



# Impact of a Cognitive-Motor Training on Legibility and Speed of Handwriting in Children with ADHD

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## Abstract

**Introduction:** Studies employing cognitive-musical training and the verbal working memory-balance program have demonstrated improvements in various linguistic and non-linguistic outcomes for children with dyslexia. Despite these findings, there is a notable gap in the literature regarding the impact of cognitive-motor interventions on handwriting performance in children with ADHD.

**Objective:** This study aims to examine how a cognitive-motor intervention affects the legibility and speed of handwriting in children with ADHD.

**Methods:** This research utilized a semi-experimental design featuring a practical application, incorporating a pre-test and post-test methodology along with a control group. After a thorough screening process, 40 children diagnosed with ADHD were chosen as participants and randomly assigned to either the intervention or control group in equal numbers. The intervention group participated in a cognitive-motor program twice weekly over an eight-week period. The Handwriting Assessment Tool was employed to evaluate both the legibility and speed of handwriting, with data analysis conducted using ANCOVA.

**Results:** The findings indicate significant differences between the intervention or control groups in handwriting characteristics, including formation ( $F=9.751, p<0.001$ ), alignment ( $F=8.639, p<0.001$ ), size ( $F=7.938, p<0.001$ ), and speed ( $F=12.527, p<0.001$ ). However, there was no significant differences between groups regarding space and slant dimensions of legibility of handwriting ( $p>0.05$ ).

**Conclusion:** Cognitive-motor exercises demonstrated in this study prove to be an effective strategy for enhancing graphomotor skills, particularly handwriting, among primary school students, including those with special needs like ADHD. This approach is not only straightforward to implement but also requires minimal adjustments to existing educational curricula.

**Keywords:** Cognition, Handwriting, Child, ADHD, Intervention

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## 1. Introduction

Attention-deficit/hyperactivity disorder (ADHD) is a neuropsychiatric condition that manifests behaviorally through developmental inattention, hyperactivity, and impulsivity (1). Systematic reviews indicate that the prevalence of ADHD in children ranges from 3% to 4% (2). A prominent explanation for the disorder's origins is Russell Barkley's hybrid model, which posits that ADHD is linked to structural or functional abnormalities in brain regions such as the prefrontal cortex, basal ganglia, cerebellum, and potentially the frontal gyrus (3). Neuroimaging research supports the association of these areas with motor skills, revealing that children with ADHD often experience deficits in both gross and fine motor abilities, with estimates suggesting that 30% to 50% of these children face motor challenges (4). Additionally, difficulties in motor coordination manifest as handwriting abnormalities, where children with ADHD typically perform worse than their peers in both the quantity and quality of their writing (5). Given that writing is a multifaceted skill requiring fine motor

control, attention, and perceptual abilities, addressing handwriting issues is crucial for the educational development of children with ADHD.

Writing serves as a fundamental method for expressing thoughts, ideas, and creativity in a nonverbal manner (6). This visual representation of language involves a sophisticated interplay of cognitive, perceptual, and motor skills, rather than being an inherent talent (7). In essence, handwriting is the result of complex psychomotor processes that transform abstract concepts into tangible forms (8). Handwriting can be defined as the ability to produce letters and numbers clearly and within a specific timeframe, emphasizing the mechanical aspects of writing, such as legibility and speed. Our primary concern here is the readability of handwriting (9). To clarify this concept, it is essential to distinguish between writing, handwriting, and calligraphy. Writing generally refers to the content of a text, such as an essay, where linguistic elements take precedence (6). In contrast, handwriting focuses on the physical characteristics of the written form, including legibility and writing speed, without regard to the content itself.



Additionally, it is important to differentiate handwriting from calligraphy; the former evaluates two main components—readability and speed—requiring that a child's writing exhibits clear letter shapes, proper alignment, adequate spacing, and appropriate size and slope, all completed within a designated time (8). Calligraphy, however, is an artistic expression that prioritizes the aesthetic quality of the lines and involves more complex cognitive processes (10). The legibility of handwriting is assessed through its various components, including the clarity of letters and words, alignment, spacing, size, and slope (11). In contemporary society, handwriting serves not only as a vital means of communication but also as a crucial life skill, utilized for composing various texts and completing forms (8,12). Research indicates a positive correlation between proficient handwriting and academic success in children (9,13). In addition, poor handwriting can significantly affect an individual's self-perception, academic progress, and overall attitudes and behaviors (14,15). Therefore, it is essential to explore the factors that influence the enhancement of handwriting skills, particularly among young learners.

