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The Effectiveness of a Computerized Cognitive Rehabilitation Program on Executive Functions in Children With Externalizing Behavioral Disorders

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A B S T R A C T

Purpose: The present study aimed to investigate the effectiveness of a computerized cognitive rehabilitation program on executive functions, including emotional control, attention shifting, behavioral control, and inhibition, in children with externalizing behavioral disorders.

Methods and Materials: The present study employed a quasi-experimental design with a pretest–posttest control group structure. The statistical population consisted of children and adolescents with externalizing behavioral disorders who received psychological services in clinics located in Rasht during 2021. Using purposive sampling, 32 participants were selected and randomly assigned into experimental and control groups, with 16 participants in each group. Participants were matched based on age, gender, and intelligence level. Data collection instruments included the Eyberg Child Behavior Inventory (ECBI) and the Behavior Rating Inventory of Executive Function (BRIEF), Parent Form. The experimental group received a computerized cognitive rehabilitation intervention consisting of Lumosity and Peak cognitive training games across 20 sessions over a three-week period, while the control group received no intervention. Data were analyzed using descriptive statistics and one-way multivariate analysis of covariance (MANCOVA) in IBM SPSS Statistics version 26.

Findings: The results of multivariate covariance analysis indicated significant differences between the experimental and control groups in executive function components after controlling for pretest scores. Significant improvements were observed in emotional control ($F = 67.369$, $p < 0.001$, $\eta^2 = 0.706$), attention shifting ($F = 22.689$, $p < 0.001$, $\eta^2 = 0.448$), behavioral control ($F = 51.472$, $p < 0.001$, $\eta^2 = 0.648$), and inhibition ($F = 63.502$, $p < 0.001$, $\eta^2 = 0.694$) in the experimental group. Multivariate test results also demonstrated a significant overall effect of the intervention on executive functioning variables, whereas no significant differences were found in the control group between pretest and posttest stages.

Conclusion: The findings suggest that computerized cognitive rehabilitation is an effective intervention for improving executive functions in children with externalizing behavioral disorders.

Keywords: *Computerized cognitive rehabilitation, executive functions, externalizing behavioral disorders, children.*

1. Introduction

Externalizing behavioral disorders in childhood refer to a broad pattern of dysregulated, outwardly directed behaviors such as impulsivity, aggression, oppositionality, rule-breaking, emotional reactivity, and poor behavioral inhibition. These problems are clinically important because they interfere not only with the child's adjustment at home and school, but also with peer relationships, academic functioning, family interaction patterns, and later psychosocial outcomes. Although externalizing symptoms may appear behaviorally heterogeneous, a major shared mechanism underlying many of these difficulties is impairment in executive functions, particularly inhibition, emotional control, cognitive flexibility, attention shifting, working memory, planning, and behavioral monitoring. Contemporary clinical guidelines emphasize that assessment of children with attention-deficit/hyperactivity disorder and related disruptive behavioral profiles should include cognitive and executive dimensions, because behavioral symptoms often reflect underlying deficits in neurocognitive regulation rather than isolated conduct problems (Malhotra et al., 2025; Musullulu, 2025). Therefore, examining interventions that directly target executive functioning is essential for improving treatment outcomes in children with externalizing behavioral disorders.

Executive functions are higher-order cognitive control processes that allow children to regulate attention, inhibit inappropriate responses, shift flexibly between tasks, manage emotions, and organize goal-directed behavior. Deficits in these functions are commonly observed in children with ADHD, oppositional symptoms, and broader externalizing profiles. Evidence suggests that children with ADHD and related behavioral difficulties show impairments in both "cool" executive functions, such as working memory and planning, and "hot" executive functions, such as emotional control and reward-related decision-making (Kamalahmadi et al., 2024; Veloso et al., 2022). These impairments can lead to difficulty delaying responses, regulating frustration, following classroom rules, completing academic tasks, and adapting behavior to changing environmental demands. Studies comparing children with ADHD and other clinical groups have shown that inhibition of automatic responses is particularly delayed in children with ADHD, indicating that behavioral dysregulation is closely connected to measurable executive dysfunction (Panvino et al., 2025). Similarly, subthreshold ADHD symptoms can be accompanied by executive dysfunction and caregiver strain, which indicates that even less severe externalizing symptoms can produce clinically meaningful consequences (Tang et al., 2023).

