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ORIGINAL ARTICLE

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Improving executive functions at school. Integrating metacognitive exercise in class and computerized training at home to ensure training intensity and generalization. A feasibility pilot study

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Abstract

Previous research has demonstrated the effectiveness of executive functions (EFs) training, both in computer-based and school-based formats. However, there is limited research on the combined effects of these training modalities. This study aims to assess the feasibility and preliminary efficacy of an EFs training programme for primary school children. The programme includes computerized training sessions for home use and school activities with metacognitive elements. The study included a sample of 53 second-grade children, with 21 children in the training group and 32 children in the control group. Feasibility questionnaires were completed by children, parents and teachers. The children also underwent an EFs evaluation. The results indicate that the training was enjoyable for children and feasible for parents and teachers. Furthermore, preliminary efficacy analysis revealed significant improvements in working memory. These findings suggest that the training model holds promise for enhancing EFs in children in the school context.

KEYWORDS

computerized training, executive functions, metacognitive training, primary school, school-based training

Practitioner notes

What is already known about this topic

- Individual differences in executive functions influence acquisitions, behaviours and competencies in several specific domains from infancy to adulthood.
- Enhancing executive functions during school-age years can contribute to reducing or preventing academic, behavioural and social difficulties.
- Among interventions targeting executive functions in school-aged children, school-based interventions have shown the highest effectiveness, followed by metacognitive interventions and computer-based interventions.

What this paper adds

- This paper presents the implementation of an innovative school-based training programme designed to improve executive functions (EFs). The programme combines metacognitive sessions conducted at school with computer-based sessions carried out at home. The goal was to enhance the effectiveness and generalizability of the training.
- The training programme was found to be enjoyable for children and feasible for both parents and teachers.
- Preliminary efficacy data indicate promising results, suggesting that the training programme is effective in achieving its intended goals.

Implications for practice and/or policy

- Integrating school-based metacognitive training with computerized sessions delivered at home can provide a high-intensity training programme that may not be achievable in the school context alone.
- The school activities, conducted in group settings with teachers and peers, were found to be the most appreciated by the children, indicating that computer sessions alone cannot replace the value of metacognitive sessions at school, within a meaningful social context for the child.
- It is crucial to actively involve families in the training process to ensure good adherence. Additionally, the availability of technological resources in each family should be evaluated before implementing the training programme.

INTRODUCTION

Executive functions (EFs) refer to a set of cognitive processes needed to regulate and control thoughts, actions and emotions to achieve goals (Miyake et al., 2000). These higher-level mental abilities involve skills such as suppressing inappropriate responses (response inhibition) and distractors (interference suppression; Diamond, 2013), being flexible in shifting between ideas and activities based on different situations and tasks (cognitive flexibility) and actively manipulating information in memory (working memory; Miyake et al., 2000). They are involved in complex and goal-directed behaviours, particularly in new situations when automatic or impulsive responses may be inefficient (Miyake & Friedman, 2012).

Due to their domain-general nature, EFs can impact various specific domains from infancy to adulthood (Korzeniowski et al., 2021). During the pre-school years and early primary school, EFs are associated with self-regulation (Sokol & Müller, 2007) and school readiness, serving as predictors of achievement in basic skills in math, literacy and science

(Rivella et al., 2021; Willoughby et al., 2019). Deficits in EFs have been shown to adversely affect school success, further cognitive and social development and strongly predict behavioural problems within the classroom (Morgan et al., 2019). Furthermore, atypical EF development is shown in a wide range of clinical conditions such as attention-deficit/hyperactivity disorder, autism spectrum disorder and learning disabilities (Zelazo, 2020). Taken together, these results highlight the protective role of EFs in development from infancy to adulthood. Consequently, promoting EF development can help prevent the cascade of negative effects of EF dysfunction on learning skills, school adjustment as well as on other areas such as sports (Scharfen & Memmert, 2021), social behaviours (Riggs et al., 2006), substance abuse and dependencies (Gustavson et al., 2017), health, academic achievement and job success (Moffitt et al., 2011).

In recent decades, there has been a growing focus on promoting EFs and, as a result, various kinds of programmes have been developed, suggesting that EFs can be enhanced through different types of interventions (Diamond & Ling, 2016, 2020). Additionally, despite the existence of contrasting results, some studies suggest that EF training can lead to improvements not only in the specifically trained EF components (near transfer effects) but also in the generalization to untrained EF components, overall cognitive abilities, domain-specific academic achievements (ie, Ruffini et al., 2024; Traverso et al., 2015, 2019) or behavioural functioning (Capodieci et al., 2019). In a recent review, Diamond and Ling (2020) highlighted that the most promising results for typically developing children were achieved through metacognitive training. Metacognition refers to the ability to monitor and regulate one's thinking, with positive effects on learning and critical decision-making (Hauser et al., 2017). A vast literature shows that metacognition may improve cognitive and behavioural training and intervention programmes. For instance, Capodieci et al. (2019) demonstrated that integrating metacognitive elements, such as discussing training goals, teaching metacognitive strategies and engaging in deliberate debates, within the working memory (WM) training programme lead to an improvement of WM abilities (near transfer effect) and a reduction of behavioural problems (far transfer effects) in a group of primary school children. This approach proved more effective compared to training programmes that solely focused on WM alone (see also Chen & McDunn, 2022 for a review).

School-based programmes are the most promising options for metacognitive EF training and offer several advantages over other approaches. Firstly, they have a broader reach, making them more accessible and equitable. By integrating the training into different activities throughout the school day, children have the opportunity to continually practice and develop their EF skills in various contexts. This approach supports the possibility of applying these skills to new and real-life situations and offers the advantage of providing more intensive and sustained stimulation compared to other training methods. Diamond and Ling's review (2020) demonstrated that the longer and more distributed the training, the better the results. An additional strength of school-based training is the increased interactions with teachers and peers, which likely contributes to the effectiveness of the training (Diamond & Ling, 2020). Nevertheless, implementing this type of intervention is not always easy for schools, as it requires the commitment of school principals, intensive teacher training and appropriate student–teacher ratios (Domitrovich et al., 2007; Lillard & Else-Quest, 2006). The need for such resources can make these programmes expensive and can reduce their feasibility.

