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Article

Impact of a cognitive training on reading of 6-year-old children

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Abstract

Numerous studies explore the effect of cognitive stimulation programs on reading skills in children, with mixed results. However, few studies question the impact of these interventions at the beginning of primary school, during the crucial period when formal reading acquisition is being consolidated. This research is the only study in the last ten years addressing the far transfer effects on letter recognition and word and pseudoword reading, from a gamified cognitive stimulation program. The main objective of this pilot study is to investigate the impact of gamified executive functions training on letter identification, and on word and pseudoword reading, in typically developing 6-year-old children. Cognitive training was conducted using the *CogniFit* platform in 12 children, comparing their performance with a comparison group of 28 children of the same age and similar socioeconomic status. This training protocol lasted for 8 weeks, averaging 19 minutes of training per week. Results indicated that the experimental group showed higher reading speed in letter recognition than the comparison group. However, no significant effect was found in the rest of the reading skills. These promising findings suggest that additional research is needed to clarify the mixed results reported in the current scientific literature regarding the modulation of executive functions and their impact on untrained skills such as reading abilities.

1. Introduction

Executive functions constitute essential cognitive processes for academic and professional success [1, 2, 3], the development of social skills and the establishment of emotional bonds, the maintenance of healthy habits, and better quality of life [2, 4, 5, 6]. They also help avoid inappropriate or criminal actions [2, 4], and reduce the risk of drug use [2, 7]. Therefore, executive functions are crucial for life and social coexistence [2, 4, 8, 9].

On the other hand, reading skills (such as phonological awareness, reading accuracy, and reading speed) as well as text comprehension are essential for the comprehensive development of individuals, being linked to academic success [10, 11, 12, 13, 14, 15], quality of life, mental health, and psychosocial functioning [16, 17, 18]. In this regard, the relevance of reading processes in an educational system in which reading and writing play a crucial and central role is unquestionable [19, 20, 21], as better reading efficiency and higher levels of reading comprehension are associated with improved academic outcomes [10, 11, 12, 13, 14, 15].

The idea that executive functions, such as working memory, inhibitory control, and cognitive flexibility, can be trained through various cognitive stimulation programs based on gamification has gained interest in recent years. These programs combine cognitive neuroscience with innovative game applications [9, 29, 31] (for a review, see [32]; for meta-analysis, see [33, 34, 35, 36]). Additionally, these interventions are shown to impact other untrained cognitive skills, such as academic abilities, social and emotional context of individuals [25, 33, 37], or more specifically, reading skills [10, 12, 15, 23, 24, 26, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47].

Therefore, the main objective of the present study was to examine whether a gamified training program targeting executive functions could lead to far transfer benefits in the reading skills of typically developing 6-year-old children.

1.1 Definition of executive functions

Executive functions are defined as a set of high-level cognitive skills, independent yet interrelated, including working memory, inhibitory control, and cognitive flexibility. These abilities are responsible for goal-directed behaviour and action [9, 10, 48] and are indispensable for the autonomous and independent execution of multiple tasks simultaneously [49, 50].

Working memory is defined as the cognitive ability to temporarily maintain and process information during the execution of complex cognitive activities [9, 13, 32, 38, 51, 52, 53]. This ability consists of a central system, responsible for general information processing, and two subsystems (verbal and visuospatial) for information storage [26, 32, 39, 52]. Verbal working memory manages phonological information, while visuospatial working memory is responsible for identifying visual features and/or remembering their location [32, 39, 51, 54].

Inhibitory control is the cognitive ability that allows the suppression of distracting information, irrelevant behaviours, or inappropriate responses during an ongoing activity [15, 32, 48, 55, 56], as well as resisting initial impulses and choosing how to react to certain stimuli [9, 28].

Cognitive flexibility refers to the ability to easily adapt to changing mental demands, goals, thoughts, perspectives, or activities, allowing individuals to handle confrontation of novel challenges when they arise unexpectedly [9, 15, 32].

1.2 Implications of executive functions in reading

Executive functions play a crucial role in the development of academic skills [25, 29, 42, 52] (for a review, see [54]; for meta-analysis, see [57]). Throughout a typical school day, students are required to remember and manipulate academic information, filter out irrelevant data, and incorporate new information to update their skills (working memory and inhibitory control). They must also quickly switch from one subject to another, alternating between tasks and/or skills in response to teacher instructions (cognitive flexibility). Additionally, they need to inhibit automatic responses, such as being distracted by a classmate, and maintain focus on the teacher (inhibitory control), among other demands [51, 56]. Consequently, these cognitive skills serve as strong predictors of academic abilities [21, 37, 51, 52].

Among academic skills, the impact of executive functions on reading skills is noteworthy [10, 11, 12, 14, 15], especially regarding working memory, inhibitory control, and cognitive flexibility.

Working memory is relevant for reading speed as it plays a significant role in the visual processing of words and pronunciation of syllables and phonemes during decoding. Simultaneously, it temporarily stores new words from the text and combines the information read with the surrounding context for reading comprehension [32, 52, 58, 59] (for a review, see [54]; for meta-analysis, see [55, 57, 60]). Working memory also allows the recall and retention of relevant information from the text, along with the reader's existing long-term memory contents, helping to construct a coherent mental model of the text [14, 39. 53, 61]. Consequently, working memory is considered highly predictive of academic success [3, 45] (for a review, see [57, 60]). Furthermore, children with deficits in working memory often exhibit reading difficulties [5, 10, 23, 26, 42, 51, 61].

Inhibitory control is also related to reading skills [11, 28] (for meta-analysis, see [57]) and subsequent reading comprehension [10] (for a review, see [54]; for meta-analysis, see [55]). Effective reading requires avoiding distractions that may interfere with reading activities, focusing attention on the letters in the text to prevent confusion, and inhibiting irrelevant information that may occupy working memory [11, 28, 32, 39, 54, 57, 58, 61]. Deficits in inhibitory control are sometimes associated with reading difficulties [11, 57], due to the presence of a higher number of irrelevant intrusions [61].

Finally, some authors such as Johann and Karbach [10], Johann *et al*. [11], Miyake and Friedman [48], or Pasqualotto and Venuti [58] defend that cognitive flexibility plays a crucial role in reading activities (for a review, see [54]; for meta-analysis, see [55, 57, 62]), especially in late childhood and early adolescence [57, 63]. Cognitive flexibility is necessary for moving flexibly from one line to another or between visual elements accompanying text information, while shifting attention between phonological, linguistic, syntactic, and semantic features [54, 62].

