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Preliminary Study on Enhancing Literacy Skills Through Intervention Targeting Inhibitory Control, Cognitive Flexibility, Working Memory, and Attentional Control

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Abstract: (1) Background: It is important to understand how inhibition, cognitive flexibility, working memory, and attentional control impact reading and writing skills to identify areas for intervention and create effective intervention programs. This pilot study explores the connection between these abilities and academic performance in children aged 6 to 8 using a design with control and experimental groups. (2) Methods: Both groups were assessed pre- and post-intervention using the Color and Word Test, Copy Test of a Complex Figure, Behavior Rating Inventory of Executive Function-2, and Literacy Analysis Test. (3) Results: The results showed significant enhancements in inhibition, cognitive flexibility, and working memory in the experimental group, underscoring the importance of executive functioning in the proper development of literacy. However, no significant differences were observed in reading or writing skills between the two groups, although the experimental group showed improvements in the correlations of all studied variables after the intervention. (4) Conclusions: These findings indicate that improving executive functions may be essential for enhancing literacy skills in children of this age group, being important both for research and for educational practice, emphasizing the importance of including executive function when developing intervention strategies to enhance reading and writing skills.

Keywords: executive functions; elementary education; intervention; academic performance

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1. Introduction

Specific learning disorders have been described in the DSM-5-TR (Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition Text Revision) under neurodevelopmental disorders, which are characterized by deficits in executive abilities (American Psychiatric Association, 2022). Although these disorders are not categorized explicitly as difficulties, various research studies have demonstrated that they underpin learning difficulties (Benedicto-López & Rodriguez-Cuadrado, 2019). The present study addresses literacy difficulties. Literacy skills are crucial not only for academic success but for every function, enabling quick and flexible behavioral adaptation to new demands (Huizinga et al., 2018). Moreover, literacy performance enhances adaptability in novel and complex situations (Abellán Roselló et al., 2019). Consequently, Gil (2020) argues that, on the one hand, literacy skills facilitate organization and the planning of actions that must be maintained throughout a task and, on the other hand, the inhibition of distracting elements and the adaptation of responses and actions depending on the context. Previous research, such as that of Peralta and Martínez (2018), indicates a strong correlation between literacy skills and academic performance. Based on these results, this study emphasizes the need

to modify elements related to the development of literacy skills. To date, studies have analyzed how these skills develop, but gaps remain regarding how difficulties in literacy tasks lead to problems in organization, planning, and task execution in the school setting. Expanding this knowledge is essential to understanding how interventions could facilitate better adaptation within educational environments.

Executive functions are higher-order skills that enable the control, direction, and regulation of cognitive functioning, as well as the management of external stimuli and their relation to prior knowledge and experiences, facilitating adaptative responses that facilitate appropriate environmental adaptation (Ambiado-Lillo et al., 2020). Furthermore, they are crucial for mental and physical well-being, as well as cognitive, social, and psychological development (Diamond, 2013, 2020). Huizinga et al. (2018) argue that the development of these functions is influenced by "brain maturation, social context, and the intervention received" (p. 1). These authors indicate that these functions are critical in novel or demanding situations that require speed and flexibility in response. This is important because they allow us to regulate our actions depending on the environment. The number of studies focused on analyzing executive functions has increased in recent years (Doebel, 2020), as these functions are considered essential for understanding individual involvement in reading (Haft et al., 2019) and writing tasks and, in general, literacy abilities in any language, culture, or age, whether or not there is a disability (Filipe et al., 2020). Despite the growing interest in executive functions, there is still a lack of knowledge about how inhibition, cognitive flexibility, working memory, and attentional control influence literacy skills in children aged six to eight. Many studies have analyzed this relationship in broader contexts, but few have specifically focused on this age group. This highlights the need for a deeper understanding of this association to develop effective interventions tailored to the needs of participants. This study follows the tripartite taxonomy, which includes inhibition, updating, and cognitive flexibility as components of executive functions (Diamond, 2013, 2020). However, although attentional control is not explicitly included in the tripartite taxonomy, it is considered a crucial component in this study due to its significant role in regulation and directing attention, which are essential for the proper functioning of inhibition, cognitive flexibility, and working memory. Therefore, this analysis will focus on the components of inhibition, cognitive flexibility, working memory, and attentional control. This analysis aims to address the previously aforementioned knowledge gap by examining the influence of these components on literacy skills in children aged six to eight.

Inhibition is crucial in literacy skills, particularly in reading and writing. It helps individuals deliberately ignore irrelevant stimuli, an important aspect of reading and reading comprehension tasks, and allows them to discard contextually inappropriate and irrelevant words, thereby maintaining a focus on achieving goals (Daucourt et al., 2018; Haft et al., 2019). This ability is linked to working memory retention, enabling us to ignore distracting information, adequately decode words, and comprehend text (Cain, 2006). This ability to inhibit irrelevant information, as argued by Cirino et al. (2017), is likely due to the retention of information in working memory. Thus, in addition to enabling complex tasks such as reading comprehension, simpler tasks such as decoding words can be performed when orthographically similar words are eliminated while reading (Haft et al., 2019). Regarding writing, the fluidities of the length of the text and the writing process are also affected, as it is necessary to suppress incorrect lexical representations and retrieve the most important ones while maintaining and updating them in working memory throughout a drafting task, per (Sesma et al., 2009). These authors suggest that without sufficient speed in this process, the resulting text will be shorter, as the individual may need to stop writing temporarily because of slower language generation, making this a reliable predictor of writing performance at a general level (Wagner et al., 2011). Previous studies have demonstrated

that inhibition is essential for literacy learning, as it is responsible for blocking irrelevant information and actions (Bonifacci et al., 2022). Furthermore, by suppressing interferences, the acquisition and consolidation of phonological awareness and spelling mastery can be achieved (Gandolfi et al., 2021; Lonigan et al., 2017). Additionally, Van Der Sluis et al. (2004) and Son et al. (2019) observed that children with difficulties in this executive function exhibit worse performance in reading tasks, while Parker (2022) noted these difficulties in reading comprehension tasks. Previous research has found an association between inhibition, phonological awareness, and spelling. Although there is a broad understanding of how inhibition supports adequate reading, there is still limited research analyzing the interaction between inhibition and working memory in word decoding. Additionally, further insight is needed into how inhibition influences the improvement of written fluency.

