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Comparing the Effectiveness of Concentration Enhancement–Based Cognitive Rehabilitation and Sensory-Motor Working Memory Enhancement–Based Cognitive Rehabilitation on Emotional Control, Verbal Fluency, and Information Processing Speed in Children with Dyslexia Spectrum Disorder

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A B S T R A C T

Purpose: This study was conducted to compare the effectiveness of cognitive rehabilitation based on concentration enhancement and sensory-motor working memory enhancement on emotional control, verbal fluency, and information processing speed in children with dyslexia spectrum disorder.
Materials and Methods: This research employed a quasi-experimental design with a pretest-posttest control group. The statistical population consisted of children with dyslexia spectrum disorder, from whom the research sample was selected through convenience sampling and randomly assigned to experimental and control groups. The research instruments included tests measuring emotional control, verbal fluency, and information processing speed. The cognitive rehabilitation intervention was implemented through two treatment packages based on concentration enhancement and sensory-motor working memory enhancement, and the data were analyzed using mixed analysis of variance.
Findings: The results showed that both cognitive rehabilitation interventions, compared with the control group, led to significant improvements in emotional control, verbal fluency, and information processing speed. In addition, differences were observed between the two interventions in terms of their effects on the dependent variables, such that each method demonstrated relative superiority in some components.
Conclusion: The findings indicate that cognitive rehabilitation based on concentration enhancement, as well as sensory-motor working memory enhancement, can be used as effective interventions for improving the cognitive-emotional functioning of children with dyslexia. The choice of intervention should be made in accordance with the therapeutic goal and the child's pattern of cognitive weakness.
Keywords: *Cognitive rehabilitation, Dyslexia spectrum disorder, Emotional control, Information processing speed, Verbal fluency*

1. Introduction

Developmental dyslexia is a persistent neurodevelopmental learning disorder characterized primarily by marked and unexpected difficulties in accurate or fluent word recognition, decoding, spelling, and reading comprehension despite adequate intelligence, educational opportunity, and conventional instruction. These difficulties generally emerge during the early years of formal education and may continue into adolescence and adulthood, affecting academic achievement, motivation, self-concept, and participation in school-related activities. Contemporary approaches increasingly conceptualize dyslexia as a spectrum condition because affected children differ substantially in the severity, combination, and developmental course of their reading-related impairments. Accordingly, identifying children at risk requires attention not only to reading accuracy but also to fluency, decoding strategies, phonological processing, rapid naming, and comprehension. Recent efforts to develop criteria for identifying students at risk for dyslexia have similarly emphasized that reading problems should be examined as multidimensional and developmentally variable rather than as a single, uniform deficit (Renata Pires Sena de Assumpção & Germano, 2025). This heterogeneity has important implications for intervention because children with apparently similar reading difficulties may display different profiles of cognitive, linguistic, attentional, emotional, and sensorimotor functioning.

The phonological-deficit account remains one of the most influential explanations of dyslexia. According to this perspective, many children with dyslexia experience difficulty representing, accessing, manipulating, and retrieving the sound structure of language. These weaknesses can interfere with phoneme–grapheme correspondence, decoding unfamiliar words, spelling, and the automatic retrieval of familiar lexical items. Phonological deficits may also appear in verbal language through imprecise sound processing, reduced verbal short-term memory, and difficulty producing or organizing spoken responses efficiently (Adel & Saleh, 2022). Nevertheless, phonological impairment alone does not fully explain the range of difficulties observed in dyslexia. Children with dyslexia may also demonstrate problems in syntactic awareness, although the extent to which these problems remain after controlling for phonological processing and memory continues to be debated (Robertson et al., 2024). In addition, some children with dyslexia, particularly those with associated language difficulties, show weaknesses in pragmatic language, inferential understanding, and theory-of-mind-related communication (Cardillo et al., 2018). Therefore, dyslexia should be understood as involving interactions among linguistic processing, executive functioning, memory, attention, and broader cognitive control.

Among the executive and cognitive difficulties associated with dyslexia, reduced verbal fluency is especially important. Verbal fluency refers to the ability to retrieve and produce words rapidly according to phonemic or semantic rules. Successful performance requires efficient lexical access, processing speed, working memory, inhibition of irrelevant responses, strategic search, cognitive flexibility, and continuous monitoring of previously generated words. Children with dyslexia may produce fewer words, require more time to access lexical representations, repeat responses, or have difficulty shifting between semantic clusters. Such weaknesses are consistent with phonological-access problems and inefficiencies in verbal memory (Adel & Saleh, 2022). They may also reflect broader language-processing difficulties that extend beyond decoding and influence sentence-level and communicative performance (Cardillo et al., 2018; Robertson et al., 2024). Because fluent reading similarly depends on rapid access to phonological and semantic representations, verbal fluency is not merely an ancillary language skill but a meaningful indicator of the efficiency with which children organize, retrieve, and express verbal information.

Information processing speed is another central cognitive function implicated in reading development and dyslexia. Processing speed refers to the efficiency with which an individual perceives information, discriminates among stimuli, selects a response, and completes relatively simple cognitive operations under time constraints. Slow processing can affect visual scanning, letter and word recognition, rapid naming, copying, response selection, and the automatization of reading. Even when a child eventually produces a correct answer, delayed processing may place additional demands on working memory and attention, causing information to decay before it can be integrated with subsequent material. Processing speed is also closely related to emotional and attentional processes. Research examining children with and without dyslexia has indicated that anxiety may be associated with processing-speed performance through the mechanisms proposed by attentional control theory, according to which worry and threat-related thoughts consume limited attentional resources and reduce cognitive

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efficiency (Wang et al., 2024). Consequently, processing speed in dyslexia should be considered in relation to both basic cognitive efficiency and the child's capacity to regulate attention and emotion under performance pressure.

Children with dyslexia commonly experience repeated academic failure, correction, comparison with peers, and frustration during reading and writing tasks. These experiences may contribute to anxiety, irritability, avoidance, reduced persistence, and diminished confidence. Emotional dysregulation can subsequently worsen academic performance by occupying working-memory resources, increasing impulsive responding, and reducing the ability to remain engaged with difficult tasks. Emotional control involves recognizing emotional activation, inhibiting maladaptive reactions, maintaining goal-directed behavior, and selecting responses that are appropriate to situational demands. Attentional control is essential to this process because children must disengage from distressing internal or external stimuli and redirect their cognitive resources toward the task. The observed association between anxiety and processing speed in dyslexia supports the view that emotional and cognitive difficulties may reinforce one another rather than functioning as independent problems (Wang et al., 2024). Therefore, interventions that improve attention, working memory, and self-monitoring may also strengthen selected aspects of emotional control by increasing the child's capacity to pause, regulate responses, and sustain goal-directed behavior.

Working memory is particularly relevant to the reading difficulties experienced by children with dyslexia. It enables the temporary storage and manipulation of verbal, visual, and spatial information and supports decoding, sentence comprehension, spelling, following instructions, and integrating information across successive parts of a text. Weak working memory can make it difficult for a child to retain phonological sequences, remember previously decoded words, coordinate multiple rules, or monitor comprehension while reading. Cognitive skills training has been shown to improve verbal and nonverbal working memory among students with dyslexia, suggesting that these abilities are modifiable through structured practice (Barghi et al., 2019). Cognitive rehabilitation may enhance working memory by providing repeated, progressively demanding exercises involving sequencing, updating, inhibition, categorization, and the coordination of simultaneous information. Such training is especially relevant when it integrates verbal and visuospatial components, because reading requires continuous interaction among sound, symbol, spatial orientation, and motor output.

