Caminhos neurocognitivos para a alfabetização: uma investigação do GraphoGame Brasil na educação infantil

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Neurocognitive Pathways to Literacy: Investigating GraphoGame Brazil in Early Childhood Education

Rutas neurocognitivas hacia la alfabetización: una investigación del GraphoGame Brasil en la educación infantil

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Abstract

From the standpoint of cognitive science, reading and writing are not natural human capacities but cultural inventions that require explicit and systematic instruction (Dehaene, 2012; Perfetti, Landi; Oakhill, 2005). Whereas oral language emerges spontaneously from universal neurobiological predispositions, literacy acquisition entails the functional reorganization of neural circuits originally dedicated to other cognitive functions (Rueckl et al., 2015). Prior research highlights the centrality of phonological awareness and the mastery of grapheme–phoneme correspondences as prerequisites for reading proficiency in alphabetic systems (Snowling; Hulme, 2013; Morais, 2013). In this context, gamified digital tools such as GraphoGame have been validated internationally as effective resources for supporting the early stages of literacy (Kamykowska et al., 2014; Morken et al., 2014). This study investigates the implementation of GraphoGame Brazil with 40 five-year-old children enrolled in a low socioeconomic status public school in Rio Grande do Sul, Brazil. The specific objectives are twofold: The specific objectives are: (1) to assess the level of early literacy skills through pre- and post-testing; and (2) to examine the effectiveness of the intervention with GraphoGame Brazil in children in the early stages of literacy acquisition. Preliminary analyses suggest that the intervention may support improvements in phonological awareness, decoding skills, and emerging orthographic knowledge. Children in the experimental group appeared to demonstrate greater gains than their peers in the control group, which may indicate the

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potential of GraphoGame as a complementary tool for classroom instruction. These findings tentatively point to the possibility that integrating digital resources with evidence-based pedagogical approaches can facilitate early reading acquisition, particularly in socioeconomically vulnerable contexts. By bridging cognitive science, educational technology, and classroom practice, the study contributes to advancing evidence-based strategies for literacy instruction and provides relevant insights for both researchers and educators.

Keywords: Reading. Phonological Awareness. Literacy. GraphoGame Brazil.

Resumen

Desde la perspectiva de la ciencia cognitiva, la lectura y la escritura no son capacidades humanas naturales, sino invenciones culturales que requieren una instrucción explícita y sistemática (Dehaene, 2012; Perfetti; Landi; Oakhill, 2005). Mientras que el lenguaje oral emerge de manera espontánea a partir de predisposiciones neurobiológicas universales, la adquisición de la alfabetización implica la reorganización funcional de circuitos neuronales originalmente dedicados a otras funciones cognitivas (Rueckl et al., 2015). Investigaciones previas destacan la centralidad de la conciencia fonológica y el dominio de las correspondencias grafema-fonema como prerrequisitos para la competencia lectora en sistemas alfabéticos (Snowling; Hulme, 2013; Morais, 2013). En este contexto, herramientas digitales gamificadas como GraphoGame han sido validadas internacionalmente como recursos eficaces para apoyar las etapas iniciales de la alfabetización (Kamykowska et al., 2014; Morken et al., 2014). Este estudio investiga la implementación de GraphoGame Brasil con 40 niños de cinco años matriculados en una escuela pública de bajo nivel socioeconómico en Rio Grande do Sul, Brasil. Los objetivos específicos son dos: (1) evaluar el nivel de habilidades iniciales de alfabetización mediante pre y post-test; y (2) examinar la efectividad de la intervención con GraphoGame Brasil en niños que se encuentran en las primeras etapas de adquisición de la alfabetización. Los análisis preliminares sugieren que la intervención puede favorecer mejoras en la conciencia fonológica, las habilidades de decodificación y el conocimiento ortográfico emergente. Los niños del grupo experimental parecieron mostrar mayores avances que sus pares del grupo de control, lo que puede indicar el potencial de GraphoGame como herramienta complementaria para la instrucción en el aula. Estos hallazgos apuntan de manera tentativa a la posibilidad de que la integración de recursos digitales con enfoques pedagógicos basados en evidencia facilite la adquisición temprana de la lectura, particularmente en contextos de vulnerabilidad socioeconómica. Al articular la ciencia cognitiva, la tecnología educativa y la práctica docente, el estudio contribuye al avance de estrategias de alfabetización basadas en evidencia y aporta perspectivas relevantes tanto para investigadores como para educadores.