1.3 Training of executive functions in reading

As a consequence of the abovementioned connections, there has been a significant interest in recent years in investigating the impact of various cognitive stimulation programs on untrained skills, such as reading skills [12, 25, 55, 56], and written text comprehension [38, 53, 56].

This impact or transfer of intervention programs can be defined as the benefit that training protocols may have on skills not directly targeted by the interventions but related to them (near transfer) or on skills unrelated to the training (far transfer) [26, 32, 34, 36, 53].

Although the current debate in the scientific community mainly concerns the far transfer effects of executive function training on reading skills [29, 44, 53] (for a review, see [32]; for meta-analysis, see [33]), short-term far transfer benefits have been observed in reading skills or reading comprehension in typically developing children from interventions based on the development of working memory [12, 23, 24, 26, 42, 53], inhibitory control [10], or cognitive flexibility [10]. Similarly, benefits in untrained reading skills have also been observed from simultaneous training of different executive functions [15, 44], or from combined protocols involving both executive functions and academic skills [22, 26, 27, 42, 61,]. Notably, these far transfer effects have been observed in gamified and playful environments [10, 15, 42, 44], with these results sometimes being maintained over time [10, 15, 23, 38, 46]. However, other studies report null effects on far transfer in similar populations [10, 21, 29, 37, 40, 53, 56, 64] (for a review, see [5, 31, 32]; for meta-analysis, see [33, 34, 35]), even when the intervention involved gamified elements [21, 29, 37, 53, 56, 64].

This lack of consistency in the far transfer impact of cognitive stimulation programs on children's academic skills may be partially due to several factors. First, results may vary depending on the tasks used in the assessment [46] or the training regimes, with protocols featuring either a single type of activity [10, 12, 37], or multiple paradigms [26, 27, 44, 53]. Similarly, reported effects may also depend on the duration and frequency of the interventions, as these factors are positively related to better outcomes post-intervention [9, 10, 53]. It is also worth noting that including a placebo group in the study facilitates result verification, as motivation and improvement expectations can sometimes influence the final results [9, 21, 27, 53]. Finally, the age of participants may be a crucial factor in such interventions, with greater transfer of cognitive training observed in younger children [10, 13, 27].

1.4 Gamified executive functions training

The use of new technologies represents an optimal opportunity to attract children's interest and increase their participation in demanding activities [64]. Recent studies have reported that motivational variables can influence the effects of cognitive training, acting as important predictors. In this context, incorporating game elements into training tasks effectively addresses modulating variables related to motivation, such as willingness and predisposition to participate in training sessions [10, 65, 66, 67, 68, 69, 70, 71, 72, 73].

Although various studies currently implement executive function training in children using gamified paradigms [3, 15, 21, 25, 29, 37, 41, 42, 43, 44, 47, 53, 56, 74], comparative research between the effects of game-based training programs and standard protocols lacking gamified elements is less common [10, 72].

Specifically, Prins *et al*. [68] and Ninaus *et al*. [72] explored the effects of gamified working memory training versus standard working memory training, reporting that the game-based protocol led to benefits in performance and training motivation [68], as well as near transfer effects to untrained working memory skills [68, 72]. Similarly, Dorrenbacher *et al*. [75] implemented a gamified stimulation program focused on task switching, reporting gains in motivation to participate in the intervention as well as improvements in untrained switching tasks compared to standard training. Finally, Johann and Karbach [10] conducted three game-based training protocols focused on working memory, inhibitory control, and cognitive flexibility, comparing the results with standard interventions targeting the same executive functions. Although the game-based and standard inhibitory control training produced near transfer effects related to inhibition post-intervention, the gamified program induced greater benefits than the standard version. Likewise, these authors reported far transfer gains in reading speed and comprehension only after game-based inhibitory control and cognitive flexibility training, but no benefits in these untrained skills were found in the standard protocols [10].

However, one of the most supported premises regarding the efficacy of gamified cognitive stimulation protocols is based on the continuous and progressive adaptation of the difficulty level of the tasks comprising the training, requiring maximum cognitive effort to complete the challenges. Thus, following authors such as Ericsson [76, 77] or Vygotsky [78], achieving greater effectiveness in cognitive training and attaining near and far transfer effects, the difficulty of cognitive games must increase as participants' skills improve. Therefore, gamified cognitive stimulation programs need to entail constant cognitive challenges for participants [9, 35, 41, 46, 68, 69, 70, 72, 79] (for meta-analysis see [64]).

1.5 The present study

Currently, numerous studies focus on the modulation of executive functions and their impact on untrained skills such as children’s reading abilities and comprehension. However, despite the assertion that the relationships between executive functions and reading are more consistent at early ages [11, 27, 36, 59, 60], there is a scarcity of research addressing the impact of such interventions in the early stages of reading, when decoding begins to solidify, and word and pseudoword reading is developing.

In the past 10 years, only Henry *et al*. [40], Lopez and Aran [29], and Roberts *et al*. [64] have investigated the far transfer impact of executive function stimulation protocols on reading skills in 6-year-old children. However, these studies exclusively focused on working memory training and did not report benefits in untrained skills such as reading skills after the intervention. Therefore, to the best of our knowledge, no studies have been published in the last decade that analyse the impact of general executive function stimulation on reading skills in novice readers, including tasks related to inhibitory control, cognitive flexibility, and working memory. Consequently, based on these considerations, this paper aims to expand the existing scientific literature regarding the feasibility and effectiveness of stimulating main executive functions in early reading skills, accompanying children in the formal acquisition process of reading.

The objective of this study is to implement and evaluate the impact of gamified executive function training (specifically in working memory, inhibitory control, and cognitive flexibility) on untrained tasks, such as the reading skills of typically developing 6-year-old children. We hypothesized that a gamified cognitive stimulation program could lead to short-term far transfer effects on the reading skills of beginner readers. More specifically, we expect post-training benefits in untrained skills such as the accuracy and speed of letter recognition and decoding, as well as in the fluency of lexical and decoding processes necessary for reading words and pseudowords.

2. Methods and Material

2.1 Design and Participants

This study responds to a quantitative quasi-experimental methodology with a design involving two groups and a single post-intervention assessment. The classes to which the participants belonged were randomly assigned to either the experimental group or the comparison group.

It should be noted that this study did not collect baseline data on reading skills, based on the understanding that formal reading instruction begins with the start of Primary School. As such, it is neither obligatory nor anticipated for children to possess reading knowledge beyond preliminary reading precursors before this educational stage. Given this context, the researchers deemed it unnecessary to gather pre-existing reading assessments, opting to initiate the study at a point where formal reading education begins according to Spanish law.