The developmental significance of executive dysfunction extends beyond immediate behavioral symptoms. Longitudinal evidence indicates that family, behavioral, and neuropsychological factors contribute to long-term functional outcomes in young adults with a history of ADHD, showing that early cognitive and behavioral vulnerabilities may continue to influence adaptive functioning over time (Miranda et al., 2021). Family functioning also appears to predict the quality of cognitive functioning among primary school students with ADHD, suggesting that executive functioning is embedded within both neuropsychological and environmental systems (Walenista et al., 2023). In addition, psychiatric comorbidity and resilience may interact with executive function in childhood and adolescence, intensifying or buffering the burden of clinical symptoms (Arruda et al., 2025). These findings support the view that childhood externalizing disorders should be approached through interventions that consider cognitive control, emotional regulation, behavioral management, and family context.

Traditional treatment approaches for externalizing behavioral disorders often include pharmacotherapy, behavioral parent training, cognitive-behavioral therapy, school-based management, and psychoeducation. Pharmacological treatment, especially stimulant medication such as methylphenidate, has shown benefits for neurocognitive impairments in children with ADHD and may improve executive function performance in some children (İzmir et al., 2022; Wang et al., 2025). Reviews of ADHD pharmacotherapy and comorbidity also indicate that medication can play an important role in reducing core symptoms and improving behavioral functioning (Doulou & Drigas, 2022). However, pharmacotherapy alone may not be sufficient for all children, and clinical reviews increasingly recommend combining pharmacological and non-pharmacological interventions to address executive dysfunction, emotional dysregulation, and functional impairment (Gálvez-Contreras et al., 2022; Wilens et al., 2024). This is especially important for children with externalizing behavioral disorders whose difficulties are not limited to attentional symptoms but include emotional and behavioral control deficits.

Cognitive rehabilitation and cognitive training have emerged as promising non-pharmacological approaches for improving executive functions in children and adolescents

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with neurodevelopmental and mental health conditions. Cognitive rehabilitation refers to structured activities designed to strengthen cognitive processes through repeated practice, adaptive difficulty, feedback, and task engagement. In pediatric populations, these programs commonly target attention, working memory, inhibition, processing speed, cognitive flexibility, planning, and self-regulation. A systematic review and meta-analysis of cognitive remediation for adolescents with mental health disorders showed that cognitive interventions can improve cognitive and functional outcomes, supporting their relevance for youth mental health care (East-Richard et al., 2025). Similarly, evidence from neurodevelopmental disorders suggests that executive function training may produce benefits not only on trained tasks but also, in some cases, on broader functional outcomes, although the strength of far-transfer effects varies across studies (Bombonato et al., 2023).

Computerized cognitive rehabilitation has particular advantages in child populations. Digital platforms can provide interactive, gamified, adaptive, and motivating training environments that are more engaging than traditional paper-and-pencil exercises. Computer-based programs also allow individualized progression, immediate feedback, structured repetition, and easier implementation across home or clinic settings. Reviews of computer-based cognitive training in children with ADHD have found that such programs may improve attention, working memory, inhibition, and other executive components, although effectiveness depends on the type, intensity, duration, and ecological relevance of training (Robledo-Castro et al., 2023; Veloso et al., 2020). A systematic review focusing on computer-based cognitive training programs also reported that rehabilitation interventions may improve cognitive skills among children with ADHD, supporting the theoretical and clinical relevance of computerized formats (Mahardika et al., 2021). Furthermore, artificial cognitive systems have been increasingly applied in executive function stimulation and rehabilitation, suggesting an expanding role for technology-assisted cognitive intervention in child development and clinical practice (Robledo-Castro et al., 2022).

Recent technology-based interventions for children with ADHD and related difficulties have included mobile applications, serious games, virtual reality environments, rhythm-based training, mindfulness-cognitive training combinations, and computerized multi-component cognitive programs. Meta-analytic evidence suggests that technology-based interventions may be effective for school-age children with ADHD, particularly when they are structured, developmentally appropriate, and designed to target core neurocognitive mechanisms (Wong et al., 2023a, 2023b). Mobile device-based cognitive games have also been developed and tested for feasibility in ADHD populations, showing that gamified digital interventions may be acceptable and practical for children (Luo et al., 2024). A pilot study of a working-memory multitasking mobile intervention further indicated that children with ADHD can engage with mobile cognitive training programs, although compliance and implementation factors remain important considerations (Jung et al., 2025). These studies demonstrate that digital cognitive rehabilitation can be delivered through accessible technologies and may be especially useful when children require repeated cognitive practice in motivating formats.

