

STUDY PROTOCOL

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A comparison of three executive function interventions on direct and far transfer in Chilean school children: a cluster-randomized controlled protocol

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Abstract

Background Executive functions (EF) are cognitive processes that support goal-directed behaviors that are essential for children's academic success, predicting school performance more strongly than IQ. However, intervention studies report mixed findings regarding the causal far-transfer effects to academic skills, such as literacy and mathematics. Age and intervention modality may moderate these effects: younger children may experience greater EF gains due to heightened neuroplasticity, and the format of delivery (digital, traditional, or mixed) could influence engagement and outcomes. This study aims to examine the effectiveness of EF interventions delivered across three modalities and two developmental stages to identify the most effective approach for enhancing both EF and academic performance.

Methods A cluster-randomized controlled trial will be conducted in four municipal schools in Chile. Using a 4×2 factorial design, schools will be randomly assigned to one of four conditions: digital, traditional, mixed-modality, or control. Two age groups will be included (5–6 and 9–10 years). Participants ($N=240$) will complete 24 intervention sessions over 12 weeks. The intervention is adapted from a previously validated digital platform targeting executive and social-emotional skills. For this study, the activities focus on stimulating working memory, inhibitory control, and cognitive flexibility. Sessions are gamified and delivered via tablets, physical materials, or a combination of both, depending on condition. Primary outcomes include the three core EF domains, assessed pre- and post-intervention. Secondary outcomes include literacy and mathematical skills. Data will be analyzed using Multivariate Analysis of Covariance (MANCOVA) and Linear Mixed Models (LMM) to examine main effects, interactions, and moderating roles of age and modality.

Discussion This study will provide key insights into how age and the intervention modality influence EF training outcomes with regard to EF and possibly academic domains. By comparing digital, traditional, and mixed delivery, we aim to identify the most effective and engaging intervention format across developmental stages. Findings may inform scalable, evidence-based educational programs, particularly for vulnerable populations, and serve as a foundation for future large-scale trials to guide best practices in EF intervention research.

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Keywords Executive functions, Far transfer, Cognitive intervention, Academic performance, School children

Background

Executive functions (EF) have emerged as a central topic in developmental psychology and educational research [1, 2]. Broadly defined, EF refer to top-down cognitive processes that enable individuals to coordinate higher-order, goal-directed thoughts and actions [3] while simultaneously managing bottom-up emotional or somatic inputs [4]. While multiple models for EF exist [5], a prevalent framework in cognitive intervention research breaks EF down into three core components: working memory, inhibitory control, and cognitive flexibility [6, 7]. Working memory encompasses updating and organizing information in memory [8], while inhibitory control governs the capacity to suppress automatic or impulsive responses [9]. Cognitive flexibility pertains to shifting between tasks, adapting thoughts or behaviors to changing conditions and the ability to approach a problem from multiple perspectives [10].

EF provide the cognitive foundation for regulating thoughts, emotions and behaviors and have a significant impact on various quality of life outcomes for children and adolescents [11, 12]. Notably, EF have been shown to be a stronger predictor of school success than IQ [13], underscoring their relevance in formal education settings. In this regard, EF have been shown to facilitate children's engagement in learning activities by supporting goal-directed regulation of cognition, emotion, and behavior [14–17].

Additionally, specific EF components have also been linked to domain-specific academic skills. Working memory, for example, is essential for comprehending complex linguistic information and solving mathematical problems [18, 19]. Inhibitory control contributes by reducing distractions and maintaining attention [3], which may play an important role in reading, especially in decoding irregular words [20]. Cognitive flexibility supports the adoption of novel strategies to varying task demands [13, 21, 22] and, along with inhibitory control, has been shown to have a significant influence over word decoding and early reading skills [23]. Collectively, these EF skills provide the necessary cognitive resources for academic achievement in early educational contexts.

