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Article

Jump Rope Exercise Improves Executive Function in Children with Attention-Deficit/Hyperactivity Disorder

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Abstract: **Objective:** This study investigated the effects of an easily implemented 8-week program centered around jump rope exercise (JRE) on executive function among children with ADHD. **Methods:** Using the Stroop Color Word Test to assess inhibitory control, the n-back task (1- and 2-back) to assess working memory, and task switching to assess cognitive flexibility. **Results:** After the intervention, there were within-group effects only for the experimental group, with higher accuracy on the 1-back working memory task ($t = -2.79$, $p = 0.011 < 0.05$, Cohen's $d = 0.60$) and on task switching after compared with before the JRE intervention ($t = -4.00$, $p = 0.01 < 0.05$, Cohen's $d = 0.85$), but with no change in reaction time. There was no significant within-group difference on the Stroop test ($P > 0.05$). Additionally, there were no between-group effects as assessed by one-way analyses of variance. **Conclusion:** 8-week program focused on JRE improved two aspects of executive function, working memory and cognitive flexibility, with no significant effect on a third aspect, inhibitory control, among children with ADHD aged 7 to 12 years.

Keywords: attention-deficit/hyperactivity disorder; Jump rope exercise; children; exercise intervention; executive function

Introduction

Attention-deficit/hyperactivity disorder (ADHD) has a global prevalence of about 6% and is considered to be the most common neurodevelopmental disorder among children [1,2]. The main symptoms of ADHD manifest as distractibility, hyperactivity/impulsivity, and executive dysfunction, which are most often seen in school-age children and often persist into adulthood [3]. Therefore, ADHD symptoms need to be viewed from a life span perspective and given adequate attention [2,3]. Children with ADHD have difficulties with hyperactivity, inattention, and impulsivity, all of which can lead to learning and behavioral problems as well as impaired emotion regulation [4].

A growing body of data suggests that individuals with ADHD often display low executive function [5,6]. Executive function, which is also referred to as executive control or cognitive control [7], involves structures that work in conjunction with multiple higher-level cognitive skills in the brain. When completing a complex cognitive task, individuals ensure that the cognitive system achieves a specific goal in a flexible and optimized way by coordinating various cognitive processes [8]. Executive function consists of three core processes: inhibitory control (IC), working memory (WM), and cognitive flexibility (CF). IC refers to the suppression of dominant responses and the control of attention [9]. WM refers to the limited-capacity memory system that temporarily stores and processes information under the control of a central system [10]. CF is the ability of an individual to adapt in response to changes in the environment and to generate new ideas that drive innovation, promote growth, and discovery, and is linked to IC and WM. Studies have found that impaired executive function can not only cause serious difficulties in a child's daily life (which positively correlates with the severity of ADHD), but it can also affect the development of a wide range of life skills to the extent that executive function deficits may have a greater impact on academics than any other core condition [11,12].

Currently, approaches for treating children with ADHD focus on pharmacological (e.g., stimulants such as methylphenidate and amphetamine), behavioral, and psychological interventions

[13]. Medication, including stimulant and non-stimulant drugs, is highly effective in reducing inattention and hyperactive/impulsive traits and related disruptive behaviors; psychosocial treatments, primarily including parent management training and school emergency management, have also been reported to improve behavior [14,15]. Although these standard ADHD treatments are widely accepted as the most compelling evidence-based interventions, not all children respond well to these medications or behavioral interventions, and the effects are rarely sustained after active intervention [16,17]. Studies have found that long-term pharmacological interventions can lead to increased drug tolerance [18], and many parents are concerned that overuse of medication may lead to headache, nausea, anorexia, and slowed growth rates. The use of medications as a treatment can also result in sleep disturbances, decreased appetite, and mood disorders, and reduced growth rates [19,20]. In addition, parents believe that behavioral or psychosocial interventions are complex and difficult to sustain and that ADHD medical costs are high [21]. As a result, the use of medication is not always accepted by parents of children with ADHD, highlighting the urgent need to find an economical, low-risk treatment for ADHD symptoms.

