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Original Research

The Effect of Equine-Assisted Activities in Children Aged 7–8 Years Inhibitory Control: An fNIRS Study

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Abstract

Background: Inhibitory control (IC), an important component of executive function, plays an important role in the overall development of children and has not been better studied in the field of equine-assisted activity (EAA). Therefore, this study investigated the effects of EAA on IC and the underlying brain neural mechanisms in children aged 7–8 years. **Methods**: Forty-eight healthy children aged 7–8 years from the Maple Leaf International School-Xi'an were randomly allocated to the equine-assisted activities group (EAAG) and control group (CG). The EAAG received 12 weeks of EAAG training from instructors at the MingLiu Horse Club while the CG continued their normal daily activities. The Flanker task was administered to both groups to assess IC pre- and post-intervention. Functional near-infrared spectroscopy (fNIRS) data were collected during the Flanker task to examine the underlying neural mechanisms. **Results**: Our findings indicate that after 12 weeks of EAA, the EAAG performed significantly better on the Flanker tasks than the CG, with congruent and incongruent higher accuracy and faster reaction ($p < 0.01$). Importantly, fNIRS data analysis revealed increased oxyhemoglobin levels in the right dorsolateral prefrontal cortex (R-DLPFC) ($p < 0.05$) of the EAAG during the Flanker congruent task after the EAA intervention. **Conclusions**: Collectively, EAA demonstrated a positive impact on IC and could effectively activate R-DLPFC in children aged 7–8 years. Furthermore, it enhanced the activation of the brain regions related to IC and increased cognitive ability in children aged 7–8 years.

Keywords: equine-assisted activities; children; inhibitory control; flanker task; fNIRS

1. Introduction

Executive function, also known as executive control or cognitive control, is a critical top-down mental process that demands attention and attentive participation [1–3]. A recent study showed that executive function is an important predictor of a child's physical and mental health, quality of life, performance at school, marital satisfaction and public safety [4]. Thus, it significantly impacts children's development during the critical periods of growth and development [5].

Executive function comprises several interrelated cognitive processes, including inhibitory control (IC), working memory and cognitive flexibility [6,7]. IC is a core component of executive function and is significantly associated with mental health, playing a pivotal role in all cognitive processes [8]. IC refers to an individual's ability to consciously control, inhibit, or override a superior response or ignore irrelevant information or environmental distractions by focusing instead on relevant information [7]. Several task paradigms have been used to study IC [6], including the Flanker task, Go/No-Go task, Stroop task, Simon task and Stop signal task. IC can be divided into two subcategories: controlled attention and cognitive inhibition [9]. Moreover, IC plays a critical role in solving complex problems such as mathematical questions [10], learning challenges [11] and emotional control [12]. Therefore, it is imperative to identify the factors that enhance IC [13].

Previous research showed that IC could improve performance in multiple sports. Studies have investigated the use of sports equipment in increasing IC. For instance, Spitzer *et al*. [14] divided 24 students into a TV-watching group and a basketball group and performed the Flanker task before and after 30 minutes of playing basketball and watching TV, respectively. The results showed that the basketball group demonstrated superior IC than the TV-watching group [14]. Similarly, Wen *et al*. [15] randomly assigned 145 children aged 7–8 years to a 40-minute resistance training, coordination training, soccer training and control group and conducted Go/No-Go task tests before and after the experiment. They reported that the soccer group showed faster responses and higher accuracy [15]. Additionally, physical exercise has also been shown to enhance IC. Cho *et al*. [16] randomly assigned 30 healthy elementary school students to the control and Taekwondo groups and used the Stroop task to test the participants' IC, with the latter receiving 60 minutes of Taekwondo training 5 times a week for 16 weeks. After the intervention, the Stroop task test scores were significantly higher in the Taekwondo group [16]. Despite the promising findings of previous research on the impact of sports equipment training or exercising on IC, there has been limited investigation into the effects of equine-assisted activities (EAA) on IC.

EAA represents a specific subgroup of activities of animal-assisted interventions comprising therapeutic horseback riding, vaulting, carriage driving and other non-riding activities with animals [17,18]. It uses various methods to guide interactions between humans and horses and promote positive activities that improve human physical functions and emotional well-being, which can alleviate physical and mental problems and improve human health and happiness [19]. Although EAA has demonstrated improvements in executive function [20], the underlying cerebral neural mechanisms via which EAA interventions improve individual cognitive function are poorly understood. To address this gap, functional near-infrared spectroscopy (fNIRS) was used to assess changes in the concentration of oxygenated and oxyhemoglobin molecules in the blood, providing a non-invasive method to measure cerebral blood oxygenation mechanisms in response to EAA [21]. Despite the potential of fNIRS in measuring the cerebral blood oxygen mechanism in EAA [22], few studies have used it to measure the cognitive benefits of EAA in the prefrontal and motor cortex of children aged 7–8 years.

The study aimed to investigate the impact of a 12-week EAA intervention on IC in 7–8-year-old children using fNIRS to explore neurological mechanisms in the prefrontal and motor cortex by measuring cerebral blood oxygenation during a cognitive task to provide insights into the impact of EAA on IC.

2. Methods

2.1 Subjects and Study Design

2.1.1 Subjects

The G*Power software (version 3.1.9.7; Franz Faul, University Kiel, Germany) was used to estimate the study sample size [23]. The specific parameters were set as follows: α = 0.05, power = 0.85, effect size = 0.35, statistical test = repeated measures, number of groups = 2, and number of measurements = 2. Under these conditions, the resulting sample size was 11 subjects per group. However, 50 subjects were recruited to improve the reliability of the study results. However, since two participants did not complete the 12-week EAA intervention, the overall cohort comprised 48 participants. They were recruited from Maple Leaf International School-Xi'an in a 1:1 boys and girls ratio. They were randomly assigned to an equine-assisted activity group (EAAG) and a control group (CG). They were instructed and recommended to avoid colds, fevers and sports injuries and continued to participate in training for 12 weeks, while the CG did not engage in more intense physical activity. The Institutional Ethical Committee of the Capital University of Physical Education and

Table 1. Basic information.