Palabras clave: Lectura. Conciencia fonológica. Alfabetización. GraphoGame Brasil.

Introduction

From the perspective of contemporary cognitive science, reading acquisition is widely understood as a learned skill rather than a biologically predetermined outcome. Unlike spoken language, which emerges naturally as part of typical human development, literacy depends on deliberate and systematic instruction (Dehaene, 2012; Perfetti; Landi; Oakhill, 2005; Azevedo, 2025). Although humans are equipped with an innate neural system specialized for processing spoken language across linguistic environments (Rueckl et al., 2015), written language represents a comparatively recent cultural invention. Writing systems appeared approximately

five millennia ago, with alphabetic systems developing only several thousand years later. As a result, learning to read requires substantial neural reorganization, whereby existing brain networks are repurposed to support the visual encoding of linguistic information, enabling the association between orthography and speech sounds.

By the time children enter formal schooling, typically around six years of age, they already exhibit robust oral language abilities in their first language (Snowling; Hulme, 2013). Reading development builds upon this preexisting linguistic foundation but demands a qualitative shift in attentional focus. Whereas young children initially prioritize meaning during spoken interaction, literacy acquisition requires attention to the formal, segmental, and structural properties of language. Developing this metalinguistic awareness is a gradual and effortful process. In its early stages, children must acquire explicit awareness of sublexical units and their organization within spoken words (Adams et al., 2012), a prerequisite for understanding how speech is represented in written form.

In alphabetic orthographies such as Portuguese, fluent and independent reading relies on the coordinated development of three core competencies: knowledge of the alphabetic principle, decoding ability, and the establishment of an orthographic mental lexicon (Alves; Finger, 2023). Mastery of the alphabetic principle entails recognizing that graphemes systematically represent phonemes. Crucially, this insight does not emerge from passive exposure to print alone; rather, it depends on structured guidance and instructional activities that foster phonemic awareness (Morais, 2013). As beginning readers learn to decode unfamiliar words, they must internalize grapheme–phoneme correspondences and gradually consolidate orthographic representations, a process central to efficient word recognition (Perfetti; Dunlap, 2007). Consequently, pedagogical approaches that prioritize phonological awareness—particularly when implemented through engaging, developmentally appropriate activities and supported by digital tools—are instrumental in facilitating early reading acquisition and learner motivation.

Within this pedagogical landscape, the expansion of educational technologies (EdTech) has opened new possibilities for literacy instruction. Digital learning environments increasingly aim to align instructional practices with evidence-based principles while addressing the realities of a highly digitalized society. One such approach is gamification, defined by Martins and Giraffa (2015) as the strategic use of game elements in educational contexts to promote engagement and goal-oriented learning, thereby enhancing the effectiveness of traditionally less motivating instructional formats.

Situated at the intersection of cognitive science, literacy instruction, and digital innovation, the GraphoGame Brazil application has emerged as a prominent educational tool. Developed for preschoolers and children in the early years of elementary education, the app is designed to support the acquisition of letters, syllables, and words through auditory input and task-based interactions in Brazilian Portuguese. GraphoGame is particularly well suited to learners who are in the process of acquiring grapheme–phoneme correspondences, a foundational component of successful decoding (Marques de Souza; Weissheimer; Buchweitz, 2022).

The GraphoGame intervention has been implemented in more than twenty countries over the past decade (Kamykowska et al., 2014; Morken et al., 2014), and a growing body of empirical research has documented its effectiveness across diverse linguistic and educational contexts. These studies suggest that the program not only facilitates early literacy development but also provides a valuable framework for investigating the cognitive mechanisms underlying reading acquisition.

Against this theoretical and empirical background, the present study investigates the implementation of GraphoGame Brazil with 40 five-year-old children enrolled in a low socioeconomic status public school in Rio Grande do Sul, Brazil. The specific objectives are twofold: (1) to assess the level of early literacy skills through pre- and post-testing; and (2) to examine the effectiveness of the intervention with GraphoGame Brazil in children in the early stages of literacy acquisition.