Cognitive flexibility enables the planning of actions based on environmental demands (Portellano, 2018). Failure in this cognitive subcomponent leads to difficulties in identifying the sounds of words, which hampers correct grapheme-to-phoneme conversion by preventing the appropriate spelling (Blair & Raver, 2015). Previous research has demonstrated that cognitive flexibility is associated with positive outcomes in reading tasks (Vadasy & Sanders, 2023), reading and writing comprehension (Arán Filippetti & Krumm, 2020; Hung & Loh, 2021), and print knowledge (Purpura et al., 2017). Despite this knowledge, there are still few studies that reveal the precise mechanisms through which cognitive flexibility influences literacy skills. Therefore, addressing this gap in understanding how to intervene to improve this component will lead to an increase in literacy performance.

Working memory allows us to retain and manipulate necessary information during task execution. Its components play a critical role in reading and writing, facilitating phonological awareness and grapheme–phoneme conversion (Haft et al., 2019). It comprises the phonological loop and visuospatial sketchpad, which are responsible for retaining auditory and visual information, respectively, that the brain then processes. These inputs are processed and integrated with the episodic buffer, which is responsible for sending information from short-term memory to long-term memory, and the central executive, which oversees and coordinates these processes (Baddeley, 2000). This executive function plays an important role in reading ability and is essential for codifying both known (Canales et al., 2020) and unknown words (Nouwens et al., 2016). For example, working memory plays a pivotal role in phonological awareness by enabling the temporary retention of phonological units, which are crucial for identifying and manipulating sounds within words. This capacity supports the segmentation of words into smaller units (phonemes), which is fundamental for both decoding new words and improving reading fluency (Maehler et al., 2019). Similarly, this function plays an important role in the writing process (Capodieci et al., 2018), affecting both writing speed and calligraphy (Ferrara & Cornoldi, 2019). Furthermore, working memory facilitates the process of fluent reading by allowing the reader to retain part of the text they have already read while processing new words or sentences. This allows for smoother reading, as the reader does not need to constantly reprocess information already encountered, thus improving both speed and comprehension (Demoulin & Kolinsky, 2016). In addition, working memory is instrumental in grapheme–phoneme conversion, a key step in word decoding. It allows the reader to store and update phonological information while simultaneously mapping graphemes (letters) to their corresponding phonemes (sounds). This dynamic process involves identifying, retaining, and updating sounds as they are decoded and combined to form meaningful words. The ability to temporarily store these elements and integrate them efficiently is a critical factor in reading success (Palmer, 2000). Previous studies have observed that positive performance in working memory is associated with a higher likelihood of developing adequate skills in reading tasks, improving subvocal rehearsal, lexical representations, and temporal encoding and retrieval (Demoulin & Kolin-

sky, 2016), as this executive function is related to eye movements (Kim, 2021). Additionally, there is an association with adequate writing skills (De Vita et al., 2021). Thus, working memory not only supports basic decoding but also enables higher-level reading processes like comprehension, where readers must hold onto portions of information while making inferences or integrating new knowledge (Haft et al., 2019). Despite these findings, there are few studies aimed at gaining a deeper understanding of how working memory contributes to proper grapheme–phoneme conversion as the text is being processed.

Attentional control consists of maintaining attention to a stimulus to prevent distractions from interfering through impulse control and eliminating irrelevant information necessary for the task at hand (Breznitz & Misra, 2003). Difficulties in attentional control affect the ability to read pseudowords and irregular words (Zoubrinetzky et al., 2019). This also complicates tracking graphemes and reading the corresponding lines (Meiri et al., 2019). Therefore, intervention is necessary to achieve proper word processing and spelling skills. In this respect, Parra et al. (2021) reported that children with reading and writing difficulties show poorer performance in memory and attention tasks; additionally, both working memory and inhibitory control are associated with reading comprehension (Haft et al., 2019). Previous studies have observed that attentional control has a direct association with reading ability (Cirino et al., 2022; Rezaei & Mousanezhad Jeddi, 2020) and, more specifically, with phonological awareness skills (Ten Braak et al., 2018) and reading comprehension mediated by vocabulary and decoding (Cirino et al., 2022; Kim, 2021). Studies such as Arrington et al. (2019) and Isbell et al. (2018) have shown that attentional control is associated with adequate writing skills. Despite the extensive knowledge gained from previous research, no clear consensus has been reached on how attentional control, first, specifically interacts with literacy tasks at different developmental stages and, second, how it influences reading comprehension and writing fluency. For this reason, it is necessary to delve deeper into how interventions focused on improving attentional control can enhance literacy skills.

Promoting executive functions in classrooms from the first school years is important (Keown et al., 2020) since this enhances, in the educational context, not only academic performance but also social development, per (Gil, 2020). The same author observed that improvements in working memory, cognitive flexibility, and overall executive functions are associated with enhancements in literacy and mathematical abilities. Marder (2023) reported that attentional control and cognitive flexibility are also essential for reading performance, as they allow one to understand what one is reading, eliminate irrelevant information, focus attention only on the necessary parts of the text, and switch between processes. Thus, understanding the effect of an executive function and its subcomponents can help teachers design teaching strategies focused on executive function training and, similarly, reduce learning difficulties to foster significant learning where previously acquired knowledge is related to new knowledge (Gil, 2020). Gao et al. (2023) suggested that including working memory training in teaching methods can achieve better results in writing and writing fluency. Horowitz-Kraus (2016) points out that improving processing speed, working memory, and visual attention enhances reading skills and literacy performance in individuals with literacy difficulties. Additionally, increasing working memory and inhibitory control can reduce orthographic errors (Malekpour & Aghababaei, 2013). García-Madruga et al. (2016) and Cartwright et al. (2020) observed that increasing executive functions not only improves reading but also enhances reading comprehension. Similarly, Turkstra and Flora (2002) indicate that enhancing executive abilities improves the capacity for written expression. Kavanaugh et al. (2019) found that employing 800 min of working memory and inhibitory control training via computers can significantly improve these skills, enhancing academic performance. However, this intervention should not just be

implemented with the students, as teachers with adequate executive functions can also significantly improve these same abilities in their pupils, specifically in inhibitory control and both visuospatial and phonological working memory (Walk et al., 2018). Despite the many studies conducted to understand, on the one hand, how executive functions influence literacy skills and, on the other hand, the effectiveness of interventions, there is still no firm consensus on how these executive functions affect literacy skills in children aged six to eight.