Another increasingly popular training modality is computerized training. These programmes have shown promising results and offer the advantage of being engaging for children and supporting motivation (Diamond & Ling, 2020). However, there are contrasting results regarding generalization, with some studies reporting effects on non-trained tasks and others not (see Melby-Lervåg & Hulme, 2013 for a review). Despite this, computerized training has the advantage of allowing for training at home. For this reason, telerehabilitation, which involves providing home-based training through computerized programs, is widely used in clinical populations to improve various cognitive abilities, including EFs (Capodieci et al., 2022).

Only a few studies investigated the combined effect of metacognitive and computerized school-based training, and no one included home sessions (Keren & Fridin, 2014; Zohar & Peled, 2008). Pozuelos et al. (2019) directly compared the effect of computerized tasks and human scaffolding on children's learning and found that combining computerized and metacognitive elements enhances training efficacy. Given this evidence, it is worthwhile to develop intervention programmes for children that are sustainable in the school setting, and which ensure transfer effects to other domains (such as behavioural functioning or school performances) together with long-term effects.

The present study aims to assess the feasibility and preliminary efficacy of an EF training programme for primary school children that includes both computerized training sessions at home and school activities with metacognitive elements. By combining these two types of training, it is expected to leverage their respective strengths and minimize weaknesses. That is, the home sessions ensure adequate training intensity while reducing the burden on teachers whereas the school sessions ensure that the training goes beyond mere exercise repetition, which is often the case in cognitive training programmes. In school sessions, teachers provide support to help children develop a full understanding of the cognitive processes being trained and acquire metacognitive strategies to enhance their effectiveness by using them in real-life tasks and situations other than those directly trained.

To evaluate the feasibility of this combined training, children, teachers and parents compiled a questionnaire to assess the users' satisfaction with the digital training, its usability and the feasibility of the training model at school and home. In addition, to assess the preliminary efficacy of the training, a battery of EF tasks measuring inhibition and WM was administered to children before and after the training.

METHOD

Participants

The study involved five second-grade classes in two different public primary schools for a total of 76 pupils. Participants were allocated to either the training group (TG) or the control group (CG) based on the school they attended. Classes in one school participated in the training, while classes in the other school served as the control group. The randomization of classes was not accepted by the teachers, who decided to designate the classes of one school as controls and the classes of the other as the experimental group. Teachers in the control classes received brief training on promoting executive functions and managing disruptive behaviours in the classroom, at the conclusion of the project.

The two schools were selected as located in the same city area and similar in terms of family and children demographic characteristics. Both schools belong to the same comprehensive institute, including two pre-primary schools, three primary schools and a junior secondary school, all administered by the same school principal. Thirty-four pupils composed the TG and 42 the CG. Children who did not take part in the pre- or posttest assessment ($N=15$) were not considered for the analysis. The final sample comprised 61 pupils ($M_{age}=7.75$, SD = 0.27, 54.1% females). Twenty-nine were in the TG ($M_{age}=7.78$, SD = 0.23, 55.2% females) and 32 in the CG ($M_{age}=7.72$, SD = 0.31, 53.1 females). All children performed within the normal range at the Coloured Progressive Matrices Test (CPM; Raven et al., 1998) which was used as a control measure of fluid intelligence. Parental consent was obtained beforehand for all the children. The study was approved by the local ethical committee of the University of Genova, Italy.

Procedure

The study was conducted between March and June 2021, when restrictions for the management of the COVID-19 pandemic were still in effect. Specifically, classes were held regularly, but nobody except for personnel was allowed to enter. For this reason, both evaluation and training sessions were held remotely via Skype and Zoom respectively.

The pre- and posttest assessments were conducted by trained psychology students through two individual remote sessions respectively. The sessions had a duration of approximately 30 minutes. The training sessions were conducted by one of the researchers connected via Zoom to the class. One or two teachers were present in the classroom during these sessions and helped ensure that all pupils participated in the proposed activities. The sessions were included in civic education and/or computer science hours. In Italy, where the research took place, civic education in primary school is not a stand-alone subject. Instead, teachers are required to conduct civic education activities within their hours of instruction for Italian, Math, etc., for a total of at least 33 hours per year. These hours are then devoted to various topics related to civil coexistence, including the importance of rules and knowing how to regulate one's behaviour.

After the completion of the training programme, participants in the training group, including children, parents and teachers, were invited to provide feedback by completing questionnaires that aimed to evaluate their training experiences.

Measures

Fluid intelligence

The Coloured Progressive Matrices Test (CPM; Raven et al., 1998) was used as a screening measure in this study. The CPM involves presenting a series of incomplete patterns to the child, who is then required to select the missing piece from a set of multiple-choice options. The patterns gradually increase in difficulty as the test progresses. For each child, the percentile corresponding to the number of correct answers on the CPM was recorded, ranging from 0 to 36.

Training compliance

To assess the feasibility of the training and the training experience, three distinct questionnaires were developed for children, parents and teachers respectively. These questionnaires were adapted from the Intrinsic Motivation Inventory (IMI; Mcauley et al., 1989; Ryan, 1982) as well as previous feasibility studies on game-based training (Corti et al., 2018; Görgen et al., 2020). The questionnaires were designed to provide a comprehensive assessment of the children's experiences, as well as the perspectives of their parents and teachers, regarding the satisfaction, usability and potential improvements of the training programme. All three versions of the questionnaires utilized a 5-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree), allowing participants to indicate their level of agreement with the provided statements.

The *self-report questionnaire*, completed by the children, comprised 11 items related to their enjoyment of the training, perceived competence acquired, level of dedicated effort and perceived usefulness of the training. An average score was calculated for each child based on their responses. In addition, to obtain a more specific evaluation of the training programme, children were asked to indicate their preferred activity among those included in the training, such as city exploration through coding, treasure rooms, metacognitive videos or integrative school activities.