In recent years, exercise, as an alternative non-pharmacological treatment, has been recognized by researchers and parents as an effective intervention for the treatment of ADHD in children. Studies have shown that exercise alters brain blood flow and serotonin and brain-derived neurotrophic factor (BDNF) release and promotes increases in catecholamines and proteases [22], thereby reducing nuclear symptoms in individuals with ADHD, improving hyperactive/impulsive behavior, memory, motor skills, emotional control, and social skills [23]. In addition, motor intervention promotes neurogenesis, neuroadaptation, and neuroprotection, mainly through the regulation of brain neural circuits, to mediate executive function [24], and has a lasting impact on the developmental trajectory of basic motor skills in children with ADHD, including improved fine motor skills, such as writing, dressing, eating, and tying shoelaces. Exercise not only produces newborn hippocampal cells that help to enhance learning and memory, but also promotes the synthesis and delivery of BDNF in the brains of children with ADHD, improving cognitive function and learning and memory [25]. Empirical studies conducted by [26], [27], and [28] have demonstrated that aerobic and mixed exercises significantly improve inhibitory control and attention, shorten reaction time, and are important contributors to the improvement of executive function in children with ADHD. A study by [29] found that exercise positively promotes executive function and attention in children with ADHD, similar to the therapeutic effect of excitatory medication; it is believed that regular moderate exercise can be used as an effective treatment for ADHD [30].

Acute, long-term moderate-intensity and high-intensity exercise interventions have been shown to significantly improve the executive function of children with ADHD. [31] assigned 18 children with ADHD (11-16 years old) and healthy children to either an experimental group (EG) or a control group (CG) and showed a general benefit in executive function after 10-15 minutes of moderate aerobic exercise and similar benefits in cognitive flexibility in children with ADHD and healthy controls, due in part to parasympathetic inhibition-induced arousal enhancement. [32] conducted an 8-week preschool physical activity program with 17 third grade children at risk for ADHD, in which participants completed 24 minutes of moderate- to high-intensity physical activity per day. That study found that 17 participants showed significant increases in motor proficiency, including gross and fine motor tasks. The authors concluded that sustained participation in structured physical activity may be beneficial for improving executive function in children with ADHD.

Although the aforementioned studies have shown that exercise interventions can effectively improve executive function among children with ADHD, most of those studies used comprehensive physical activity intervention programs without exploring the effects of single-sport program interventions. Research assessing individuals with ADHD symptoms has primarily examined the impact of general physical activity and exercise on behavioral aspects and cognitive performance [33]. Fewer studies have investigated the association between the physical and mental health of children with ADHD and the characteristics, degree of difficulty, acceptability, and ease of replication of specific exercise programs. In particular, exercise interventions have not focused on one specific sport around which to construct an adaptive exercise program for children with ADHD. Thus, an

overarching goal of this study was to design a simple, easy-to-implement, and affordable program at the elementary school level to meet the physical and mental health needs of children with ADHD. This study also specifically aimed to use this suitable, acceptable, and adaptable physical activity program focused on a single-exercise intervention to investigate its effects on executive function among children with ADHD.

Children with ADHD require not only the movement of large muscles or muscle groups throughout the body during exercise, but also the concerted participation of fine and gross motor movements in areas such as the wrist and fingers [34]. Such concerted participation of movement is capable of generating sufficient stimulation in the brain to facilitate the improvement of executive function in children with ADHD. Jump rope exercise (JRE), a safe and efficient exercise suitable for healthy and sub-healthy populations regardless of gender and age [35,36], incorporates both fine and gross motor movements. JRE also improves bone mineral content, response strength, and stiffness comparable to traditional weight training [37]. JRE is relatively simple and easy to incorporate into school physical activity programs. Thus, we selected JRE as the single-exercise intervention around which to design a physical activity program that may enhance the cognitive developmental of children by providing training in IC, WM, and CF.