Despite many students achieving a satisfactory level of handwriting legibility by ages 6 to 7, literacy challenges persist in 10-30% of elementary school children, including those with average intelligence and no apparent neurological issues (16,17). This prevalence has become a significant factor in the referral of students to pediatric occupational therapy centers (18). Consequently, it is essential to thoroughly understand the underlying mechanisms and contributing factors to handwriting difficulties, as well as to implement early therapeutic interventions to address these issues before they become more challenging to rectify. In numerous instances, handwriting legibility issues cannot be effectively addressed without therapeutic interventions (19). These problems may stem from external factors, such as the use of an unsuitable pen, an inadequate writing surface, or poor body positioning during writing (8). Alternatively, they can arise from internal factors related to a student's inherent abilities, including visual-motor coordination, motor planning, fine motor control, and the skillful manipulation of writing tools, which may vary between male and female students (20). Proper coordination of the small muscles in the hand is essential for effective pen control; without it, writing does not become an automatic process, hindering a child's writing ability (21). This can lead to slower writing speeds, increased fatigue, and diminished accuracy. Developmentally, children aged 6 to 7 are at a critical stage for fine motor skill development, and achieving a mature grip on a pen typically occurs during this period (22).

Generally, research on handwriting and literacy among children with ADHD remains limited. Hence, it is crucial to focus on methods that can enhance and rehabilitate their handwriting skills. Understanding the underlying mechanisms and factors contributing to handwriting difficulties is essential, as early therapeutic interventions can prevent these issues from becoming entrenched. Evidence suggests that without such interventions, problems with handwriting legibility often persist. Barkley's behavioral inhibition model suggests that the most effective treatment occurs within a natural environment and at a specific performance point (23).

This performance point is crucial, as the proximity of the treatment to the relevant time and place enhances its efficacy. To facilitate behavior-change in real-life situations, targeted programs can be implemented to promote and sustain desired behaviors over time. Additionally, cognitive motor exercises can serve as valuable tools in this therapeutic approach. Research has predominantly focused on linguistic training; however, there is a growing interest in non-linguistic training methods, such as motor training, to enhance both motor control and reading skills (24,25). For instance, studies employing cognitive-musical training and the verbal working memory-balance program have demonstrated improvements in various linguistic and non-linguistic outcomes for children with dyslexia (26-28). Despite these findings, there is a notable gap in the literature regarding the impact of cognitive-motor interventions on handwriting performance in children with ADHD. Therefore, this study aims to examine how a cognitive-motor intervention affects the legibility and speed of handwriting in this population.

This research presents a significant advancement by integrating cognitive and motor training specifically tailored for handwriting in children with ADHD. Unlike many existing interventions that isolate either fine-motor skills or cognitive functions, this study uniquely combines both elements into a cohesive program, a combination that has been largely overlooked in handwriting research related to ADHD. Furthermore, it is the first to assess the effects of this dual-target approach on both handwriting speed and legibility concurrently, providing a more holistic understanding of handwriting performance. The introduction of a novel therapeutic protocol, encompassing specific tasks, sequences, and cognitive-motor integration, adds to the literature and offers a framework for replication in clinical and educational settings. By addressing handwriting - a critical yet under-researched skill for children with ADHD - this study fills a significant gap, providing empirical evidence for an intervention that directly impacts academic performance. The application of objective, standardized assessment tools further strengthen the research's rigor, moving beyond the subjective evaluations often used in this area. Lastly, by investigating both cognitive and motor components, the study may yield novel insights into the mechanisms of change, potentially revealing how factors like visual-motor integration and sustained attention contribute to improved handwriting outcomes in children with ADHD.

## 2. Methods

### 2.1. Participants

This study employed a semi-experimental design with a practical application, utilizing a pre-test and post-test framework alongside a control group. The study's statistical population comprised all second and third-grade elementary school children with ADHD. A convenience sampling approach was employed to select participants, utilizing Connors' (1997) teacher and parent scales to identify children with ADHD (29). A qualified psychologist, experienced in working with ADHD children, collaborated with classroom teachers to pinpoint those suspected of having the disorder. Subsequently, both teachers and parents of these

identified children were interviewed and asked to complete the relevant scales. The cut-off scores for the Connors' scales were set at 57 for teachers and 34 for parents; children scoring at or above these thresholds were classified as having ADHD. This screening process resulted in the identification of 40 children with ADHD, including 12 boys and 8 girls from the second grade, and 12 boys and 8 girls from the third grade. These children were then divided into an experimental group and a control group, each consisting of 20 participants, matched for age, gender, and % and educational level. The sample size was computed by GPower 3.1, by selecting "ANOVA: Repeated measure, within-between interaction" as statistical test, effect size  $f = 0.25$ ,  $\alpha$  err prob = 0.05, power ( $1-\beta$  err prob) = 0.80, number of groups = 2, number of measurements = 2, and keeping the rest of the parameters default. The study adhered to ethical guidelines, with written consent obtained from parents for their children's participation. Inclusion criteria specified that participants must be elementary school students with ADHD. Withdrawal from the study occurred due to a lack of willingness from children and families to continue or complete the intervention or questionnaires.

