Effect of an Ecological Executive Skill Training Program for School-aged Children with Attention Deficit Hyperactivity Disorder: A Randomized Controlled Clinical Trial

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Abstract

Background: As medication does not normalize outcomes of children with attention deficit hyperactivity disorder (ADHD), especially in real-life functioning, nonpharmacological methods are important to target this field. This randomized controlled clinical trial was designed to evaluate the effects of a comprehensive executive skill training program for school-aged children with ADHD in a relatively large sample.
Methods: The children (aged 6–12 years) with ADHD were randomized to the intervention or waitlist groups. A healthy control group was composed of gender- and age-matched healthy children. The intervention group received a 12-session training program for multiple executive skills. Executive function (EF), ADHD symptoms, and social functioning in the intervention and waitlist groups were evaluated at baseline and the end of the final training session. The healthy controls (HCs) were only assessed once at baseline. Repeated measures analyses of variance were used to compare EF, ADHD symptoms, and social function between intervention and waitlist groups.
Results: Thirty-eight children with ADHD in intervention group, 30 in waitlist group, and 23 healthy children in healthy control group were included in final analysis. At posttreatment, intervention group showed significantly lower Behavior Rating Inventory of Executive Function (BRIEF) total score (135.89 ± 16.80 vs. 146.09 ± 23.92, $P = 0.04$) and monitoring score (18.05 ± 2.67 vs. 19.77 ± 3.10, $P = 0.02$), ADHD-IV overall score (41.11 ± 7.48 vs. 47.20 ± 8.47, $P < 0.01$), hyperactivity-impulsivity (HI) subscale score (18.92 ± 5.09 vs. 21.93 ± 4.93, $P = 0.02$), and inattentive subscale score (22.18 ± 3.56 vs. 25.27 ± 5.06, $P < 0.01$), compared with the waitlist group. Repeated measures analyses of variance revealed significant interactions between time and group on the BRIEF inhibition subscale ($F = 5.06$, $P = 0.03$), working memory ($F = 4.48$, $P = 0.04$), ADHD-IV overall score ($F = 21.72$, $P < 0.01$), HI subscale score ($F = 19.08$, $P < 0.01$), and inattentive subscale score ($F = 12.40$, $P < 0.01$). Multiple-way analysis of variance showed significant differences on all variables of BRIEF, ADHD-rating scale-IV, and WEISS Functional Impairment Scale-Parent form (WFIRS-P) among the intervention and waitlist groups at posttreatment and HCs at baseline.
Conclusions: This randomized controlled study on executive skill training in a relatively large sample provided some evidences that the training could improve EF deficits, reduce problematic symptoms, and potentially enhance the social functioning in school-aged children with ADHD.
Clinical Trial Registration: http://www.clinicaltrials.gov; NCT02327585.

Key words: Attention Deficit Hyperactivity Disorder; Executive Function; Executive Skill Training; Randomized Controlled Trial

Introduction

Attention deficit hyperactivity disorder (ADHD) is now increasingly recognized as a developmental impairment that involves deficient executive function (EF).[1,2] The term "executive function" refers to a set of regulatory processes that are needed to select, initiate, implement, and oversee thought, emotion, behavior, and certain facets of motor

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and sensory functions.[3] It comprises several domains, such as inhibition, initiation, sustaining attention, set shifting, working memory, emotional regulation, planning, organizing, and monitoring.[4] Studies have indicated that children with ADHD who experienced executive dysfunction were at a higher risk for academic failure and poor psychosocial and occupational outcomes than those who had intact EF.[5,6]

Although substantial literature has demonstrated the efficacy of medication on improving EF in ADHD through short/medium-term therapy, medications have several potential limitations including partial response or nonresponse,[7] possible side effects,[8] uncertainty about the long-term costs and benefits,[9] and poor adherence.[10] Moreover, except sustained attention, evidence showed that medications did not necessarily normalize the neuropsychological outcomes of children with ADHD.[11] For these reasons, pharmacological treatment alone might not be sufficient to remediate the deficits associated with ADHD, and it is thus necessary to develop additional treatment methods that target core neuropsychological deficits.[12,13]

EF training has been investigated as a potential treatment method for ADHD that might have more long-term benefits and fewer side effects than pharmacological treatment. It is hypothesized that EF training might reduce ADHD symptoms and improve functioning by targeting neuropsychological deficits to mediate ADHD pathophysiology. There are two types of EF training: facilitative intervention training (FIT), which fosters the development of EF through the use of computer-based training programs,[14-20] and compensatory EF training, which is based on behavioral therapy. Regarding FIT, although some evidence indicated that training working memory could improve working memory measures, no significant improvements were found for attention and/or mixed EF training in a meta-analysis.[14] The effects on working memory did not transfer to other neuropsychological tests, behavior, or academic function,[14] which suggested the need to develop ecologically effective EF training programs. The compensatory EF training based on behavioral therapy might fit such need.