Virtual reality and serious gaming represent newer extensions of computerized cognitive rehabilitation. Systematic review evidence on immersive virtual reality in cognitive rehabilitation for ADHD suggests that such technologies may enhance engagement, realism, and user experience, although further controlled research is needed to establish long-term effects (Single, 2025). Randomized clinical trial evidence also indicates that serious video games may contribute to emotional regulation in children with ADHD, directly connecting digital intervention with one of the central executive-behavioral domains relevant to externalizing disorders (Martín-Moratinos et al., 2025). Other digital and non-digital intervention reviews emphasize that ADHD management increasingly requires multimodal approaches across the lifespan, integrating physical activity, digital tools, behavioral strategies, and individualized clinical assessment (Martín-Rodríguez et al., 2025). These developments show that computerized rehabilitation is not merely a technological substitute for traditional therapy, but a potentially distinct method for delivering intensive, adaptive, and child-friendly executive function training.

Several studies have specifically examined cognitive training and executive function improvement in pediatric clinical conditions. Computer-based multiple-component cognitive training has shown preliminary promise in children with ADHD, suggesting that training programs targeting several cognitive domains simultaneously may be beneficial (Wu et al., 2023). Neurofeedback and working memory training have also been evaluated in children and adolescents with ADHD, with findings showing immediate and sustained effects on some cognitive functions, although

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outcomes vary by intervention type and participant characteristics (Hasslinger et al., 2022). In children with autism spectrum disorder, systematic review evidence indicates that cognitive training may improve aspects of executive function, supporting the broader applicability of executive rehabilitation across neurodevelopmental conditions (Pasqualotto et al., 2021). Moreover, intervention research in very preterm children with working memory deficits shows that cognitive training protocols are being used to address visuospatial and working memory weaknesses in vulnerable developmental groups (Gire et al., 2021). These findings collectively support the feasibility of cognitive rehabilitation for children with diverse executive function vulnerabilities.

In addition to ADHD-focused research, computer-based training has also been applied to other pediatric populations in which executive functioning is compromised. For example, computerized cognitive training has been studied in children with epilepsy, with findings supporting its feasibility and potential efficacy for improving executive functions (Tapia et al., 2024). Protocols comparing computer-based cognitive training with paper-and-pencil training in typically developing children also show growing methodological interest in determining whether digital formats provide additional developmental advantages over conventional approaches (Robledo-Castro et al., 2024). Rhythm-based assessment and training has also been proposed as a feasible method for children with ADHD, reflecting the increasing diversity of cognitive and neuropsychological intervention modalities (Shin et al., 2023). In parallel, combined approaches such as mindfulness plus cognitive training are being investigated to determine whether attention, emotion regulation, and executive control can be strengthened simultaneously (Badia-Aguarón et al., 2024). These studies suggest that executive function intervention is moving toward integrated, technology-supported, and developmentally tailored programs.

Despite the promise of computerized cognitive rehabilitation, several conceptual and empirical gaps remain. First, much of the existing research has focused primarily on ADHD, whereas externalizing behavioral disorders include a wider range of disruptive and dysregulated behaviors. Second, many studies evaluate attention or working memory as primary outcomes, while fewer studies examine multiple executive components such as emotional control, attention shifting, behavioral control, and inhibition together. Third, although digital cognitive training may improve performance on trained tasks, the extent to which it improves parent-rated behavioral manifestations of executive function remains an important question. Some reviews have warned that far-transfer effects are not always consistent, and therefore intervention studies should examine meaningful behavioral indicators rather than relying only on cognitive task performance (Bombonato et al., 2023; Robledo-Castro et al., 2023). Fourth, children with externalizing symptoms often have emotional dysregulation and aggression, and protocols targeting such symptoms must consider both cognitive control and behavioral expression (Vacher et al., 2022).