1 GraphoGame and GraphoGame Brazil: An Evidence-Based Digital Approach to Early Reading Development

Research on reading development draws on converging evidence from cognitive science, neuroscience, education, and linguistics (Bach et al., 2013; Hintikka et al., 2008; Pugh et al., 1996). Within this interdisciplinary framework, the Finnish educational context has become a reference point for evidence-based literacy practices. Central to this tradition is the Jyväskylä Longitudinal Study of Dyslexia (JLD), initiated in 1992, which followed children at familial risk for dyslexia from birth into adulthood (Ojanen et al., 2015).

Developed at the University of Jyväskylä in collaboration with the Niilo Mäki Institute, GraphoGame provides systematic training in grapheme–phoneme correspondences through an adaptive digital environment. The program progresses from transparent letter–sound mappings to more complex syllabic and lexical units, adjusting difficulty based on individual performance and providing continuous positive feedback to sustain engagement (Lyytinen et

al., 2009). Its effectiveness has been examined across multiple languages and educational contexts for more than a decade (Kamykowska et al., 2014; Morken et al., 2014).

The Brazilian Portuguese version, GraphoGame Brazil, was developed between 2015 and 2016 by researchers at the Brain Institute of Rio Grande do Sul, in partnership with the Ministry of Education. Officially launched in 2020 during the COVID-19 pandemic, the app is freely accessible, operates offline, and is available across digital platforms.

GraphoGame Brazil is structured into 49 progressively complex sequences, beginning with isolated phonemes and advancing through syllabic structures to word-level decoding, including polysyllabic forms. Progression is contingent upon performance criteria, ensuring mastery at each level, while variation in stimulus presentation minimizes automatized responding. Upon completion, the system generates individualized reports detailing time on task, accuracy, and levels attained.

2 The Neurobiology of Reading: Phonological Awareness as a Foundation for Literacy

Unlike spoken language, whose acquisition typically unfolds as part of biologically guided development, learning to read constitutes a fundamentally different challenge. Oral language emerges spontaneously in most children, much like motor skills, without the need for formal, systematic instruction. Reading, however, is not an evolutionarily preprogrammed capacity and therefore relies heavily on explicit teaching practices to be successfully acquired.

From an instructional standpoint, Azevedo (2025) emphasizes that the quality and structure of early literacy instruction play a decisive role in shaping reading development and in preparing learners for more advanced stages of literacy. This instructional dependency reflects the neurobiological nature of reading itself. As argued by Da Costa, Azambuja, and Buchweitz (2021), the human brain accommodates reading through a process of neural recycling, repurposing circuits originally evolved for other perceptual and cognitive functions. Consequently, the neural networks that support spoken language processing substantially overlap with those recruited for reading and writing. In this sense, literacy acquisition can be understood as building upon, yet extending beyond, oral language, as reading “piggybacks” on speech while demanding additional neural adaptations to meet its specific cognitive requirements.

Neuroimaging and behavioral evidence converge on the existence of three major neural systems that underpin skilled reading (Dehaene, 2012; Seidenberg, 2017; Shaywitz; Shaywitz, 2020). The temporo-parietal system plays a central role in phonological decoding, enabling readers to segment written words into their constituent sound units. The occipito-temporal

system supports the rapid and automatic recognition of familiar word forms, thereby contributing to reading fluency and comprehension. Frontal regions, in turn, are engaged in articulatory planning and phonological processing, interfacing spoken and written language during reading.

At a functional level, reading begins with the visual analysis of orthographic input in occipital visual areas, where written symbols are initially processed. This visual information is then integrated through dynamic, bidirectional interactions with phonological and semantic networks. A pivotal hub within this reading network is the region Dehaene (2012) designated as the Visual Word Form Area (VWFA), often referred to as the "letterbox" region. Prior to literacy, this area is primarily involved in face and object recognition. With reading instruction and increasing exposure to print, however, the VWFA undergoes progressive specialization for orthographic processing. Its reliable activation during word recognition has therefore been widely interpreted as a neural signature of fluent reading.