The total sample for this study consisted of 48 participants (M = 80.38 months, SD = 3.647; 41.7% girls) from three different 1st grade primary education classes, originating from two different educational centres. However, some participants from the experimental group did not complete the minimum intervention objectives established, so data from 16.7% of the participants (N = 8) were not included. Exclusion criteria considered the presence of any deficits, learning disorders, or neurodevelopmental disorders.

The final study sample consisted of 40 participants aged between 5 and 6 years (M = 80.3 months, SD = 3.47; 47.5% girls), whose classes were randomly assigned to the two designated research groups (one class was assigned to the experimental group, and two classes were assigned to the comparison group). The experimental group included 12 children (M = 80.9 months, SD = 4.21; 50% girls), who participated in gamified cognitive training, while the comparison group consisted of 28 children (M = 80 months, SD = 3.15; 46.4% girls), who continued with their regular academic program during the intervention period. The students were first-grade children from two public educational centres in the Valencian Community of Spain. Table 1 describes the demographic variables of the participants, showing no significant differences between groups in age (U = 140; p = .414) or socioeconomic status (U = 159; p = .785), according to the Mann-Whitney mean comparison test, as these variables did not meet the normality assumption (as measured by the Shapiro-Wilk test). The measure obtained from the MacArthur scale, described in the following section, indicated that 5% of families belonged to a low socioeconomic context (experimental group N = 2, comparison group N = 0), 67.5% to a medium status (experimental group N = 6, comparison group N = 21), and 27.5% to a high socioeconomic context (experimental group N = 4, comparison group N = 7).

Table 1. Descriptives and between-group comparison of control variables

	Group	*N*	*M (SD)*	*U*	*p*
Age	EG	12	80.9 (4.21)	140	.414
	CG	28	80 (3.15)		
Socioeconomic Status	EG	12	6.42 (1.68)	159	.785
	CG	28	6.61 (1.10)		

Note: Age is reported in months. SES corresponds to the estimated socioeconomic status on a 1-to-10 scale. The acronym EG corresponds to the experimental group, and CG to the comparison group.

The selection and data acquisition of the respective participants were carried out following the criteria of Organic Law 3/2018 on the Protection of Personal Data, approved by the Research Ethics Committee of Antonio de Nebrija University, and following the requirements and ethical standards agreed in the Declaration of Helsinki (UNNE 2021-010). Participation in this study was voluntary, as stated in the different information sheets shared with families and teachers. In addition, the study was conducted after obtaining parental authorization through a signed consent form. All participants could withdraw from the project at any time. Participants were also informed about the confidential treatment of their data, collected solely for research purposes. Finally, all participants in the study were rewarded with licenses for *CogniFit* cognitive training until the end of the school year.

2.2 Measurement instruments

The socioeconomic context to which participants' families belonged (compared to the rest of their community) was measured, as this variable has a high predictive value for executive function performance [15, 66, 80]. This assessment was carried out using the MacArthur Scale [81], individually completed by family members and/or legal guardians.

Untrained reading skills were measured after training using four of the nine tests from the *Battery for the Assessment of Reading Processes, Revised* (PROLEC-R) [82]. This battery was used to measure the far transfer effect of training. PROLEC-R is designed to diagnose reading difficulties in children between 6 and 11 years old, identifying which cognitive processes may be responsible for these difficulties. For each of the four selected tests, three main indicators were collected: Accuracy (the number of correct answers), Speed (the time spent to complete the task), and Main Index, which is calculated using the previous two indicators: the number of correct answers divided by the time spent, multiplied by 100 [25, 82, 83].

Specifically, the tests used were *Name or sound of letters* (Cronbach's alpha = .49), and *Same-Different* (Cronbach's alpha = .48), which assess initial letter identification processes; and *Words Reading* (Cronbach's alpha = .74), and *Pseudowords Reading* (Cronbach's alpha = .68), which evaluate the developmental of lexical processes or visual word recognition. In *Name or sound of letters* task, children are required to name each of the 20 presented letters or their corresponding sounds. The accuracy score for this test ranges from 0 to 20 correct answers, and the time required to complete the task is measured in seconds. The *Same-Different* task evaluates the segmentation and identification of letters in each presented word. For this task, 10 pairs of words and 10 pairs of pseudowords are shown, which may be identical (e.g., amigo-amigo; calzapo-calzapo) or different (e.g., carreta-caseta; bequefo-biquefo). Similar to the previous test, the score for this test also ranges from 0 to 20 correct answers. A low score in this test may indicate attentional difficulties or that children are still in a pre-reading phase, employing a logographic reading approach in which words are recognized as a whole rather than decoded letter by letter. In *Words Reading* task, a total of 40 words are presented, comprising 20 high-frequency and 20 low-frequency words, each with a length of two or three syllables. The accuracy score of this test ranges from 0 to 40 points, and the reading time is measured in seconds. Finally, the *Pseudowords Reading* task assesses the ability to pronounce new or unfamiliar words. This test presents 40 pseudowords, which are similar in length and syllabic structure to the words in the *Words Reading* task. The evaluation for this task has the same minimum and maximum score as the *Words Reading* task. According to the authors [82], better performance in word reading compared to pseudoword reading suggests that children engage in lexical reading. Similarly, poorer performance in pseudoword reading indicates difficulties in grapheme-phoneme conversion. Similar levels of accuracy and speed in both tasks suggest that children may be reading through a sublexical route, possibly because they have not yet acquired an orthographic representation of words.

2.3 Intervention

The gamified cognitive stimulation program *CogniFit* (CogniFit Inc., San Francisco, CA, USA) was implemented. This tool has been used and validated in previous research [84, 85], demonstrating its capability to enhance executive functions in children [6].

More specifically, *CogniFit* is focused on training various cognitive skills, including reasoning, memory, attention, coordination, and perception [44, 86, 87]. These cognitive abilities have undergone several statistical measurements to verify their validity and reliability. Specifically, the internal consistency of *CogniFit* shows a Cronbach's Alpha coefficient ranging from .571 to 1, depending on the cognitive task evaluated. Similarly, test-retest reliability, used to demonstrate data stability, provides scores ranging from .696 to .998 [88].