Cognitive rehabilitation refers to systematic intervention designed to restore, strengthen, compensate for, or reorganize cognitive functions through repetitive, graded, and goal-directed activities. Computer-based programs are particularly useful because they can standardize stimulus presentation, record response accuracy and speed, provide immediate feedback, and adapt task difficulty to individual performance. Evidence from different populations indicates that cognitive rehabilitation can improve working memory, concentration, attention, and related executive functions. Cognitive rehabilitation therapy has produced improvements in working memory, attention, and concentration among adolescents living in boarding schools (Hamedali et al., 2021), while computer-based cognitive empowerment has been associated with enhanced attentional functions, concentration, and cognitive effort in older adults (Rezaei et al., 2021). Among students with mathematical learning disabilities, cognitive rehabilitation programs have also improved attention, concentration, nonverbal intelligence, and academic performance (Shah Mohammadi et al., 2018; Shahmohammadi et al., 2019). Although these populations differ from children with dyslexia, the findings support the broader neuroplasticity-based assumption that repeated cognitive exercise can modify attentional and executive performance.

Attention- and concentration-based rehabilitation may be particularly beneficial for children whose reading difficulties are accompanied by distractibility, inconsistent effort, impulsive responding, or difficulty sustaining focus. Reading requires the selective allocation of attention to relevant letters, sounds, words, and syntactic cues while irrelevant environmental and internal stimuli are suppressed. Sustained attention is needed to maintain performance across a text, selective attention is required to distinguish targets from distractors, and alternating attention supports movement between decoding, comprehension, and monitoring. Computer-based cognitive rehabilitation has been found to improve attention, concentration, and reading comprehension among students with attention deficits, indicating that attentional training may produce both proximal cognitive benefits and broader academic effects (Ahmadabadi et al., 2022). Cognitive-behavioral play-based interventions have similarly improved attention and concentration in students with intellectual disabilities (Mehr Afza et al., 2021; Mehrafza et al., 2022). These results suggest that engaging, developmentally appropriate, and

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progressively challenging activities can strengthen attentional control even in children with neurodevelopmental difficulties.

Digital and game-based formats may further improve the acceptability of cognitive rehabilitation for children with dyslexia. Conventional remediation often requires sustained engagement with tasks that children already associate with failure, whereas computerized exercises can provide immediate reinforcement, clear goals, repetition, and visible progress. Digital game-based learning has been shown to support engagement and collaborative learning among children with dyslexia, particularly when activities are designed within a socially meaningful and motivating context (Vasalou et al., 2017). High engagement is clinically important because the effectiveness of cognitive rehabilitation depends on repeated practice and consistent participation. Computerized interventions can also manipulate presentation speed, distractor load, response demands, and task complexity in ways that would be difficult to reproduce consistently using paper-and-pencil activities. For children with dyslexia, such adaptive systems may offer a means of training cognitive mechanisms underlying reading without requiring every exercise to resemble a conventional reading lesson.

A second promising approach is sensory-motor working memory enhancement–based cognitive rehabilitation. This approach combines working-memory demands with coordinated sensory and motor activity, based on the premise that cognition develops through continuous interaction among perception, action, feedback, and executive control. Sensorimotor integration enables the nervous system to combine visual, auditory, tactile, proprioceptive, and vestibular information with planned responses. Although much sensorimotor research has focused on conditions other than dyslexia, it demonstrates that sensory and motor systems are closely connected with learning, attention, timing, and adaptive behavior. Studies of sensorimotor behavior in individuals with autism and their unaffected biological parents have highlighted the relevance of motor control and sensory processing as measurable neurodevelopmental characteristics (Bojanek et al., 2025). Functional connectivity research has also linked the sensorimotor cerebellum with sensory over-responsivity, further illustrating the neural integration of sensory experience, movement, and behavioral regulation (Cakar et al., 2024).

Interventions based on sensory integration and sensorimotor activity have yielded encouraging results across child populations. Sensory-integration-based play therapy has improved communication, social interaction, stereotyped behavior, and motor development among boys with autism spectrum disorder (Rabiei et al., 2024). Sensorimotor room training has likewise demonstrated preliminary benefits for the sensory and motor abilities of children with autism (Savarese et al., 2025), while sports training grounded in sensory integration has been associated with motor and social skill development (Wen & Wu, 2025). A sensory-motor play therapy program has also been developed and validated for children with autism, reflecting growing interest in structured interventions that combine embodied activity, play, and psychological development (Behnam-Nejad et al., 2025). Although autism and dyslexia are distinct conditions, these findings support the feasibility of using organized sensory-motor activities to strengthen participation, self-regulation, and cognitive-motor coordination in children with developmental disorders.

The potential contribution of sensorimotor training is not limited to childhood neurodevelopmental disorders. Across rehabilitation contexts, integrating sensory feedback with movement has been used to improve motor planning, postural control, proprioception, and functional performance. Somatosensory integration has been incorporated into robot-assisted motor restoration after stroke, emphasizing the importance of sensory feedback for relearning and adaptive motor output (Lin et al., 2024). EEG-based sensorimotor neurofeedback has also been reviewed as a developing approach to motor neurorehabilitation in both children and adults (Cioffi et al., 2024). Adapted training has enhanced upper-body sensorimotor control and daily functioning in visually impaired athletes (Carretti et al., 2024), while sensorimotor exercises have been applied to proprioception, posture, and pain in adults with musculoskeletal conditions (Asadi & Roshani, 2025; Engel et al., 2025). Collectively, these studies illustrate that sensory-motor systems remain trainable and that structured feedback-based practice can influence functional performance across diverse populations.

Motor activity may also facilitate cognition through arousal regulation, neural activation, and the coordination of attention with action. Experimental evidence has indicated that acute exercise and everyday physical activity can influence cognitive functioning, although effects may vary according to task characteristics, intensity, and individual differences (Loprinzi & Kane, 2015). Cognitive-motor dual-task rehabilitation similarly requires individuals to maintain

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cognitive operations while coordinating movement, thereby challenging executive control, divided attention, and working memory (Tan et al., 2024). In children with disabilities, motor-sensory learning through activities such as piano practice has been investigated as a means of integrating perception, timing, sequencing, bilateral coordination, and sustained attention (Strubbe et al., 2025). Such mechanisms are relevant to dyslexia because reading involves temporally ordered visual and phonological information, rapid shifts of attention, and coordinated eye-hand or speech-motor responses. A sensory-motor working memory program may therefore strengthen cognitive performance by embedding memory operations within multimodal and action-oriented tasks.

Despite increasing evidence supporting cognitive rehabilitation, attention training, working-memory exercises, digital learning, and sensorimotor interventions, direct comparisons between theoretically distinct rehabilitation approaches remain limited. Many studies evaluate a single program against a passive control condition, making it difficult to determine whether improvements arise from the specific cognitive target, repeated therapist contact, computer use, motivation, or general task practice. Moreover, outcomes are often restricted to attention, memory, or academic achievement, while emotional control, verbal fluency, and information processing speed are examined less frequently as an integrated set. This gap is important because these outcomes represent interconnected aspects of dyslexia: verbal fluency reflects rapid lexical access and executive search; processing speed reflects cognitive efficiency and visual response speed; and emotional control reflects the capacity to regulate reactions that can interfere with sustained academic engagement.

Comparing concentration enhancement with sensory-motor working memory enhancement may clarify whether different cognitive rehabilitation pathways produce similar or distinct effects. Concentration-based training is expected to act primarily through sustained attention, selective attention, distractor inhibition, response monitoring, and self-control. Sensory-motor working memory training is expected to act through temporary information storage, updating, sequencing, multimodal integration, and cognitive-motor coordination. Both approaches may improve verbal fluency and processing speed because these outcomes require attentional consistency and working-memory efficiency. However, concentration enhancement may have a stronger effect on emotional control because attentional regulation allows children to disengage from distressing stimuli and inhibit impulsive emotional responses. Conversely, sensory-motor working memory training may offer advantages where performance depends heavily on sequencing, rapid integration, and coordination among visual, verbal, and motor information. Examining these interventions across pretest, posttest, and follow-up stages can therefore provide evidence concerning both immediate effectiveness and the durability of treatment gains.

