Computational Thinking Training and Its Effects on Working Memory, Flexibility, and Inhibition: Controlled Trial in Fifth-Grade Children

Carolina Robledo-Castro
crobledoc@ut.edu.co
University of Tolima
Luis Fernando Castillo-Ossa
University of Caldas
Christian Hederich-Martínez
Universidad Autonoma de Manizales

Research Article

Keywords: Computational thinking, executive functions, cognitive science, working memory, inhibition, cognitive flexibility

Posted Date: January 1st, 2025

DOI: https://doi.org/10.21203/rs.3.rs-5707155/v1

Additional Declarations: No competing interests reported.

Abstract

This study sought to integrate the discussion on the teaching of computational thinking in elementary school and the development of executive functions in childhood. It evaluated the effect of a training program in computational thinking on working memory, flexibility and inhibition in fifth grade children. A randomized controlled trial was conducted with a sample of 111 typically developing children (mean age = 10.75, SD 0.82). Participants were randomly assigned to either an intervention group (computational thinking training for 12 weeks with disconnected activities and activities connected with game programming and educational robotics) or an active control group (in a regular treatment). The executive functions were assessed before and after the intervention using valid and reliable neuropsychological tests. After the training program, the experimental group showed a significant improvement in several executive functions compared to the control group. A large effect size was observed in auditory working memory, a medium effect in visual and visuospatial working memory, and a small effect on inhibition skills. No changes in cognitive flexibility associated with the intervention were observed. The results suggest that teaching computational thinking through disconnected and connected activities achieves a significant effect on the development of some executive functions.

Highlights

Strengthening computational thinking skills and executive functions can be integrated into primary school through educational programs.

The study evaluated the effects of a program that integrated the teaching of computational thinking through disconnected and connected activities (game programming and educational robotics).

The computational thinking training program showed varying degrees of improvement: 1) large in auditory working memory, 2) moderate in visual-spatial working memory, and 3) small in inhibition.

No effects on cognitive flexibility, attributable to participation in the intervention, were observed.

The findings suggest that teaching computational thinking applied in a structured way may improve some key executive functions in elementary school children.

1. Introduction

This study seeks to integrate two theoretical categories in the field of cognitive development that have acquired increasing prominence in the scientific literature in recent decades: the development of executive functions and computational thinking skills. On the one hand, executive functions have been widely studied in the field of the cognitive sciences; they have also been the subject of detailed analyses that address their nature, neurological bases and developmental trajectories throughout the life cycle. On the other hand, computational thinking has been predominantly explored in the field of educational sciences, particularly in studies related to teaching in STEM disciplines (Science, Technology, Engineering and Mathematics). This paper aims to establish a bridge between both variables, highlighting their potential interrelation and underlining the importance of approaching their study from an integrative approach based on the cognitive sciences.

Executive functions have gained prominence in studies of cognitive development and are widely recognized as an essential component in behavioral regulation and cognitive control. One of the first scholars to define this construct was Luria (1973), who described it as a regulatory cognitive activity that allows the individual to act with intention and purpose, modulating behavior through a specific program in which language plays a fundamental role. Such an early definition is still relevant nowadays, as it captures the essence of executive functioning as a coordinating process that integrates various skills to achieve defined goals.

Since then, the concept of executive functions has evolved and established itself as an umbrella term that encompasses a variety of higher-order processes, such as planning, inhibition, working memory, and cognitive flexibility (Mareva, 2024). These processes are mainly carried out by prefrontal areas of the brain, and are related to the control of cognitive, affective, and behavioral processes (Goldstein et al., 2013).

Executive functions are not only fundamental in the adaptation and regulation of behavior but are also linked to the development of complex skills such as decision-making and problem-solving, which makes them a focus of interest for both cognitive neuroscience and developmental psychology (Robledo & Ramírez, 2023). Consequently, studies in the area have found that the development of executive functions has significant implications for academic success, emotional self-regulation, and social adaptation (Poon et al., 2022; Meruelo et al., 2024; Rufini et al., 2024).

Among the executive function models developed to date, the three-component model proposed by Miyake et al. (2000) is one of the most widely accepted and empirically supported. This model provides an organizational structure that allows researchers to differentiate this construct into specific subcomponents: mental set change (Change), information updating and monitoring (Update), and inhibition of overbearing responses (Inhibition). Through confirmatory factor analysis, Miyake and his team showed that these components are both separable and interdependent: each plays a different role in cognitive processing, but all contribute together to global executive functioning. This structure has facilitated research in various areas, allowing a differential analysis of the processes that make up executive functioning (Miyake et al., 2000).

Unlike the concept of executive functions that emerged in the 1970s, the construct of computational thinking (CT) has had a much more recent emergence. In the 1980s, Papert had suggested the term procedural thinking to refer to the ability to understand and design procedures or sets of structured instructions to solve problems. In 2006, Wing formulated the term "computational thinking" for the first time to refer to the thought processes involved in formulating and solving problems, following the principles of computer science, so that these solutions can be represented in such a way that an agent, human or computational, can execute them effectively. In other words, CT is a reasoning approach that applies principles from computer science to solve problems in a structured and efficient way (Wing, 2006; Chen et al., 2017; Nardelli, 2019). Such an approach includes processes such as breaking down complex problems into more manageable parts, abstracting to identify patterns and essential elements, designing and applying algorithms to solve problems, debugging solutions, and using automation to execute solutions efficiently (Shute 2017; Selby & Woollard, 2013).

Papert's (1987) initiative in teaching procedural thinking to children was to foster cognitive development by allowing children to interact with computer systems, helping them understand abstract concepts through concrete experiences to develop higher cognitive skills, such as logical reasoning and problem-solving skills (Kalelioğlu, 2015). Wing, on the other hand, popularized CT as a skill that is not limited to computer areas, as it is transversal and applicable to all disciplines (Wing, 2008; Aho, 2012).

Currently, CT is considered a fundamental competency in STEM fields (Kong et al., 2019) and its inclusion in early education has become a priority in many countries (Lee et al., 2022), including Colombia (MinTic, 2022). The implementation of CT in K-12 education has led to initiatives to incorporate coding and programming activities that develop skills in algorithmic design and modeling, promoting students' ability to solve problems using computational tools (Shute et al., 2017; Kong et al., 2019). Although programming is a key tool in this context, the main objective of CT is to promote structured and systematic reasoning applicable to a wide variety of situations, beyond specific programming languages (Arfè & Vardanega, 2019; Wing, 2006).

The literature suggests that CT has positive effects in academic areas such as mathematics and science and that it can facilitate the application of problem-solving strategies in daily life (Gover & Pea, 2013; Hickmott et al., 2018). In addition, recent studies have begun to investigate the relationship and impact of computational thinking on other cognitive processes (Liao & Bright, 2000; Scherer et al., 2024), including executive functions (Montuori et al., 2023).

Various systematic reviews and meta-analyses have explored studies on the effects of learning to code, finding that, in addition to improving programming skills, they contribute to the development of higher-order cognitive processes, such as critical thinking, mathematical reasoning, creative thinking, and metacognition (Liao & Bright, 2000; Scherer et al., 2024). The meta-analysis by Montuori et al. (2023) reviewed 11 studies focused on the effect of CT on EF and problem-solving. The results of this analysis reveal that CT has a particularly notable positive effect on planning and problem-solving, with moderate effects on working memory and inhibition, but without significant results on cognitive flexibility. Montuori and colleagues conclude that these effects, while moderate, are consistent and underscore the importance of further investigation of the relationship between CT and EF. The review by Montuori et al. (2023) also suggests that the educational context, the type of activities selected, and the quality of interventions play a critical role in the degree of impact that CT can have on cognitive skills.

Initiatives to explore the effects of CT on EF in preschool children include the work of Di Lieto et al., (2017; 2021), Gerosa et al. (2019; 2021), Wang et al. (2021), Canbeldek (2022), Pellas (2024), and Zurnaci et al. (2024); most of these endeavors have studied interventions based on robotics' devices and disconnected activities. Among their findings, they have identified favorable effects on working memory and inhibitory control. Studies of the school population have been less frequent, some have been oriented towards the first grades of primary school (Arfé et al., 2019, 2020, 2022, Montuori et al., 2024), others in the last grades (Pardamean, 2011, Robertson, 2020, Tsarava, 2019, 2022), or throughout primary school (Román et al. 2017, Liu, 2024). Most of these studies have evaluated block language-based interventions on integrated development platforms such as code.org and schatch, with different findings depending on the type of intervention and the measurement instruments selected.

All studies emphasize the need to continue contributing to and expanding the evidence on the effects and relationship of computational thinking with the development of executive functioning, especially exploring the effects between different interventions and different population groups. Additionally, the need to guarantee studies with methodological rigor is suggested.

The present study focuses on late childhood, specifically in fifth-grade children between 9 and 11 years old; this developmental period stands out for being a time of significant cognitive challenges for children, such as the transition from primary to secondary school. At this stage, EF, such as working memory and cognitive flexibility, are in a crucial period of development (Monarca, 2014), and teaching CT can offer an opportunity to strengthen these processes. Exploring the relationship between EF and CT in this population is relevant, as it allows us to identify educational strategies that not only improve computational skills, but also promote cognitive development in a broader sense.

Based on the identified problem and with the purpose of contributing to this field of study, the present study aims to investigate the effect of a twelve-week computational thinking training that integrates disconnected activities and activities connected with educational robotics on executive functions (working memory, inhibition and cognitive flexibility) in fifth grade children.

2. Method

The present study was conducted as a randomized controlled trial (RCT), using an intra-subject and inter-subject evaluation design with two parallel groups: an experimental group and an active control group that received treatment as usual (TAU). The measurements were carried out at two times, pre-test (T0) and post-test (T1). The trial protocol was developed following the guidelines of the CONSORT Declaration (Consolidated Standards of Reporting Trials) (Moher et al., 2010), which establishes evidence-based recommendations to ensure quality, standardization, and transparency in the reporting of randomized trials (Schulz et al., 2010). To ensure the transparency of the process, the trial was registered in an International Clinical Trials Registry Platform (ISRCTN11380198) and its protocol was published prospectively (Anonymous, 2023a), in accordance with best clinical research practices.