Thus, the goals of the present study were (1) to develop an adaptive, simple, easy-to-implement, and affordable exercise program focused on JRE, and (2) to assess whether this intervention could effectively improve executive function as assessed by changes from baseline in the three core processes of executive function—namely, IC, WM, and CF—in children with ADHD.

Materials & Methods

Study design

The EG received an 8-week intervention focused on JRE, with two sessions per week for 60 minutes each session. Before and after the 8-week intervention, participants were given executive function tests with the consent of the school director and the child's parents or guardians. Participants were assessed the day before the test and were asked not to participate in any other strenuous exercise on the day of the test. executive function pretests and posttests were administered to both the EG and CG (CG1 and CG2) (**Table 1**). CG participated in an 8-week daily school sports activities (60 minutes/twice a week). Children with ADHD in the EG received an 8-week JRE program as an alternative to their daily school sports activities, twice a week (Tuesday and Thursday afternoons). The intensity of the intervention in the EG was medium to high and was monitored using the BHT TEAM Polar heart rate sensor (H10; from Beijing Bohaotong Technology Development Co., Ltd.) throughout the process. This study was approved by the Ethics Committee of Shanghai Sport University.

Participants

A total of 945 children in grades 1 to 5 (ages 7 to 12 years) from two general public elementary schools in Shanghai were recruited. Children were initially screened using the Conners Comprehensive Behavior Rating Scale. Two professional psychiatrists then provided diagnoses based on the *Diagnostic and Statistical Manual of Mental Disorders (DSM-5)* combined with the results of the Wechsler Intelligence Scale. Of 51 children diagnosed as having ADHD, 13 were excluded from the study due to severe psychiatric disorders (e.g., severe intellectual disability or organic neurological disorders) or other cardiovascular or endocrine disorders. Thus, 38 children with ADHD (27 boys and 11 girls) were included in this study. All students in one school were assigned to the EG (22 children), and all students in the other school were assigned to the CG1 (16 children), while 17 typically developed children in the same age range were also recruited to form CG2 (**Table 1**). Written informed consent was provided by the parents or guardians of all participants. All participants were tested 1 week before the start of the intervention (baseline pretest) and 1 week after (posttest) the end of the intervention, and were committed to not participating in regular guided physical activity outside of school during the 8-week intervention period.

Assessment tools and tests

E-primer 3.0 software (Psychology Software Tools) was used to test the three aspects of executive function assessed in this study as described below: IC was assessed using the Stroop Color and Word Test; WM was assessed using the n-back test; and CF was assessed using a cued-task switching paradigm. Taking into account the cognitive and behavioral characteristics of inattention and hyperactivity/impulsivity among children with ADHD, the research team optimized the testing procedures and task paradigms for this population. These optimizations included adding repeated practice trials before the formal test to ensure that each child correctly understood the test rules, and simplifying the test content to reduce the memory load. Before the formal testing of each of the three tasks, the tester explained the instructions. The child pressed the "j" key on a computer keyboard to enter the practice trial. At the end of the practice, the child could press the "j" key to practice again or press any other key to enter the formal test trial. During the tests, children used the left and right mouse buttons to make judgments about the presented stimuli.

IC Test: IC in children was assessed with the Stroop Color and Word Test, with stimulus types being the meaning of the word and the color of the word. At the beginning of the test, a black fixation cross "+" appeared on the screen, and then one of two Chinese characters—the character meaning red or the character meaning green—appeared randomly. The color of the Chinese characters could be red or green. The task was to ignore the meaning of the Chinese characters and judge only the color. When the meaning of the Chinese character and the color of the character were the same, the condition was considered consistent, otherwise inconsistent. Key press responses were performed after the appearance of each Chinese character, with a stimulus interval of 1000-1500 ms. The task consisted of 32 trials, half of which were of the consistent condition and the remainder were of the inconsistent condition, presented in a random order. The test metrics included reaction time (RT)—which consisted of RT for the inconsistent condition, RT for the consistent condition, and the difference between the reaction times of the two conditions—and accuracy, which consisted of the percentage of correct trials in the inconsistent condition, and the percentage of correct trials in the consistent condition.