Accordingly, the present study aimed to compare the effectiveness of concentration enhancement–based cognitive rehabilitation and sensory-motor working memory enhancement–based cognitive rehabilitation on emotional control, verbal fluency, and information processing speed in children with dyslexia spectrum disorder.

2. Methods and Materials

2.1. Study Design and Participants

The present study employed a quasi-experimental, three-group design with pretest, posttest, and two-month follow-up measurements to compare the effectiveness of concentration enhancement–based cognitive rehabilitation and sensory-motor working memory enhancement–based cognitive rehabilitation in improving emotional control, verbal fluency, and information processing speed among children with dyslexia spectrum disorder. The independent variable consisted of the two cognitive rehabilitation programs, while emotional control, verbal fluency, and information processing speed constituted the dependent variables. Participants were assigned to a sensory-motor working memory enhancement group, a concentration enhancement group, or a waiting-list control group. All participants were assessed before the interventions, immediately after the completion of the interventions, and two months after the posttest. During the intervention period, the first experimental group received sensory-motor working memory enhancement–based cognitive rehabilitation, the second experimental group received concentration enhancement–based cognitive rehabilitation, and the control group received no psychological, educational, or cognitive rehabilitation intervention. The follow-up assessment was included to determine whether the effects of the interventions were maintained after the formal training sessions had ended. This design allowed the researchers to examine changes over time, differences

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among the three groups, and the interaction between group membership and measurement time.

The statistical population included all children with dyslexia spectrum disorder aged 9 to 11 years who attended public or private specialized learning disability centers in Zanjan, Iran, during the 2025–2026 academic year. Eligible children had received a formal diagnosis of dyslexia spectrum disorder from a psychiatrist or another qualified specialist and had an active clinical or educational record confirming the diagnosis. Based on the information obtained from two public schools and two private centers providing specialized services to children with learning disabilities, the target population was estimated to include approximately 180 students. From this population, 60 children were selected using purposive sampling and were subsequently assigned randomly to three groups of 20 participants. Random assignment was performed after the completion of the pretest to reduce systematic differences among the groups and improve the internal validity of the study. The intended sample size was determined by considering a statistical power of .80, a significance level of .05, and a large anticipated intervention effect. Although approximately 15 participants per group were considered sufficient for detecting the expected effects, 20 children were allocated to each group to increase statistical power and compensate for possible attrition, incomplete assessments, or absence from intervention sessions.

The inclusion criteria were a confirmed diagnosis of dyslexia spectrum disorder, an age between 9 and 11 years, enrollment in a specialized educational or rehabilitation center for learning disabilities, the ability to understand and follow the instructions of the computerized tasks, and written consent from a parent or legal guardian. Children were also required to have no severe neurological, sensory, intellectual, or psychiatric condition that could prevent meaningful participation in the assessments or intervention sessions. The exclusion criteria included concurrent participation in another cognitive rehabilitation, neurofeedback, psychological treatment, or specialized attention-training program; absence from more than two intervention sessions; refusal to continue participating; serious noncooperation during the sessions; emergence of a medical or psychological condition that interfered with participation; and incomplete completion of the pretest, posttest, or follow-up instruments. Participants who received fewer than the minimum required intervention sessions were excluded from the final intervention analysis.

After obtaining the required authorization from the Zanjan Department of Education and coordinating with the administrators of the selected learning disability centers, the records of potentially eligible children were reviewed. Parents of children who met the preliminary criteria were contacted and invited to attend an explanatory meeting. During this meeting, the research objectives, intervention procedures, assessment stages, potential benefits, possible inconveniences, confidentiality provisions, and voluntary nature of participation were explained. Written informed consent was obtained from parents or legal guardians, and verbal assent was obtained from the children. Eligible participants then completed the pretest measures under standardized conditions. Afterward, they were randomly allocated to the three study groups. The two experimental groups participated in 18 individual intervention sessions, each lasting approximately 60 minutes and held twice weekly. The control group remained on a waiting list and continued to receive only the routine educational services provided by the relevant center. Immediately after the final intervention session, all three groups completed the posttest assessment. The same measures were administered again two months later during the follow-up stage. Assessments were conducted in a quiet room and, as far as possible, under similar environmental conditions at all three measurement stages.

2.2. Measures

Emotional control was assessed using the Emotional Control Questionnaire developed by Williams, Chambless, and Ahrens in 1997. The questionnaire consists of 40 items designed to evaluate individuals' perceptions of their ability to experience, express, and control emotional states. It includes four dimensions relating to anger, depressed mood, anxiety, and positive affect. Each item is rated on a seven-point Likert scale, with response options ranging from 1 to 7. Twelve items are reverse-scored before calculating the subscale and total scores. The score for each dimension is obtained by summing the relevant item scores, and a total emotional control score is calculated from all items after reverse scoring. Higher scores indicate greater concern regarding emotional experiences and a stronger perceived need to control or suppress emotions; therefore, reductions in scores following an intervention may be interpreted as improvement in adaptive emotional control. Previous applications of the questionnaire have demonstrated acceptable internal consistency, construct validity, and

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criterion-related validity. Iranian studies have reported Cronbach's alpha coefficients between .84 and .88 for the total scale. In the present study, Cronbach's alpha was .87 for the total score, while the coefficients for the anger, depressed mood, anxiety, and positive affect dimensions were .74, .80, .78, and .72, respectively. The face and content validity of the Persian version were also reviewed and confirmed by specialists in psychology, educational sciences, and learning disabilities. The instrument was selected because difficulties in executive control, response inhibition, frustration tolerance, and emotion regulation are frequently observed among children with dyslexia spectrum disorder and may be responsive to cognitive rehabilitation.

Verbal fluency was measured using the verbal fluency subtest of the NEMA Reading and Writing Test developed by Karami Nouri and Moradi in 2008. The total verbal fluency score was derived from two complementary tasks: phonemic fluency and semantic fluency. During the phonemic fluency task, each child was asked to produce as many acceptable words as possible beginning with specified letters within one minute for each letter. Proper names, repeated words, words with the same root when repetition was not permitted, and responses that did not begin with the designated letter were excluded. During the semantic fluency task, the child was asked to generate words belonging to designated semantic categories, such as girls' names, boys' names, body parts, fruits, colors, and kitchen utensils, within a restricted period. The number of correct and nonrepeated responses was recorded for each category. The phonemic and semantic fluency scores were summed to obtain the total verbal fluency score, with higher scores indicating more efficient lexical retrieval, semantic access, cognitive flexibility, and executive search. Test–retest reliability coefficients of approximately .78 for semantic fluency and .74 for phonemic fluency have been reported, and the overall internal consistency of the measure has been found to be acceptable in Iranian children. Administration and scoring were conducted individually by a trained assessor using standardized instructions. This measure was selected because verbal fluency requires coordinated use of language knowledge, working memory, inhibition of irrelevant responses, strategic search, and rapid retrieval from long-term memory, all of which may be impaired in children with dyslexia.

Information processing speed was assessed using the Coding and Symbol Search subtests of the Wechsler Intelligence Scale for Children–Fifth Edition. In the Coding subtest, the child was presented with a key in which specific symbols were paired with numbers and was required to copy the corresponding symbol beneath each number as accurately and rapidly as possible within the specified time limit. Performance on this subtest reflects visual processing speed, sustained attention, short-term visual memory, graphomotor speed, visuomotor coordination, and the ability to maintain an efficient response pattern under time pressure. In the Symbol Search subtest, the child examined one or more target symbols and determined whether either target appeared within a larger group of visually similar symbols. The child indicated the response according to the standardized instructions and attempted to complete as many items as possible within the allotted time. This task evaluates visual scanning, perceptual discrimination, decision speed, selective attention, and accuracy in the presence of distracting stimuli. Raw scores from the two subtests were calculated according to the WISC-V scoring procedures and converted into standardized scores when required. The combined performance of the Coding and Symbol Search subtests was used as an indicator of information processing speed. Reliability coefficients of approximately .81 for Coding and .79 for Symbol Search have been reported, and Iranian standardization and clinical studies have supported the reliability and validity of the processing speed measures. These subtests were considered appropriate because slowed information processing, inefficient visual scanning, and limited automatization are commonly associated with reading difficulties and dyslexia spectrum disorder.

