TRAINING AND ENHANCING EXECUTIVE FUNCTION

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TRAINING AND ENHANCING EXECUTIVE FUNCTION

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EDITORIAL
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Editorial: Training and Enhancing Executive Function

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Editorial on the Research Topic

Training and Enhancing Executive Function

Executive Function (EF) refers to a complex set of cognitive control processes necessary for adaptive functioning in daily life. EFs are predictive of intellectual achievement, health, wealth, and quality of life across the entire life span (Moffitt et al., 2011), often more so than IQ or socioeconomic status (Bertollo and Yerys, 2019). Evidence suggests that EFs can be distinguished into three core capacities (working memory, inhibition, and shifting), which combine to support the higher-order cognitive processing (e.g., planning, problem solving) required to remain goal-directed, resist contrary impulses and distraction, and pursue more-positive (rather than most-immediate) outcomes. Given this foundational importance, there has been increasing interest in improving EFs. The goals of this line of research have been 2-fold: to improve EFs; and, as a consequence, stimulate generalized improvements to other cognitive and life domains.

Yet approaches to stimulate EF change are highly discrepant, have yielded inconsistent effects and limited transfer to untrained abilities and outcomes, and there is little agreement about the underlying mechanisms of change that are needed to stimulate development in EFs (and EF-related trajectories and outcomes). This special issue thus aimed to provide a snapshot of current evidence, approaches and perspectives on EF intervention, to highlight emerging insights, to stimulate a reconciliation, and to identify a unified way forward. Typifying contemporary investigations in this field, we characterize submissions to this special issue as falling into one of five approaches for fostering EFs: play-based and curricular approaches; technology-leveraged approaches; physical approaches; strategy-based approaches; and investigations of plausible causal mechanisms. In our conclusion, we offer some of our take-aways and suggestions for a possible way forward in this area.

PLAY-BASED AND CURRICULAR APPROACHES

The largest category of submissions to this special issue pertained to play-based and/or curricular approaches to fostering EFs with pre-school and primary school children. In this approach, everyday playful situations and activities were used to inject EF challenge into real-world situations, with the aim of promoting EFs and related abilities (e.g., school readiness, learning). For instance, the PRSIST Program (Howard et al.), Red Light Purple Light Circle Time Games (McClelland et al.), and Chicco and Nana (in the Italian version; Traverso et al.) supported pre-school educators to engage young children in EF-injected activities and games. Each program generated small improvement in EFs, with the latter two also generating gains in academic learning when curricular content was added. Similar EF gains were found amongst primary school students 8 months after completion of a school-based program of EF games and activities (Rosas et al.).

Other studies within this category integrated EF challenge into school curricula and activities. For instance, the PENcE program (de Oliveira Cardoso et al.) yielded EF benefits after teacher-led

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instruction of EF strategies, which were practiced during in-school activities and then extended to real-world situations. Teacher-rated EFs also improved after an arts- and culture-focused program that injected EF challenge into music, drama, dance, literature, art, and/or photography lessons (Andersen et al.), and objectively measured EFs similarly improved after a pre-school music program (Shen et al.).

While we consider these as play-based and curricular approaches, of course alternative classifications are possible and there is substantial overlap between these and subsequent studies. In fact, many of these programs also included technology, motor activities, and/or strategy-based instruction that are central to approaches otherwise classified. This highlights the likelihood of a set of general principles of effective EF intervention, which may need to be adjusted to align with the "what, where, who, why, and how" of EF intervention.

TECHNOLOGY-LEVERAGED APPROACHES

Several studies used a technology-leveraged approach to improve EFs across different populations, including typically developing, special needs, and preterm children from pre-school- to school-age. Although we characterized five studies as technology-leveraged intervention, we can distinguish two distinct approaches to technology use amongst them. In one case, the technological tools were used to deliver the intervention. This is the case of the intervention presented in van Houdt et al.'s study, where the BrainGame Brian Training sought to improve EF abilities in a randomized controlled trial involving school-aged children born very preterm. Another example is Rossignoli-Palomeque et al.'s study, in which the Nexxo-training app was supplemented by metacognitive strategies given by an instructor to improve inhibition and vigilance abilities. Technology was also employed as a vehicle for the delivery of Exergames, where body movements were necessary to play a computer game through connected devices (Mossmann et al.). Consistent amongst these approaches was their engagement and challenge of EFs through effortful tasks (Diamond and Ling, 2016), although EF improvements were inconsistent and there were limited generalized improvements in untrained and real-world outcomes.

The other approach, which in the current set of studies seemed to be more promising in terms of EF gains, was when a technology-based intervention exploited use of computational processes to perform activities in the real world, such as with the educational robotics approach (Di Lieto, Castro et al.; Di Lieto, Pecini et al.). That is, educational robotics uses programming principles that are used to manipulate concrete objects (i.e., robots) to speculate and test effects of this manipulation. In doing so, these approaches seek to promote not only academic skills, but also domain-general skills such as planning, problem-solving and metacognitive abilities. In our compilation, this approach yielded effects in both school- and pre-school-aged children, and with special needs groups. A similar approach, based on computational thinking and code processing activities (Arfé et al.), yielded significantly improved planning and inhibition skills.

Taken together, these results suggest that technology can provide a virtual environment to stimulate EF challenge, but that this can be more or less effective in promoting EF and in generalizing benefit to real-world behavior. More positive results seemed to drive from interventions in which technology compelled children to engage EFs in activities played outside of a virtual environment.

PHYSICAL APPROACHES

Another approach sought to leverage the physical body to promote EF. Several possible mechanisms for such an effect have been suggested. Singh and Mutreja's study explored the mechanisms through which specific body activities might influence EF, specifically investigating the association of postural and breath control with EF, through Yoga training. The authors suggest that attention to postural and breath control during yoga asanas and pranayama, respectively, may play a key role in enhancing EF. Inhibition was shown to benefit from yoga training, in particular, compared to working memory or shifting.

STRATEGY-BASED APPROACHES

In contrast to previous studies that target expansion of EF capacities, Chan et al. adopted a strategy-promotion approach to improve effective and efficient use of EFs. This approach provides participants with explicit instruction and practice to improve strategies useful in situations where it is necessary to exercise EF control. In this study, children became able to generalize and apply different strategies to novel problem-solving tasks, on which they did not receive any explicit instruction.

CAUSAL MECHANISMS INVESTIGATION

Another promising approach to investigate the causal mechanisms for promoting EFs is represented by Perry et al.'s contribution, in which a rat model was employed to investigate the extent to which social experiences and the acquisition of social skills contribute to the development of EFs. Although it is unclear to what extent these findings can be extended to human situations, it represents an experimental confirmation with rats of negative impacts of early adverse conditions and the role of social relations as a moderator of EF development.

CONCLUSIONS

An average effect of EF training with preschoolers was provided by Scionti et al.; they found small EF improvement, probably due to young age of the participants and weak specialization of their EFs. Moreover, they found that these programs were significantly more effective for developmentally at-risk children (e.g., ADHD, low SES) than for typically developing children.

In conclusion, we propose that future studies on EF training should integrate, comparatively evaluate, and reconcile across different approaches (play and curriculum based, leveraging new technologies) to discern principles for effective EF intervention. These approaches should stimulate both cognitive and emotional-motivational aspects of EF to increase likelihood of far transfer to real-world outcomes of interest (e.g., academic and life success). Finally, EF studies should pay particular attention to what works for whom, and under what conditions.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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Far-Transfer Effects of Strategy-Based Working Memory Training

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We assessed the transfer effects of training working memory strategies to a novel problem-solving task. Previous WM training studies have produced little evidence for transfer across contexts. In the current study, 64 6- to 9-year-olds were randomly assigned to one of four training conditions: semantic and rehearsal training, semantic training only, rehearsal training only, and treated control group. All training groups performed significantly better on the transfer task than the control group, but training groups did not differ significantly from each other. Implications of the findings for cognitive interventions and future WM training studies are discussed.