Conceptual accounts of reading fluency are closely associated with the Dual-Route Model of Reading (Ellis, 1995), which proposes two complementary pathways for word recognition: a phonological route and a lexical route. Both pathways originate in a visual analysis system responsible for identifying letters, encoding their positions, and grouping them into coherent units. The phonological route operates through grapheme–phoneme conversion procedures, allowing readers to decode unfamiliar words by translating visual symbols into speech sounds. The lexical route, by contrast, relies on stored representations of known words within a visual input lexicon, which is gradually established through repeated exposure and practice. Efficient functioning of this route presupposes systematic instruction and sustained experience with print, enabling rapid and automatic whole-word recognition.

Within this framework, phonological awareness emerges as a core cognitive foundation for reading automatization. Phonological awareness refers to a broad set of metalinguistic abilities that involve the conscious reflection upon and manipulation of spoken language units, such as words, syllables, onsets, rimes, and rhymes. As children acquire alphabetic knowledge, including letter names, phonological values, and visual forms, these broader skills give rise to phonemic awareness. This more refined ability involves the intentional manipulation of phonemes, the smallest contrastive units of speech.

According to Alves and Finger (2023), phonological awareness enables individuals not only to detect speech sounds but also to evaluate and consciously restructure the sound patterns of words. The authors distinguish multiple levels of phonological awareness, ranging from sensitivity to rhymes and alliteration, through syllabic awareness, to phonemic awareness. All

of these levels contribute to successful literacy acquisition, particularly in alphabetic writing systems, where decoding depends directly on sound–symbol correspondences.

Finally, discussions of phonological awareness and reading development must consider the role of orthographic depth. As highlighted by Moll et al. (2014), writing systems vary considerably in the consistency of their mappings between graphemes and phonemes. Alphabetic languages differ in the transparency of these mappings, as illustrated by contrasts among languages such as Finnish, German, and English. Greater transparency corresponds to more consistent symbol–sound relationships, whereas increased inconsistency results in orthographic opacity (Azevedo et al., 2023; Dehaene, 2012). In practical terms, the deeper the orthography, the greater the cognitive demands placed on learners, underscoring the importance of explicit instruction and robust phonological awareness in literacy acquisition.

3 Method

Initially, forty-eight (n = 48) preschool children were recruited for participation in the study. The initial sample included twenty-three female and twenty-five male participants, all enrolled in the same educational institution. To assess protocol effectiveness, participants were assigned to either an experimental group (n = 24) or a control group (n = 24). The experimental group initially included twenty-four students (n = 24; thirteen females and eleven males), who completed a series of pedagogical tasks designed to foster phonological awareness using GraphoGame Brazil for three consecutive months, five times a week and for twenty minutes during school hours. However, participants were allowed to use the software for a longer period if they so wished, and time of software use was included as a variable in the data analysis. Conversely, the control group, which initially included twenty-four participants (n = 24; ten females and fourteen males), did not receive the cognitive stimulation.

After initial recruitment, schoolchildren with visual or auditory impairments, behavioral disorders, current use of psychotropic medication or a diagnosis of autism spectrum disorder (due to potential impacts on cognitive flexibility, communication, and social interaction) were excluded from the study. Although participants were selected based on school attendance, many parents or legal guardians were unable to ensure their children's regular attendance, possibly due to the fact that the school serves a socioeconomically disadvantaged community. Another factor that affected participants' attendance were the May 2024 floods in Rio Grande do Sul, which significantly impacted the school's neighborhood. Taking into account these factors, as well as the aforementioned exclusion criteria, the final sample included twenty-two

participants (n = 22; M age[5] = 64.59 months; SD = 3.32) in the experimental group and eighteen participants (n = 18; M age = 65.06 months; SD = 2.98) in the control group.

3.1 Instruments

The following instruments were used for data collection:

Rapid Automatized Naming (RAN) test. The Rapid Automatized Naming (RAN; Denckla; Rudel, 1976) test was administered both in the pre- and post-stimulation stages to assess participants' speed in sequentially naming highly familiar stimuli (colors, numbers, objects, and letters). The test was administered individually to participants in both the experimental and control groups. RAN performance allows for an assessment of the time a participant takes to access the lexical representation of the stimuli.