The training protocol implemented in this study was individually adjusted and personalized to each child's cognitive level, based on the initial evaluation from the *Cognitive Assessment Battery* (CAB) of *CogniFit* [88], as well as the performance recorded during training sessions. This constant adaptation of task difficulty throughout the intervention was made possible by an algorithm powered by *CogniFit*'s patented *Individualized Training System™* (ITS) software (CogniFit Inc., San Francisco, CA, EE. UU.). This system detects and automatically adjusts the difficulty of each training session by collecting performance data across the five evaluated cognitive domains (reasoning, memory, attention, coordination, and perception), requiring maximum cognitive effort from the participant. Additionally, it provides detailed graphical and verbal feedback on performance during and after each training task [6, 44, 85, 86, 87, 89].

Although the general *CogniFit* training program consists of a total of 57 tasks focused on cognitive stimulation through a variety of gamified activities, for this study, only tasks suitable for the developmental level of the study population were selected. These tasks did not require advanced reading or mathematical skills. Specifically, the program selected for the intervention included seven cognitive games, each designed to stimulate different executive functions, with an approximate duration of 5 minutes per game. These cognitive games were: *Candy Line Up* (working memory) [90], *Reaction Field* (inhibitory control and cognitive flexibility) [91], *Bee Balloon* (cognitive flexibility) [92], *Neuron Madness* (inhibitory control), *Match It!* (inhibitory control), *Happy Hopper* (inhibitory control) [93], and *Penguin Explorer* (inhibitory control) [94]. A description of each cognitive game, along with the specific cognitive skills it stimulates, can be found in Appendix 1.

Similarly, before starting each activity, the instructions and the cognitive skills to be trained were provided. Additionally, each time a cognitive game was played for the first time, there was a practice level to ensure the instructions were understood. Once the practice level was completed, the software assumed instructions had been correctly understood, and the game began automatically. The games could be paused at any time, and the instructions could be reviewed in the pause menu [87].

Thus, each participant had a customized protocol that included various gamified cognitive tasks with individually adjusted difficulty levels, making the training experience entirely personalized.

2.4 Procedure

Teachers and participating children were recruited for the study through email and/or social media, enrolling in the program with prior authorization from the children's families or legal guardians. The educational centres invited to participate in this project were randomly selected, with the only requirement being that the centre had at least two first-grade classes. Along with enrolment, which took place between October and November 2021, families completed an assessment of their socioeconomic context. After the implementation of the gamified cognitive training protocol, in early March 2022, the assessment of reading processes was carried out.

The intervention took place between December 2021 and February 2022, with a two-week break due to the Christmas holidays. During the intervention period, the comparison group continued with their regular academic program. The educational context and classroom activities programmed by teachers limited the implementation to sessions of 15-20 minutes, once or twice a week, for a total duration of 8 weeks. It is important to note that none of the participants in the final sample completed fewer than six sessions, as this was a pre-established exclusion criterion, based on the assumption that outcome measures would not be sensitive enough to detect changes produced by a lower number of training sessions. Consequently, the average training time was 155.16 minutes (SD = 37.11), distributed over an average of 11.33 sessions (SD = 4.20). The intervention took place during school hours in the participants' classroom and reference group.

Likewise, to familiarize teachers with the platform and its proper implementation in the classrooms, the authors of this study conducted a brief initial training session of 30 minutes.

2.5 Data analysis

A descriptive analysis of the measured variables was conducted. The effects among the study variables were compared using independent group mean difference tests, with a significance level of .05. The classes to which the participants belonged were randomly assigned to either the experimental group or the comparison group.

Time, accuracy, and the main index (see Methods) obtained by the children in each test were measured to quantify the study variables. A non-parametric test (Mann-Whitney's U) was used to compare means for 11 of the 12 dependent variables (accuracy, speed, and main index for the *Name or Sound of Letters* task; accuracy and main index for the *Same-Different* task; accuracy, speed, and main index for the *Words Reading* task; accuracy, speed, and main index for the *Pseudowords Reading* task), as these variables did not meet the assumption of normality (as measured by the Shapiro-Wilk test, all $ps < .043$) and/or did not follow a homogeneous distribution of variance (as measured by the Levene test, all $ps < .043$). The Mann-Whitney U test is robust against outliers and is used to compare the results of two independent groups in terms of their medians. It is particularly useful when data do not meet the normality assumptions required for parametric tests like Student's t-test [95]. Additionally, the effect size for these variables was calculated using the biserial rank correlation r_B. According to Castejon [95], biserial rank correlation is suitable in psychological and educational research contexts due to its ability to handle the association between dichotomous variables and ordinal variables converted into ranks, providing a clear interpretation of the relationship between these variables.

However, the variable related to speed in the *Same-Different* task, which did meet the assumption of normality (p = .283) and followed a homogeneous distribution of variance (p = .182), was analysed using the Student's t-test. This statistical test is essential for comparing the means of two independent groups and determining whether the difference between the means is statistically significant [95]. The effect size for this variable was provided using Cohen's d, which allows for assessing the practical significance of the results beyond statistical significance [95].

These analyses were also complemented with Bayesian t-tests. Bayesian factors allow for the comparison of the evidence provided by the data for two hypotheses, quantifying the strength of the evidence in favour of one hypothesis over another [95]. In this study, the Bayes Factors (BF_{10}) were explored under the hypothesis that the experimental group would show higher values in accuracy and main index if the training had an effect (i.e., EG > CG) and lower values in speed measures (i.e., GE < GC). Similarly, effect size was calculated based on r_B.

Finally, these statistical analyses were performed using the Jamovi software.

3. Results

3.1 *Name or sound of letters* task

In the *Name or sound of letters* task, the Mann-Whitney U tests revealed statistically significant differences in the speed at which children performed (U = 98.5, p = .021, see Table 2), suggesting that children who underwent the cognitive stimulation program demonstrated a higher speed in letter recognition than those in the comparison group. These results yielded a medium effect size (r_B = -.414), and the Bayes Factor indicated strong evidence in favour of the alternative hypothesis (BF_{10} = 5.18).

Conversely, no significant differences were found between groups in the accuracy with which children performed this task (p = .132).

Lastly, significant differences were found in the main index (p = .038), with a small effect size (r_B = .360), as well as evidence favouring the alternative hypothesis (BF_{10} = 3.29). As there were no differences in accuracy in this task (p = .132), these results suggest that the trained group showed far transfer effects of gamified cognitive training related to the speed at which children identified letters presented after the intervention, compared to the comparison group.