Due to their critical role in development and academics, EF have become a prominent target for research and interventions. In these experimental studies, outcomes are often classified by the level of transfer; that is, the degree to which skills learned in the intervention (in this case, EF) can be applied to tasks of similar or dissimilar domains [24, 25]. Most studies include a measure of the

particular executive function being trained (direct transfer), and other measures of untrained EF may also be included (near transfer) [26].

However, the most ambitious goal for EF training is far transfer, meaning benefits extend to different domains, such as academic skills [27]. While some randomized studies have documented promising far transfer effects [28–32], several meta-analyses have reported small or non-significant effects [24, 33, 34].

This discrepancy between the theoretical importance of EF and the mixed empirical evidence poses a critical question for researchers: although EF are fundamental to children's academic success, why are the results from these interventions so varied when it comes to effects in academic skills? This heterogeneity may arise from multiple factors related to intervention design and participant characteristics. Specifically, participant's age and the way in which the intervention is presented may influence training outcomes [35, 36].

Age has emerged as a particularly relevant moderator due to its relationship with developmental changes in neuroplasticity [37]. EF begin to manifest as early as one year of age [38], becoming more structured around three years [3]. Neural development, particularly in the prefrontal cortex, exhibits critical periods of increased plasticity in early childhood (ages five to eight), which then diminish through adolescence [39, 40]. Due to these developmental windows, younger children may be more disposed to gains from EF interventions [41, 42]. Some empirical evidence for this comes from a study by Best et al. [9], which demonstrated that children aged five to eight years old experienced the most significant EF development compared to older children and adolescents. Additionally, EF showed its strongest correlations with academic abilities, suggesting heightened responsiveness to interventions during this period. However, much of the literature on age moderation remains inconclusive as many experimental studies tend to focus on comparing children with adults [43, 44], suggesting further study is needed.

Along with this experimental evidence, systematic reviews and meta-analyses on EF interventions also vary in their age range inclusion criteria and report inconsistent findings on the moderating effects of age. Some of the meta-analyses have focused on children aged 3–12 years [27, 45–47], while others have included broader age ranges encompassing adolescents [24] and adults [33, 47]. However, only one meta-analysis has shown significant moderation for age, suggesting that younger children

may be more likely to benefit from an intervention [27]. This lack of consistent findings again underscores a need for further research.

In addition to age, several reviews have shown that the format in which an intervention is presented to participants can affect its outcomes [27, 45–47]. While there is a large variety of types of interventions [see 6 for a review], the most common tend to be interventions that attempt to train EF directly by using either digital media (using computers, tablets, phones) or traditional formats (i.e., using physical space or objects) [46]. We refer to these formats as modalities, and each offers their distinct advantages and limitations.

On the one hand, digital interventions provide immediate feedback and adaptive individualized attention, crucial for tasks that require precise timing and accuracy [35] or children with special needs [48]. In contrast, traditional interventions may better engage spatial and motor skills and allow direct human interaction, potentially enhancing motivation and facilitating social-emotional engagement [6]. However, comparative studies and meta-analyses provide conflicting results regarding which modality is more effective. For instance, Diamond and Ling [6] found higher success rates in traditional interventions, whereas Takacs and Kassai [46] reported larger effect sizes for digital interventions. Moreover, few studies have directly compared or combined these modalities, limiting our understanding of their comparative effectiveness.

Additionally, modality effectiveness may differ across developmental stages. Digital interventions may require more advanced cognitive and fine motor skills that younger or developmentally atypical children might struggle to master, possibly influencing intervention outcomes negatively [27, 49]. Conversely, technology-based approaches could also enhance motivation through gamification, especially appealing to children and adolescents who frequently interact with digital platforms [35].

Given the uncertainty around these critical moderators, this study aims to address these gaps through an experimental randomized controlled design. The research will systematically compare a modified version of a tablet-based EF intervention, known as “Japi” [50, 51], across three modalities (traditional, digital, and mixed) in children at two key developmental stages (early childhood: 5–6 years; late childhood: 9–10 years). The objectives are to evaluate the efficacy of these interventions in terms of direct EF gains and far-transfer effects to academic skills.