2.1. Participants

122 children from four fifth-grade classes in public schools in two cities in Colombia were invited to participate in the study. 111 children met the inclusion criteria, which ranged from 9 years to 11 years and 11 months at baseline. Exclusion criteria included the presence of medical conditions that could limit their participation in activities, diagnosis of neurodevelopmental disorders, or uncorrected sensory disabilities. The mean age of the participants was 10.75 years (SD = 0.82), and the final sample was made up of 38 girls and 73 boys.

Since the intervention was carried out in an educational setting, randomization was not individual but by natural groups; thus, the four fifth-grade classes were randomly assigned, with two classes to the experimental group (N = 57) and two classes to the control group (N = 54). Regarding socioeconomic level, 75.7% of the participants belonged to low strata and 24.3% to medium-low strata. No significant differences were found between the groups in any of the sociodemographic variables ($p > 0.05$ in all of them).

Table 1
Sociodemographic Variables Observed in the Study

Variable	*Total Sample*	*Experimental Group*	*Control Group*	*t*	*p*
N	111 (100%)	57 (51.3%)	54 (48.7%)		
Age in years; mean (SD)	10.75 (0.82)	10.78 (0.78)	10.73 (0.87)	t = 0.350	0.727
Sex				$X^2 = 0.990$	0.320
Female	38 (34.23%)	35 (61.40%)	38 (70.37%)		
Male	73 (65.77%)	22 (28.59%)	16 (29.63%)		
Social Strata	**(N = 107)**			$X^2 = 1.385$	0.239
Low-Low	35 (32.71%)	13 (23.21%)	22 (43.14%)		
Low	46 (42.99%)	32 (57.14%)	14 (27.45%)		
Medium-Low	20 (18.69%)	9 (16.07%)	11 (21.56%)		
Medium	6 (5.60%)	2 (3.57%)	4 (7.84%)		

2.2. Bias Control

The study followed Cochrane guidance for controlling for risk of bias in one RCT (Higgins et al., 2011). To minimize selection bias, the assignment of the groups was carried out through a randomization process with a sealed envelope method by an external investigator to the study. To ensure the concealment of the assignment, the researcher responsible for the pre-test and post-test evaluation was unaware of the assignment of the participants to the groups, which allowed blinding in the selection and performance phase. To reduce detection bias, outcome assessors remained blind to the type of intervention applied. Given the nature of the study and the use of an active control group that received treatment as usual, blinding was not possible for participants.

To control for attrition bias or incomplete data, we adopted an intention-to-treat (ITT) analysis approach, whereby data imputations were performed for participants who did not complete the intervention. These data were compared with a per-protocol analysis ensuring the integrity of the results.

2.3. Primary Measures

To assess executive functions and computational thinking, the measurement instruments that were selected had solid evidence of their validity and reliability.

2.3.1. Verbal Working Memory

Verbal Working Memory was assessed with the Wechsler Intelligence Scale for Children digit test (WISC-V, 2014), which measures the ability to retain and manipulate auditory information temporarily. The test consists of remembering sequences of numbers of ascending difficulty and is composed of three subtasks: direct order (repetition of the sequence in the original order), reverse order (repetition in reverse order) and increasing order (repetition in ascending order). For this study, the main indicator of performance in auditory working memory is the total score, corresponding to the sum of correct answers in the three subscales; however, the findings of the three subscales are reported since they offer a more complete view of the individual's performance by differentiating unemployment in short-term memory (digits in direct order) and working memory (digits in reverse order and in growing order). The digit test shows high internal consistency in children aged 10 to 11 years ($\alpha = 0.91$) (Wechsler, 2015).

2.3.2. Visual Working Memory

Visual Working Memory was assessed with the Visual Span test of the Wechsler Intelligence Scale for Children (WISC-V, 2014), which measures immediate visual memory capacity and visual working memory. In this test, the participant briefly observes a series of visual stimuli and then must identify the drawings seen in the same order among other distractors. The score is based on the number of correct answers and the *span* value of drawings, calculated from the total number of stimuli on the sheet (Wechsler, 2014). This test shows adequate internal consistency, with a Cronbach's alpha of 0.85 in 10-year-olds and 0.80 in 11-year-olds (Wechsler, 2015).

2.3.3. Visuo-spatial Working Memory

Sequential Visuo-spatial Working Memory was assessed with the Corsi Cube Test in reverse order (Corsi, 1972). This test consists of two parts: cubes in progression and cubes in regression. The regression part assesses the ability to retain and manipulate visuospatial sequences by replicating, in reverse order, a sequence of cubes touched by the evaluator. The difficulty increases as the sequences become longer and more complex. The indicator in this test is the number of correct answers obtained by the person being evaluated. This test has proven to be reliable in the assessment of visuospatial working memory in children and adults (Guevara et al., 2014), with a Cronbach's alpha of 0.76 and a generability coefficient of 0.72 (Wechsler, 2014).

2.3.4. Cognitive Flexibility

Cognitive flexibility was assessed with the Wisconsin Card Sorting Test (WCST) in its abbreviated version of 48 cards, validated for children and adolescents in Latin America (Arango-Lasprilla et al., 2017; Schretlen, 2010). This test measures the ability to change cognitive strategies in response to changes in environmental contingencies (Heaton et al., 2001) and is widely used in clinical practice, especially in Spanish-speaking countries. In this study, the number of errors in category selection and perseverations, which reflect the repetition of previous errors, were analyzed. WCST direct scores have shown high Spearman–Brown Split-Half Reliability Coefficients (rSB ≥ 0.90) (Kopp et al., 2021).

2.3.5. Inhibitory Control

To assess inhibitory control, the Stroop test was used. This test has proven to be reliable in measuring the subjects' ability to inhibit automatic responses and manage interference (Rodríguez Barreto et al., 2016). The test consists of three slides: the first presents words and the second colored stimuli, both used as control measures. The third slide contains color names printed in a different color, assessing the subject's ability to inhibit the automatic response to read the word and instead name the color of the ink, which requires selective attention. The indicator used to evaluate performance in the test is the number of correct answers in a period of time (45 seconds), although the main indicator is the word/color task, the results in the first two tasks will also be presented to support the interpretation of the findings. The original test has shown adequate internal consistency ($\alpha = 0.73$) and a test-retest reliability of 0.69 (Golden, 1975; Rivera, 2017).

2.3.6. Sociodemographic Variables

To measure sociodemographic variables, a sociodemographic questionnaire implemented and validated in previous studies (Anonymous, 2023b) was applied; it collects information on the family's level of schooling, access to electronic media. Additionally, the family sociodemographic stratum was established according to the stratification scheme of the DANE (National Administrative Department of Statistics of Colombia).

2.4. Interventions

2.4.1. Experimental Group

The experimental group participated in a 12-week intervention, two hours a week and a final closing session for a total of 26 hours of computational thinking training. Over the 12 weeks, the 20 modules that made up the intervention called COGNI-MACHINE (Anonymous., 2023d) designed by the first author (for more information, see www.cognimachine.org). In each session, the children worked in groups of peers, except for exceptional cases of children who interrupted the intervention, the pairs were preserved throughout the program.

The modules of the COGNI-MACHINE program integrated disconnected activities and connected activities (see Table 2). The disconnected activities were collected from initiatives such as CSunplugged, Bebras Challenger and the modules of the "Coding for Kids" program of MinTic (2022); these activities were included in different modules throughout the program (Fig. 2). The connected activities included three modalities: 1) block programming exercises on the code.org platform in which students designed games and animations (Fig. 2). 2) projects with a micro:bit device programmed on the MakeCode platform (Fig. 2). 3) projects developed from a micro: bit-based robotics kit developed by Elecfreaks and an educational robotics device developed by the University of Virginia called Roversa (for more information see roversa.com).

Each session was conducted as a workshop, from a problem-based learning perspective. Problem-based learning (PBL) is an instructional method that uses complex and real problems as a starting point for learning, in this way students work on solving these problems, which forces them to investigate, apply knowledge and develop critical thinking skills and collaborative work (Hmelo-Silver, 2004). Throughout the training, the activities followed the principles of low threshold and high ceiling (Grover & Pea, 2013); therefore, their level of difficulty was progressively increased. The content validity of the intervention was evaluated through the evaluation of four expert judges, with experience in teaching computational thinking to school children, containing an acceptable content validity index (CVI < .70 in all modules).

Table 2
COGNI-MACHINE Program Modules

	Module focus	Disconnected activity	Connected activity
1	Introduction to Computational Thinking.	1). Find the letters in the maze. 2) Robots playing hide-and-seek.	NA
2	Algorithmic thinking. What is an algorithm and what are its structures?	1). Simulation game: how a processor, a programmer and a program work?	NA
3	Decomposition. Introduction to code.org	1). Sequences in daily life. 2). Let's make burgers.	Sequencing exercises in code.org.
4	Pattern recognition. What is a loop and what is its function?	1). Help CONI get out of the looped maze. 2). Choreography in loops.	Loop exercises in code.org.
5	Purification.	1). Recycling sorting. 2). Code necklace.	Purification exercises in code.org.
6	What are conditional loops and when are they used?	1). Conditional loops in daily life. 2). Get COGNI out of the maze with conditional loops.	Exercises with conditional loops in code.org.
7	What are events and what function do they fulfill?	1). Events in sport.	Exercises with events in code.org.
8	What are logical conditionals and how are they formulated?	1). Get COGNI out of the maze using logical conditionals.	Exercises with logical conditionals in code.org.
9	Introduction to using micro:bit and makecode.	NA	Exercises with basic blocks in makecode. Projects with micro:bit: Beating Heart, Name, Hamster.
10	What are inputs in a computer system (Micro:bit)?	NA	Exercises with input blocks in makecode. Projects with micro:bit: tamagochi, bicycle lights, Dice.
11	What is a variable and what function does it fulfill in an algorithm?	1). Animals with variable parts.	Exercises in variable blocks and loops. Projects with micro:bit. Accelerometer: Pedometer, Countdown.
12	What are the control structures?	1). Weaving with logical conditionals.	Conditional block exercises and math in makecode. Projects with micro:bit. Temperature sensor and accelerometer: Rock, paper or scissors, temperature regulator.

