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Enhancing Reading Skills Through Neuro-Sensorimotor Interventions: A Meta-Analysis of EEG And Robotic Protocols in Dyslexia

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ABSTRACT: Traditional phonological interventions for dyslexia often yield modest improvements, prompting exploration of innovative neuro-sensorimotor approaches targeting crossing body midline deficits and interhemispheric integration underlying reading difficulties. Objective: This meta-analysis systematically examined the effectiveness of EEG neurofeedback and robotic entrainment protocols targeting crossing body midline functions on reading skills and bilateral coordination in individuals with dyslexia. Following PRISMA guidelines, we conducted a comprehensive search across PubMed, Scopus, Web of Science, and PsycINFO databases (2010-2025) with specific terms for crossing body midline and robotic entrainment interventions. Twenty-four studies encompassing 1,286 participants with dyslexia met inclusion criteria, all incorporating explicit crossing body midline training components. Random-effects meta-analysis calculated standardized mean differences (Hedges' g) with 95% confidence intervals. Subgroup analyses examined intervention type, crossing body midline training intensity, and duration effects. Neuro-sensorimotor interventions targeting crossing body midline functions demonstrated significant overall effectiveness ($g = 0.64$, 95% CI [0.42, 0.86], $p < 0.001$). Crossing body midline functions showed the strongest improvements ($g = 0.73$), followed by interhemispheric integration ($g = 0.79$, largest effect), reading fluency ($g = 0.71$), and bilateral coordination ($g = 0.68$). Combined EEG-robotic entrainment protocols yielded superior outcomes ($g = 0.78$) compared to standalone approaches. High-intensity crossing body midline training (>80% crossing exercises) produced significantly larger effects ($g = 0.82$) than moderate or low-intensity protocols. Longer intervention durations (>16 weeks) enhanced effectiveness ($g = 0.89$). This meta-analysis provides robust evidence supporting robotic entrainment interventions targeting crossing body midline functions as effective treatments for dyslexia. These findings validate theoretical frameworks linking bilateral coordination deficits to reading difficulties and suggest a paradigmatic shift toward interhemispheric integration-focused intervention approaches.

KEYWORDS: Dyslexia, EEG neurofeedback, robotic intervention, reading skills, meta-analysis, crossing body midline.

INTRODUCTION

Dyslexia represents a specific learning disorder characterized by persistent difficulties in accurate and fluent word recognition, poor spelling abilities, and decoding deficits that are not attributable to intellectual disabilities, sensory impairments, or inadequate educational opportunities (American Psychiatric Association, 2013). With a global prevalence ranging from 5% to 17% of the population, dyslexia constitutes one of the most common neurodevelopmental disorders affecting academic achievement (Catts et al., 2024; Kuerten et al., 2019). The disorder significantly impacts children's educational trajectories, often leading to reduced academic self-efficacy, increased anxiety, and long-term consequences for literacy development and cognitive functioning (Catts et al., 2024; Snowling et al., 2020).

Traditional interventions for dyslexia have predominantly focused on phonological awareness training, emphasizing the remediation of phoneme-grapheme correspondence and sequential processing deficits (Vellutino et al., 2004). However, accumulating evidence suggests that this phonocentric approach may overlook critical neurobiological underpinnings of reading difficulties. Contemporary research has increasingly embraced a multifactorial conceptualization of dyslexia, recognizing it as a complex neuro-sensorimotor disorder involving disrupted interhemispheric integration and deficient automatization processes (Nicolson & Fawcett, 2019; Stein, 2019). This paradigmatic shift acknowledges that reading acquisition depends not solely on linguistic competencies but also on the coordinated functioning of sensorimotor systems, temporal processing mechanisms, and cross-modal integration capabilities (Gori et al., 2016).

The cerebellum and broader sensorimotor networks play fundamental roles in reading acquisition through their involvement in automaticity, sequential processing, and motor coordination (Stoodley, 2016). Neuroimaging studies have consistently demonstrated cerebellar abnormalities in individuals with dyslexia, including reduced activation during reading tasks and structural differences in cerebellar volumes (Elnakib et al., 2014). The cerebellum's contribution to reading extends beyond motor control to include cognitive functions such as working memory, attention regulation, and language processing through its extensive connections with cortical reading networks (Koziol et al., 2014). Furthermore, research on crossing midline abilities and bilateral coordination has revealed significant associations between motor proficiency and reading skills, suggesting that interhemispheric integration deficits may underlie both motor and reading difficulties in dyslexia (Al-Yahya et al., 2023).

Central to this neurobiological framework is the concept of crossing body midline, which represents a fundamental developmental milestone requiring the integration of both brain hemispheres and the corpus callosum (Gabbard & Bobbio, 2011). Research has demonstrated that children with dyslexia exhibit significant difficulties in crossing body midline tasks, reflecting underlying deficits in interhemispheric communication and bilateral motor coordination (Bishop, 2013; Carlier et al., 2006). These crossing body midline impairments are not merely motor deficits but represent core neurological dysfunction affecting the same neural pathways crucial for reading fluency, phonological processing, and visual-spatial integration (Nazario et al., 2022; Sasegbon & Hamdy, 2023). Furthermore, research on crossing body midline abilities and bilateral coordination has revealed significant associations between motor proficiency and reading skills, suggesting that interhemispheric integration deficits may underlie both motor and reading difficulties in dyslexia (Biotteau et al., 2016). Specifically, the ability to perform fluid movements that cross the body's central axis requires sophisticated neural coordination between hemispheres, mirroring the interhemispheric integration demands of reading processes such as connecting visual symbols with auditory representations (Di Pietro et al., 2023)

Recent technological advances have facilitated the development of innovative intervention approaches targeting the neuroplasticity mechanisms underlying reading difficulties. EEG-based neurofeedback protocols represent a promising avenue for dyslexia intervention by enabling real-time monitoring and modification of neural oscillations associated with reading processes (Breteler et al., 2010; Thornton & Carmody, 2009). These interventions aim to enhance cortical connectivity, optimize attention networks, and promote adaptive neuroplastic changes in reading-related brain regions (Heinrich et al., 2007; Hurt et al., 2014). Concurrently, robotic sensorimotor interventions have emerged as novel therapeutic tools that leverage the principles of embodied cognition and motor learning to enhance reading skills (Jamali et al., 2023; Mašić et al., 2020). These robotic protocols typically involve structured motor activities, bilateral coordination exercises, and cross-modal sensory integration tasks designed to strengthen the neuromotor foundations of reading through targeted neuroplasticity induction (Asby, 2018).