Studies have been conducted to understand how executive functions influence reading and writing abilities and whether interventions produce significant changes. However, few investigations have specifically analyzed how inhibition, cognitive flexibility, working memory, and attentional control influence these abilities in children aged six to eight. For this reason, it has been impossible to determine how these executive functions influence reading and writing indicators in children of these ages. However, several studies have analyzed the use of intervention programs to improve executive functions. For example, Dias and Seabra (2017) noted that classroom interventions can improve executive functions in the early years of primary school, with positive effects on learning. The most effective methodology is play-based work, as it yields good results in improving cognitive skills, whether working individually or in groups (Brito & León, 2024; Segretin et al., 2016). Regarding timing, studies like that of Bernal et al. (2020) suggest that interventions lasting 12 weeks have positive effects in terms of cognitive performance improvement. Moreover, it has been demonstrated that these interventions are particularly important in the early years of schooling, as executive function skills predict future cognitive performance, playing an important role in academic achievement, specifically in acquiring academic skills (Muchiut et al., 2021; Urquijo et al., 2017). These findings highlight the importance of designing diverse, engaging, and age-appropriate interventions, as well as achieving cognitive improvements in educational contexts. However, there is a lack of understanding of how the components of inhibition, cognitive flexibility, working memory, and attentional control differentially influence reading and writing skills in children aged six to eight. Although studies have analyzed intervention programs aimed at improving executive functioning in the early years of primary school, few have specifically analyzed these components in relation to reading and writing abilities in children of this age. Therefore, this study aims to fill this gap by investigating the role these components play in the reading and writing skills of children in this age group through an intervention that simultaneously targets these components. Additionally, it seeks to provide findings that enable the design of effective intervention programs for children aged six to eight to improve both cognitive and academic skills.

Successful interventions to improve executive functions in educational contexts share several common elements. They should include various executive function components, and specific organization and implementation parameters, and make use of new technologies (Cerda, 2021; Jimenez, 2022). Additionally, they are typically long-term, integrated into the school curriculum, and targeted at specific age groups (Llosa et al., 2020). Research indicates that interventions focused on motor activities, computerized programs, and mindfulness lead to significant improvements in the participants' executive functioning (Erazo Santander, 2022). These findings emphasize the importance of incorporating specific aspects into educational interventions to support teaching–learning processes and improve academic, personal, and social performance by enhancing executive functions. Although previous studies have identified the necessary characteristics for interventions to be effective, few have determined how these interventions should be designed when combining the components of inhibition, cognitive flexibility, working memory, and attentional control in children aged six to eight. Therefore, the present study aims to investigate how these

interventions should be structured. To this end, each component has been analyzed independently, in addition to employing a design adapted to the participants' age. Furthermore, a methodology incorporating technological tools has been implemented. This approach could expand knowledge on ways to design intervention programs that promote both cognitive and academic achievement.

The present study aimed (1) to analyze the direct impact of implementing an intervention program that can enhance inhibition, cognitive flexibility, working memory, and attentional control for participating children and (2) to analyze the impact of this intervention on the participating children. The results were obtained to expand educational practices, as they can supply information about several factors in learning and depicting academic skills, such as, for example, literacy, which must be considered when planning learning approaches.

Three hypotheses are proposed for the sample under study: (a) that the correlations between the executive functions of inhibition, cognitive flexibility, working memory, and attentional control, on the one hand, and the reading and writing skills of the children aged six to eight years, on the other, are highly significant; (b) that in the post-test, the experimental group will demonstrate an increase in the relationship between, on the one hand, inhibition, cognitive flexibility, working memory, and attentional control and, on the other, reading and writing abilities compared with the same students at the pretest stage; and (c) that there are significant differences in the levels of reading and writing between the control and experimental groups, the latter of which is engaged in an intervention program for executive functions comprising inhibition, cognitive flexibility, working memory, and attentional control.

2. Materials and Methods

2.1. Participants

An intentional, non-probabilistic sample of 23 children participated in this pilot study, 12 (52%) from the first year of primary education and 11 (48%) from the second, with ages ranging from 6 to 8 years (M = 6.65, SD = 0.647). Sixteen males (M = 6.69, SD = 0.647) and seven females (M = 6.57, SD = 0.787) were part of the study. There were no significant differences in age between the control and experimental groups (U = 51, Z = −1.023, $p = 0.305$). To be eligible for the study, participants had to be in either their first or second year of primary education, have or not have difficulties with reading and/or writing, and have signed informed consent from their parent or legal guardian.

The participants were assigned randomly to the control group ($n = 11$) or the experimental group ($n = 12$), with an equal number of children from the first and second grades in the latter (Table 1). This randomization was carried out to decrease potential biases that could impact the study, thus improving its internal validity.

Table 1. Demographic characteristics of the participants.

	Age		Sex				N				
	M	SD	Male		Female		1º Grade		2º Grade		N
			N	%	N	%	N	%	N	%	
Control group	6.82	0.751	9	82	2	18	6	55	5	45	11
Experimental group	6.50	0.522	7	58	5	42	6	50	6	50	12

Note. The demographic characteristics of the participants, including age, sex, and grade distribution, for both the control group and experimental group should be noted. *M* = Mean; SD = Standard deviation; *N* = Number of participants.