The *parent-report questionnaire* consisted of 15 items addressing satisfaction (4 items), perceived satisfaction of their children (3 items) and usability (8 items). An average score was calculated for each of the three domains based on parents' responses. Moreover, parents were asked three qualitative questions: (i) reasons behind any difficulties in carrying out the three required sessions per week; (ii) whether they encountered any technical issues; and (iii) suggestions for modifying the serious game.

The *teacher-report questionnaire* consisted of 11 items related to satisfaction (4 items), usability (3 items) and perceived satisfaction of the children (3 items). An average score was calculated for each domain based on the teachers' responses Furthermore, teachers were asked to provide suggestions for further improvement of the serious game.

In line with previous studies (Boelens et al., 2022; Corti et al., 2018) in all questionnaires, an average score of 3 on the Likert scale was considered a neutral evaluation of the training, while a score higher than 3 indicated a positive evaluation of the training.

Executive functions

WM and inhibition were assessed through two different measures for each one. To assess WM, children were administered the *backward digit span* (backward span; Bisiacchi et al., 2005) and the *dual working memory task* (Dual Span; Scalisi et al., 2003). In the backward span task, the child is presented with a series of numbers spoken at a rate of 1 per second and is required to repeat them in reverse order. The length of the series increases, starting from 2 up to 7 numbers to recall. The child has three opportunities at each sequence length. If the child provides a correct answer for two sequences, he is presented with a longer list. The test continues until the child fails all three sequences of the same length. The span score is calculated based on the number of series of digits correctly recalled.

The dual span task consists of 12 sentence blocks. Every three blocks, the number of sentences increases, starting from two up to five sentences. After each sentence, the child is required to determine whether it is true or false. Additionally, at the end of each block, the child is asked to recall the last word from each sentence. For each block, the child is assigned 1 point for each correctly recalled word, regardless of the order. The task continues until the child fails in all three blocks of the same length. The sum of the correctly recalled words is calculated and used for further analysis, with scores ranging from 0 to 42.

To assess inhibition, children were administered the *matching familiar figures test* (MF-20; Marzocchi et al., 2010) and the *inhibition task* of the NEPSY-II (Korkman et al., 2007). In the MF-20, the child is presented with a figure and is asked to find the matching one among six choices. The test comprises 20 items. The number of errors made by the child (range 0–100) and the average time for the first response were calculated. In the inhibition task of the NEPSY-II, the child is required to rapidly name shapes or arrows in an opposite manner (eg, saying 'square' when shown a circle or saying 'up' when shown a down arrow). Errors, including self-corrections, and response time were recorded. The combined scaled score ($M=10$, SD = 3) was also calculated based on the normative data.

Elli's World training

Elli's World is a comprehensive school-based intervention programme designed for primary school children to enhance their EF skills and self-regulation behaviours. It includes (1) school activities designed to promote metacognitive reflection about self-regulated behaviour, (2) integrative school activities that provide children with the opportunity to use their self-regulation skills and (3) Elli's World serious game, a digital game-based training to be used as a home activity and aimed at promoting inhibition, interference suppression, working memory and cognitive flexibility. At the time of the study presented in this paper, the cognitive flexibility section of the serious game was not yet developed and this EF was not trained.

By combining these three components, Elli's World aims to create a cohesive and integrated approach to EF training and self-regulation development. The programme encourages children to reflect on their self-regulation skills, apply them in real-life situations at school and further enhance the cognitive processes underlying self-regulation through engaging and interactive home-based serious game training (see Figure 1).

'Elli' stands for 'Cervelli', which means brains in Italian. The main character of the serious game is Little Ello, a young brain that the children can customize. Big Ello, an elder brain, supervises the activities of Little Ello in his/her adventures. The player must help Little Ello explore Elli's World, an urban scenario, to reach a given number of treasure rooms containing tasks to enhance EF skills. Elli's World is divided into neighbourhoods, each representing an EF skill (interference control, response inhibition, working memory and cognitive flexibility). This division allows children to focus on and practice different aspects of EF skills in a structured and engaging manner. The child moves throughout the city through coding activities that play an important role in promoting EF skill development, as they require planning and impulse management (Di Lieto et al., 2020). Each neighbourhood of the city contains two treasure rooms with EF activities focusing on both the verbal-auditory and visuospatial channels. The activities are organized in six levels of increasing difficulty. The game is auto-adaptive, so the difficulty increases as the child improves. This auto-adaptive feature helps maintain an optimal level of challenge for everyone, promoting continuous growth and skill

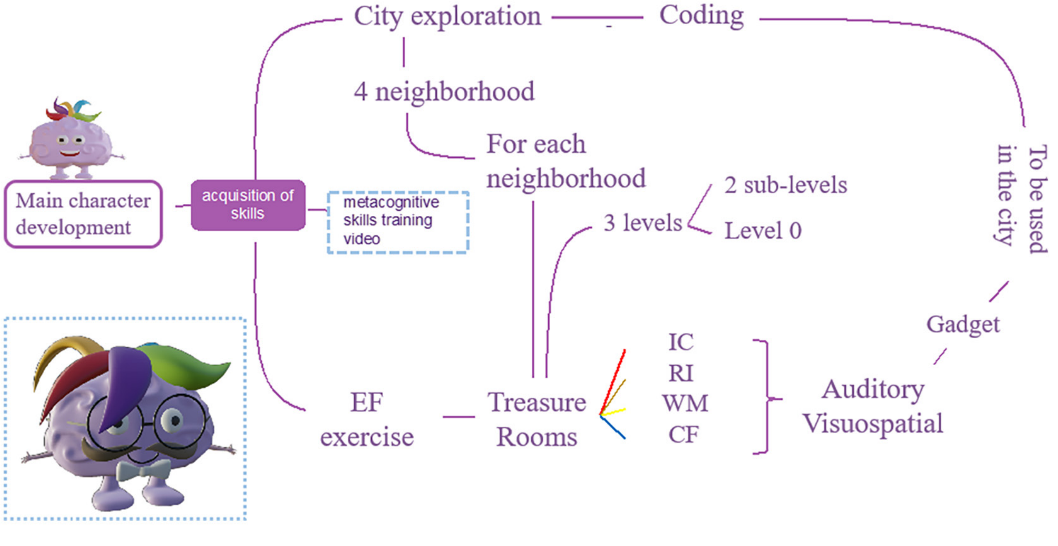

FIGURE 1 Elli's World training model.

development. In addition, a Level 0 is provided for children who may have more significant difficulties or special educational needs. This ensures that the game remains accessible to most children, regardless of their starting point.