Bateria de Avaliação Metafonológica Bilíngue (BAMBI; Bilingual Metaphonological Assessment Battery). BAMBI (Azevedo et al., 2024) is a protocol designed to assess phonological awareness both at syllabic and phonemic levels in Brazilian Portuguese speakers. Syllable-level awareness is evaluated through five subtests, which assess first-syllable identification and exclusion, syllable blending, and rhyme identification. Phonemic-level awareness is assessed through four subtests that involve first-phoneme identification and deletion and last-phoneme identification and exclusion.

Raven's Progressive Matrices (RPM). RPM (Raven; Raven; Court, 1988) is a non-verbal test that measures general intelligence ("g" factor), designed for children aged 5 to 11 years. The test assesses abstract reasoning and problem-solving abilities through visual pattern-completion tasks.

GraphoGame Brazil-based stimulation protocol. GraphoGame Brazil is a pedagogical software designed to support literacy development in children aged 4 to 9 years by training grapheme-phoneme correspondences. The Brazilian version was developed between 2015 and 2016 by researchers from the Rio Grande do Sul Brain Institute (Instituto do Cérebro do Rio Grande do Sul; INSCER). The software is freely available and can be used on smartphones, tablets, and computers. The game is structured into 49 sequential levels, which gradually increase in complexity, ranging from isolated vowel and consonant sounds to more complex letter combinations (e.g., consonant–vowel, consonant–vowel–consonant, consonant–consonant–vowel).

3.2 Procedures

[5] The mean age refers to participants' age at the beginning of the intervention.

Sample recruitment started in the first semester of 2024 at a municipal elementary school in Rio Grande do Sul, Brazil. To ensure adherence to the stimulation protocol, participants were selected with the collaboration of their respective teachers. The study was conducted with the approval of the school administration and the Ethics Committee (CAAE: 48815821.3.0000.5336 – PUCRS). During the pre-stimulation phase, both the RAN test and the BAMBI battery were administered to participants in the experimental and control groups individually. In addition, participants' intelligence quotient (IQ) was assessed using Raven's Progressive Matrices (RPM).

Following the administration of these instruments, participants in the experimental group engaged in the stimulation protocol using GraphoGame Brazil. Overall, the stimulation protocol lasted three months (September, October, and November 2024), and consisted of five sessions per week (Monday to Friday). Sessions were conducted in-person, with participants using the application for approximately 30 minutes per session.

The GraphoGame Brazil software was installed in electronic devices and individual user profiles were created for each participant. Participants received initial guidance on how to use the application. Throughout the stimulation, the classroom teacher and monitor accompanied the sessions to provide support as needed without interfering with game flow. Observations regarding behavior, adherence, and specific difficulties were recorded in individual assessment sheets developed for this purpose. Each session was recorded daily, including information on the levels completed in the GraphoGame Brazil software, time of use, and percentage of correct responses. After the three-month stimulation period, an individual report was generated for each participant to assess overall progress. In the post-stimulation stage, the RAN test (Denckla; Rudel, 1976) and the BAMBI battery (Azevedo et al., 2024) were administered in both experimental and control groups in order to assess differences between pre- and post-stimulation scores.

For data analysis, a series of mixed-effects multiple linear regression models was conducted. These models were developed using the RStudio interface (version 2021.09.0). In total, six mixed-effects multiple linear regression models were created: two models pertaining to BAMBI scores (syllabic and phonemic awareness) and four pertaining to RAN scores (colors, numbers, letters, and objects). Changes in test performance were examined as a function of sex, age (in months), software usage time, and IQ.

4 Results and Discussion

The linear mixed-effects regression models implemented in this study were designed to examine variability across six response variables (hereafter denoted as BAMBIPHON, BAMBISYL, RANCOLORS, RANLETTERS, RANOBJECTS, and RANNUMBERS, described in detail below) as a function of the fixed effects Group x Time (i.e., experimental versus control groups assessed at pre- and post-test), intelligence quotient (IQ), cumulative duration of GraphoGame exposure, chronological age (in months, measured at the pre-test), and biological sex (male/female).