Some studies have discussed the effectiveness of executive skill training programs that are designed to enhance EF in children's daily lives,[21-25] three of which were open trials, and two were randomized waitlist control trials. Almost all of them reported significant improvement in ADHD symptoms rated by parents, teachers, and a blinded clinician. Some also reported significant differences between treated and untreated patients in neuropsychological measures including visual-spatial memory, planning, visual/auditory attention, and cognitive flexibility, corresponding to the improvements in parent ratings of ecological executive functioning. Notably, Abikoff *et al*.[25] compared skill training with a performance-based intervention and found that the former improved academic performance and proficiency to a greater extent than the latter. These previous studies suggested that executive skill training might be an ecologically valid treatment that deserves development and validation in a larger sample. Furthermore, most previous studies were performed in children younger than 7 years old. As the period from 6 to 12 years of age represents a period of "pruning" synaptic connections, and this pruning process helps consolidate learning skills, this period might be a good time to train skills in school-aged children.

We thus hypothesized that intervention targeting executive dysfunction in everyday life might relieve the EF deficits of children with ADHD, and the core symptoms of ADHD and social dysfunction might be improved with the relief of executive dysfunction. This randomized controlled clinical trial was designed to evaluate the effects of a comprehensive executive skill training program for school-age children with ADHD in a relatively large sample. This program was to target the putative dysfunction underlying ADHD and promote the development of EF. The effects of the training were systemically evaluated using neuropsychological tests and behavioral ratings of EF, symptoms of ADHD, and social function.

Methods

Ethical approval

The study was conducted in accordance with the *Declaration of Helsinki* and was approved by the Institutional Review Board of Peking University Sixth Hospital. Parents and children signed separate informed written consent before their enrollment in this study.

Participants

All participants were children with ADHD recruited from a mental health hospital in Beijing. The diagnosis of ADHD was first made according to the *Diagnostic and Statistical Manual of Mental Disorders-IV* (DSM-IV) criteria based on parent ratings of the ADHD-rating scale-IV (ADHD-RS-IV)[26] and was then confirmed by a semi-structured interview conducted by experienced pediatric psychiatrists using the clinical diagnostic interview scale.[27] Children were excluded if they met the following criteria: a history of head injury, a diagnosis of other congenital or acquired neurological conditions, an estimated full-scale IQ <80, a diagnosis of autism spectrum disorder, psychosis, or an emergent psychiatric condition that needed immediate medication. Ten participants had maintained steady dosage of medications for more than half a year and remained unchanged during the entire study. New medications could not be initiated during the study. The participants aged from 6 years to 12 years and were randomized to the intervention or waitlist groups. A healthy control group was composed of gender- and age-matched healthy children from a primary school nearby.

Study design and procedure

The study adopted a randomized block design to balance the individuals between the intervention and waitlist groups. Children with ADHD who met the eligibility criteria were randomized to a block that comprised a permutation of four participants, two for each group separately. The grouping scheme was concealed in envelopes, and the recruited participant was notified of his or her group sequentially. During the study, the intervention group received a 12-session training program for multiple executive skills once a week, whereas the waitlist group did not receive any new intervention. After the postintervention data collection, participants in the waitlist group had the opportunity to receive the same intervention to adhere to ethical considerations.

Executive skill training

The training program, based on Dawson and Guare's (2010) training of executive skills for children, aimed to improve the everyday performance of executive skills among children with ADHD. We added some culturally adapted information, following the theory of cognitive behavioral therapy, to ensure that the concepts were acceptable to Chinese children.

The training program included 12 weekly 1-h sessions in a clinical setting and was applied in groups of 6 to 8 families. Regarding the parents' involvement, all parents received the first and last sessions and were instructed to help their children finish the homework outlined in the handbook between sessions. As for the children, all children attended the other ten sessions and were asked to complete the homework in the handbook between sessions with the help of their parents. Further details are described in Supplementary Material 1.

The intervention was provided by a senior pediatric psychiatrist and a trained graduate student. All the training principles and processes described above were documented in a manual for the trainer.

Outcome measurement

EF, ADHD symptoms, and social functioning in the intervention and waitlist groups were evaluated at baseline and the end of the final training session. The healthy controls (HCs) were only assessed once at baseline.