Group	Number	Age	Height (cm)	Weight (kg)	BMI (kg/m^2)
EAAG	24	7–8	126.6 $\pm$ 6.1	26.7 $\pm$ 3.6	16.6 $\pm$ 1.4
CG	24	7–8	128.6 $\pm$ 8.2	26.5 $\pm$ 3.5	16.0 $\pm$ 1.6

BMI, body mass index; EAAG, equine-assisted activities group; CG, control group.

Sports (Beijing, China) approved all procedures and protocols (No.2021A41). It should be noted that all subjects were accompanied by their parents as they learned about the contents of the training intervention and signed an informed consent form. The specific information of all participants is shown in Table 1.

Previous studies showed that medications [24], obesity [25], intelligence [26] and activity frequency [27] may impact IC. However, different from other sports, EAA has certain requirements for subjects. Specific requirements are shown in Table 2.

2.1.2 Study Design

A randomized controlled experimental design of 2 (group: EAAG, CG) $\times$ 2 (time: pre-test, post-test) was used in this study. The subjects were numbered and randomly divided into 2 groups of 24 each by the randomized function method in Excel 2019 (Microsoft., Redmond, WA, USA). The relevant experimental pre-test indicators included demographic variables (height and weight), Flanker task (congruent and incongruent task response times and accuracy) and fNIRS data (prefrontal and motor cortex oxyhemoglobin) during the completion of the Flanker task. The post-test was conducted at the end of the 12-week EAA intervention, and the test indicators were consistent with the pre-test (Fig. 1).

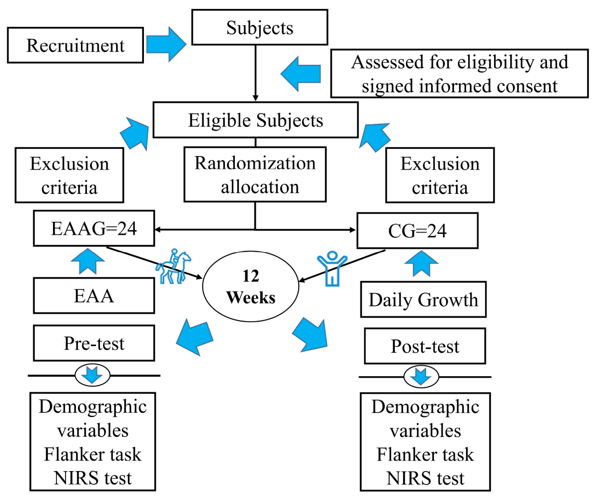

Fig. 1. Flow diagram of the study design. EAAG, equine-assisted activities group; CG, control group; NIRS, nearinfrared spectroscopy.

Table 2. Specific requirements information.

Inclusion criteria	Exclusion criteria
(1) Age 7–8 years with normal intelligence and no cognitive disorders	(1) Obesity, BMI ≥24
(2) Right-handed	(2) Motor impairment and physical disability
(3) In good health, without sports injuries and mental illnesses and taking no medications	(3) Participation in multiple sports training on Saturdays and Sundays
(4) Not enrolled in horseback riding training in the last 6 months	(4) Unwillingness to cooperate with horseback riding-related movements in the experimental intervention
(5) No history of horsehair allergies	(5) Fear of horses
(6) No fear of horses, with boldness, strong will and high interest in horseback riding	

Table 3. Equine-assisted activity (EAA) training Periodic protocol.

Time	Content
Weeks 1–4 (Basic training week)	
Week 1	Knowledge about horses and the enhancement of children's sensory processing abilities.
Week 2	Sensory processing abilities, the ability to perceive things and increase self-confidence and memory.
Week 3	Brief rides under the guidance of an equestrian instructor to enhance self-affirmation and further improve sensory processing.
Week 4	Establishment of correct neuromuscular control, training of children's cognitive functions.
Weeks 5–8 (Improvement training week)	
Week 5	Perceptual processing abilities, proprioception and spatial awareness.
Week 6	Perceptual processing abilities, proprioceptive and spatial senses, and core control.
Week 7	Perceptual processing abilities, proprioceptive and spatial, increase the gait of the horse for neuromuscular control in children.
Week 8	Perceptual processing abilities, proprioceptive and spatial, enhance neuromuscular control of the horse's gait for the children through rhythmic changes.
Weeks 9–12 (Intensive training week)	
Week 9	Perceptual processing abilities, proprioceptive and spatial, enhance neuromuscular control of the horse's gait for the children through rhythmic changes.
Week 10	Perceptual processing abilities, proprioceptive and spatial, enhancing neuromuscular control of the horse's gait for children through rhythmic changes.
Week 11	Perceptual processing abilities, proprioceptive and spatial; enhancement of neuromuscular control of the horse's gait for children through rhythmic changes; enhancement of children's memory and attention.
Week 12	Perceptual processing ability, proprioception, and spatial sense; enhancement of neuromuscular control of children's gait through rhythmic changes; enhancement of children's attention, discrimination, and information processing ability.

2.2 Intervention

The experimental protocol utilized in this study was adapted from Cook *et al.*'s work [28], entitled "Incorporating Game in Hippotherapy A Companion Book to the Brown Pony Series", which has been shown effective in improving various aspects of cognitive function, social interaction skills, neural control and coordination in riders. The content of the 12 weeks of EAA training is shown in Table 3.