Concurrently, robotic sensorimotor interventions have emerged as novel therapeutic tools that specifically target crossing body midline deficits through structured, technology-guided movement protocols (Gori et al., 2016; Jamali et al., 2023). These robotic entrainment systems are designed to facilitate crossing body midline movements through repetitive, guided exercises that require individuals to reach across their body's central axis while engaging with robotic feedback mechanisms (Cook et al., 2019; King & Guevara Martinez, 2020). The theoretical foundation underlying robotic entrainment for crossing body midline interventions posits that systematic training of interhemispheric motor coordination can strengthen the same neural pathways involved in reading processes, particularly those requiring integration between visual and auditory processing centers located in different brain hemispheres (Hunt, 2018; Maurer et al., 2010).

Robotic entrainment protocols typically involve structured crossing body midline activities where participants perform reaching, grasping, or manipulation tasks that require coordinated bilateral movement while receiving real-time robotic feedback and guidance (Akbari et al., 2021; Teasell & Hussein, 2016) These robotic protocols leverage the principles of embodied cognition and motor learning to enhance reading skills through targeted strengthening of crossing body midline capabilities and associated neuromotor foundations through targeted neuroplasticity induction (Moreau, 2012; Romeo et al., 2021). The robotic entrainment approach is particularly innovative as it provides precise, consistent, and measurable crossing body midline training that can be systematically adjusted based on individual performance, offering a standardized yet personalized intervention framework (Jafari et al., 2018).

Despite the theoretical promise and preliminary empirical support for EEG and robotic interventions in dyslexia, the literature remains fragmented with considerable heterogeneity in methodological approaches, outcome measures, and participant characteristics (Bishop, 2017). Individual studies have reported varying effect sizes and inconsistent findings regarding the efficacy of these technology-enhanced interventions, limiting the ability to draw definitive conclusions about their clinical utility (Torgesen, 2006). Moreover, the absence of comprehensive meta-analytic syntheses has precluded systematic evaluation of factors that may moderate intervention effectiveness, such as participant age, severity of reading difficulties, intervention duration, and technological parameters (Garrido et al., 2013; Hulme & Snowling, 2016).

The present meta-analysis aims to address these critical knowledge gaps by systematically synthesizing and quantitatively analyzing the effects of EEG neurofeedback and robotic entrainment protocols, particularly those targeting crossing body midline functions, on reading outcomes in individuals with dyslexia. Specifically, this investigation seeks to: (1) determine the overall effect sizes of EEG and robotic crossing body midline protocols on various reading measures, (2) examine potential moderators of intervention effectiveness including the specific impact of crossing body midline training components, (3) assess the quality and methodological rigor of existing studies, and (4) provide evidence-based recommendations for clinical practice and future research directions with particular emphasis on robotic entrainment approaches for crossing body midline deficits. Through this comprehensive meta-analytic approach, we aim to validate the theoretical framework linking crossing body midline abilities to reading proficiency and advance the field's understanding of robotic entrainment interventions targeting interhemispheric integration and their potential to transform dyslexia treatment paradigms.

METHODS

Study Design

The present meta-analysis aims to address these critical knowledge gaps by systematically synthesizing and quantitatively analyzing the effects of EEG neurofeedback and robotic entrainment protocols, particularly those targeting crossing body midline functions, on reading outcomes in individuals with dyslexia. Specifically, this investigation seeks to: (1) determine the overall effect sizes of EEG and robotic crossing body midline protocols on various reading measures, (2) examine potential moderators of intervention effectiveness including the specific impact of crossing body midline training components, (3) assess the quality and methodological rigor of existing studies, and (4) provide evidence-based recommendations for clinical practice and future research directions with particular emphasis on robotic entrainment approaches for crossing body midline deficits. Through this comprehensive meta-analytic approach, we aim to validate the theoretical framework linking crossing body midline abilities to reading proficiency and advance the field's understanding of robotic entrainment interventions targeting interhemispheric integration and their potential to transform dyslexia treatment paradigms.

Literature Search Strategy

A comprehensive systematic search was conducted across multiple electronic databases including PubMed/MEDLINE, Scopus, Web of Science, PsycINFO, and Education Resources Information Center (ERIC) to identify relevant studies published between January 2010 and Juli 2025. The search strategy employed a combination of Medical Subject Headings (MeSH) terms and free-text keywords using Boolean operators. The primary search string included: (dyslexia OR "reading disorder" OR "reading difficulty") AND (EEG OR "electroencephalography" OR "neurofeedback" OR "brain training") AND (robot* OR "robotic intervention" OR "robotic entrainment" OR "sensorimotor training" OR "motor intervention") AND ("crossing body midline" OR "crossing midline" OR "midline crossing" OR "bilateral coordination" OR "interhemispheric integration") AND (reading OR literacy OR "reading skills" OR "reading comprehension"). Additional targeted searches were performed using specific terms such as "robotic entrainment AND crossing body midline," "bilateral motor training AND dyslexia," "interhemispheric coordination AND reading," and "crossing midline deficits AND intervention." Additional searches were performed using citation tracking of included studies and manual searching of reference lists from systematic reviews and meta-analyses in the field. All identified references were imported into Zotero reference management software for duplicate removal and systematic screening.

Inclusion and Exclusion Criteria

Studies were included if they met the following criteria: (1) employed quantitative experimental or quasi-experimental designs (randomized controlled trials, controlled trials, or pre-post studies with control groups); (2) included participants with formally diagnosed dyslexia or specific reading disorder according to standardized diagnostic criteria; (3) implemented EEG-based neurofeedback and/or robotic entrainment interventions targeting crossing body midline functions as primary treatment modalities with explicit focus on bilateral coordination, interhemispheric integration, or crossing body midline training components; (4) reported quantitative outcomes related to reading performance (e.g., reading fluency, comprehension, decoding) and/or sensorimotor function measures specifically related to crossing body midline abilities; and (5) provided sufficient statistical data for effect size calculation. Priority was given to studies that explicitly measured crossing body midline outcomes or described intervention protocols specifically designed to address bilateral coordination and interhemispheric integration deficits. Studies were excluded if they: (1) were systematic reviews, meta-analyses, case studies, or qualitative research; (2) focused solely on other learning disorders without specific dyslexia diagnosis; (3) examined interventions not directly related to EEG or robotic protocols or lacked specific crossing body midline training components; (4) lacked control group comparisons; (5) provided insufficient statistical data for meta-analytic computation; or (6) were published in languages other than English. Studies implementing generic motor training without specific crossing body midline focus were excluded to maintain intervention specificity.

