Caspian Journal of Pediatrics
Babol University of Medical Sciences
e-ISSN: 2383-3106

Effectiveness of Working Memory Interventions on Metamemory and Phonological Awareness in Dyslexic Primary School Children

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Article Info.

Article type:
Research Article

Received: 3 July 2025
Revised: 29 Sep. 2025
Accepted: 27 Oct. 2025
Published: 26 Nov. 2025

Keywords:
Cognitive Remediation,
Dyslexia,
Metamemory,
Phonological Awareness,
Working Memory

ABSTRACT

Background and Objective: Specific learning disorders (SLDs), particularly dyslexia, present significant developmental challenges in childhood, imposing substantial academic and psychological burdens. The aim of this study was to investigate the effects of working memory interventions on enhancing metamemory and phonological awareness among dyslexic primary school children the Rah-e Bartar Counseling and Psychology Center in Isfahan, Iran.

Methods: This quasi-experimental study used a pre-test, post-test, and two-month follow-up design with a control group. Forty dyslexic primary school children, purposively sampled from those attending learning disability centers in Isfahan during the 2022-2023 academic year, were divided into an experimental group (n=20) and a waitlist control group (n=20). The experimental group received 16 individual working memory intervention sessions involving verbal and visuospatial tasks (30-35 minutes each, four times weekly over one month). Data were collected using the Multifactorial Metamemory Questionnaire and the Phonological Awareness Test. Statistical analyses, including descriptive statistics, repeated measures ANOVA, and Bonferroni post-hoc tests, were performed using SPSS.

Findings: The findings indicated that working memory interventions yielded statistically significant improvements in both metamemory and phonological awareness in dyslexic children (F=642.11, P<0.001, 95% CI [12.45, 15.77] for metamemory; F=604.08, P<0.001, 95% CI [9.29, 12.61] for phonological awareness). Significant group-by-time interaction effects were observed, with the experimental group showing greater improvements than the control group.

Conclusion: The results strongly suggest that working memory interventions are an effective strategy for enhancing both metamemory and phonological awareness in dyslexic primary school children, offering a valuable approach for improving their cognitive and literacy skills.

Cite this Article: Raji F, Bahramipour Isfahani M, Ghamarani A. Effectiveness of Working Memory Interventions on Metamemory and Phonological Awareness in Dyslexic Primary School Children. Caspian J Pediatrs June 2025; 11: e9.

Introduction

Developmental dyslexia, a common specific learning disorder (SLD), profoundly impacts children's academic performance and emotional well-being [1]. Characterized by difficulties in reading, spelling, and writing, dyslexia affects 5-15% of school-aged children, regardless of intellectual ability [2]. These challenges manifest as struggles with word recognition, reading fluency, decoding, and comprehension, often leading to academic frustration. Beyond academics, children with dyslexia face psychosocial issues, including low self-esteem, social withdrawal, anxiety, and depression, which affect their emotional health [3]. Despite normal or above-normal intelligence, these children require targeted interventions supported by rigorous empirical evidence, such as randomized controlled trials or systematic reviews, to address their unique learning needs within often ill-equipped educational systems [4]. Early identification and intervention are critical to mitigate these challenges and promote positive developmental outcomes.

Metamemory, a core aspect of metacognition, involves awareness and control of one's memory processes and strategies [5]. It includes declarative knowledge (e.g., understanding memory functions) and procedural regulation (e.g., monitoring and self-correcting during learning). Metamemory is essential for effective learning, enabling strategic planning and comprehension monitoring, particularly in reading [6]. In children with dyslexia, metamemory is often impaired, with limited knowledge of effective comprehension strategies [7]. While some develop compensatory metacognitive skills, persistent reading difficulties can undermine self-efficacy, hindering metamemory development [8]. Enhancing metamemory is thus vital for fostering learning autonomy and academic resilience in this population.

Phonological awareness, a key linguistic skill, entails recognizing and manipulating the sound structure of spoken language [9]. It develops progressively, beginning with awareness of words and syllables in early childhood, advancing to rhymes and onset-rime units, and culminating in phonemic manipulation by school age, essential for reading acquisition [10]. This skill underpins decoding, sound blending, and letter-sound mapping, critical for reading and spelling proficiency [11]. Dyslexia is marked by deficits in phonological processing, causing difficulties in sound manipulation and letter-sound correspondence [12]. These phonological impairments are a primary cause of reading and spelling challenges, highlighting the need for targeted interventions to support literacy development.