The 12-week EAA comprised 2 training sessions per week for 45–55 minutes each. The experimental intervention took place every week 1 and 3 from 15:50–17:50 and was performed by 6 MingLiu Horse Club instructors, each responsible for 2–3 children. An example of the lesson is shown in Fig. 2 [28].

2.3 Measures

Each EAAG and CG subject underwent a pre-test within 1 week prior to training and a post-test within 3 days after training.

2.3.1 Flanker Task

The Flanker task, a traditional conflict paradigm for studying the influence of task-irrelevant information on processing task-relevant information [29], was used for assessing IC [6]. It was designed using the E-Prime software (version 2.0, Psychology Software Tools Inc., Pittsburgh, PA, USA). The congruent and incongruent Accuracy and Reaction times (RT) statistics were performed on the test results. During the experimental task, the participants were instructed to focus on the "+" symbol in the center of the screen as a cue to start the task. Subsequently, a sequence of five letter combinations was displayed on the screen for

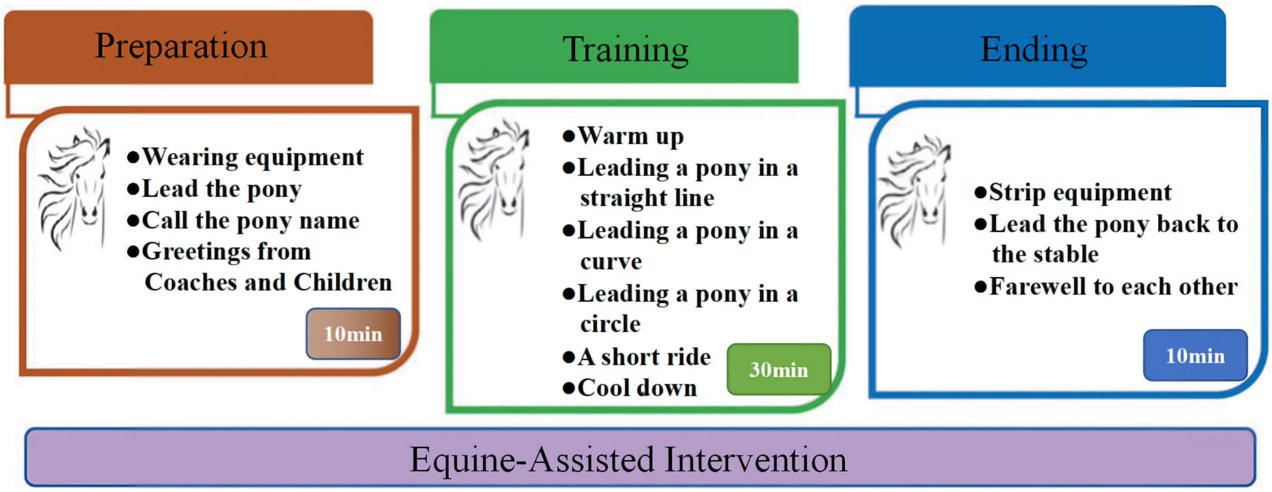

Fig. 2. Flow diagram of an EAA Intervention lesson.

1000 ms, with the middle arrow serving as the point of gaze and a stimulus interval of 1 second. This sequence of letters can occur in the following two conditions: consistent conditions, such as "FFFFFF" and "LLLLLL", and inconsistent conditions, such as "LLFLL" and "FFLLFF". The participants were required to respond as quickly and correctly as possible to the middle letter of each sequence by pressing the "F" key on the keyboard with their index finger if it was an "F" and the "L" key if it was an "L". The two conditions were presented in an equal and randomized manner, with the formal test comprising two segments, each of which required 60 judgments and 12 practice sessions before the formal test.

2.3.2 fNIRS Measurements

In this study, a portable NirSmart63 was used to collect raw signal light intensities from the prefrontal and motor cortex of the brain during the Flanker task. Then, we calculated the mean value concentration change of oxyhemoglobin (Oxy-HB) in the prefrontal and motor cortex using the absorbance difference based on the improved Beer-Lambert law [30]. The experimental acquisition system comprised 14 signal sources and 14 detectors, forming the following 35 channels: 1=S1-D1, 2=S1-D6, 3=S2-D2, 4=S2-D7, 5=S3-D2, 6=S3-D3, 7=S3-D8, 8=S4-D3, 9=S4-D4, 10=S4-D9, 11=S5-D4, 12=S5-D10, 13=S6-D5, 14=S6-D11, 15=S7-D1, 16=S7-D6, 17=S7-D12, 18=S7-D13, 19=S8-D2, 20=S8-D7, 21=S8-D8, 22=S9-D3, 23=S9-D8, 24=S9-D9, 25=S10-D4, 26 =S10-D9, 27=S10-D10, 28=S11-D5, 29=S11-D11, 30=S12-D12, 31=S12-D13, 32=S13-D11, 33=S13-D14, 34=S14-D11 and 35=S14-D14. According to Bordmann's partition, they were placed in the prefrontal and motor cortex, respectively (Fig. 3: Top, Front, Right and Left). The distance between the two probes on the signal acquisition cap was 3 cm, and they were arranged in a certain pattern to monitor the signals of the 35 channels covering the prefrontal and motor cortex. In addition, the more pronounced the activation of brain areas, the darker the color on the brain area map (pink > purple > blue).