WM Test: Children's WM was tested using an n-back task, with memory load conditions of n=1 and n=2. In the 1-back task, children were asked to determine whether the currently appearing letter was the same as the previously appearing letter; in the 2-back task, whether the currently appearing letter was the same as the letter presented two trials previously. Each task consisted of 8 practice trials and 16 formal trials (of which the 1-back task contained one additional trial and the 2-back task contained two additional trials; the additional trials were not included in the analyses). The character stimuli were presented in a pseudo-random order. Children pressed a key to respond to the stimulus, which was followed by a blank screen for 500-1000 ms. Upon completion of the 1-back task, children navigated to an introduction page for the 2-back task, during which they rested to prevent fatigue from affecting task performance. RT and accuracy were measured for this task across conditions.

CF Test: A simple task cued-task paradigm was used to assess CF in children. This was a dual task (shape, color) of two levels (blue-orange and square-circle), with two shapes, (square and circle), and two colors (blue and orange). In this task, a pair of images appeared on the screen, and a cue word appeared above the images. Participants needed to determine whether the two images had the same shape or color based on the cue word. The experiment was divided into three subtasks corresponding to three conditions, namely, shape, color, and transformation, where the two judgments in the transformation condition were randomized. Each of the three conditions consisted of 16 trials, and each condition was preceded by five practice trials, with an intertrial interval of 500-1000 ms. In each task, children were allowed to take a short break at the cue word screen of the next task to avoid the effects of fatigue on task performance. The outcomes of this task were RT and accuracy across the different conditions.

Procedure

The pre- and post-test were conducted in a school computer room with E-Prime 3.0 software installed to ensure that each child had an undisturbed, independent testing space. Assessments of IC,

WM, and CF in children with ADHD were completed sequentially in task order [38]. Assessment metrics included RT and accuracy, with shorter reaction times and higher accuracy rates representing better performance on that function. Before each test, the children practiced until their accuracy was at least 85%. They then started the formal test. Children could take a short break between each task. The total testing time per person was 15-20 minutes.

After recruiting the children with ADHD, a researcher went to the schools to observe the children's daily physical activities, including physical education classes, recess activities, and interest development classes. Consistent with the existing research on the basic motor skills of children with ADHD, it was found that the children not only experienced a wide variety of motor skill deficits, including running, jumping, and throwing, and deficits in motor coordination, but also appeared to be at risk for poor physical health [39,40].

During the intervention period, the team of teachers consisted of one head teacher with extensive experience in JRE and two assistant teachers majoring in physical education. The specific 8-week exercise intervention program was designed by the researcher in collaboration with the head teacher and a special education teacher taking into account the physical and mental characteristics of the children and thus moderating the expected intervention goals. A single intervention session was divided into three parts: preliminary warm-up portion, a fundamental portion, and a concluding portion (**Table 2**). The fundamental portion contained sports games, JRE skills practice, and physical fitness exercises and used a stage. JRE progressed to gradually increase the difficulty of the exercises, with a cutoff of 2 weeks for each stage. JRE progressed from ropeless hand and foot coordination exercises, to the breakdown of JRE, and finally to the complete JRE movements and group relay exercises, which included JRE. The physical fitness exercises accompanying JRE, which included upper and lower extremity coordination, lower extremity footwork and strength, and animal flow crawling, were performed as a fixed-distance round-trip relay to facilitate time and intensity control. The degree of difficulty of the assigned exercises was designed to increase across the weeks as the children's jumping rope motor skills progressed. Training for the EG required attendance at each scheduled session and participation throughout each timed event. Children were allowed 20 minutes of rest at the end of the session.