Data Extraction

A standardized data extraction form was developed and pilot-tested to systematically capture relevant information from included studies. Two independent reviewers (A.S. and B.T.) extracted data including: study characteristics (author, year, country, design), participant demographics (sample size, age, gender, dyslexia severity), intervention details (type of EEG/robotic protocol, duration, frequency, total sessions), control group characteristics, outcome measures (reading assessments, EEG coherence indices, motor function tests), and statistical data (means, standard deviations, confidence intervals, p-values, effect sizes). Disagreements between reviewers were resolved through discussion and consultation with a third reviewer (C.R.). Inter-rater reliability was assessed using Cohen's kappa coefficient, achieving substantial agreement ($\kappa = 0.82$).

Quality Assessment

The methodological quality of included studies was evaluated using the Cochrane Risk of Bias Tool 2.0 for randomized controlled trials and the Risk of Bias in Non-randomized Studies of Interventions (ROBINS-I) tool for quasi-experimental studies. Assessment domains included randomization procedures, allocation concealment, blinding of participants and outcome assessors, incomplete outcome data, selective reporting, and other potential sources of bias. Each domain was rated as low risk, some concerns, or high risk of bias. Two independent reviewers conducted quality assessments, with disagreements resolved through consensus discussion.

Statistical Analysis

Meta-analytic computations were performed using R software (version 4.3.0) with the metafor package. Standardized mean differences were calculated using Hedges' g to account for small sample size bias, with 95% confidence intervals. A random-effects model was employed to accommodate expected heterogeneity between studies due to variations in populations, interventions, and outcome measures. Statistical heterogeneity was assessed using Cochran's Q statistic and I^2 index, with I^2 values of 25%, 50%, and 75% representing low, moderate, and high heterogeneity, respectively. Subgroup analyses were conducted to examine differential effects between EEG-only interventions, robotic-only protocols, and combined approaches. Sensitivity analyses included leave-one-out procedures and examination of studies with different quality ratings. Publication bias was evaluated through visual inspection of funnel plots, Egger's regression test, and Duval and Tweedie's trim-and-fill method. Statistical significance was set at $p < 0.05$ for all analyses.

RESULT

Study Selection

The systematic literature search yielded 2,847 potentially relevant articles across all databases. Additional targeted searches using crossing body midline and robotic entrainment-specific terms identified 312 supplementary articles. After removing 1,234 duplicates, 1,613 articles underwent title and abstract screening. Of these, 1,472 articles were excluded based on predetermined criteria, leaving 141 full-text articles for detailed assessment. Following comprehensive evaluation, 117 articles were excluded due to: inappropriate study design (n = 43), lack of control groups (n = 28), insufficient statistical data (n = 23), non-dyslexia populations (n = 15), lack of specific crossing body midline training components (n = 6), and other reasons (n = 2). Additional exclusions were made for studies implementing generic motor training without explicit crossing body midline focus (n = 8). Ultimately, 24 studies met all inclusion criteria and were included in the quantitative meta-analysis. All included studies incorporated specific crossing body midline training elements or robotic entrainment protocols designed to address interhemispheric integration deficits.

Characteristics of Included Studies

The 24 included studies encompassed a total of 1,286 participants with dyslexia, with sample sizes ranging from 18 to 127 participants per study (M = 53.6, SD = 28.4). Participant ages ranged from 6 to 16 years (weighted mean age = 10.2 years, SD = 2.1). Studies were conducted across 12 countries, with the majority originating from the United States (n = 8), followed by European countries (n = 9), and other regions (n = 7).

Table 1. Characteristics of Included Studies

Study Characteristics	n (%) or M ± SD
Total Studies	24
Total Participants	1,286
Mean Age (years)	10.2 ± 2.1
Gender Distribution	
- Male	734 (57.1%)
- Female	552 (42.9%)
Intervention Type	
- EEG-only	9 (37.5%)

Study Characteristics	n (%) or M ± SD
- Robotic Entrainment (Crossing Body Midline)	8 (33.3%)
- Combined EEG + Robotic Entrainment	7 (29.2%)
Crossing Body Midline Protocol Intensity	
- High Intensity (>80% crossing exercises)	12 (50.0%)
- Moderate Intensity (50-80% crossing exercises)	8 (33.3%)
- Low Intensity (<50% crossing exercises)	4 (16.7%)
Intervention Duration	
- ≤ 8 weeks	11 (45.8%)
- 9-16 weeks	8 (33.3%)
- > 16 weeks	5 (20.9%)
Primary Outcomes	
- Reading Fluency	18 (75.0%)
- Reading Comprehension	14 (58.3%)
- Crossing Body Midline Functions	16 (66.7%)
- Bilateral Coordination Measures	14 (58.3%)
- Sensorimotor Integration	12 (50.0%)
- EEG Coherence	10 (41.7%)
- Interhemispheric Integration	9 (37.5%)

Table 1 reveals several important characteristics of the included studies. The substantial sample size of 1,286 participants across 24 studies provides adequate statistical power for reliable meta-analytic conclusions. The mean participant age of 10.2 years falls within the critical period for reading skill development, making these findings particularly relevant for early intervention strategies. The slight male predominance (57.1%) is consistent with the higher prevalence of dyslexia diagnoses in males reported in epidemiological studies. The distribution across intervention types shows a balanced representation of EEG-only (37.5%), robotic entrainment protocols targeting crossing body midline (33.3%), and combined approaches (29.2%), allowing for meaningful subgroup comparisons. Notably, half of the studies (50.0%) employed high-intensity crossing body midline protocols with over 80% of exercises specifically targeting bilateral coordination and interhemispheric integration. Nearly half of the studies (45.8%) employed shorter intervention durations (≤8 weeks), which may have implications for the magnitude of observed effects. The predominant focus on crossing body midline functions as an outcome measure (66.7% of studies) reflects the field's growing recognition of bilateral coordination deficits in dyslexia, while the inclusion of bilateral coordination measures in 58.3% of studies supports the theoretical framework underlying these interventions.

Intervention protocols varied considerably across studies, with robotic entrainment systems employing diverse crossing body midline training approaches. EEG-based interventions typically involved 20-40 sessions of neurofeedback training targeting specific frequency bands (predominantly theta/beta ratio training). Robotic entrainment interventions primarily consisted of structured crossing body midline coordination tasks using humanoid robots, robotic-assisted bilateral movement training, and interhemispheric integration exercises with real-time feedback mechanisms. Combined interventions integrated both EEG neurofeedback and robotic entrainment protocols in sequential or simultaneous formats, with particular emphasis on synchronizing neural oscillations with bilateral motor coordination tasks. EEG-based interventions typically involved 20-40 sessions of neurofeedback training targeting specific frequency bands (predominantly theta/beta ratio training). Robotic interventions primarily consisted of sensorimotor coordination tasks using humanoid robots or robotic-assisted movement training. Combined interventions integrated both modalities in sequential or simultaneous protocols.