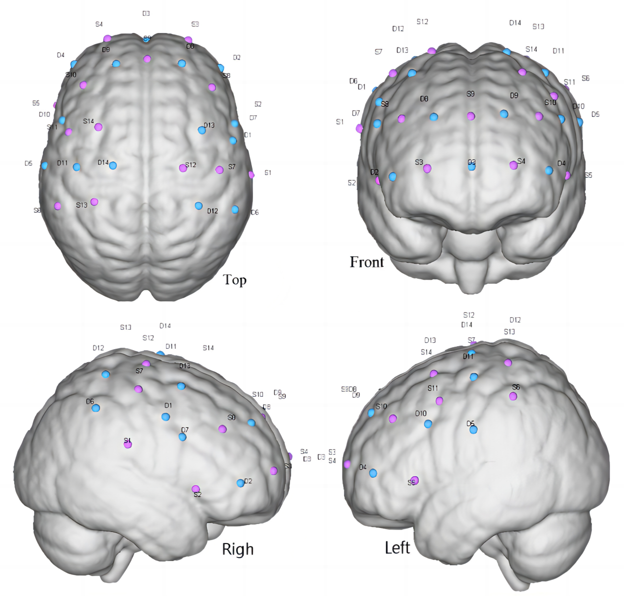

Fig. 3. Distribution of signal sources and detectors in the prefrontal and motor cortex.

2.4 Statistics and Analysis

Descriptive results are reported as means ± standard deviations. The assumption of normality was verified using the Shapiro-Wilk test. The *t*-test was used to perform the difference test between the EAAG and CG and the Oxy-Hb of each channel. The Flanker task data were analyzed using repeated measures Analysis of Variance (ANOVA). All statistical analyses were performed using the SPSS software version 26.0 (IBM Corp., Armonk, NY, USA), and

Table 4. Demographic and Flanker task data difference comparison.

Variables		EAAG	CG	T	p
Years		7.5 ± 0.5	7.5 ± 0.5	-	-
Height (cm)		126.6 ± 6.1	128.6 ± 8.2	–0.94	0.35
Weight (kg)		26.7 ± 3.6	26.5 ± 3.5	0.45	0.96
BMI (kg/m^2)		16.6 ± 1.4	16.0 ± 1.6	0.23	0.82
Accuracy (%)	Congruent task	0.86 ± 0.06	0.86 ± 0.06	–0.22	0.83
	Incongruent task	0.84 ± 0.07	0.86 ± 0.07	–1.12	0.25
RT (ms)	Congruent task	718.1 ± 100.3	708.6 ± 81.6	0.36	0.72
	Incongruent task	771.5 ± 87.9	762.9 ± 90.7	0.34	0.74

RT, reaction times.

significant differences are indicated by $p < 0.05$, whereby * represents $p < 0.05$ and ** represents $p < 0.01$.

3. Results

3.1 Demographic Variables and Flanker Task Difference Examination

The demographic variables included age, height, weight, body mass index (BMI), and the Flanker task, which included congruent and incongruent Accuracy and RT. The data were assessed for the EAAG and CG samples to reduce the effect of these factors on the experimental results by excluding demographic and IC differences between the two groups (Table 4).

Before conducting the independent samples *t*-test and chi-square test, all data underwent normal distribution testing, with a significance level of $p > 0.05$. We observed no significant difference between the EAAG and CG groups in terms of height (cm) (126.6 ± 6.1 vs. 128.6 ± 8.2; T = –0.94, p = 0.35), weight (kg) (26.7 ± 3.6 vs. 26.5 ± 3.5; T = 0.45, p = 0.96), BMI (kg/m^2) (16.6 ± 1.4 vs. 16.0 ± 1.6; T = 0.23, p = 0.82), congruent task accuracy (0.86 ± 0.06 vs. 0.86 ± 0.06; T = –0.22, p = 0.83), incongruent task accuracy (0.84 ± 0.07 vs. 0.86 ± 0.07; T = –1.12, p = 0.25), congruent task RT (718.1 ± 100.3 vs. 708.6 ± 81.6; T = 0.36, p = 0.72) and incongruent task RT (771.5 ± 87.9 vs. 762.9 ± 90.7; T = 0.34, p = 0.74). Altogether, these results indicated no difference in demographic variables and Flanker task between the two groups in the pre-test.

3.2 Flanker Task Results

To investigate the changes in EAA on the IC of children aged 7–8 years, this study used 2 (group: EAAG, CG) × 2 (time: pre-test, post-test) repeated measures ANOVA to determine the Flanker task data pre-and-post and the results (Table 5).

In the congruent task accuracy (%), no significant main effect of group was observed, F(1,46) = 0.58, p = 0.45 > 0.05, η^2 partial = 0.01, while there was a significant main effect of time, F(1,46) = 12.91, p = 0.001 < 0.01, η^2 partial = 0.22, indicating a significant interaction effect of group*time, F(1,46) = 9.21, p = 0.004 < 0.01, η^2 partial = 0.17 (Table 5). In the analysis of simple effects, a highly significant difference ($p < 0.01$) pre-and-post experiment was observed in EAAG, with a congruent task accuracy (%) pre-and-post experiment of 0.85 ± 0.06 and 0.89 ± 0.05, indicating an increase by 0.04, as well as in CG, which was 0.84 ± 0.07 and 0.87 ± 0.05, with an increase of 0.03 (Table 6).

Table 5. Statistical results of repeated measures ANOVA for two groups.

Variables	df	F	p	η^2 partial
Congruent task accuracy (%)				
Time	1	12.91	0.001**	0.22
Time*Group	1	9.21	0.004**	0.17
Error	46			
Group	1	0.58	0.45	0.01
Error	46			
Incongruent task accuracy (%)				
Time	1	5.85	0.02*	0.11
Time*Group	1	3.29	0.08	0.07
Error	46			
Group	1	0.46	0.51	0.10
Error	46			
Congruent task RT (ms)				
Time	1	11.52	0.001**	0.20
Time*Group	1	19.42	0.000**	0.30
Error	46			
Group	1	0.87	0.36	0.20
Error	46			
Incongruent task RT (ms)				
Time	1	40.57	0.000**	0.47
Time*Group	1	24.49	0.000**	0.35
Error	46			
Group	1	0.89	0.35	0.02
Error	46			

Note: $^*p < 0.05$; $^{**}p < 0.01$.