2.2. Instruments

For a comprehensive assessment of executive functions, various tests were used to evaluate the participants, including the Color and Word Test of inhibitory capacity; the Copy Test of a Complex Figure for attentional capacity and visual memory; and the Behavior Rating Inventory of Executive Function-2.

Color and Word Test (Stroop) (Golden, 2020): This test evaluates the ability to resist interference as a measure of inhibition. It comprises three subtests: (a) the word condition (W), where the task is to read a color name; (b) the color condition (C), which involves naming the ink color; and (c) the word–color condition (WC), which requires performing a similar task but with added difficulty, as the color names are different from the ink color. Each subtest consists of 100 items distributed across five columns. The time limit for each subtest is 45 s. The score is calculated based on the number of correctly answered items within this time frame. The maximum possible score is 100. However, these scores may vary depending on age. Therefore, when evaluating performance on this test, the maximum score is not considered; instead, the obtained performance is compared to age-based norms, allowing for a more precise interpretation of the results. The test shows acceptable internal consistency ($\alpha = 0.70$).

Copy Test of a Complex Figure (Rey, 2009): This test assesses attentional capacity, visual memory, and perceptual–motor development by evaluating the subject's ability to reproduce a figure through copying and from memory. It measures the number of secondary elements reproduced, the proportional size of these elements, and their relative positions concerning the four principal figures. Additionally, 2 points are awarded for each recognizable element; 1 point if it is difficult to recognize or draw out of place; and 0 points if it is not drawn or is unrecognizable. The maximum possible score is 82 points. However, this may vary depending on age. Therefore, the analysis focuses on comparing the obtained performance with aged-based norms to achieve a more precise interpretation of the results. The test shows acceptable internal consistency ($\alpha = 0.72$).

Behavior Rating Inventory of Executive Function-2, school version (Brief-2) (Kenworthy et al., 2017): This instrument comprises 63 Likert-type items, whose answers range from 1 to 3 points (never, sometimes, or frequently), focused on assessing executive functions (inhibition, self-monitoring, cognitive flexibility, emotional control, initiative, working memory, planning and organization, task monitoring, and organization of materials). The maximum score that can be obtained is 189 points. These scores are converted into standard scores, according to the normative benchmarks, to determine the level of executive functioning. The results are taken from the three general indices of behavioral, emotional, and cognitive regulation. The test shows excellent internal consistency ($\alpha = 0.94$).

Literacy Analysis Test (TALE) (Toro & Cervera, 2014): This test assesses reading (letters, syllables, texts, and reading comprehension) and writing (copying, dictation, and spontaneous writing) abilities. This instrument identifies and classifies the error made during reading and writing tasks, so it does not have a direct or maximum score. The number of errors is compared with normative benchmarks, and the interpretation is based on the final score obtained, that is, the total number of errors made. Therefore, an adjustment is made in the evaluation according to the specific criteria of the test. Although there are no sample items, the instrument follows progressive tasks that allow for the real-time recording and analysis of the errors made. As a result, more accurate information can be obtained about the individual's literacy performance. The test shows suitable internal consistency ($\alpha = 0.86$).

Two teachers for each grade completed Brief-2, while the researchers administered the other tests individually to each child. To ensure inter-rater reliability, the criteria for administering the instrument and interpreting the obtained results were agreed upon,

ensuring consistent and uniform evaluation. To achieve this, the instructions provided in the manual for each instrument were strictly followed, and the normative benchmarks were rigorously applied, making the necessary adjustments based on the participants' performance being increased.

2.3. Procedure

This process was authorized by the Ethics Research Committee of Valladolid University, which applies ethical rules to research involving humans. The study was conducted in accordance with the Declaration of Helsinki.

The pilot study aimed to analyze the effects of an intervention focused on inhibition, cognitive flexibility, working memory, and attentional control on reading and writing abilities. Therefore, authorization was sought from the General Directorate of Innovation and Teacher Training of Castilla y Leon, whose resolution was favorable. Subsequently, the participating educational center was contacted to provide information about the study's aims and solicit its participation. After obtaining consent from the educational center, further authorization was sought from the parents or legal guardians. Finally, a training session was held to implement the intervention program.

To conduct the study and achieve its objective, assessments were performed both before (pretest) and after (post-test) the implementation of the intervention program. The assessments were conducted during the early hours of the school day to avoid symptoms of exhaustion or fatigue typically observed at the end of the day. Each assessment period consisted of three sessions. In the first session, both the Rey and Stroop tests were applied; in the second session, the reading subtest of the TALE was administered; and in the third session, the subtest dedicated to writing was administered. The same order was followed in both assessment phases. Brief-2 was completed by the teachers using a questionnaire for each participating child.

Before the pretest, the control and experimental groups were formed by randomly assigning their components to eliminate the possibility of bias. The intervention lasted 12 weeks, during which 22 sessions were held, each lasting between 15 and 20 min and consisting of 3 or 4 activities, none exceeding 5 min. The sessions were held twice a week on nonconsecutive days. The intervention generally aimed to enhance the executive functions of inhibition, cognitive flexibility, working memory, and attentional control.

To achieve this, the program employed techniques that enhance extensive learning through focused attention and concentration. In addition to the targeted executive functions, each session began with a relaxation activity. Furthermore, activities were designed to foster group interaction and enhance cooperative learning. In each session, all subcomponents of executive functions were addressed, as the designed activities focused on their various aspects.