Working memory, a cognitive system for temporarily storing and processing information, is crucial for learning, reasoning, and problem-solving [13]. In dyslexia, deficits in the phonological loop and central executive components impair verbal information processing, contributing to reading difficulties [14]. Working memory interventions aim to enhance capacity and efficiency, potentially benefiting other cognitive domains and academic skills [15]. While some studies show short-term improvements in working memory [16, 17], systematic reviews suggest limited generalization to skills like decoding or overall cognition [18]. In dyslexia, training often yields inconsistent long-term gains in phonological or central executive functions, with more consistent benefits in visuo-spatial working memory [19]. However, verbal working memory interventions have shown promise in improving capacity and, occasionally, reading comprehension, though not always speed or accuracy [20, 21]. These mixed findings highlight the complexity of working memory training and the need for further research to clarify its impact on dyslexia-related cognitive domains.

The profound impact of dyslexia on academic and psychosocial development necessitates interventions grounded in robust empirical evidence. Given the critical roles of working memory, metamemory, and phonological awareness in literacy and learning, and their impairments in dyslexia, targeted interventions are essential. The literature shows inconsistent generalizability of working memory training to metamemory and phonological awareness in dyslexic populations, underscoring a research gap. This study aims to evaluate the efficacy of working memory interventions in improving metamemory and phonological awareness in primary school children with dyslexia, contributing empirical evidence to enhance interventions for learning disabilities.

Methods

Design and Participants

This quasi-experimental study included pre-test, post-test, and a two-month follow-up assessment, alongside a control group. The target population comprised all primary school children diagnosed with developmental dyslexia, characterized by deficits in accurate and fluent word recognition, decoding, and spelling, as defined by the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) who had sought services at the Rah-e Bartar Counseling and Psychology Center across the six educational districts of Isfahan, Iran, during the 2022-2023 academic year. From this population, 40 students were selected using a convenience sampling method, with participants chosen based on accessibility and willingness to participate, following referrals from educational psychologists at the center. Participants were then assigned to either an experimental group (n=20) or a control group (n=20). Allocation was determined by the center's scheduling and participant availability, ensuring balanced groups based on age and severity of dyslexia symptoms. Inclusion criteria required a formal diagnosis of dyslexia confirmed through the Wechsler Intelligence Scale for Children (WISC-IV) and the Dyslexia Screening Test-Junior (DST-J), administered by certified educational psychologists, active primary school enrollment, and informed parental consent. Exclusion criteria included the presence of other diagnosed learning disabilities, co-occurring neurological or psychiatric disorders, or significant uncorrected sensory impairments. All ethical considerations were rigorously observed, including obtaining informed written consent from parents/guardians, child assent, ensuring confidentiality, and affirming the right to withdraw from the study at any time. The study protocol was approved by the Ethics Review Board of Islamic Azad University, Isfahan Branch. The study was not blinded, as both participants and researchers were aware of group assignments due to the quasi-experimental design.

Procedure

Following ethical approval from the institutional review board, the study began with participant recruitment. Potential participants were identified through collaborating learning disability centers in Isfahan, specifically the Rah-e Bartar Counseling and Psychology Center. After initial screening based on the inclusion and exclusion criteria, eligible children and their parents/guardians received detailed information about the study, and informed consent and child assent were obtained. All 40 participants then completed a comprehensive pre-test assessment using the specified research instruments. Following the pre-test, the experimental group commenced the working memory intervention program, while the control group served as a waitlist control, receiving routine educational support, including standard literacy tutoring provided by the center, but no specific working memory intervention during the study period. After the intervention, both groups participated in a post-test assessment. A final follow-up assessment was conducted two months later to evaluate the sustained maintenance of any observed effects. All assessments and interventions were conducted within the facilities of the cooperating learning disability centers to ensure a consistent and supportive environment. Intervention fidelity was maintained by adhering to a standardized protocol, with sessions conducted by trained psychologists and monitored via session logs to ensure consistency in content and duration.

Instruments

Multifactorial Metamemory Questionnaire: This questionnaire was used to assess various aspects of participants' metamemory. Developed by Troyer and Rich [22], the instrument comprises 57 items rated on a 5-point Likert scale, with scores ranging from 0 (e.g., 'strongly disagree') to 4 (e.g., 'strongly agree'). The total score is calculated by summing all item scores, resulting in a possible range of 0 to 228. A higher total score indicates a more developed or appropriate level of metamemory. The instrument is specifically designed to capture an individual's awareness and knowledge of their own memory processes. It typically covers areas such as metamemory knowledge (e.g., understanding memory strategies), metamemory monitoring (e.g., judgment of learning, feeling of knowing), and metamemory regulation (e.g., strategy use, effort allocation). The questionnaire demonstrated strong psychometric properties, with a Cronbach's alpha of 0.87 and test-retest reliability of 0.82, validated in pediatric populations [23].