Data and statistical analyses

SPSS 23.0 was used to statistically analyze all the data, and measures were expressed as mean \pm standard deviation (Mean \pm SD) when they met the normal distribution and satisfied the conditions of variance alignment, and one-way ANOVA was used to test the differences between groups before and after the exercise intervention, and two-by-two comparisons were made using the LSDtest; when variance alignment was not satisfied, Welch's ANOVA, and the Games-Howell test was used for further two-by-two comparisons. Paired-samples t-tests were used to analyze within-group changes in basic motor skills before and after their own intervention within each group, and Cohen's d was used to indicate the effect size of the t-tests, with $0.2 \leq d < 0.5$ as a small effect, $0.5 \leq d \leq 0.8$ as a medium effect, and $d > 0.8$ as a large effect. For all statistical analyses, $P < 0.05$ was used as the criterion for statistically significant differences.

Results

Baseline body measurements and executive function scores between the EG and CG

Differences in height, weight, body mass index, and executive function subscale scores (IC, WM, and CF) between children in the EG and CG before the exercise intervention were analyzed using one-way ANOVA. The results showed that there was no statistically significant difference between the three groups of subject children ($p > 0.05$), which satisfied the chi-square, and two-by-two comparisons using the LSDtest revealed that the correct rate of cognitive flexibility in the experimental group of children with ADHD was statistically significant from the control 2 group of healthy children ($p = 0.037$) and the rest of the indicators were not statistically significant ($p > 0.05$). Measures at baseline were broadly comparable across the three groups (**Table 3**).

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Inhibitory control

One-way ANOVA results indicated that there were also no significant differences on the Stroop test between the three groups before and after the exercise intervention ($P > 0.05$). The within-group effects of each group before vs after the intervention were analyzed using paired-samples t-tests. There was no significant within-group effects for accuracy or for RT before and after the exercise intervention (**Table 4**). These findings indicated that 8 weeks of JRE and related exercises did not effectively improve IC in the EG.

Working memory

One-way ANOVA was used for the between-group analysis, with group as the between-group factor. The results for each group were analyzed using paired-sample t-tests, with the within-group factor being time (i.e., pretest vs posttest), which was a significant within-group difference for accuracy in the 1-back task in the EG ($t = -2.79$, $p = 0.011 < 0.05$, Cohen's $d = 0.60$). There was a significant within-group difference for accuracy in the response time task in the CG2 ($t = 2.13$, $p = 0.050 \leq 0.05$, Cohen's $d = 0.52$). Between-group results showed that 2-back correctness did not satisfy the chi-square test ($p = 0.044$), and the use of Welch's ANOVA test showed that 2-back correctness ($F = 0.67$, $p = 0.519$) was not statistically significant. Therefore, no statistically significant ($p > 0.05$) between-group differences were seen in the correct rates and response times of the 1-back and 2-back tasks for all three groups of subject children after the intervention. No other cognition indicators were statistically significant. These results indicated that before the exercise intervention, the WM capacity of children with ADHD was impaired and was comparable to the level of the WM in children with ADHD in the CG1. After the JRE intervention, there was a significant improvement in both accuracy and RT on the 1-back test in the EG compared with the CG1 (**see Table 5**), indicating that the 8-week JRE intervention improved WM in children with ADHD.