For EF measurement, performance-based tasks were selected from the Chinese neuropsychological battery used by our research group.[28] This battery includes the Stroop Task, Rey-Osterrieth Complex Figure Test, and Trail-making Test [Supplementary Material 2]. The interrater reliability kappa coefficients of the tests ranged from 0.70 to 0.75 ($P < 0.01$).

The Behavior Rating Inventory of Executive Function (BRIEF) parent form is a questionnaire that assesses EF behaviors in daily life environments.[29] The instrument includes eight subscales: initiation, working memory, planning, organization of materials, monitoring, inhibition, shifting, and emotional control. This scale has been translated into Chinese and has good psychometric properties and clinical discrimination, with a test-retest reliability of 0.68–0.89 and a Cronbach's coefficient of 0.74–0.96.[30]

For ADHD symptom measurement, the ADHD-RS-IV[26] was used to assess symptoms. This scale consists of 18 items corresponding to the DSM-IV criteria for ADHD. The overall symptom scores as well as the inattention and hyperactivity-impulsivity (HI) scores were calculated based on different symptom domains. This scale was translated into Chinese by Su *et al*.,[31] with a test-retest reliability of 0.72 and a Cronbach's coefficient of 0.91.

The WEISS Functional Impairment Scale-Parent form (WFIRS-P) used for social function measurement is a questionnaire including six subscales: assessing family, learning and school, life skills, self-concept, social activities, and risky activities. This scale was implemented in China by Qian *et al*.,[32] with a test-retest reliability of 0.61–0.87 and a Cronbach's coefficient of 0.70–0.92.

Statistical analysis

In this study, group differences in demographic and initial clinical variables of ADHD were assessed using Student's *t*-test for quantitative data and Chi-square test for categorical data. The 2 × 2 repeated measures analyses were used to evaluate the effects of time (pre- and post-treatment), group (intervention vs. waitlist), and the group-time interaction on EF, ADHD symptoms, and social function, with group as a between-subject factor and time as a within-subject factor. The neuropsychological, behavioral, and functional measurements of the intervention and waitlist groups at the end of training were compared to those of the HCs using multiple-way analysis of variance (MANOVA) with gender, age, and IQ as covariates to determine whether the training normalized the deficits of ADHD. The measurement data were shown as mean ± standard deviation (SD). Statistical analyses were performed using SPSS version 19.0 (SPSS Inc., Chicago, IL, USA). All statistical tests were two-tailed, and a $P < 0.05$ was considered statistically significant.

Results

A total of 86 children with ADHD were randomized to the intervention ($n = 44$) or waitlist groups ($n = 42$). Sixty-eight children (79.1%) completed the whole study; 18 children dropped out due to scheduling problems and time conflicts, six of whom were in the intervention group (13.6%) and 12 in the waitlist group (28.6%). The 86.4% (38/44) of children in intervention group complied with the training, completing ten or more sessions in the 12-session period. All of the missed group sessions were administered to the trainee individually. Thirty-eight children in intervention group (including 32 boys and 6 girls) and thirty in waitlist group (including 22 boys and 8 girls) were included in final analysis. The demographic and clinical characteristics of these participants are presented in Table 1. For intervention group, the mean age was 8.3 ± 1.3 years, and the mean IQ was 105.7 ± 13.9; for waitlist group, the mean age was 7.8 ± 1.2 years, and the mean IQ was 101.8 ± 10.4. There were no significant differences in age, gender, IQ, ADHD subtypes, and comorbidity between two groups at baseline (all $P > 0.05$). At baseline, no significant differences were also found in EF, ADHD symptoms, and social function between intervention and waitlist groups (all $P > 0.05$).

Table 1: Demographic and clinical characteristics of the children with ADHD in this study

Characteristics	Intervention group (*n* = 38)	Waitlist group (*n* = 30)	Statistical values	*P*
Age (years), mean ± SD	8.3 ± 1.3	7.8 ± 1.2	1.47*	0.15
Gender, *n* (%)				
Female	6 (15.8)	8 (26.7)	1.21†	0.27
Male	32 (84.2)	22 (73.3)		
IQ (mean ± SD)	105.7 ± 13.9	101.8 ± 10.4	1.28*	0.21
ADHD subtypes, *n* (%)				
Inattentive	17 (44.7)	16 (53.3)	2.00†	0.37
HI	0	1 (3.3)		
Combined	21 (55.3)	13 (43.3)		
Comorbidity, *n* (%)				
ODD	7 (18.4)	7 (23.3)	0.25†	0.62
Learning disorder	8 (21.1)	4 (13.3)	0.69†	0.41
Special phobia	5 (13.2)	2 (6.7)	0.77†	0.38

**t* value, †Chi-square value. ADHD: Attention deficit hyperactivity disorder; IQ: Intelligence quotient; ODD: Oppositional-defiant disorder; SD: Standard deviation; HI: Hyperactivity-impulsivity.