Overall, the combination of the urban scenario, treasure rooms and coding activities creates an immersive and interactive experience for children to enhance their EF skills while enjoying the adventures of Little Ello. In addition, by tailoring the experience to meet the needs of a diverse range of learners, Elli's World promotes a supportive and inclusive learning environment.

The timeline of the Elli's World training is presented in Figure 2. It lasted 10 weeks (8 weeks in the present study without the cognitive flexibility section) and comprised 3 home sessions with the serious game and 1 school session for the metacognitive reflection per week. Each EF component (interference suppression, response inhibition, working memory and cognitive flexibility) was trained for 2 weeks, for a total of two school sessions and six home sessions. Every school session lasted 1 hour and focused on metacognitive reflection, allowing children to engage in discussions and activities that promoted self-awareness and strategic thinking about their self-regulated behaviours (Figure 3a). The home sessions involved playing the Elli's World serious game and were designed to be shorter, lasting between 15 and 20 minutes, to fit into children's daily routines and ensure regular practice (Figure 3b for the structure of the session and Figures 4 and 5 for examples of EF activities). In addition, throughout the training period, teachers were encouraged to incorporate integrative school activities into their regular classroom instruction. These activities provided additional opportunities for children to apply their EF skills across different academic subjects and social contexts. By integrating EF training into school hours, the programme aimed to enhance the transfer and generalization of EF skills into real-world situations.

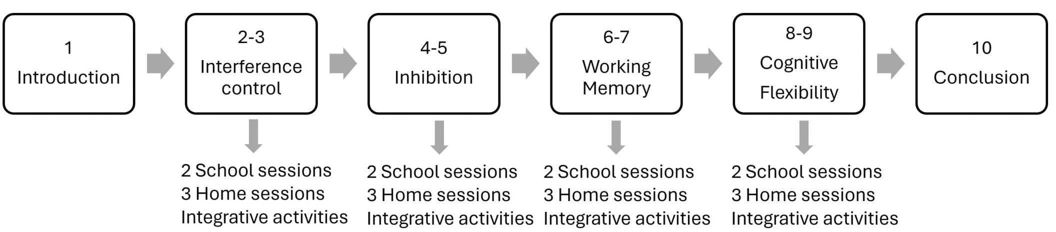

FIGURE 2 Elli's World training timeline.

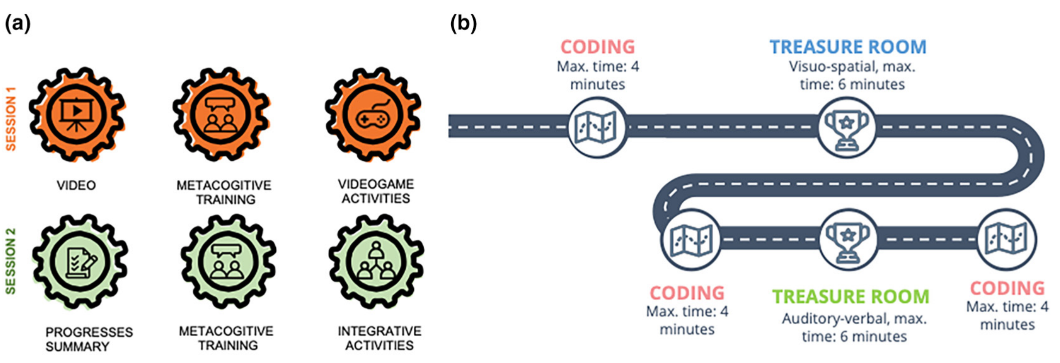

FIGURE 3 (a) School session structure; (b) home session structure.

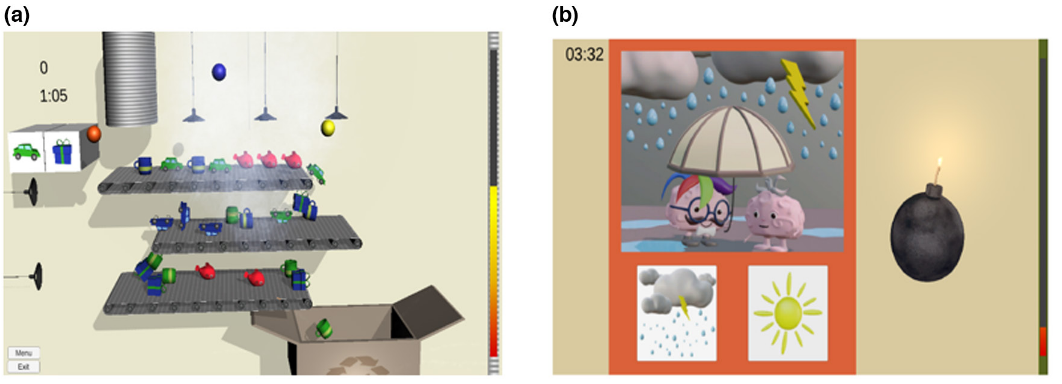

FIGURE 4 Examples of EF activities. (a) Interference control: objects scroll on a ribbon, and the child must click on the same ones as those shown at the top left of the screen. (b) Response inhibition: the child hears a sentence and must press on the image representing the opposite meaning of the sentence before the bomb goes off.

FIGURE 5 Examples of coding activities.