Methods

Study design and setting

This study utilizes a cluster-randomized controlled design with two independent variables: intervention modality (digital, traditional, mixed, and control) and

age group (5–6 and 9–10 years old). Thus, the study employs a 4×2 factorial design, resulting in eight distinct experimental groups. Due to the complexity of the factorial design and the naturalistic school setting, four public schools from a mid-sized regional city in Chile, with comparable demographic characteristics and standardized curricular practices, will each be randomly assigned to one of the four modality conditions (digital, traditional, mixed, or control). Each school serves as an experimental cluster including participants from both targeted age groups. Although clustering inherently introduces variability, demographic similarity and consistent curricular approaches across the selected schools are expected to minimize potential confounding factors. Within each school, participants from both age groups will be recruited, enabling the analysis of the main effects for modality and age, as well as their interaction. A total of three primary outcomes (working memory, inhibitory control, cognitive flexibility) and two secondary outcomes (literacy and math ability) will be evaluated at baseline, prior to beginning the intervention, as well as after the intervention period (12 weeks) has been completed.

Inclusion criteria for schools.

1. Schools are located within the same regional city of Chile.
2. Schools are classified by the ministry of education to be in an urban setting.
3. Schools with high vulnerability (greater than 70%) according to the School Vulnerability Index (IVE) [52], which reflects parental educational level and total monthly household income. Schools with a higher percentage have higher proportions of students with parents that have less formal education and lower household income.
4. Government funded municipal schools.
5. Schools that have at least one kindergarten class.

Exclusion criteria for schools.

1. Schools that are classified as being in a rural setting.
2. Schools that are privately funded or receive a combination of government subsidies and are privately run. This criterion is important for maintaining similar demographics among schools, as well as maintaining a standardized curriculum.

Inclusion criteria for students.

1. Children that are regularly attending kindergarten or fifth grade at the schools that meet the inclusion criteria.

Exclusion criteria for students.

1. Children with an intellectual disability.
2. Children unable to understand and speak Spanish.

Interventions

This study implements an intervention designed to train EF through three different modalities: digital, traditional (physical, paper-based games), and a mixed modality that combines both digital and physical materials. While the format varies across groups, all modalities follow the same intervention program, with activities designed to stimulate specific EF (i.e., working memory, inhibitory control and cognitive flexibility). These activities, or ones similar to the activities here, have significantly improved EF in Chilean school children in previous studies [19, 53, 54]. Furthermore, to enhance intrinsic motivation and engagement, all of the activities incorporate elements based on the principles of gamification [55]. Research comparing cognitive interventions with and without gamification has found that gamified interventions lead to lower attrition rates, improved performance, and higher motivation [30, 56, 57]. Finally, all of the interventions are of minimal risk to participants' health and well-being as they utilize materials and methods that are common within a formal educational setting.

This study utilizes a modified version of the tablet-based intervention known as Japi, originally developed to stimulate executive functions and social-emotional skills in early childhood [51]. The latest version, Japi 2.0, is a gamified platform composed of 24 sessions, targeting a combination of cognitive and non-cognitive skills including working memory, inhibitory control, emotion recognition, social competence, empathy, and planning [50]. For the current study, we isolated the components of the platform that specifically target working memory and inhibitory control and developed additional activities to stimulate cognitive flexibility, ensuring that all three core executive functions are equally targeted.

These activities were adapted into a traditional modality using physical materials such as paper, cards, and blocks, maintaining the structure and sequence of the original digital games. In both the digital and traditional modalities, each intervention session lasts approximately 20 min, with participants completing a total of 24 sessions (two per week) over 12 weeks. Additional time during the session (25 min) has been allocated to taking attendance as well as handing out and collecting materials. Each executive function is targeted in eight sessions, ensuring balanced coverage across the intervention period. Recognizing the potential advantages of each of these modalities, we also developed a mixed-modality condition, in which children alternate between digital and traditional sessions. This approach allows us to

compare the effects of each modality independently and in combination.