Twenty-three gender- and age-matched children without ADHD (including 15 boys and 8 girls) voluntarily participated in the study as HCs. The HCs completed the same cognitive function test battery at baseline. The mean age of HCs was 8.4 ± 0.9 years, and the mean IQ was 108.6 ± 12.2.

At posttreatment, intervention group showed significantly lower BRIEF total score (135.89 ± 16.80 vs. 146.09 ± 23.92, $P = 0.04$) and monitoring score (18.05 ± 2.67 vs. 19.77 ± 3.10, $P = 0.02$), ADHD-IV overall score (41.11 ± 7.48 vs. 47.20 ± 8.47, $P < 0.01$), HI subscale score (18.92 ± 5.09 vs. 21.93 ± 4.93, $P = 0.02$), and inattentive subscale score (22.18 ± 3.56 vs. 25.27 ± 5.06, $P < 0.01$), compared with the waitlist group. The inhibition factor on BRIEF (17.13 ± 3.77 vs. 19.17 ± 4.84, $P = 0.05$) and learning/school subscale of the WFIRS-P (6.32 ± 3.63 vs. 8.03 ± 3.77, $P = 0.06$) in the intervention group also showed a decreased trend, compared with the waitlist group.

Repeated measures analyses of variance revealed significant interactions between time and group on the BRIEF inhibition subscale ($F = 5.06$, $P = 0.03$), working memory ($F = 4.48$, $P = 0.04$; Table 2), ADHD-IV overall score ($F = 21.72$, $P < 0.01$), HI subscale score ($F = 19.08$, $P < 0.01$), and inattentive subscale score ($F = 12.40$, $P < 0.01$; Table 3). Trend significance was also observed for the BRIEF total score ($F = 3.89$, $P = 0.05$) and monitoring subscale ($F = 3.91$, $P = 0.05$), the forgotten structure score on the ROCF ($F = 4.27$, $P = 0.05$), risky activities subscale ($F = 3.78$, $P = 0.06$), and learning/school subscale ($F = 4.03$, $P = 0.05$) of the WFIRS-P [Table 4].

MANOVA showed significant differences on all variables of BRIEF, ADHD-RS-IV, and WEISS among the intervention and waitlist groups at posttreatment and HCs at baseline [Table 5]. Both intervention and waitlist groups showed significant differences almost on all scales, compared with the HC group.

Discussion

The executive skill training program used in this study was developed as an ecological nonpharmacological intervention for children with ADHD. This study provided some evidence that this program improved EF and ADHD symptoms, which potentially promoted social function.

Barkley[33] proposed that inhibition impairment might be a core deficit of ADHD. This inhibition deficit was expressed as impulsivity.[34] In children with ADHD, impulsivity was often manifested as the inability to wait in a variety of situations and as the tendency to interrupt others' conversations or to respond before the end of a question.[35] Children with more prominent HI symptoms showed more risk-taking behaviors.[36,37]

This randomized waitlist-controlled study found that executive skill training improved the inhibition factor of the BRIEF, HI score of the ADHD-RS-IV, and possibly the risky activities subscale of the WFIRS-P, indicating that the targeted training of inhibitory skills could alleviate inhibition deficits, decrease HI symptoms, and potentially reduce risk-taking behavior in daily life settings. The results of this study were consistent with the possible mechanisms of HI behavior and related functions, which were supported by Barkley's hypothesis.[33]

This study did not find significant differences between the intervention group and the waitlist group on the Stroop test (performance-based test) although significant differences were found on the inhibition subscale of the BRIEF (valid ecological rating). The low agreement between the performance-based and ecological ratings of EF has been reported in other studies as well.[38,39] An explanation of this result was that neuropsychological tests have less ecological validity in evaluating children's behaviors in everyday life. Behavioral questionnaires for parents and teachers or direct observations of behaviors are probably more sensitive to the adaptive modifications occurring in natural contexts.[22]

Table 2: Repeated measures analyses of variance in executive function among the intervention and waitlist groups at baseline and posttreatment