3.2 *Same-Different* task

Regarding the untrained *Same-Different* task, it should be noted that the Student's t-test indicated a trend towards significance in the speed at which children performed this task (p = .061), yielding a medium effect size (d = -.547), and anecdotal evidence in favour of the alternative hypothesis (BF_{10} = 1.57). These results suggest that children who participated in the training protocol obtained slight far transfer benefits related to the speed of recognizing the letters composing each pair of words presented after the intervention, although the results were not entirely clear.

However, no statistically significant differences between groups were found based on the Mann-Whitney U test for accuracy (p = .814) and the principal index (p = .327) of this task.

These data indicate that children did not obtain far transfer benefits in letter recognition as assessed by the *Same-Different* task after gamified cognitive training.

3.3 *Words reading* task

Similarly, the Mann-Whitney U test also showed marginal differences in the speed at which children read the presented words (p = .074), with a small effect size (r_B = .295), as well as evidence in favour of the null hypothesis (BF_{10} = .652).

Conversely, no significant differences were observed in accuracy (*p* = .476) or the principal index (*p* = .137) as assessed by this task.

These results suggest that children did not obtain far transfer benefits in the fluency of lexical processes required for reading isolated words after gamified cognitive training.

3.4 *Pseudowords reading* task

The rest of the variables related to lexical and decoding skills necessary for pseudoword reading did not show statistically significant differences between the study groups.

Thus, the results indicate that children did not gain far transfer benefits in speed (*p* = .113) or accuracy (*p* = .35) for pronouncing new or unfamiliar words after gamified cognitive training.

Table 2. Descriptive statistics and between-group comparison of reading skills

	Group	*N*	*M (SD)*	*U*	*p*	r_B	BF_{10}
Accuracy *Name or sound of letters*	EG	12	17 (4.97)	131	.132	.223	.243
	CG	28	17.5 (1.53)				
Speed *Name or sound of letters*	EG	12	73 (19.7)	98.5	.021**	.414	5.18
	CG	28	89.5 (20.5)				
Main Index *Name or sound of letters*	EG	12	26.1 (12.4)	108	.038**	.360	3.29
	CG	28	20.5 (4.63)				
Accuracy *Same-Different*	EG	12	15.6 (2.64)	139	.814	.176	.252
	CG	28	16 (3.21)				
Speed *Same-Different*	EG	12	169 (74.7)	-1.58■	.061*	-.547	1.57
	CG	28	201 (51.2)				
Main Index *Same-Different*	EG	12	11 (6.34)	153	.327	.092	1.51
	CG	28	8.75 (2.90)				
Accuracy *Words Reading*	EG	12	32.2 (10.9)	166	.476	.015	.221
	CG	28	33.9 (5.65)				
Speed *Words Reading*	EG	12	270 (146)	119	.074*	.295	.652
	CG	28	302 (96.2)				
Main Index *Words Reading*	EG	12	16.2 (9.83)	131	.137	.223	1.11
	CG	28	12.9 (5.83)				
Accuracy *Pseudowords Reading*	EG	12	29.8 (9.59)	155	.35	.08	.286
	CG	28	30.3 (6.52)				
Speed *Pseudowords Reading*	EG	12	282 (156)	127	.113	.247	.605
	CG	28	313 (101)				
Main Index *Pseudowords Reading*	EG	12	14.3 (9.74)	147	.272	.125	.995
	CG	28	11.4 (5.66)				

Note: The "Speed" variable in the subtests is expressed in seconds. The acronym EG corresponds to the experimental group, and CG corresponds to the comparison group.

BF_{10} under H_1: EG > CG in the accuracy measures and main index of the evaluation test; EG < CG in the speed measurements of the evaluation tests.

■ This variable met the assumption of normality and followed a homogeneous distribution of variance, so the comparison of means was carried out using Student's *t*, and the effect size was reported using Cohen's *d*.

*$p < .10$; **$p < .05$.

4. Discussion

This study aimed to examine the far transfer impact of a relatively short gamified executive functions training (an average of 156 minutes per participant across all sessions) on the reading skills of 6-year-old children.

The results obtained reveal that, immediately after training, the experimental group showed greater speed in untrained skills such as letter recognition (*Name or sound of letters* task) than the comparison group. Indeed, the Bayes Factors for this variable demonstrated weak evidence for the null hypothesis. However, as it is described in the Method section, the main index of *Name or sound of letters* test is supported by the results obtained in both accuracy and speed for the *Name or sound of letters* task. Since differences in accuracy for the *Name or sound of letters* task were not significant (p = .132), it appears that these results are powered by the performance in the speed at which children performed the *Name or sound of letters* task. These findings align with the strong relationship between executive functions and letter identification [8, 57, 96], as well as with improvements in reading performance resulting from working memory stimulation [22, 23, 25].

Furthermore, the gamified cognitive stimulation program could be potentially associated with a far transfer effect on the speed of decoding letters in the *Same-Different* task. Previous studies have reported positive effects of interventions targeting executive function training on decoding speed [22, 23, 25, 47]. These results contribute to the body of evidence indicating a strong relationship between the main executive functions (working memory and inhibitory control) and decoding and word recognition [8, 28, 96, 97, 98].

However, contrary to expectations based on current studies [10, 12, 15, 22, 24, 25, 27, 29], only marginal differences were observed in untrained skills such as word recognition (*Same-Different* task) or word reading (*Words Reading* task) performance after the intervention. Similarly, no significant differences were observed between both groups in the accuracy of letter recognition (*Name or sound of letters* task), nor in the fluency of the lexical processes necessary for reading words and pseudowords (accuracy and speed performed in *Words Reading* and *Pseudowords Reading* tasks). These results add to the growing evidence that executive functions-based training does not improve untrained skills such as reading words and pseudowords [40, 42, 64] (for a review, see [10]; for meta-analysis, see [34, 35, 60]).

Thus, the use of gamified cognitive programs has gained importance in neuroeducation [79]. According to authors like Silva *et al.* [79], it is essential that these tools promote neuroplasticity and cognitive development. This is possible through the personalization of training protocols, providing immediate feedback, enhancing individual autonomy, and fostering motivation and engagement in the activities undertaken [9, 10, 35, 41, 46, 65, 66, 67, 68, 69, 70, 71, 72, 73, 79]. In this regard, it seems reasonable to highlight that these characteristics especially support the effectiveness of gamified cognitive programs [99, 100, 101]. Indeed, Peretz *et al.* [100] argue that gamified cognitive training, when personalized and adapted to each participant's performance, seems to be more effective than traditional gamified training, even though the latter also includes varied, challenging, and regularly used resources. This may be because gamified training involves numerous processes that can overwhelm participants' abilities if not properly adapted to their individual performance [100]. In this way, *CogniFit* serves as an ideal tool for stimulating key executive functions, as many standard non-gamified protocols struggle to adapt training levels to the individual performance of participants [79].