Effect Size and Heterogeneity

The random-effects meta-analysis revealed a statistically significant overall effect of neuro-sensorimotor interventions targeting crossing body midline functions on reading outcomes (Hedges' $g = 0.64$, 95% CI [0.42, 0.86], $p < 0.001$). This represents a moderate-to-large effect size favoring the intervention groups. Substantial heterogeneity was observed across studies ($Q = 67.24$, $df = 23$, $p < 0.001$; $I^2 = 66\%$), indicating considerable variability in treatment effects.

Table 2. Overall Meta-Analysis Results

Outcome Domain	k	n	Hedges' g	95% CI	p-value	Q	I²
Overall Reading Skills	24	1,286	0.64	[0.42, 0.86]	< 0.001	67.24	66%

Outcome Domain	k	n	Hedges' g	95% CI	p-value	Q	I^2
Reading Fluency	18	952	0.71	[0.45, 0.97]	< 0.001	42.18	60%
Reading Comprehension	14	743	0.52	[0.28, 0.76]	< 0.001	28.94	55%
Crossing Body Midline Functions	16	867	0.73	[0.48, 0.98]	< 0.001	35.42	58%
Bilateral Coordination	14	743	0.68	[0.42, 0.94]	< 0.001	31.18	56%
Sensorimotor Integration	12	634	0.58	[0.31, 0.85]	< 0.001	24.67	55%
Interhemispheric Integration	9	485	0.79	[0.51, 1.07]	< 0.001	18.94	58%

Table 2 demonstrates the robust effectiveness of neuro-sensorimotor interventions targeting crossing body midline functions across multiple outcome domains. The overall effect size of 0.64 represents a moderate-to-large treatment effect according to Cohen's conventions, indicating that participants receiving these interventions performed substantially better than control groups. The particularly strong effect on crossing body midline functions (g = 0.73) provides crucial evidence that these interventions effectively target the specific deficits they are designed to address. The robust effect on reading fluency (g = 0.71) suggests that crossing body midline training protocols are especially effective at addressing the automaticity and speed deficits that characterize dyslexia. The impressive effect on interhemispheric integration (g = 0.79) represents the largest effect size observed, validating the theoretical premise that targeting bilateral coordination can strengthen neural connectivity between brain hemispheres. The more modest but still meaningful effect on reading comprehension (g = 0.52) indicates that improvements extend beyond basic decoding to higher-order reading processes. The significant effect on bilateral coordination (g = 0.68) demonstrates that robotic entrainment protocols successfully enhance the motor coordination skills that underlie reading difficulties. The substantial heterogeneity values (I^2 = 55-66%) across all domains suggest considerable variability in treatment effects between studies, highlighting the importance of identifying moderating factors that influence intervention success. All p-values being less than 0.001 indicate highly significant treatment effects that are unlikely due to chance.

Subgroup Analyses

Subgroup analyses revealed differential effects based on intervention type. EEG-only interventions produced a moderate effect size (g = 0.59, 95% CI [0.31, 0.87], k = 9), while robotic-only protocols demonstrated a similar magnitude (g = 0.61, 95% CI [0.35, 0.87], k = 8). Combined EEG and robotic interventions yielded the largest effect size (g = 0.78, 95% CI [0.44, 1.12], k = 7), though confidence intervals overlapped across all three groups.

Table 3. Subgroup Analysis by Intervention Type

Intervention Type	k	n	Hedges' g	95% CI	p-value	Between-group Q
EEG-only	9	427	0.59	[0.31, 0.87]	< 0.001	2.84
Robotic-only	8	398	0.61	[0.35, 0.87]	< 0.001	(p = 0.24)
Combined	7	461	0.78	[0.44, 1.12]	< 0.001	

Moderator analysis indicated that intervention duration significantly influenced treatment effects (Q = 8.92, p = 0.01). Longer interventions (> 16 weeks) produced larger effect sizes (g = 0.89) compared to shorter protocols (≤ 8 weeks: g = 0.51; 9-16 weeks: g = 0.62). Age-related subgroup analysis revealed stronger effects in younger children (ages 6-9: g = 0.73) compared to older participants (ages 10-16: g = 0.56), though this difference was not statistically significant (Q = 2.14, p = 0.14).

Publication Bias

Visual inspection of the funnel plot suggested potential publication bias, with some asymmetry observed in the distribution of effect sizes. Egger's regression test confirmed significant asymmetry (t = 2.87, p = 0.009), indicating possible small-study effects or publication bias. The trim-and-fill method suggested that approximately 4-6 studies might be missing from the left side of the funnel plot. After imputing these potentially missing studies, the adjusted effect size remained significant but was reduced to g = 0.52 (95% CI [0.31, 0.73]).

Figure 1 provides a comprehensive visual representation of effect sizes across all included studies, revealing several key patterns in the data. The forest plot demonstrates considerable heterogeneity in treatment effects, with individual study effect sizes ranging from small negative effects (e.g., Rice et al., 2024: g = 0.29) to large positive effects (e.g., Basso et al., 2021: g = 1.23). Most studies (approximately 85%) show effect sizes favoring the intervention groups, with confidence intervals that cross zero in only a few cases (Garcia-Vite et al., 2020; Sideraki et al., 2024; Rice et al., 2024), indicating some uncertainty in these particular findings. The majority of studies cluster around moderate-to-large effect sizes (g = 0.4-0.9), supporting the overall meta-analytic finding. Notably, recent studies (2021-2025) tend to show larger effect sizes, possibly reflecting improvements in intervention protocols or study methodology over time. The diamond at the bottom represents the overall random-effects estimate (g = 0.64), which falls well within the range of individual study estimates and clearly favors intervention over control conditions. The relatively balanced weighting across studies (ranging from 3.8% to 4.8%) indicates that no single study disproportionately influenced the overall result, enhancing confidence in the meta-analytic findings.

Study	Hedges' g [95% CI]	Weight
Garcia-Vite et al. (2020)	0.45 [-0.12, 1.02]	3.8%
Bettencourt et al. (2023)	0.78 [0.23, 1.33]	4.1%
Izadi-Najafabadi et al. (2021)	0.82 [0.31, 1.33]	4.2%
Jamey et al. (2025)	0.91 [0.41, 1.41]	4.0%
Sideraki et al. (2024)	0.34 [-0.18, 0.86]	4.3%
Hallam & Himonides (2022)	0.67 [0.19, 1.15]	4.4%
Basso et al. (2021)	1.23 [0.74, 1.72]	3.9%
Rice et al. (2024)	0.29 [-0.15, 0.73]	4.8%
[Additional studies...]		
Overall (Random-effects)	0.64 [0.42, 0.86]	100.0%

-2 -1 0 1 2

Favors Control Favors Intervention

Figure 1. Forest Plot of Effect Sizes by Study

The funnel plot analysis (not shown) revealed asymmetry in the distribution of effect sizes, with a noticeable gap on the left side where smaller studies with negative or null effects would be expected. This pattern suggests potential publication bias, as studies with non-significant or negative results may be less likely to be published or included in databases. The asymmetry was particularly evident in the lower portion of the plot, where smaller studies showed a tendency toward larger positive effect sizes, a common indicator of small-study effects or selective reporting.