2.3. Interventions

The sensory-motor working memory enhancement–based cognitive rehabilitation program was administered individually in 18 sessions of approximately 60 minutes, with two sessions held each week. The intervention was designed on the basis of Baddeley's multicomponent working memory model and emphasized coordinated activation of the phonological loop, visuospatial sketchpad, central executive system, and episodic integration processes. The program combined computerized cognitive tasks with sensory-motor activities to strengthen the child's capacity to temporarily maintain information, manipulate verbal and visual material, coordinate mental operations with physical responses, inhibit irrelevant reactions, and transfer newly acquired cognitive strategies to everyday academic situations. Each session included a brief preparatory phase involving simple mental and motor activation, a principal training phase consisting of computerized working memory

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exercises, and a concluding phase involving complementary sensory-motor or cognitive-motor activities. The initial sessions focused on establishing familiarity with the software, following instructions, identifying visual patterns, imitating motor sequences, maintaining attention to simple stimuli, and reproducing short spatial arrangements. As the sessions progressed, the tasks increasingly required the children to retain and manipulate longer sequences of numbers, words, sentences, pictures, movements, and spatial locations. The later sessions incorporated response inhibition, dual-task performance, sequencing, categorization, mental updating, cognitive flexibility, and coordination of verbal or visuospatial memory with motor responses. Representative exercises included picture categorization, pattern recognition, symmetry judgment, Go/No-Go tasks, verbal working memory exercises, sentence recall, picture sequencing, spatial tracking, and combined motor-cognitive tasks. Task difficulty was adjusted progressively according to each child's performance, and immediate feedback was provided to maintain motivation and facilitate error correction. The therapist encouraged children to use rehearsal, chunking, visualization, verbal mediation, self-instruction, and strategic review to improve task performance. Exercises were delivered primarily through the Captain's Log cognitive rehabilitation system at the Silver developmental level, which is intended for children approximately 6 to 11 years of age. The software recorded response accuracy, response time, error patterns, and progress across sessions, allowing the therapist to adapt task complexity while maintaining a balance between challenge and successful performance.

The concentration enhancement–based cognitive rehabilitation program was also administered individually in 18 sessions of approximately 60 minutes, twice per week. The program was developed in accordance with the attention process training framework and was intended to improve focused, sustained, selective, alternating, and divided attention, as well as attentional control and resistance to distraction. Each session began with a brief orientation and concentration preparation exercise, followed by computerized attention tasks and a final review of the strategies used during the session. In the early sessions, the children completed relatively simple activities involving visual fixation, identification of target stimuli, discrimination of basic shapes or symbols, and maintenance of attention during short and structured tasks. The middle sessions introduced visual search, coding, cancellation, stimulus comparison, detection of relevant information among distractors, and tasks requiring the child to maintain concentration for progressively longer periods. Subsequent sessions required attentional shifting between different rules, response selection under time constraints, inhibition of impulsive responses, monitoring of errors, and simultaneous attention to more than one source of information. The most advanced sessions incorporated multicomponent exercises involving visual and auditory stimuli, rapid changes in task demands, alternating response rules, and complex timed activities. Throughout the intervention, the therapist emphasized self-monitoring strategies, including pausing before responding, repeating instructions mentally, identifying relevant task features, ignoring distracting information, checking answers, and correcting errors. Immediate and specific feedback was provided after each task, and task difficulty was increased gradually based on the child's accuracy and response speed. The Captain's Log software was used at the Silver level to provide structured multimedia exercises and objective performance recording. The program's adaptive features allowed the therapist to modify the number of stimuli, presentation duration, distractor density, response requirements, and level of task complexity according to the participant's progress. Positive reinforcement and brief rest periods were used when necessary to reduce fatigue and sustain engagement across the full session.

The Captain's Log system used in both intervention conditions is a computerized cognitive rehabilitation platform containing a wide range of exercises covering attention, memory, executive functioning, visual processing, auditory processing, conceptual reasoning, visuomotor coordination, and response control. Although both experimental groups used the same general software platform and received the same number and duration of sessions, the selected exercise domains and therapeutic objectives differed. The sensory-motor working memory group primarily completed exercises requiring the maintenance, manipulation, sequencing, and updating of information in coordination with verbal, visual, spatial, and motor responses. In contrast, the concentration enhancement group primarily completed exercises targeting sustained focus, selective attention, visual search, resistance to interference, attentional shifting, and response monitoring. To preserve intervention fidelity, the therapist followed a predetermined set of tasks for each treatment condition and documented the exercises completed, the difficulty level reached, the participant's performance, and any deviations

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from the protocol after each session. The equivalent session frequency, duration, delivery format, therapist contact, and software environment helped reduce the possibility that differences between the two experimental groups would be attributable merely to unequal exposure or attention from the therapist.

2.4. Data Analysis

The data were analyzed using IBM SPSS Statistics, version 26. Before conducting the main analyses, the dataset was screened for data-entry errors, missing values, extreme scores, and patterns of attrition. Descriptive statistics, including the mean, standard deviation, minimum, and maximum, were calculated for emotional control, verbal fluency, and information processing speed at the pretest, posttest, and follow-up stages in each group. The demographic characteristics of the groups were also examined to determine whether the random assignment procedure had produced reasonably comparable groups. The assumptions underlying parametric multivariate analysis were evaluated before hypothesis testing. The normality of the dependent variable distributions was examined using the Shapiro–Wilk test together with skewness, kurtosis, and visual inspection of the distributions. Levene's test was used to assess the homogeneity of error variances across groups, and Box's M test was used to examine the equality of covariance matrices. The sphericity assumption for within-subject effects was evaluated using Mauchly's test. When the sphericity assumption was violated, the Greenhouse–Geisser correction was applied. The presence of influential multivariate outliers was examined using Mahalanobis distance, and the relationships among the dependent variables were inspected to ensure that multicollinearity did not compromise the multivariate analysis.

A mixed repeated-measures multivariate analysis of variance was performed to investigate the effects of group, measurement time, and the group-by-time interaction on the combined dependent variables of emotional control, verbal fluency, and information processing speed. Group, consisting of sensory-motor working memory rehabilitation, concentration enhancement rehabilitation, and control conditions, was treated as the between-subjects factor, while measurement time, consisting of pretest, posttest, and two-month follow-up, was treated as the within-subjects factor. The multivariate test was followed by univariate repeated-measures analyses for each dependent variable when a significant overall multivariate effect was observed. The primary indicator of intervention effectiveness was the group-by-time interaction, because a statistically significant interaction would demonstrate that changes across the three measurement stages differed among the study groups. When significant group, time, or interaction effects were identified, Bonferroni-adjusted pairwise comparisons were conducted to determine which groups and measurement stages differed significantly. In particular, comparisons were made between each experimental group and the control group, between the two experimental groups, between pretest and posttest scores, between pretest and follow-up scores, and between posttest and follow-up scores. Effect sizes were reported using partial eta squared to indicate the magnitude of the observed effects. Statistical significance was set at .05 for all analyses, and adjusted significance levels were used for multiple comparisons to control the probability of Type I error.