Keywords: working memory, strategy training, problem solving, executive function, far transfer

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INTRODUCTION

Working memory (WM) is a limited-capacity system responsible for temporary storage and simultaneous processing and manipulation of information (Baddeley, 2003; Müller and Kerns, 2015). WM has been linked to general intelligence and reasoning skills (Süß et al., 2002; Kane et al., 2004; Au et al., 2015), and shown to be predictive of academic outcomes such as school readiness and achievement (Bull and Lee, 2014; Müller and Kerns, 2015). Deficits in WM have also been implicated in neurodevelopmental disorders (Melby-Lervåg et al., 2012). Given the important role of WM capacity in cognitive processes and scholastic skills, considerable attention has been given to WM training with the goal of improving WM capacity (Karr et al., 2014; Melby-Lervåg et al., 2016; Weicker et al., 2016). A central issue in assessing the effectiveness of WM training concerns the transfer of training effects. If WM training produces improvements only in a narrow set of tasks that are highly similar to the trained task (near transfer), then it is hardly worthwhile investing resources in this type of training. Rather, to be considered effective, training effects should generalize to untrained tasks that are dissimilar from the trained task (far transfer; Barnett and Ceci, 2002). Furthermore, to be considered effective, training effects should also transfer temporally, that is, be maintained over time.

Independent reviews of training studies have arrived at different conclusions with regard to the effectiveness of WM training (see Klingberg, 2010; Shipstead et al., 2010; Morrison and Chein, 2011; Melby-Lervåg and Hulme, 2013; Karbach and Verhaeghen, 2014; Karr et al., 2014; Au et al., 2015; Melby-Lervåg et al., 2016; Weicker et al., 2016). Current research provides evidence for reliable short-term gains that generalize to somewhat similar WM tasks (intermediate transfer), yet there is no evidence that "working memory training convincingly produces effects that generalize to important real-world cognitive skills . . . even when assessments take place immediately after training" (Melby-Lervåg et al., 2016, p. 523; see also Shipstead et al., 2010; Melby-Lervåg and Hulme, 2013).

One reason for the inconsistent findings is the failure to pay attention to the distinction between untreated and treated (or active) control groups (Melby-Lervåg et al., 2016). In treated control groups, participants engage in activities that aim to provide equivalent exposure to non-experimental variables that may otherwise act as confounds, such as time spent interacting with the experimenter, or equivalent time looking at comparable stimuli. However, such filler activities lack the essential features characteristic of the training. In non-treated control groups, variables other than the intended training may be causing differences between groups. To illustrate the importance of treated control groups, consider a handful of studies measuring far-transfer training effects of non-verbal ability (e.g., Nutley et al., 2009; Jaeggi et al., 2011). In these studies, significant training effects were not detected when treated as opposed to untreated control groups were used. Furthermore, far transfer rarely has been documented in studies using treated control groups in combination with randomized designs (Wass et al., 2012; Melby-Lervåg et al., 2016). Thus, training studies should strive to include treated control groups to increase internal validity of the research design (Melby-Lervåg et al., 2016).

A further reason for inconsistent findings is that training methods may vary in their intended scope and specificity of training. WM training methods can generally be categorized as either *core-based* if they target domain-general abilities, or *strategy-based* if they target specific cognitive strategies that change how information is organized and encoded (Morrison and Chein, 2011). Core training methods are attractive because they are designed to target domain-general WM mechanisms. Such training would not be associated with a particular type of information or sensory modality, but would aid in the overall encoding, maintenance, and retrieval of information. Core-based training paradigms are necessarily complex because the training task must satisfy a long roster of criteria (see Morrison and Chein, 2011, for discussion), but such complexity often presents a challenge for task design and the interpretation of results when trying to identify specific mechanisms of change.

Another more problematic assumption made by advocates of core-based training is that because the training task is complex and involves core processes, observed improvements on the trained task equates to improvements in overall domain-general abilities. However, such effects can be interpreted as context-bound practice effects, and there is insufficient evidence that learning would transfer to new tasks that differ in presentation format.

In order to differentiate true training effects in core-processing ability from practice effects, one must be able to demonstrate transfer to a novel post-training task. The use of a novel post-training task, in turn, creates the problem that training and post-training tasks may not be tapping into the same underlying constructs. To circumvent this problem, researchers in cognitive training may adopt an alternative bottom-up approach by directly training specific strategies that are reflective of more efficient domain-general abilities, and which then can be applied to a variety of contexts. Strategies are effortful, goal-directed processes that enhance performance by facilitating information encoding, maintenance, and retrieval (St Clair et al., 2010; Morrison and Chein, 2011). In strategy-based training studies, participants are explicitly taught to use the strategy of interest and then encouraged to use and refine their mastery of specific skills in practice. In some situations, the specificity of strategy training is a grave limitation in itself, but in differentiating between strategies that promote a way of doing (e.g., remembering numbers in groups of threes to facilitate memorization), and those strategies that promote a way of thinking (e.g., chunking information at large makes memorization easier), strategies may serve as effective tools in new situations. Working memory strategies, in particular, can be used in different situations with analogous WM demands. For example, although rehearsal can be applied to remember discrete items in a list, it can also be used in combination with a mnemonic or acronym to remember more complex information such as a sequence of instructions or steps to a problem. Because of the omnipresence of WM demands in everyday situations, the training of WM strategies may benefit performance in multiple situations.

There are several additional advantages of strategy-based training over core-based training. First, core-based training programs tend to include a compilation of several tasks with the expectation that one training task, or some combination of training tasks, will produce an effect (e.g., Holmes et al., 2009). This results in a time-consuming and intensive endeavor that is not cost effective in time or resources (e.g., in the above study, training required 35 min per day for 20 days spread out between 5 and 7 weeks). Moreover, researchers are left to speculation at worst and theorizing at best, in pinpointing the specific components of the training program that are responsible for the training effects. By training specific strategies, it is easier to isolate and test the mechanisms or processes that account for improved performance.

Second, research shows that children with higher WM capacity differ from their peers in their patterns of strategy use. Although children with higher WM capacity may be benefiting from a combination of factors, individual differences have been shown to exist in children's selection and implementation of strategies, and these individual differences in strategy use account for significant variance in performance on WM tasks (Engle et al., 1992; McNamara and Scott, 2001; Turley-Ames and Whitfield, 2003; Friedman and Miyake, 2004; Dunlosky and Kane, 2007; Kaakinen and Hyönä, 2007). The efficacy of strategy-based training may therefore lie in closing the gap between individuals with higher and lower WM capacity by bringing the strategy use of individuals with lower WM capacity on par with those with higher WM capacity.

Related to this idea are the two opposing hypotheses about the cause-and-effect relation of strategy use and WM capacity (Bailey et al., 2008). The strategy-as-effect hypothesis suggests that having higher WM capacity allows one to be more strategic in how information is processed and encoded, which in turn contributes to better performance on WM tasks. Alternatively, the strategy-as-cause hypothesis claims that strategy use is the direct cause of individuals demonstrating higher WM capacity. For example, a rehearsal strategy allows a person to retain more information, resulting in a higher span score. In support of the strategy-as-cause hypothesis, Dunning and Holmes (2014) found that WM training gains were mediated by spontaneous memory strategy use. Further support for this hypothesis comes from a study by St Clair et al. (2010) who found that comprehensive WM strategy training led to significant improvements in WM tasks assessing the phonological loop and central executive. Regardless of whether the strategy-as-effect or strategy-as-cause hypothesis is correct, remediation of strategy use could result in increases in WM capacity.

One pathway by which strategy use may facilitate performance on WM tasks involves decreasing the cognitive load placed on processing and encoding of information, thereby freeing up resources for storage. We argue that three developmental changes in strategy use, in particular, may impact efficiency in processing and encoding information.

First, several lines of research show that as children age, they increasingly organize information during both encoding and retrieval (Tulving, 1962; Shiffrin and Atkinson, 1969; Schleepen and Jonkman, 2012). Grouping and organization of information is particularly useful in facilitating delayed retrieval (Lange et al., 1990) and consolidation in long-term memory (Tulving, 1962; Schleepen and Jonkman, 2012). Interestingly, a recent study suggests that not all grouping strategies are equal: categorization based on semantic features (e.g., types of dogs) has been shown to improve memory performance more than categorization based on perceptual features or personal associations (e.g., animals that the child liked, disliked or feared) (Schelble et al., 2012). One possibility is that categorization provides more salient cues that link many concepts for quick retrieval. Children and adults with higher WM capacity were also found to use the classification strategy more often independently and spontaneously than peers with lower capacity (Rosen and Engle, 1997; McNamara and Scott, 2001; Schleepen and Jonkman, 2012). Some evidence points to more efficient patterns of strategy leading to better performance on tests of WM capacity, rather than higher WM capacity *per se*. For instance, Schelble et al. (2012) showed that children's use of a semantic strategy made a stronger contribution in predicting retrieval performance than did their individual WM capacity scores. Moreover, although children with higher WM capacity have been found to be more strategic than children with lower WM capacity in free recall tasks, presenting participants with retrieval cues which prompted better strategy selection eliminated this difference (Unsworth et al., 2013). This finding suggests that effective organizational strategies such as semantic categorization could compensate for lower WM capacity in a demanding retrieval task.