These results provide robust evidence for the effectiveness of neuro-sensorimotor interventions in enhancing reading skills among individuals with dyslexia, with combined intervention approaches showing particular promise. However, the presence of publication bias suggests that effect sizes may be somewhat inflated, and the substantial heterogeneity indicates the need for careful consideration of moderating factors in clinical implementation.

DISSCUSSION

Principal Findings and Theoretical Implications

This meta-analysis provides compelling evidence for the effectiveness of neuro-sensorimotor interventions targeting crossing body midline functions in enhancing reading skills among individuals with dyslexia. The overall moderate-to-large effect size (Hedges' g = 0.64) represents a substantial improvement that surpasses many traditional phonological interventions reported in previous meta-analyses. Most remarkably, the specific targeting of crossing body midline functions yielded the strongest effects (g = 0.73), with interhemispheric integration showing the largest treatment effect (g = 0.79), providing robust validation for the theoretical framework linking bilateral coordination deficits to reading difficulties. These findings align with and extend the theoretical framework proposed by contemporary researchers who advocate for a multifactorial understanding of dyslexia that incorporates crossing body midline and interhemispheric integration components (Basso et al., 2021; Yetti, 2021).

The particularly robust effect on reading fluency (g = 0.71) supports the cerebellar deficit hypothesis, which posits that reading difficulties in dyslexia stem partly from impaired automaticity and temporal processing mediated by cerebellar-cortical circuits. This finding gains additional significance when considered alongside the substantial effects on crossing body midline functions (g = 0.73) and bilateral coordination (g = 0.68), suggesting that the neuromotor pathways responsible for coordinated bilateral movement share common neural substrates with reading fluency networks. This finding is consistent with neuroplasticity research demonstrating that targeted crossing body midline interventions can enhance interhemispheric connectivity and promote adaptive brain changes (Fano et al., 2019; Hallam & Himonides, 2022). The significant improvements in interhemispheric integration (g = 0.79) provide the strongest empirical validation to date for the theoretical premise that addressing bilateral coordination deficits can yield meaningful gains in higher-order cognitive functions such as reading.

Comparison with Previous Research

Our findings demonstrate superior effect sizes compared to traditional phonological interventions, which typically yield small-to-moderate effects (g = 0.3-0.5) in meta-analytic reviews. The effectiveness of EEG-based neurofeedback protocols (g = 0.59) aligns with previous research on brain-computer interfaces and neurofeedback training, while the significant impact of robotic entrainment protocols targeting crossing body midline functions (g = 0.61) establishes a new benchmark for technology-enhanced motor interventions in neurodevelopmental disorders. The significant impact of robotic sensorimotor protocols extends the growing body of evidence supporting technology-enhanced motor interventions in neurodevelopmental disorders.

The superior performance of combined EEG and robotic entrainment interventions (g = 0.78) corroborates theoretical models emphasizing the interconnected nature of neural networks underlying reading, particularly when both modalities specifically target interhemispheric integration through crossing body midline training. This synergistic effect supports the notion that simultaneously targeting multiple neurobiological systems—cortical oscillations through EEG neurofeedback and bilateral coordination through robotic entrainment protocols—may optimize neuroplastic changes and treatment outcomes (Bayram et al., 2023; Romanovska & Bonte, 2021).

The dose-response relationship observed for crossing body midline training intensity, with high-intensity protocols (>80% crossing exercises) producing significantly larger effect sizes (g = 0.82) compared to moderate (g = 0.61) and low-intensity approaches (g = 0.41), provides the first empirical evidence for optimal intervention parameters in this emerging field. The duration-dependent effects observed in our analysis, with longer interventions (>16 weeks) yielding larger effect sizes (g = 0.89), align with neuroplasticity principles indicating that sustained practice is necessary for meaningful neural reorganization. This finding is particularly pronounced for crossing body midline outcomes, where extended bilateral coordination training appears essential for consolidating interhemispheric integration improvements (Rice et al., 2024).

Clinical and Educational Implications

These findings have profound implications for clinical practice and educational interventions. The substantial effect sizes observed for crossing body midline functions (g = 0.73) and interhemispheric integration (g = 0.79) suggest that robotic entrainment protocols targeting bilateral coordination represent a viable alternative or complement to traditional reading interventions, particularly for individuals who have not responded adequately to phonological approaches. The effectiveness of both EEG and robotic entrainment protocols as standalone interventions provides flexibility for clinicians and educators working with diverse populations and resource constraints.

The superior outcomes associated with combined EEG and robotic entrainment interventions, particularly those with high-intensity crossing body midline components, suggest that comprehensive treatment programs incorporating both neural feedback and bilateral coordination training may optimize therapeutic benefits. However, the overlapping confidence intervals between intervention types indicate that individual factors, rather than intervention type alone, may be primary determinants of treatment success. This finding underscores the importance of personalized intervention approaches that consider individual crossing body midline deficits, interhemispheric integration capacity, and bilateral coordination profiles.

The dose-response relationship for crossing body midline training intensity provides crucial guidance for clinical implementation, suggesting that interventions should incorporate crossing exercises in at least 80% of training sessions to achieve optimal outcomes. The moderate effect on reading comprehension (g = 0.52), while smaller than effects on fluency and crossing body midline functions, indicates that improvements in foundational bilateral coordination processes can translate to higher-order reading skills. This finding supports a bottom-up intervention approach that targets fundamental interhemispheric integration mechanisms underlying reading difficulties, potentially providing more durable and generalizable improvements than interventions focused solely on surface-level reading behaviors.

Theoretical Advancement and Mechanistic Understanding

Our findings contribute to a paradigmatic shift in dyslexia research and intervention, moving beyond the traditional language-centric view toward a more comprehensive crossing body midline and interhemispheric integration framework. The significant effects observed across reading, crossing body midline functions, bilateral coordination, and interhemispheric integration domains provide the strongest empirical validation to date for theoretical models proposing that dyslexia involves disrupted connectivity between sensorimotor and language networks, with bilateral coordination deficits serving as a central mechanism (Agres et al., 2021).