In regard to the activities, the first eight sessions are planned to target inhibitory control. Here, all the activities focus on either having participants inhibit a prepotent or on-going response, or having the participants give a correct response toward a target stimulus. For example, one activity requires participants to tap (either their desks or the tablet screen) when the correct stimulus (pictures of fruits and vegetables) appears either on screen or shown by a person on the research team. When the incorrect stimulus is shown, participants are instructed to inhibit their responses.

Next, working memory is stimulated over the course of eight sessions. The games here require the students to order items on-screen or on their desks in the same order in which they are either shown visually or are heard through sound. Some of the activities require participants to order these items, while others require that they manipulate items to, for example, create an image of a butterfly. The sessions are split evenly between visual and auditory working memory, and the number of items increases as the sessions progress.

Finally, the last eight sessions stimulate cognitive flexibility. The games here require that participants either switch between rules, or that they use outside the box thinking in their response. For example, one of the activities has the participants create a "bridge" with blocks that can be put together according to either color or shape.

All of the activities, regardless of modality, have implemented elements of gamification, including narratives or stories behind each activity, as well as acknowledgement in the form of rewards and feedback from the instructors. However, the modalities differ by means of how quickly the feedback is delivered to the participant, as well as in how the participant can manipulate and code the activity through either embodied or non-embodied actions.

Control group

In order to have a minimum impact on the students' school day, it was decided that participants in the control group will conduct their normal curricular activities and will not receive a placebo activity.

General objective

The general objective of this study is to evaluate the effectiveness of three executive function stimulation programs incorporating gamification principles (digital, traditional, and mixed modalities) at two distinct developmental stages (kindergarten and fifth grade), in both the targeted skills (EF) and academic skills (literacy and mathematics).

Specific objectives

1. Determine which intervention modality (digital, traditional, or mixed) leads to the most significant improvements in executive functions.
2. Determine which intervention modality (digital, traditional, or mixed) leads to the most significant improvements in literacy and mathematics skills.
3. Identify the age at which executive function stimulation produces the greatest effects on executive functions, literacy skills, and mathematics skills.

Outcomes and data collection

This trial considers three primary outcomes and two secondary outcomes. The three primary outcomes are the three EF variables, and the two secondary outcomes are measures of literacy and math ability. Each of these outcomes will be measured prior and post intervention utilizing direct cognitive measures. Each of these outcomes will be assessed by a trained research assistant on the research team and by the principal investigator.

In addition to these outcomes, upon receiving informed consent from the participant's parent or guardian, we will collect demographic data related to possible control variables. This data will be collected in the form of a short survey and will ask questions related to the participant's age, sex, native language, parent or guardian's formal education, as well as a question regarding the possible participation in another cognitive reinforcement program (e.g., tutoring).

Primary outcomes

Working memory

Working memory will be measured using a direct task known as the Corsi Block Test [58]. This task assesses the visuospatial dimension of working memory and consists of repeating a sequence of blocks. The blocks appear separately and are identical. When a trial begins, the blocks light up in a random order to produce a sequence that the participant must repeat. The trials start easy and then become more difficult, with sequences of up to nine blocks. The test has an internal consistency of 0.93 (95% confidence interval of 0.84–0.97) in children [59].

Inhibitory control

To measure inhibitory control, the direct task Hearts & Flowers [60] will be used. This task combines elements of the Stroop task and the Simon task, incorporating both congruent and incongruent trials. In the congruent trials, the participant must press a button corresponding to the side where a heart appears (right or left). In the incongruent task, the participant must press a button on the opposite side of where a flower appears. This task

places greater demands on inhibitory control skills, as the participant must inhibit an automatic response and respond on the opposite side. Both tasks provide a score for accuracy (% of correct responses) and reaction time (milliseconds). This task was adapted in Chile and had a Cronbach's alpha of 0.83 [61].