Below are a few example activities that were part of the intervention program. Firstly, an activity was conducted where participants were shown white or red cards. Whenever they saw a white card, they had to tap the table, and whenever they saw a red card, they had to clap their hands. This activity aimed to stimulate inhibition, as the participants had to suppress irrelevant information by ignoring non-pertinent visual elements for the task and avoid inappropriate automatic responses. It also required them to direct their attention toward what was necessary to perform the task correctly. This required cognitive flexibility, as they alternated between colors, exercising their ability to flexibly interchange mental strategies, and attentional control, as they needed to focus on the colors and avoid distractions, crucial for carrying out the activity correctly. Diamond (2013) demonstrated that this type of activity develops cognitive skills by enhancing attentional control and inhibition. Similarly, Breznitz and Misra (2003) highlighted the importance of including

cognitive flexibility in such interventions to carry out tasks that require switching between different instructions. The activity was timed to increase task demands and encourage quick, accurate responses.

Secondly, participants were shown a PowerPoint presentation containing images with one or two figures. Each time one figure appeared, participants had to draw a cross; if two figures appeared, they had to draw a line. The objective of this activity was to stimulate attentional control, as they needed to maintain concentration throughout the activity to identify the number of figures presented on each slide; inhibition, as they had to control automatic responses and draw the correct figure; working memory, as they had to remember the given instructions and retain them throughout the activity while processing the presented images; and cognitive flexibility, as they switched between two different responses based on the number of figures presented. García-Madruga et al. (2016) observed the relationship between inhibition, attentional control, cognitive flexibility, and working memory, supporting the design of tasks aimed at simultaneously targeting multiple executive functions. To ensure engagement, the presentation included randomized intervals between slides and distractor elements, further challenging participants to stay focused.

Thirdly, participants were shown a series of codes, each associated with a specific drawing. Subsequently, they were given a sheet with several of these drawings randomly repeated so they could write the corresponding codes underneath. This activity worked on working memory as they had to recall the corresponding codes for the drawing throughout the task; inhibition, as they had to ignore distractors and pay attention solely to the correct association between the code and the drawing to complete the task accurately; attentional control, as they needed to maintain focus throughout the activity to ensure that the associations made were correct; and cognitive flexibility, as they remembered the different codes and alternated between them to select the appropriate one based on the corresponding drawing. Previous research has demonstrated that working memory, inhibition, cognitive flexibility, and attentional control are essential for successful cognitive processing, per (Huizinga et al., 2018). The same authors emphasize the role of attentional control in tasks that require sustained concentration for successful completion, as well as the ability to ignore distracting elements. Additionally, Ambiado-Lillo et al. (2020) state that when cognitive flexibility and inhibition work together, they enable smooth task switching while effectively regulating responses. The task was structured with increasing levels of difficulty, with more distractors, additional codes, and more complex visual elements introduced as the activity progressed. By doing so, the intervention challenged the participants' executive functions in a gradual and developmentally appropriate way, promoting cognitive growth through repetition and adaptation.

Finally, participants were given a sheet with various drawings, one of which was repeated. They had to cross out this repeated drawing. This activity aimed to train attentional control, as they had to concentrate on the presented drawings and identify the one that was repeated; working memory, as they had to remember those drawings seen previously to compare and identify the repetition; inhibition, as they needed to suppress automatic responses and cross out only the drawing that was repeated; and cognitive flexibility, as they had to switch between different drawings while visually reviewing the others to identify the repetition. Aspuac Arens and Van Tuylen Domínguez (2021) emphasize the strong link between working memory and academic skills. Regarding cognitive flexibility and attentional control, Diamond (2013, 2020) and Breznitz and Misra (2003) observed that these two subcomponents are essential for tasks requiring constant shifts between different rules and making correct associations while ignoring distractions. Huizinga et al. (2018) found that inhibition is necessary to prevent automatic responses

and maintain focus on a task. To increase complexity, some drawings included subtle differences to further challenge perceptual and cognitive skills.

These activities were age-appropriate, engaging, and progressively challenging, ensuring that participants remained motivated while targeting key executive functions. By integrating a variety of stimuli and task demands, the intervention aimed to provide a comprehensive approach to enhancing cognitive and academic skills in children aged six to eight.

2.4. Design

This experimental, cross-sectional, and correlational study was designed to quantitatively assess the differences in correlations between the pretests and post-tests of the control and experimental groups, as well as to observe the effects of the intervention on the latter group. By comparing the correlations between the pretest and post-test results, it was possible to determine whether improving executive functioning and the analyzed subcomponents led to a greater improvement in reading and writing skills. This examination increased our comprehension of the interconnectedness of these variables, which can be applied to enhance educational methods in school.

To evaluate the specific effects of the intervention on each executive function (inhibition, cognitive flexibility, working memory, and attentional control), a differentiated analysis was carried out since each function was examined independently to identify its impact on literacy skills. This approach allowed for a more precise and direct observation of how improvements in each of these executive functions correlate with changes in literacy skills.

The independent variable was the intervention aimed at improving inhibition, cognitive flexibility, working memory, and attentional control. The dependent variables were performances in reading and writing tasks, both before and after the intervention. The control variable was group membership, either experimental or control, which allowed for a comparative analysis and isolation of the intervention's potential effects. This enabled more rigorous statistical analyses to detect the effects of the intervention, as both dependent and independent variables were continuous. An experimental design was chosen to accurately and objectively assess the effects of the intervention and control for external variables such as the assignment of participants to the control or experimental groups.

2.5. Analysis of Data

Thorough statistical analyses were conducted to scrutinize the data, enabling the evaluation of performance differences between participants and the relationship between study variables in the pretest and post-test for both the control and experimental groups. A data analysis was conducted using the statistical software SPSS 29 (https://www.ibm.com/es-es/products/spss-statistics, accessed on 5 March 2024).

To observe the associations between the independent variables of inhibition, cognitive flexibility, working memory, and attentional control and the dependent variables of reading and writing in both the pretest and post-test for the control and the experimental groups, Spearman correlations were employed. Consequently, analyzing the differences in correlations at each assessment phase allowed us to assess the impact on the experimental group and understand associations within each group between the pretest and post-test. To determine whether there were performance differences between the two groups, the Mann–Whitney U test was employed, and the nonparametric effect size was calculated to quantify the statistical significance and practical importance of the observed differences. A confidence level of 95% was maintained throughout the analysis.