	Module focus	Disconnected activity	Connected activity
13	Putting into practice what has been learned: Optimizing algorithms.	NA	Exercises with music blocks in makecode. Projects with micro:bit. Speaker: Heart, Automatic lamp.
14	What are micro:bit pins and what are they used for? Types of pins.	NA	Exercises with pin blocks in makecode. Project with micro:bit analog pins: Humidity reader.
15	New micro:bit entries.	1). Set the right path with flowcharts.	Project with micro:bit: Compass.
16	Components of a robotic system (Roversa, Kit elecfreaks)	NA	Sequencing exercises with Roversa.
17	Motion programming in Robot with motor.	NA	Projects with the Elecfreaks Kit Robots with a motor: Spider, Bigfoot, Dog, Drafting robot.
18	Robot programming with external sensors and software extensions.	NA	Projects with the Elcreaks Kit: Ultrasound Robots: Point Reader.
19	Robot programming with two motors and ultrasonic sensor.	NA	Projects with the Elecfreaks Kit. Robots with two motors and ultrasound: Obstacle avoidance robot and line follower.
20	What are the functions and what role do they play in programming?	1). Assembling and programming a cardboard robot (Octopus)	Exercises with functions in code.org. Robot with servomotor: Octopus.
	Closure.	NA	Free project with the Elecfreaks kit.

2.4.2. Control Group

Para el grupo de control activo se seleccionó en tratamiento como de costumbre (TAU), el cual consiste en que el grupo control reciba el tratamiento acostumbrado de forma paralela al grupo experimental (Burns, 2009). En este caso, el grupo control en TAU recibe las clases tradicionales de Tecnología e Informática durante el mismo número de semanas y con la misma intensidad horaria en que los participantes del grupo experimental reciben el entrenamiento en pensamiento computacional. Durante estas clases, los estudiantes aprenden sobre las partes de la computadora, aplicaciones de Microsoft office y el uso de la internet.

2.5. Analysis Plan

For the missing data, an intention-to-treat (ITT) analysis approach was used. Therefore, instead of eliminating the subjects who did not complete the intervention, data imputation was performed through multiple imputation based on monotonic regression models performed in the SPSS (version 30) software.

To evaluate the effect of the intervention, a hypothesis test was performed through a Mixed Repeated Measures Analysis of Variance (RM-ANOVA) where the pre-test (T0) and post-test (T1) measurements acted as a repeated measures factor (intrasubject), and the difference between the experimental group and the control group was considered as an intersubject factor. The effect size was calculated using partial eta squared. The assumptions of this analysis include a metric and continuous dependent variable, with an approximately normal distribution and homoscedasticity in each group. After determining the existence of significant differences between the means, a post hoc Tukey test for the Honestly Significant Difference (HSD) was performed. The statistical analyses were run in the specialized software JASP.

3. Results

Of the 111 children assigned to the study arms, 6 children discontinued the intervention (2 from the control group and 4 from the experimental group) as they were withdrawn from educational institutions. For the lost data of these students, a synthetic data imputation was performed. Figure 3 presents the Consort diagram used to transparently describe the flow of participants throughout the different phases of the clinical trial.

Figura 3. Consort Diagram

Table 3 presents the measures of central tendency (mean and standard deviation) of each of the indicators of the primary measures. For the indicators of the number of correct answers in the Stroop test, the number of categories in WSCT in the digit test, and the number of correct answers in the Corsi block test and visual spam, a higher score is interpreted as better performance. However, in the Wisconsin card test, the measures of errors and perseverations are negative, therefore a lower score is associated with better performance on the test.

Table 3. Central tendency measures in the pretest and posttest in both groups

Prueba	Task/Scale	Control N=54		Experimental N=57	
		Pretest	Post-test	Pretest	Post-test
A-WM (Digit Test)	Direct Order	6.96 (1.44)	7.33 (1.67)	7.17 (1.67)	8.23 (1.19)
	Reverse Order	6.67 (1.22)	6.94 (1.78)	6.94 (1.37)	8.25 (1.57)
	Increasing Order	5.67 (2.09)	6.29 (1.76)	5.67 (1.46)	7.31 (1.53)
	Total Score	19.54 (3.19)	20.49 (3.56)	18.99 (2.98)	22.72 (3.70)
VS-WM (Corsi Cube Test)	Direct Order	5.17 (1.21)	5.48 (1.19)	5.23 (1.32)	6.19 (1.33)
	Reverse Order	5.33 (1.98)	6.17 (1.85)	5.16 (167)	6.91 (1.49)
V-WM (Visual Span Test)	Score	21.56 (6.31)	24.24 (5.94)	21.79 (4.76)	27.05 (5,44)
	Span Level	3.81 (0.71)	4.02 (0.66)	3.69 (0.51)	4.12 (0.63)
CF (WCST)	Errors	15.06 (6.73)	16.31 (8.11)	15.96 (6.63)	15.75 (4.86)
	Perseveraciones	1.61 (0.86)	1.67 (0.91)	1.46 (0.82)	1.59 (0.91)
	Categories	1.61 (0.90)	1.67 (0.89)	1.35 (0.82)	1.56 (0.91)
IC (Stroop Test)	Word	67.77 (9.59)	73.37 (11.05)	69.41 (11.19)	78.45 (11.27)
	Color	47.32 (8.43)	51.87 (8.37)	47.22 (10.26)	55.19 (10.11)
	Word/Color	28.24 (6.21)	29.81 (7.66)	27.10 (7.39)	31.46 (6.33)

Note: A-WM: Auditory (verbal) Working Memory; VS-WM: Visuo-spatial Working Memory; V-WM: Visual Working Memory; CF: Cognitive Flexibility; IC: Inhibitory Control

As a prerequisite to the application of parametric tests, the assumptions of normality of the data and the homogeneity of variances (homoscedasticity) were verified through the Levene test, which guarantees that the variances between the groups are similar and comparable (Field, 2013). All primary measures met these assumptions ($p>0.05$ in all measures). Likewise, the difference between groups was examined through a Tukey test to confirm that there were no significant differences between the groups at the time of the pretest (see complementary material).

Table 4 presents the cognitive processes and their tasks/scales. Next to these columns appear the results of the RM-ANOVA, namely, the overall difference between the pre-test and post-test, the difference associated with the interaction between the intervention and the test -pretest and post-test-, and the difference between subjects (control group vs. experimental group). The partial eta square was used to measure effect size, where a value around 0.01 is interpreted as a small effect, values around 0.06 a medium effect, and above 0.14 a large size (Cohen, 1988).

Table 4. Results of the RM-ANOVA

Cognitive Process	Task/Scale	Global difference between pre-test and post-test			Difference associated with the interaction between group and intervention			Effect between subjects		
		F(1, 109)	*p*	η^2_p	F(1, 109)	*p*	η^2_p	F(1, 109)	*p*	η^2_p
A-WM (Digit Test)	Direct Order	31.64	<.001	0.225	7.27	**0.008**	**0.063**	5.95	0.016	0.052
	Reverse Order	26.16	<.001	0.194	11.73	**<.001**	**0.097**	10.05	0.002	0.084
	Increasing Order	60.93	<.001	0.359	12.19	**<.001**	**0.101**	3.036	0.084	0.027
	Total Score	61.31	<.001	0.360	21.893	**<.001**	**0.167**	2.10	0.153	0.019
VS-WM (Corsi Cube Test)	Direct Order	27.26	<.001	0.200	7.03	**0.009**	**0.061**	3.48	0.065	0.031
	Reverse Order	76.07	<.001	0.411	9.63	**<.001**	**0.081**	0.92	0.341	0.008
V-WM (Visual Span Test)	Score	60.87	<.001	0.358	6.40	**0.013**	**0.055**	2.62	0.108	0.024
	Span Level	23.61	<.001	0.178	3.16	0.781	0.028	0.02	0.894	0.000
CF (WCST)	Errors	0.52	0.477	0.005	0.993	0.321	0.009	0.029	0.864	0.001
	Perseveraciones	0.10	0.745	0.000	0.559	0.456	0.005	0.85	0.358	0.008
	Categories	0.89	0347	0.009	0.14	0.712	0.001	0.82	0.367	0.008
IC (Stroop Test)	Word	59.24	<.001	0.365	3.28	0.073	0.031	3.27	0.077	0.030
	Color	35.63	<.001	0.086	10.40	**0.002**	**0.025**	0.67	0.414	0.006
	Word/Color	19.29	<.001	0.150	4.25	**0.042**	**0.038**	0.05	0.823	0.000

Note: *: .01<p<.05; **: .001<p<.01; ***: p<.001

3.1 Effects on Auditory Working Memory (Digit Test)

When examining the results of the total score of the digit test (constituted by the sum of the three individual tasks), a significant difference was observed in the interaction between the group and the time of the test, with a large effect size (see Table 4). After the post hoc tests, it was confirmed that the control group did not present significant differences between pre- and post-test $t=-2.302$, $p=.104$, while the experimental group did $t=-8.579$, $p<.001$, $d=-1.117$, with a large effect size. These results suggest that the intervention had a significant effect on the auditory-verbal working memory performance of the experimental group, measured through the Digit Test.

When reviewing the individual tasks of the Digits test, similar results were observed in the three tests (See Figure 4). The interaction between the intervention and the test was significant for all three tasks, although the direct digit task showed a small effect size, while the reverse digit and increasing order digit tasks had medium effect sizes. These results were confirmed by Tukey corrections, which revealed significant differences between the pretest and post-test measures of the experimental group in the direct order tasks *t= -4.370 p<.001 d=-0.560,* reverse order tasks *t=* -5.324 *p<.001 d=* -0.652 and increasing order tasks *t= -8.099 p< .001 d= -0.958.* On the other hand, the tests carried out in the control group did not show significant differences between the pretest and the posttest in any of the tasks: direct order *t= -2.043 p= .261*, reverse order *t= -1.179 p= .723* and increasing order *t= -2.491 p= .086*.