The present study is grounded in the assumption that executive dysfunction is a modifiable mechanism underlying externalizing behavioral problems in children. Because emotional control, attention shifting, behavioral control, and inhibition are central to the regulation of overt behavior, a structured computerized cognitive rehabilitation program may help children strengthen the cognitive capacities needed for adaptive functioning. Previous evidence suggests that cognitive interventions in preschool and school-aged children can improve executive functions and may reduce ADHD and externalizing symptoms, supporting the rationale for early intervention (Pauli-Pott et al., 2020). In addition, applied research has shown that cognitive rehabilitation training can improve executive function and reduce antisocial behaviors and legal problems in children with ADHD, indicating that cognitive rehabilitation may influence behavioral outcomes directly relevant to externalizing disorders (Jalilvand et al., 2022). Therefore, testing a computerized cognitive rehabilitation program in children with externalizing behavioral disorders can contribute to both clinical practice and the broader literature on technology-assisted executive function intervention.

The aim of the present study was to determine the effectiveness of a computerized cognitive rehabilitation program on executive functions, including emotional control, attention shifting, behavioral control, and inhibition, in children with externalizing behavioral disorders.

2. Methods and Materials

2.1. Study Design and Participants

This study employed a quasi-experimental design with a pretest–posttest format and a control group. The statistical population consisted of all children and adolescents with externalizing behavioral disorders who received services at psychological treatment centers in Rasht during 2021. The

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sampling method was purposive, followed by random assignment into experimental and control groups. Participants were recruited from two psychology clinics in Rasht among children who met the diagnostic criteria for externalizing behavioral disorders based on clinical interviews and scores obtained on the Eyberg Child Behavior Inventory. The participants were matched on the basis of age and gender and homogenized in terms of intelligence scores using Raven's Progressive Matrices. A total of 32 children participated in the study, with 16 individuals assigned to the experimental group and 16 individuals assigned to the control group. The sample size was determined according to the methodological recommendations of Cohen and Manion (2014), who suggested that a minimum of 15 participants per group is adequate for experimental studies. The inclusion criteria included obtaining clinically significant scores on the Eyberg Child Behavior Inventory, informed consent from both participants and their parents, and the absence of other severe psychiatric or neurological disorders that could interfere with the research outcomes. The exclusion criteria included dissatisfaction with the intervention process, absence from more than two intervention sessions, and the emergence of comorbid psychiatric symptoms during the study process.

2.2. Measures

Data collection was conducted using standardized psychological instruments with established psychometric properties. The first instrument was the Eyberg Child Behavior Inventory (ECBI), originally developed by Sheila Eyberg and Ross in 1978 to assess disruptive and problematic behaviors in children and adolescents aged 2 to 16 years. The ECBI consists of 36 items and includes two scales measuring the intensity and frequency of disruptive behaviors as well as the extent to which parents perceive these behaviors as problematic. Parents respond to the intensity scale using a seven-point Likert scale, while the problem scale is scored dichotomously as "Yes" or "No." Scores are obtained by summing the responses for each scale separately. Previous studies conducted on the Iranian population have demonstrated satisfactory psychometric properties for the inventory, with Cronbach's alpha coefficients reported as 0.93 for the intensity scale and 0.92 for the problem scale. Test–retest reliability coefficients ranging from 0.86 to 0.88 and inter-rater reliability values between 0.79 and 0.86 have also been reported, indicating acceptable reliability and stability of the instrument in clinical assessments.

The second instrument was the Behavior Rating Inventory of Executive Function (BRIEF), Parent Form, developed by Gioia, Isquith, Guy, and Kenworthy in 2000. The BRIEF is a standardized behavioral assessment tool designed to evaluate executive functioning in children and adolescents aged 5 to 18 years. The parent form contains 86 items rated on a three-point Likert scale ranging from "Never" to "Always," and it assesses executive functioning behaviors in both home and school environments. The questionnaire evaluates two major domains of executive functioning, including behavioral regulation skills and metacognitive skills. The behavioral regulation domain includes inhibition, shifting, and emotional control, while the metacognitive domain includes initiation, working memory, planning and organization, organization of materials, and monitoring. In the present study, the total executive functioning score was used for analysis. Higher scores reflected better executive functioning abilities. The BRIEF has demonstrated strong psychometric characteristics in both clinical and normative populations. Previous studies have reported Cronbach's alpha coefficients ranging from 0.80 to 0.98 for the parent form. The Persian version of the questionnaire has also shown acceptable validity and reliability in Iranian clinical samples, with internal consistency coefficients reported between 0.87 and 0.94 and test–retest reliability coefficients ranging from 0.71 to 0.91 across subscales.