3. Results

Statistical analyses were carried out on each of the study variables at both assessment points. Table 2 shows that during the pretest, the control group performed better than the experimental group in all variables except attentional control. However, in the post-test, the experimental group scored higher in all variables except inhibition and cognitive flexibility.

Table 2. Descriptive Analysis of Study Variables at Pretest and Post-test.

		Pretest		Post-Test	
		Mdn	**SD**	**Mdn**	**SD**
Control group	READ	153	42.740	149.50	23.745
	WRIT	74	22.235	148	26.065
	INH	17	14.866	13	8.808
	CF	12	4.735	12	3.139
	WM	13	6.138	12	6.898
	AC	37	7.144	39	3.139
	EF	93	36.085	81	24.179
Experimental group	READ	152.50	38.016	164	32.405
	WRIT	68.50	23.362	164	32.405
	INH	7.50	8.195	11.50	15.983
	CF	8.50	3.062	11.50	3.482
	WM	12.50	4.377	12.50	4.984
	AC	38	7.364	41	5.467
	EF	80	22.412	81.50	34.710

Note. Differences in median values for various study variables between the pretest and post-test phases for the control and experimental groups. The experimental group showed greater improvements in the median scores for several cognitive measures compared to the control group. The intervention had a positive effect on inhibition (INH), cognitive flexibility (CF), working memory (WM), and global executive functioning (EF), demonstrating marked differences in these areas of cognition. The enhancements in reading (READ) and writing (WRIT) were not as noteworthy as those seen in cognitive abilities, indicating that they were less remarkable. *Mdn* = Median; *SD* = Standard deviation.

Between the pretest and post-test, the control group showed decreased performance in reading and global executive functioning, while writing performance improved. In contrast, the capacities for inhibition, cognitive flexibility, working memory, and attentional control remained stable, showing comparable median values in both evaluations. Conversely, the experimental group reported improvements in reading, writing, inhibition, cognitive flexibility, attentional control, and global executive functioning between the pretest and post-test. Working memory showed similar median values at both assessment points.

Statistical tests, namely, Spearmen correlations and the Mann–Whitney U test, were used to either confirm or reject the hypothesis. The first hypothesis proposed a solid connection between inhibition, cognitive flexibility, working memory, attentional control, and literacy skills. Spearman correlations were employed to assess the magnitude and orientation of these connections before and after the intervention. Table 3 shows that reading and writing significantly correlated with inhibition and cognitive flexibility in the pretest. In contrast, global executive functioning approached significance, while working memory and attentional control did not show significant correlations with reading and writing. No substantial relationship was found in the post-test between the independent and dependent variables.

Table 3. Spearman Correlations Between Variables in the Pretest and Post-test for the control group.

	Pretest				Post-Test				Gains	
	Reading		Writing		Reading		Writing		Reading	Writing
	rs	*p*	rs	*p*	rs	*p*	rs	*p*	rs	rs
INH	−0.82	0.001	−0.74	0.007	−0.32	0.409	−0.33	0.449	−0.50	−0.41
CF	−0.64	0.033	−0.89	<0.001	−0.31	0.379	−0.31	0.368	−0.33	−0.57
WM	−0.53	0.099	−0.50	0.122	−0.50	0.144	−0.38	0.317	−0.03	−0.11
AC	0.37	0.266	0.50	0.118	0.25	0.489	0.31	0.414	0.13	0.19
EF	−0.60	0.055	−0.73	0.009	−0.31	0.374	−0.29	0.449	−0.30	−0.44

Note. The pretest for the control group showed inverse relationships between inhibition (INH) and reading/writing, as well as between cognitive flexibility (CF) and reading/writing. In the post-test, there were still clear negative associations between inhibition (INH) and writing, and executive functioning (EF) and writing. The gains exhibited weaker and nonsignificant correlations across all variables. *WM*: Working memory; *AC*: Attentional control.

Table 4 shows that during the pretest, there was a significant negative correlation between reading and writing skills and inhibition in the experimental group but a positive and significant correlation with attentional control. Conversely, cognitive flexibility, working memory, and global executive functioning did not show any correlations. During the post-test, literacy skills demonstrated negative and significant associations with cognitive flexibility, while working memory exhibited a comparable correlation with writing. There were no notable connections between reading ability and inhibition, working memory, attentional control, or overall executive function. Similarly, there were no significant associations between writing skills and inhibition, attentional control, or overall executive functioning.

Table 4. Spearman Correlations Between Variables in the pretest and post-test for the experimental group.

	Pretest				Post-Test				Gains	
	Reading		Writing		Reading		Writing		Reading	Writing
	rs	*p*	rs	*p*	rs	*p*	rs	*p*	rs	rs
INH	−0.77	0.002	−0.63	0.025	−0.26	0.475	−0.27	0.474	−0.51	−0.36
CF	−0.40	0.205	−0.33	0.298	−0.61	0.036	−0.59	0.041	0.21	0.26
WM	−0.33	0.309	−0.32	0.323	−0.34	0.313	−0.91	<0.001	0.01	0.59
AC	0.67	0.016	0.66	0.018	0.46	0.137	0.45	0.145	0.21	0.21
EF	−0.39	0.220	−0.35	0.272	−0.46	0.161	−0.47	0.162	0.07	0.12

Note. Significant negative correlations were discovered in the pretest between inhibition (INH) and reading as well as writing, and between cognitive flexibility (CF) and reading as well as writing, in the control group. In the post-test, notable detrimental associations remained for inhibition (INH) and writing, as well as executive functioning (EF) and writing. Gains exhibited weaker and nonsignificant correlations across all variables. *WM*: Working memory; *AC*: Attentional control.

The second hypothesis proposed that the correlations between the analyzed executive functions and literacy abilities would be stronger in the experimental group than in the control group after the intervention. To test this hypothesis, the differences between the correlations obtained in the pretest and post-test were calculated. This approach also allowed us to assess whether the intervention positively impacted the experimental group. In the control group, correlations declined, while in the experimental group, they rose, except for inhibition and attentional control in reading and writing (Tables 4 and 5).