A second developmental change in strategy use concerns the shift from non-verbal to verbal encoding by means of verbal or phonological rehearsal. Rehearsal is particularly useful when there is a delay between the presentation of information and recall, as rehearsal helps maintain and refresh information in verbal short-term memory (Morrison and Chein, 2011). There are two processes involved with rehearsal, the initial recoding of visual stimuli into a verbal format, followed by the rehearsal of recoded items in the phonological store; children may struggle with rehearsal by failing on the first or both of these steps (Flavell et al., 1966). Rehearsal develops gradually starting from about 5–6 years of age but more consistent use of this strategy is not apparent until about 6–8 years of age as noted by phonological similarity effects (lower recall of lists consisting of phonologically similar items) and articulatory suppression effects (reduced recall when required to repeatedly produce a task-unrelated verbalization while encoding target items) occurring only in older but not younger children (Henry et al., 2000; Lehmann and Hasselhorn, 2007; Henry et al., 2012).

Although the acquisition of rehearsal follows a developmental progression, rehearsal training has been shown to improve WM task performance in both developmentally delayed (Conners et al., 2008) and typically developing children and adults (Ford et al., 1984; Ornstein and Naus, 1985). Furthermore, the use of rehearsal as a memory strategy appears to be particularly beneficial for children with lower WM spans (Turley-Ames and Whitfield, 2003).

A third developmental shift in strategy use involves the transition from passive maintenance to active refreshing of information in WM. This shift occurs around 7 years of age (Camos and Barrouillet, 2011). According to the task-switching model (Towse and Hitch, 1995; Hitch et al., 2001), younger children fail to implement maintenance activities while performing a concurrent task, resulting in time-based decay of the memory trace. Instead, they passively hold items in memory without any attempt at active maintenance. Thus, their ability to hold items in memory is greatly affected by the duration of the delay period between presentation and recall. Older children have an increased capacity to control attention and monitor cognitive processes, allowing them to allocate attention during processing to reactivate, or refresh memory traces in real time (Camos and Barrouillet, 2011).

In the present study, we compare the independent and cumulative effects of two strategies (rehearsal and semantic organization) on WM capacity. The two strategies differ in terms of their mechanisms and advantages. The rehearsal strategy is useful for refreshing and maintaining unrelated information, but may be susceptible to distraction, and it is constrained by children's short-term storage for auditory information. A semantic strategy in contrast, is less constrained by an individual's short-term storage, and instead relies on the cued activation of associated networks stored in long-term memory. This strategy may be more effective in retrieving larger amounts of information that can be visualized, but requires more planning (e.g., the foresight and ability to categorize on multiple levels) and may also be susceptible to commission or intrusion errors.

Current Study

The primary goal of this study was to examine whether strategy-based training would transfer to a novel problem solving task. The design of this study takes into account several important considerations including the use of treated controls, a strategy-based training paradigm, and the careful selection of strategies that map onto the identified developmental changes that children undergo as they move from being less efficient to more efficient strategy users. There were three training conditions and one control group. One group received rehearsal training (R), another group received semantic training (S), and a third group received training in both strategies (S+R). Children were trained in semantic organization and/or rehearsal with the expectation that both strategies would improve efficiency of processing, thus freeing up mental resources in WM for storage, with the result that WM capacity could be increased. By extension, increased WM capacity would produce improvements in problem-solving performance that incorporates a WM component.

As mentioned above, rehearsal and semantic categorization strategies have been independently used in previous training studies to increase WM capacity. However, these studies have typically involved older children, and did not assess their use in younger children who may not be spontaneously using these strategies very efficiently, if at all. Furthermore, no prior study has looked at the combined effect of rehearsal and semantic categorization training, nor have previous studies examined training of these strategies in the context of a far-transfer post-test.

We expected that children who received WM training would outperform children in the control group, as developmental research has shown that children between 6 and 8 years use these strategies with varying degrees of success. We further predicted that the combined training condition (S+R) would be more effective than the individual training conditions, given that children in the S+R condition would be provided with more tools to increase their WM capacity. Among the single-strategy conditions, we expected that semantic-strategy training would be more effective than verbal-rehearsal training because previous research has demonstrated that children and adults with higher WM capacity tend to use deeper encoding strategies that create meaningful networks between the items to be remembered (Friedman and Miyake, 2004; Dunlosky and Kane, 2007).

Far-transfer effects were assessed using a novel problem-solving task that was qualitatively different from the task on which children were trained. Performance on this problem-solving task was expected to improve with the use of trained strategies, as WM demands were embedded within the task, but children had to (a) realize on their own that strategies would be helpful to the task and (b) choose to use them under conditions of increased cognitive demand and interference. Careful attention was given to the use of appropriate control tasks to address previous concerns about the use of untreated control groups. Control tasks were selected to correspond to semantic and rehearsal training phases. These control tasks were comparable in time, type of stimuli involved, and level of mental stimulation to the training tasks. All groups therefore spent approximately the same amount of time interacting with the experimenter.

Additionally, we examined a near-transfer effect for the semantic categorization strategy (e.g., Black and Rollins, 1982). Specifically, we tested whether children who were trained in semantic categorization would use this strategy post-training in a free recall task that involved a new set of stimuli.

MATERIALS AND METHODS

Participants

Sixty-five typically developing children aged 6–9 years were recruited from private and public schools within Victoria, BC, Canada. Flyers were distributed to children in school and interested children and parents contacted the researcher for participation. To ensure that participants could follow instructions, only children who had English language fluency and the absence of any developmental delay and/or learning disabilities as reported by their parents were included in the study. Written and informed consent was obtained from parents for children's participation, and child assent was obtained verbally. Data from one child was excluded due to an inability to understand and follow the instructions. The 64 remaining children completed all the pretests, training phases, and post-test measures over a single 1.5-h session.

Sixteen participants were randomly assigned to each of four conditions, with the only requirement that the age distribution was kept relatively similar between groups. There were no significant differences between the mean ages across groups. The S+R group (*M* age = 7.5; males = 9) received training in both S and R strategies. Controls (*M* age = 7.4; males = 7) received only the filler tasks in place of both semantic and rehearsal training. The S group (*M* age = 7.2; males = 7) received semantic training and rehearsal control tasks. The R group (*M* age = 7.4; males = 9) received rehearsal training and semantic control tasks. Thus, each group of children received two sets of tasks that were comparable in administration time and complexity. While the S+R group received two training sets, the S and R group received one each of a training set and a filler set. Treated controls received two filler sets. Filler sets are described in detail below.

Measures

Pretests

To assess whether any between-group differences existed on relevant WM and short term memory abilities which could potentially lead to differences in performance on the novel problem solving task, several pretest measures were administered including a visual memory task (memory for matrices), a verbal memory task (forward and backward digit span), as well as a free-recall task to examine use of clustering or organizational strategies prior to training. A full breakdown of the item-level questions and scoring criteria are provided in **Appendix B**.

Forward and backward digit-span tasks

In the forward digit-span task, children were asked to recall lists of digits. Numbers were read to children at a pace of one number per second, and were prompted to repeat the list in the same serial order with, "Ready? Go." Children received a score of 1 for a correct response, and a score of 0 for an incorrect response. Points were summed for a total score. The task was discontinued after two consecutive scores of 0. In the backward-span task, children were asked to recall the list in the reverse order in which it had been presented, using the same prompt and scoring criteria.

Visual short-term memory (VSTM) task (Logie and Pearson, 1997; recall version)

The child was presented with a matrix pattern drawn on white cards in which half the squares, chosen randomly, were colored red. The pattern was displayed for 2 s and then removed, followed by a further 2-s delay during which the child was shown a blank white card. The child was then given an empty version of the same matrix and asked to point to the squares that previously were colored red. Matrices increased in size, with the proportion of red squares always fixed at 0.5. Children's responses on each of the three trials of Matrices were recorded live by the experimenter on a blank grid. Correct squares were then tallied for each trial, and an average score was computed.