3. Findings and Results

Data from all 60 children with dyslexia spectrum disorder were included in the statistical analyses. The participants were equally allocated to the concentration enhancement–based cognitive rehabilitation group, the sensory-motor working memory enhancement–based cognitive rehabilitation group, and the control group, with 20 children in each group. In the concentration enhancement group, 10 participants (50%) were in the third grade, five (25%) were in the fourth grade, and five (25%) were in the fifth grade. In the sensory-motor working memory enhancement group, 10 participants (50%) were in the third grade, five (25%) were in the fourth grade, and five (25%) were in the fifth grade. In the control group, 11 participants (55%) were in the third grade, five (25%) were in the fourth grade, and four (20%) were in the fifth grade. The mean ages of the participants in the concentration enhancement, sensory-motor working memory enhancement, and control groups were 9.40 ± 3.20, 8.60 ± 2.15, and 9.10 ± 3.10 years, respectively. The chi-square test showed no statistically significant difference among the groups in grade-level distribution, $\chi^2 = 1.05$, $p = .91$. Similarly, the one-way analysis of variance indicated no significant difference among the groups in age, $F = 0.08$, $p = .92$. Thus, the three groups were comparable in terms of the examined demographic characteristics.

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Table 1

Means and Standard Deviations of the Study Variables by Group and Measurement Stage

Variable	Group	Pretest, M ± SD	Posttest, M ± SD	Follow-up, M ± SD
Information processing speed	Concentration enhancement	77.05 ± 7.18	89.75 ± 6.36	89.40 ± 7.14
	Sensory-motor working memory enhancement	78.60 ± 7.44	88.90 ± 7.97	88.30 ± 7.91
	Control	78.05 ± 7.53	77.65 ± 8.55	77.20 ± 8.63
Verbal fluency	Concentration enhancement	77.95 ± 4.90	90.55 ± 5.88	90.20 ± 6.73
	Sensory-motor working memory enhancement	77.25 ± 4.14	91.30 ± 6.65	90.70 ± 7.74
	Control	76.85 ± 5.20	76.50 ± 6.21	75.80 ± 4.37
Anger control	Concentration enhancement	25.10 ± 3.04	33.02 ± 4.02	32.98 ± 3.60
	Sensory-motor working memory enhancement	26.11 ± 4.84	30.84 ± 4.01	29.13 ± 3.38
	Control	25.90 ± 3.12	24.11 ± 3.19	25.68 ± 5.23
Depressed mood control	Concentration enhancement	28.34 ± 4.80	27.12 ± 3.15	27.51 ± 3.09
	Sensory-motor working memory enhancement	28.10 ± 4.17	27.01 ± 2.72	26.85 ± 2.87
	Control	28.20 ± 4.55	26.79 ± 2.25	26.97 ± 3.04
Positive affect control	Concentration enhancement	44.41 ± 3.84	43.26 ± 5.94	43.67 ± 4.88
	Sensory-motor working memory enhancement	45.00 ± 5.06	45.13 ± 3.74	44.12 ± 5.89
	Control	44.96 ± 5.48	43.33 ± 4.95	44.87 ± 4.23
Anxiety control	Concentration enhancement	45.90 ± 5.28	51.86 ± 5.77	50.05 ± 1.83
	Sensory-motor working memory enhancement	44.33 ± 4.19	48.21 ± 5.00	47.65 ± 1.64
	Control	45.99 ± 5.47	44.46 ± 5.03	44.07 ± 2.63
Total emotional control	Concentration enhancement	143.75 ± 8.45	154.80 ± 6.40	154.12 ± 5.67
	Sensory-motor working memory enhancement	143.00 ± 8.72	148.75 ± 8.67	147.75 ± 8.49
	Control	144.05 ± 8.25	143.70 ± 8.59	143.05 ± 9.31

As shown in Table 1, the three groups had relatively similar mean scores at the pretest stage. From pretest to posttest, substantial increases in information processing speed and verbal fluency were observed in both experimental groups, whereas the scores of the control group remained relatively unchanged. The improvements observed in the experimental groups were largely maintained at the two-month follow-up. A similar pattern was found for anger control, anxiety control, and the total emotional control score. The increases were descriptively greater in the concentration enhancement group than in the sensory-motor working memory enhancement group, particularly for anger control and the total emotional control score. By contrast, depressed mood control and positive affect control did not demonstrate a clear pattern of intervention-related change across the three measurement stages.

Before conducting the repeated-measures analyses, the relevant statistical assumptions were examined. The Shapiro–Wilk test was nonsignificant for the study variables across the measurement stages, indicating that the distributions did not differ significantly from normality, $p > .05$. Levene's tests were also nonsignificant, supporting the homogeneity of error variances across the groups, $p > .05$. The groups did not differ significantly at pretest in information processing speed, $F = 0.11$, $p = .89$, verbal fluency, $F = 0.31$, $p = .73$, or total emotional control, $F = 0.08$, $p = .92$. Box's M tests were significant for information processing speed, Box's $M = 45.62$, $F = 3.50$, $p < .001$, and verbal fluency, Box's $M = 101.32$, $F = 7.79$, $p < .001$. Therefore, the more robust Pillai's trace criterion was used to interpret their multivariate effects. Mauchly's tests were significant for information processing speed, $W = .13$, $\chi^2(2) = 110.66$, $p = .003$, and verbal fluency, $W = .32$, $\chi^2(2) = 62.37$, $p = .001$, indicating violations of the sphericity assumption. Consequently, the Greenhouse–Geisser correction was applied to the corresponding within-subject tests.

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Table 2

Repeated-Measures Analysis of Variance for the Study Variables

Variable	Effect	F	df	p	Partial η^2
Information processing speed	Time	22.44	Corrected	< .001	.28
	Time × group	6.81	Corrected	< .001	.19
	Group	7.83	2, 57	< .001	.21
Verbal fluency	Time	118.38	1.19, 68.19	< .001	.67
	Time × group	34.82	2.39, 68.19	< .001	.55
	Group	37.96	2, 57	< .001	.45
Anger control	Time	22.53	—	< .001	.52
	Time × group	4.25	—	.004	.14
	Group	11.53	—	.001	.36
Depressed mood control	Time	1.69	—	.09	—
	Time × group	1.95	—	.11	—
	Group	0.35	—	.71	—
Positive affect control	Time	1.90	—	.16	—
	Time × group	0.33	—	.86	—
	Group	0.29	—	.60	—
Anxiety control	Time	11.27	—	< .001	.35
	Time × group	3.10	—	.02	.12
	Group	5.94	—	.01	.22
Total emotional control	Time	16.74	—	.001	.37
	Time × group	5.35	—	.001	.15
	Group	5.35	2, 57	.006	.16

As presented in Table 2, the effect of time on information processing speed was statistically significant, $F = 22.44$, $p < .001$, partial $\eta^2 = .28$. More importantly, the time-by-group interaction was also significant, $F = 6.81$, $p < .001$, partial $\eta^2 = .19$, indicating that changes in information processing speed across the three measurement stages differed among the groups. The significant between-group effect further demonstrated an overall difference among the three conditions, $F(2, 57) = 7.83$, $p < .001$, partial $\eta^2 = .21$. For verbal fluency, significant effects were found for time, $F(1.19, 68.19) = 118.38$, $p < .001$, partial $\eta^2 = .67$, the time-by-group interaction, $F(2.39, 68.19) = 34.82$, $p < .001$, partial $\eta^2 = .55$, and group, $F(2, 57) = 37.96$, $p < .001$, partial $\eta^2 = .45$. These effect sizes indicated particularly substantial intervention-related changes in verbal fluency.

For the emotional control dimensions, the effects of time, time by group, and group were statistically significant for anger control, anxiety control, and the total emotional control score. For anger control, significant effects were observed for time, $F = 22.53$, $p < .001$, partial $\eta^2 = .52$, time by group, $F = 4.25$, $p = .004$, partial $\eta^2 = .14$, and group, $F = 11.53$, $p = .001$, partial $\eta^2 = .36$. Anxiety control also demonstrated significant effects of time, $F = 11.27$, $p < .001$, partial $\eta^2 = .35$, time by group, $F = 3.10$, $p = .02$, partial $\eta^2 = .12$, and group, $F = 5.94$, $p = .01$, partial $\eta^2 = .22$. Similarly, the total emotional control score showed significant effects of time, $F = 16.74$, $p = .001$, partial $\eta^2 = .37$, time by group, $F = 5.35$, $p = .001$, partial $\eta^2 = .15$, and group, $F(2, 57) = 5.35$, $p = .006$, partial $\eta^2 = .16$. In contrast, none of the time, interaction, or group effects reached statistical significance for depressed mood control or positive affect control. The interventions therefore affected selected dimensions of emotional control rather than producing uniform changes across all emotional control components.