Table 5. Differences in Scores Obtained in the pretest and post-test between the control and experimental groups.

	Pretest		Post-Test		U	Z	*p*	r
	Mdn CG	Mdn EG	Mdn CG	Mdn EG				
READ	153	152.50	150	164	46.5	−0.600	0.549	-
WRIT	74	68.50	150	164	45	−2.778	0.481	-
INH	17	7.5	13	11.5	21	−2.778	0.005	0.58
CF	12	8.5	11.5	11.5	25	−2.338	0.019	0.53
WM	13	12.5	11	12.5	29	−2.075	0.038	0.48
AC	37	38	39	41	36.5	−1.555	0.120	-
EF	93	80	80.5	81.5	23	−2.442	0.015	0.55

Note. Differences in scores from pretest to post-test were found in both the control group (CG) and experimental group (EG). The experimental group displayed significantly greater improvements in inhibition (INH), cognitive flexibility (CF), working memory (WM), and global executive functioning (EF) compared to the control group. *U* = Mann–Whitney U statistic; *Z*: Z statistic; *p*: *p*-Value; *r*: Effect size.

Moreover, the third hypothesis anticipated that the experimental group would improve literacy skills after receiving intervention. To evaluate this, a comparative analysis was carried out using the Mann–Whitney U test to examine differences in scores between the pretest and post-test for both groups. This analysis aimed to determine whether significant differences existed in the study variables between the groups (Table 5).

The results indicated significant differences between the control and experimental groups in inhibition, cognitive flexibility, working memory, and global executive functioning. However, no significant differences were found in the reading, writing, and attentional control variables.

4. Discussion

This research aimed to examine the effects of an intervention targeting enhancements of inhibition, cognitive flexibility, working memory, and attentional control in children between the ages of 6 and 8. Furthermore, we aimed to determine whether the intervention improved the connection between these cognitive and literacy skills in the intervention group.

The results align with those of Follmer (2018), who conducted a meta-analysis and found an association between executive functioning and reading comprehension, though he noted no differences related to age or the measure used. Similarly, García-Madruga et al. (2016) and Cartwright et al. (2020) reported that higher levels of executive functioning correlate with better reading and comprehension skills.

Parra et al. (2021) found that children with reading and writing difficulties performed worse in working memory and attentional control, findings that match those of the present study. Horowitz-Kraus et al. (2016) reported similar results. A study by Aponte-Henao and Zapata-Zabala (2013) found deficits in working memory among children with writing difficulties, supporting the observed correlations between these variables.

Unlike Haft et al. (2019), this study found significant associations between working memory and word decoding in reading tasks among preschool children, a finding not observed by Jacobson et al. (2017) in children aged 8 to 16 years. Nonetheless, this study found significant associations between working memory and writing ability.

Furthermore, Locascio et al. (2010) observed that children with low inhibitory control and poor working memory had weaker word-decoding skills, supporting the correlations seen in this pilot study between these executive functions and reading.

The intervention was carried out over 22 sessions spread across 12 weeks, with each session lasting between 15 and 20 min. Evaluations were conducted both before and after the implementation of the program. The results were analyzed using statistical tests, namely, the Mann–Whitney U test and Spearman's correlation. The intervention results showed improvements in inhibition, cognitive flexibility, attentional control, working memory, and overall executive functioning. Gao et al. (2023) confirmed these findings. However, consistent with Stein et al. (2017), this study's post-test results did not show significant improvements in working memory, suggesting that such interventions do not always enhance executive functioning.

This study yielded positive results; however, potential confounding variables that could have influenced the outcomes were not adequately addressed. These include socioeconomic status, school environment, motivation, learning strategies, and support from parents or teachers. These factors may have impacted the performance of the instruments used to assess literacy skills and executive functioning. Additionally, emotional variables were not considered, which could have also influenced the results. Furthermore, the statistical analyses showed that the improvements in working memory were not as pronounced. Therefore, further research is needed using more diverse and larger samples, rigorously controlling potential confounding variables to obtain more precise results on the effectiveness of the intervention and to reduce their impact.

Overall, the findings demonstrate that executive functions like inhibition, cognitive flexibility, working memory, and attentional control are closely linked to literacy abilities in the study sample. The interventions aimed at enhancing these executive functions appear to have positively impacted their literacy tasks.

However, it is important to highlight the limitations of this study and suggest directions for future research. Firstly, this study involved a small group of 23 children, which is a small sample size and limits how broadly we can apply the findings. It would be helpful to include more children of different ages and backgrounds to obtain a clearer understanding of how well these interventions work for different groups of people. Secondly, the intervention was short-term; therefore, we could not assess the long-lasting intervention impacts. It would be helpful to carry out studies over several years to see whether the improvement in literacy skills is sustained. Thirdly, there may be other factors that were not considered that might have impacted the results, for example, the grade level of the students, their engagement in other programs, other academic support, or the instructor's quality of teaching. Future studies should control these factors and consider elements like intrinsic motivation and emotional states to better understand how these external influences affect executive functions and literacy skills. Exploring these research avenues will provide a deeper understanding of the relationship between executive functioning and literacy skills, confirming the effectiveness of targeted interventions in different educational settings.

5. Conclusions

An experimental and cross-sectional study was conducted with 23 children from the first and second grades of elementary education. The descriptive analysis revealed differences between the control group and experimental group in terms of reading, writing, inhibition, cognitive flexibility, working memory, attentional control, and global executive functioning. During the pretest, the control group outperformed the experimental group in all variables except for attentional control. However, in the post-test, the experimental group

outscored the control group in all variables except for inhibition and cognitive flexibility. The experimental group showed improvements across almost all areas, particularly in reading and writing, though their working memory scores remained unchanged in the pretest. In contrast, the control group's performance decreased in reading, working memory, and global executive functioning, unlike the improvements observed in the experimental group. The control group showed slight improvements in inhibition and attentional control, while cognitive flexibility scores remained similar to those at baseline. The significant improvements in reading and writing in the experimental group can be attributed to the intervention program, while the gains observed in the control group might be due to ongoing educational activities at the school.