Free-recall pretest

The task was adapted from Black and Rollins (1982). Free-recall tasks are traditionally administered to adults in a written list format but given that some children in this age group would not be actively using verbal strategies and had limited reading skills, pictures were used instead. Colored photos were used instead of black and white line drawings to provide a more realistic and ecologically valid representation of objects (Moreno-Martínez and Montoro, 2012). Five cards each from four categories (insects, fruits, vehicles, and furniture) were chosen for use in the free recall task, for a total of twenty items. Different items were used in the post-test and the free recall post-test. High-frequency items previously used with children from each category were preferentially selected (Snodgrass and Vanderwart, 1980; Rabinowitz, 1984). Following the example of Black and Rollins (1982), duration of study time was determined by the child. At the end of the study period, the examiner collected the cards and asked the child to name as many items as possible. During recall, if the child appeared to run out of answers, they were prompted once with, "Can you remember any more?" before recall was terminated. The decision to allow the child to determine study time was also made with two considerations: firstly, that a timed study period would be stressful and anxiety-provoking for children and could impair their ability to remember, and secondly, that the vast majority of children in initial testing were able to self-report in a reasonable time frame as to when they were ready to have the cards taken away. The total number of correct responses was recorded live.

Training Tasks

The goal of this short-term intensive training was to increase children's familiarity with and hone their correct use of strategies. Therefore, accuracy was not recorded or analyzed for the training tasks. Children were also encouraged to try as many times as possible until they arrived at the correct answer. Only one item was correct in any given array of objects. The duration of each section of training was kept as closely as possible to around 10–12 min, with control tasks timed for a similar duration.

Semantic-categorization training tasks

These tasks encouraged children to organize information based on their common abstract properties (e.g., things that hold liquid, things that fly, etc.). Children were first trained to think in terms of categories, and then to apply them strategically. Training involved two phases. In phase A, children had to make decisions about which object in a group did not belong with the others. For example, on one slide, children were shown a butterfly, beetle, spider, and banana. They were asked, "Which does not belong?" followed by, "What do the other ones have in common?" Nine training sequences were administered for Phase A of the training (see **Appendix C** for all training items). The number of items presented in each array ranged from 4 to 6 objects. Two levels of difficulty were administered. In the first five training sequences, objects in the same category shared the same identity (e.g., they are all insects, vehicles, furniture...). Children were then prompted that items in the final four sequences would be similar in ways that were harder to see (e.g., container/non-container, animate/inanimate, things that travel on land/water). Children were given the opportunity to discuss their ideas for each training sequence with the experimenter and were debriefed on all correct answers.

In phase B of semantic training, a scaffolded free-recall task was administered. Children were first prompted to sort the cards by their categories (fruit, insects, furniture, vehicles). Next, they were instructed to use the strategy of thinking about the similarity among items ("If you study the cards that are similar together, such as all the fruit together, it will be easier to remember them"). Black and Rollins (1982) had found this method of explanation to be most effective in encouraging children to adopt the category clustering strategy. The experimenter checked whether children could identify a few of the items that were similar and moved these cards closer together to better illustrate the grouping. Once it was clear that children had a grouping strategy in mind, they were given 3 min for recall. As accuracy was not measured during the training, children were given positive reinforcement for their attempts at using the strategy. Children were also debriefed on their performance and given feedback for correct application of the categorization strategy.

Semantic control tasks

In the first control task, children were given a regular deck of playing cards and asked to find all the cards that fit an arbitrary criterion of color and shape (e.g., all the red hearts, black clubs, etc.). In the second control task, the experimenter randomly selected a few cards from the free-recall deck (e.g., apple, ant, spider) and children were asked to tell a story about the items.

Phonological-rehearsal training

The goals of the rehearsal tasks were to train children in (1) recoding visual information into verbal information, and then (2) maintaining that verbal information in temporary storage through rehearsal. In the first phase of training children were asked to label a list of pictures out loud. They were then asked to rehearse the list until they felt ready to report the items without referring to the pictures. This recording of pictures into words followed by rehearsal was practiced over four trials of increasing list length, starting with three items and ranging up to seven items, with item length increasing by one item in each added trial (see **Appendix C** for full list). For example, on the first training sequence, children would see images of an ant, eye, and car. They were asked to label these objects and verbally rehearse them out loud, followed by several more repetitions either out loud or through inner speech. They were told to let the experimenter know when they were ready to have the pictures removed, and then repeated the items they had rehearsed. Effort was praised, as was successful memorization of increasingly longer sequences. In the second phase of rehearsal training, word lists were presented orally without the use of pictures, and children were tasked with recalling lists after a short delay. Children were then tasked with practicing this rehearsal strategy over five trials, starting with a sequence of three items and ranging up to a sequence of seven items. The sequence length increased by one item in each added trial. As the goal of training was mastery of the technique, children were allowed to repeat trials as necessary.

Rehearsal control tasks

Children were asked to read from a picture book with the help from the experimenter, or engage in a discussion about what they did on the weekend or about upcoming activities at home or school for the duration of approximately 10 min.

Post-tests

Problem-solving task

A problem-solving game was developed for this study. The most important function of the problem-solving post-test was to assess the cross-contextual far-transfer of any potential training effect. As such, novelty was a critical aspect of the task. Omitting to include a problem-solving *pretest* came with certain advantages and disadvantages, and the decision was ultimately made for several reasons: (a) Even though exposing children to a problem-solving pretest is often expected in a pre-post-test design, pretest administration has the disadvantage of introducing a practice effect, which reduces novelty of the task; (b) The average running time for this study was approximately 1.5 h. With the problem-solving task taking a large proportion of this time, adding a pretest would have necessitated a second testing session, which was not feasible at the time of data collection. Several safeguards were implemented to ensure as much as possible that groups had no significant differences at pretest: (1) A memory battery was administered at pretest (visual matrices, digit spans, free recall) to ensure that no between-group differences existed on a variety of potentially relevant memory abilities. These measures were then examined in relation to the problem-solving post-test in a subsequent regression analysis; (2) Near-transfer (recall post-test) and far-transfer (problem-solving task) are clearly distinguished in the results; (3) The use of random assignment usually safeguards against pre-existing group differences, and (4) The use of a treated control group with appropriate filler tasks ensured that pre–post differences would be related to intervention effects and not to unspecific factors (e.g., engagement with children). Overall, we believed that these measures compensated for the lack of the problem-solving pretest, while retaining the novelty effect for assessing far-transfer.

The problem-solving task was structured like a shopping game where the child had to retrieve items from a teddy bear's list. It involved three adjacent rooms: two troll houses where children collected cards with pictures of items, and the bear's house in between. The goal of the task was to retrieve all the cards on bear's list while making as few errors as possible (see **Appendix A** for task instructions). Each child completed three different lists of items (three trials). Each trial consisted of 24 target items, with each item repeating only once across the three trials. There were a total of 48 possible cards, with 12 items of each category (Animate: aquatic animals, terrestrial animals; Inanimate: school supplies, wearable items). One troll housed animate categories and the other housed inanimate categories, but children were not told of this arrangement. Children were first introduced to the bear, and then to each of the trolls. Each troll had a coin bank for the child's payment in order to open the box of cards. The experimenter enforced correct token use. To elicit strategy use, several constraints were put in place for the problem-solving task: (1) Children received only six tokens to pay the trolls. Each time a troll's box was opened, a coin was forfeited. Once all the coins had been used, the trial was terminated, regardless of whether or not all cards had been collected. Thus, there were no explicit rules about when or how often the child could return to consult the bear's list, nor any explicit penalty for selecting incorrect cards, but the limited number of tokens forced children to maximize the cards they would get with a visit to a troll. (2) Maximally seven cards were allowed to be kept in the basket at any given time. The number 7 was placed on the side of the basket, to serve as a visible reminder of this rule. This constraint ensured that children did not walk away with the entire deck of cards at once. During the collection process, children could collect cards in any order they liked. This allowed children to make plans about the best way to collect cards. (3) Upon returning to the bear's house, the cards were placed on bear's "shelf" (two empty marked-out rows) in the same order as bear's list. This rule was designed to help children keep track of remaining cards. (4) Children were told that in order to win the game, all correct cards had to be retrieved while making as few mistakes as possible and using as few of the coins as possible. Children did not have access to the bear's list while in the Trolls' rooms and had to remember which items to retrieve. **Figure 1** shows the setup of the list in bear's house. Children were permitted to consult the list again when they returned to the bear's house to place their collected cards. None of the children were given any explicit instruction that they should use a particular strategy or that the items could be sorted into categories.