Executive function tests	Baseline		Posttreatment		*F* (1, 49; IA)	*P*
	Intervention group (*n* = 38)	Waitlist group (*n* = 30)	Intervention group (*n* = 38)	Waitlist group (*n* = 30)		
BRIEF						
Inhibition	17.9 ± 4.86	18.04 ± 4.16	17.13 ± 3.77	19.17 ± 4.84	5.06	0.03
Shifting	12.74 ± 2.67	12.36 ± 2.26	12.37 ± 2.29	12.30 ± 2.87	0.52	0.47
Emotion control	15.61 ± 3.87	16.54 ± 4.32	15.18 ± 4.12	16.90 ± 4.26	1.40	0.24
Initiation	14.03 ± 2.69	14.89 ± 2.97	14.24 ± 2.48	15.37 ± 3.01	0.67	0.42
Working memory	21.97 ± 2.79	21.33 ± 3.72	20.58 ± 2.84	21.93 ± 4.08	4.48	0.04
Planning	26.50 ± 4.79	26.61 ± 4.03	25.97 ± 3.67	26.97 ± 4.35	1.29	0.26
Organizing	13.16 ± 2.26	13.57 ± 3.05	12.37 ± 2.61	13.67 ± 3.01	1.16	0.29
Monitoring	19.18 ± 3.48	19.31 ± 3.31	18.05 ± 2.67	19.77 ± 3.10	3.91	0.05
Total score	141.08 ± 20.31	142.17 ± 18.44	135.89 ± 16.80	146.07 ± 23.92	3.89	0.05
TMT						
Ln (Trail B-A)	5.09 ± 0.65	5.15 ± 0.53	4.71 ± 0.61	4.94 ± 0.59	0.01	0.92
Stroop test						
Color interference	9.40 ± 18.55	7.17 ± 10.96	9.59 ± 7.74	9.20 ± 13.50	0.05	0.82
Word interference	31.24 ± 12.44	42.50 ± 31.42	27.05 ± 13.42	33.79 ± 17.82	0.86	0.36
ROCF						
Forgotten structure score	−0.08 ± 1.29	−0.44 ± 1.25	−0.19 ± 0.88	0.20 ± 1.21	4.27	0.05
Forgotten detail score	0.16 ± 2.39	0.06 ± 2.31	0.30 ± 2.56	−0.07 ± 2.46	0.03	0.86

All data are shown as mean ± SD. BRIEF: Behavior Rating Scale of Executive Function; ROCF: Rey-Osterrieth Complex Figure Test; TMT: Trail-making test; IA: Interaction; SD: Standard deviation.

Table 3: Repeated measures analyses of variance in ADHD symptoms among the intervention and waitlist groups at baseline and posttreatment

Subscales of ADHD-RS-IV	Baseline		Posttreatment		*F* (1, 49; IA)	*P*
	Intervention group (*n* = 38)	Waitlist group (*n* = 30)	Intervention group (*n* = 38)	Waitlist group (*n* = 30)		
Inattentive	25.95 ± 3.83	24.50 ± 5.10	22.18 ± 3.56	25.27 ± 5.06	12.40	<0.01
HI	21.39 ± 6.07	19.60 ± 5.07	18.92 ± 5.09	21.93 ± 4.93	19.08	<0.01
Overall score	47.34 ± 8.20	44.10 ± 7.77	41.11 ± 7.48	47.20 ± 8.47	21.72	<0.01

All data are shown as mean ± SD. ADHD-RS-IV: Attention deficit hyperactivity disorder-rating scale-IV; HI: Hyperactivity-impulsivity; IA: Interaction; SD: Standard deviation.

As the training in this study focused more on ecological executive skills, it might have been difficult to detect the changes on performance-based tasks.

ADHD is acknowledged to be the most common cognitive disorder in childhood. Many cognitive studies have suggested that there are working memory deficits in ADHD children.[40-42] Inattention and impaired cognitive abilities serve as dual pathways between ADHD and later academic achievement.[43-46] This study found that the executive skill training improved immediate or delayed recall scores of the ROCF, the working memory subscale of the BRIEF, ADHD-RS-IV inattention score, and possibly the learning and school subscale of the WFIRS-P, which suggested that the executive skill training improved ADHD children's working memory (in laboratory performance as well as in everyday life settings) and attention, both of which contributed to better academic performance. The effects of the training on school and academic performance provided important support for the hypothesis that executive skill training is ecologically valid and potentially leads to the transfer of treatment gains. Completing the homework assigned to the participants in the 12-week training period promoted generalization of the learned skills.