Principles of Elli's World digital training

Gamification

The core of the Elli's World is gamification, that is, the process of incorporating game elements into non-game contexts to engage and motivate individuals (Wang et al., 2019). Key characteristics of game-based training include embedding the training in a compelling storyline, featuring animated characters and providing interactive environments. Additionally, activities gradually increase in difficulty, requiring the player to overcome challenges to progress in the game. Together, these characteristics make standard cognitive training more interesting (Lumsden et al., 2016) and ensure better results compared to non-serious game training (see Cao et al., 2020, for a review).

Auto-adaptiveness

It refers to the training's ability to dynamically adjust the difficulty of activities based on the child's performance. The auto-adaptiveness ensures that the child is consistently challenged at an appropriate level, maximizing the effectiveness of the training (Diamond & Ling, 2016). For this reason, all the serious game activities include six difficulty levels, which automatically adapt to the child's abilities, ensuring that the child is continuously engaged in tasks that are neither too easy nor too difficult.

Inclusion

Each serious game activity includes a Level 0 for children who need appropriate pretraining to tackle Level 1. Moreover, to prevent frustration and maintain a positive learning experience, Elli's World provides flexibility in progression. Reaching the highest level in each activity is an option and teachers can manually unlock the next set of activities, considering the individual needs and abilities of each child. This approach helps tailor the training to each child's specific requirements, ensuring appropriate challenges are presented without overwhelming them.

Feedback

To support motivation, children receive feedback at the end of each serious game session in the form of points. However, the points are not solely based on performance, or the level reached, but rather on the amount of time spent actively engaging in the session to encourage consistent participation and effort. Furthermore, after successfully progressing through all the levels of a neighbourhood, children get an extra reward (such as a pen drive for working memory) as a tangible representation of their accomplishment.

Principles of Elli's World school activities

Metacognitive school sessions

Several studies showed that metacognitive scaffolding during cognitive training supports generalization of the results. Indeed, this approach not only enables children to practice and improve their performance in specific tasks but also facilitates their understanding and self-awareness of cognitive processes and strategies to optimize them in situations different from the training task and in real life. The school sessions were designed to promote metacognitive reflection on the EF functioning and their usefulness at school and in everyday life.

During the metacognitive school sessions, an animated video was shown to the children, depicting various scenes from everyday life that emphasize the involvement of EFs. Each video focused on a specific component. The purpose of these videos was to provide children with an understanding of which EF they would be training in the upcoming section of the training programme and why it was important to train it. For instance, in a video illustrating WM, children were shown examples of students solving mental calculations and a child engaging in grocery shopping. Following the video, the teacher facilitated metacognitive reflection and discussion among children using a set of guided questions provided in the manual. Some examples of the questions used were as follows: ‘In what other situations do you think working memory is useful?’, ‘What are the benefits of using working memory?’, ‘What strategies could we use to make the best use of working memory?’ and ‘How can we help a classmate who is struggling with working memory?’. Through these guided discussions, the children were encouraged to think critically about the practical applications of the EF being discussed, its advantages and strategies to optimize its use.

Integrative school activities

Teachers were provided with games and school activities to promote EF that could be easily integrated into the school routine. Examples of such activities were collected in a teacher manual and included both individual and group activities, for both typical children and children with special needs. In this way, children could train their EF through different modalities (eg, verbal and visuospatial), school contexts and school subjects, supporting generalization.

STATISTICAL ANALYSIS

The feasibility of the training programme was assessed by analysing descriptive statistics of the questionnaires. Reverse items were recoded so that higher scores indicate a positive evaluation. Qualitative suggestions provided by parents and teachers were carefully reviewed and analysed. Common themes, recurring issues and specific areas requiring attention were identified through a systematic examination of the feedback.

As for the training efficacy, eight children were removed from the training group as they performed less than 50% of the home sessions. Differences between the training group (TG) and control group (CG) were examined in terms of age, fluid intelligence and EFs at the pretest stage, through a series of independent samples *t*-tests. Then, to assess the impact of the training programme on EF skills, a series of univariate analyses of variance with EF pretest performance as covariate (ANCOVA) was performed. This analysis allowed for the examination of any significant changes in EF skills between the two groups controlling for differences at pretest.

RESULTS

Elli's World feasibility

The three feasibility questionnaires with item-per-item descriptive statistics and percentage of positive answers (4–5 of the Likert scale) are reported in the Supplemental Materials (Table S1). Results are reported separately for the total sample of children and parents regardless of the number of serious game sessions completed ($N=29$) and for the partial sample of children (and their parents) who had completed nine sessions or more ($N=21$). However, some data are missing because some children and parents did not fill out the questionnaire (See Table S1). By comparing the results of the two groups, it is possible to understand whether the low adherence to the training was due to its low feasibility (eg, training being not enjoyable) or other factors. Results of the partial sample of children show that they rated enjoyment with an average of 3.84 (SD = 0.64). In addition, almost all items have a percentage of positive responses (4–5) above 50% (Table S1). Observing the data of the children who performed a low number of home sessions, they perceived the training as less fun compared to the partial group and they felt they did less well in the training. However, they reported to be improved because of the training more than the partial group.

Parents (partial group) and teachers reported similar scores of perceived enjoyment of their children/pupils, with an average score of 3.84 (SD = 0.86) and 4.11 (SD = 0.38) respectively. The higher score reported by teachers indicates that metacognitive school sessions and integrative school activities may have been more enjoyable than the serious game activities to be carried out at home.

As for feasibility, both parents and teachers rated the training positively ($M=3.79$, SD = 0.65 and $M=3.92$; SD = 0.14 respectively), suggesting that it was possible to integrate the training into everyday life and school settings. Finally, the mean global satisfaction score reported by parents was 3.51 (SD = 0.67), while that reported by teachers was 3.73 (SD = 0.11). As for the parents of children who completed less than nine sessions, they reported lower satisfaction ($M=2.83$; SD = 1.04) and lower enjoyment perceived ($M=3.5$; SD = 0.69), but globally similar feasibility ($M=3.71$; SD = 0.68) compared to the parents of the partial sample.