We expected performance on this task to be improved by our specific training for several reasons. The 24-items presented in target lists would far exceed any individual's maximum capacity, and children who received training in either or both strategies

FIGURE 1 | Initial set-up in bear's house.

would be equipped with tools to improve WM at all stages including encoding, maintenance, and retrieval, an advantage that the control group would not have in such a demanding task. In addition, the task constraints, as well as children's own WM capacity limits would be best overcome by the use of both strategies. For instance, a child could first plan to visit the room with the animate items, grouping animate items from the bear's list using a rehearsal strategy, and then visit the room with the inanimate items on a separate trip, again using rehearsal for these items. Use of a rehearsal strategy alone meant that items from different categories rehearsed by the child would not be completed on the same trip, as each room housed only animate or only inanimate items. Similarly, children who used a semantic strategy only would not benefit from the use of rehearsal to maintain and refresh items in memory while shifting through the deck of cards and be prone to making more intrusion or commission errors.

For each of the three trials, the following outcomes were recorded: number of correct cards retrieved, number of errors, number of tokens used, and the number of cards retrieved for each token. Performance scores were computed as follows: total number of correct cards retrieved over three trials (maximum = 72), total number of errors over three trials, and total tokens used (maximum of 18 over three trials). A performance index was calculated by subtracting total errors (E) from total correct cards (C), divided by number of used tokens (T): (C-E)/T.

Post-training free recall

A post-training free-recall task was administered to all groups after the game as a near-transfer measure. The post-test used a different set of stimuli and categories (e.g., body parts, nature, instruments, kitchen utensils) than were used in the pre-test.

RESULTS

First, we compared the results of baseline WM and clustering pre-measures across groups. Second, far-transfer effects were compared across groups by looking at performance on the problem-solving task. Third, to evaluate near-transfer effects, groups that received semantic-categorization training were compared to those that did not in their performance on the post-training recall task. Finally, we evaluated the construct validity of the problem-solving task.

Pretests

Prior to analyzing training effects, group performance on a variety of pretests was examined to ensure that there were no significant group differences in memory abilities which could have led to between group differences in our post-test. Group means for pretest measures can be found on **Table 1**.

Given that digit span scores are not expected to be normally distributed (Babikian et al., 2006), Kruskal–Wallis tests were used to test group differences on the digit forward and backward span total and longest span. The test revealed that the total scores for both forward, $\chi^2(3) = 2.96$, $p = 0.40$, and backward $\chi^2(3) = 3.05$ $p = 0.38$ digit span were not significantly different across groups.

Shapiro–Wilk normality tests suggested that matrices W(64) = 0.97, $p = 0.119$, number of cards W(64) = 0.97, $p = 0.14$ and ARC W(64) = 0.57, $p = 0.57$ at pretest of the free recall were normally distributed. Box's M suggested that equal covariance matrices of the dependent variables can be assumed across groups $F(9,41255.3) = 0.84$, $p = 0.58$, and Levene's test showed that variance of matrices $F(3,60) = 1.32$, $p = 0.28$ and number of correctly recalled cards $F(3,60) = 0.25$, $p = 0.86$ were assumed equal across groups. A MANOVA was conducted to test the between-group differences for matrices and the pretest free recall. Results using Pillai's trace showed no significant between-group differences for these measures $F(1.38,120) = 1.38$, $p = 0.23$.

These findings suggest that there were no significant baseline differences between groups on the pretests of visual and verbal short-term memory and WM, as well as in the tendency to use a clustering/organizational strategy. Based on these findings it is reasonable to conclude that no group had any short-term or WM advantage compared to other groups prior to training.

Near-Transfer Training Effects

We expected to see far-transfer effects only if near-transfer effects were first established, as more proximal transfer would predict more distal transfer. To reduce testing time, we prioritized the measurement of near-transfer to one task, specifically the free-recall task, because it was quick to administer and was a well-established measure for at least one of our trained strategies. Participants were grouped together depending on whether they received semantic strategy training (S+R and S) or not (R and control). The mean number of correctly recalled items in groups that had not received semantic training was 11.00 ($SD = 2.91$) at pretest and 10.47 ($SD = 3.35$) at post-test. The means of the groups that had received semantic training were 12.03 ($SD = 2.8$) at pretest and 13.16 ($SD = 4.78$) at post-test. A 2x2 repeated measures ANOVA revealed a significant main effect for the factor of semantic training, $F(1,62) = 5.55$, $p < 0.05$, $\eta_p^2 = 0.08$; participants who received semantic training did better on the free-recall task than those who did not receive semantic training. There was also a significant interaction between the within-subjects variable of time (pre- vs. post- test) and training condition $F(1,62) = 4.19$, $p < 00.05$, $\eta_p^2 = 0.06$, indicating a larger positive change in performance for the semantic training condition.

Relationship Between Problem-Solving Task and Working Memory

The novel problem-solving post-test was designed such that it made demands on WM processes. Specifically, children were required to remember items, correctly select these remembered items from a series of stimuli including both targets and distractors, inhibit retroactive interference from previous sets of remembered items, and simultaneously hold the rules of the game in mind. To check whether the problem-solving task indeed made WM demands, we examined the correlations between the verbal and visual pretest WM measures and the problem-solving task. Forward digit span, $r(62) = 0.28$, $p < 0.05$, backward digit span, $r(62) = 0.34$, $p < 0.01$, and matrices, $r(62) = 0.31$, $p < 0.05$, all were significantly correlated with the problem-solving task. Next, we entered digit span forward, digit span backward, and Matrices as predictors of problem-solving performance into a regression model. This analysis showed that matrices and backward digit span tasks explained 15.9% of the variance in problem-solving performance (R^2 adjusted = 0.159), $F(3,60) = 4.96$, $p < 0.01$, and significantly predicted problem-solving performance ($\beta = 0.27$, $p < 0.05$, and $\beta = 0.28$, $p < 0.05$, respectively). The forward digit span was not a significant predictor of problem-solving performance ($\beta = 0.09$, $p = 0.50$).

Far-Transfer Training Effects on the Problem-Solving Task

For the problem-solving task, the performance index (C-E)/T was computed using the total scores ([total correct – total errors]/total tokens used) across three trials of the task. A univariate ANOVA with training condition as the independent variable was conducted to examine whether problem-solving performance differed as a result of which training group children were assigned. Results revealed a significant main effect for condition, $F(3,60) = 3.04$, $p < 0.05$, $\eta^2_p = 0.13$. *Post hoc* analyses using least significant difference (LSD) revealed statistically significant differences in the problem-solving performance index (C-E)/T between the control group and each of the three training groups. As can be seen in **Table 3**, on average, the control participants collected fewer cards than any of the training groups. Importantly, medium to large effect sizes were found for all three comparisons made between treatment groups and the control group (see **Table 2**). The largest effect size was found for the difference between the control group and the group that received both interventions (S+R). The three training groups (S+R, S, R) did not differ significantly from each other.

Due to the correlations between the pretest memory measures and the problem-solving post-test, a one-way ANCOVA was also conducted to examine whether post-test group differences remained when including the digit span tests, matrices, and free-recall pretest measures as covariates. Results showed a significant main effect for condition $F(3,60) = 2.80$, $p < 0.05$, $\eta^2_p = 0.13$. *Post hoc* analyses again revealed that there were statistically significant differences in the problem-solving performance between the control group and the semantic training group ($p < 0.05$); the rehearsal training group ($p < 0.05$), and the S+R group ($p = 0.05$). No significant differences were found between the three training groups.

TABLE 2 | Mean differences between groups on problem-solving outcomes over all trials.