Phonological Awareness Test: The phonological awareness test [24], specifically developed for Farsi-speaking children, was used to evaluate participants' phonological processing abilities. This comprehensive instrument is originally structured with three sections—syllabic, intra-syllabic, and phonemic awareness—comprising a total of 11 subtests. However, for the present study, only the phonemic awareness component was utilized. This specific component consists of seven subtests: phonemic blending, identifying words with the same initial phoneme, identifying words with the same final phoneme, phonemic segmentation, naming and deleting the final phoneme, deleting the middle phoneme, and naming and deleting the initial phoneme. The test is administered individually, with each of these seven subtests containing 11 items. Responses are scored as "1" for correct and "0" for incorrect, yielding a total score ranging from 0 to 70 [24]. The test has high reliability (Cronbach's alpha=0.89) and validity, established through correlations with reading outcomes in Iranian children.

Intervention

The experimental group participated in a structured working memory intervention program, comprising 16 individual sessions. Each session lasted approximately 30-35 minutes and was administered four times per week over a one-month period. The intervention primarily focused on exercises meticulously designed to incrementally challenge and enhance various components of working memory, including verbal tasks (e.g., digit span, word recall, sentence repetition) and visuospatial tasks (e.g., spatial grid recall, mental rotation exercises) (Table 1). The control group received routine literacy tutoring, focusing on basic reading and writing skills, as part of their standard care at the center.

Data Analysis

Descriptive statistics, including means and standard deviations, were calculated to summarize participants' performance. Inferential statistical analyses involved repeated measures ANOVA to assess within-group changes and between-group differences across the pre-test, post-test, and two-month follow-up phases. When significant main effects or interactions were identified, Bonferroni post-hoc tests were subsequently conducted to determin the specific sources of these differences. All statistical analyses were performed using SPSS software.

Table 1. Summary of working memory intervention sessions

Session	Key Topics/Activities
1-4	Introduction to memory concepts; Simple digit/word span; Auditory memory for short sentences; Basic visual sequence recall.
5-8	Increasing complexity in digit/word span; Mental manipulation of words (e.g., reverse order); Spatial memory grids; Recall of object locations.
9-12	Dual-task activities (e.g., recall numbers while categorizing words); Complex sentence comprehension with recall; Pattern reproduction from memory; Mental rotation tasks.
13-16	Advanced verbal recall and sequencing; Visuospatial problem-solving with memory load; Strategic memory games; Generalization of working memory strategies to academic tasks (e.g., note-taking for recall).

Results

The current study included 40 primary school children diagnosed with dyslexia, selected through convenience sampling from those referred to learning disability centers. Participants were aged 6 to 12 years, with a mean age of 9.51±3.39 years. Descriptive statistics, including means and standard deviations for metamemory and phonological awareness scores across the pre-test, post-test, and follow-up phases for both intervention and control groups, are presented in Table 2. As indicated in the table, the mean scores for both metamemory and phonological awareness in the experimental group increased more substantially from pre-test to post-test and follow-up compared to the control group.

Before conducting inferential analyses, the normality of the data was assessed using the Shapiro-Wilk test. The results confirmed that the dependent variables in both groups followed a normal distribution (metamemory: P=0.152 for intervention, P=0.187 for control; phonological awareness: P=0.134 for intervention, P=0.165 for control). The assumption of equality of variances and covariances for the dependent variables was also met. However, Mauchly's test of sphericity was rejected for both variables, necessitating the reporting of Greenhouse-Geisser corrected values for the repeated measures ANOVA.

A repeated measures ANOVA was conducted to examine the within-subjects effects on metamemory and phonological awareness (Table 3). For both metamemory and phonological awareness, a statistically significant main effect of time was observed (P<0.001). The interaction effect between time and group membership was also significant for both variables (P<0.001), indicating that the change in scores across the pre-test, post-test, and follow-up phases differed significantly between the groups. Specifically, the effect size for the main effect of time was 0.89 (95% CI [0.82, 0.93]) for metamemory and 0.89 (95% CI [0.81, 0.94]) for phonological awareness. The interaction effect size was 0.77 (95% CI [0.65, 0.85]) for metamemory and 0.71 (95% CI [0.58, 0.80]) for phonological awareness. Furthermore, a significant main effect of group was found for both metamemory (P<0.001) and phonological awareness (P<0.001), explaining 32.0% and 45.0% of the individual differences, respectively.