In order to understand whether adjustments were needed in the adaptiveness system of the game, we also looked at the difficulty level reached in each EF neighbourhood by the 21 children who completed more than half of the home sessions. The percentage of children who reached Level 3 is 60, 66 and 25 for the interference control, response inhibition and

WM task respectively. Fifteen, 22 and 12 are the percentages of children who reached Level 2, respectively, in the different domains. To note, due to the variability of sessions completed, 21 children were trained in the interference control neighbourhood, 18 trained in the response inhibition and 8 in the WM.

Qualitative information

The children reported that they appreciated the serious game and its characters, with a satisfaction rate of 100% for Ello and 89% for Big Ello. They also expressed that the coding activities in the serious game and the school sessions were the most enjoyable, while the EF activities in the treasure rooms received less positive feedback.

Parents were asked to provide information about the frequency of the home sessions and any technical difficulties they encountered. The entire sample was considered, as it was presumed that even parents whose children participated in fewer sessions could mention challenges that should be taken into account. Of the 23 parents considered, 82.6% (19 parents) reported that their children did not complete the home sessions with the required frequency. The primary reason cited was the challenge of finding three time slots during the week to dedicate to the activity, which accounted for 56.52% of the responses. Forgetfulness was the second most common reason, reported by 30.43% of parents. Furthermore, many parents emphasized that the ongoing COVID-19 pandemic exacerbated these difficulties since their children were already receiving remote lessons via computer. In only two cases (8.7%), the difficulties were attributed to the child's lack of motivation or interest in completing the sessions. Additionally, 43% of parents reported experiencing difficulties accessing the video game at least once during the training. However, these technical problems did not hinder the success of the programme as they were resolved within a couple of hours, either by parents themselves or with the assistance of the experimenters. Regarding the bugs and technical malfunctions of the serious game, issues such as slow downs, freezes and inaccuracies in recognizing the child's responses (eg, when the child clicks on an item and the system does not register it) were reported. This feedback was actively used during and after the experimentation phase to address the encountered issues. Furthermore, parents made suggestions for improvements, including modifying the required frequency of sessions (39% of parents), enhancing the sound quality (30%) and improving the graphics (30%).

Regarding the teachers, we requested their suggestions to enhance the training. Among the various options proposed, all of them recommended adding new EF activities in the serious game, while two of them suggested modifying the frequency of the home sessions. A concluding meeting was held, where parents and teachers shared their impressions. Despite facing technical issues and encountering some difficulties, both parents and teachers provided positive feedback. They reported that Elli's World had a notable impact on the children, as they began discussing EFs with their peers and recognizing tasks and situations where these skills were beneficial in real life. Parents and teachers noted that this positive outcome resulted in improved self-regulation abilities for the children.

Training outcomes

The comparison between the TG and the CG showed no significant differences in fluid intelligence, age and sex between the two groups at pretest (Table 1). The *t*-test showed significant differences in the number of errors in both the inhibition tasks (MFFT $p=0.013$; inhibition $p=0.009$; inhibition composite score $p=0.016$), with the CG showing the lower performance.

TABLE 1 Descriptive characteristics and differences between groups.

	Total sample *M*(ds)	TG *M*(ds)	CG *M*(ds)	*T*	*p*
Fluid intelligence	71.77 (21.70)	76.43 (23.89)	68.72 (19.92)	1.225	0.228
Age	7.75 (0.28)	7.80 (0.24)	7.72 (0.31)	1.109	0.273
	Frequency (%) male/female			X^2	*p*
Sex	21 (39.6)	6 (28.6)	15 (46.9)	1.776	0.183
	32 (60.4)	15 (71.4)	17 (53.1)		

As for EF performances at posttest, results (Table 2) showed a significant difference between the two groups in both the WM tasks [backward span task: ($F(1, 51) = 20.404$, $p < 0.001$); dual span task ($F(1, 51) = 5.203$, $p = 0.027$)], indicating the efficacy of the training on WM (Figure 6). No significant training effect emerged for any of the inhibition indices except for the inhibition time score ($F(1, 51) = 4.859$, $p = 0.032$), where the CG improved significantly more than the TG.

DISCUSSION

The present study illustrates the development of a new EF training model integrating elements of metacognitive training, school-based training and computer-based training. The literature shows that metacognitive EF training shows the greatest results in typically developing children (see Diamond & Ling, 2020, for a review), ensuring persistent and intensive training in the context of the child's daily life and promoting generalization of the results to skills not directly trained. However, implementing such training programmes necessitates appropriate teacher training, preparation of the learning environment and adaptation of the curriculum. On the other hand, computerized training has gained significant popularity due to its low requirement for personnel resources and its ability to generate high levels of motivation among learners. Additionally, one notable advantage of computer-based training is that it allows children to engage in training activities at home. However, it is important to acknowledge that digital learning taking place at home can further exacerbate existing inequities if students do not have access to necessary devices, reliable internet connections and appropriate support from their caregivers. These factors should be carefully considered to ensure that all learners have equal opportunities to participate in and benefit from computerized training programs. Computerized training is widely utilized in the clinical setting for telerehabilitation purposes (Camden et al., 2020). However, to the best of our knowledge, there have been no studies conducted to date that specifically examine the feasibility and effectiveness of integrating home training sessions into school-based training programmes.

The primary objective of this study was to assess the feasibility of Elli's World training. This training programme stands out from others due to its unique combination of school-based training and computer game-based training conducted at home. Furthermore, significant efforts have been made to ensure that the training is inclusive and suitable for children with special needs or pronounced EF difficulties. By incorporating both school and home sessions into the training programme, a substantial number of children can be reached while maintaining an optimal training intensity. The inclusion of integrative activities at school allows children to train EF skills across multiple tasks and in various situations, thereby facilitating the generalization of training outcomes.

The usability of a training programme is essential for maximizing its impact. Even if a training programme is effective, its effectiveness may be diminished if it is not user-friendly or practical. In our study, investigating feasibility was particularly important due to the

TABLE 2 Pre- and posttest comparison between groups.