### 2.2. Handwriting Tool

The handwriting assessment utilized in this study was derived from the Handwriting Assessment Tool (HAT), which is designed to evaluate the writing abilities of second and third-grade primary school students (30). The HAT comprises two main sections: demographic information and handwriting tasks. The demographic section collects data on factors such as class, gender, handedness, and the use of glasses or hearing aids. The handwriting component includes tasks for copying, where students are instructed to replicate words as accurately as possible. Legibility is assessed through dimensions such as formation, size, spacing, alignment, and slant, with most components rated on a five-point Likert scale ranging from very poor (1) to very good (5), while size is evaluated on a scale from very small (1) to very big (5). During the copying task, the time taken to complete the task in seconds was recorded to measure writing speed. The legibility of the handwriting is evaluated by two independent judges who are unaware of the children's performance conditions, using a specially designed evaluation form, achieving an inter-rater reliability of  $r > 0.70$ . For subsequent analyses, data from the first reviewer were utilized. In this research, the internal consistency of the HAT was evaluated, revealing high reliability scores ranging from 0.88 to 0.98 across different dimensions of legibility.

### 2.3. Procedure

The research commenced with vital collaboration from the Education Department, which was essential for obtaining the necessary permissions to proceed. Following this, a briefing session was conducted to inform students and their parents about the study's goals, methods, and the intervention's execution. After securing written consent from the parents, participants in the intervention group were invited to take part in the cognitive-motor program (27), which was structured to include two sessions each week over a span of eight weeks, with each session lasting 45 minutes. The format comprised four distinct segments:

a 10-minute warm-up featuring arm circles, cross-body arm swings, and shoulder rolls; followed by 15 minutes focused on upper limb coordination through activities such as ball toss and call-out, ball passing, and handball juggling. This was succeeded by another 15 minutes dedicated to visuospatial orientation, which included direction changes, drawing and following, and mirror exercises. The final five minutes were reserved for cooling down and stretching. The program incorporated motor and cognitive exercises at two levels of difficulty, each maintained for a duration of four weeks. Participants took the HAT both one day prior to the intervention (pre-test) and one day following it (post-test). The control group did not receive any additional interventions during this period.

### 2.4. Statistical Analysis

In this study, the research variables were established by calculating the mean, standard deviation (SD), frequency, and percentage of frequency. The normality of the data distribution was assessed using the Kolmogorov-Smirnov test, with all results showing P values greater than 0.05. To compare pre-test scores among the research groups, an independent t-test was conducted. Additionally, analysis of covariance (ANCOVA) was used to investigate the differences between the two groups from pre-test to post-test. In this study, we employed ANCOVA to address baseline differences among groups, particularly given the varied handwriting performance observed in children with ADHD. By statistically controlling for pre-test scores in handwriting legibility and speed, ANCOVA ensures that any differences noted in post-test results are not merely a reflection of initial disparities between groups. A significance level of 0.05 was maintained for all statistical analyses, which were carried out using SPSS version 27.

## 3. Results

The demographic analysis revealed that the average age of the participants was 8.12 years. Additionally, a significant majority of the children were right-handed, accounting for 95% of the sample, and the vast majority did not require corrective eyewear, with 90% not using glasses, while all participants (100%) did not use hearing aids.

Table 1 displays the mean and standard deviation for legibility and handwriting speed performance during both the pre-test and post-test across the different groups. The results show that the mean formation scores in the pre-test were 2.23 for the intervention group and 2.19 for the control group, indicating a generally low level of formation among participants. Statistical analysis confirmed no significant differences between the groups in this area ( $p=0.638$ ). Similarly, the mean scores for spacing were 3.04 for the intervention group and 3.10 for the control group, again reflecting a low level of spacing, with no significant differences noted ( $p=0.473$ ). For alignment, the pre-test mean scores were 2.35 for the intervention group and 2.40 for the control group, which also indicated low alignment levels, with no significant differences ( $p=0.741$ ). The mean scores for size were 4.44 for the intervention group and 4.38 for the control group, further demonstrating low size levels and no significant differences ( $P=0.824$ ). Additionally, the

mean scores for slant were 2.64 for the intervention group and 2.59 for the control group, again showing low slant levels with no significant differences ( $p=0.625$ ). Lastly, the pre-test mean scores for handwriting speed were 86.29 for the intervention group and 85.13 for the control group, indicating similarly low speed levels, with no significant

differences found ( $p=0.863$ ). The findings indicate that both the intervention and control groups demonstrated similar handwriting performance conditions at the baseline assessment.

