The Effect of Neurocognitive-Academic Training to Improve Chinese Handwriting in Children with ADHD

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HOW TO CITE:
Jiang, H., Johnstone, S. J., Sun, L., Zhang, D-W., & Jing Cheng, J. (0000). The Effect of Neurocognitive-Academic Training to Improve Chinese Handwriting in Children with ADHD. *International Journal of Special Education, 39*(2), 87-101.

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DOI:
https://doi.org/10.52291/ijse.2024.39.24

ABSTRACT:

Neurocognitive-academic training (NAT) is an innovative training model that aims to concurrently improve academic behavior and achievement for children with ADHD. We used a single-subject design with a changing criterion design to investigate the effects of NAT on improving behavior and performance during Chinese handwriting tasks for children with ADHD. Four children from varied backgrounds received the training in three phases (i.e., Behavioral Presentation, Strategy and Progression, and Maintenance and Self-reflection). Functional relationships have been established between NAT and on-task behavior, speed, and quality in Chinese handwriting tasks. Overall, increasing trends with large or very large effect sizes in the Maintenance and Self-reflection phase and the three-week follow-up could be concluded. This case study supports the use of NAT to improve academic-related behavior and achievement in practicing Chinese handwriting in children with ADHD. We also discussed the implications and limitations of this preliminary study and encouraged future inquiry.

Keywords: ADHD, Neurocognitive Training (NCT), Academic Training, Chinese Handwriting, on-task Behavior, Case Study

INTRODUCTION

Attention-deficit/hyperactivity disorder (ADHD) is a common neurodevelopmental disorder of childhood that is characterized by persistent inattentive and/or hyperactive-impulsive symptoms (APA, 2013). It is linked to executive function deficits, affecting academic and social performance (Barkley, 2015). US surveys indicate a rise in the prevalence of ADHD among children and adolescents from 6.1% to 10.2% over 20 years (Xu et al., 2018), with China reporting a similar rate of 10.4% (Li et al., 2022). In learning environments, external distractions exacerbate ADHD symptoms, with children more prone to off-task behavior in academic settings (DuPaul & Joshua, 2015; Imeraj et al., 2013). Behavioral interventions can improve on-task behavior in controlled settings but not in classrooms (Jiang et al., 2021).

Handwriting is a complex process that involves cognitive processes, skills, emotional well-being, and content (Vekaria & Peverly, 2018). Learners need to master legibility (e.g., overall clarity), writing speed, and spatial arrangement (e.g., tortuosity, sizing) to perform well in handwriting tasks (Rosenblum, 2018). Children with ADHD often struggle with these aspects, showing poorer performance than their peers (Graham et al., 2016). Handwriting difficulties such as erasing more often, using more pressure, and spending more "in-air" time during writing contribute to lower task efficiency, lead to more inattentive behavior, and ultimately form a negative cycle in learning outcomes. Their challenges, including frequent erasing, excessive pressure, and prolonged "in-air" time, diminish writing efficiency and can lead to a cycle of inattention and diminished learning outcomes (Rosenblum, 2018).

Chinese Handwriting in Children with ADHD

In the context of Chinese handwriting, which is regulated by strict orthographic and syntactic rules, the assessment criteria revolve around speed, accuracy, and legibility (Lam & McBride, 2018). Mastery of written Chinese necessitates the knowledge of at least 3000 frequently used characters, emphasizing character recognition and writing as foundational literacy goals within the national Chinese language curriculum (MOE, 2022). Furthermore, the process of mastering a Chinese character encompasses three key dimensions: adherence to stroke order and radicals, comprehension of the character's structural framework, and cultivation of an aesthetic sensibility towards the written form.

Prior research underscores the challenges children with ADHD encounter in writing Chinese characters (Hung & Chang, 2022), with four key insights: First, they struggle with character memorization and often omit strokes or radicals (Lee et al., 2014). Second, attention plays a pivotal role in writing performance (Hung & Chang, 2022), affecting both accuracy and speed (Shih et al., 2018). Third, the interplay between cognitive-linguistic skills and fine motor abilities is essential for handwriting improvement (Hung & Chang, 2022; Li-Tsang et al., 2018). Lastly, in complex writing tasks like sentence construction, children with ADHD can achieve performance levels comparable to their typically developing peers (Lee et al., 2014).

Neurocognitive-Academic Training: A Dual Training Model

A substantial body of research correlates executive function (EF) deficits with handwriting challenges in children with ADHD. Specifically, working memory capacity has been shown to predict handwriting legibility, the frequency of erasures, and the pressure applied while writing (Rosenblum, 2018). Completing writing tasks, such as note-taking in class, necessitates the integration of various competencies—including verbal, visual, and spatial skills—within the working memory domain (Vekaria & Peverly, 2018). Inhibitory control is crucial for mitigating distractions and sustaining focus during academic tasks (Barkley, 2015). It directly impacts handwriting fluency and spelling and indirectly influences text length, syntactic complexity, and narrative content through its effect on handwriting fluency (Drijbooms et al., 2015). Coordinating diverse EF domains is essential for regulating handwriting processes, including writing pressure (Rosenblum, 2018), text production (Salas & Silvente, 2020), and overall writing output (Young-Suk, 2022).

For children with ADHD, an effective intervention must prioritize the enhancement of cognitive functions, particularly attention and memory, to support sustained attention during handwriting tasks (Racine et al., 2008). It should also foster basic Chinese character writing skills and an aesthetic sense under this focused state. It should also nurture fundamental Chinese character writing skills and an appreciation for the aesthetics of writing within a focused state. The intervention strategy must carefully balance task difficulty with the child's attention to optimize skill development, steering clear of overwhelming complexity on one hand and under-challenging simplicity on the other (DuPaul & Joshua, 2015).