	TG		CG		Pretest		Posttest		
	Pretest *M*(ds)	Posttest *M*(ds)	Pretest *M*(ds)	Posttest *M*(ds)	*T*	*p*	*F*	*p*	η^2
Working memory									
Backward span	9.00 (2.24)	10.86 (2.63)	8.78 (2.07)	8.00 (2.17)	0.364	0.717	20.40	<0.001	0.290
Dual span	25.76 (3.32)	28.05 (3.92)	24.76 (5.56)	25.06 (5.62)	0.676	0.502	5.203	0.027	0.094
Inhibition									
MF20-time	25.01 (20.96)	23.56 (17.98)	16.70 (6.88)	14.74 (6.52)	1.720	0.099	2.086	0.155	
MF20-errors	7.90 (4.95)	7.86 (6.53)	12.79 (7.19)	10.78 (5.94)	−2.583	0.013	0.043	0.838	
Inhibition time	95.15 (19.24)	85.84 (25.18)	106.88 (26.45)	84.27 (14.51)	−1.704	0.094	4.859	0.032	0.089
Inhibition errors	4.95 (3.11)	2.19 (1.54)	7.85 (4.21)	3.81 (2.48)	−2.732	0.009	3.348	0.0733	
Inhibition combined	8.81 (2.75)	11.62 (2.46)	7.16 (2.1)	10.09 (2.18)	2.480	0.016	1.311	0.258	

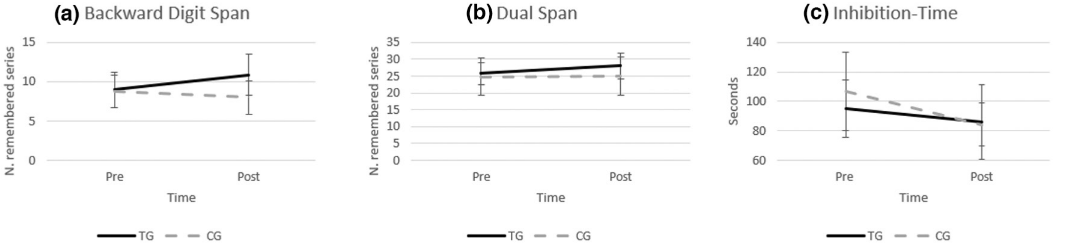

FIGURE 6 Improvement after training in the backward span (a) and dual span (b) tasks for the TG and in (c) the inhibition time index for the CG.

complexity of the model, which involved both school and home sessions. Unlike existing school-based curricula programmes like Tools of the Mind, which primarily involve teachers and children at school, ‘Elli's World’ was specifically designed to actively involve parents and reduce teachers' workload. Therefore, it was crucial to assess the level of assistance children needed during the home sessions and the level of parental commitment required. According to parental reports, children were able to carry out the sessions independently without adult support. The game provided age-appropriate instructions, and the activities were appropriately challenging. This feedback indicates that the training programme's instructions and activities were suitable for children to engage in autonomously during home sessions, demonstrating a positive aspect of the programme's usability.

Secondly, our aim was to assess the feasibility of the prescribed session frequency. The evidence of the eight children who participated in less than half of the home sessions, along with the ratings provided by parents in the questionnaires, indicated some challenges in adhering to the training schedule. It is important to note that the children themselves showed engagement and willingness to participate, but difficulties primarily arose from parental time constraints or forgetfulness. In terms of technical problems or difficulties with the usage of the serious game, no significant concerns were reported. Any technical issues that were encountered were attributed to the utilization of a beta version of the serious game, indicating that the final version is expected to offer a smoother user experience. These findings contribute to our understanding of the feasibility of the training programme, highlighting the need for flexibility in session frequency to accommodate parental constraints and emphasizing the importance of a stable and user-friendly technical platform for optimal training implementation.

Regarding the home sessions, another important consideration should be done, particularly as regards socioeconomically disadvantaged contexts. While home sessions allow for more frequent training, thereby increasing the likelihood of training effectiveness, they can present challenges as they require access to a personal computer and internet connection, resources that not all families have access to. In our sample, two children were unable to participate in the home sessions due to this reason, and overall, the technical difficulties related to PC usage were not related to the computer skills of children and families. However, it is important to recognize that inequities in access and use of technology exist, and this can impact the feasibility and effectiveness of home-based training programmes like Elli's World. To address this concern, Elli's World was designed to be flexible and adaptable to different situations. For instance, an alternative option could be to conduct these sessions at school. This would ensure that all children have equal access to the training, regardless of their home circumstances. If this is not an option, Elli's World provides a range of integrative tasks, games and activities that do not necessarily rely on digital devices. By offering a variety of options, the programme can accommodate different contexts and provide training opportunities that are suitable for diverse settings and available resources.

Overall, parents expressed satisfaction with their participation in the study, regardless of the number of sessions their child conducted. Almost 70% of parents reported being satisfied in the total sample, which increased to 76% for those who completed the home sessions. Due to the limited number of teachers involved in the study (only three), the results pertaining to teachers are limited as well. Additionally, as this was a pilot study, teachers received significant support from the research staff during all the school sessions. Despite the limitations mentioned, it is noteworthy that teachers, like the parents, expressed satisfaction and indicated that the programme demonstrated good feasibility within the school setting.

Another important aspect was the enjoyment of the children, as it directly influenced their adherence and potential effectiveness. Based on the results of the self-report questionnaire, more than 50% of the sample rated almost all items positively, indicating that the children had fun during the training and would recommend it to their friends. Additionally, the children reported feeling engaged in the training and perceived improvement after completing it, suggesting that the programme not only provided an enjoyable experience but also had a positive impact on their perception of their own progress.

It is not entirely unexpected that both the children and teachers expressed hesitation about repeating the training. This could be attributed to the repetition of the same serious game activities until a certain level of accuracy is achieved. While repetition can be beneficial for cognitive skill training, it may negatively impact enjoyment and motivation. This finding aligns with the higher appreciation of school activities since they offer higher variety. A final consideration regards auto-adaptability. Results suggest that the programme's adaptivity system worked effectively, maintaining an appropriate challenge skill, as children, parents and teachers agree in describing the serious game activities as appropriate in terms of difficulty.