In addition to the mentioned personalization and adaptability, gamified cognitive training programs like the one implemented in this study offer multiple advantages over non-gamified training tools. Such programs are often more interactive and visually engaging, provide immediate feedback on participants' performance [102], and can therefore generate greater motivation, improved performance during training, and higher expectations of improvement [10, 103]. In this context, authors such as Diamond [104] and Roughan and Hadwin [105] argue that gamified protocols enhance certain factors, such as perceived enjoyment, feelings of social belonging, support, and self-efficacy, which contribute to the improvement of executive functions in cognitive interventions [32].

Although the findings of this study are promising, they should be interpreted with caution, as this research represents a pilot study involving only two educational centres. Therefore, studies with a larger sample size could reflect more robust, accurate, and generalizable results to the rest of the population [21, 31, 46], as well as ensure the equivalence of the groups [12]. Some authors, such as Melby-Lervag *et al.* [35] and Studer-Luethi *et al.* [37] argue that this limitation leads to exploratory data and weak statistical analyses, recommending a minimum of 20 participants per group [31, 106]. Despite this, the sample size of this study is comparable to recent literature on similar topics, which has reported benefits from cognitive interventions in reading skills such as word decoding [12, 23, 24, 74] and reading comprehension [23, 39, 43, 74].

On the other hand, as this involved implementing an intervention in educational centres, a quasi-experimental design was used. This approach has the associated disadvantage that the observed differences may be more attributable to inherent group differences than to the applied training protocol [24, 38]. Following the suggestions of authors such as Sondergaard and Lopez [13], it is advisable to investigate these aspects within the experimental design, including motivational variables previously mentioned in the analysis, to facilitate the detection of potential strange variables that may influence the results obtained.

Similarly, in this study, as in some recently published studies [12, 22, 25, 26, 29, 39, 42, 44, 46], only one experimental group and one comparison group were used. This limitation makes it difficult to identify intrinsic factors that may have acted as potential strange variables in the group that participated in the gamified cognitive training in our study. In this regard, authors such as Appelgren *et al.* [107] or Diamond and Ling [9] point to possible environmental factors affecting intervention outcomes, such as improvement expectations [9, 107], which can lead to greater effort in task execution [66], or the degree of motivation in performing activities, which can influence the effort invested in task execution [21, 27, 39, 53, 76]. Considering these factors, including placebo groups participating in non-adaptive training in future studies would help control for and detect potential strange variables influencing intervention transfer results [9, 21, 24, 39, 53] (see also meta-analyses [31, 34, 35, 36]).

The reported benefits in untrained skills such as letter recognition and decoding speed in our study, along with the absence of far transfer effects on the speed and accuracy of reading words and pseudowords, may be attributed to the tasks employed for training. Although the implemented training includes a range of gamified activities targeting the three main executive functions, the tasks selected for this study were predominantly focused on inhibitory control. Thus, while the intervention included four tasks focused on inhibition, only one task was aimed at developing working memory, and two activities targeted cognitive flexibility. Spiegel *et al.* [57] argue that, in the early years of primary education, when children are in the stage of decoding development, the relationships between executive functions and reading vary depending on the specific reading skills involved. During this stage, while the connection between inhibitory control and cognitive flexibility with letter naming and identification is more robust than with other reading skills, working memory is more consistently related to reading words and pseudowords [10, 57, 60]. This is because novice readers need to focus on letter identification, avoiding potential distractors [58], while using working memory to remember syllables as they read the word, especially in complex or unfamiliar words [57, 60].

In this regard, the PROLEC battery used in this study for assessing word and pseudoword reading incorporates only 20 high-frequency words, while the remaining 60 are low-frequency words or invented words, requiring greater use of working memory than when reading common words [15, 60]. Therefore, this could justify the benefits reported in letter recognition speed after our intervention, as well as the lack of benefits in reading words and pseudowords.

These results are consistent with recent studies that base their intervention protocols exclusively on working memory, which report gains in reading words and pseudowords after training [12, 23, 24]. Consequently, it is possible that interventions incorporating additional tasks beyond those used in this study and involving working memory could lead to benefits, not only in letter recognition but also in the lexical processes required for reading words and pseudowords.

An alternative justification could be that none of the children who participated in this study were diagnosed with neurodevelopmental disorders, and teachers did not report any educational difficulties. Additionally, more than half of the participants scored within the normal range for reading words and pseudowords according to the accuracy standards of the applied assessment. Given that the PROLEC battery for assessing reading processes is designed to detect reading difficulties, the authors report a "ceiling" effect at normal performance on the test, considering it close to the theoretically maximum achievable [82]. Furthermore, at these ages, skills such as decoding and lexical processes are continuously developing and are greatly enhanced by specific strategies and methodologies inherent to the educational context [14]. These factors might limit the potential for the gamified executive function-based intervention to show significant effects in the far transfer of reading skills in children with typical development [53].

Likewise, the lack of far transfer benefits in word and pseudoword reading reported in our study might be attributed to the duration and frequency of the applied cognitive intervention. The educational context and classroom activities scheduled by the teachers limited the implementation to 15-20 minute sessions once or twice a week, over 8 weeks. Consequently, the gamified executive function training program was relatively short. In this regard, current scientific literature has not yet precisely defined the appropriate number of sessions, the optimal duration of each session, or the frequency needed to produce far transfer effects, specifically in children's reading skills [12, 53]. This is because interventions that show benefits in untrained skills have been designed with protocols ranging from 10-12 minutes per session [24] to a maximum of 50 or 60 minutes [26, 42].

Regarding the frequency of these interventions, the minimum number of sessions reporting benefits ranges from 10 sessions [15, 38] to 20 or more [10, 12, 22, 25, 26, 44, 46], conducted over periods ranging from 2 weeks [24] to 13 or more weeks [25]. Despite the gains reported by these authors, studies such as those conducted by Hitchcock and Westwell [56], Jones *et al*. [21], Lopez and Aran [29], and Roberts *et al*. [64] did not find far transfer benefits to reading even with more than 20 training sessions. Therefore, further research is needed to establish a consensus on the optimal duration necessary to achieve far transfer effects to reading skills from gamified executive function training.