We introduce Neurocognitive-Academic Training (NAT), an innovative model designed to elevate on-task behavior and academic performance in Chinese hand-

writing tasks for children with ADHD. NAT has three key elements: Neurocognitive Training (NCT), positive teacher feedback, and academic tasks, all of which have been proven effective in our previous research and are integrated across every phase to progressively build children's capabilities. As children's skills advance, the difficulty, duration, and complexity of NCT tasks and academic assignments are incrementally increased, with teachers providing increasingly detailed and comprehensive positive feedback to meet the evolving needs of the children

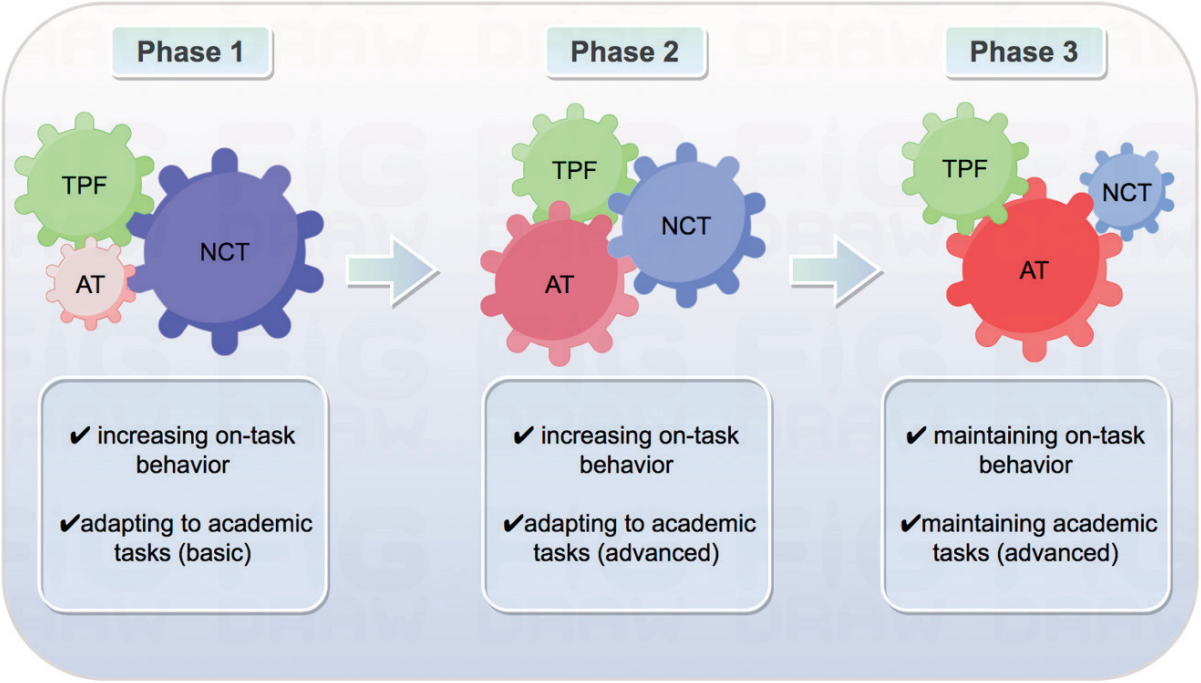
NAT model is structured into three distinct phases (Figure 1), each designed to incrementally enhance on-task behavior and academic performance in Chinese handwriting tasks for children with ADHD. Below is a detailed breakdown of each phase and their specific contributions to behavioral and academic changes:

Phase 1: Behavioral Presentation. This foundational phase is crucial for establishing on-task behavior. It introduces children to academic tasks at a comfortable level of difficulty and duration, ensuring that they can engage without being overwhelmed. The primary goal is to foster an initial period of focused attention, laying the groundwork for more complex tasks ahead. The specific contribution of this phase is to initiate and reinforce on-task behavior, providing a stable starting point for subsequent phases.

Phase 2: Strategy and Progression. Building on the on-task behavior established in Phase 1, this phase introduces more challenging academic tasks. The focus shifts to developing strategies that help children maintain their focus and manage distractions effectively. As the tasks become more complex, children learn to apply behavioral and academic strategies, such as time management and self-monitoring, to stay on-task. The specific contribution of Phase 2 is to enhance on-task behavior in the context of increasing academic demands, preparing children for higher levels of challenge.

Phase 3: Maintenance and Self-reflection. In the final phase, the emphasis is on sustaining the on-task behavior while further increasing the difficulty and length of academic tasks. Children are encouraged to self-reflect on their performance, identify areas for improvement, and set personal goals. This phase is designed to help children adapt to more demanding tasks with high on-task behavior, accumulating learning experiences that foster self-regulation and independent learning. The specific contribution of Phase 3 is to solidify on-task behavior and self-regulation skills, enabling children to independently manage their learning and maintain academic progress in the face of escalating challenges.

NAT represents an advancement over traditional approaches in addressing the complex needs of children with ADHD. Conventional methods often focus on



Note: NCT refers to neurocognitive training, TPF refers teachers' positive feedback, AT refers to academic tasks

Figure 1 Concept map of the NAT training program

symptom management rather than enhancing cognitive functions and academic skills, which are crucial for the holistic development of children with ADHD (Hinshaw & Arnold, 2015). It is designed to foster basic Chinese character writing skills and an aesthetic sense under focused attention, balancing task difficulty with attention levels to optimize skill development, avoiding both overwhelming complexity and under-challenging simplicity (DuPaul & Joshua, 2015). The model rests on two research foundations.

Firstly, it is grounded in neurocognitive training (NCT), which integrates cognitive exercises with neurofeedback to enhance cognitive functions and psychological self-regulation (Johnstone et al., 2012). NCT has been shown to normalize brain electrical activity and improve executive functions such as working memory and inhibitory control, which are commonly impaired in ADHD and directly impact academic performance (Luo et al., 2023).