The Bonferroni post-hoc test was conducted to investigate specific pairwise differences between the research stages for metamemory and phonological awareness (Table 4). For metamemory, statistically significant differences were observed between the pre-test and post-test phases (P<0.001), as well as between the pre-test and follow-up phases (P<0.001). However, the difference between the post-test and follow-up phases for metamemory was not statistically significant (P=0.058). In contrast, for phonological awareness, significant differences were found across all pairwise comparisons: pre-test versus post-test (P<0.001), pre-test versus follow-up (P<0.001), and post-test versus follow-up (P<0.001). These findings indicated sustained effects of the intervention over time, particularly for phonological awareness.

Table 2. Descriptive indices of research variable scores by groups

Variable	Groups	Pre-test (Mean ± SD)	Post-test (Mean ± SD)	Follow-up (Mean ± SD)
Metamemory	Intervention	138.95±4.60	153.05±5.39	150.35±5.72
	Control	137.45±4.92	138.22±5.30	138.75±5.41
Phonological awareness	Intervention	32.20±3.31	43.15±2.88	40.00±2.71
	Control	31.75±3.64	32.24±3.70	31.49±3.38

Table 3. Results of within-subjects effects in repeated measures ANOVA for metamemory and phonological awareness

Variable	Source	SS	df	MS	F	P	Effect Size	95% CI
Metamemory	Time	2867.26	1.54	1854.70	642.11	0.001	0.89	[0.82, 0.93]
	Interaction (Time × Group)	1116.71	1.54	725.14	83.36	0.001	0.77	[0.65, 0.85]
	Group	2238.47	1	2238.47	11.72	0.001	0.32	-
Phonological awareness	Time	3027.81	1.36	2234.89	604.08	0.001	0.89	[0.81, 0.94]
	Interaction (Time × Group)	929.93	1.36	683.77	61.84	0.001	0.71	[0.58, 0.80]
	Group	1523.31	1	1523.31	20.71	0.001	0.45	-

Table 4. Results of Bonferroni post-hoc test for comparing mean scores of metamemory and phonological awareness across research stages

Variable	Stages	Mean Difference	P
Metamemory	Pre-test vs. Post-test	14.11	0.001
	Pre-test vs. Follow-up	11.40	0.001
	Post-test vs. Follow-up	2.72	0.058
Phonological awareness	Pre-test vs. Post-test	10.95	0.001
	Pre-test vs. Follow-up	7.83	0.001
	Post-test vs. Follow-up	3.15	0.001

Discussion

The present study investigated the efficacy of working memory interventions in enhancing metamemory and phonological awareness among primary school children diagnosed with dyslexia. The findings, supported by repeated measures ANOVA and Bonferroni post-hoc tests, suggest that targeted interventions can yield significant improvements in these cognitive domains. Comparisons with previous research reveal both consistencies and contradictions, providing insights into the effectiveness of working memory training. For instance, Söderqvist and Bergman Nutley [17] reported short-term improvements in working memory skills following training, aligning with our findings of enhanced metamemory and phonological awareness. Similarly, Karimi Bahrasemany et al. [25] found that working memory interventions improved math performance and self-efficacy in children with learning disabilities, supporting the potential for cognitive training to impact related skills. However, Melby-Lervåg and Hulme [18] reported limited generalization of working memory training to untrained skills such as decoding, contrasting with our observed improvements in phonological awareness. This difference may be due to variations in intervention focus, as our study targeted both verbal and visuospatial working memory, unlike the more generalized approaches in some reviews. Additionally, Conway et al. [19] found inconsistent long-term gains in phonological working memory, primarily observing benefits in visuospatial tasks. This may explain the partial regression in phonological awareness at follow-up in our study, possibly due to the specificity of training tasks. Bayat Shahbazi et al. [20] reported improved visuospatial working memory in preschoolers at risk for learning difficulties, which is consistent with our findings but limited by the younger age group, suggesting that developmental differences may influence outcomes. Sharif et al. [8] found that metacognitive training directly improved reading skills in dyslexic students, in contrast to our indirect approach via working memory, indicating that direct metacognitive interventions might yield different effect sizes. These contradictions highlight the role of intervention specificity, participant age, and training duration in shaping outcomes.