Cognitive flexibility

Cognitive flexibility will be measured using a modified version of the Dimensional Change Card Sort [62]. This task requires participants to group images on cards based on their shape, size, color, and quantity. This test requires children to switch between grouping rules for the images, as well as engage in 'out-of-the-box' thinking [3]. The test score is calculated based on the number of correct groupings, where a higher number of correct groupings indicates greater cognitive flexibility. This instrument has a reliability coefficient of 0.92 [63].

Secondary outcomes

Literacy

For literacy, the Tejas LEE instrument [64] will be used. This instrument evaluates various reading competencies through four scales and was adapted in Chile by Medina et al. [65]. The instrument reports an internal consistency of 0.88–0.98 [66] for Spanish-speaking children in first to third grade.

Math skills

To measure mathematical skills, a standardized test called the Woodcock-Muñoz III Battery [67] will be used. This test was adapted from English to Spanish and contains several subtests designed to assess academic and cognitive skills. For the dimension of mathematical skills, the battery includes four subtests: quantification, verbal counting, number identification, and applied problems. Among Spanish-speaking children aged 4–13 years, the reliabilities of these subtests range between 0.84 and 0.97 [68].

Randomization and allocation

For the random selection, random number generation will be used to select and assign four schools to one of the interventions, or control, from a list that meets the inclusion criteria. The list and information of the schools will be obtained from the public data [52]. Next, the randomly selected schools will be contacted through their directors, either via their institutional email or the preferred contact method specified on the institution's website. Using this contact information, the directors of each school will receive a letter which details the study's procedures and any possible risks. If the director of a school agrees to participate, the research team will move forward with the recruitment process. If the director does

not agree to participate, another school will be randomly selected from the list.

Recruitment

Once authorization from the school's director is obtained, the principal investigator will schedule a meeting with teachers and curriculum coordinators to present information about the research and address any questions or concerns. Following this meeting, and with prior approval, the principal investigator will present the study at a parent/guardian meeting. During this presentation, the study's purpose, objectives, potential benefits, procedures, risks, data storage and confidentiality, and result dissemination will be explained in non-scientific language. Additionally, any questions or concerns that arise will be addressed. To prevent any hierarchical relationship from developing between the research team, participants, and/or their guardians, the study's independence from the school will be emphasized. This ensures that potential participants do not feel obligated to participate and that they clearly understand that their participation will not result in any school-related benefits for the students.

At the end of the meeting, parents/guardians who agree with their child's participation in the study will be asked to sign the informed consent form (supplementary materials I) by the principal or co-investigators. If a parent/guardian is unable to attend the meeting, the school's official communication channels will be used to contact them. In all cases, the parent/guardian must confirm receipt of the document. Regardless of the method, the research team will always be available to schedule a meeting if requested, to clarify any doubts. Parent and guardians will be asked to sign both an informed consent, as well as a data collection form that informs them of the storing of anonymized data on the OSF website. Additionally, the child's assent will also be requested through an age-appropriate assent form. Both the informed parent/guardian consent forms, as well as the child assent forms, will be issued and handled by only the principal or co-investigators of this project.

Blinding

The participants, nor the researchers, will be blind to any of the interventions used in the study.

Participant timeline

The participant timeline begins in May of 2025 with the recruitment process. Recruitment is planned to end by the end of July, and the data collection process will begin the last week of July. The intervention period is planned to begin in August, and the end date for participants will be December of 2025 with the communication of results.

A detailed outline of the timeline for the study is presented in Table 1.

Participant retention

During the recruitment phase, schools, students, and their families will be thoroughly informed about the study's structure and requirements. Emphasis will be placed on the significance of completing the full trial design, including the pretest, intervention and post-test periods. From the outset of administering assessments and implementing the interventions, students will be encouraged to stay engaged and actively participate throughout the entire project. While no extrinsic rewards or compensation will be given to participants, we have implemented the use of gamification in each of the interventions in an attempt to keep participants intrinsically engaged.