Secondly, combining NCT with educational elements has been shown to improve academic performance, as indicated by enhanced on-task behavior and homework completion in single-subject studies (Jiang & Johnstone, 2015). However, the effectiveness of NCT appears context-dependent, with children exhibiting more off-task behavior in group settings compared to individual study environments (Jiang et al., 2021). To amplify the impact of NCT, we have included teachers' positive feedback as a strategic instructional tool, a practice supported by Fellman and colleagues (2020). After six sessions, children who received this feedback outperformed their peers in untrained tasks, highlighting the significance of strategic instruction in cognitive training outcomes (Jiang et al., 2022).

Our central goal in this study is to unlock the potential of NAT as a transformative intervention for children with ADHD, specifically targeting their Chinese handwriting skills - a critical yet challenging domain for this population. We aim to demonstrate the effectiveness of NAT in improving on-task behavior, writing speed, and handwriting quality and understand how these behavioral and performance changes evolve throughout the training program. This study is guided by three primary research questions to explore the effectiveness of NAT in enhancing academic-related behavior and performance among children with ADHD. 1) Is there a functional relationship between NAT and students' on-task behavior in Chinese handwriting tasks? 2) What is the effect of NAT on increasing Chinese handwriting speed? 3) What is the effect of NAT on increasing Chinese handwriting quality? The secondary research aim is to describe how behavior and handwriting performance changed throughout the training program.

METHOD

Participants and Setting

Student A, a 6-year-old male, was in the transfer period from kindergarten to primary school. His intellectual development level was normal, with an IQ of 100 based on Raven's Test results. He exhibits the symptoms and was diagnosed with the combined subtype (AD/HC-C) recently and was not on medication. His teacher has reported that Student A had a shorter sustained attention span than other children his age and that he could not sit quietly in the classroom while listening to stories or looking at picture books, often left his seat, and frequently disrupted the class. According to his mother, Student A was prone to impulsive behavior and had difficulty following adult instructions or advice when he became excited.

Student B, a 7-year-old female, was in the first grade of a regular primary school. Her intellectual development level was normal, with an IQ of 95 based on Raven's Test results. She was clinically diagnosed with ADHD predominantly inattentive presentation (ADHD-I) 6 months prior to this study but had not received medication treatment. According to the schoolteachers and parents, Student B was easily distracted, forgetful, and often procrastinated in academic work. Her Chinese handwriting speed was slow, and her Chinese language performance was below average compared to her classmates. Despite these challenges, the student had a positive attitude toward learning and adult instructions.

Student C, a 9-year-old male, was studying in the fourth grade of a regular primary school. His intellectual development level was good, scoring 110 on the Raven's test. He was clinically diagnosed with ADHD-I at the age of 8 and has been receiving medication treatment. While his attention symptoms had improved, his Chinese language scores were consistently at the bottom of the class. His main challenges in Chinese language learning included being off-task during class, limited language expression skills with frequent linguistic errors, and poor handwriting quality.

Student D, a 13-year-old male, was studying in the seventh grade at a special school. This school primarily admits children with neurodevelopmental disorders who struggle to adapt to regular schools. Student D had been clinically diagnosed with moderate to severe ADHD of the combined presentation (ADHD-C). His intellectual development level was below average, scoring 68 on

the Raven's test. He had difficulty concentrating and had a short attention span. During class, he displayed hyperactivity, inappropriate activities, and impulsive behavior. In the third grade, he transferred from a regular school to a special school. According to his current teacher, Student D's attention span was lower than his peers, and he frequently interrupted and left his seat during class. His homework was poorly completed, and his handwriting for Chinese copywriting assignments was messy.

These students were selected for their distinct ADHD presentations to explore the intervention's effectiveness across different cases (Yin, 2009). The intervention was conducted at a certified rehabilitation center in Eastern China, staffed by experienced special education teachers trained by the study's first author. The training included principles, steps, and procedures, with all teachers achieving 100% procedural fidelity before implementation.

INTERVENTION OVERVIEW

Tools and Techniques

NCT. We used *Focus Pocus*, a themed software application developed by the University of Wollongong (For a detailed introduction, please refer to Johnstone et al., 2017). The training program consists of 25 sessions, each taking 15 to 20 minutes to complete and consisting of 14 mini-games: four inhibitory control, four working memory, and six neurofeedback presented in a random order. Inhibitory control games required a tap or press response to frequently occurring 'Go' stimuli and no reaction to infrequently occurring 'Nogo' stimuli. Working memory games require storing information in memory and recalling it to act. Of the six neurofeedback games, two were attention-driven (mainly related to EEG beta power), two were relaxation-driven (mainly related to EEG alpha power), and two were a combination of attention and relaxation indices (referred to as 'Zen'). The difficulty of all games was self-adjusting, based on previous performance in that game type. A dry-sensor EEG device (Mindwave Mobile II, Neurosky, USA) was used to record brain electrical activity with an algorithmically derived summary score (e.g., attention and relaxation) used to control game-play during NF games and quantify attention levels during the inhibitory control and working memory games (for a review of the technique and device, see Zhang et al., 2023).

Handwriting tasks. We used a Chinese characters copying task, selecting characters based on the following criteria: 1) characters required for mastery in the national curriculum standards, 2) characters already learned by the children in school (excluding Student A), and 3) characters matching the grade level of the child. For instance, Student C was in the fourth grade, and he copied the characters learned in fourth grade, such as "亿", "予", "纠", and "闯". As Student A has not yet entered first grade, he was required to copy Chinese characters with three strokes or fewer such as "一", "二", "上", and "大". An HB pencil and A4 grid paper were used in the task. The duration of the task varied depending on the child's grade level. For grade 1, the baseline period and initial Phase 1 lasted for 5 minutes. For each subsequent grade level, the baseline period and initial Phase 1 duration were increased by an additional minute. In this study, Students A, B, C, and D completed the baseline period and initial Phase 1 tasks for four, five, eight, and eight minutes, respectively.