2.3. Intervention

After the initial assessment phase, participants in the experimental group entered the intervention phase. A computerized cognitive rehabilitation program consisting of the cognitive training games Lumosity and Peak was installed on either the child's mobile device or the parents' smartphone. The intervention was conducted over a three-week period and included 20 sessions, each lasting approximately 60 minutes. Every session consisted of 25 minutes of cognitive exercises using Lumosity, followed by a 10-minute rest interval, and then 25 minutes of training using Peak. The intervention protocol was individualized according to each participant's baseline cognitive performance within the software environment, allowing the difficulty level and type of exercises to be adapted to the child's executive functioning profile. The training activities primarily targeted attention, working memory, cognitive

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flexibility, response inhibition, processing speed, and problem-solving skills. Parents were instructed regarding the implementation schedule and monitoring procedures to ensure adherence to the intervention plan. During the intervention period, participants in both the experimental and control groups did not receive any additional psychological interventions that could interfere with the effects of the cognitive rehabilitation program. At the conclusion of the intervention phase, the BRIEF parent form was re-administered to both groups as a posttest measure.

2.4. Data Analysis

The collected data were analyzed using both descriptive and inferential statistical methods in IBM SPSS Statistics version 26. Descriptive statistics included the calculation of means, standard deviations, and variances for the study variables. Inferential analyses were performed using one-way analysis of covariance (ANCOVA) to compare posttest executive functioning scores between the experimental and control groups while controlling for pretest differences. Prior to conducting the main analysis, statistical assumptions associated with ANCOVA were examined. The Shapiro–Wilk test was used to assess the normality of data distribution, and homogeneity assumptions were evaluated before hypothesis testing. The differences between pretest and posttest scores in the two groups were then analyzed to determine the effectiveness of the computerized cognitive rehabilitation program on executive functioning in children with externalizing behavioral disorders.

3. Findings and Results

The descriptive findings were examined to compare the pretest and posttest scores of executive function components in the experimental and control groups. Table 1 presents the mean and standard deviation of emotional control, attention shifting, behavioral control, and inhibition across the two measurement stages.

Table 1

Descriptive Statistics of Executive Function Components by Group and Measurement Stage

Variable	Group	Stage	N	Mean	SD
Emotional control	Experimental	Pretest	15	1.560	0.112
Emotional control	Experimental	Posttest	15	1.127	0.171
Attention shifting	Experimental	Pretest	15	1.309	0.318
Attention shifting	Experimental	Posttest	15	0.764	0.309
Behavioral control	Experimental	Pretest	15	1.578	0.202
Behavioral control	Experimental	Posttest	15	1.044	0.205
Inhibition	Experimental	Pretest	15	1.581	0.173
Inhibition	Experimental	Posttest	15	1.014	0.215
Emotional control	Control	Pretest	15	1.540	0.083
Emotional control	Control	Posttest	15	1.500	0.131
Attention shifting	Control	Pretest	15	1.376	0.283
Attention shifting	Control	Posttest	15	1.418	0.299
Behavioral control	Control	Pretest	15	1.593	0.296
Behavioral control	Control	Posttest	15	1.474	0.264
Inhibition	Control	Pretest	15	1.595	0.254
Inhibition	Control	Posttest	15	1.552	0.262

As shown in Table 1, the experimental group demonstrated a clear reduction in posttest scores across all executive function components compared with the pretest stage. The mean score of emotional control decreased from 1.560 to 1.127, attention shifting from 1.309 to 0.764, behavioral control from 1.578 to 1.044, and inhibition from 1.581 to 1.014. In contrast, the control group showed only minor changes between pretest and posttest scores. These descriptive results indicate that the computerized cognitive rehabilitation program was associated with improvement in executive function components among children with externalizing behavioral disorders.

Before conducting covariance analysis, the required statistical assumptions were examined. The results of the Kolmogorov–Smirnov and Shapiro–Wilk tests mostly supported the normality of the distributions, particularly in the experimental group, where all significance values were greater than 0.05. Levene's test also indicated that the assumption of homogeneity of error variances was met for all four dependent variables in both groups, because the

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significance values for emotional control, attention shifting, behavioral control, and inhibition were greater than 0.05. Therefore, the assumptions required for conducting covariance analysis were considered acceptable.