Despite the benefits reported in this study, it is not without limitations, as described to some extent in the previous paragraphs. Notably, future research would benefit from analysing the effects of similar gamified cognitive interventions on reading skills in children starting primary education with a larger participant sample, although this would increase financial costs and the time required for protocol implementation. A larger sample would not only allow for the inclusion of a placebo group in which it would also be advisable to analyse motivational variables [13, 27], but would also enable a more robust experimental design. This would facilitate randomization and provide a more efficient analysis of the individual measures demonstrated by participants [34].

On the other hand, this study does not evaluate near transfer effects on executive functions, measured through untrained cognitive tasks, either before or after treatment. Meta-analytic studies like those by Melby-Lervag and Hulme [34] or Melby-Lervag *et al.* [35] suggest that evaluating potential near transfer effects is necessary after an executive functions' modulation protocol. This would allow for a stronger assertion that the observed effects following the intervention are indeed due to the enhancement of executive functions, rather than potential external factors. Additionally, since this study did not assess far transfer effects on reading skills before the intervention, the observed benefits may be due to pre-existing group differences that were not detected. Therefore, it is advisable for future research to introduce both pre- and post- intervention assessments to identify any such differences before training begins [24]. Moreover, long-term evaluation measures, such as a follow-up assessment a few months after the training, would be valuable to detect and/or confirm a possible sleeper effect on reading skills, as suggested by Garcia-Madruga *et al.* [39].

Finally, a limitation of this particular study could be the use of the PROLEC battery for assessing reading skills. Some authors, such as Borella *et al.* [30], Carretti *et al.* [38], or Johann and Karbach [10] suggest that the observed far transfer effects may be influenced by the specific tasks and reading skills evaluated, recommending the use of different assessment batteries to help corroborate the results. Therefore, future research should consider evaluating the transfer of reading skills from gamified cognitive stimulation programs using multiple sets of measures, which would facilitate the detection of potential benefits.

5. Conclusions

Thus, the use of gamified protocols to stimulate executive functions has gained importance as a notable option for implementing cognitive interventions in school settings, compared to standard programs. This is because these types of programs generate greater motivation, higher performance during training, and better outcomes for participants [71, 73, 79]. Specifically, *CogniFit* serves as an ideal tool for training key executive functions, as these gamified protocols include crucial elements for the effectiveness of the intervention, such as adaptation to the individual performance of participants, immediate feedback on performance, and increased motivation and willingness to participate in the training.

This work contributes to meta-analytic studies and current scientific literature on the benefits of gamified cognitive training in untrained skills, such as the reading skills of typically developing children. The primary objective of this study was to implement a gamified program aimed at stimulating executive functions in untrained reading skills, including letter recognition, and the reading of words and pseudowords, in 6-year-old typically developing children. To the best of our knowledge, this research is the only one published in the last ten years that addresses the transfer to letter recognition and the reading of words and pseudowords from a general gamified executive functions' stimulation protocol. This protocol includes tasks focused on inhibitory control, cognitive flexibility, and working memory during the early years of primary education, when children are in the decoding development stage and the formal processes of reading acquisition are being consolidated.

Our study demonstrated short-term far transfer benefits in letter recognition speed among 6-year-old children who participated in the *CogniFit* gamified cognitive stimulation program for 8 weeks. Although these results are not particularly robust, they are promising. However, the intervention did not result in far transfer effects in terms of the accuracy with which children identified letters in these tests, nor did it improve fluency in reading words and pseudowords.

The findings reported in this pilot study, along with the previously mentioned limitations and the proposed new research directions, indicate that further research is still needed on the effects of computer-based training focused on executive functions and their impact on reading skills. Future research on this topic should ideally include larger sample sizes, enabling experimental designs that incorporate both a placebo group and a control group to better contrast the results obtained by the experimental group. Additionally, it would be beneficial for new research to include measures that evaluate both near and far transfer effects of gamified executive function training, using a variety of assessment batteries and tests.

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Conflicts of interest

The authors declare that there is no conflict of interest in conducting this study.

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Ethical approval and consent to participate

This study has been approved by the Research Ethics Committee of Nebrija University and complies with the ethical standards outlined in the Declaration of Helsinki (Protocol Code UNNE 2021-010, approved on October 6, 2021) for studies involving human subjects.

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Appendix

Table 3. List of the seven cognitive games implemented in the training

Name of the activity	Link	Cognitive abilities trained
Candy Line Up	https://www.cognifit.com/candy-line-up	Planning Working memory Monitoring Processing speed

Description: *Candy Line Up* is a puzzle game in which participants must strategically plan their moves. *Candy Line Up* is a brain game designed to train mental planning, working memory and updating.
The purpose of this game is to fill the vases with candies of the same type. Participants can only place candies of the same type and colour on top of each other. As the levels progress, there will be caps blocking the candies from reaching the selected base, making decision-making more challenging [86].

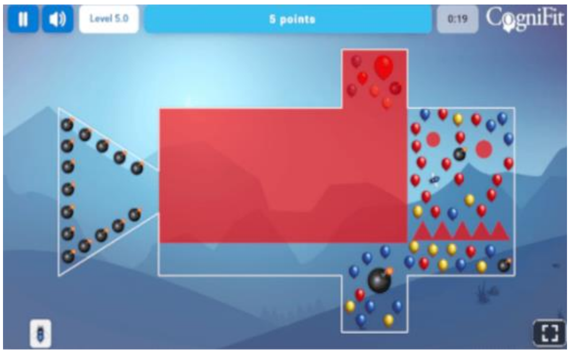
Name of the activity	Link	Cognitive abilities trained
Reaction Field	https://www.cognifit.com/whack-a-mole	Inhibition Response time Cognitive flexibility

Description: *Reaction Field* is a brain training game designed to stimulate inhibitory control, cognitive flexibility and response time.
To progress in this mental game, participants must hit the target mole, avoiding the others, especially those with dynamite attached. As the game's level increases, the cognitive demands will be greater [87].

Table 3. Continuation

Name of the activity	Link	Cognitive abilities trained
Bee Balloon	https://www.cognifit.com/bee-balloon	Eye-hand coordination Cognitive flexibility Response time

Description: *Bee Balloon* is a brain training game designed to stimulate cognitive flexibility, eye-hand coordination and response time.
To advance through the levels, participants must explode all the balloons by passing over them while avoiding bombs and red zones. As participants progress, the cognitive challenge will be even greater [88].