Teacher Positive Feedback. Teachers provided positive feedback during the NCT and handwriting tasks. The positive and specific feedback was formatted in four ways: 1) acknowledging performance, 2) offering suggestions, 3) motivating, and 4) answering questions. For various types of positive feedback and examples to NCT, please refer to Jiang et al. (2021). For the handwriting tasks, please refer to Appendix 1.

Training Procedure

A typical session consisted of NCT training and a Chinese character copying task. A child and a teacher formed a dyad. The training was undertaken in an independent room about 10 m^2 in size. Training frequency was three times per week. All training was video recorded by high-definition cameras. Each session contained four steps (see Appendix 1): **Step 1:** Warm-up (5 min). The dyad greeted each other. The child undertook preparations such as drinking water and using the restroom. **Step 2:** NCT training (25 to 30 min). The teacher sat next to the child during the training and only provided feedback before or after a specific game. **Step 3:** Break (10 min). The child left the training room and rested alone or played a game with the teacher. **Step 4:** Copying task (4 to 10 min). Before beginning the task, the teacher instructed the child (refer to Appendix 1 for details). The teacher then left the training room and entered the observation room while the child worked independently for a designated time. Once the task was over, the teacher returned to the training room and gave the child feedback.

Study Design

This study used a changing criterion design (CCD) to assess the effect of NAT on on-task behavior and out-

comes in Chinese handwriting tasks. CCD is a suitable single-case design for behavioral change associated with shaping or extending duration (Klein et al., 2017). CCD outperforms other single-case designs (e.g., reversal designs) in its insurance of continuous implementation and teaching ethics. This study used three periods to demonstrate the effectiveness of intervention, which is the most common design in CCD (Klein et al., 2017).

Baseline (A). The participants completed independent copying tasks in training rooms. The tasks (content and duration) were tailored to each child's study level and Chinese language curriculum. Each child completed six tasks at a frequency of three per week.

Treatment (B). This period consisted of three linear developmental sub-phases (B1, B2, and B3) based on the criteria of continuous progress. Additionally, B1, B2, and B3 corresponded to Behavior Presentation (Phase 1), Progression and Strategy (Phase 2), and Maintenance and Self-reflection (Phase 3), respectively. For the criteria of treatment acceptance, please refer to Appendix 1.

Follow-up (C). This period occurred two weeks after the termination of treatment. The participating children completed one copy task per week for three consecutive weeks. The protocol was the same as Baseline (A).

Dependent Variables

On-task behavior. We defined typical on-task behavior as looking at the proper materials and using the appropriate stationery to write assigned Chinese characters while quietly seated. Unrelated behavior included 1) leaving the seat, 2) looking away from study materials for more than 2 seconds, 3) putting head on the desk and not doing the assignment, and 4) writing unrelated characters or other things. The behavior was considered occurrent if observed at an interval of 10 consecutive seconds.

Handwriting speed. The speed assessment measured the average speed at which the students completed writing individual Chinese characters within a time frame (e.g., 5 minutes). We calculated the time taken to write each character. Then, we referred to the 'Measures for Grading and Assessing the Writing of Chinese Characters for Primary and Secondary School Students' (preliminary draft) developed by the State Language Commission of China (MOE, 2008). According to this standard, primary school students in grades 1 and 2 should write 60 to 70 qualified characters on grid paper within 20 minutes, while primary school students in grades 3 and 4 should write 150 correct characters on grid paper within 20 minutes. The writing speed criteria were three characters per minute for Cases A and B and 7.5 characters per minute for Case C. As Case D's writing level did not meet the typical developmental level of children the same age and is lower than that of Case C, we have adopted the same standard Case C for Case D.

Chinese handwriting quality. We utilized the assessment criteria from Meng's (2004) Chinese character copying test, which included evaluating the structure (size, strokes, and component structure), space (distance, proportion, and orientation), power, and legibility of the characters. The assessment scale was a 5-point scale (1= poor, 2= mostly poor, 3= neutral, 4= mostly good, 5= good). Two experienced primary school Chinese language teachers who had previously judged calligraphy competitions for primary school students rated Chinese handwriting quality. Firstly, the raters marked each work independently. Next, the two raters compared their scores for the same work. If the difference in their average scores was less than 0.5, then the average of their scores was used as the final score for the work. If the difference between their averages was more than 0.5, the two raters collaborated to score the work again and discuss any areas of disagreement until the difference between them was less than 0.5. During the scoring, 88% of the work had a score difference of less than 0.5 points between the raters.

Interobserver Agreement (IOA) and Procedural Fidelity (PF)

We conducted IOA and PF evenly across all conditions on 50% of each child's training sessions by reviewing the video records. The two observers were postgraduate students who majored in Special Education and achieved an A in an Applied Behavioral Assessment course. We determined IOA by tallying the number of observations in agreement, dividing it by the total number of observations (both in agreement and disagreement), and multiplying by 100. IOA were 89.3%, 92.3%, 93.7%, and 93.2% for Students A, B, C, and D, respectively. PF was checked by observing the videos from the entire training session (from Step 1 to Step 4). It was 100% across all children.

Data Analysis

Visual inspection of the level and descriptive statistics of the trend of the dependent variables were used to determine the participating children's performance in each phase. The 'nonoverlap of all pairs' (NAP) was used to analyze the variability during the baseline, as recommended by the What Works Clearinghouse panel (WWC, 2022). According to the WWC guideline, a baseline with a NAP of less than 0.85 indicates qualification to proceed with

the intervention. The 'percentage of all nonoverlapping data' (PAND; Parker et al., 2007) was used to determine the effect size between the baseline and B3 (the last treatment phase; Tanious & Onghena, 2021). We used the scheme proposed by Scruggs and Mastropieri (1998) to interpret the magnitudes of the nonoverlapping indices (>90% = very effective, 70-90% = effective, 50-70% = questionable, <50% = ineffective). Additionally, we used an analytical formula for the range-bound changing criterion designs based on the criterion level +/- 10% (CCD+/-10%) proposed by Manolov and colleagues (2020) to interpret the functional relation between the training and dependent variables and also to triangulate with PAND for the effect size.