The response measures BAMBIPHON and BAMBISYL operationalize participants' performance on the BAMBI assessment at the phonemic and syllabic levels, respectively. Specifically, BAMBIPHON constitutes a composite accuracy index derived from four phonological awareness subcomponents: initial phoneme identification, initial phoneme deletion, final phoneme identification, and final phoneme deletion. Performance scores were normalized and expressed as percentages, computed on a 100-point scale.

Performance on the RAN tasks (namely, RANCOLORS, RANLETTERS, RANOBJECTS, and RANNUMBERS) was operationalized using response latency. In accordance with the test protocol, shorter naming times indicate superior performance, such that faster item naming reflects greater automaticity and processing efficiency.

For all models, the experimental group at post-test was specified as the reference category, allowing for the direct interpretation of both the intervention effects (GE-PRE vs. GE-POST) and the between-group comparison at post-test (GC-POST vs. GE-POST).

Regarding the BAMBIPHON outcome, the model revealed a statistically significant improvement in performance within the experimental group from pre-test to post-test ($\beta = -35.19$, $p < .001$). Furthermore, at post-test, the experimental group showed significantly higher scores than the control group ($\beta = -19.64$, $p = .04$), even after controlling for age, IQ, sex, and duration of use. The gains observed in the experimental group, both longitudinally and relative to the control group at post-test, provide great evidence that phonemic awareness is instruction-dependent rather than developmentally emergent (Alves; Finger, 2023; Azevedo, 2025). These effects directly support neurobiological accounts of reading acquisition that posit the functional reorganization of pre-existing phonological networks, particularly within temporo-parietal systems subserving phonological decoding (Dehaene, 2012; Shaywitz; Shaywitz, 2020).

By aligning auditory phonemes with visual graphemes, GraphoGame Brazil seems to engage the phonological route in the Dual-Route Model of Reading (Ellis, 1995), promoting increased phonemic representational precision. The absence of modulation by age, IQ, or

duration of use indicates that these gains reflect intervention-driven specialization of phonological processing, rather than maturational progression or domain-general cognitive effects.

For the BAMBISYL measure, a statistically significant improvement in performance was observed in the experimental group from pre-test to post-test ($\beta = -28.65$, $p < .001$). However, no statistically significant difference was detected between the experimental and control groups at post-test ($\beta = -6.59$, $p = .60$). This pattern reflects the relative robustness of syllabic representations, which emerge early and are largely stabilized through spoken language experience rather than through instruction-dependent reorganization (Alves; Finger, 2023). From a neurobiological standpoint, syllabic awareness does not represent a central constraint in reading acquisition, given that decoding efficiency in alphabetic systems depends on phonemic, not syllabic, refinement (Dehaene, 2012; Moll et al., 2014).

For the RAN color-naming task, operationalized as response latency, a significant Group × Time effect was observed. The experimental group exhibited a significant reduction in response times from pre-test to post-test ($\beta = 16.82$, $p = .006$), indicating improved performance. Moreover, at post-test, the experimental group demonstrated significantly shorter response times than the control group ($\beta = 29.17$, $p = .039$). A significant effect of IQ was also detected, with higher IQ scores associated with faster response times ($\beta = -0.41$, $p = .022$). These results provide evidence of a positive effect of the intervention on color-naming speed and accuracy in the experimental group, alongside significant effects of IQ.

Analyses of the letter-naming task showed a statistically significant difference was identified between the experimental group's pre-test and post-test assessments, with significantly longer response times at pre-test relative to post-test ($\beta = 27.93$, $p = .007$). However, no statistically significant between-group differences were observed at post-test. The covariates age, IQ, sex, and duration of use did not exert significant effects in the model ($p > .05$). Substantial inter-individual variability was observed, indicating that response latency in letter naming is highly heterogeneous and strongly dependent on individual differences. This pattern suggests intervention-driven gains in visual–phonological integration and processing speed within neural systems supporting fluent reading, despite the non-orthographic nature of the task (Dehaene, 2012; Seidenberg, 2017; Shaywitz; Shaywitz, 2020).