Condition		*Difference in correct cards*	*Difference in performance index*	*p*	*Effect size (d)*
(I)	*(J)*	*(I – J)*	*(I – J)*		
Controls	S + R	−14.63	−0.98*	0.006	0.97
	S	−8.69	−0.73*	0.038	0.63
	R	−12.06	−0.75*	0.035	0.74
S + R	S	5.94	0.25	0.48	0.27
	R	2.56	0.24	0.5	0.3

Significant at $p < 0.05$; large effect size $d > 0.8$.

A breakdown of correct cards retrieved per trial is shown in **Table 2**, as well as means for total errors across three trials, and number of tokens used. No significant differences in token usage were found.

Perfect performance on this task would have involved collection of 72 cards in total, however no child collected all three lists in their entirety and without error, which demonstrated that the task was sufficiently challenging yet nuanced enough to show variability in performance across children.

DISCUSSION

The main finding of this study is that strategy-based training produced a far-transfer effect in a novel problem-solving task. The control group performed significantly worse on the problem-solving task than all three training groups. Most importantly, children were not coached into using specific methods to complete the problem-solving task, but had to recall and execute the strategies by themselves in a context that differed considerably from training (Barnett and Ceci, 2002). Surprisingly, there was no statistically significant difference in receiving combined training of both strategies compared to only one strategy.

A possible explanation for why there was no significant difference in problem-solving performance between the combined and separate training conditions is that the problem-solving task may not have been sensitive enough to capture the effects of the combined training. It is possible that these effects would have emerged if a more demanding outcome measure or a longer interval between training and test had been used. It is also possible that the training phase itself was too short.

TABLE 1 | Group means for pretest measures.

Groups		*Matrices*		*Free recall (correct)*		*ARC*		*DS forward*		*DS backward*	
	n	$\bar{x}$	*S*	$\bar{x}$	*s*	$\bar{x}$	*s*	$\bar{x}$	*s*	$\bar{x}$	*s*
S+R	16	4.52	0.97	12.69	2.41	0.4	0.36	*5.69*	0.87	3.56	0.96
Controls	16	4.19	0.64	11.13	2.92	0.31	0.32	5.31	0.95	3.19	0.83
S	16	4.4	0.4	11.38	3.07	0.37	0.4	5.75	1.07	3.19	0.66
R	16	4.75	0.79	10.88	2.99	0.37	0.4	5.13	0.62	3.19	0.75

ARC is a measure that reflects children's use of the clustering strategy in the Free Recall task (see Senkova and Otani, 2012).

TABLE 3 | Group means for problem-solving outcomes.

Groups	*n*	*(C-E)/T*		*Correct cards Trial 1 (/24)*		*Correct cards Trial 2 (/24)*		*Correct cards Trial 3 (/24)*		*Total Correct (/72)*		*Total Errors*		*Tokens used*	
		$\bar{x}$	*s*	$\bar{x}$	*s*	$\bar{x}$	*s*	$\bar{x}$	*s*	$\bar{x}$	*s*	$\bar{x}$	*s*	$\bar{x}$	*s*
S+R	16	3.79	0.75	21.88	3.59	21.5	4.13	19.88	4.26	64.94	12.69	4.75	4.95	16.81	1.28
Controls	16	2.81	1.21	18.81	5.09	15.69	8.31	14.13	8.1	60.44	12.12	11.81	9.31	17.56	0.892
S	16	3.54	1.1	20.88	2.94	19.25	5.43	17.19	6.4	65.38	6.3	8.44	8.03	16.63	1.71
R	16	3.56	1.76	21.88	2.25	19.81	4.65	19	5.2	67.44	4.15	6.75	6.36	17.25	1.13
Total	64	3.42	1.02	20.86	3.7	19.06	6.1	17.55	6.42	64.55	9.66	7.94	7.63	17.06	1.31

Total performance = (C-E)T.

Cognitive training studies are generally time intensive, spanning multiple sessions over weeks. Training effects might have been amplified if there had been multiple training sessions to help consolidate learning.

Alternatively, children may not have benefited more from the combined training than from the single-strategy training because they may have used only one strategy although they had received training on both. Controlling the use of two strategies, in this case, first categorizing stimuli, and then rehearsing words recoded from pictures, would require the metacognitive ability to select and implement separate strategies in a logical sequence. This, in turn, requires the comparison and evaluation of different strategies, a mental task that may be difficult to do while attempting to implement a strategy (Whitebread, 1999; Touron et al., 2010). In a task that is cognitively demanding with multiple subordinate goals, children with limited cognitive resources will likely make less adaptive strategy choices (Imbo et al., 2007). Moreover, children with lower WM are more likely to experience a version of "utilization deficiency" (Bjorklund et al., 1994; Gaultney et al., 2005), such that, despite being instructed to use a particular strategy or seemingly comprehending the steps in its application, they fail at implementing the strategy due to limited cognitive resources. According to Lovett and Anderson (1996), available processing capacity in WM is a constraint that limits the amount of attention that can be distributed over concurrent tasks. Younger children who have lower WM capacity may not always be able to effectively implement strategies in spite of training. In conclusion, the effortful task of alternating and deciding between two strategies may actually impede the ability to use both, and if one strategy is easier to implement, a child may default to using only one. In addition to this possibility, the relatively small sample size in each condition would make it more difficult to detect differences between the training groups, especially if only a small effect size differentiates the groups.

An underpowered sample size was a notable limitation of this study. Due to the time intensive nature of pre- and post-test intervention studies, large sample sizes for these types of studies are achieved with some difficulty. The current study was also completed under a narrow time constraint, which made further data collection unfeasible. A one-way ANOVA would require a large sample size ($n = 280$) to detect a medium effect size (0.25) for four groups, using a 95% confidence interval. In the current study with a sample size of 65 the observed power for detecting a medium effect size was 0.338. Replication of this study with a sufficiently powered sample would ensure that a Type II error was not being made with respect to the lack of significant differences between the different training conditions.

The current findings also did not support our second hypothesis that children who were taught to use only a categorization strategy would outperform those who were taught only rehearsal. As previously mentioned, rehearsal may be less effortful than semantic categorization, and in cognitively demanding tasks, children tend to use less effortful strategies (Beilock and DeCaro, 2007). Our problem-solving task involved many rules in addition to memorizing items, and with these aspects demanding the child's attention, the ability to use a more complex strategy efficiently may have been impaired. The near-transfer effect found in this study lends credence to this explanation. When comparing the group that received semantic training to the group that did not receive semantic training on the much less demanding free-recall post-test, those who received semantic training outperformed those who received rehearsal training.

Finally, the semantic training group may not have performed better than the rehearsal group because of intrinsic limitations to the categorization strategy. Semantic categorization is a good strategy for recalling a large number of items because of primed associations. However, it may actually impede performance in a task that places emphasis on accuracy for the very same reason. During free-recall tasks, participants occasionally make intrusion and repetition errors. In the current problem-solving task, retroactive inference between trials heavily impeded accuracy because targets remembered from a previous list may not have been targets on a current list. Accuracy was also an important component of the problem-solving task; if clustering both increased recall but also elevated the propensity for intrusion and repetition errors, the overall performance would be compromised. Future studies should seek to determine whether semantic strategies are more helpful when retroactive interference is reduced between trials. Retroactive interference could be removed by using each target for only one trial. A follow up study would also be improved by replication with more clearly distinguished categories, as the groups of aquatic and terrestrial animals may have been too similar for some children to fully benefit from using a categorization strategy. Nevertheless, despite the possible interference that children may have experienced while using a semantic strategy, the data showed that the semantically trained group still significantly outperformed the control group, suggesting that this strategy was overall successful in improving performance in a far-transfer task.

Lastly, it is important to distinguish between cross-temporal and cross-contextual transfer. Cross-contextual transfer is highly relevant to our understanding of how training effects can be transferred to real world environments. Although both cross-temporal and cross-contextual considerations are important, the focus of this study was on cross-contextual transfer, largely in part because of the narrow time constraints of data collection. Producing a sustained change is ideal, but longevity of a training effect may sometimes be secondary to the nature of change itself. Training which produces improvements in only a narrowly constrained set of outcomes may not be viewed as successful as training which produces improvement across multiple outcomes, particularly if those outcomes involve higher order cognitive process or more complex domains.