Name of the activity	Link	Cognitive abilities trained
Neuron Madness	https://www.cognifit.com/brain-games/neuron-madness	Focused attention Visual scanning Inhibition

Description: *Neuron Madness* is an online brain training game, focused on stimulating inhibition, focused attention, and visual scanning.
To advance through the game, players need to collect the balls (neurons) in the specified order, while avoiding collisions and passing through balls of a different colour. As participants progress through the levels, the cognitive challenge increases.

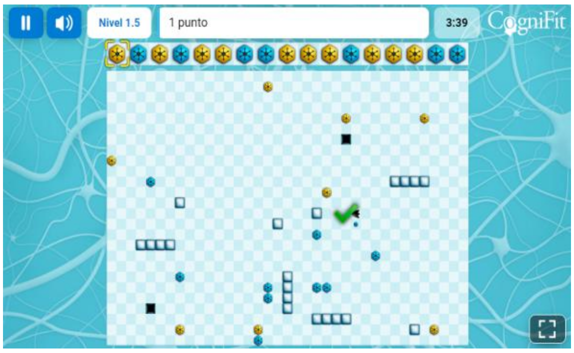
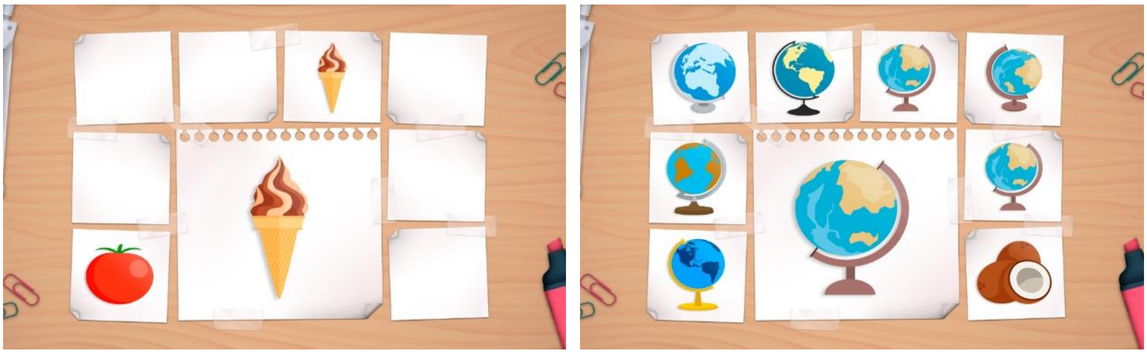


Table 3. Continuation

Name of the activity	Link	Cognitive abilities trained
Match it!	https://www.cognifit.com/match-it	Visual perception Inhibition Processing speed

Description: Matching brain games are designed to stimulate mental agility. *Match it!* is a brain game aimed at training inhibition, visual perception, and processing speed.
The goal is to find all the objects in the centre as quickly as possible. As participants progress through the levels, the task becomes more challenging, as images will disappear. At higher levels, multiple images will appear, and participants will need to recognize the correct one.



Name of the activity	Link	Cognitive abilities trained
Happy Hopper	https://www.cognifit.com/happy-hopper	Inhibition Response time Estimation

Description: *Happy Hopper! i*s a great way to challenge participants' response time, estimation, and inhibition skills. The game aims to reach the cloud of flies by jumping on the stones while avoiding obstacles [89].

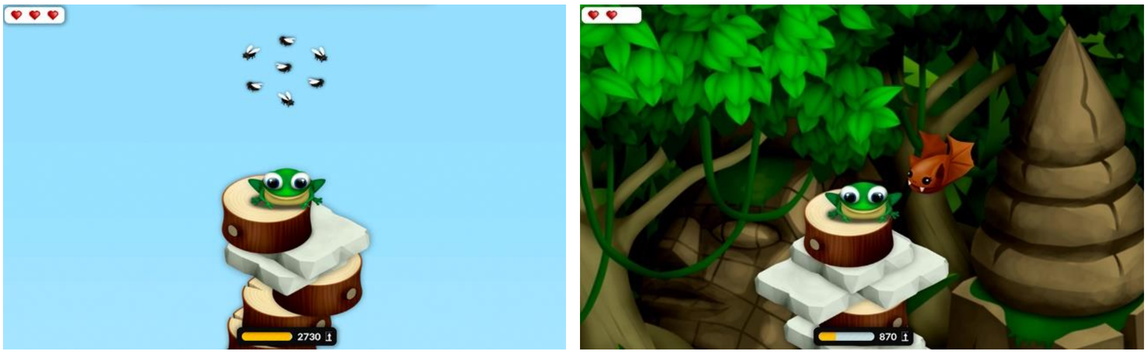
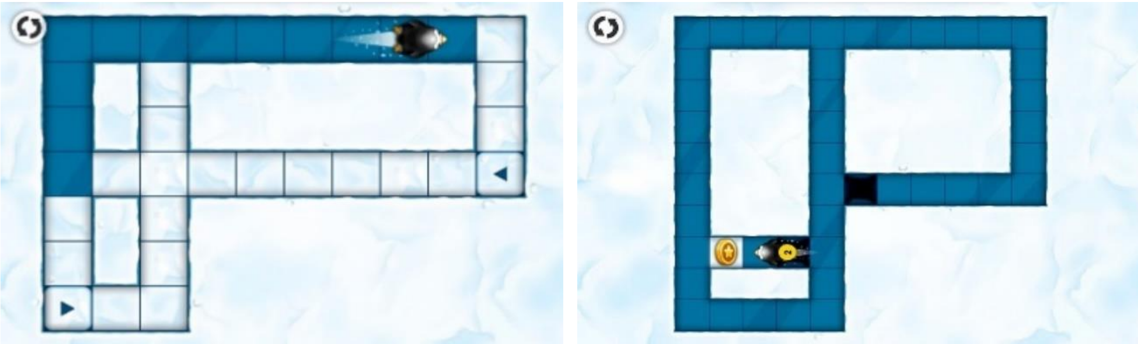


Table 3. Continuation

Name of the activity	Link	Cognitive abilities trained
Penguin Explorer	https://www.cognifit.com/penguin-maze	Spatial perception Planning Inhibition

Description: *Penguin Explorer* is a problem-solving game based on maze-like puzzles. It is an excellent way to challenge skills such as planning, spatial perception, and inhibition.
The main objective is to slide the penguin to clear the snow while avoiding obstacles. As participants progress to higher levels, the complexity of the map will increase and time will become a crucial factor. They must plan their moves quickly to clear the snow from the entire map [90].



Note. All links were available in March 2024.