurer, U., Kronbichler, M., Schurz, M., Richlan, F., Blau, V., Reithler, J., van der Mark, S., Schulz, E., Bucher, K., Moll, K., Landerl, K., Martin, E., Goebel, R., Schulte-Körne, G., Blomert, L., Wimmer, H., & Brandeis, D. (2020). Visual word form processing deficits driven by severity of reading impairments in children with developmental dyslexia. *Scientific Reports, 10*(1), Article 18728. https://doi.org/10.1038/s41598-020-75111-8

Brock, L. L., Kim, H., & Grissmer, D. W. (2018). Longitudinal associations among executive function, visuomotor integration, and achievement in a high-risk sample. *Mind, Brain, and Education, 12*(1), 23–27. https://doi.org/10.1111/mbe.12164

Buha, N. S., Banković, S. M., & Gligorović, M. G. (2023). The relationship between reading skills and fine motor abilities in younger school-age children. *Specijalna Edukacija i Rehabilitacija, 22*(2), 149–165. https://doi.org/10.5937/specedreh22-41085

Caldani, S., Gérard, C., Peyre, H., & Bucci, M. P. (2020). Visual attentional training improves reading capabilities in children with dyslexia: An eye tracker study during a reading task. *Brain Sciences, 10*(8), Article 558. https://doi.org/10.3390/brainsci10080558

Ceruti, C., Pecini, C., & Marzocchi, G. (2025). Executive function in children with signs of specific learning disorders. *Research in Developmental Disabilities, 164*, Article 105069. https://doi.org/10.1016/j.ridd.2025.105069

Dong, R., Yin, L., Zheng, K., & Chen, K. (2026). Executive function and writing performance among primary school students with writing difficulties: The mediating role of visual-motor integration. *Journal of Learning Disabilities*. Advance online publication. https://doi.org/10.1177/00222194261417608

Farah, R., Dworetsky, A., Coalson, R., Petersen, S. E., Schlaggar, B. L., Rosch, K., & Horowitz-Kraus, T. (2024). An executive-functions-based reading training enhances sensory-motor systems integration during reading fluency in children with dyslexia. *Cerebral Cortex, 34*(4), Article bhae166. https://doi.org/10.1093/cercor/bhae166

Franceschini, S., Bertoni, S., Puccio, G., Gori, S., Termine, C., & Facoetti, A. (2022). Visuo-spatial attention deficit in children with reading difficulties. *Scientific Reports, 12*(1), Article 13930. https://doi.org/10.1038/s41598-022-16646-w

Gray, J. S., & Powell-Smith, K. A. (2025). Rapid automatized naming: What it is, what it is not, and why it matters. *Annals of Dyslexia, 75*(1), 1–18. https://doi.org/10.1007/s11881-024-00312-z

Guerra, A., Remaud, J., Cadeau, O., Charbonnier, V., Dubrey, M.-C., Proteau, J., Daheron, M., Le Roch, M., Roulin, J.-L., Fournet, N., Le Gall, D., & Roy, A. (2026). Assessing executive functions in children with developmental dyslexia: A comprehensive approach. *Dyslexia, 32*(1), Article e70016. https://doi.org/10.1002/dys.70016

Horowitz-Kraus, T. (2023). The role of executive functions in fluent reading: Lessons from reading acquisition and remediation. *Mind, Brain, and Education, 17*(4), 373–382. https://doi.org/10.1111/mbe.12357

Horowitz-Kraus, T., Cirino, P. T., Cutting, L. E., Hughes-Berheim, S. S., Wilkey, E. D., Barnes, M. A., Rosch, K., & Church, J. A. (2026). The interplay between executive function and learning disabilities: Developmental cognitive neuroscience perspectives on reading, math, and ADHD. *Developmental Cognitive Neuroscience, 79*, Article 101722. https://doi.org/10.1016/j.dcn.2026.101722

Horowitz-Kraus, T., Ismaeel, T., Badarni, M., Farah, R., & Rosch, K. (2025). Greater audiovisual integration with executive functions networks following a visual rhythmic reading training in children with reading difficulties: An fMRI study. *Network Neuroscience, 9*(4), 1264–1278. https://doi.org/10.1162/netn.a.31

Lee, C. S. C. (2024). Executive functions underlie word reading and reading fluency in Chinese children with attention deficit/hyperactivity disorder, reading disabilities, and comorbid attention deficit/hyperactivity disorder and reading disabilities. *Child Neuropsychology, 30*(1), 60–86. https://doi.org/10.1080/09297049.2023.2179981