Targeted training for EF deficits adopts two forms: computerized cognitive training and noncomputerized skill training. Sonuga-Barke *et al*.[47] systematically reviewed the available psychological treatments for ADHD.[44] A meta-analysis revealed that computerized cognitive training only improved working memory in laboratory settings, with a limited transfer of effects on ADHD symptoms and academic functions. For behavioral interventions, although the standardized mean difference was near zero, none of the included studies focused on executive skill training that targeted the core impairment of ADHD. Few studies focused on noncomputerized executive skill training programs. Halperin *et al*.[21] combined executive, attention, and motor skill training and found that ADHD severity improved significantly as rated by the parent and teacher

Table 4: Repeated measures analyses of variance in social functioning among the intervention and waitlist groups at baseline and posttreatment

WFIRS-P subscales	Baseline		Posttreatment		*F* (1, 49; IA)	*P*
	Intervention group (*n* = 38)	Waitlist group (*n* = 30)	Intervention group (*n* = 38)	Waitlist group (*n* = 30)		
Family	7.26 ± 5.00	7.83 ± 5.36	7.00 ± 4.99	8.53 ± 5.97	1.92	0.17
Learning/school	8.21 ± 4.07	7.93 ± 4.37	6.32 ± 3.63	8.03 ± 3.77	4.03	0.05
Social activities	5.76 ± 3.15	5.68 ± 3.88	5.79 ± 3.00	5.70 ± 3.04	0.02	0.88
Life skills	7.61 ± 4.14	9.79 ± 5.70	8.24 ± 3.41	9.50 ± 4.41	0.58	0.45
Self-concept	2.79 ± 1.85	2.39 ± 1.89	2.16 ± 1.78	2.63 ± 2.06	3.67	0.06
Risky activities	4.11 ± 2.86	3.56 ± 2.89	2.97 ± 1.92	3.60 ± 1.89	3.78	0.06
Total score	35.74 ± 13.54	35.00 ± 16.74	32.47 ± 12.38	38.00 ± 15.43	2.69	0.11

All data are shown as mean ± SD. WFIRS-P: WEISS Functional Impairment Scale-Parent form; IA: Interaction; SD: Standard deviation.

Table 5: Executive function, ADHD symptoms, and social functioning in posttreatment intervention and waitlist groups and healthy controls

Subscale/tests	Posttreatment		Healthy controls (*n* = 23)	*F*	*P*	LSD
	Intervention group (*n* = 38)	Waitlist group (*n* = 30)				
BRIEF						
Inhibition	17.13 ± 3.77	19.17 ± 4.84	11.61 ± 1.64	27.08	<0.01	c < a < b
Shifting	12.37 ± 2.29	12.30 ± 2.87	9.35 ± 1.64	13.74	<0.01	c < a, b
Emotion control	15.18 ± 4.12	16.90 ± 4.26	11.87 ± 2.38	11.50	<0.01	c < a, b
Initiation	14.24 ± 2.48	15.37 ± 3.01	10.22 ± 2.21	27.40	<0.01	c < a, b
Working memory	20.58 ± 2.84	21.93 ± 4.08	14.04 ± 3.82	36.07	<0.01	c < a, b
Planning	25.97 ± 3.67	26.97 ± 4.35	18.13 ± 4.51	35.19	<0.01	c < a, b
Organizing	12.37 ± 2.61	13.67 ± 3.01	9.39 ± 2.37	16.86	<0.01	c < a < b
Monitoring	18.05 ± 2.67	19.77 ± 3.10	12.96 ± 3.34	35.61	<0.01	c < a < b
Total score	135.89 ± 16.80	146.07 ± 23.92	97.57 ± 18.45	42.36	<0.01	c < a < b
TMT						
Ln (Trail B-A)	4.71 ± 0.61	4.94 ± 0.59	4.73 ± 0.59	1.43	0.24	
Stroop test						
Color interference	9.59 ± 7.74	9.20 ± 13.50	6.17 ± 5.13	0.99	0.38	
Word interference	27.05 ± 13.42	33.79 ± 17.82	24.96 ± 8.61	2.97	0.06	
ROCF						
Forgotten structure score	−0.19 ± 0.88	0.20 ± 1.21	−0.30 ± 0.82	2.01	0.14	
Forgotten detail score	0.30 ± 2.56	−0.07 ± 2.46	0.09 ± 1.31	0.22	0.81	
ADHD-RS-IV						
Inattentive	22.18 ± 3.56	25.27 ± 5.06	14.91 ± 3.76	41.64	<0.01	c < a < b
HI	18.92 ± 5.09	21.93 ± 4.93	14.65 ± 4.34	14.61	<0.01	c < a < b
Overall score	41.11 ± 7.48	47.20 ± 8.47	29.57 ± 7.16	34.21	<0.01	c < a < b
WFIRS-P						
Family	7.00 ± 4.99	8.53 ± 5.97	1.91 ± 1.65	13.32	<0.01	c < a, b
Learning and school	6.32 ± 3.63	8.03 ± 3.77	1.04 ± 1.02	15.09	<0.01	c < a < b
Social activities	5.79 ± 3.00	5.70 ± 3.04	0.83 ± 0.94	34.43	<0.01	c < a, b
Life skills	8.24 ± 3.41	9.50 ± 4.41	4.74 ± 2.14	12.43	<0.01	c < a, b
Self-concept	2.16 ± 1.78	2.63 ± 2.06	0.43 ± 0.59	12.10	<0.01	c < a, b
Risky activities	2.97 ± 1.92	3.60 ± 1.89	2.61 ± 1.38	11.63	<0.01	c < a, b
Total score	32.47 ± 12.38	38.00 ± 15.43	11.57 ± 3.84	33.71	<0.01	c < a, b