These superior results in the test of digits in overall may be due to a cumulative effect; that is, the total score is composed of the sum of the individual subtests, therefore, it is possible that small changes in each of them accumulate when adding the scores, resulting in a larger effect size in the total score, as this measure achieves greater statistical power.

Figure 4. Graph tests of working memory in both groups.

3.2 Effects on Visuo-spatial Working Memory (Corsi Cube Test)

The results of the Corsi task in direct order showed a significant difference associated with the interaction between the intervention and the time of test, with a medium effect size (see Table 4). Post hoc tests revealed that the control group did not present significant changes t = -1.792, p = .283, while the experimental group showed significant improvement with a large effect size t = -5.644, p <.001, d = -0.762. These results suggest that the intervention had a medium effect on the visuospatial immediate memory capacity of the experimental group (see Figure 4).

In the Corsi task in reverse order, the interaction between the intervention and the time of test was significant with a medium effect size. Post hoc tests showed significant improvements in both groups: the control group with a moderate effect t = -3.920, p < .001, d = -0.475 and the experimental group with a large effect t = -8.478, p < .001, d = -1.001, suggesting that the interventions had a greater impact on visuo-spatial working memory in the experimental group, compared to the control group.

3.3 **Effects on Visual Working Memory (Visual Span Test)**

The total score of the visual span test showed a significant difference in the interaction between intervention and test with a small effect size in favor of the experimental group (Table 4). Post hoc tests indicate significant changes between the pretest and posttest of both groups, but while the effect size in the control group was medium t = -3.378, p = .002, d = -0.477, in the experimental group it was large t = -7.407, p < .001, d = -0.935. These results suggest that the intervention had a greater impact on the experimental group in performance on the visual working memory test.

For the visual span test level indicator, no significant interaction was found between the intervention and the time of assessment, although significant differences were observed between the pre-test and the post-test of the global sample, with a large effect size. This indicates that both the experimental and control groups showed similar improvement in this task, without a differentiated impact attributable to the intervention.

3.4 **Effects on Cognitive Flexibility (WSCT)**

Analyses of the number of errors in the Wisconsin card test showed no significant differences in the interaction between intervention and the time of assessment (Table 4; Figure 5). There were also no significant differences between the pre-test and the post-test in the global sample, nor difference between the groups. These findings suggest that there were no improvements in cognitive flexibility in either group.

Regarding the number of perseverations, no significant changes were observed in the overall sample between the pre-test and the post-test, nor in the interaction between intervention and test timing. The number of categories had a similar behavior, no differences were observed between the pre-test and post-test of the global sample, nor significant changes associated with the interaction between the intervention and the test. Overall, none of the Wisconsin card test indicators showed changes between the pre-test and post-test in either group.

Figure 5. Graph of the tests of inhibition and flexibility in both groups.

3.5 Effects on Inhibitory Control (Stroop Test)

The results of the word/color task of the Stroop test showed significant differences in the interaction between the group and the time of the test with a small effect size (Table 4). Post hoc tests indicated that the experimental group showed significant improvement with a medium effect size $t = -5.418$, $p < .001$, $d = -0.703$, while the control group showed no significant changes $t = -2.404$, $p = .082$. These results suggest that the intervention had a significant, albeit small, effect on cognitive inhibition capacity in the experimental group (Figure 5).

The results of the control tasks of the Stroop test were also analyzed, although these are not indicators of inhibitory control, they contribute to the interpretation and differentiation of the effects. In the Letters task of the Stroop Test, it showed a significant difference in the overall performance of the sample; however, the interaction between the intervention and the test did not reach statistical significance, indicating that changes in performance cannot be attributed to the intervention. On the other hand, the results of the Color task of the Stroop Test showed a significant difference in the overall performance of all participants, while the interaction between the group and the test also showed significant differences with a small effect in favor of the experimental group compared to the control group. Post hoc tests revealed significant improvements in both the control group $t=-3.250$, $p=.009$, $d=-0.496$ and in the experimental group $t=-6.004$, $p<.001$, $d=-0.883$. However, the effect size was larger in the experimental group.

Taken together, these findings indicate that the intervention not only led to small improvements in the cognitive inhibition capacity of the experimental group, but also had an impact on cognitive processes related to attentional control and speed in complex tasks such as color management.

4. Discussion

The objective of this group-randomized controlled trial was to evaluate the effect of a 12-week computational thinking training with disconnected and connected activities on executive functions (inhibition, flexibility, and working memory) in fifth-grade children. The findings revealed a positive effect of the intervention on executive functions, particularly on auditory-verbal, visuospatial and visual working memory, and to a lesser extent on cognitive inhibition.

This study sought to contribute to an emerging field in cognitive sciences that has gained relevance in the last decade: computational thinking. It revolves around exploring the effects of the teaching of computational thinking on other cognitive processes. These initiatives are based on the premise that learning coding and participating in both connected and disconnected activities in school contexts not only favors the transfer of specific computational thinking skills, such as algorithmic thinking, decomposition, abstraction, debugging, and generalization, but can also generate transfer effects to other cognitive areas, such as executive functions. Previous studies have explored this problem. Some of them have sought to investigate the effects of learning coding and programs in computational thinking on executive functions as a unifactorial construct (Yang et al., 2023, Zurnaci & Turan, 2024), and some others have been interested in particular processes of executive functioning such as working memory (Di Lieto et al., 2017; 2020; Gerosa et al., 2019; Wang, 2023; Liu, 2024; Anonymous, 2023b; 2023c; Pellas, 2024), cognitive flexibility (Özcan et al. (2021; Pellas, 2024; Liu, 2024; Pardamean et al., 2011) or inhibitory control (Robertson, 2020; Liu, 2024; Di Lieto et al., 2017; 2020; Pellas, 2020; Montuori, 2023; Arfé et al., 2019).

Among these works, both observational and experimental studies can be observed. Most studies have been limited to the preschool population and the first years of primary school, although some studies have also been identified in the last years of primary school. In view of this background, the current study intended to ensure a robust and rigorous methodological design, so it selected an intervention program that would allow the integration of both disconnected and connected educational activities, including both block programming and educational robotics projects. The results obtained are discussed below.

In the current study, working memory was addressed as a multifactorial cognitive process (Baddeley, 2016). For this reason, different outcome measures were included to evaluate the different components of working memory. Regarding visuospatial working memory, assessed by the reverse cube task of the Corsi test, a medium effect size associated with the intervention was observed. Although the control group also showed moderate improvements in this task, the impact was markedly greater in the experimental group.

These findings are consistent with those reported in other studies, such as that of Di Lieto et al. (2017; 2020), who observed significant improvements in the Corsi test in preschool children after a ten-week intervention with educational robotics. Likewise, the study by Gerosa et al. (2019) found a moderate positive correlation between computational thinking skills and performance on the Corsi Cube test in preschool children after an 8-week robotics program. However, other correlational studies in preschool children with programming experience showed no relationship between computational thinking skills and performance on the Corsi test (Wang, 2023). This difference between studies could suggest that the type of intervention differentially influences the results obtained from the studies.

Studies on visuospatial working memory in the school population have been less frequent. Nonetheless, in a correlational study that included the Corsi Cube test, a correlation between visuo-spatial working memory and pattern recognition was observed in a computational thinking test in children in grades three to eight (Liu, 2024). On the other hand, the pilot study previously carried out with fifth-grade children, using the visuospatial working memory test of the BANFE-2 battery (Flores-Lázaro et al., 2014), showed significant improvements both in the reduction of the number of errors and in the maximum sequence achieved by the children who participated in the "Coding for Kids" program (Anonymous, 2023c). Therefore, the findings of the current study confirm the preliminary results obtained in the pilot study and in other similar studies conducted with different age groups.

Additionally, in our study, the Corsi Cube test in progression also showed an improvement in the experimental group with a medium effect size, suggesting that the intervention, in addition to having an effect on visuo-spatial working memory, also had an effect on visuo-spatial short-term memory skills measured with this test.

In the Visual Span test, used to assess the effect on visuo-spatial memory, a significant improvement was also observed with a medium effect size associated with the intervention in the total test score, however, in the level of visual span, referring to the maximum number of images that the child managed to retain, both groups showed similar improvements. Therefore, although on average the students in the experimental group improved their performance on the test, the number of visual elements they can retain did not change.

The visual dimension of working memory, explored independently of visuo-spatial memory, has been less studied in the literature on this topic. However, the findings of the present study are in line with other studies that have addressed this cognitive dimension. Pellas (2024) observed that preschool children with advanced experience in educational robotics outperformed beginners or children with intermediate experience in a visual working memory test; nevertheless, the authors do not provide details on the reliability or characteristics of the test used. In the pilot study conducted by our research team (Anonymous, 2023c), a significant difference was observed in the number of correct answers of the experimental group in the ordering test, a test designed to assess visual working memory (Flores-Lázaro et al., 2014).

These findings can be considered complementary to those obtained with the Corsi test, since both the visual and visuo-spatial working memory tasks contribute to evaluate the "visuospatial loop" proposed by Baddeley (2016), one of the three temporal stores of information in working memory, responsible for the representation, processing and manipulation of visual and spatial information. Therefore, the findings of the present study, consistent with previous studies, seem to suggest that computational thinking training may have a moderate effect on visual and visuospatial working memory skills.

In relation to auditory-verbal working memory, measured with the Digit test, the experimental group showed a significant improvement between the pre-test and the post-test with a large effect size, while the control group did not present significant differences. In fact, this was the measure that was shown to have the greatest effect associated with the intervention. This finding suggests that the intervention significantly strengthened auditory-verbal working memory skills. When reviewing performance on the individual tasks that make up the Digit test, significant improvements in the experimental group are observed. In fact, the direct order task, associated with short-term memory, had a medium effect, while the reverse and increasing order tasks, which involve more the ability to manipulate and update the visual-spatial working memory, had larger effect sizes. Therefore, the greatest effects of the intervention were associated precisely with tasks that demand greater additive-verbal working memory.

Most studies that have explored the effect of computational thinking on working memory have included outcome measures associated with the visuospatial or the visual dimension. Therefore, there is little evidence about the effects on auditory-verbal working memory, except for the pilot study in which the BANFE-2 battery task of ordering was included (Anonymous, 2023c). However, no significant differences were observed in this study that could be associated with the intervention.