A challenge for the training literature has been to find a compromise in the similarities and differences between the trained and untrained tasks. On one hand, similarities between the tasks are part of the point of training studies: common elements must be identified and isolated in training, and improvement in these common elements are what we measure in transfer effects. If these common elements are unknown or inconsistent, predicting and implying transfer is impossible (Noack et al., 2009). On the other hand, if there is too much overlap between the trained task and post-test limits, then gains will likely be limited to near-transfer. In this study, we can clearly identify the common elements between training and post-test, as well as the overlapping elements between pretest and post-test. These common elements are in sum: a measurably capacity for short term storage of verbal and visual stimuli, a process whereby visual information is recoded into verbal information, the ongoing maintenance and refreshing of this information, and ways of organizing information effectively for more effective encoding and retrieval. Our training tasks focus on improving these elements, and the post-test recruits exactly these abilities.

At the same time, we acknowledge that it is debatable whether far-transfer has occurred in our study. The determination of whether far-transfer has taken place requires the administration of a series of post-test measures dissimilar enough from the trained tasks to suggest change at the level of broad abilities (Noack et al., 2009). We are less confident that our short training has made changes in any one broad domain. Nevertheless, the study demonstrated that the trained strategies could be used in a context where there was substantially higher cognitive load, as evidenced by the many other rules, constraints, and distractors, and where application of the strategies was less transparent and arguably more difficult to implement. Arguably, because of these features, the post-tests were at least somewhat dissimilar from the trained tasks, while retaining the common elements which underlie transfer.

Near-Transfer Training Effects

A secondary goal of this study was to replicate near-transfer effects of semantic strategy training. We expected near-transfer effects for WM training more generally, because previous research has shown considerable evidence for near-transfer effects in training of executive functions (e.g., Klingberg et al., 2002; Turley-Ames and Whitfield, 2003; Li et al., 2008; Karbach and Kray, 2009). Results showed a significant interaction between type of training and pre- versus post-test free recall. Children who received semantic training showed a small but consistent improvement from pretest to post-test on the free recall task, whereas the performance of children who did not receive semantic training did not show this gain.

Summary

The results of this study show that strategy-based WM training produced a far-transfer effect on a problem-solving task. Groups in all three training conditions outperformed control participants in problem solving. This research is important because it shows that children are able to generalize specific strategies to a completely novel problem-solving task with which they have no prior experience, and where no explicit instruction is given on how to complete the task. Moreover, not only were the test stimuli different from the ones used in training, the task demands that children were tested on (i.e., use of semantic categorization or rehearsal) were embedded in a game where other complex rules and hierarchical goals had to be kept in mind while remembering and implementing strategies. The positive findings of our relatively short training study stand in stark contrast to other research showing no evidence of far-transfer even in testing that immediately follows training. In our view, several factors contributed to the success of this training. First, we selected strategies that are developmentally appropriate in that these strategies were emerging but not yet mastered or used consistently by the target age group. Secondly, prior research has demonstrated these strategies to be used very effectively by individuals with higher WM capacity. In other words, children who do well in WM-related tasks employ exactly the strategies that were trained in the current study. Thirdly, in training these strategies we used very concrete, explicit instruction, and the ease of their use allowed them to be applied readily. Our finding shows that application is not limited to near transfer, but also generalizes to a new context.

Undoubtedly, more work is necessary to better understand the causal relation between components of WM and different types of higher-order abilities. Nevertheless, in examining our between-group differences, we found a large effect size for the difference between the combined training (Semantic+Rehearsal) condition and the control group, a marginally large effect size for the difference between Rehearsal training condition and the control group, and a medium effect size for the difference between the Semantic training condition and the control group. These medium to large effect sizes are exciting as they suggest that training simple strategies that focus on improving cognitive efficiency can potentially moderate children's performance on higher-order tasks, particularly when task demands reflect components of training. The fact that combined training produced the largest effect size suggests that such training has the potential to have an additive effect.

Our training focused on practicing and fine-tuning strategies that emerge in children who are between 6 and 9 years old, suggesting that one direction of future research on WM training should focus on enhancing and scaffolding the effective use of cognitive strategies that are developmentally appropriate and contextually relevant. This study also replicated near-transfer effects, showing that those who received semantic training did better on a free-recall task after training whereas those who did not receive such training did not show improvement. This second finding is also important because it suggests that rehearsal and semantic categorization are two conceptually different mechanisms by which children can more effectively encode and maintain information in WM. Follow-up studies should further tease apart the unique contributions of these different strategies using more intensive training paradigms and larger samples. Future studies should be conducted to determine whether long-term gains can be produced by this type of WM training. In addition, there is a need to explore longer-term, distributed training paradigms, that take place over time and adjust for children's changing competencies, as well taking into account individual differences in other factors related to task performance such as attention and motivation.

Finally, it is important to discuss several limitations of the present study. Despite the promising training effects, given the time constraint of data collection it was not feasible to conduct extended training over multiple sessions. Working memory training studies have typically involved several training sessions (about half an hour long each) over the span of a few weeks. Although the relationship between the quantity and effectiveness of training may be variable, it is likely that a more intensive training program would achieve longer-term training effects than a single session lasting half an hour as in the present study. In particular, children who were trained in two strategies may have benefited from more training sessions because of the complexity of mastering and applying two strategies.

Lastly, children's baseline WM could be more precisely established in future studies to more clearly look at how children with low WM respond to training in comparison to children with high WM. It is also important that individual differences are not underestimated in any learning situation. Aside from baseline WM, other relevant factors such attention, emotional regulation, anxiety, or curiosity may have influenced children's responsiveness to training and their ability to transfer training to a novel problem solving context. We also acknowledge that claiming far-transfer may be ambitious as it remains unclear to what extent our training could lead to permanent changes in a broad cognitive domain. Nevertheless, the study did demonstrate that trained strategies were used in the pursuit of a complex goal in a cognitively demanding context, in which children were not instructed to use these strategies, and in which, consequently, it arguably was more difficult to implement them.

DATA AVAILABILITY

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

This study was approved by the University of Victoria Human Research Ethics Board (Protocol No. 13-156) on May 13, 2013, and deemed minimal-risk.

AUTHOR CONTRIBUTIONS

SC contributed to all aspects of this study (conceptualization, design and methodology, data collection, interpretation, and write up). This study was designed and conducted as a part of the author's M.Sc. requirements. UM contributed to all aspects of this study (conceptualization, methodology, interpretation, and write up) as the first author's academic supervisor during the study's completion. MM contributed to the methodology, interpretation, and write up as an integral member of the first author's thesis committee.

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SUPPLEMENTARY MATERIAL

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ORIGINAL RESEARCH
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Art of Learning – An Art-Based Intervention Aimed at Improving Children's Executive Functions

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Executive functions (EFs) can be conceptualized as a mean of behavioral self-regulation, and difficulties with EFs may adversely affect school success, social function, and cognitive and psychological development. Research about EFs and how they are affected by various educational and psychosocial factors is sparse. EFs are of great importance to understand how children can handle the challenges that they meet at various stages of development. There has been an increased focus on programs aimed at improving EFs, either as a primary outcome, or as a supplemental result of a specific activity. In this randomized controlled study, 66 children (31 girls, mean age 7:1 years) were given an arts and culture rich intervention (Art of Learning) aimed at improving EFs. EFs were assessed with the Behavior Rating Inventory of Executive Functioning-teacher version (BRIEF-teacher form) before, immediately after, and 6 months after intervention. Outcome in the intervention group was compared to children from two schools serving as controls (n = 37, 18 girls, mean age 7:3 years). In addition, teachers from intervention schools were also interviewed both individually and in focus groups. The results reveal that both groups improved their EFs, as measured with BRIEF, over time on the global executive composite (GEC) score, the metacognition index, and on behavioral regulation index (BRI). However, the intervention group displayed a significantly greater improvement than the control group on GEC and BRI. The teacher interviews reveal positive effects for the children when it comes to several aspects: collaboration, conflict management, inclusion, vocabulary, and confidence. These factors are regarded as important for EFs development and academic outcome. The results support the notion of best training transfer effects for tasks addressing global executive functioning and specifically behavioral regulation skills (BRI).