RESULTS

On-Task Behavior

On-task behavior across each phase is shown in Figure 2. During baseline, Student A displayed low on-task behavior (mean = 32%, range = 25-38%) with a NAP of 0.33, indicating acceptable variability. After implementing B1 (i.e., Behavior Presentation), Student A immediately displayed an increasing trend in on-task behavior (mean = 80%, range = 71-88%). After the intervention proceeded to B2 (i.e., Progression and Strategy), Student A demonstrated a slightly higher level of on-task behavior (mean = 82%, rang e= 67-90%). During B3 (i.e., Maintenance and Self-reflection), Student A displayed a higher level of on-task behavior than during B1 and B2, averaging 88% (range = 79-95%). After termination of the intervention, Student A displayed the highest level of on-task behavior in three weeks, with an average of 90% (range = 88-93%). The PAND is 100% between the baseline and B3. Visual inspection of the graphic presentation of CCD +/-10% indicated that all values (except S15, which was lower than the low criterion) fell into the range, demonstrating the functional relation between the on-task behavior and the three-phase training.

During baseline, Student B displayed a medium level of on-task behavior (mean = 66%, range = 53-73%) with a NAP of 0.17. During B1, Student B exerted a higher level of on-task behavior (mean = 85%, range = 80-90%) with a steady and increasing trend. After entering B2, Student B displayed a slightly higher level of on-task behavior (mean = 87%, range = 69-97%), but two values (S16 and S17) fell into the range of baseline. During B3, Student B displayed a very high level of on-task behavior (mean = 97%, range = 93-100%) in an increasing and steady trend. Such a trend was maintained during the follow-up weeks (mean = 93%, range = 90-95%). The PAND was 100% between the baseline and B3. Visual inspection of the graphic presentation of CCD +/-10% indicated that most of the values fell into the range despite S16 and S17 being lower than the low criterion.

During baseline, Student C displayed a low to medium level of on-task behavior (mean = 62%, range = 42-73%) with a NAP of 0.28. During B1, Student C displayed a higher level of on-task behavior (mean = 88%, range = 81-93%) with a steady and increasing trend. After entering B2, Student C exerted a slightly lower level of on-task behavior (mean = 81%, range = 55-98%) with more fluctuations than B1. Three values (S12, S14, and S15) fell into the baseline range. During B3, Student C demonstrated a higher level of on-task behavior (mean = 94%, range = 88-97%) in an increasing and steady trend. The PAND was 100% between the baseline and B3. Visual inspection of the graphic presentation of CCD +/-10% indicated that most of the values fell into the range despite S12, S14, and S15 being lower than the low criterion.

During baseline, Student D displayed a low level of on-task behavior (mean = 22%, range = 13-27%) with a NAP of 0.39. After implementing B1, Student D displayed high on-task behavior (mean = 86%, range = 83-94%). During B2, Student D did not maintain the high level of the previous phase and demonstrated a lower level of on-task behavior (mean = 73%, range = 46-89%) with significant fluctuations. After entering B3, Student D displayed a high on-task behavior (mean = 91%, range = 88-93%) with an increasing and steady trend. During the three weeks of follow-up, Student D demonstrated a high level of on-task behavior (mean = 86%, range = 80-92%) but with a decreasing trend. The PAND was 100% between the baseline and B3. Visual inspection of the graphic presentation of CCD +/-10% indicated that nine out of 13 values fell into the range, but the values S12, S15, S16, and S17 were lower than the low criterion Figure 2).

Chinese Handwriting Speed

Chinese handwriting speed across each phase is shown in Table 1. During the baseline, only Student B reached the criteria for speed. During the intervention and follow-up, all the students met the requirements. Students A and B demonstrated increasing trends, whereas C and D showed decreasing trends. A post-hoc Pearson correlation analysis between on-task behavior and handwriting speed showed significant correlations between the two variables for Students A, C, and D (p = 0.000) and Student B (p = 0.012).