In this order of ideas, the findings of the present study contribute to broaden the discussion on the differential effects in each modality of working memory. Most studies argue that experiences in block coding, disconnected activities, and educational robotics to learn computational thinking have a high demand on visual and visuospatial working memory (Di Lieto, 2020). This is associated with the nature of the activities with a high load of manipulation of visual information, thus, as an experience that puts into play the ability to maintain and retain visuospatial information, it can become an opportunity for development. This premise has led researchers to explore the relationship between this dimension of working memory, with results that, as already shown, suggest that learning computational thinking manages to generate a distant transfer to visual working memory and visual and spatial vision.

Conversely, the nature of computational thinking training programs in school contexts, such as the COGNI-MACHINE program, also implies a strong demand for collaborative problem-solving skills, which implies the ability of students to socialize, communicate, and follow verbal instructions. In other words, it is not a task where the child is exclusively programming instructions in a computer through blocks and visual supports; on the contrary, the entire intervention was developed with group or pair activities, with the support of guides with verbal and visual instructions, which the student had to socialize with the classmates to solve the challenges of each module. Unquestionably, it is an experience with a high demand on their auditory-verbal working memory capacity, similar to other types of interventions with mixed connected and disconnected activities.

In the case of findings related to inhibitory control, assessed with the Stroop test, the results revealed that the intervention led to a significant, small-sized improvement in the performance of the word/color task of the Stroop test in fifth-grade children. These findings are consistent with those of other studies conducted with first graders. For example, Arfé et al. (2019) reported significant improvements in the number of errors of the Stroop task, with a small effect size, while the NEPSY-II battery inhibition scale showed a medium effect size in terms of time and accuracy. In a subsequent study, Arfé et al. (2020) confirmed these results, observing moderate effect sizes in both tests.

Several correlational studies in the school population have identified changes in inhibition tests associated with computational thinking skills. Robertson (2020), for example, found moderate to strong relationships between computational thinking and inhibition and self-control skills, in fifth grade students. Likewise, Liu's (2024) study found a correlation between inhibition and other computational thinking skills, such as pattern recognition and abstraction. In line with these findings, the pilot test conducted for this study found significant improvements in performance on the Stroop test, both in terms of timing and accuracy, suggesting a positive impact of computational thinking on these executive skills (Anonymous, 2023c). In a similar context, other studies with preschoolers also reported significant improvements in cognitive inhibition tests (Di Lieto et al., 2017; 2020; Pellas, 2020). However, the study by Montuori (2023), which used the NEPSY-II inhibition scale, did not observe significant differences in any of the indicators of inhibition in first grade children after a computational thinking program with both connected and disconnected activities.

Apart from Montuori's (2024) study, previous works showed moderate to small magnitude effects on cognitive inhibition tests, as well as correlations between small and medium-sized cognitive thinking and computational thinking. Overall, both previous and current studies agree that inhibitory control skills can improve after computational thinking training. However, the findings suggest that these effects tend to be more pronounced in preschool and first grade children (Di Lieto, 2020; Pellas et al., 2024), while in the current study, and others conducted with school-age children, the changes were more conservative (Arfé et al., 2019; Anonymous., 2023c).

Cognitive inhibition is one of the executive functions that develops earlier, showing a significant peak of evolution during preschool age (Flores-Lázaro & Ostrosky, 2012; Robledo & Ramírez, 2023). For this reason, inhibitory abilities are particularly sensitive to stimulation in the early school years. This could be reflected in the fact that, for preschool children, the inhibition tasks show greater improvements compared to older children, in the event that the task shows a ceiling effect in this.

Another relevant aspect to consider in this study is the nature of the test used. The Stroop task involves a high demand on higher-order cognitive processes, such as reading and color recognition. To control for these factors, the word/color task was preceded by two control tests: one for word reading and the other for color recognition. The RM-ANOVA analyses performed did not show significant effects on the word reading task, but a small effect on the color recognition task. These results suggest consistency between the three measures; however, it is important to consider that, since the participants are elementary school children, who are developing their reading and writing skills, if they present reading difficulties from the beginning, this could interfere with their performance in the task and mask the effect of the intervention. In addition, from the post hoc tests, a significant retest effect was observed in both groups during the post-test. Based on these observations, it is suggested that future studies include other inhibitory control measures, using alternative paradigms such as Flanker or Go/No-Go, which could minimize the confounding effect of reading skills or reduce the possible effect of practice.

To assess cognitive flexibility, the Wisconsin card test, an abbreviated version of 48 cards, was used. The results of the study showed no statistically significant differences related to participation in the intervention in any of the measures explored (number of errors, number of perseverations, number of categories). These findings are consistent with the results of the meta-analysis by Montuori et al. (2023), who, from an analysis of multivariate fixed-effect models, found that teaching coding had a small to medium effect on executive functions such as inhibition and working memory, but revealed no significant effects on cognitive flexibility. In the same vein, the study by Özcan et al. (2021) also found no significant differences in cognitive flexibility associated with the 10-week intervention with code.org and scratch.

Contrary to the findings of the present study and the results reported in previous research (Montuori et al., 2023; Özcan et al., 2021), there are some studies that have explored the effects or association between computational thinking and cognitive flexibility, obtaining positive results. For example, Pellas (2024) revealed a significant correlation between flexibility and advanced coding experience in preschool children. However, this study does not provide details on the nature or reliability of the test used. Liu (2024), on the other hand, found a small correlation between one of the components of computational thinking, algorithmic thinking, and cognitive flexibility. Likewise, the study by Pardamean et al. (2011) reported a marginally significant improvement ($p = 0.045$) in the cognitive flexibility of fifth grade children, measured through a creative thinking test, following a Logo-based program. The diversity of measurement instruments used to assess cognitive flexibility in each study make it difficult to interpret the findings. Some studies associated this ability with fluid intelligence (Özcan et al., 2021), while others linked it to creative thinking (Pardamean et al., 2011) or did not provide details about the tests used or their reliability.

Cognitive flexibility has been the least studied executive function in this type of study. But overall, the results found in the current study and the ones in previous studies seem to suggest that there is no strong association between cognitive flexibility skills and the teaching of computational thinking. Further research is still needed to replicate these studies in other populations in a way that confirms these claims.

As can be seen, the results of the study find points in common with some previous studies and points of disagreement with others. In general, an important aspect to consider is the characteristics of the intervention. On this occasion, an intervention was designed that sought to bring children closer to computational thinking from basic exercises to more complex and demanding activities, included the concepts associated with algorithmic thinking through disconnected exercises that were later articulated with connected activities, and took students from simple problems to solving problems of daily life through the programming of robotics devices. A cross-cutting aspect of the program was collaborative work in pairs or groups, which was a differential aspect of the intervention.

As the findings of the study reveal, it is possible to contribute to the development of executive functions, through the development of computational thinking skills. In other words, integrating the teaching of computational thinking into K-12 education is not only a valuable opportunity to introduce children to STEM training, but also favors the development of problem-solving skills by integrating computational principles. At the same time, it strengthens auditory-verbal working memory and visual-spatial skills and, to a lesser extent, students' inhibitory control skills.

5. Limitations

One of the limitations of the study was the choice of instrument to assess computational thinking. Although a significant difference of small size was observed in favor of the experimental group in the post-test, the overall effect between the pre-test and post-test reveals that there was an important retest effect. On the other hand, since this test is strongly dependent on reading skills, the latter could affect the subject's performance by masking the real effect of the intervention on inhibition. For future studies, the inclusion of other tests such as the Flanker task or the Go/No Go task is suggested as an alternative to evaluate inhibitory control.

Another limitation is the duration of the intervention, although it is a brief intervention of 12 weeks, for future studies it is suggested to study the effect of programs that extend for a longer time, so that the learning curve of the participating children can be strengthened and thus increase the possible effects of the intervention. On the other hand, as mentioned above, studies in the school population are scarce, which is why it is important to replicate studies on other population groups to observe the differential effects between age groups and between different types of interventions.

6. Conclusions

The present study provides evidence on the effects of computational thinking training on the executive functions of fifth grade children, especially in the areas of auditory-verbal, visuospatial and visual working memory, as well as on cognitive inhibition. The findings corroborate the premise that teaching computational thinking skills, such as coding and educational robotics, not only improves competencies directly related to algorithmic thinking, but also favors transfer to other cognitive functions, particularly those underlying working memory processes. This study adds to the emerging body of research suggesting that introducing the teaching of computational thinking from elementary school can have a significant impact on strengthening children's executive skills, and overall, on students' cognitive development.

Despite the positive results observed, some areas of development for future research seem worth mentioning. In particular, the intervention had a limited impact on cognitive flexibility, which coincides with some previous studies that have not found significant improvements in this executive function associated with computational thinking programs. This finding suggests that cognitive flexibility, which is more related to the ability to adapt to new cognitive demands, might not be as sensitive to interventions of this type, or might require specific approaches to its development. Also, it is important to consider the inclusion of more alternative measures of cognitive flexibility and other executive functions, in addition to refining methodological approaches in the design of intervention programs, in order to maximize their effectiveness in the development of all dimensions of executive functions in school-age children.

Declarations

Ethical Considerations

The activity complied with all the ethical requirements described in the Declaration of Helsinki and the Resolution 8430, which establishes the standards for health research, according to which this study would be classified as risk-free (1993, art.11). Informed consent was signed by the parents and guardians of the children, and an informed assent by the children. A risk minimization protocol was also useful for the study. The study was previously approved and endorsed by the bioethics committee of the anonymous through Act 10 of December 13, 2022.

Funding

The study is part of the 430121-project attached to the curriculum, university and society research group of the University of Tolima, with funding from the Research Fund of the Universidad del Tolima and the Bicentennial Doctoral Excellence Scholarships, financed by the Science, Technology and Innovation Fund of the General System of Royalties of Colombia.

Author Contribution

Authorship Statement CRediTCarolina Robledo-Castro: Conceptualization, Research, Resources, Methodological Design, Intervention Design, Original Writing, Project Management, Measure Selection, Data Analysis, Data Curation, and Editing.Luis Fernando Castillo-Ossa: Conceptualization, Methodological Design, Writing review, Consultancy. Christian Hederich-Martínez: Consulting, Methodological Design, Statistical Analysis, Writing review.