Table 2

ANCOVA Results for Executive Function Components

Dependent variable	Source	SS	df	MS	F	p	Partial η^2
Emotional control	Group	1.408	1	1.408	67.369	0.000	0.706
Attention shifting	Group	2.231	1	2.231	22.689	0.000	0.448
Behavioral control	Group	2.133	1	2.133	51.472	0.000	0.648
Inhibition	Group	2.408	1	2.408	63.502	0.000	0.694
Emotional control	Error	0.021	28	0.021	—	—	—
Attention shifting	Error	0.098	28	0.098	—	—	—
Behavioral control	Error	0.041	28	0.041	—	—	—
Inhibition	Error	0.038	28	0.038	—	—	—

The ANCOVA results presented in Table 2 show that the effect of group was statistically significant for all executive function components. Significant differences were found between the experimental and control groups in emotional control, $F = 67.369$, $p < 0.001$, partial $\eta^2 = 0.706$; attention shifting, $F = 22.689$, $p < 0.001$, partial $\eta^2 = 0.448$; behavioral control, $F = 51.472$, $p < 0.001$, partial $\eta^2 = 0.648$; and inhibition, $F = 63.502$, $p < 0.001$, partial $\eta^2 = 0.694$. These findings indicate that the computerized cognitive rehabilitation program had a significant effect on improving executive function components in children with externalizing behavioral disorders.

4. Discussion and Conclusion

The present study aimed to investigate the effectiveness of a computerized cognitive rehabilitation program on executive functions in children with externalizing behavioral disorders. The findings demonstrated that the intervention significantly improved emotional control, attention shifting, behavioral control, and inhibition in the experimental group compared with the control group. The results of multivariate covariance analysis showed statistically significant differences between pretest and posttest scores across all executive function dimensions in the experimental group, whereas no significant changes were observed in the control group. These findings indicate that computerized cognitive rehabilitation can effectively enhance executive functioning among children with externalizing behavioral symptoms and support the growing evidence regarding the utility of technology-assisted cognitive interventions in pediatric neuropsychological rehabilitation.

One of the most important findings of the study was the significant improvement in emotional control among children who participated in the computerized cognitive rehabilitation program. Emotional regulation difficulties are among the most common features observed in children with externalizing behavioral disorders and ADHD-related symptoms. Children with deficits in executive functioning often experience difficulty modulating emotional responses, controlling frustration, and inhibiting impulsive emotional reactions. The current findings are consistent with research demonstrating that executive dysfunction and emotional dysregulation are closely interconnected in pediatric behavioral disorders (Kamalahmadi et al., 2024; Tang et al., 2023). Furthermore, serious game and virtual reality interventions have recently shown beneficial effects on emotional regulation in children with ADHD, suggesting that digital cognitive interventions may indirectly improve emotional self-regulation through repeated practice of inhibitory and attentional control processes (Martín-Moratinos et al., 2025; Single, 2025). It is likely that the repetitive and adaptive structure of the computerized rehabilitation tasks strengthened neural mechanisms associated with self-monitoring and emotional inhibition, thereby contributing to improved emotional control in the experimental group.

The significant reduction in deficits related to attention shifting also supports the effectiveness of computerized cognitive rehabilitation in strengthening cognitive flexibility. Attention shifting refers to the ability to move efficiently between cognitive tasks, environmental stimuli, and behavioral demands. Children with externalizing behavioral disorders frequently display rigidity in attention allocation and difficulty adapting to changing task requirements. The intervention used in the present study involved multiple game-based exercises that continuously required children to redirect attention, update responses, and

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adapt to changing task demands. Such repeated stimulation likely improved attentional flexibility and adaptive cognitive control. Previous systematic reviews have similarly shown that computerized cognitive training programs can improve attentional performance and executive flexibility in children with ADHD and related neurodevelopmental disorders (Robledo-Castro et al., 2023; Veloso et al., 2020). Moreover, mobile-based multitasking interventions and rhythm-based cognitive training protocols have also demonstrated positive feasibility and attentional benefits in children with ADHD (Jung et al., 2025; Shin et al., 2023). Therefore, the present findings further support the argument that technology-assisted cognitive exercises can strengthen attentional regulation mechanisms in children with executive dysfunction.