Cognitive flexibility

One-way ANOVA was used to analyze the between-group differences among the three groups of subjects. Paired-sample t-tests were used for within-group analyses, there was a significant between-group difference in baseline levels between the CG2 and the EG (Table 3). Accuracy on task switching was significantly higher within the EG after the exercise intervention ($t = -4.00$, $p = 0.001 < 0.05$, Cohen's $d = 0.85$), whereas no other measures were statistically significant ($P > 0.05$) (**see Table 6**). The between-group results showed that the percentage of correctness in the Task-switching task did not satisfy the chi-square ($p = 0.00$), and the use of Welch's ANOVA test showed that the percentage of correctness ($F = 2.936$, $p = 0.069$) was not statistically significant. Therefore, there was no statistically significant difference ($p > 0.05$) between the cognitive flexibility groups of all three groups of children subjects. These findings indicated that the CF of children with ADHD in the EG was significantly improved and came close to reaching the pre-test level of the CG2 after 8 weeks of the JRE intervention, whereas the CF of children with ADHD in the CG1, who did not receive the JRE intervention, lagged behind that of the executive function, suggesting the existence of a lag in the development of CF in children with ADHD in the CG1.

Discussion

The main objectives of this study were to develop an adaptive, simple, easy-to-implement, and affordable exercise program focused on JRE and to investigate whether this 8-week JRE intervention improved executive function among children with ADHD. Overall, the 8-week JRE intervention showed beneficial effects on the executive function of children with ADHD, with positive significant differences in indicators of WM and CF, but not IC.

IC is one of the core deficits of ADHD and was assessed in this study using the Stroop test. At the end of the 8-week JRE intervention, there was no significant difference in any indicator of IC within or between the groups ($P > 0.05$), suggesting that JRE does not have a positive effect on improving IC in children with ADHD. Similar findings have been reported in a study by [41]. That study showed that a 10-week aerobic exercise intervention did not produce significant improvements in response inhibition in children with ADHD. However, in a study by [42], after an 8-week table tennis intervention, the Go/No-Go task and Stroop test indicated significantly better scores for participants than those in the non-exercise group. The difference in findings between that study and ours could be due to differences in the type of exercise, intensity of exercise, or type of cognitive task used. There is no conclusive evidence regarding the specific mechanisms by which exercise improves IC in children with ADHD, largely because the core symptoms of ADHD are multidimensional and complex. Studies have found neurochemical, structural, and functional differences in cognitive function among children with ADHD [4]. One of the most studied executive control deficits in individuals with ADHD is motor inhibition, which is characterized by a lack of activation of the brain's anterior parietal and prefrontal striatal circuits, resulting in a blockage of information flow through the prefrontal-striatal-cerebellar circuitry [43]. Children with ADHD show numerous abnormalities in neurotransmitter transmission, particularly in the catecholamine system—for example, in the number of dopamine and norepinephrine transporter proteins and for dopamine D1 and D4 receptors [44,45]. Such abnormalities lead to dysfunction not only of the attention circuits that are regulated by those neurotransmitters but also of IC in children with ADHD. It is also possible that high levels of blood lactate induced by an exhaustive exercise could adversely affect executive function of the prefrontal cortex [46]. The present study considered whether JRE could promote skill improvement in children with ADHD because of a strong positive correlation between children's motor skill development and inhibitory functioning [47]. However, we did not take into consideration the children's problems with classroom interaction, postural and motor control, and classroom environmental climate, which could result in frequent classroom discipline problems. In addition, the present study was conducted during the spring season, when children in both groups may have been absent from class due to chickenpox and influenza viruses. These additional factors may have contributed to the lack of effect for the JRE intervention in IC among children with ADHD. Subsequent targeted enrichment of the JRE program or combining it with other forms of exercise that may more effectively stimulate and improve IC in children with ADHD should be explored.

In this present study, the pre- and post-test differences in WM 1-back accuracy in the EG were significant ($P < 0.05$) after 8 weeks of the JRE intervention program. During the JRE intervention, the main focus was on improving JRE skills in a relatively short time, which required the children to have a high WM capacity in order to complete all the exercise skills during the assigned weeks. A study by [48] found that only training that requires a significant investment of attention and memory can positively affect children's WM. The present study used an aerobic exercise intervention in which the fixed jumping motion of the floating rope and the original bipedal jumping motion can be effective in enhancing WM in children with ADHD in this closed exercise. This is consistent with the findings of [49] that aerobic exercise significantly improves reaction speed in WM tasks, and that those who performed aerobic exercise on bicycles and treadmills performed better and processed faster on visual WM tasks. A potential mechanism by which JRE affects WM in children with ADHD is that aerobic-based JRE may affect the brain and cognition at multiple levels: molecular and cellular, brain structure and function, mental state and behavior (e.g., sleep) [50]. [30] demonstrated that repetitive aerobic exercise (e.g., running, biking) had an effect on angiogenesis, increased cerebral blood volume in children with ADHD, and upregulated the growth factor BDNF. Neurological chemicals (e.g., norepinephrine, dopamine) immediately increase learning and memory, which in turn increase