Acknowledgement

AcknowledgementsWe highly thank the educational institutions involved, as well as the teachers, students and their families for agreeing to participate in this research. We also thank the early childhood education students at Universidad del Tolima who supported the development of the intervention, as well as the evaluators and research assistants who accompanied us throughout the process.

References

1. Aho, A. (2012). Computation and computational thinking. The Computer Journal, 55 (7) 832–835. http://dx.doi.org/10.1093/comjnl/bxs074.
2. Anderson, P. (2002). Assessment and development of executive function (EF) during childhood. Child neuropsychology, 8 (2), 71–82. https://doi.org/10.1076/chin.8.2.71.8724
3. Arango-Lasprilla, J.C., Rivera, D., Nicholls, E., Aguayo Arelis, A., García de la Cadena, C., Peñalver Guía, A.I., Vergara-Moragues, E., Rodriguez-Lorenzana, A., Marín-Morales, A., Soto-Añari, M., Lara, L., Rodríguez-Agudelo, Y., Alcazar Tebar, C., Galarza-Del-Angel, J., Rodriguez-Irizarry, W., Ibañéz-Alfonso, J. A., García-Guerrero, C. E., Delgado-Mejía, I. D., Pohlenz Amador, S., & Sánchez-SanSegundo, M. (2017). Modified Wisconsin Card Sorting Test (M-WCST): Normative data for Spanish-speaking pediatric population. NeuroRehabilitation, *41*(3), 617–626. https://doi.org/10.3233/NRE-172242
4. Arfe, B & Vardanega, T. (2019). Imparare a ragionare: il ruolo del pensiero computazionale a scuola. Giornale Italiano di Psicologia. *46*. 765–769. 10.1421/95548
5. Arfé, B., Vardanega, T. & Ronconia, L. (2020). The effects of coding on children's planning and inhibition skills. Computers and Education, *148*, 2–16. https://doi.org/10.1016/j.compedu.2020.103807

6. Arfé, B., Vardanega, T., Montuori, C., & Lavanga, M. (2019). Coding in Primary Grades Boosts Children's Executive Functions. Frontiers in psychology, *10*, 2713. https://doi.org/10.3389/fpsyg.2019.02713
7. Best, J; Miller, P. y Jones, L. (2009) Executive Functions after Age 5: Changes and Correlates. *Develomental Review* (29). 180–200
8. Best, J. R. & Miller, P. H. (2010). A developmental perspective on executive function. Child development, *81* (6), 1641–1660. https://doi.org/10.1111/j.1467-8624.2010.01499.x
9. Burns, T. (2009). End of the road for treatment-as-usual studies? The British Journal of Psychiatry, *195* (1) 5–6. https://doi.org/10.1192/bjp.bp.108.062968
10. Chen, G. Shen, J., Barth-Cohen, L., Shiyan, J., Huang, X. & Eltoukhy, M. (2017). Assessing elementary students' computational thinking in everyday reasoning and robotics programming. Computers & Education, *109*, 162–175. https://doi.org/10.1016/j.compedu.2017.03.001
11. Corsi, A. (1972). *Human Memory and the Medial Temporal Region of the Brain.* McGillUniversity.
12. Di Lieto, M.C., Castro, E., Pecini, C., Inguaggiato, E., Cecchi, F., Dario, P., Cioni, G. & Sgandurra, G. (2020). Improving Executive Functions at School in Children with Special Needs by Educational Robotics. Frontiers in psychology, *10*, 2813. https://doi.org/10.3389/fpsyg.2019.02813
13. Di Lieto, M.C., Castro, E., Pecini, C., Inguaggiato, E., Cecchi, F., Dario, P., Cioni, G. & Sgandurra, G. (2020). Empowering Executive Functions in 5- and 6-Year-Old Typically Developing Children Through Educational Robotics: An RCT Study. Frontiers in Psychology; 10 (1) Doi:10.3389/fpsyg.2019.03084
14. Di Lieto, M.C., Inguaggiato, E., Castro, E., Cecchi, F., Cioni, G., Dell'Omo, M., Laschi, C., Pecini, C., Santerini, G., Sgandurra, G. & Dario, P. (2017). Educational Robotics Intervention on Executive Functions in preschool children: a pilot study. Computers in Human Behavior, *71*. 10.1016/j.chb.2017.01.018.
15. Diamond, A. (2012). Executive Functions. Annual Review of psychology, *64*. 135–168 https://doi.org/10.1146/annurev-psych-113011-143750
16. Diamond, A. (2013). Activities and Programs That Improve Children's Executive Functions. Current Directions in Psychological Science, *21* (5) 335–341. http://journals.sagepub.com/doi/pdf/10.1177/0963721412453722
17. Flores-Lázaro, J. & Ostrosky, F. (2012). *Desarrollo neuropsicológico de los lóbulos frontales y funciones ejecutivas*. Manual Moderno.
18. Flores-Lázaro, J., Castillo, R.E. & Jiménez, N.A. (2014). Desarrollo de funciones ejecutivas, de la niñez a la juventud. Anales de psicología, *30* (2) http://dx.doi.org/10.6018/analesps.30.2.155471
19. Flores-Lázaro, J.C., Otrosky-Shejet, F., y Lozano-Gutierrez, A. (2014). *Batería neuropsicológica de funciones ejecutivas y lóbulos frontales*. Manual moderno.
20. Gerosa, A., Koleszar, V., Gómez, L., Tejera, G. & Carboni A. (2019). Educational Robotics and Computational Thinking Development in Preschool. *XIV Latin American Conference on Learning Technologies (LACLO).* 226–230. https://dx.doi.org/10.1109/LACLO49268.2019.00046.
21. Gerosa, A., Koleszar, V., Gómez, L., Tejera, G. & Carboni, A. (2021). Cognitive abilities and computational thinking at age 5: Evidence for associations to sequencing and symbolic number comparison. Computers and Education Open, 2.
https://dx.doi.org/100043
. 10.1016/j.caeo.2021.100043.
22. Goldberg, E. (2015). El director ejecutivo del cerebro: Una mirada a los lóbulos frontales. En: *El cerebro ejecutivo* (pp. 29–33). Editorial Planeta.

23. Golden, C. (2020). *STROOP. Test de Colores y Palabras. Madrid*: TEA Ediciones; 2020.
24. Goldman-Rakic P. (1996). The prefrontal landscape: implications of functional architecture for understanding human mentation and the central executive. Philosophical Transactions of the Royal Society of London (351) pp.1445–1453 http://doi.org/10.1098/rstb.1996.0129
25. Goldstein, S., Naglieri, J. A., Princiotta, D., & Otero, T. M. (2013). Introduction: A history of executive functioning. In S. Goldstein & J. A. Naglieri (Eds.), *Handbook of executive functioning* (pp.3–12). Springer. https://doi.org/10.1007/978-1-4614-8106-5_1
26. Grover, S. & Pea, R. (2013). Computational Thinking in K–12 A Review of the State of the Field. Educational Researcher. 42:38–43. https://doi.org/10.3102/0013189X12463051.
27. Guevara, M., Hernández, J., Orozco, E., Rizo, L., & Sepúlveda, M. (2014). Memoria de trabajo visoespacial evaluada a través de los Cubos de Corsi: cambios con relación a la edad. Revista Neuropsicología, Neuropsiquiatría y Neurociencias, *14* (1), 208–222
28. Heaton, R.K. (2001). WCST test de clasificción de cartas de Wisconsin: Manual. TEA Ediciones Resource Inc.
29. Hickmott, D., Prieto-Rodriguez, E. & Holmes, K.A. (2018). Scoping Review of Studies on Computational Thinking in K–12 Mathematics Classrooms. Digit Exp Math Educ. *4*: 48–69. Doi:10.1007/s40751-017-0038-8
30. Hmelo-Silver, C. E. (2004). Problem-Based Learning: What and How Do Students Learn? Educational Psychology Review, *16*(3), 235–266. https://doi.org/10.1023/B:EDPR.0000034022.16470.f3
31. Injoque-Ricle, I., Barreyro, J. P., Calero, A., & Burin, D. (2014). Tower of London: Planning development in children from 6 to 13 years of age. Spanish Journal of Psychology, *17*(e77), 1–7. http://dx.doi.org/10.1017/sjp.2014.83
32. Injoque-Ricle, I., Barreyro, J. P., Calero, A., & Burin, D. I. (2017). Poder predictivo de la edad y la inteligencia en el desempeño de una tarea de planificación: Torre de Londres. Avances en Psicología Latinoamericana, *35*(1), 107–116.
http://dx.doi.org/10.
12804/revistas.urosario.edu.co/apl/a.4116
33. Kalelioğlu, F. (2015). A new way of teaching programming skills to K-12 students: Code.org. Computers in Human Behavior, (52), 200–210. https://doi.org/10.1016/j.chb.2015.05.047
34. Kong, S. C., Abelson, H. & Lai, M. (2019). Introduction to Computational Thinking Education. In: S.C. Kong & H. Abelson (Eds.), *Computational Thinking Education* (pp. 1–10). Springer. https://doi.org/10.1007/978-981-13-6528-7_1
35. Kopp, B., Lange, F., & Steinke, A. (2021). The Reliability of the Wisconsin Card Sorting Test in Clinical Practice. Assessment, *28*(1), 248–263. https://doi.org/10.1177/1073191119866257
36. Liao, Y. K. (2020). A Meta-analysis of Computer Programming on Cognitive Outcomes: An Updated Synthesis. In J. Bourdeau & R. Heller (Eds.), *Proceedings of ED-MEDIA 2000–World Conference on Educational Multimedia, Hypermedia & Telecommunications* (pp. 563–569). Association for the Advancement of Computing in Education (AACE). https://www.learntechlib.org/primary/p/16132/
37. Liao, Y. K. & Bright, G. (1991). Effects of Computer Programming on Cognitive Outcomes: A Meta-Analysis. Journal of Educational Computing Research, *7* (3), 251–266. https://doi.org/10.2190/E53G-HH8K-AJRR-K69M
38. Lozano, A. & Ostrosky, F. (2011). Desarrollo de las funciones ejecutivas y de la corteza prefrontal. *Revista Neuropsicología, Neuropsiquiatría y Neurociencias, 11* (1) 159–172. https://nebula.wsimg.com/23d17fba27aba5be26e37ab83ecb164a?AccessKeyId=F7A1C842D9C24A6CB962&disposition=0&alloworigin=1