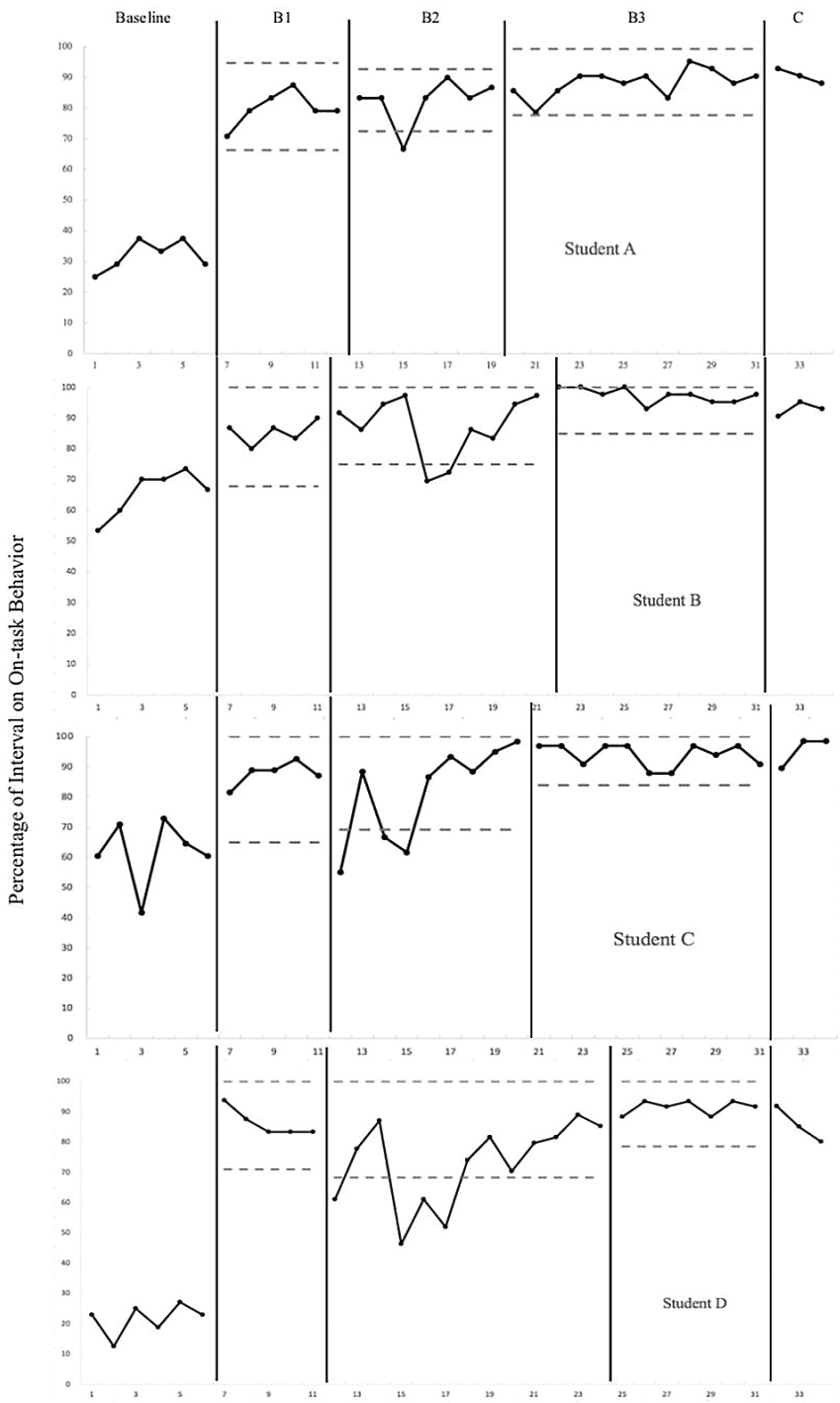


Figure 2 Percentage of intervals of on-task behavior across the baseline, interventions, and follow-up periods.

Chinese Handwriting Quality

The average rating of Chinese handwriting quality across each phase is shown in Table 1. Each student displayed low quality in the baseline and had made improvements since B1. The increasing trend was maintained in the successive training phases and follow-up. Students A, B, and C received positive ratings (>3) since B3, B2, and B1, respectively. The ratings of Student D were negative (<3) across the phases, and in B3 and follow-up were close to positive. A post-hoc analysis of the percentage of nonoverlapping data (PND; Scruggs & Mastropieri, 1998) compared the effect size of B2, B3, and C to B1. The PND indicated large to very large effect sizes for B3 and very large effect sizes for C across the students. A post-hoc Pearson correlation analysis of on-task behavior and handwriting quality showed significant correlations between the two variables (p = 0.000) for all the students.

Table 1 **Mean (SD) of Chinese handwriting speed and quality for Students A, B, C, and D across phases**

	Baseline	B1	B2	B3	C
Handwriting speed					
Student A	0.7 (0.10)	3.8 (2.44)	5.6 (2.39)	11.0 (1.06)	12.7 (0.54)
Student B	3.0 (1.15)	5.6 (2.34)	3.3 (1.77)	6.1 (3.24)	6.6 (1.37)
Student C	2.7 (0.89)	12.4 (1.22)	9.44 (2.11)	10.5 (1.16)	10.9 (0.44)
Student D	3.3 (1.53)	10.0 (1.59)	8.3 (3.04)	8.2 (3.00)	8.0 (1.65)
Handwriting quality					
Student A	1.0 (0.00)	1.8 (0.56)	2.4 (0.72)	3.8 (0.39) **	4.0 (0.20) **
Student B	2.3 (0.25)	2.8 (0.42)	3.4 (0.32)	3.6 (0.23) *	3.8 (0.12) **
Student C	1.8 (0.31)	3.2 (0.10)	3.2 (0.33)	4.0 (0.31) **	4.5 (0.00) **
Student D	1.3 (0.42)	2.3 (0.27)	2.2 (0.58)	2.9 (0.26) *	2.9 (0.12) **

Note: The effect sizes of B2 and B1, B3 and B1, and C and B1 were calculated for handwriting quality. ** refers to a very large effect size, * refers to a large effect size.

DISCUSSION

This pioneering study introduces a novel training model, Neurocognitive Academic Training (NAT), which innovatively fuses Neurocognitive Training (NCT) with academic instruction. It represents the first application of such an integrated approach aimed at enhancing Chinese language behavior and achievement in children with ADHD. The study's primary objective was to assess the impact of NAT on on-task behavior and academic performance in Chinese handwriting. Notably, both visual inspection and rigorous statistical analyses revealed a robust functional relationship between NAT and the targeted outcomes, characterized by substantial effect sizes. These compelling results underscore the potential of NAT as an intervention to significantly improve both behavioral and academic dimensions for children with ADHD.

Our previous research used NCT to improve symptoms and problem behaviors in children with ADHD (Luo et al., 2023). We also trained the teachers (Jiang et al., 2021) or parents (Jiang & Johnstone, 2015) as intervention implementers. We involved the school context (Jiang et al., 2022) to enhance the ecological validity of the intervention. However, the nature of the training in these studies could be considered a 'Train and Hope' approach (Stokes & Baer, 1977), which posits a simplistic, one-way impact of behavior on academic performance (Veloso et al., 2020). Our study adopts a sophisticated perspective: it acknowledges the intricate, bidirectional relationship between symptoms, behavior, and academic trajectories (Di Lonardo Burr et al., 2022). The NAT model goes beyond traditional approaches by viewing behavioral and academic development as interconnected parts of a unified academic functioning framework. This perspective is pivotal in understanding the complex dynamics of how behavior and academic performance mutually shape each other in the educational journey of children with ADHD.