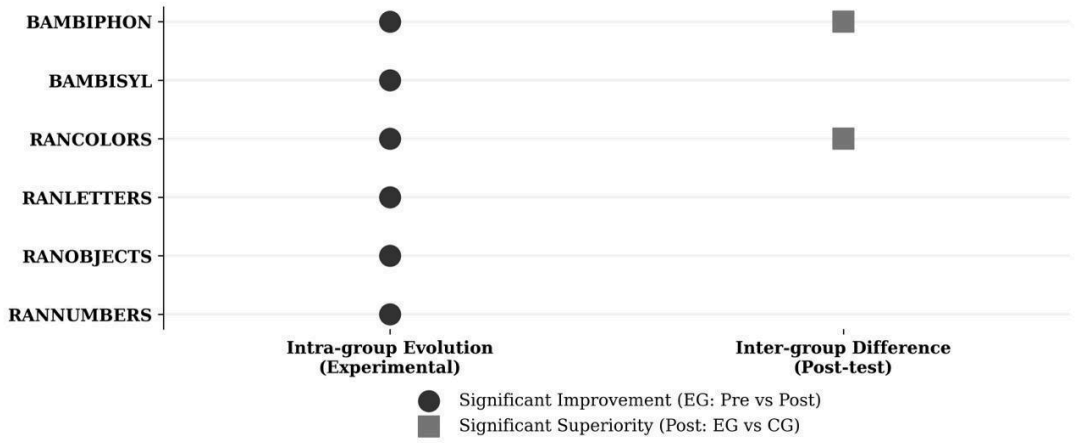
In the object naming task, the experimental group showed a significant reduction in response time from pre- to post-test ($\beta = 27.09$, $p < .001$), indicating faster naming, thus improved performance, following the intervention. However, no significant differences were

observed between the experimental and control groups at post-test, nor were there significant effects of the covariates age, IQ, sex, or amount of use.

Below, we have Figure 1 that summarizes the findings.

Figure 1. Map of statistically significant results ($p < .05$)

ALT: Scatter plot with tasks on the y-axis (BAMBIPHON, BAMBISYL, RANCOLORS, RANLETTERS, RANOBJECTS, RANNUMBERS) and comparison type on the x-axis (left: intra-group evolution—experimental; right: inter-group difference—post-test). All tasks show significant pre–post improvement (black circles). The variables BAMBIPHON and RANCOLORS show significant post-test superiority over the control group (gray squares).



Source: the authors (2026).

The absence of significant between-group differences at post-test may be attributed to the fact that object naming skills are broadly stimulated in early childhood education contexts, regardless of experimental condition.

In the Brazilian preschool curriculum, activities that promote lexical access are encouraged for children, once BNCC (Brasil, 2018) explicitly prescribes the expression of ideas, desires, and feelings through oral language, leading to vocabulary expansion as well as the perception and production of speech sounds. Given that object naming relies heavily on lexical access and oral language proficiency, both the experimental and control groups were likely exposed to comparable language-enriching experiences, which may have reduced observable between-group differences while still permitting within-group improvements in the experimental group.

In the numbers task, a statistically significant improvement was observed in the experimental group from pre- to post-test, with significantly longer response times at pre-test compared to post-test ($\beta = 29.39$, $p < .001$), indicating enhanced performance after

intervention. No statistically significant differences were found between the experimental and control groups at post-test. The covariates age, IQ, sex, and amount of use did not present significant effects in the model ($p > .05$). Notably, high interindividual variability was observed, suggesting that response time in natural number processing is heterogeneous and strongly influenced by individual differences. These findings are consistent with the BNCC (Brasil, 2018), which establishes early and continuous exposure to numerical concepts in preschool education, including the representation of quantities, the identification of numerals, and their organization in numerical sequences. Such systematic stimulation is likely to promote automatization in number naming across children, independently of the intervention.