In the pretest, significant correlations were observed in the control group between inhibition and cognitive flexibility and between reading and writing abilities. The relationship between these factors and global executive functioning approached significance. These correlations approached significance with global executive functioning, suggesting that lower mastery of these abilities leads to more errors in literacy tasks. In the post-test, these correlations decreased, indicating a reduced association between the variables over time. In the experimental group's pretest, significant correlations were found between literacy abilities and inhibition and attentional control. This implies that better control of inhibitory impulses and enhanced attentional control correlate with better literacy performance in the analyzed sample. The post-test results showed significant correlations between cognitive flexibility and literacy and between working memory and writing, highlighting the importance of targeted training in executive functions for enhancing reading and writing performance. Significant differences between the control and experimental groups were noted, with the experimental group showing stronger correlations post-intervention. This suggests that the intervention program was beneficial for literacy performance and enhancing executive functions.

While both groups showed improvements in writing abilities, reading improvements were only noted in the experimental group. These improvements were not associated with the same executive functions, as no significant correlations were observed in the control group's post-test in the analyzed sample. These improvements can be attributed to significant changes in correlations between the variables of literacy, cognitive flexibility, working memory, and global executive functioning in the experimental group due to the intervention, which strengthened several of the executive functions analyzed. In contrast, in the experimental group, stronger correlations with cognitive flexibility and working memory were noted. This suggests that the intervention may have positively affected the experimental group, for the sample analyzed, by improving executive functions and their subcomponents along with literacy abilities. Increased correlations between literacy variables and cognitive flexibility, working memory, and global executive functioning were observed post-intervention in this group.

It is important to consider the correlations between the study variables and their changes over time, particularly after the intervention. The control group showed a decrease in correlations, whereas the experimental group showed an increase, except in inhibition and attentional control in both reading and writing. These outcomes suggest that the improvements in the experimental group were directly due to the intervention rather than external factors. Additionally, it appears that cognitive flexibility and working memory may be linked to challenges in literacy tasks, as evidenced by stronger correlations associated with improvements in these academic skills.

The significant differences between the control and experimental groups in inhibition, cognitive flexibility, working memory, and global executive functioning can be attributed to the intervention program. No significant differences were observed in the reading and

writing variables, but the enhanced correlations suggest the positive effects of the intervention on these variables in the experimental group in the analyzed sample. Nonetheless, the results demonstrated significant changes in correlation between the pretest and post-test in the experimental group, with an increase noted between literacy and cognitive flexibility, working memory, and global executive functioning. Therefore, although no significant differences in reading or writing were observed between the groups, the enhancements in correlations suggest that the intervention positively affected these variables in the analyzed sample.

Moderately large effect sizes were observed for inhibition, with moderate effects for cognitive flexibility, working memory, and global executive functioning, indicating that, in the analyzed sample, the intervention positively impacted the experimental group more than the control group.

The results confirm the initially proposed hypotheses and can assess the impact of the applied intervention. First, there was a significant association between literacy skills and the executive functions of inhibition, cognitive flexibility, working memory, and attentional control in the study sample, with global executive functioning nearing significance. Higher correlations in the post-test indicate that better mastery of executive functions leads to improved literacy skills. Therefore, the first hypothesis is confirmed, demonstrating a clear relationship between the independent and dependent variables.

The second hypothesis suggesting stronger correlations between all analyzed executive functions and literacy skills post-intervention in the experimental group was partially confirmed. Enhancements in correlations between cognitive flexibility, working memory, and global executive functions and literacy skills were observed, although no such enhancements were noted for inhibition or attentional control.

No significant differences in literacy skills were found between the control and experimental groups, rejecting the third hypothesis. However, the stronger correlations of cognitive flexibility, working memory, and global executive functioning with reading and writing skills in the experimental group post-intervention illustrate how the experimental group achieved improvements compared with the control group after receiving the intervention.

These findings highlight the significance of considering executive functions in literacy development. Understanding the role of executive functioning in children's literacy improvement is vital. Future studies need to build on these findings to discover how executive functioning relates to overall educational performance. Despite being a pilot study, these findings offer precious insights for the scientific community, particularly for educators, psychologists, and child neuropsychologists. This study has practical applications in educational practice, highlighting priority areas for attention and intervention.

The importance of considering executive functioning in children's literacy development cannot be overestimated. Thus, it is pressing to investigate the role of academic executive functioning with reference to literacy and, subsequently, its relationship with academic outcomes. This study establishes that executive functioning is a crucial predictor of literacy and overall academic performance. This affirms previous work suggesting that interventions meant to enhance the capacities of executive skills can help enhance literacy. The present study provides guidance for the development and implementation of interventions geared toward advancing reading and writing skills in the 6-to-8-year-old age group by targeting key areas such as inhibition, cognitive flexibility, working memory, and attentional control. Overall, our results contribute new evidence of the link between executive functioning and literacy, suggesting ways in which targeted interventions based on executive functions can advance literacy skills. The results provided developmental guidance on which executive functions are most important for the development of literacy

in children aged 7 to 8 years. These programs target various aspects of executive functions, such as inhibition, cognitive flexibility, working memory, and attentional control. We have also shown how improving specific executive functions can help children become better readers and writers.

These effects provide valuable insights into which executive functions are critical for the growth of literacy skills in children aged 6 to 8 years. This information can help us design better techniques to improve academic performance and identify areas where students might need more help with literacy problems, with a view to earlier and extra personalized interventions.

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Abbreviations

The following abbreviations are used in this manuscript:

READ	Reading
WRIT	Writing
INH	Inhibition
CF	Cognitive flexibility
AC	Attentional control
EF	Executive function

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