All data are shown as mean ± SD. a: Intervention group; b: Waitlist group; c: Healthy control group; LSD: Fisher's least significant difference, the comparison between each group posttreatment; BRIEF: Behavior Rating Scale of Executive Function; ROCF: Rey-Osterrieth complex figure test; TMT: Trail-making test; ADHD-RS-IV: Attention deficit hyperactivity disorder-rating scale-IV; HI: Hyperactivity-impulsivity; WFIRS-P: WEISS Functional Impairment Scale-Parent form; SD: Standard deviation.

on the ADHD-RS-IV from pre- to post-treatment. Both inattention and HI domain scores declined. However, it is challenging to disentangle the effects of executive skill training. Miranda *et al*.[22] analyzed the effects of an intensive psychosocial intervention on EF, which taught children a set of cognitive-behavioral techniques. Improvement was observed in both cognitive function (visual-spatial memory and planning) and ADHD symptoms (HI and inattention). Tamm *et al*.[23,24] developed a metacognitive EF training program for young children with ADHD. Open as well as randomized waitlist-controlled trials showed that the training had effects on both laboratory performance and parent-rated EF. Thus, high consistency was found between this study and previous studies, and we further assessed functional outcomes. All of the findings described above strongly indicate that executive skill training is a potentially effective nonpharmacological intervention for EF, ADHD symptoms, and school performance.

The results of this study indicated that the intervention group did not catch up with the HCs on almost all variables at the end of the study. Thus, although the executive skill training provided in this study was shown to be an effective nonpharmacological treatment for school-aged children with ADHD, it still needs to be modified or combined with other types of therapy to help children reach full recovery.

There were some limitations in this study. This study used nonblind parent ratings as the primary outcome measure, which might have been influenced by the subjective expectations of the parents. However, the changes observed in neuropsychology, behavior, and social function, which were consistent with previous studies, potentially corresponded to the rational of the training. In addition, the improvement was not pervasive, which decreased the possibility of subjective bias. Another limitation was the trend toward significant improvement in social function, which might have been due to insufficient training intensity or the short follow-up time. In the future, these limitations can be addressed by revising the protocol to increase the training intensity, adding more assessment measures, and focusing on subgroups of ADHD patients (e.g., ADHD with mild impairment).

In summary, this study supported the hypothesis that executive skill training could improve EF deficits, reduce problematic symptoms, and consequently improve the social function of school-aged children with ADHD. However, the improvements were still insufficient to normalize the symptoms of the participants.

Supplementary information is linked to the online version of the paper on the Chinese Medical Journal website.

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Conflicts of interest

There are no conflicts of interest.

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Part 1: The 12 sessions in the clinical setting

Supplementary Material 1: Content of the executive skill training programme		
Times	**Targeted executive function**	**Content**
1	Introduction	The first session introduced the concept of each executive function domain and explained the principles of behavioural modification (removing distracting toys, posting rule sheets, reinforcement for appropriate behaviour, ignoring, time-out and response cost). It aimed to help parents establish behavioural objectives, action plans, environmental modifications, and reward systems for their children. The rewards were stratified as small, medium, and large rewards according to their potential value for short- (daily, e.g., pens, small toys), medium- (weekly, e.g., movies), and long-term (end of training, e.g., watches) appropriate behaviors.
2,3	Inhibition	First, we used scenariosto reproduce the impulsive behavior thatchildren might exhibit and introduced skills. We taught the children alternativeskills to replace the impulsive behaviour, including how to presenta reasonable requestbefore acting and thinking before they acted. Then, we used the scenariosto let them practice the skills and reinforced them when they used the skill properly. After the class, we advised the parents to implementsome environmental modifications, including keeping their child away from settings in which they might get in trouble, enhancing supervision and promptingthe child to use the skills when appropriate.
4,5	Planningand timemanagement	The children were first asked to noteand record the time they spent onroutine tasks. Then, planning and time management skills were trained through task training. For example, the children were asked to make a task timetable for their homework, and after that, they were required to follow the schedule.
6	Sustainedattention	The children were shown howto break down tasks into small parts that were compatible with their attentional capacity. Then, they were taught to self-prompt with a rehearsedscript such as "I must pay attention". They were instructedto record the times they were distracted and to try to reduce the number of times they were distracted once a day. Additionally, the parents provided supervision, cued the child when he or she wasdistracted, and reinforced the child for successfullyfollowing through with atask.
7,8	Organization	Through desk and room organization tasks, the therapist helped the children develop templates to separate and categorize their possessions. The children were then asked to organize their desk once a week and their room once a month to attainthe organizational skill practiced.
9,10	Cognitive flexibility	By introducing pictures that depicted confused characters, the therapist helped the children understand that there were several right answers to a question or solutions to aproblem when different directions and perspectives were used. Parents were then instructedto help their child develop more flexible reasoningto reduce absolutist thinking.
11	Working memory	The children were taught to make a list of tasks they needed to accomplish and cross them off one-by-one when completed. They could use this strategy to meet objectives before and after school. Parents were advisedto help their child develop more self-promptingmechanisms. Some curriculum activities were also provided. Participants were asked to recall the words and numbers of a 4*6 rectangulargrid that increased in difficulty and then to reproduce the grid and recall the picture in different sequences at different times.
12	Conclusion	Principles of behaviouralmodificationwere mentioned again to encourage the parents to continue to use the learned skills. Possible mistakes were remedied to make sure that the parents used the skills correctly.