The secondary research aim was to describe the change patterns of on-task behavior change and handwriting performance across the entire training program. On-task behavior showed an upward trend, with its highest and most stable level observed during the third training phase. During the first training phase, on-task behavior significantly increased compared to the baseline. However, in the early stage of the second training phase, students showed varying degrees of decline in on-task behavior. This situation improved in the latter half of the second stage. Therefore, the change pattern in on-task behavior was summarized as increasing quickly in Phase 1, significant fluctuations in Phase 2, and increasing steadily in Phase 3 and the three-week follow-up.

When considering Chinese handwriting performance, writing speed showed an upward trend. During training phase 1, writing speed met the criteria and was maintained in all subsequent phases. However, writing speed was prone to fluctuations and only showed a plateau after the follow-up. Therefore, the change pattern in writing speed was summarized as generally increasing and easy to improve but fluctuating. The intervention effect showed stability during the follow-up period. Writing quality showed a steady upward trend but reached positive or near-positive (Student D) rating levels in training phase 3. Phase 3 was more effective than the first two phases,

but the best intervention effect was observed during the follow-up period. Thus, the pattern of change in writing quality could be summarized as a steady increase with a slower onset of results, positive results until Phase 3, and best results during follow-up.

An old Chinese proverb says, "Give a man a fish, and you feed him for a day; teach a man to fish, and you feed him for a lifetime."This means that instead of providing material support, teaching people how to acquire things independently is better. It advocates for an educational paradigm that equips children with ADHD with adaptive learning strategies and enriches them with positive experiences, enabling them to cultivate self-sustaining, positive cycles of behavior and learning (such as Phase C in this study). The study's findings reveal that when provided with autonomy in task selection, students' engagement, speed, and quality of handwriting surged, underscoring the efficacy of NCT in comfortable task contexts. This finding echoes our previous study that reported that children with ADHD are prone to exert on-task behavior in the learning context with minimal external distractions (Jiang et al., 2021).

Conversely, the fluctuation in on-task behavior during the transition to prescribed tasks underscores the necessity for a dual focus on cognitive and academic skill development, especially in the context of Chinese character learning, which is inherently systematic and requires deliberate practice. It may not be that these children "do not want" to participate but find it "difficult" to participate due to insufficient skills. As age increases, the impact of academic factors on whether young adults with ADHD can enter higher education and career development may even exceed symptoms. Kuriyan and colleagues (2013) call for academic interventions for ADHD during primary and secondary school to promote long-term educational achievements. When controlling the negative effects of ADHD symptoms, factors such as academic engagement, motivation, and especially study skills are strong predictors of academic achievement in undergraduate students with ADHD (Dou et al., 2022).

The systematic representation of Chinese characters is reflected in their radicals and structures (Lam & McBride, 2018). Characters of the same type, such as '什', '仨', '休', and '作' , which are composed of the radical '亻', or characters like '乞', '公', '市', and '尖', which are the same width at the top and bottom (structure), have high internal relevance and are easily distinguished from other types. This makes them suitable for categorized teaching and practice. Learning to write Chinese characters is a continuous and technical process. Beginners need to master the Chinese character system and invest much time practicing writing to become proficient in penmanship (Hsiao et al., 2023). Therefore, providing a dual intervention model for cognitive development and learning skills conforms to the regularity of Chinese character practice and the developmental needs of children with ADHD. This may explain the steady increase in on-task and writing performance from the second half of B2, which was maintained or elevated until three weeks after the intervention was terminated.

Limitations and Implications for Future Research

The present study, while shedding light on the potential of Neurocognitive-Academic Training (NAT) for children with ADHD, comes with several limitations that warrant acknowledgment and further exploration. Firstly, our findings suggest that NAT may be more responsive to the academic needs of children with ADHD than traditional Neurocognitive Training (NCT). However, this assertion requires rigorous verification through future randomized controlled experiments to establish the comparative academic effectiveness and efficacy of NAT versus NCT.

Secondly, this study did not involve a participant with clinically diagnosed ADHD of predominantly hyperactive/impulsive presentation (ADHD-HI) due to a lack of volunteers. There are two possible reasons for this. Firstly, ADHD-HI is diagnosed less frequently in China compared to the other two subtypes (ADHD-I and ADHD-C). Epidemiological surveys in the country have shown that ADHD-I accounts for 61.8% of the entire population of children with ADHD (Li et al., 2017). Secondly, due to inattention, cognitive impairments, and academic functional deficits, the learning difficulties of ADHD-I and ADHD-C are particularly prominent. According to Gong and colleagues (2022), around 75% of primary school students with ADHD-I or ADHD-C experience academic difficulties.

In contrast, only 20% of primary school students with ADHD-HI have learning problems. Future research should aim to include participants across all ADHD subtypes to provide a comprehensive assessment of NAT's impact on academic performance. Such studies should also consider intergroup comparisons to elucidate differential responses to the intervention, offering valuable insights for tailoring NAT to specific subtypes.

Thirdly, this study did not conduct a detailed assessment of the deficiencies in Chinese handwriting skills among participants. The reliance on teacher nominations and evaluations may not fully encapsulate the intricate challenges that children with ADHD face in Chinese

handwriting. To address this gap, future research should undertake a detailed examination of the nuances within handwriting skills, such as pen-holding techniques, stroke precision, and character composition (Lu et al., 2023). Such an in-depth analysis will elucidate the mechanisms through which NAT exerts its positive influence on these critical aspects of handwriting, providing a more granular understanding of how NAT can be optimized to support children with ADHD in their academic endeavors.