In the incongruent task accuracy (%), there was no significant main effect of group, F(1,46) = 0.46, p = 0.51 > 0.05, η^2 partial = 0.10, while there was a significant main effect of time, F(1,46) = 5.85, p = 0.02 < 0.05, η^2 partial = 0.11, as shown by post hoc multiple comparisons,

Table 6. Comparison of Flanker task data differences between the two groups.

Test name	Group	Pre-test	Post-test	WGV
				Mean of values
Congruent task accuracy (%)	EAAG	0.85 ± 0.06	0.89 ± 0.05	0.04**
	CG	0.84 ± 0.07	0.87 ± 0.05	0.03
	DBG	0.03	0.02	
Incongruent task accuracy (%)	EAAG	0.84 ± 0.07	0.87 ± 0.05	0.03**
	CG	0.86 ± 0.07	0.87 ± 0.06	0.01
	DBG	–0.02	0.01	
Congruent task RT (ms)	EAAG	718.07 ± 100.34	663.52 ± 71.65	–54.55**
	CG	708.89 ± 90.61	715.63 ± 74.57	6.74
	DBG	9.18	–52.11**	
Incongruent task RT (ms)	EAAG	771.07 ± 87.88	699.86 ± 73.69	–71.21**
	CG	762.89 ± 90.68	753.91 ± 92.94	–8.98
	DBG	8.18	–54.05*	

Note: WGV, Within-group variation; DBG, Differences between groups; *$p < 0.05$; **$p < 0.01$.

whereby the EAAG of pre-and-post experiment measurements were highly significantly different ($p < 0.01$), while no significant interaction effect for group*time was observed, F(1,46) = 3.29, $p = 0.08 > 0.05$, η^2 partial = 0.07 (Table 5).

In the congruent task RT (ms), there was no significant main effect of group, F(1,46) = 0.87, $p = 0.36 > 0.05$, η^2 partial = 0.20, but there was a significant main effect of time, F(1,46) = 11.52, $p = 0.001 < 0.01$, η^2 partial = 0.20. In addition, there was also a significant interaction effect of group*time in the congruent task RT, F(1,46) = 19.42, $p = 0.000 < 0.01$, η^2 partial = 0.30 (Table 5). In the analysis by simple effects, a highly significant difference was observed in EAAG pre-and-post experiment ($p < 0.01$), with a congruent task RT of 718.07 ± 100.34 and 663.52 ± 71.65 (an improvement of 54.55), and in CG, with a congruent task RT pre-and-post experiment of 708.89 ± 90.61 and 715.63 ± 74.57 (a decrease of 6.55). The congruent task RT in the EAAG improved by 61.29 compared to the CG (Table 6). However, in terms of targeting between groups, there was a highly significant difference between the EAAG and CG post-experiment ($p < 0.01$).

In the incongruent task RT (ms), there was no significant main effect of group, F(1,46) = 0.89, $p = 0.35 > 0.05$, η^2 partial = 0.02, while there was a significant main effect of time, F(1,46) = 40.57, $p = 0.000 < 0.01$, η^2 partial = 0.47. Additionally, we also observed a significant interaction of group*time effect, F(1,46) = 24.49, $p = 0.000 < 0.01$, η^2 partial = 0.35 (Table 5). In the analysis by simple effects, there was a highly significant difference in EAAG pre-and-post experiment ($p < 0.01$), with an incongruent task RT of 771.07 ± 87.88 and 699.86 ± 73.69 (an improvement of 71.21), and in the CG, with an incongruent task RT pre-and-post experiment of 762.89 ± 90.68 and 753.91 ± 92.94 (an improvement of 8.21). The incongruent task RT of the EAAG was 62.23 higher than that of the CG (Table 6).

3.3 fNIRS Results

After 12 weeks of EAA intervention, the raw signals from the congruent task test were collected using NirSmart63 during the Flanker task in the two groups, followed by transformation using the NirSpark software (version 1.7.5, NirScan, HuiChuang, Beijing, China) to derive the change in Oxy-Hb concentration in each channel in the prefrontal and motor cortex in the EAAG and CG, respectively. The mean values of each channel in each of the 24 subjects were processed separately and combined with the paired-samples t-test to yield significant differences in the changes of each channel pre-and-post EAAG and CG, respectively (Table 7).

In this study, a pair of adjacent light sources and a detector were used to form a channel, and we calculated the intra-group average of the mean at the channel level. Then, the image was generated by the interpolation method of inverse distance [31], as shown in Figs. 4,5.

The values of changes in Oxy-Hb in each channel in the prefrontal and motor cortex in the pre-and-post congruent task in EAAG and CG were examined by a paired-sample t-test. The results showed a statistical difference ($p < 0.05$) between the EAAG pre-and-post in channels 7, 21 and 23 (pink areas), as shown in Fig. 6. However, there was no statistical difference in CG. According to Bordmann, channels 7, 21 and 23 belong to the right dorsolateral prefrontal cortex (R-DLPFC).

In the Flanker task test, the paired-sample t-test for the incongruent task individual channels data was not significantly different between EAAG and CG ($p > 0.05$).

4. Discussion

Our results showed that 12 weeks of EAA in EAAG can improve performance based on the Flanker task, as indicated by a reduction in RT and an increase in accuracy, and enhance brain activation of the R-DLPFC in children

Table 7. Channel changes of Oxy-Hb in each channel.