As for the second aim of the study, the preliminary efficacy results are promising, showing an improvement in working memory at the end of the training. The lack of efficacy on inhibition is not completely unexpected, as previous studies highlight the relative malleability of WM compared to inhibitory abilities (Sala & Gobet, 2020; Takacs & Kassai, 2019; Traverso et al., 2019). In addition, the fact that efficacy emerges for the WM component, which was the one on which children trained the least at home, demonstrates the usefulness of having a multicomponential training programme, which includes sessions at home, at school and supplementary activities. In addition, it is in line with the idea that FEs are not entirely independent and separable from each other, but that all subcomponents, especially WM, is required in all types of complex tasks (Miyake et al., 2000). Indeed, WM is crucial for keeping instructions in mind and completing tasks, regardless of the specific domain the task requires (Bergman-Nutley & Klingberg, 2014).

LIMITATIONS AND FUTURE DIRECTIONS

There are several limitations that should be acknowledged. Firstly, this pilot study had a small sample size, emphasizing the importance of conducting larger studies to validate and expand upon these initial findings. The limited sample size prevented us from conducting separate analyses on the children who completed a low number of home sessions. Future research should also consider analysing the individual contributions of the metacognitive school sessions and the serious game home activities. Additionally, our study did not include a specific measure of interference control, which was one of the trained components. Future studies should incorporate a measure specifically designed for assessing this EF component. Furthermore, there is a need to investigate far transfer effects on other cognitive abilities, behavioural functioning or school performance, as the literature suggests that, in some instances, enhancement in EF due to training can generalize to other abilities. Given that the training was specifically designed for use in a school setting, exploring its impact on school adaptation and performance could provide insights into its potential to promote learning skills, self-regulation and mitigate disparities between children with high and low EF.

Other limitations are related to the experimental procedure. First, the absence of randomization of the class in the control and training groups was due to the decision of the school to allocate the classes of one school to a group and the classes of the other school to the other group. Another important limitation concerns the absence of an active control group and the fact that teachers and parents were not blind to the experimental conditions. However, they were primarily asked to provide feasibility feedback, while the efficacy of the training was assessed by direct performance on EF tasks. Also, the researchers leading the online pre-/posttesting session were not blind to the experimental condition children were in. In future research, greater efforts should be made in this direction.

In addition, it is worth noting that not all families were able to provide adequate support for their children to complete the training. According to the questionnaires, parents had difficulties in reminding their children to engage in the home session or finding a suitable time during the day to conduct it. This raises concerns about the potential amplification of the socio-cultural gap, as is reasonable to think that families from disadvantaged backgrounds may have more difficulties in ensuring adherence to the training, and their children may have less opportunity to engage in the training at home compared to their peers from more affluent backgrounds. This disparity in access and support could have implications for the effectiveness and equity of the intervention. In these cases, teachers should support the use of serious games at school in order to guarantee the same amount of training for all the pupils. Although the computerized sessions are proposed primarily as home sessions, it is also possible to provide these sessions at school. That is, in schools with a high prevalence of children from disadvantaged families, the training can be easily adapted to reduce the risk of low training compliance.

As concerns parental involvement, it is worth considering the impact of potential low parental involvement at the beginning of the training. Telerehabilitation studies have shown high training adherence, particularly in the context of children with neurodevelopmental disorders (Capodieci et al., 2022; Pecini et al., 2019). In these cases, parents are often aware of the training's benefits in addressing their children's difficulties and acknowledge the importance of consistent participation. However, when it comes to training designed for the typical population, parents may not always fully comprehend the potential advantages of the training and the positive effects it can have on children, regardless of whether they have existing difficulties (Rothschild et al., 2022). This discrepancy in parental awareness and understanding may have contributed to the varying levels of parental involvement observed in our study. Indeed, parents reported that they would have liked to receive more information about the training and gain a better understanding of its purpose and usefulness. Given these considerations, a more detailed manual and training videos will be provided in the future to parents, as those already planned for teachers. This will ensure a higher knowledge about the training and possibly more adherence to the training home sessions.

The results and identified limitations of the Elli's World training serious game provide insights and guidance for its further development. Based on the feedback received, several improvements will be implemented. Firstly, the technical issues reported by parents will be addressed to ensure a smoother user experience. Secondly, explanatory videos will be created to provide parents with a better understanding of the training and enhance their involvement, aiming to increase adherence and the number of home sessions conducted. Efforts will also be made to enhance the game's engagement and children's enjoyment. This includes improving the graphics and audio features of the game, which is expected to enhance the appeal of the activities. Additionally, a new neighbourhood focusing on cognitive flexibility will be added to the game, providing a comprehensive training experience.

The coding activities will also be enhanced by incorporating constraints such as obstacles to increase the complexity as the training progresses. Finally, the teachers' manual will be improved with additional examples of supplementary activities that can be integrated into the classroom setting, further supporting the training programme. A dedicated section of the manual will be included to assess the suitability of children's family context for conducting home-based training and strategies will be provided to teachers to overcome this challenge, such as incorporating classroom sessions. Detailed examples will be provided to guide teachers in implementing these strategies effectively. Additionally, a monitoring platform will be developed to enable teachers to track their student's progress and identify any difficulties they may encounter. This platform will facilitate timely interventions and support from teachers to ensure better outcomes for each student.

CONCLUSION

To summarize, the results show that combining metacognitive school-based training with computerized home session is feasible, as children, parents and teachers reported positive evaluations of Elli's World training. Helpful insights are also provided concerning the importance of the parent's involvement to ensure training adherence. Finally, also the preliminary efficacy data are promising, indicating that the training was effective in improving WM.

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CONFLICT OF INTEREST STATEMENT

Research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the author C.R.

ETHICS STATEMENT

The study was carried out according to the recommendations of the Ethical Code of the Italian National Council of Psychologists and the Ethical Guidelines of the Italian Association of Psychology. In addition, Ethics approval was obtained by the local ethical committee of the University of Genoa.

PATIENT CONSENT STATEMENT

Parental consent was obtained for all the participants.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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