Another important finding of the study was the improvement in behavioral control among participants in the experimental group. Behavioral control involves the ability to regulate actions in accordance with situational demands, inhibit impulsive reactions, and maintain goal-directed responses. Children with externalizing disorders often display impulsive behaviors because of deficiencies in inhibitory control and self-regulation mechanisms. The observed improvement in behavioral control is consistent with evidence suggesting that executive training interventions may reduce disruptive and antisocial behaviors in children with ADHD and behavioral disorders (Jalilvand et al., 2022). In addition, reviews examining technology-based interventions have reported that computerized training may improve behavioral functioning through enhancement of cognitive monitoring and response regulation (Wong et al., 2023a, 2023b). From a neuropsychological perspective, computerized cognitive rehabilitation repeatedly activates frontostriatal networks associated with inhibitory control, sustained attention, and behavioral monitoring. Through adaptive and repeated practice, these interventions may facilitate neurocognitive plasticity and improve children's ability to regulate overt behavior in everyday settings.

The improvement in inhibition observed in the present study is particularly important because inhibitory dysfunction is widely considered one of the central mechanisms underlying externalizing behavioral disorders and ADHD symptomatology. Inhibition deficits contribute to impulsivity, premature responding, aggression, and poor self-regulation. Research comparing children with ADHD and anxiety disorders has shown that children with ADHD require significantly more time to inhibit automatic responses, indicating a specific weakness in inhibitory control systems (Panvino et al., 2025). The computerized rehabilitation program used in this study required children to suppress incorrect responses, maintain attentional focus, and respond selectively to changing cognitive stimuli. Such repeated inhibitory practice may strengthen neural pathways associated with executive control. These findings align with evidence from cognitive remediation and working memory training studies showing that structured cognitive exercises can enhance inhibitory functioning and executive regulation in pediatric populations (East-Richard et al., 2025; Hasslinger et al., 2022). The large effect sizes observed for inhibition in the present study further suggest that computerized interventions may be especially beneficial for executive domains closely related to impulse control and behavioral regulation.

The findings of the current study are also consistent with broader theoretical models emphasizing the plasticity of executive functioning during childhood. Executive functions develop progressively through repeated interaction between neurobiological maturation and environmental stimulation. Cognitive rehabilitation programs may enhance this developmental process by providing structured, intensive, and adaptive cognitive challenges. The game-based format of the intervention likely increased motivation and engagement, which are particularly important in children with attention and behavioral difficulties. Studies examining mobile game prototypes and artificial cognitive systems for children with ADHD have highlighted the value of gamification, immediate feedback, and adaptive difficulty levels in maintaining children's participation and cognitive engagement (Luo et al., 2024; Robledo-Castro et al., 2022). Therefore, the effectiveness observed in the present study may partially reflect the motivational advantages of computerized interventions compared with traditional therapeutic methods.

Another explanation for the effectiveness of the intervention may involve the simultaneous activation of multiple executive domains. The cognitive rehabilitation package used in this study included activities targeting attention, working memory, inhibition, processing speed, cognitive flexibility, and problem-solving. Research suggests that interventions addressing multiple executive components simultaneously may produce broader cognitive and behavioral improvements than single-domain training approaches (Bombonato et al., 2023; Wu et al., 2023). In addition, evidence from interventions involving mindfulness combined with cognitive training suggests that integrated approaches may produce synergistic effects on executive

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regulation and attentional control (Badia-Aguarón et al., 2024). The present findings therefore support multidimensional rehabilitation approaches that engage several cognitive systems concurrently rather than focusing narrowly on isolated cognitive tasks.

The lack of significant changes in the control group further strengthens the interpretation that the observed improvements were related to the computerized cognitive rehabilitation program rather than natural developmental changes or repeated testing effects. Children in the control group did not receive structured cognitive intervention and showed minimal variation between pretest and posttest scores across executive function components. This pattern supports prior meta-analytic findings indicating that targeted cognitive interventions produce greater executive function improvements than passive or non-specific conditions (Pauli-Pott et al., 2020). Moreover, systematic reviews of cognitive training programs in ADHD populations consistently report stronger gains in intervention groups relative to untreated controls (Mahardika et al., 2021; Robledo-Castro et al., 2023). Therefore, the present study contributes additional evidence supporting the causal role of structured computerized cognitive rehabilitation in enhancing executive functioning among children with behavioral dysregulation.