Data management and confidentiality

The study will collect participants' performance on two five assessments at two time points, as well as sociodemographic information that may influence intervention effects. Data will be stored in a CSV file on the personal computers of the principal investigator and co-investigators, with participant identification being encrypted using an alphanumeric code. Only general results will be reported, and both participant and participating schools' anonymity will be retained in a future dissemination of results.

The study will follow open science guidelines by preregistering on the Open Science Framework, where anonymized data and the analysis script will be made available. Parents/guardians will be informed of this process in the informed consent form. Participants' accuracy, reaction times, performance scores, and sociodemographic data will be recorded. If a participant or parent/guardian requests data deletion, the principal investigator will remove their information. Consent and assent forms will be retained for five years to allow for potential data removal requests or review by relevant authorities before being permanently deleted.

Provisions for trial care

This study was reviewed and approved by the University's scientific ethics committee (name and number withheld for anonymization of peer-review process, please see anonymized version of the certificate in Supplementary Material II). This committee will also follow up with the research team upon completion of this project and may make an unannounced audit of the project to ensure its adherence to the protocol presented. Additionally, if the research team deems any necessary changes to the protocol, these must be solicited through an official emendation.

Table 1 Standard protocol items, recommendations for interventional trials (SPIRIT) diagram[illegible]

This study poses minimal risk to participants, as both the interventions and assessment tools use devices commonly found in school settings. There is no increased risk of physical, social, or psychological harm. While similar studies have reported possible frustration or boredom at levels comparable to school activities [49, 69, 70], the game-based format of the interventions is designed to enhance self-efficacy and intrinsic motivation, helping to mitigate these effects. If a participant experiences frustration, they will be encouraged to take a break and resume when ready or will complete an activity with their normal teacher. Any other unexpected situation will follow the school's internal protocols, ensuring the well-being of the child, and the principal investigator will follow up with the school as well as the parent or guardians if necessary.

Sample size

To determine an appropriate sample size for detecting a significant effect, a review of the literature on executive function interventions was conducted. This review identified randomized controlled trials with participants of similar age and comparable interventions that reported large effect sizes: $d = 1.55$ [30], $\eta^2 = 0.42$ [71], and $\eta^2 = 0.52$ [72]. However, two recent meta-analyses report moderate effect sizes in children of a similar age with typical development, ranging from $g = 0.46$ [27] to $g = 0.60$ [46]. Based on this, a moderate effect size of $g = 0.53$ is estimated.

Using this information, a power analysis was conducted with an 80% power level and a 5% error rate using R statistical software (version 4.4.1) [73] within the RStudio integrated development environment [74], utilizing the “pwr” package [75]. The results indicate that 26 children per group are required. Although previous studies with similar interventions in school-aged children have reported attrition rates ranging from 0% [49, 70, 72] to 7% [19], an attrition rate of 15% has been anticipated. This suggests a final sample size of 30 children per group, amounting to 240 children will be attempted to be recruited.

Statistical methods for primary and secondary outcomes

To address the study's objectives, a Multivariate Analysis of Covariance (MANCOVA) will be conducted to examine the effects of intervention modality (digital, traditional, and mixed) and age group (5–6 years and 9–10 years) on the five dependent variables: working memory, inhibitory control, cognitive flexibility, literacy, and math skills [76]. This approach allows for the inclusion of covariates, such as socioeconomic status and baseline test performance, ensuring a more precise and adjusted analysis of the main and interactive effects of the independent variables [77]. The results will be interpreted using multivariate statistics, including Wilks' Lambda,

Pillai's Trace, Hotelling's Trace, and Roy's Largest Root [78], assessing both the main effects and interactions between independent and dependent variables.

In addition to this analysis, a Linear Mixed Model (LMM) will be conducted as a post-hoc analysis. The LMM includes both fixed effects, representing the variables of interest (intervention modality and age), and random effects, which account for variability between groups. Several control variables will also be included: main guardian's education level, baseline performance and intervention adherence. This approach is particularly suitable for handling hierarchical data (i.e., participants nested within schools) and analyzing moderating relationships, providing a robust and flexible model [79]. If significant interactions are found, simple effects analyses will be conducted to interpret how age influences the effectiveness of the interventions.