**Table 1.** Mean and SD of the Handwriting Performance across Groups.

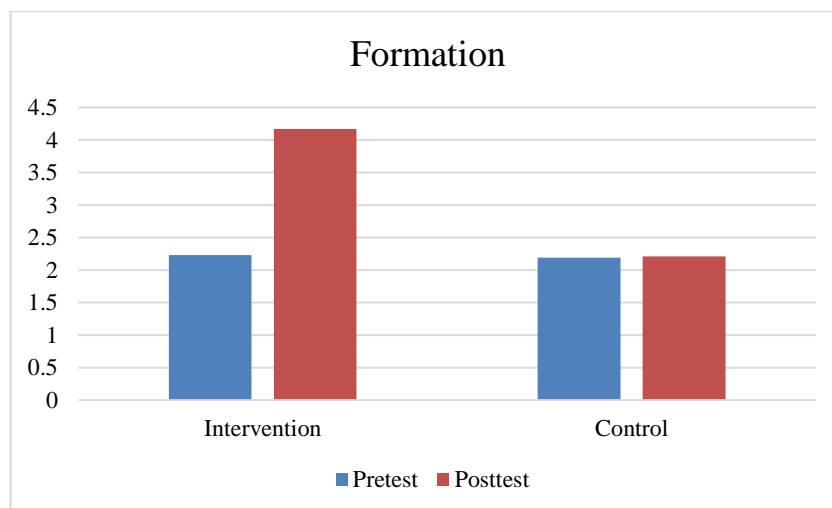
Variable		Intervention	Control
<b>Legibility</b>		Mean $\pm$ SD	Mean $\pm$ SD
	Formation		
	Pre-test	2.23 $\pm$ 0.11	2.19 $\pm$ 0.13
	Post-test	4.17 $\pm$ 0.20	2.21 $\pm$ 0.14
Space	Pre-test	3.04 $\pm$ 0.16	3.10 $\pm$ 0.15
	Post-test	3.06 $\pm$ 0.18	3.08 $\pm$ 0.17
Alignment	Pre-test	2.35 $\pm$ 0.15	2.40 $\pm$ 0.11
	Post-test	4.20 $\pm$ 0.28	2.37 $\pm$ 0.18
Size	Pre-test	4.44 $\pm$ 0.30	4.38 $\pm$ 0.32
	Post-test	2.27 $\pm$ 0.17	4.40 $\pm$ 0.30
Slant	Pre-test	2.64 $\pm$ 0.13	2.59 $\pm$ 0.10
	Post-test	2.60 $\pm$ 0.12	2.63 $\pm$ 0.11
<b>Speed (second)</b>	Pre-test	86.29 $\pm$ 3.71	85.13 $\pm$ 3.63
	Post-test	72.76 $\pm$ 4.28	86.37 $\pm$ 3.45

**Table 2** presents a comparison of handwriting performance between the intervention and control groups during both the pre-test and post-test phases. The findings indicate significant differences in handwriting characteristics, including formation ( $F=9.751$ ,  $p<0.001$ ), alignment ( $F=8.639$ ,  $p<0.001$ ), size ( $F=7.938$ ,  $p<0.001$ ), and speed ( $F=12.527$ ,  $p<0.001$ ). However, there was no significant differences between groups regarding space and slant dimensions of

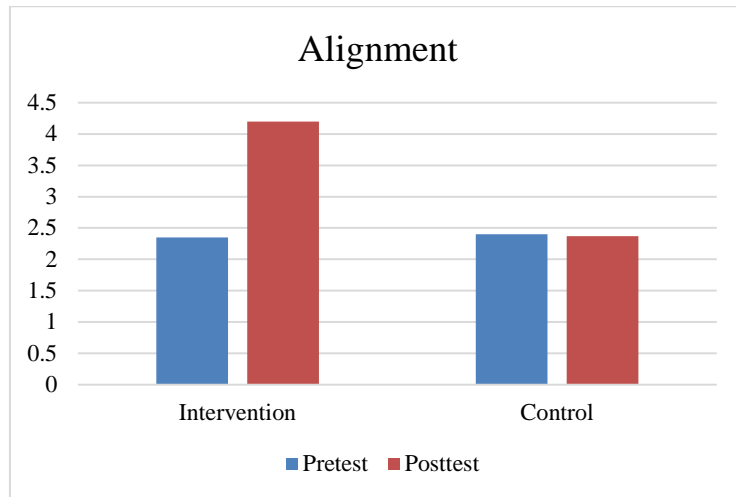
legibility of handwriting ( $p>0.05$ ). Notably, the data suggest that children with ADHD demonstrated improvements in legibility-encompassing formation, alignment, and size-as well as writing speed after participating in the cognitive-motor intervention. **Figures 1** to 4 show the pre-test and post-test scores of significantly changed variables including formation, alignment, size and speed of handwriting among the intervention and control groups.

**Table 2.** Comparison of Pre-test and Post-test.

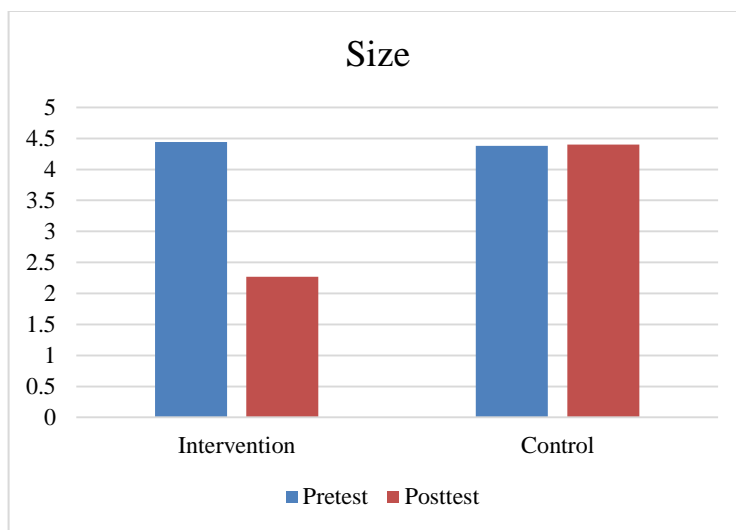
	SS	df	MS	F-Value	p-Value	$\eta^2$
<b>Legibility</b>						
Formation	102.505	1	52.749	9.751	<0.001	0.124
Space	2.419	1	1.360	0.147	0.867	0.002
Alignment	97.638	1	42.749	8.639	<0.001	0.105
Size	56.938	1	33.746	7.938	<0.001	0.098
Slant	1.857	1	0.578	0.110	0.908	0.001
<b>Speed</b>	128.638	1	63.867	12.527	<0.001	0.153