Lastly, while our study indicates positive changes in on-task behavior and handwriting performance, the long-term sustainability of these improvements is yet to be determined. Future research should not only track the enduring effects of NAT over time but also explore strategies to adapt this model for larger classroom settings. This could involve examining the feasibility of integrating NAT components into regular curriculum activities or developing group-based interventions that preserve individualized attention while catering to a larger student population. Additionally, investigating the applicability of NAT to other academic domains, such as reading comprehension and mathematical problem-solving, could unveil its comprehensive potential to enhance educational outcomes for children with ADHD. By extending NAT to various academic areas and classroom environments, we can better understand its role in supporting the holistic educational experience of children with ADHD.

CONCLUSION

This study advances the understanding of neurocognitive training's role in enhancing academic performance among children with ADHD by introducing the neurocognitive-academic training (NAT) model. Addressing a gap in research and societal needs, we concentrated on the Chinese handwriting skills of these children. Our findings indicate that NAT significantly enhances on-task behavior, writing speed, and handwriting quality. The correlated improvements across these outcomes underscore the interconnected nature of these skills. Future studies should consider the broader application of NAT in various academic areas to further support children with ADHD.

ACKNOWLEDGEMENT

None.

DECLARATION OF INTEREST STATEMENT

The authors reported no potential conflict of interest.

FUNDING

The author(s) disclosed receipt of the following financial support for the research, authorship, and publication of this article: This study was supported by a grant from the National Natural Science Foundation of China (NSFC), China (62007030).

ETHICAL STATEMENT

Ethical approval to report these cases was obtained from the Human Research Ethics Committee at Zhejiang Normal University (ZSRT2020002).

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Appendix 1 Instructions and Criteria of Acceptance

Phase One: Behavior Presentation

Objective 1: The child adapts to NCT

Instructions	Criteria
a. Teach the procedure and rehearsal before the formal training. b. During the initial training, ask the child to explain the rules of each game. c. In the following training sessions, offer detailed instructions to the child to become more familiar with the games.	a. The child understands the rules of each game and can play independently. b. The child has increased by at least one level in IC, WM, and NF games compared to his/her average level of S1 and S2.

Objective 2: Displaying on-task behavior in basic copying tasks

Instructions	Criteria
a. Discuss with the child how to maintain on-task behavior in the copying task. b. Inform the child about the writing task for the day, including which characters to write and how long to write them. c. Allow the child to choose the words they prefer to write. The teacher can make substitutions for words that the child may find challenging. d. Ask the child to state the elements of the Chinese character they will be writing. The first step is to recognize the character, the second step is to state the structure of the character (e.g., upper and lower structure), and the third step is to state the number of strokes and the character's stroke order. e. Explain specific points to keep in mind when writing Chinese characters. f. Have the child write a Chinese character while the teacher observes to ensure it is written correctly. g. Once the teacher has confirmed that the child can write the Chinese characters correctly, the writing task can begin. The teacher will then leave the training room and observe and record in the control room. h. At the end of the task, the teacher will knock on the door to prompt the child and then enter the training room. The teacher will give the child feedback and help them revise incorrect writing.	a. The average level of on-task behavior has increased by at least 20% compared to the baseline or reached 80%. b. The average speed and quality of Chinese characters' handwriting should be at least the average level during the baseline.

Phase Two: Progression & Strategy

Objective 1: Increasing task difficulties in NCT

Instructions	Criteria
a. Start by reviewing the previous training session with the child and agreeing on today's goals. b. Remind the child to use the agreed-upon strategy. If necessary, rehearse the strategy with the child before beginning the training. c. Provide feedback to the child during training on whether the strategy is being used correctly. d. After the training, communicate with the child about the results, including goal attainment and if any new strategies emerged.	a. The child has mastered two strategies for achieving higher levels in the IC, WM, and NF games. b. The average level of IC, WM, and NF games has increased at least one level compared to Phase 1.

Objective 2: Displaying on-task behavior in advanced copying tasks

Instructions	Criteria
a. Start by reviewing the previous task with the child, setting goals for today, and reminding them to use the agreed-upon strategies. If needed, rehearse the strategies with the child. b. Repeat Steps b to h of Objective 2 in Phase 1, excluding Step c. c. Discuss with the child about the results and if any new strategies emerged.	a. The average level of on-task behavior has increased by at least 40% compared to the baseline or reached 80%. b. The handwriting speed has reached the corresponding level (refer to Handwriting Speed in Dependent Variable) or improved by at least 20% compared to the average speed in the baseline. c. The average score of handwriting quality has reached 3.0 or improved by at least 20% compared to his/her average score in the baseline. d. The average task duration has increased by 1 minute compared to Phase 1 and has been trained at least 5 times.

Phase Three: Maintenance & Self-Reflection

Objective 1: Maintaining the advanced levels in NCT

Instructions	Criteria
a. Repeat Steps a to d of Objective 1 in Phase 2. b. Review the strategies used for IC, WM, and NF games with the child in Phases 1 and 2. Help the child to recognize the differences and outcomes of these strategies, which will promote the development of better self-awareness and metacognition in the child.	a. The child has mastered two strategies for maintaining the current levels in the IC, WM, and NF games. b. The child has maintained or enhanced the game levels compared with Phase 2.

Objective 2: Maintaining on-task behavior and writing quality in advanced copying tasks

Instructions	Criteria
a. Repeat Steps a to c of Objective 2 in Phase 2. b. Engage in a discussion with the child regarding the writing techniques of Chinese characters with a specific structure (such as semi-enclosed structures). Review the behavior and writing quality during the copying tasks, and encourage the child to recognize the progress and reflect on the experience.	a. The child has maintained or enhanced the level of on-task behavior compared with Phase 2. b. The handwriting speed has reached the corresponding level or improved by at least 20% compared to the average speed in Phase 2. c. The average score of handwriting quality has reached 3.5 or improved by at least 20% compared to the average score in Phase 2. d. The average task duration has increased by 1 minute compared to Phase 2 and has been trained at least 5 times.

Note: IC refers to inhibitory control, WM refers to working memory, NF refers to neurofeedback, S1 refers to session 1, S2 refers to session 2