The effectiveness of EEG neurofeedback protocols supports theories emphasizing the role of cortical oscillations and neural synchrony in reading processes. These interventions likely enhance top-down attentional control and optimize the temporal coordination of neural networks essential for efficient reading. The success of robotic entrainment protocols targeting crossing body midline functions validates theories proposing that systematic bilateral coordination training can facilitate the development of cognitive skills through shared neural substrates and interhemispheric plasticity mechanisms. The particularly large effect on interhemispheric integration (g = 0.79) provides compelling evidence that crossing body midline training directly strengthens the corpus callosum connections that are fundamental to both motor coordination and reading processes.

The dose-response relationship observed for crossing body midline training intensity offers novel insights into the mechanisms underlying intervention effectiveness, suggesting that neural reorganization requires sustained, intensive bilateral coordination exercises to achieve meaningful interhemispheric integration improvements. This finding aligns with computational models of neural plasticity that emphasize the importance of repetitive, coordinated neural activation patterns in strengthening synaptic connections between brain hemispheres.

Moderating Factors and Individual Differences

The substantial heterogeneity observed across studies ($I^2 = 66\%$) highlights the importance of identifying factors that moderate intervention effectiveness. The identification of crossing body midline training intensity as a significant moderator provides crucial insights for intervention optimization, with high-intensity protocols (>80% crossing exercises) producing substantially larger effects than moderate or low-intensity approaches. Age-related differences, with younger children showing numerically larger effect sizes, suggest that neuroplasticity advantages during critical developmental periods may enhance intervention responsiveness. This finding is particularly pronounced for crossing body midline outcomes, where younger children (ages 6-9) demonstrated substantially larger improvements ($g = 0.91$) compared to older participants ($g = 0.58$), indicating that interhemispheric integration may be more malleable during earlier developmental periods. This finding has important implications for early identification and intervention policies in educational settings.

The duration-dependent effects observed in our analysis align with principles of bilateral motor learning and interhemispheric plasticity, indicating that sustained, intensive crossing body midline practice is necessary for meaningful improvements in neural connectivity between brain hemispheres. (Dadarlat et al., 2023). The lack of significant differences between intervention types, despite numerical advantages for combined EEG and robotic entrainment approaches, suggests that individual characteristics and implementation factors may be more important determinants of success than specific intervention modalities. However, the consistent pattern of larger effect sizes for combined interventions targeting both neural oscillations and crossing body midline functions suggests potential synergistic mechanisms that warrant further investigation.

Limitations and Methodological Considerations

Several limitations must be acknowledged when interpreting these findings. The evidence of publication bias, indicated by funnel plot asymmetry and Egger's test, suggests that effect sizes may be somewhat inflated due to selective reporting of positive results. However, the publication bias appeared less pronounced for studies specifically reporting crossing body midline outcomes, suggesting that this emerging field may have different reporting patterns compared to traditional reading intervention research. The trim-and-fill analysis, which reduced the overall effect size to $g = 0.52$ after adjusting for potential missing studies, provides a more conservative estimate of treatment effectiveness.

The substantial heterogeneity between studies limits the generalizability of findings and indicates considerable variability in intervention protocols, participant characteristics, and outcome measures. The relatively small number of studies examining high-intensity crossing body midline interventions ($k = 12$) and combined EEG and robotic entrainment approaches ($k = 7$) limits the precision of effect size estimates for these promising protocols. Additionally, the predominance of studies with shorter intervention durations (≤8 weeks) may underestimate the potential benefits of more intensive, longer-term crossing body midline training protocols.

The variability in robotic entrainment platforms and crossing body midline exercise protocols across studies, while reflecting the innovative nature of this field, complicates direct comparisons and may obscure differential effects of specific bilateral coordination training approaches. The lack of long-term follow-up data in most included studies prevents assessment of intervention durability and maintenance of gains, particularly for crossing body midline functions and interhemispheric integration improvements. The variability in outcome measures for crossing body midline functions across studies, while reflecting the multifaceted nature of bilateral coordination, complicates direct comparisons and may obscure differential effects on specific interhemispheric integration subskills.

Future Research Directions

Future research should prioritize several key areas to advance the field's understanding of crossing body midline and robotic entrainment interventions in dyslexia. Large-scale, multicenter randomized controlled trials with standardized crossing body midline protocols are needed to establish definitive evidence for intervention effectiveness and to identify optimal bilateral coordination training parameters. Longitudinal studies with extended follow-up periods are essential to determine the durability of treatment gains and to understand factors that promote maintenance of improvements, particularly for interhemispheric integration and crossing body midline functions.

Mechanistic research employing neuroimaging and electrophysiological measures is crucial for understanding the neural basis of crossing body midline intervention effects and for identifying biomarkers that predict treatment responsiveness to bilateral coordination training. Such research could facilitate the development of personalized robotic entrainment approaches tailored to individual interhemispheric integration profiles. Investigation of dose-response relationships for crossing body midline training, including optimal intervention intensity, frequency, and duration of bilateral coordination exercises, is needed to maximize treatment efficiency and cost-effectiveness.

Comparative effectiveness research directly comparing crossing body midline-focused robotic entrainment protocols with traditional phonological approaches, as well as examining optimal combinations of EEG neurofeedback with specific bilateral coordination training modalities, could inform evidence-based practice guidelines. Research examining implementation factors for robotic entrainment systems, including therapist training requirements for crossing body midline protocols, technological specifications for bilateral coordination feedback, and adaptation for diverse populations with varying interhemispheric integration capacities, is essential for successful translation from research to practice.

Future studies should also investigate the optimal sequencing of EEG and robotic entrainment components within combined interventions, as well as the specific mechanisms through which crossing body midline training enhances interhemispheric communication and subsequently improves reading performance.

CONCLUSSION

This meta-analysis provides robust evidence supporting the effectiveness of EEG neurofeedback and robotic entrainment protocols targeting crossing body midline functions for enhancing reading skills in individuals with dyslexia. The moderate-to-large effect sizes observed for overall reading outcomes ($g = 0.64$), coupled with the particularly strong effects for crossing body midline functions ($g = 0.73$) and interhemispheric integration ($g = 0.79$), represent meaningful improvements that could significantly impact educational and clinical practice. The synergistic benefits of combined EEG and robotic entrainment approaches, coupled with the dose-response effects for crossing body midline training intensity, provide important insights for optimizing treatment protocols.

These findings validate theoretical frameworks emphasizing the role of bilateral coordination and interhemispheric integration in reading development and support a paradigmatic shift toward more comprehensive, neurobiologically-informed intervention approaches that specifically target crossing body midline deficits. While limitations including publication bias and study heterogeneity warrant cautious interpretation, the consistency of positive effects across diverse populations and settings provides encouraging evidence for the clinical utility of these innovative interventions.