39. Lozano, I., Roldán, D., Bacelo, A. & Martín, E. (2019). Blue Thinking, a programming tool for the development of executive functions at childhood. *Proceedings of the XX International Conference on Human Computer Interaction*, (31). https://doi.org/10.1145/3335595.3335640
40. Luria, A. (1973). *Higher cortical functions in man*. Basic books
41. Miller & Cohen, 2001
42. Ministerio de Educación Nacional de Colombia (MEN). (2009). Educación para la innovación y la competitividad. *Boletín educación superior* (12). https://www.mineducacion.gov.co/1621/articles-92779_archivo_pdf_Boletin12.pdf
43. Ministerio de Salud y Protección Social de Colombia (1993). *Resolución 8430 de 1993.* Por la cual se establecen las normas científicas, técnicas y administrativas para la investigación en salud.
44. MinTic – Ministerios de tecnologías de la información y la telecomunicación. (2020). Misión TIC 2022: el programa que formará a 100.000 jóvenes en programación. https://talentodigital.mintic.gov.co/734/w3-propertyvalue-180162.html
45. MinTic – Ministerios de tecnologías de la información y la telecomunicación. (2022). Programación para niños y niñas. https://www.mintic.gov.co/portal/inicio/Sala-de-prensa/MinTIC-en-los-medios/150117:Mision-TIC-2022-el-programa-que-formara-a-100-000-jovenes-en-programacion
46. Miyake, A., Friedman, N.P., Emerson, M.P., Witzki, A., Howerter, A. & Wager, T.D. (2000). The Unity and Diversity of Executive Functions and Their Contributions to Complex "Frontal Lobe" Tasks: A Latent Variable Analysis. Cognitive Psychology, *41* (1), 49–100. https://doi.org/10.1006/cogp.1999.0734
47. Moher, D., Hopewell, S., Schulz, K.F., Montori, V., Gøtzsche, P., Devereaux, P.J., Elbourne, D., Egger, M. & Altman, D.G. (2010). CONSORT 2010 Explanation and Elaboration: updated guidelines for reporting parallel group randomised trials. BMJ (Clinical research *ed.)*, 340, c869. https://doi.org/10.1136/bmj.c869
48. Monarca, H. A. & Rincón, J. (2010). Tránsito a la ESO, ¿continuidad o ruptura?. Cuadernos de pedagogía, (401), 28–31. https://iesrdguezmonino.educarex.es/recursos/orientacion/TRANSITOP.pdf
49. Montuori C, Pozzan G, Padova C, Ronconi L, Vardanega T, Arfé B. Combined Unplugged and Educational Robotics Training to Promote Computational Thinking and Cognitive Abilities in Preschoolers. Education Sciences. 2023; 13(9):858. https://doi.org/10.3390/educsci13090858
50. Montuori et al., 2024
51. Montuori, C., Gambarota, F., Altoé, G., & Arfé, B. (2024). The cognitive effects of computational thinking: A systematic review and meta-analytic study. Computers & Education, *210*, 1–23. https://doi.org/10.1016/j.compedu.2023.104961
52. Nardelli, E. (2019). Do we really need computational thinking?. Communications of the ACM, *62*. 32–35. 10.1145/3231587.
53. Papert, S. (1987). Computer Criticism vs. Technocentric Thinking. Educational Researcher, *16* (1), 22–30. https://doi.org/10.3102/0013189X016001022
54. Pellas, N. (2024). Enhancing Computational Thinking, Spatial Reasoning, and Executive Function Skills: The Impact of Tangible Programming Tools in Early Childhood and Across Different Learner Stages. Journal of Educational Computing Research, *0*(0). https://doi.org/10.1177/07356331241292767
55. Porteus, S. (2003). *Laberintos de porteus.* TEA ediciones
56. Robertson, J., Gray, S., Martin. T. & Booth, J. (2020). The Relationship between Executive Functions and Computational Thinking. International Journal of Computer Science Education in Schools. 3 (4)

Doi:10.21585/ijcses.v3i4.76

57. Anonymous (2023a).
58. Anonymous (2023b).
59. Anonymous (2023c).
60. Anonymous (2023d).
61. Rodríguez-Barreto, L., Pulido, N., & Pineda Roa, C. (2016). Psychometric properties of the Stroop color-word test in non-pathological Colombian population. Universitas Psychologica, *15*(2), 255–272. http://dx.doi.org/10.11144/Javeriana.upsy15-2.ppst
62. Scherer, R., Siddiq, F. & Sánchez-Viveros, B. (2019). The cognitive benefits of learning computer programming: A meta-analysis of transfer effects. Journal of Educational Psychology, 111 (*5*), 764–792. Doi:10.1037/edu0000314
63. Scherer, R., Siddiq, F. & Sánchez, B. (2020). A meta-analysis of teaching and learning computer programming: Effective instructional approaches and conditions. Computers in Human Behavior, *109*. https://doi.org/10.1016/j.chb.2020.106349
64. Schretlen, D. (2010). *Modified Wisconsin Card Sorting Test: MWCST*. Professional Manual. PAR.
65. Shallice T. (1982). Specific impairments of planning. Philosophical transactions of the Royal Society of London. Series B, Biological sciences, *298*(1089), 199–209. https://doi.org/10.1098/rstb.1982.0082
66. Shute, V.J., Sun, C. & Asbell-Clarke, J. (2017). Demystifying computational thinking. Educational Research Review, *22*, 142–158. https://doi.org/10.1016/j.edurev.2017.09.003
67. Šimleša, S. & Cepanec, M. (2015). Executive Functions during Childhood, Development of. In: J. D. Wright, *International Encyclopedia of the Social & Behavioral Sciences* (Second Edition, pp. 489–496). Elsevier. https://doi.org/10.1016/B978-0-08-097086-8.23083-3
68. Spieler, B., Kemény, F., Landerl, K., Binder, B. & Slany, W. (2020). The learning value of game design activities: association between computational thinking and cognitive skills. *Proceedings of the 15th Workshop on Primary and Secondary Computing Education*, (19), 1–4. https://doi.org/10.1145/3421590.3421607
69. Tsarava, K., Moeller, K. Román-González, M., Golle, J., Leifheit, L., Butz, M. & Ninaus, M. (2022). A cognitive definition of computational thinking in primary education. Computers & Education, *179*. 104425. https://doi.org/10.1016/j.compedu.2021.104425.
70. Wang, L., Shi, D., Geng, F., Hao, X., Chanjuan, F., & Li, Y. (2022). Effects of cognitive control strategies on coding learning outcomes in early childhood. The Journal of Educational Research, 115(2), 133–145. https://doi-org.ezproxy.uniandes.edu.co/10.1080/00220671.2022.2074946
71. Wechsler, D: (2004). Wechsler Memory Scale-Third Edition. TEA Ediciones
72. Wechsler, D. (2014). *Escala de inteligencia de Wechsler para niños versión V: Manual técnico y de interpretación*. Psychcorp.
73. Wing, J. (2006). Computational thinking. Communications of the ACM, *49* (3), 33–35. https://www.cs.cmu.edu/afs/cs/Web/People/15110-s13/Wing06-ct.pdf
74. Wing, J. (2008). Computational thinking and thinking about computing. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 366 (1881), 3717–3725. https://doi.org/10.1098/rsta.2008.0118
75. Yang, W., Gao, H., Jiang, Y., & Li, H. (2023). Beyond computing: Computational thinking is associated with sequencing ability and self-regulation among Chinese young children. Early Childhood Research Quarterly, 64,

324–330. https://doi.org/10.1016/j.ecresq.2023.04.006

76. Zelazo, P. D., & Carlson, S. M. (2012). Hot and cool executive function in childhood and adolescence: Development and plasticity. Child Development Perspectives, *6*(4), 354–360.
77. Zurnacı, B., & Turan, Z. (2024). Educational robotics or unplugged coding activities in kindergartens?: Comparison of the effects on pre-school children's computational thinking and executive function skills. Thinking Skills and Creativity, 53(101576), 101576. https://doi.org/10.1016/j.tsc.2024.101576