Channel	S-D	EAAG		T	*p*	CG		T	*p*
		Pre	Post			Pre	Post		
1	S1-D1	–0.0035	0.0042	–1.34	0.27	–0.0178	–0.0076	0.24	0.83
2	S1-D6	0.0078	–0.0040	0.78	0.49	0.0067	0.0025	1.65	0.14
3	S2-D2	0.0012	0.0013	–0.08	0.94	–0.0155	–0.0165	–0.13	0.90
4	S2-D7	0.0007	–0.0001	0.49	0.65	–0.0300	–0.0228	–1.14	0.11
5	S3-D2	0.0041	0.0058	–0.39	0.71	0.0014	–0.0202	1.20	0.30
6	S3-D3	–0.0008	0.0028	–0.89	0.42	0.0023	–0.0180	1.82	0.14
7	S3-D8	0.0003	0.0055	–3.08	0.04*	–0.0045	–0.0176	1.79	0.15
8	S4-D3	–0.0007	0.0052	–0.84	0.45	0.0043	–0.0090	1.28	0.27
9	S4-D4	0.0052	0.0071	–0.29	0.79	–0.0098	–0.0184	0.83	0.45
10	S4-D9	–0.0022	0.0038	–1.28	0.27	0.0063	0.0003	0.51	0.64
11	S5-D4	–0.0044	0.0043	–1.91	0.13	–0.0074	–0.0088	0.88	0.43
12	S5-D10	–0.0017	0.0022	–1.87	0.14	–0.0218	–0.0129	–0.81	0.46
13	S6-D5	0.0082	0.0026	0.94	0.42	0.0065	–0.0165	2.31	0.10
14	S6-D11	0.0111	0.0028	0.87	0.45	–0.0167	–0.0158	1.89	0.16
15	S7-D1	0.0043	0.0052	–0.41	0.71	–0.0155	0.0000	–0.84	0.46
16	S7-D6	0.0057	0.0020	–0.02	0.99	0.0003	–0.0136	–0.16	0.88
17	S7-D12	0.0097	0.0084	–0.04	0.97	–0.0277	–0.0285	–0.92	0.42
18	S7-D13	0.0011	0.0049	–0.77	0.50	0.0085	–0.0171	0.88	0.45
19	S8-D2	0.0036	0.0033	0.07	0.95	0.0097	–0.0117	1.22	0.29
20	S8-D7	0.0039	0.0001	0.67	0.54	0.0020	0.0014	–0.08	0.94
21	S8-D8	0.0044	0.0085	–4.28	0.01*	0.0081	–0.0149	0.75	0.49
22	S9-D3	–0.0004	0.0057	–2.05	0.11	–0.0094	–0.0121	0.03	0.98
23	S9-D8	–0.0040	0.0020	–4.09	0.01*	0.0085	–0.0192	0.70	0.52
24	S9-D9	–0.0042	–0.0002	–0.89	0.42	0.0236	–0.0291	2.06	0.11
25	S10-D4	–0.0022	0.0060	–1.33	0.25	–0.0097	–0.0016	0.31	0.77
26	S10-D9	0.0003	0.0037	–1.16	0.31	0.0065	–0.0140	1.60	0.18
27	S10-D10	0.0019	0.0062	–0.80	0.47	0.0198	–0.0121	2.41	0.07
28	S11-D5	–0.0026	–0.0046	0.28	0.79	0.0008	0.0175	–1.87	0.16
29	S11-D11	–0.0025	0.0017	–0.79	0.49	0.0246	–0.0051	0.65	0.56
30	S12-D12	0.0059	0.0006	0.80	0.48	–0.0198	–0.0179	–0.03	0.97
31	S12-D13	0.0134	0.0042	0.85	0.46	0.0000	–0.0045	–0.15	0.89
32	S13-D11	0.0114	0.0010	1.02	0.38	0.0055	0.0018	0.48	0.67
33	S13-D14	0.0037	0.0031	0.02	0.99	–0.0157	–0.0216	0.71	0.53
34	S14-D11	0.0004	0.0046	–1.00	0.39	0.0011	0.0001	–0.04	0.97
35	S14-D14	–0.0041	0.0041	–0.97	0.40	0.0062	–0.0107	1.01	0.39

Note: $^{*}p < 0.05$.

aged 7–8. Thus, EAA may improve the IC and enhance the activation of the brain regions related to IC, at least using this study setting.

4.1 IC Changes

Our findings suggest that 12 weeks of EAA increased IC to some extent in children aged 7–8 years. Previous studies have shown that IC development rates vary at different stages. Anderson *et al*. [32] found that 6–7 years was a sensitive period for development, with growth slowing down after age 7 and leveling off after age 10. In this study, the subjects belonged to this age group. Training load has always been an important aspect of sports and must be emphasized, as the amount of exercise intensity and time may also directly affects IC. A previous study showed that a chronic exercise cycle of 12–24 weeks, with an exercise time of 50–90 min/week and frequency of 2–3 times/week, significantly affected IC [33]. The training load requirements of our experiment were largely consistent with these findings and may have a positive impact. Additionally, supportive evidence was found in a study on open- and closed-skill sports [34]. It is well known that closed skills sports are performed in a relatively stable and predictable environment, in which motor actions are repetitive and unrelated to the external environment, whereas open skills sports are performed in a dynamic and changing environment that requires constant adaptation to external stimuli [35]. EAA is an open-skill sport that requires overcoming the distractions of the external environment, maintaining a high level of concentration, and ultimately automating a complex physical activity. These complex movements require increased cognitive involvement [36], avoiding incorrect technical