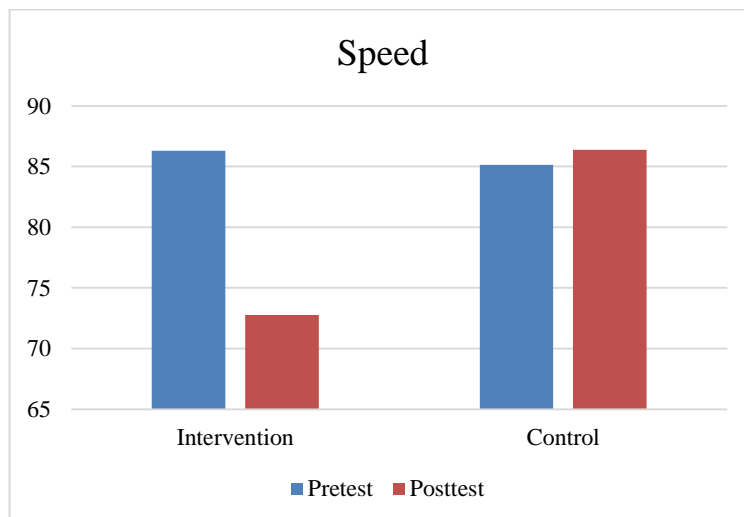
**Figure 1.** The Pre-test-Post-test Scores of Formations across Groups.



**Figure 2.** The Pre-test and Post-test Scores of Alignments across Groups.



**Figure 3.** The Pre-test and Post-test Scores of Size across Groups



**Figure 4.** The Pre-test and Post-test Scores of Speed across Groups.

#### 4. Discussion

There exists a significant gap in existing research concerning the effects of cognitive-motor

interventions on handwriting abilities in children diagnosed with ADHD. This study seeks to investigate the influence of such interventions on both the legibility and speed of handwriting within this

demographic. The results reveal that children with ADHD exhibited marked improvements in legibility—specifically in aspects such as letter formation, alignment, and size—as well as writing speed following the cognitive-motor intervention. These findings support previous research (27, 31,32) that has identified various benefits of cognitive-motor interventions for enhancing handwriting performance among children with ADHD.

To interpret these findings, it can be stated that the observed enhancements may stem from an implicit increase in cerebellar activity and central plasticity among participants. Each cognitive and motor task emphasized in the cognitive-motor program may activate specific regions of the brain, particularly the left fusiform gyrus and Crus II of the cerebellum, which are crucial for various reading and writing abilities (8,33). Future research could investigate the relationship between the activation of these cerebral and cerebellar areas induced by the cognitive-motor program and executive functions related to reading and writing. In addition, engaging in cognitive-motor activities, such as ball toss, ball passing, and handball juggling as well as drawing and mirror exercises activates multiple muscle groups and enhances overall body coordination. This engagement not only strengthens muscles and alleviates hand tension but also fosters the development of both fine and gross motor skills, ultimately leading to improved writing performance (27,28). Additionally, the cognitive-motor exercises utilized in this study may enhance letter memorization and understanding of language rules, as evidence suggests a close relationship between learning handwriting and letter retention. Furthermore, the enjoyment derived from ball activities plays a significant role in this process; children are often drawn to these fun and challenging experiences, which positively influence their cognitive and physical development (34).

Handwriting is a multifaceted skill that encompasses intricate visual-perceptual and motor processes, all of which are influenced by attention, perception, memory, movement, and executive functions. These cognitive and motor functions work in harmony at various levels to facilitate the formation of words (35). Essential to handwriting development are visual-motor skills, which involve the coordination of visual input with motor actions. For children with ADHD, critical components such as motor planning, hand-eye coordination, visual perception, fine motor control, and sustained attention are vital. Research highlights that visual-motor integration serves as a significant predictor of handwriting legibility, particularly in tasks like letter copying among children (19,36). Due to the fact that engaging in cognitive-motor activities used in this study mostly are based on visual-motor skills, it can be assumed that cognitive-motor training strengthened hand-eye coordination and fine motor control, ultimately led to improved handwriting performance in children with ADHD. Future research should identify the mechanism behind the effects of cognitive-motor activities on handwriting performance in children with ADHD.