Discussion

The proposed study is a randomized controlled trial designed to systematically compare executive function interventions across three modalities (traditional, digital, and mixed) in children at two key developmental stages (early childhood: 5–6 years; late childhood: 9–10 years). The primary objective is to evaluate the efficacy of these interventions in improving EF skills and assessing their far-transfer effects on literacy and mathematical abilities. Unlike previous studies, which have reported mixed results, this study aims to provide a more rigorous examination of how different intervention modalities influence cognitive and academic outcomes across different age groups.

This study has significant implications for educational equity. Children with EF deficits, whether due to socioeconomic disadvantages or neurodevelopmental conditions such as ADHD and autism, could benefit greatly from targeted interventions. By identifying which intervention type is most effective at which developmental stage, this research can inform the design of more inclusive educational programs, enhancing learning opportunities for all students. Additionally, the integration of gamification elements in the interventions may enhance intrinsic motivation, making cognitive training more engaging and effective.

This study has several strengths. First, it leverages a school-based design, which enhances feasibility and engagement while increasing external validity. Second, the intervention is designed to be accessible and cost-effective, making it suitable for resource-limited schools. Third, by including students from municipal schools with a high Vulnerability Index (IVE greater than 70%), this study will target populations with the greatest need for EF support [80]. Fourth, evaluating interventions within the educational context will help ensure sustainability,

as findings can be more easily generalized toward school curricula and guide future large-scale implementations.

However, there are potential challenges. First, school recruitment and gaining guardian consent may be difficult, as some may be reluctant to participate. To mitigate this, the principal investigator will provide both school officials and guardians with a complete description and calendarization of the activities that are planned through a series of letters and formal presentations. These letters and presentations have been reviewed and approved by the University's ethics committee to ensure their lack of bias. If recruitment proves to provide significantly fewer participants than anticipated, investigators will include more schools as a means of compensation.

A second challenge for this study may be ensuring participant fidelity to the intervention and consistent implementation across schools. To address this, trained research assistants will record individual attendance and time spent in the intervention during each session, regardless of modality. These records will help assess adherence and potential implementation issues.

The results of this study will provide critical insights into the effectiveness of different EF intervention modalities and offer evidence-based recommendations for their integration into educational settings. These findings could inform policy decisions, guide educational program development, and contribute to a more equitable and effective approach to supporting children's cognitive and academic growth. Ultimately, this study aims to lay the groundwork for future large-scale randomized controlled trials, ensuring that EF interventions are optimized, scalable, and impactful.

Abbreviations

EF	Executive functions
IVE	School vulnerability index (índice de vulnerabilidad escolar in Spanish)
MANCOVA	Multivariate analysis of covariance
LMM	Linear mixed models

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s40359-025-03075-3>.

Supplementary Material 1
Supplementary Material 2
Supplementary Material 3
Supplementary Material 4

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Author contributions

NN & CAR-B conceived the study, led the proposal, protocol development, study design, and methodology. CAR-B, JG & RA they have worked on part of

the game presented in the study and reviewed the protocol. All authors read and approved of the final manuscript.

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Data availability

The datasets analysed during the current study will be available in the OSF repository, <https://osf.io/9mp83>.

Declarations

Ethics approval and consent to participate

This study was reviewed and approved by the Scientific Ethics Committee at the University of Talca, Chile (CEC 45/2024, January 29, 2025). Written and informed consent to participate will be obtained from all parents or legal guardians of the participants, and verbally informed assent to participate will be obtained from the students.

Consent for publication

Written and informed consent to publish will be obtained from all parents or legal guardians of the participants. No personal data will be presented in the publications, and personal identification will be removed or encrypted for data analyses. Consent materials are available from the corresponding author on request.

Competing interests

The authors declare no competing interests.

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