The claim of robust statistical analyses in this study is supported by the use of repeated measures ANOVA with Greenhouse-Geisser corrections and Bonferroni post-hoc tests, which are appropriate for longitudinal designs with non-spherical data. However, alternative methods, such as mixed-effects modeling, could provide additional insights into individual variability, suggesting a need for future studies to compare analytical approaches for greater robustness. A particularly noteworthy finding is the substantial improvement in metamemory observed in the experimental group, with these gains effectively maintained from the post-test to the two-month follow-up assessment. Metamemory, defined as an explicit awareness of one's own memory processes and strategic approaches to learning, is a cornerstone of effective learning and academic autonomy [5]. Children diagnosed with dyslexia frequently exhibit impairments in metamemory, often experiencing difficulties in understanding effective learning strategies and monitoring their own comprehension [2]. The results of the current study suggest that enhancing working memory capacity facilitates metamemory development, though this relationship is likely influenced by additional factors such as motivation, self-efficacy, and prior metacognitive knowledge, which warrant further exploration [5, 8]. The sustained nature of these metamemory gains further underscores the potential for working memory interventions to confer lasting benefits for learning independence in children with dyslexia [25].

Similarly, the study revealed a significant positive impact of the intervention on phonological awareness. Phonological awareness includes the ability to recognize and manipulate the sound structure of spoken language, is widely acknowledged as an indispensable prerequisite for successful reading acquisition and a primary area of deficit in dyslexia [9]. The observed improvements support the intricate and well-established link between working memory and phonological processing. Working memory, particularly its phonological loop component, is vital for the temporary retention and manipulation of auditory information- a process fundamental to executing phonological awareness tasks such as sound blending, segmentation, and rhyming [25]. By strengthening working memory, the intervention likely enhanced the efficiency of the phonological loop, enabling children with dyslexia to more effectively process and manipulate speech sounds. This finding supports the theoretical premise that targeting underlying cognitive deficits, such as those in working memory, can elicit a beneficial cascade effect on more specific literacy-related skills, including phonological awareness [27].

However, a critical nuance concerning the phonological awareness results requires careful consideration. While significant improvements were observed from the pre-test to both the post-test and follow-up, a statistically significant, though modest, decline in phonological awareness scores occured from the post-test to the two-month follow-up. Despite this regression, follow-up scores consistently remained significantly higher than the initial pre-test scores, indicating that the substantial initial gains were not entirely lost. This particular pattern suggests that while the working memory intervention effectively initiated improvements in phonological awareness, maintaining these gains may require ongoing reinforcement or more explicitly targeted phonological instruction beyond the working memory training alone [28]. It is plausible that the enhanced cognitive processes developed through working memory training facilitate the initial acquisition of phonological skills, yet consistent application and practice are essential for their full consolidation and for preventing regression in a skill as complex and foundational as phonological awareness for dyslexic learners. This finding underscores the persistent need for multi-modal and sustained educational support for literacy development in this population.

Limitations

Despite these promising findings, the study acknowledges several limitations. Its quasi-experimental design and small sample size (n=40) may limit generalizability and full representation of dyslexia's heterogeneity. The use of a waitlist control group also presents potential confounds. Although initial gains were observed, the partial decline in phonological awareness maintenance suggests that future research should examine optimal intervention duration, employ active control groups, and integrate working memory training with direct literacy instruction to achieve enhanced and lasting benefits.

Conclusion

The significant main effect of group observed for both metamemory and phonological awareness further substantiates the efficacy of the implemented intervention. The considerable effect sizes recorded for both the main effect of time and the time-by-group interaction highlight the practical significance of these improvements, strongly suggesting that the intervention produced meaningful and measurable changes in the cognitive profiles of the participating dyslexic children. These findings have important implications for current educational practices, indicating that strategically incorporating working memory training into existing intervention programs for dyslexia could provide a powerful means of addressing not only core literacy deficits but also broader learning strategies. Such an integrated and comprehensive approach may be more holistic and ultimately more effective than interventions focused solely on traditional reading instruction.

Acknowledgments

The authors extend their deepest thanks to the children and their families whose participation made this research possible, as well as the personnel of the learning disability centers in Isfahan for their invaluable assistance throughout the study.

Ethical Considerations

Ethical approval for the present study was obtained from the Ethics Review Board of Islamic Azad University, Isfahan Branch. The study was officially approved under reference number IR.IAU.KHUISF.REC.1404.121.

Funding

There was no financial support for this research.

Conflict of interest

There is no conflict of interest.

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