The study presents an innovative combined cognitive-motor training program that simultaneously addresses executive function and fine-motor coordination, two critical factors contributing to handwriting challenges in children with ADHD. This integrated approach marks a significant improvement

over conventional interventions that focus solely on handwriting skills. Furthermore, the evaluation of handwriting legibility and speed utilized standardized, validated assessment tools, enhancing the reliability and objectivity of the findings. The intervention is clinically relevant as it targets essential skills that influence both academic performance and daily activities, making the results immediately applicable for occupational therapists, educators, and clinicians working with ADHD populations. Additionally, the structured nature of the cognitive-motor training protocol facilitates its implementation in various educational and clinical environments, promoting future replication. Lastly, this research contributes to the limited existing literature on handwriting interventions that combine motor and cognitive elements for children with ADHD, providing valuable insights into this emerging field.

The study presents several limitations that may affect the validity of its findings. Firstly, the small sample size could diminish statistical power and limit the applicability of the results to the wider ADHD population. Additionally, the research focuses solely on immediate or short-term outcomes, leaving unanswered questions about the long-term sustainability of improvements in handwriting legibility and speed. Furthermore, potential selection bias may arise if participants were drawn from a single clinic or school, particularly if they represent families highly motivated to seek intervention, which could skew the results. Moreover, the study's limited exploration of ADHD subtypes and severity may overlook important variations in handwriting performance, thereby reducing the depth of interpretation. Lastly, if the fidelity of the intervention was not rigorously monitored, inconsistencies in training delivery could affect the outcomes, and the ecological validity of the handwriting tasks may not accurately reflect the complexities of real classroom environments, where distractions and time constraints are prevalent.

#### 4.1. Conclusion

Cognitive-motor exercises demonstrated in this study prove to be an effective strategy for enhancing graphomotor skills, particularly handwriting, among primary school students, including those with special needs like ADHD. This approach is not only straightforward to implement but also requires minimal adjustments to existing educational curricula. Future research should explore methods for integrating cognitive-motor exercises into educational settings tailored for students with special needs. One potential avenue is the miniaturization of these exercises, which could facilitate their incorporation while simultaneously amplifying their beneficial effects.

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#### Footnotes

**Authors' Contribution:** This study was carried out solely by the corresponding author.

## Conflicts of Interest

Non to declare.

**Data Availability:** The data that support the findings of this study are openly available upon request from the corresponding author.

**Ethical Approval:** This research was carried out in compliance with the ethical principles set forth in the Declaration of Helsinki and received approval from the University Ethics Committee (Code: IR.IAU.AK.REC.1398.012). Informed consent was obtained from both the participants and their guardians.

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**Informed Consent:** Informed written consent was obtained from all participants