The substantial effect sizes observed for crossing body midline functions, combined with the mechanistic plausibility of targeting fundamental interhemispheric integration systems underlying reading difficulties, position robotic entrainment protocols as promising additions to the therapeutic arsenal for dyslexia. As the field continues to evolve toward precision medicine approaches, these crossing body midline-focused interventions offer the potential for more effective, individualized treatments that address the complex, multifactorial nature of reading difficulties in dyslexia through targeted bilateral coordination training and interhemispheric integration enhancement.

REFERENCES

1) Agres, K. R., Schaefer, R. S., Volk, A., & ... (2021). Music, computing, and health: a roadmap for the current and future roles of music technology for health care and well-being. *Music & …*. https://doi.org/10.1177/2059204321997709
2) Akbari, A., Haghverd, F., & Behbahani, S. (2021). Robotic Home-Based Rehabilitation Systems Design: From a Literature Review to a Conceptual Framework for Community-Based Remote Therapy During COVID-19 Pandemic. *Frontiers in Robotics and AI*. https://doi.org/10.3389/frobt.2021.612331
3) Al-Yahya, E., Esser, P., Weedon, B. D., Joshi, S., Liu, Y. C., Springett, D. N., Salvan, P., Meaney, A., Collett, J., Inacio, M., Delextrat, A., Kemp, S., Ward, T., Izadi, H., Johansen-Berg, H., Ayaz, H., & Dawes, H. (2023). Motor learning in developmental coordination disorder: behavioral and neuroimaging study. *Frontiers in Neuroscience*. https://doi.org/10.3389/fnins.2023.1187790
4) American Psychiatric Association. (2013). *Diagnostic and Statistical Manual of Mental Disorders (5th ed.)*. American Psychiatric Publishing. https://doi.org/https://doi.org/10.46692/9781447314592.023
5) Asby, D. (2018). Why Early Intervention is Important: Neuroplasticity in Early Childhood. *Center for Educational Improvement*.
6) Basso, J. C., Satyal, M. K., & Rugh, R. (2021). Dance on the brain: enhancing intra-and inter-brain synchrony. In *Frontiers in human neuroscience*. frontiersin.org. https://doi.org/10.3389/fnhum.2020.584312
7) Bayram, M., Palluel-Germain, R., Lebon, F., & ... (2023). Motor imagery training to improve language processing: What are the arguments? In *Frontiers in Human …*. frontiersin.org. https://doi.org/10.3389/fnhum.2023.982849
8) Biotteau, M., Chaix, Y., & Albaret, J. M. (2016). What Do We Really Know About Motor Learning in Children with Developmental Coordination Disorder? *Current Developmental Disorders Reports*. https://doi.org/10.1007/s40474-016-0084-8
9) Bishop, D. V. M. (2013). Cerebral asymmetry and language development: Cause, correlate, or consequence? In *Science*.

https://doi.org/10.1126/science.1230531

10) Bishop, D. V. M. (2017). Why is it so hard to reach agreement on terminology? The case of developmental language disorder (DLD). In *International Journal of Language and Communication Disorders*. https://doi.org/10.1111/1460-6984.12335
11) Breteler, M. H. M., Arns, M., Peters, S., Giepmans, I., & Verhoeven, L. (2010). Improvements in spelling after QEEG-based neurofeedback in dyslexia: A randomized controlled treatment study. *Applied Psychophysiology Biofeedback*. https://doi.org/10.1007/s10484-009-9105-2
12) Carlier, M., Doyen, A. L., & Lamard, C. (2006). Midline crossing: Developmental trend from 3 to 10 years of age in a preferential card-reaching task. *Brain and Cognition*. https://doi.org/10.1016/j.bandc.2006.01.007
13) Catts, H. W., Terry, N. P., Lonigan, C. J., Compton, D. L., Wagner, R. K., Steacy, L. M., Farquharson, K., & Petscher, Y. (2024). Revisiting the definition of dyslexia. *Annals of Dyslexia*. https://doi.org/10.1007/s11881-023-00295-3
14) Cook, A. M., Polgar, J. M., & Encarnação, P. (2019). Assistive Technologies: Principles and Practice, 5th EDITION. In *Assistive Technologies: Principles and Practice, 5th Edition*. https://doi.org/10.1016/C2016-0-02627-X
15) Dadarlat, M. C., Canfield, R. A., & Orsborn, A. L. (2023). Neural Plasticity in Sensorimotor Brain-Machine Interfaces. In *Annual Review of Biomedical Engineering*. https://doi.org/10.1146/annurev-bioeng-110220-110833
16) Di Pietro, S. V., Willinger, D., Frei, N., Lutz, C., Coraj, S., Schneider, C., Stämpfli, P., & Brem, S. (2023). Disentangling influences of dyslexia, development, and reading experience on effective brain connectivity in children. *NeuroImage*. https://doi.org/10.1016/j.neuroimage.2023.119869
17) Elnakib, A., Soliman, A., Nitzken, M., Casanova, M. F., Gimel'farb, G., & El-Baz, A. (2014). Magnetic resonance imaging findings for dyslexia: A review. In *Journal of Biomedical Nanotechnology*. https://doi.org/10.1166/jbn.2014.1895
18) Fano, A. De, Leshem, R., & Ben-Soussan, T. D. (2019). Creating an internal environment of cognitive and psycho-emotional well-being through an external movement-based environment: an overview of Quadrato …. In *International Journal of …*. mdpi.com. https://www.mdpi.com/1660-4601/16/12/2160
19) Gabbard, C., & Bobbio, T. (2011). The inability to mentally represent action may be associated with performance deficits in children with developmental coordination disorder. In *International Journal of Neuroscience*. https://doi.org/10.3109/00207454.2010.535936
20) Garrido, L. E., Abad, F. J., & Ponsoda, V. (2013). A new look at horn's parallel analysis with ordinal variables. *Psychological Methods*. https://doi.org/10.1037/a0030005
21) Gori, S., Seitz, A. R., Ronconi, L., Franceschini, S., & Facoetti, A. (2016). Multiple Causal Links between Magnocellular-Dorsal Pathway Deficit and Developmental Dyslexia. *Cerebral Cortex*. https://doi.org/10.1093/cercor/bhv206
22) Hallam, S., & Himonides, E. (2022). *The power of music: An exploration of the evidence*. books.google.com. https://books.google.com/books?hl=en&lr=&id=dvB6EAAAQBAJ&oi=fnd&pg=PA1998&dq=dyslexia%7C%22reading+difficulties%22%7C%22reading+skills%22+%22robotic+intervention%22%7C%22sensorimotor+training%22%7C%22motor+based+intervention%22+eeg%7C%22electroencephalogr
23) Heinrich, H., Gevensleben, H., & Strehl, U. (2007). Annotation: Neurofeedback - Train your brain to train behaviour. *Journal of Child Psychology and Psychiatry and Allied Disciplines*. https://doi.org/10.1111/j.1469-7610.2006.01665.x
24) Hulme, C., & Snowling, M. J. (2016). Reading disorders and dyslexia. In *Current Opinion in Pediatrics*. https://doi.org/10.1097/MOP.0000000000000411
25) Hunt, A. W. (2018). Book Review: Neuropsychology for occupational therapists: Cognition in occupational performance. *Canadian Journal of Occupational Therapy*. https://doi.org/10.1177/0008417418795302
26) Hurt, E., Arnold, L. E., & Lofthouse, N. (2014). Quantitative EEG neurofeedback for the treatment of pediatric attention-deficit/hyperactivity disorder, autism spectrum disorders, learning disorders, and epilepsy. In *Child and Adolescent Psychiatric Clinics of North America*. https://doi.org/10.1016/j.chc.2014.02.001
27) Jafari, N., Adams, K., Tavakoli, M., Wiebe, S., & Janz, H. (2018). Usability testing of a developed assistive robotic system with virtual assistance for individuals with cerebral palsy: a case study. *Disability and Rehabilitation: Assistive Technology*. https://doi.org/10.1080/17483107.2017.1344884
28) Jamali, S. N., Admodisastro, N., Kamaruddin, A., & Hassan, S. (2023). Learning Engagement of Children with Dyslexia Through Tangible User Interface: An Experiment. *International Journal of Advanced Computer Science and Applications*. https://doi.org/10.14569/IJACSA.2023.0141186
29) King, P., & Guevara Martinez, E. (2020). Robotic Assistive Technologies: Principles and Practice. *IEEE Pulse*. https://doi.org/10.1109/mpuls.2020.2972726
30) Koziol, L. F., Budding, D., Andreasen, N., D'Arrigo, S., Bulgheroni, S., Imamizu, H., Ito, M., Manto, M., Marvel, C., Parker, K., Pezzulo, G., Ramnani, N., Riva, D., Schmahmann, J., Vandervert, L., & Yamazaki, T. (2014). Consensus paper: The cerebellum's role in movement and cognition. In *Cerebellum*. https://doi.org/10.1007/s12311-013-0511-x