BDNF. Aerobic exercise, such as jumping rope and ball games, also improves physical fitness and neurotransmission in children with ADHD, promotes the speed of attentional processing in the temporal lobe for WM tasks, and stimulates positive changes in brain activation patterns, which in turn improves their WM [51].

CF plays an important role in an individual's ability to adapt to the environment and is often understood as the ability to adjust one's behavior to changing task requirements and to change perspectives and thought patterns when necessary [52]. Children with ADHD display reduced CF [53]. The present study showed a significant within-group effect on CF for children ($P < 0.01$) after the 8-week JRE intervention, providing evidence for a positive impact of JRE on improving CF in children with ADHD, which has been correlated with motor learning ability [54]. This finding is consistent with the results of previous exercise intervention studies, including [25] and [55], that showed significantly improved CF among children with ADHD after long-term regular exercise. In the present study, the JRE program included exercises—such as jumping and rope flinging movements and passing of obstacles using different routes in the shortest possible time—in which the children needed to flexibly switch between different movement tasks when specific commands were given by the trainer to improve their response abilities. Changes in heart rate variability (HRV) of children correlate with executive function, and moderate- to high-intensity intermittent exercise interventions elicit changes in HRV in children with ADHD. HRV is associated with activation of neural structures in the prefrontal cortex. The favorable changes in prefrontal cortex activity in children with ADHD while completing alternating-use tasks can be attributed in part to the increase in arousal induced by parasympathetic withdrawal, which improves their CF [31]. In addition, the present study used a homogeneous group teaching format, with a task-driven competitive jump rope relay task to increase brain arousal levels in children with ADHD. This increase may be because moderate- to high-intensity exercise also increases cellular activity, generating more BDNF and improving metabolism and blood-oxygen supply, which in turn better utilizes the neuromodulatory effects of exercise to promote CF [56].

This study has limitations. The ages of the children with ADHD in this study were between 7 and 12 years, limiting the generalizability of our results to other age groups. This study did not assess the effects of JRE on ADHD core symptoms or school-adaptive behavioral performance of children with ADHD. In addition, this study did not investigate the effects of varying the amount, duration, or intensity of the JRE on executive function, nor did it assess how long after the intervention that the positive effects remained evident. Therefore, the generalizability of the study findings are limited to the effects 1 week after a 8-week JRE intervention for 7- to 12-year-old children with ADHD.

In summary, this study found that the designed 8-week JRE program was to a safe and efficient exercise suitable for children with ADHD. The JRE program developed in this study took into account the physical and mental developmental needs of children with ADHD. Rope skipping practice requires the coordination of multiple abilities, including postural control, spatial position perception, hand-eye coordination, and movement rhythm. Therefore JRE requires the mobilization of cognitive resources involving inhibition, memory, and task switching, which in turn improves the arousal level and activates more cognitively related neural connections. Indeed, the regular long-term JRE program used in this study improved executive function in children with ADHD.

Conclusions

An 8-week intervention of regular JRE with 7- to 12-year-old children with ADHD had a positive effect on improving their executive function and contributed to improvements in WM and CF, but had a less significant effect on improving IC.

Study Limitations

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki and was approved by the Ethics Committee of Shanghai University of Sport (protocol code 102772022RT123 on 23 December 2022).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

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