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## References

- Sapkale B, Sawal A. Attention Deficit Hyperactivity Disorder (ADHD) Causes and Diagnosis in Adults: A Review. *Cureus*. 2023;**15**(11):e49144. [PubMed ID: 38130507]. [PubMed Central ID: PMC10733572]. <https://doi.org/10.7759/cureus.49144>
- Makki R. The Relationship between Impulsivity and Time Perception in Adolescents with ADHD. *Phys Act Child*. 2024;**1**(1):39-44. <https://doi.org/10.6186/PACH.2024.462027.1011>
- Long Y, Pan N, Ji S, Qin K, Chen Y, Zhang X, He M, Suo X, Yu Y, Wang S, Gong Q. Distinct brain structural abnormalities in attention-deficit/hyperactivity disorder and substance use disorders: A comparative meta-analysis. *Transl Psychiatry*. 2022;**12**(1):368. [PubMed ID: 36068207]. [PubMed Central ID: PMC9448791]. <https://doi.org/10.1038/s41398-022-02130-6>
- D'Anna C, Carlevaro F, Magno F, Vagnetti R, Limone P, Magistro D. Gross Motor Skills Are Associated with Symptoms of Attention Deficit Hyperactivity Disorder in School-Aged Children. *Children*. 2024;**11**(7):757. [PubMed ID: 39062207]. [PubMed Central ID: PMC11274859]. <https://doi.org/10.3390/children11070757>
- Shimko GA, James KH. The Relationship Between Motor Development and ADHD: A Critical Review and Future Directions. *Behav Sci*. 2025;**15**(5):576. [PubMed ID: 40426354]. [PubMed Central ID: PMC12108854]. <https://doi.org/10.3390/bs15050576>
- Ghorbani S, Yadolahzadeh A, Shakki M, Noohpisheh S. Association between Second to Fourth Digit Ratio with Handwriting Quality and Speed among Elementary School Children. *J Pediatr Perspect*. 2020;**8**(9):12053-12060. <https://doi.org/10.22038/ijp.2020.47498.3854>
- Chen D, Su J, Wang R. Differences in perceptual representations in multilinguals' first, second, and third language. *Front Hum Neurosci*. 2024;**18**:1408411. [PubMed ID: 39010892]. [PubMed Central ID: PMC11246912]. <https://doi.org/10.3389/fnhum.2024.1408411>
- Seyyedrezaei SH, Khajeaflaton S, Ghorbani S, Dana A. Relative Age Effects on Children's Handwriting: Role of Visual-Motor Integration. *J Pediatr Perspect*. 2021;**9**(1):12775-12783. <https://doi.org/10.22038/ijp.2020.52763.4179>
- Truxius L, Sägesser Wyss J, Maurer MN. Early handwriting development: a longitudinal perspective on handwriting time, legibility, and spelling. *Front Psychol*. 2025;**15**:1466061. [PubMed ID: 39845535]. [PubMed Central ID: PMC11752449]. <https://doi.org/10.3389/fpsyg.2024.1466061>
- Yuan Q, Yang G, Lyu R. Aesthetic Judgment in Calligraphic Tracing: The Dominant Role of Dynamic Features. *Behav Sci (Basel)*. 2025;**15**(4):525. [PubMed ID: 40282149]. [PubMed Central ID: PMC12024151]. <https://doi.org/10.3390/bs15040525>
- Farhangnia S, Hassanzadeh R, Ghorbani S. Handwriting Performance of Children with Attention Deficit Hyperactivity Disorder: The Role of Visual-Motor Integration. *J Pediatr Perspect*. 2020;**8**(11):12317-12326. <https://doi.org/10.22038/ijp.2020.47633.3857>
- Van der Weel FRR, Van der Meer ALH. Handwriting but not typewriting leads to widespread brain connectivity: a high-density EEG study with implications for the classroom. *Front Psychol*. 2024;**14**:1219945. [PubMed ID: 38343894]. [PubMed Central ID: PMC10853352]. <https://doi.org/10.3389/fpsyg.2023.1219945>
- Takahata S, Hagihara H, Ishihara H, Enomoto D, Ienaga N, Noda H, Ishida S, Terayama K. Comprehensive search for assessment indicators that influence the level of handwriting difficulties among children in educational settings. *Sci Rep*. 2025;**15**(1):22795. [PubMed ID: 40594238]. [PubMed Central ID: PMC12218408]. <https://doi.org/10.1038/s41598-025-03634-z>
- Hwang S. Unpacking the Impact of Writing Feedback Perception on Self-Regulated Writing Ability: The Role of Writing Self-Efficacy and Self-Regulated Learning Strategies. *Behav Sci*. 2025;**15**(2):100. [PubMed ID: 40001731]. [PubMed Central ID: PMC11852132]. <https://doi.org/10.3390/bs15020100>
- Wiley RW, Rapp B. The Effects of Handwriting Experience on Literacy Learning. *Psychol Sci*. 2021;**32**(7):1086-1103. [PubMed ID: 34184564]. [PubMed Central ID: PMC8641140]. <https://doi.org/10.1177/0956797621993111>
- Engel C, Lillie K, Zurawski S, Travers BG. Curriculum-Based Handwriting Programs: A Systematic Review With Effect Sizes. *Am J Occup Ther*. 2018;**72**(3):7203205010p1-7203205010p8. [PubMed ID: 29689170]. [PubMed Central ID: PMC5915229]. <https://doi.org/10.5014/ajot.2018.027110>
- Puyjarinet F, Chaix Y, Biotteau M. Is There a Deficit in Product and Process of Handwriting in Children with Attention Deficit Hyperactivity Disorder? A Systematic Review and Recommendations for Future Research. *Children*. 2023;**11**(1):31. [PubMed ID: 38255345]. [PubMed Central ID: PMC10813961]. <https://doi.org/10.3390/children11010031>
- Mills C, Ritchie S, Zucco A, Hazeltine K, Sheaves J, Liu KPY. Descriptive evaluation of community-based children's occupational therapy services using COPM. *Hong Kong J Occup Ther*. 2025;15691861251354878. [PubMed ID: 40585752]. [PubMed Central ID: PMC12204992]. <https://doi.org/10.1177/15691861251354878>
- Han W, Wang T. From Motor Skills to Digital Solutions: Developmental Dysgraphia Interventions over Two Decades. *Children (Basel)*. 2025;**12**(5):542. [PubMed ID: 40426721]. [PubMed Central ID: PMC12110418]. <https://doi.org/10.3390/children12050542>
- Fajariani D, Suyama N, Yamanishi Y, Phadsri S, Komariyah DA, Ito Y. Analyzing Occupational Performance of Children With Handwriting Difficulties: Parent and Teacher Experiences and Perspectives. *Occup Ther Int*. 2025;**2025**:8882049. [PubMed ID: 40213081]. [PubMed Central ID: PMC11985230]. <https://doi.org/10.1155/oti/8882049>
- Gerth S, Festman J. Muscle Activity during Handwriting on a Tablet: An Electromyographic Analysis of the Writing Process in Children and Adults. *Children*. 2023;**10**(4):748. [PubMed ID: 37189997]. [PubMed Central ID: PMC10137273]. <https://doi.org/10.3390/children10040748>
- Faber L, Hartman E, Houwen S, Schoemaker MM. Sharp Skills or Snipping Struggles? Qualitative Paper-Cutting Performance in 5- to 10-Year-Old Children Using Hands-On! *Behav Sci*. 2025;**15**(4):489. [PubMed ID: 40282111]. [PubMed Central ID: PMC12024428]. <https://doi.org/10.3390/bs15040489>
- Panah MT, Tareman F, Dolatshahi B, Seddigh SH, Raeisian FS, Panah E. A comparison of Barkley's behavioral inhibition model (1997) with Barkley's updated executive functioning model in predicting adult ADHD symptoms: A preliminary report using structural equation modeling. *Appl Neuropsychol Adult*. 2025;**32**(1):140-152. [PubMed ID: 36576870]. <https://doi.org/10.1080/23279095.2022.2158441>
- Ben Dhia A, Bucci MP, Naffeti C, Ben Saad H, Hammouda O, Driss T. Combined Cognitive and Motor Training Improves Reading, Writing and Motor Coordination in Dyslexic Children. *Pediatr Rep*. 2025;**17**(2):46. [PubMed ID: 40278526]. [PubMed Central ID: PMC12030611]. <https://doi.org/10.3390/pediatric17020046>
- Hao Y, Kong L, Wang X, Yu X. The impact of structured motor learning intervention on preschool children's executive functions. *Sci Rep*. 2025;**15**(1):18167. [PubMed ID: 40414940]. [PubMed Central ID: PMC12104419]. <https://doi.org/10.1038/s41598-025-01385-5>
- Okur M, Aksoy V. The Effect of Verbal Working Memory Intervention on the Reading Performance of Students with Specific Learning Disabilities. *Behav Sci*. 2025;**15**(3):356. [PubMed ID: 40150251]. [PubMed Central ID: PMC11939609]. <https://doi.org/10.3390/bs15030356>
- Ben Dhia A, Bucci MP, Naffeti C, Ben Saad H, Hammouda O, Driss T. Combined Cognitive and Motor Training Improves Reading, Writing and Motor Coordination in Dyslexic Children. *Pediatr Rep*. 2025;**17**(2):46. [PubMed ID: 40278526]. [PubMed Central ID: PMC12030611]. <https://doi.org/10.3390/pediatric17020046>
- Ramezani M, Behzadipour S, Pourghayoomi E, Joghataei MT, Shirazi E, Fawcett AJ. Evaluating a new verbal working memory-balance program: a double-blind, randomized controlled trial study on Iranian children with dyslexia. *BMC Neurosci*. 2021;**22**(1):55. [PubMed ID: 34525977]. [PubMed Central ID: PMC8442443]. <https://doi.org/10.1186/s12868-021-00660-1>
- Musululu H. Evaluating attention deficit and hyperactivity disorder (ADHD): a review of current methods and issues. *Front Psychol*. 2025;**16**:1466088. [PubMed ID: 40066184]. [PubMed Central ID: PMC11891363]. <https://doi.org/10.3389/fpsyg.2025.1466088>
- Sparaci L, Fantasia V, Bonsignori C, Provenzale C, Formica D, Taffoni F. Handwriting in primary school: comparing