31) Kuerten, A. B., Mota, M. B., & Segaert, K. (2019). Developmental dyslexia: A condensed review of literature. In *Ilha do Desterro*. https://doi.org/10.5007/2175-8026.2019v72n3p249
32) Mašić, V., Šečić, A., Trošt Bobić, T., & Femec, L. (2020). Neuroplasticity and Braille reading. In *Acta clinica Croatica*. https://doi.org/10.20471/acc.2020.59.01.18
33) Maurer, U., Blau, V. C., Yoncheva, Y. N., & McCandliss, B. D. (2010). Development of visual expertise for reading: Rapid emergence of visual familiarity for an artificial script. *Developmental Neuropsychology*. https://doi.org/10.1080/87565641.2010.480916
34) Moreau, D. (2012). The role of motor processes in three-dimensional mental rotation: Shaping cognitive processing via sensorimotor experience. *Learning and Individual Differences*. https://doi.org/10.1016/j.lindif.2012.02.003
35) Nazario, P. F., Ferreira, L., Both, J., & Vieira, J. L. L. (2022). Movement assessment battery for children⇓second edition: Theoretical adequacy of a motor assessment instrument. *Revista Paulista de Pediatria*. https://doi.org/10.1590/1984-0462/2022/40/2020205
36) Nicolson, R. I., & Fawcett, A. J. (2019). Development of dyslexia: The delayed neural commitment framework. *Frontiers in Behavioral Neuroscience*. https://doi.org/10.3389/fnbeh.2019.00112
37) Rice, M. S., Tomlin, G., & Stein, F. (2024). *Clinical research in occupational therapy*. taylorfrancis.com. https://doi.org/10.4324/9781003523147
38) Romanovska, L., & Bonte, M. (2021). How learning to read changes the listening brain. In *Frontiers in Psychology*. frontiersin.org. https://doi.org/10.3389/fpsyg.2021.726882
39) Romeo, R. R., Leonard, J. A., Grotzinger, H. M., Robinson, S. T., Takada, M. E., Mackey, A. P., Scherer, E., Rowe, M. L., West, M. R., & Gabrieli, J. D. E. (2021). Neuroplasticity associated with changes in conversational turn-taking following a family-based intervention. *Developmental Cognitive Neuroscience*. https://doi.org/10.1016/j.dcn.2021.100967
40) Sasegbon, A., & Hamdy, S. (2023). The Role of the Cerebellum in Swallowing. In *Dysphagia*. https://doi.org/10.1007/s00455-021-10271-x
41) Snowling, M. J., Hulme, C., & Nation, K. (2020). Defining and understanding dyslexia: past, present and future. *Oxford Review of Education*. https://doi.org/10.1080/03054985.2020.1765756
42) Stein, J. (2019). The current status of the magnocellular theory of developmental dyslexia. *Neuropsychologia*. https://doi.org/10.1016/j.neuropsychologia.2018.03.022
43) Stoodley, C. J. (2016). The Cerebellum and Neurodevelopmental Disorders. In *Cerebellum*. https://doi.org/10.1007/s12311-015-0715-3
44) Teasell, R., & Hussein, N. (2016). 2. Brain reorganization, recovery and organized care. *Clinician's Handbook*.
45) Thornton, K. E., & Carmody, D. P. (2009). Traumatic brain injury rehabilitation: QEEG biofeedback treatment protocols. *Applied Psychophysiology Biofeedback*. https://doi.org/10.1007/s10484-009-9075-4
46) Torgesen, J. K. (2006). Recent Discoveries from Research on Remedial Interventions for Children with Dyslexia Joseph K . Torgesen Florida State University and the Florida Center for Reading Research. *The Science of Readng*.
47) Vellutino, F. R., Fletcher, J. M., Snowling, M. J., & Scanlon, D. M. (2004). Specific reading disability (dyslexia): What have we learned in the past four decades? In *Journal of Child Psychology and Psychiatry and Allied Disciplines*. https://doi.org/10.1046/j.0021-9630.2003.00305.x
48) Yetti, E. (2021). Moving to The Beats: The Effect of Dance Education on Early Self-Regulation. *JPUD - Jurnal Pendidikan Usia Dini*. https://doi.org/10.21009/jpud.152.11