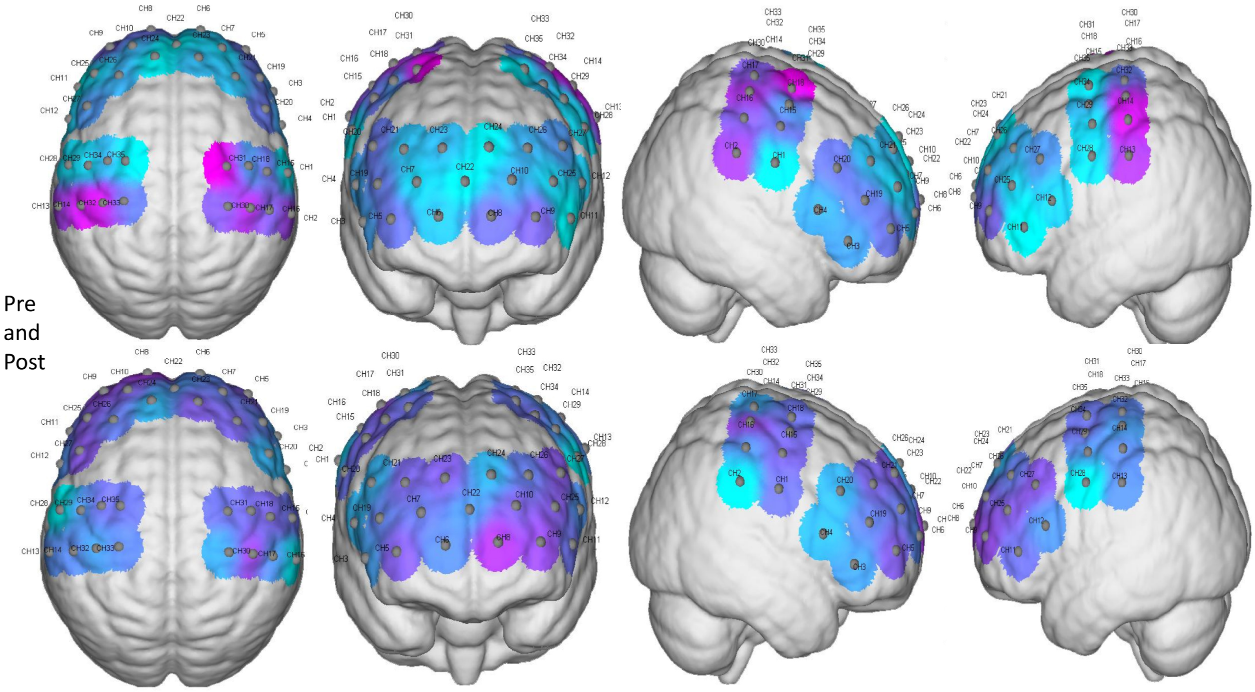

Fig. 4. Brain activation of prefrontal and motor cortex congruent task test in EAAG. The color reflects the mean of each region on the time scale, and the purple color represents higher activation than the blue–colored regions. The gray node represents the channel formed by each light source probe and detector probe, and the channel number is the label of the channel.

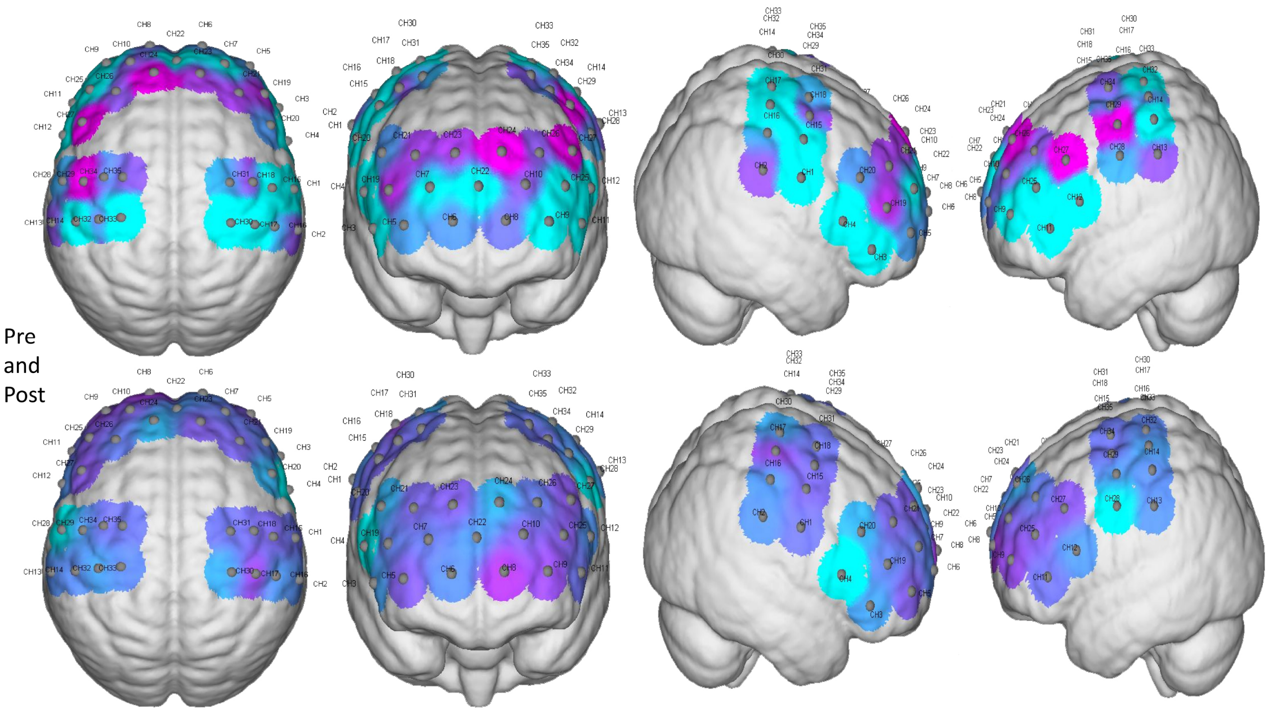

Fig. 5. Brain activation of prefrontal and motor cortex congruent task test in CG.