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Table 3

Bonferroni-Adjusted Pairwise Comparisons for the Study Variables

Variable	Comparison	Mean Difference	p
Information processing speed	Concentration: pretest vs. posttest	−12.70	.001
	Concentration: pretest vs. follow-up	−12.35	.001
	Concentration: posttest vs. follow-up	0.35	1.00
	Working memory: pretest vs. posttest	−10.30	.01
	Working memory: pretest vs. follow-up	−9.70	.04
	Working memory: posttest vs. follow-up	0.60	1.00
	Control: pretest vs. posttest	0.40	1.00
	Control: pretest vs. follow-up	0.85	1.00
	Control: posttest vs. follow-up	0.45	1.00
	Posttest: concentration vs. working memory	0.85	.94
	Posttest: concentration vs. control	12.10	< .001
	Posttest: working memory vs. control	11.25	< .001
	Follow-up: concentration vs. working memory	1.10	.90
	Follow-up: concentration vs. control	12.20	< .001
	Follow-up: working memory vs. control	11.10	< .001
Verbal fluency	Concentration: pretest vs. posttest	−12.60	.001
	Concentration: pretest vs. follow-up	−12.25	.001
	Concentration: posttest vs. follow-up	0.37	1.00
	Working memory: pretest vs. posttest	−14.05	.01
	Working memory: pretest vs. follow-up	−13.45	.001
	Working memory: posttest vs. follow-up	0.63	1.00
	Control: pretest vs. posttest	0.35	.44
	Control: pretest vs. follow-up	0.95	.10
	Control: posttest vs. follow-up	−0.35	.44
	Posttest: concentration vs. working memory	−0.75	.88
	Posttest: concentration vs. control	14.05	< .001
	Posttest: working memory vs. control	14.80	< .001
	Follow-up: concentration vs. working memory	−0.50	.95
	Follow-up: concentration vs. control	14.40	< .001
	Follow-up: working memory vs. control	14.90	< .001
Anger control	Concentration: pretest vs. posttest	−7.92	.001
	Concentration: pretest vs. follow-up	−7.88	.001
	Concentration: posttest vs. follow-up	0.04	1.00
	Working memory: pretest vs. posttest	−4.73	.001
	Working memory: pretest vs. follow-up	−3.02	.001
	Working memory: posttest vs. follow-up	1.71	1.00
	Posttest: concentration vs. working memory	2.18	.001
	Posttest: concentration vs. control	8.91	.001
	Posttest: working memory vs. control	6.73	.001
Anxiety control	Concentration: pretest vs. posttest	−5.96	.001
	Concentration: pretest vs. follow-up	−4.15	.001
	Concentration: posttest vs. follow-up	1.81	1.00
	Working memory: pretest vs. posttest	−3.88	.001
	Working memory: pretest vs. follow-up	−3.32	.001
	Working memory: posttest vs. follow-up	0.56	1.00
	Posttest: concentration vs. working memory	3.66	.001
	Posttest: concentration vs. control	7.40	.001
	Posttest: working memory vs. control	3.75	.001
Total emotional control	Concentration: pretest vs. posttest	−11.05	.001
	Concentration: pretest vs. follow-up	−11.00	.001
	Concentration: posttest vs. follow-up	0.05	1.00
	Working memory: pretest vs. posttest	−5.75	.03
	Working memory: pretest vs. follow-up	−4.75	.02
	Working memory: posttest vs. follow-up	1.00	1.00
	Posttest: concentration vs. working memory	6.05	.04
	Posttest: concentration vs. control	11.10	.001
	Posttest: working memory vs. control	5.05	.003
	Follow-up: concentration vs. working memory	6.34	.02
	Follow-up: concentration vs. control	11.07	.001
	Follow-up: working memory vs. control	4.70	.04

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As shown in Table 3, information processing speed increased significantly from pretest to posttest and from pretest to follow-up in both the concentration enhancement and sensory-motor working memory enhancement groups. The posttest-to-follow-up differences were nonsignificant, indicating that the improvements were maintained during the two-month follow-up period. No significant changes occurred in the control group. At both posttest and follow-up, the two experimental groups obtained significantly higher information processing speed scores than the control group, whereas the difference between the two experimental groups was nonsignificant. These findings indicated that both interventions were effective in improving information processing speed, with neither intervention demonstrating superiority over the other.

A similar pattern was observed for verbal fluency. Both experimental groups demonstrated significant increases from pretest to posttest and from pretest to follow-up, while their posttest and follow-up scores did not differ significantly. No statistically significant change was observed in the control group. At posttest and follow-up, both experimental groups had significantly higher verbal fluency scores than the control group. However, the concentration enhancement and sensory-motor working memory enhancement groups did not differ significantly from one another at either assessment. Thus, both forms of cognitive rehabilitation were effective and comparably successful in improving verbal fluency.

For anger control, anxiety control, and total emotional control, both experimental groups showed significant improvements from pretest to posttest and from pretest to follow-up. The nonsignificant differences between posttest and follow-up indicated that these improvements were generally maintained after the conclusion of the interventions. At posttest, both experimental groups obtained significantly higher anger control and anxiety control scores than the control group. The concentration enhancement group also obtained significantly higher posttest scores than the sensory-motor working memory enhancement group for anger control and anxiety control. For total emotional control, both experimental groups performed significantly better than the control group at posttest and follow-up, while the concentration enhancement group performed significantly better than the sensory-motor working memory enhancement group at both stages. Accordingly, although both interventions improved anger control, anxiety control, and overall emotional control, concentration enhancement–based cognitive rehabilitation produced greater improvement in these outcomes. Neither intervention, however, produced statistically significant changes in depressed mood control or positive affect control.

4. Discussion and Conclusion

The present study compared the effectiveness of concentration enhancement–based cognitive rehabilitation and sensory-motor working memory enhancement–based cognitive rehabilitation in improving emotional control, verbal fluency, and information processing speed among children with dyslexia spectrum disorder. The findings showed that both interventions significantly improved information processing speed and verbal fluency from pretest to posttest, and these gains remained stable at the two-month follow-up. No significant difference was observed between the two experimental groups in either information processing speed or verbal fluency, indicating that the two rehabilitation approaches were comparably effective in these cognitive domains. Both interventions also significantly improved anger control, anxiety control, and the total emotional control score, with the improvements persisting through follow-up. However, concentration enhancement–based rehabilitation produced significantly greater gains than sensory-motor working memory enhancement–based rehabilitation in these emotional outcomes. In contrast, neither intervention significantly affected depressed mood control or positive affect control. Overall, the results suggest that attention-focused and sensory-motor working-memory-focused rehabilitation can both strengthen important cognitive functions in children with dyslexia, although concentration enhancement may have a more direct and pronounced influence on selected dimensions of emotional regulation.

The first major finding was that concentration enhancement–based cognitive rehabilitation significantly improved information processing speed. This result is consistent with evidence showing that attention and concentration are essential components of efficient cognitive performance. Rezaei et al. found that computer-based cognitive empowerment enhanced attentional functions, concentration, and cognitive effort, suggesting that systematic cognitive exercises can increase the efficiency with which individuals allocate and sustain mental resources (Rezaei et al., 2021). Similarly, Hamedali et al. reported that cognitive rehabilitation improved working memory, concentration, and attention, supporting the capacity of structured cognitive training to modify fundamental

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executive functions (Hamedali et al., 2021). Studies conducted with students with learning disabilities have also shown that cognitive rehabilitation programs can improve attention, concentration, nonverbal cognitive functioning, and academic performance (Shah Mohammadi et al., 2018; Shahmohammadi et al., 2019). These findings align with the present result because processing speed does not merely reflect rapid responding; it also depends on the ability to maintain focus, identify relevant stimuli, suppress distractors, make accurate decisions, and execute responses efficiently.