Figures

Figure 1

Example of disconnected activities and activities connected to code.org

Figure 2

Example of activities connected with micro:bit and robotics kits

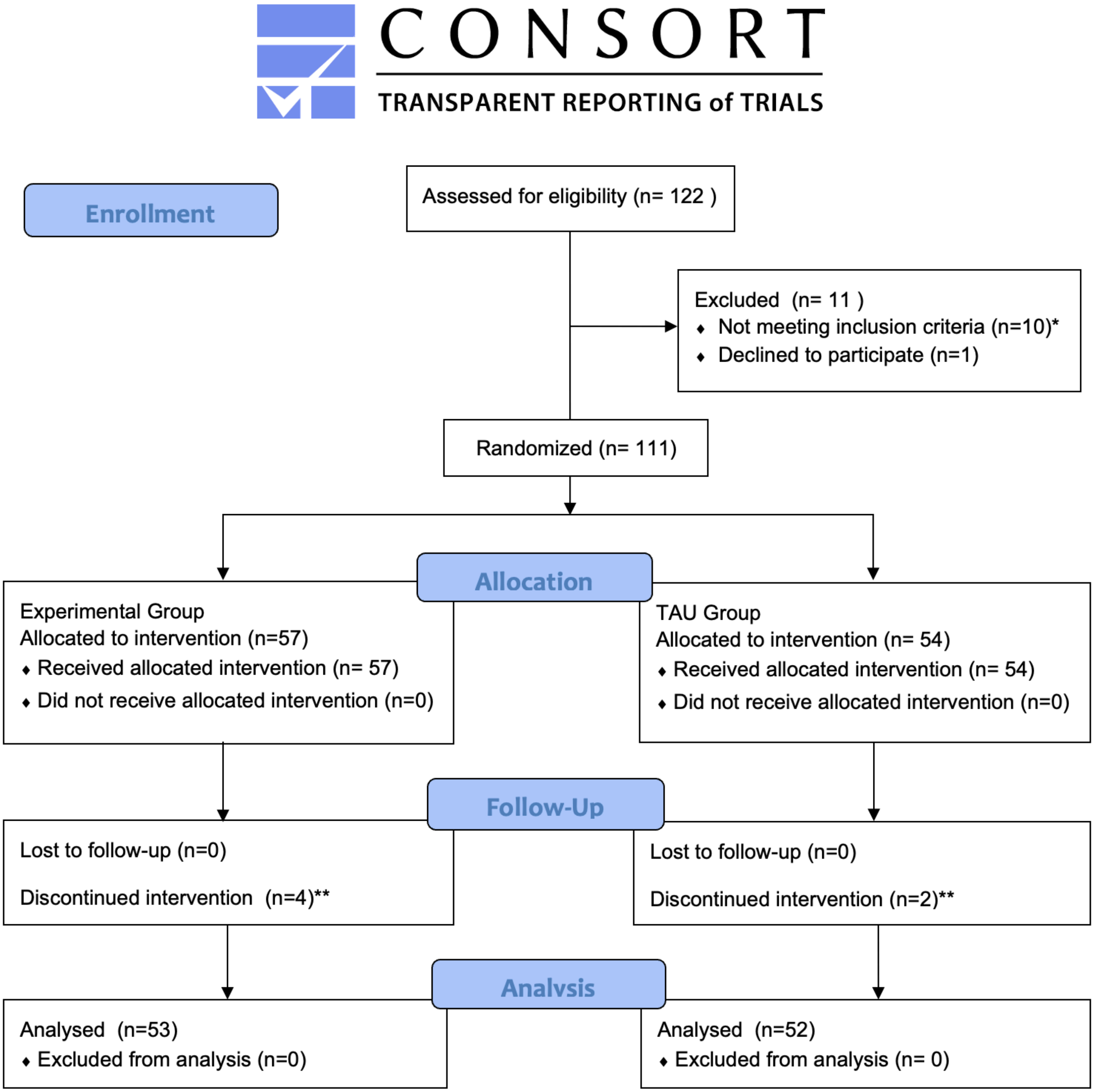

Figure 3

Consort Diagram

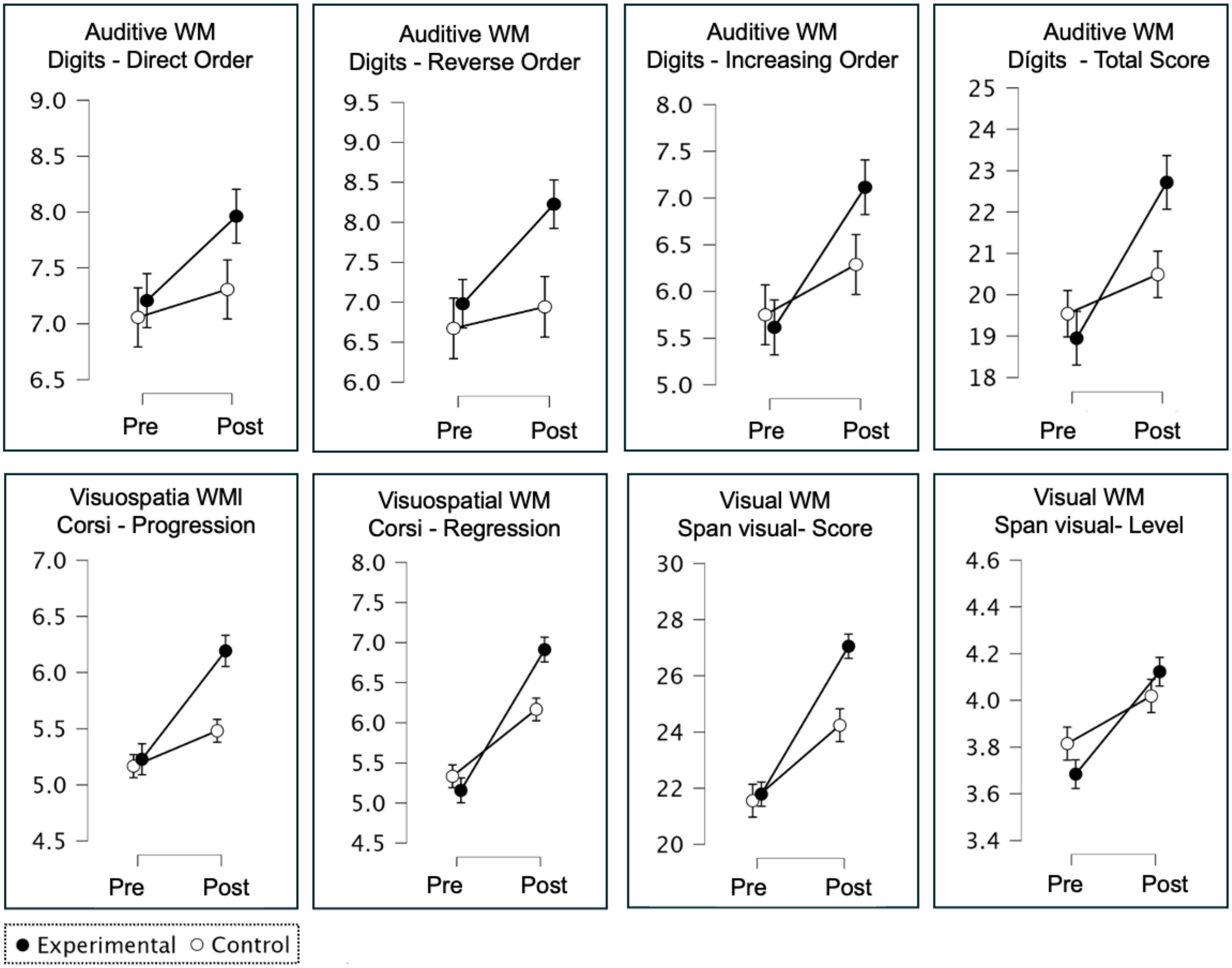

Figure 4

Graph tests of working memory in both groups.

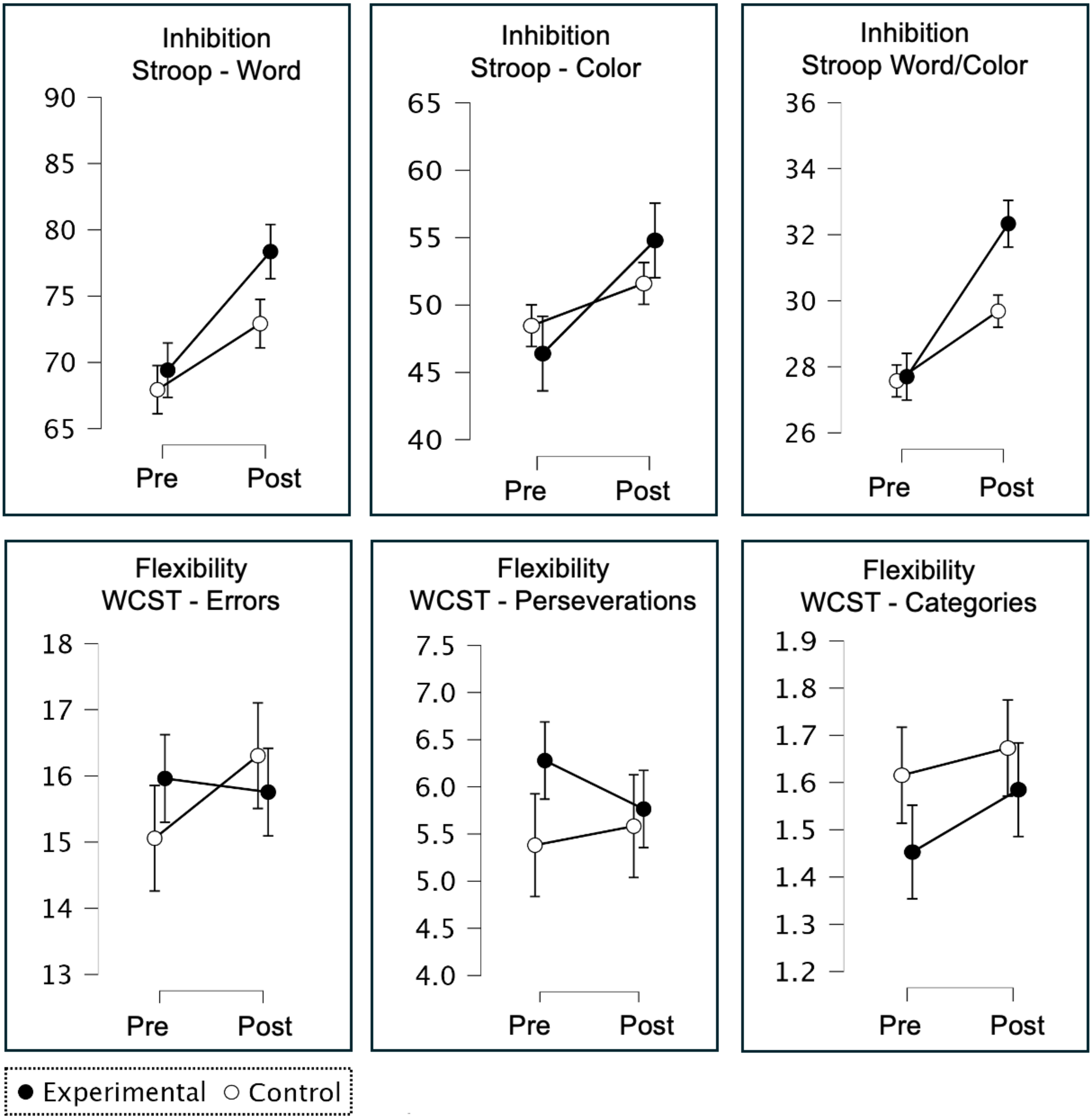

Figure 5

Graph of the tests of inhibition and flexibility in both groups.