Part 2: Handbook for homework between sessions

The object of the homework assignments was toask the family to use what they had learned inthe training in their everyday life and to increasethe effects of the training. Each session had its own homework assignment. For example, making a task timetable wasthe assignmentfor session 4. The children were askedto make their own timetable for that week. If they successfully performedtheir daily life activities according to the timetable, the parents would give them a certain type of reward.

Supplementary Material 2: Performance-based test of executive function

Tests	Content
The Stroop Colour and Word Test	This test was used to capture the inhibition component of EF. It consisted of four parts, represented by three cards (21×29.7 cm). The participants were requiredto name 30 stimuli in a 10×3 matrix as quickly and correctly as possible. Part 1 was a word card containing four differentcolourwords (red, green, yellow, and blue) that were printed in black ink and presented in a random order. Part 2 involved acolouredcard that contained blocks printed in red, green, yellow, and blue. Part 3 involved a colour-word card. The participantswere required to name the words of the colour-content that did not match the colour words. In Part 4, the same colour-wordcards were used, but the participants were required to name the colours. The distracter was the colour meaning of the word. The time the children took to complete all 30 items and the number of errors they made was recorded for each part. The time taken to complete Part 3 was subtracted from that ofPart 1 to indicate thecolour interference, and the time taken to complete Part 4 was subtracted from that ofPart 2 to indicate word interference.
The Rey-Osterrieth Complex Figure Test (ROCF)	This testwas used to evaluate visual-spatial construction ability, visual working memory, and organizational skills. In the test, the participants were required to observe a complex geometric figure for 30 s and to then reproduce it from memory immediately and after a brief delay (–20 min) without prompting. This test allowed us to observe the participants' short- and long-term memory performanceandforgetfulness. Two traditional methods were used to assess structural and detailed memory. The structural score system divided each Rey geometric figure into five configural elements: a large rectangle, a diagonal cross, the vertical midline, the horizontal midline, and the vertex of the triangle on the right. The participants received points for constructing each element as an unfragmented unit. The large rectangle was assigned two points to reflect its importance inthe fundamentalorganization of the figure. All of the other elements were each assigned one point, which resulted in a range of scores from 0 to 6. The detailed score system deconstructedeach figure into 18 storable elements. Two points were awarded if an element was correct and properly placed, and one if it was the correct element but incorrectlyplaced or distorted but correctly placed. The participants' performance onthe ROCF was scored by both systems, and the immediate scores were subtracted from the delayed scores to generate "forgotten" scores that indicated the information that was lost during the 20 min interval.
The Trail-Making Test (TMT)	This test was used to assess visual scanning, motor speed, and cognitive flexibility. In Part A, the participants were instructed to connect 25 circles with numbers (1–25) that were randomly distributed ona sheet of paper (21×29.7 cm). This provided a baseline indication of their visual search speed and visual-motor functioning. Part B required the participants to connect 25 circles that contained numbers (1–13) or letters (A–L) and to alternate sequentially between the numbers and letters (that is, 1-A-2-B-3-C, etc.). This enabledthe incorporationof the additional component of shift flexibility. The participants were instructed to connect the circles as rapidly as possible and received feedback when they connected them in the wrong order. The time taken to complete the task and the errors made in each part were recorded. The time for Part A was subtracted from the time for Part B to indicate the shift time.