The present findings also have important implications for current ADHD and externalizing disorder treatment models. Clinical reviews increasingly emphasize the need for multimodal interventions integrating pharmacological and non-pharmacological strategies (Malhotra et al., 2025; Wilens et al., 2024). Although stimulant medications may improve some executive deficits, many children continue to experience emotional, behavioral, and functional difficulties despite pharmacotherapy (İzmir et al., 2022; Wang et al., 2025). Computerized cognitive rehabilitation may therefore serve as an important complementary intervention that targets executive functioning directly. Furthermore, because digital cognitive interventions can often be implemented in home settings with parental supervision, they may increase accessibility and continuity of care for children who cannot consistently attend in-person therapy sessions.

The findings may also be interpreted within developmental and ecological frameworks. Executive functioning is influenced not only by neurocognitive factors but also by family dynamics, resilience, environmental stimulation, and psychosocial stressors. Previous research has shown that family functioning and caregiver strain are associated with executive and behavioral outcomes in children with ADHD and related disorders (Tang et al., 2023; Walenista et al., 2023). Cognitive rehabilitation programs implemented within supportive family environments may therefore yield stronger and more sustainable outcomes. Additionally, research on psychiatric comorbidity and resilience indicates that executive functioning can influence adaptive coping and psychological adjustment in children and adolescents (Arruda et al., 2025). Consequently, interventions that strengthen executive control may have secondary benefits extending beyond cognition to broader emotional and behavioral functioning.

Although the findings of the present study support the effectiveness of computerized cognitive rehabilitation, the results should also be interpreted cautiously. Some previous reviews have suggested that transfer effects from cognitive training to everyday functioning may vary depending on intervention intensity, participant characteristics, and outcome measurement methods (Bombonato et al., 2023; Pasqualotto et al., 2021). In the present study, improvements were observed using parent-reported executive function measures, which suggests ecologically meaningful behavioral changes. Nevertheless, future research incorporating neuropsychological tasks, teacher reports, and long-term follow-up assessments may provide a more comprehensive understanding of the durability and generalizability of these effects.

One limitation of the present study was the relatively small sample size and the restriction of participants to children receiving services in psychological clinics in Rasht, which may limit the generalizability of the findings to broader populations of children with externalizing behavioral disorders. In addition, the study relied primarily on parent-report measures of executive functioning and did not include neurophysiological or observational assessments. The absence of long-term follow-up evaluation also prevented examination of the stability of treatment effects over time. Furthermore, possible moderating variables such as socioeconomic status, parental involvement, medication use, and severity of comorbid symptoms were not controlled systematically.

Future research should examine the long-term effects of computerized cognitive rehabilitation programs using larger and more diverse clinical samples. Studies comparing different forms of digital intervention, including virtual reality, neurofeedback, mobile applications, and serious games, would provide valuable information regarding the most effective formats for executive function enhancement. Future investigations should also incorporate multimethod

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assessment approaches involving neuropsychological tests, teacher reports, neuroimaging methods, and behavioral observations. Examining the interaction between computerized cognitive rehabilitation and pharmacological treatment, family-based interventions, or school-based support programs may also contribute to a more comprehensive understanding of integrated treatment models for children with externalizing behavioral disorders.

The findings of the present study suggest important practical implications for clinicians, psychologists, schools, and rehabilitation centers working with children who display externalizing behavioral symptoms. Computerized cognitive rehabilitation programs may serve as accessible and engaging interventions for improving executive functioning, particularly in emotional regulation, inhibition, and behavioral control. Mental health professionals may incorporate digital cognitive training alongside traditional behavioral and psychological interventions to strengthen treatment effectiveness. Schools and educational centers may also benefit from integrating structured cognitive training activities into support services for children with attentional and behavioral difficulties. In addition, involving parents in the implementation and monitoring of cognitive rehabilitation activities may improve treatment adherence and facilitate generalization of cognitive gains to everyday environments.

Authors' Contributions

All authors significantly contributed to this study.

Declaration

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

Transparency Statement

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

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Declaration of Interest

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