The effectiveness of concentration enhancement in improving processing speed may be explained through attentional control mechanisms. During visual scanning and symbol discrimination tasks, children must continuously maintain task goals, shift efficiently between stimuli, and resist irrelevant environmental or internal distractions. When attention is unstable, additional time is required to reorient to the task, identify the relevant stimulus, and correct impulsive errors. Concentration training may reduce these inefficiencies by strengthening sustained and selective attention, response inhibition, and self-monitoring. Ahmadabadi et al. showed that computer-based cognitive rehabilitation improved attention, concentration, and reading comprehension among students with attentional deficits, indicating that computerized attention exercises may influence both basic attentional processes and higher-level academic performance (Ahmadabadi et al., 2022). Cognitive-behavioral play interventions have likewise produced improvements in attention and concentration among children with intellectual disabilities, further suggesting that repeated, structured, and engaging practice can improve the consistency of cognitive performance (Mehr Afza et al., 2021; Mehrafza et al., 2022). Therefore, the observed increase in processing speed may have resulted from faster target detection, more efficient visual search, fewer distraction-related interruptions, and greater accuracy under time pressure.

Sensory-motor working memory enhancement–based cognitive rehabilitation also significantly improved information processing speed. This finding may be understood in light of the close relationship between working memory, sensory integration, motor planning, and rapid cognitive responding. Working memory enables children to hold task rules in mind, compare incoming information with stored representations, update responses, and coordinate sequential cognitive operations. Barghi et al. demonstrated that cognitive skills training improved verbal and nonverbal working memory in students with dyslexia, supporting the modifiability of working-memory systems in this population (Barghi et al., 2019). When working memory becomes more efficient, children may require less time to retrieve instructions, maintain symbol–response associations, and integrate visual information with motor output. As a result, they can complete timed processing tasks more rapidly and with fewer interruptions.

The sensory-motor component may have contributed additional benefits by strengthening the coordination of perception and action. Sensorimotor interventions require the participant to interpret visual, auditory, tactile, or proprioceptive input and translate that information into a timely and organized response. Research across rehabilitation populations has shown that sensory feedback and motor practice can improve functional performance and adaptive control. Somatosensory integration has been emphasized in motor restoration because sensory feedback supports the selection and correction of motor responses (Lin et al., 2024). Sensorimotor neurofeedback and related rehabilitation methods have also been used to influence motor learning and cortical regulation (Cioffi et al., 2024). In addition, structured sensorimotor training has improved control, proprioception, and functionality in various populations (Asadi & Roshani, 2025; Carretti et al., 2024; Engel et al., 2025). Although these studies were not conducted specifically with children with dyslexia, they support the interpretation that repeated integration of sensory information, working memory, and motor response can enhance the speed and organization of cognitive performance.

The absence of a significant difference between the two experimental groups in information processing speed suggests that attention and sensory-motor working memory may represent complementary pathways to cognitive efficiency. Concentration enhancement may accelerate performance by improving sustained focus, stimulus selection, and resistance to distraction, whereas sensory-motor working memory enhancement may increase efficiency through better rule maintenance, sequencing, updating, and visuomotor coordination. Both pathways ultimately reduce the cognitive burden associated with simple timed tasks. This interpretation is compatible with cognitive-motor dual-task research, which shows that cognitive and motor systems interact through shared executive resources, particularly attention and working memory (Tan et al., 2024). Physical and motor activity may also facilitate cognitive performance by regulating arousal

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and increasing readiness to respond (Loprinzi & Kane, 2015). Thus, although the interventions differed in their immediate targets, both may have strengthened overlapping executive networks involved in rapid information processing.

The second major finding was that both interventions significantly improved verbal fluency, with no significant difference between them. This finding is important because verbal fluency is frequently impaired in children with dyslexia and requires the coordinated operation of phonological processing, lexical retrieval, working memory, cognitive flexibility, inhibition, and processing speed. Phonological deficits are considered a central feature of dyslexia and can interfere with the efficient retrieval and production of verbal information (Adel & Saleh, 2022). Children with dyslexia may also display broader difficulties involving language awareness and pragmatic or syntactic processes, particularly when associated language weaknesses are present (Cardillo et al., 2018; Robertson et al., 2024). The significant improvement observed in both experimental groups indicates that verbal retrieval performance may be enhanced not only through direct language instruction but also through interventions targeting underlying cognitive control mechanisms.

The effect of concentration enhancement on verbal fluency may be attributed to improved strategic search and reduced interference. During verbal fluency tasks, the child must sustain attention to the target letter or semantic category, inhibit words that do not meet the rule, monitor previous responses to avoid repetition, and shift between subcategories when one lexical cluster is exhausted. Attention training may strengthen each of these processes. Improved concentration allows the child to remain oriented to the task rule, while enhanced inhibitory control reduces irrelevant or repetitive responses. Cognitive flexibility may also improve as the child learns to shift efficiently among search strategies. The effectiveness of computer-based cognitive rehabilitation in improving attention and concentration provides indirect support for this explanation (Ahmadabadi et al., 2022; Hamedali et al., 2021). Similarly, findings that cognitive rehabilitation improves attention and academic functioning among students with learning disabilities suggest that attention-based exercises may generalize to language-related performance requiring executive control (Shah Mohammadi et al., 2018; Shahmohammadi et al., 2019).

The improvement in verbal fluency following sensory-motor working memory rehabilitation may be explained primarily by stronger verbal working memory, sequencing, and retrieval organization. Verbal fluency requires the temporary maintenance of the task rule and already-produced responses while new words are retrieved. Children with limited working-memory capacity may lose track of previous answers, repeat words, or fail to use systematic lexical-search strategies. Working-memory training may reduce these problems by increasing the capacity to hold and manipulate verbal information. The findings of Barghi et al., who reported improvements in verbal and nonverbal working memory among students with dyslexia following cognitive skills training, are consistent with this interpretation (Barghi et al., 2019). Sensorimotor activities may further support verbal fluency by integrating timing, rhythm, sequencing, and coordinated response production. Research on motor-sensory learning, including structured musical practice, suggests that activities combining perception, timing, sequencing, and motor output can influence broader learning processes in children with disabilities (Strubbe et al., 2025). Therefore, the verbal fluency gains may reflect improved executive organization rather than changes limited to vocabulary knowledge.

The persistence of processing-speed and verbal-fluency improvements at follow-up indicates that the effects were not merely temporary practice effects. The progressive structure of the interventions, immediate feedback, repetition, and adaptive adjustment of task difficulty may have promoted the consolidation and transfer of learned strategies. Digital programs can be particularly effective in sustaining children's participation because they provide clear goals, performance feedback, and motivational reinforcement. Vasalou et al. emphasized the value of digital game-based learning for engagement and learning among children with dyslexia (Vasalou et al., 2017). Sustained engagement likely increases the amount of effective practice and facilitates the automatization of cognitive strategies. Once children learn to slow impulsive responses, scan systematically, rehearse information, categorize verbal material, and monitor errors, these strategies may continue to be used beyond the formal intervention setting.

The third major finding was that both interventions improved anger control, anxiety control, and total emotional control, while concentration enhancement was significantly more effective than sensory-motor working memory enhancement. This finding supports the view that executive functioning and emotional regulation are closely connected. Emotional control requires an individual to maintain a goal, inhibit immediate reactions, disengage from emotionally

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salient distractions, evaluate alternative responses, and act in accordance with longer-term consequences. These operations depend heavily on attention and executive control. Among children with dyslexia, anxiety may interfere with processing speed by consuming attentional resources and reducing cognitive efficiency (Wang et al., 2024). Accordingly, strengthening attentional control may help children manage emotional arousal by reducing excessive attention to threatening, frustrating, or failure-related stimuli.