movements and activating more brain systems [37]. Thus, the nervous system regulates and controls both simple and complex movements, with the brain playing the most significant and prominent regulatory role. Related studies have found that sports with greater cognitive involvement are more effective in exerting further positive effects on chil-

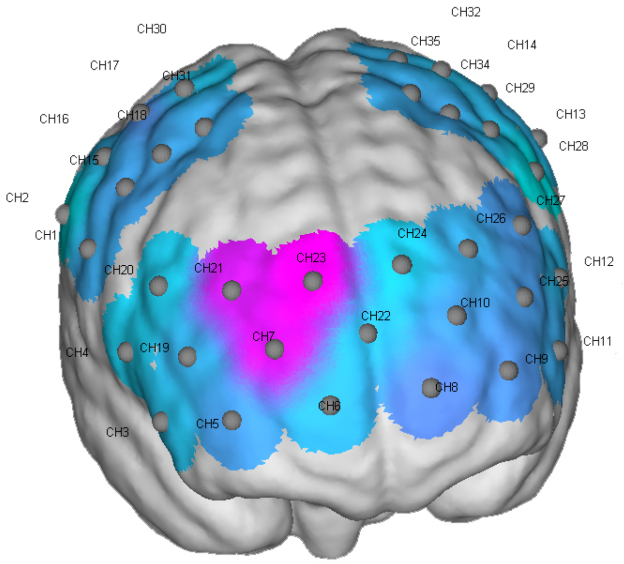

Fig. 6. Brain activation of significant channel regions in EAAG.

dren's cognitive abilities than sports without cognitive involvement [37]. In addition, riders are required to maintain a high degree of attention and tension during the whole process, which helps improve their attention retention. Studies have shown that EAA can effectively improve children's attention [38,39] and may further improve their IC.

4.2 Brain Activation Status

In this study, it was observed that 12-week EAA activated the R-DLPFC in the Flanker congruent task. The changes in the Oxy-Hb in the R-DLPFC of the brain indicate an increase in local cerebral blood flow triggered by the activation of neuronal cells in the cerebral cortex. According to the principle of neural cell coupling, increased local brain oxygenation suggests that the brain needs to recruit more neural resources [40], which in turn indicates that EAA training requires constant activation of neural processing associated with the R-DLPFC to adapt to the more complex cognitive demands of the relevant training task. It has been shown that high accuracy during the execution of attentional network tasks may originate from the high neural activation of the right frontoparietal network [41], which showed a clear right hemisphere dominance [42,43]. Moreover, meta-analysis correlation results also showed that the brain activation sites associated with the Flanker task were mainly found in the R-DLPFC [44] and that different types of cue conditions were associated with frontoparietal network activation. Comparatively, R-DLPFC is thought to be an important component of neural processing in the right frontoparietal network [45]. Significant activation in this region also reflected reliable performance in extrinsic behavior, as indicated by the observed increased accuracy and decreased reaction time in the Flanker task. The dorsolateral prefrontal cortex coordinates the rest of the human brain and plays a crucial role in arithmetic and executive functions. Numerous investigations closely related to the activation model of brain regions in the Flanker task show that the activation is mainly present in the R-DLPFC [44]. In addition, fNIRS has also been used to monitor prefrontal cortex oxygenation in other sports and showed that testing different sports effectively activated R-DLPFC. Miao Yu *et al*. [46] found significant activation of the R-DLPFC in all three groups through a comparison between elite, expert and novice ice hockey athletes, which was concordant with our present study.

Neuropsychological and neuroimaging findings link dorsolateral prefrontal activation and top-down attentional control [47]. In addition, recent findings reveal an important role of R-DLPFC in task preparation [48], which plays an irreplaceable and important role in human development. In this present research, the children selected were 7–8 years old and did not undergo relevant training, and there was a greater need to enhance top-down attentional control to always pay attention to the outside world and changes in the trainer's commands. This continuous state probably enhanced the attentional control of the riders, signifying that EAA training might lead to greater stimulation of the right R-DLPFC, which is related to attentional control in cognitive function. Previous studies have shown the importance of R-DLPFC activation in top-down attention [49]. Thus, it could be deduced that EAA training activated the R-DLPFC and improved the ability to process conflicting information, which in turn enhanced participants' cognitive functioning. The result of better performance in completing cognitive tasks provides neurophysiological evidence that EAA training promotes the development of cognitive function and further supports the behavioral findings of this study.

Other prefrontal and motor cortex regions did not show significant activation changes. One possible explanation could be that cognitive changes depend to a substantial extent on prefrontal cortex function, which leads to a possible reason for the lack of significant changes before and after activation of the motor cortex. In addition, important subcortical areas, such as the hippocampus, are difficult to detect and could be considered a limitation of the present study.

5. Conclusions

The EAA positively impacts IC and effectively activates R-DLPFC. It also demonstrated promising abilities to activate the brain regions related to IC and increase cognitive ability in children aged 7–8 years.

Availability of Data and Materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Author Contributions

HW and QT designed the research study. LQ and YZF performed data processing. XDC for data processing, interpretation of results, editing and writing. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

All participants signed a written informed consent form according to the Helsinki Declaration and satisfied the criteria for fNIRS. The Institutional Ethical Committee of the Capital University of Physical Education and Sports (Beijing, China) approved all procedures and protocols (No.2021A41).

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Conflict of Interest

The authors declare no conflict of interest.

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