Mahé, G., Grisetto, F., Macchi, L., Javourey-Drevet, L., & Roger, C. (2024). Error-monitoring: A predictor of future reading skills? A 3-year longitudinal study in children. *Developmental Cognitive Neuroscience, 66*, Article 101350. https://doi.org/10.1016/j.dcn.2024.101350

Marks, R. A., Pollack, C., Meisler, S. L., D'Mello, A. M., Centanni, T. M., Romeo, R. R., Wade, K., Matejko, A. A., Ansari, D., Gabrieli, J. D. E., & Christodoulou, J. A. (2024). Neurocognitive mechanisms of co-occurring math difficulties in dyslexia: Differences in executive function and visuospatial processing. *Developmental Science, 27*(2), Article e13443. https://doi.org/10.1111/desc.13443

Martínez-Pérez, C., Oliveira, A. P., & Baltazar, I. (2026). Visual and oculomotor function in developmental dyslexia: A systematic review and meta-analysis. *Ophthalmic and Physiological Optics, 46*(2), 152–169. https://doi.org/10.1007/s44402-026-00044-0

Martins, B., Verrone, I. A. B., Sakamoto, M., Baba, M. Y., Yvata, M. E., Lukasova, K., & Nucci, M. (2025). Resting-state functional MRI in dyslexia: A systematic review. *Biomedicines, 13*(5), Article 1210. https://doi.org/10.3390/biomedicines13051210

McCoy, D. C. (2019). Measuring young children's executive function and self-regulation in classrooms and other real-world settings. *Clinical Child and Family Psychology Review, 22*(1), 63–74. https://doi.org/10.1007/s10567-019-00285-1

McWeeny, S., Choi, S., Choe, J., LaTourrette, A., Roberts, M. Y., & Norton, E. S. (2022). Rapid automatized naming (RAN) as a kindergarten predictor of future reading in English: A systematic review and meta-analysis. *Reading Research Quarterly, 57*(4), 1187–1211. https://doi.org/10.1002/rrq.467

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*, Article e180178. https://doi.org/10.1590/1982-0275202138e180178

Meng, Z.-L., Wydell, T. N., & Bi, H.-Y. (2019). Visual-motor integration and reading Chinese in children with/without dyslexia. *Reading and Writing, 32*(2), 493–510. https://doi.org/10.1007/s11145-018-9876-z

Norton, E. S., & Wolf, M. (2012). Rapid automatized naming (RAN) and reading fluency: Implications for understanding and treatment of reading disabilities. *Annual Review of Psychology, 63*, 427–452. https://doi.org/10.1146/annurev-psych-120710-100431

Pereira, N., Costa, M. A., & Guerreiro, M. (2024). Integrating cognitive factors and eye movement data in reading predictive models for children with dyslexia and ADHD-I. *Journal of Eye Movement Research, 16*(4), Article 6. https://doi.org/10.16910/jemr.16.4.6

Ramezani, M., & Fawcett, A. J. (2024). Cognitive-motor training improves reading-related executive functions: A randomized clinical trial study in dyslexia. *Brain Sciences, 14*(2), Article 127. https://doi.org/10.3390/brainsci14020127

Taran, N., Farah, R., DiFrancesco, M., Altaye, M., Vannest, J., Holland, S., Rosch, K., Schlaggar, B. L., & Horowitz-Kraus, T. (2022). The role of visual attention in dyslexia: Behavioral and neurobiological evidence. *Human Brain Mapping, 43*, 1720–1737. https://doi.org/10.1002/hbm.25753

Taran, N., Farah, R., Gashri, C., Gitman, E., Rosch, K., Schlaggar, B. L., & Horowitz-Kraus, T. (2023). Executive functions–based reading training engages the cingulo-opercular and dorsal attention networks. *Network Neuroscience, 7*(4), 1452–1482. https://doi.org/10.1162/netn_a_00335

Yang, Y., Hou, J., Huang, H., Wei, C., Chen, J., Wu, T., Liu, J., Deng, D., Ling, S., Yang, W., Yan, J., Chang, S., & Yu, X. (2025). Reading ability in children with intermittent exotropia and its association with binocular visual function and visual information processing capability. *BMC Ophthalmology, 25*, Article 497. https://doi.org/10.1186/s12886-025-04326-y

Zuckerman, A. P., Cutting, L. E., & McCardle, P. (2023). Executive functions and reading: Implications for neuroscience, assessment, and intervention—Introduction to the special issue. *Mind, Brain, and Education*, *17*(4), 224–225. https://doi.org/10.1111/mbe.12394