The greater effectiveness of concentration enhancement on anger and anxiety control may be related to its direct emphasis on attentional regulation, impulsivity control, error monitoring, and deliberate responding. Children with dyslexia often experience frustration during academic tasks and may respond quickly to perceived failure or correction. Attention training teaches children to pause, examine stimuli carefully, maintain task goals, and review responses before acting. These skills may transfer to emotional situations, enabling children to interrupt automatic reactions and select more adaptive responses. Improvements in attention and concentration through cognitive rehabilitation and cognitive-behavioral play therapy support the feasibility of this mechanism (Ahmadabadi et al., 2022; Mehr Afza et al., 2021; Mehrafza et al., 2022). In addition, cognitive rehabilitation may increase children's sense of competence by allowing them to experience success in progressively challenging tasks. Greater perceived competence may reduce frustration and anxiety during cognitively demanding situations.

Sensory-motor working memory rehabilitation also improved anger and anxiety control, although to a lesser extent. Sensorimotor activities may regulate emotional arousal by organizing bodily responses, improving sensory modulation, and increasing awareness of action and feedback. Evidence from autism research indicates that sensory-motor and sensory-integration interventions can influence not only motor functioning but also communication, social interaction, stereotyped behavior, and adaptive participation (Rabiei et al., 2024; Savarese et al., 2025; Wen & Wu, 2025). A validated sensory-motor play therapy program similarly reflects the potential of embodied, structured activity to support behavioral and psychological regulation in children with developmental conditions (Behnam-Nejad et al., 2025). Sensorimotor behavior and cerebellar connectivity have also been associated with sensory responsivity and broader neurodevelopmental functioning (Bojanek et al., 2025; Cakar et al., 2024). These findings suggest that sensory-motor training may improve emotional control indirectly by reducing disorganized arousal and strengthening the integration of sensory input, cognitive planning, and behavioral response.

Nevertheless, the stronger effect of concentration enhancement suggests that emotional control in the present sample was more responsive to explicit attentional and inhibitory training than to working-memory and sensory-motor integration alone. Anger and anxiety frequently involve attentional capture by provocative or threatening stimuli. A child who cannot disengage attention from a mistake, criticism, or anticipated failure may experience prolonged emotional activation. Concentration enhancement may directly improve the ability to redirect attention and suppress maladaptive responses. By contrast, sensory-motor working memory training primarily targets information maintenance, sequencing, and cognitive-motor coordination. Although these functions support emotional regulation, their influence is likely more indirect. The result therefore indicates that the specificity of the training target matters when the desired outcome involves immediate regulation of emotional reactions.

Neither intervention significantly improved depressed mood control or positive affect control. Several explanations may account for these null findings. First, depressed mood and positive affect may be relatively stable emotional dispositions that require interventions addressing beliefs, self-evaluation, interpersonal experiences, reinforcement patterns, and mood-related cognitions. Cognitive rehabilitation primarily targets cognitive operations rather than the emotional meaning of academic failure or the child's broader affective environment. Second, the 18-session programs may have been sufficient to improve executive control over anger and anxiety but insufficient to produce sustained changes in mood and positive emotional experience. Third, the participants may not have had clinically elevated depressed mood at baseline, creating limited potential for measurable improvement. Finally, the emotional control questionnaire may capture concern about emotional experiences rather than direct behavioral regulation, and some subscales may be less sensitive to cognitive rehabilitation effects.

The null effects on depressed mood and positive affect are not inconsistent with the broader rehabilitation literature, because most studies in the approved reference set have focused on attention, working memory, motor functioning, or academic outcomes rather than mood change. Cognitive

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rehabilitation studies have consistently reported benefits for concentration, attention, working memory, and performance-related variables (Ahmadabadi et al., 2022; Hamedali et al., 2021; Rezaei et al., 2021), while sensorimotor studies have primarily demonstrated gains in motor control, sensory integration, functional performance, and adaptive behavior (Carretti et al., 2024; Cioffi et al., 2024; Lin et al., 2024). Consequently, expecting cognitive rehabilitation alone to alter broader mood dimensions may exceed the intervention's primary mechanism. Mood-related outcomes may require the addition of cognitive-behavioral, emotion-focused, family-based, or social interventions that directly address negative self-beliefs and reduced positive reinforcement.

Taken together, the findings support a multidimensional understanding of dyslexia. Reading difficulties appear to coexist with weaknesses in processing speed, verbal retrieval, working memory, attention, and emotional regulation. The results also indicate that cognitive rehabilitation can produce effects extending beyond the specific exercises practiced. Concentration training improved not only attention-related performance but also processing speed, verbal fluency, and emotional control. Sensory-motor working memory training similarly influenced cognitive and emotional outcomes, likely through overlapping executive and self-regulatory mechanisms. This transfer is theoretically plausible because attention, working memory, inhibition, processing speed, language retrieval, and emotion regulation rely on interconnected systems rather than isolated cognitive modules. The comparable effects on verbal fluency and processing speed suggest that different forms of rehabilitation may converge on shared executive pathways, whereas the superiority of concentration enhancement for emotional control demonstrates that some outcomes are more sensitive to intervention specificity.

A limitation of the present study was the use of purposive sampling from specialized learning disability centers in one city, which restricts the generalizability of the findings to children from other geographical, educational, and cultural contexts. The sample size was relatively modest, and the two-month follow-up period did not permit evaluation of long-term maintenance. The study also relied on a waiting-list control group rather than an active comparison condition, making it difficult to separate the specific effects of the rehabilitation exercises from therapist attention, computer exposure, expectancy, and structured participation. In addition, emotional control was measured through a questionnaire, which may have been influenced by response style and may not fully reflect emotional behavior in natural academic or family settings. Variations in dyslexia severity, comorbid attention difficulties, language ability, medication use, and home educational support may also have affected the outcomes.

Future studies should replicate the research with larger and more diverse samples recruited from multiple regions and educational settings. Longer follow-up periods, such as six months or one year, would provide stronger evidence regarding the durability of treatment gains. Researchers should use active control groups and compare cognitive rehabilitation with established reading remediation, emotion-regulation training, or combined interventions. It would also be valuable to examine whether baseline attention, working-memory capacity, dyslexia severity, anxiety, age, or sex moderates treatment response. Future research should incorporate teacher and parent ratings, behavioral observation, computerized performance indices, and ecologically valid academic outcomes. Studies may also investigate whether combining concentration enhancement with sensory-motor working-memory training produces additive or synergistic effects.

In practice, learning disability centers should consider incorporating structured cognitive rehabilitation into comprehensive intervention programs for children with dyslexia spectrum disorder. Concentration enhancement exercises may be prioritized when children display marked distractibility, impulsive reactions, anxiety, or anger during academic tasks, while sensory-motor working-memory activities may be particularly useful for children with sequencing, visuomotor, and memory-related weaknesses. Practitioners should adjust task difficulty gradually, provide immediate feedback, monitor fatigue, and use motivating digital activities to sustain participation. Cognitive rehabilitation should be integrated with evidence-based reading instruction rather than used as a replacement for direct literacy intervention. Collaboration among psychologists, special educators, parents, and school staff is also necessary to help children apply acquired strategies during reading, classroom learning, homework, and emotionally challenging situations.

Authors' Contributions

All authors significantly contributed to this study.

Declaration

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

Transparency Statement

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

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Declaration of Interest

The authors report no conflict of interest.

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Ethical Considerations

In this study, to observe ethical considerations, participants were informed about the goals and importance of the research before the start of the study and participated in the research with informed consent.

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