The results revealed distinct patterns across tasks. For phonological awareness (BAMBIPHON) and color naming (RANCOLORS), a clear advantage of the GraphoGame intervention was observed, with the experimental group outperforming all other conditions at post-test; in the latter task, performance was additionally influenced by IQ. In contrast, for syllabic awareness (BAMBISYL), letter naming (RANLETTERS), object naming (RANOBJECTS), and number naming (RANNUMBERS), significant improvements from pre- to post-test were found regardless of group, with no reliable differences between experimental and control groups at post-test. As discussed in the theoretical framework, oral language emerges naturally and is continuously refined through interaction, unlike reading, which depends on explicit and systematic instruction. Consequently, tasks that depend predominantly on oral lexical representations may be less sensitive to literacy-focused interventions that target phoneme–grapheme mappings.

Although all rapid automatized naming (RAN) tasks involve rapid access to verbal labels, the results indicate differential sensitivity to the intervention. A selective advantage was observed for color naming, suggesting that GraphoGame Brazil enhanced processing efficiency and visual–phonological mapping, abilities closely related to the early cognitive demands of reading acquisition (Dehaene, 2012; Snowling; Hulme, 2013). In contrast, no intervention-specific effects were detected for object or number naming, skills that are systematically stimulated in Brazilian preschool education (Brasil, 2018).

Conclusion

Grounded in contemporary cognitive models that conceptualize reading as a learned cultural skill dependent on explicit instruction, this study set out to examine early literacy development and the effectiveness of GraphoGame Brazil in a preschool population from a low socioeconomic background. Specifically, the study aimed to assess emergent literacy skills

through pre- and post-testing and to evaluate whether a gamified, evidence-based digital intervention, GraphoGame Brazil, could support the development of phonological awareness and related cognitive processes during the initial stages of literacy acquisition.

The results indicate that GraphoGame Brazil produced robust and selective effects on phonemic awareness and processing efficiency, as reflected in significant gains in the BAMBIPHON and color-naming measures. These effects persisted after controlling for age, sex, intelligence quotient, and duration of exposure, highlighting the specificity of the intervention in targeting foundational decoding-related skills that are critical for alphabetic reading. In contrast, improvements in syllabic awareness and in rapid naming of letters, objects, and numbers were observed across both experimental and control groups, a pattern likely attributable to maturational factors and to systematic stimulation within Brazilian preschool education, as prescribed by the National Common Core Curriculum (BNCC).

From a theoretical perspective, these findings align with models that emphasize the central role of explicit phoneme-level instruction in the acquisition of the alphabetic principle. While oral language and syllabic sensitivity are largely fostered through naturalistic and curricular classroom activities, phonemic awareness appears to benefit from structured, targeted, and repetitive practice, conditions that are intrinsic to the design of GraphoGame Brazil. Thus, the intervention may be particularly effective in supporting neural and cognitive reorganization processes that underlie the mapping between orthography and speech sounds, complementing, rather than replacing, classroom-based instruction.

As for the limitations, the relatively short intervention period, modest sample size, and reliance on a single school context may constrain the generalizability of the findings. In addition, the absence of long-term follow-up measures limits conclusions regarding the durability of the observed effects. Nonetheless, the present results provide ecologically valid evidence that well-designed educational technologies can yield measurable cognitive-linguistic gains even within contexts characterized by high curricular exposure and developmental variability. In this sense, GraphoGame Brazil emerges not merely as a motivational digital resource, but as a theoretically grounded and empirically supported tool that may be capable of strengthening the foundations upon which successful reading acquisition is built.

Competing Interests

The authors declare no conflicts of interest.

AI Use Statement

The authors declare that no AI tools were used in the creation of this manuscript or in any part of the work reported.

Data Availability Statement

The data reported in this article were made available in the SciELO Preprints Dataverse and can be accessed via the following link: https://doi.org/10.48331/SCIELODATA.L0MGKR.

The record contains the dataset, a README file with the codebook, and two analysis scripts: one implementing the multiple linear regression analyses and another generating Figure 1.

All shared data were anonymized prior to publication to ensure participant confidentiality.

Ethics

Given the participants involved in this study were underage, legal guardians signed an Informed Consent Form before data collection. This research study is part of a project called "Literacia e EdTech: um estudo sobre o impacto do GraphoGame na Alfabetização", which was approved by the Pontifícia Universidade Católica do Rio Grande do Sul (PUCRS) Ethics Committee under the CAAE (*Certificado de Apresentação para Apreciação Ética*) 48815821.3.0000.5336.

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