- standardized tests and evaluating impact of grapho-motor parameters. *Read Writ.* 2025;**38**(5):1409-1434. [PubMed ID: 40337598]. [PubMed Central ID: [PMCI2052790](#)] <https://doi.org/10.1007/s11145-024-10562-3>
31. Bonneton-Botté N, Miramand L, Bailly R, Pons C. Teaching and Rehabilitation of Handwriting for Children in the Digital Age: Issues and Challenges. *Children (Basel)*. 2023;**10**(7):1096. [PubMed ID: 37508593]. [PubMed Central ID: [PMCI0378357](#)] <https://doi.org/10.3390/children10071096>
  32. Ramezani M, Fawcett AJ. Cognitive-Motor Training Improves Reading-Related Executive Functions: A Randomized Clinical Trial Study in Dyslexia. *Brain Sci.* 2024;**14**(2):127. [PubMed ID: 38391702]. [PubMed Central ID: [PMCI0887110](#)] <https://doi.org/10.3390/brainsci14020127>
  33. Chrabaszc A, Lear K, Durisko C, Fiez JA. Contributions of the multiple demand network to emergent and skilled reading. *Sci Rep.* 2025;**15**(1):20878. [PubMed ID: 40596257]. [PubMed Central ID: [PMCI2219379](#)] <https://doi.org/10.1038/s41598-025-05756-w>
  34. Wawrzyniak S, Cichy I, Matias AR, Pawlik D, Kruszwicka A, Klichowski M, Rokita A. Physical Activity With Eduball Stimulates Graphomotor Skills in Primary School Students. *Front Psychol.* 2021;**12**:614138. [PubMed ID: 33746835]. [PubMed Central ID: [PMC7969879](#)] <https://doi.org/10.3389/fpsyg.2021.614138>
  35. Bonneton-Botté N, Miramand L, Bailly R, Pons C. Teaching and Rehabilitation of Handwriting for Children in the Digital Age: Issues and Challenges. *Children.* 2023;**10**(7):1096. [PubMed ID: 37508593]. [PubMed Central ID: [PMCI0378357](#)] <https://doi.org/10.3390/children10071096>
  36. Maldarelli JE, Kahrs BA, Hunt SC, Lockman JJ. Development of early handwriting: Visual-motor control during letter copying. *Dev Psychol.* 2015;**51**(7):879-88. [PubMed ID: 26029821]. [PubMed Central ID: [PMC4478098](#)] <https://doi.org/10.1037/a0039424>