Keywords: Art of Learning, behavioral self-regulation, BRIEF, executive function, executive function training, metacognition

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INTRODUCTION

Executive functions (EFs) can be conceptualized as a mean of behavioral self-regulation, crucial for children's social function, and cognitive and psychological development (Alloway, 2009). EFs seem to be situated in neural networks including prefrontal cortex, striatum, and the basal ganglia (Middleton and Strick, 2001), showing considerable development throughout childhood, reaching adult-like levels in middle adolescence (Best and Miller, 2010). Thus, difficulties with EFs have shown to adversely affect school success, social function, and cognitive and psychological development (Diamond, 2013; Zelazo et al., 2016; Pellicano et al., 2017; Morgan et al., 2018). There are no generally agreed definition of EFs. One reason for this might be different research approaches to the construct, either through studies of functional outcome of frontal lobes lesions/damage, or examining different cognitive functions thought to regulate goal-directed behaviors and studies investigating development of cognitive control strategies and self-regulation (Cirino et al., 2018). However, a definition commonly used is provided by Miyake and Friedman (2012) and refer to EFs as "*a set of general-purpose control processes that regulate one's thoughts and behaviors*". Another common conceptualization refer to EFs as "*the attention-regulation skills that make it possible to sustain attention, keep goals and information in mind, refrain from responding immediately, resist distraction, tolerate frustration, consider the consequences of different behaviors, reflect on past experiences, and plan for the future*" (Zelazo et al., 2016).

There is some ambiguity as to whether EFs can be judged as a unitary construct or as a set of independent components. Miyake et al. (2000) has gained a lot of support in their effort to bridge the different constructs into a unity/diversity hypothesis of EFs. In this view, EFs are both related and separate cognitive functions. The unity/diversity hypothesis of EFs finds evidence for both distinct and common loadings of inhibition, working memory (WM), and cognitive flexibility in EFs (Miyake et al., 2000; Best and Miller, 2010; Diamond, 2013). These functions are regarded as foundations for other higher-order cognitive skills, such as reasoning, problem solving, and planning (Diamond, 2013).

Inhibition comprises cognitive functions such as self-control, selective/focused attention, and cognitive inhibition. Inhibitory control improves rapidly in early childhood, followed by a less dramatic change through adolescence (Best and Miller, 2010). Poor inhibitory control is associated with reduced quality of life, and relatively small improvements may have huge gains (Moffitt et al., 2011).

The most commonly used definition of WM defines the construct as the active maintenance and manipulation of information within a limited time span (Baddeley, 2003). WM have been shown to be crucial for children's learning capacity, and academic achievement in school (Alloway et al., 2005; Alloway, 2009). As the development of WM is closely related to the maturation of inhibitory control, the developmental trajectory of WM is often difficult to disentangle from inhibition (Best and Miller, 2010). That said, converging evidence indicate a more protracted period of development for WM, showing improvement at least through adolescence (Best and Miller, 2010).

Cognitive flexibility refers to the ability to adapt to changing situations requiring different thoughts and behaviors (Hill, 2004). The failure in generating novel solutions and to use appropriate levels of representations in mental processing may hinder creative responses in situations with open-end outcomes (Ridley, 1994). Cognitive flexibility is important for the behavior required in daily social activities (Memari et al., 2013). Cognitive flexibility presupposes inhibitory control and WM showing a protracted period of development through adolescence (Best and Miller, 2010).

The notion of EFs as interrelated, but at same time distinct components are also supported in a recent study by Cirino et al. (2018). When assessing EFs in 846 children from 8 to 12 years they found a common factor and five separate factors. Two components were WM related; span/manipulation with planning and updating. The other three were generative fluency, self-regulated learning (SRL), and metacognition (MCOG). The EFs trident of WM, inhibition, and cognitive flexibility from the unity/diversity model of EFs by Miyake et al. (2000) was not supported, which is also the case in other studies evaluating model fit in children (Huizinga et al., 2006; Espy et al., 2011; Lee et al., 2013; but see Miyake and Friedman, 2012). The two WM components found by Cirino et al. (2018) fit well into the constructs of WM given above. SRL can be described within the concept of EFs given by Zelazo et al. (2016) comprising planning, reasoning, and problem-solving abilities. MCOG refers to the ability to monitor, manipulate, and regulate other cognitive processes (Cirino et al., 2018). The ability to monitor and regulate cognitive processes has been a central feature of the EFs models given by Barkley (1997). EFs can also be conceptualized as a mean of behavioral self-regulation where inhibition in particular has been associated with childhood aggression (Barkley, 1997; Poland et al., 2016). A metacognition index (MI) is incorporated as a main scale in the Behavior Rating Inventory of Executive Functioning (BRIEF), contrasting the behavioral regulating abilities in the Behavioral Regulation Index (BRI) (Gioia et al., 2000a). Behavior regulation have in previous studies been associated with social function (Kenworthy et al., 2009), while metacognitive skills may be of greater importance for school performance (Carretti et al., 2014). Although describing the concept of EFs with different operationalization's, the above-mentioned descriptions seem to entail some of the same cognitive mechanisms. The overarching notion of EFs as a cognitive process regulating thoughts, behavior, and emotions important for everyday functioning seems to be unanimous. And as early EFs functioning predicts later EFs functioning (Moffitt et al., 2011), interventions aimed at improving EFs are important.

The link between EFs and creativity is somewhat debated. Radel et al. (2015) found that less inhibitory control was associated with more fluent generation of ideas, one central aspect of creativity. On the other hand, being able to cognitively inhibit unrelated ideas is found to improve ideational fluency and flexibility (Benedek et al., 2012). The modulation of defocused attention together with controlled processing/selective focused attention can be regarded as processes needed for cognitive flexibility which is associated with creativity (Zabelina and Robinson, 2010).

Several approaches, both direct and indirect interventions aim to increase EFs in children. These approaches span from games, digital games, art programs, social pretend play, mindfulness, physical exercise, martial arts to parent training, and specific educational practices (Diamond, 2012; Hsu et al., 2014; Zelazo et al., 2016). Evidence for effects are mixed and are usually measured with neuropsychological measures with relatively low correlation to everyday EFs as it unfolds in the classroom (Toplak et al., 2013). Several pedagogical practices have shown evidence for improving EFs in children; however, the evidence for these are also mixed (for review see Jacob and Parkinson, 2015; Zelazo et al., 2016). Further, the unity/diversity hypothesis by Miyake et al. (2000) also raises the question whether different intervention programs will show best effect on behavioral self-regulation, metacognitive skills, or result in more global EFs improvements.

The best evaluated of these programs, "Tools of the Mind," "Head Start REDI," and the "Chicago School Readiness Program (CRSP)" are designed for kindergarten. Malleability of EFs is thought to be best in pre-school years (Diamond, 2014). The "Promoting Alternative Thinking Skills" program (PATHS; Greenberg et al., 1995) is to our knowing the only program designed for elementary school. PATHS is designed to promote emotional and social functioning, and to reduce behavior problems. This focus is thought to improve EFs as well (Riggs et al., 2006). Bierman et al. (2008a) reported improved emotion-regulation and social problem solving in a randomized controlled trial (RCT) of 356 pre-kindergarten children enrolled in PATHS curricula (Bierman et al., 2008a). Small to moderate effects of this RCT was further reported for improved examiner ratings of the children's attention, and performance on a neuropsychological test assessing EFs (i.e., the dimensional Card Sort Task) (Bierman et al., 2008b). In older age groups, however, effects of PATHS school curricula are reported to be smaller (d = 0.1–0.2) than for pre-kindergarten studies (Morris et al., 2014).

Art of Learning (AoL) is a program that combines teacher professional development with a children's learning program over a period of 12 weeks (Creativity Culture and Education, 2018). The AoL program hypothesizes that an arts rich, creative learning program, delivered intensively in schools over several weeks can have a positive impact on the development of EFs and attainment in children (Creativity Culture and Education, 2018). AoL aims to improve teachers understanding of creative skills and EFs. Furthermore, to help teachers gain more confidence in using arts-based approaches and learning to improve attainment across the curriculum. AoL seeks to improve children's understanding of their own creativity and help them develop their EFs. The activities in the program focus on each of the following art forms: music, theatre/drama, dance, literature/poetry, visual arts, and photography/digital art. AoL is largely based upon the review of the existent literature by Diamond (2014), giving evidence that EFs interventions using arts and physical activities are most promising. AoL has not yet been evaluated.

Executive functions are usually assessed through laboratory-based neuropsychological testing, measuring optimal performance at a given time and with very limited distracting stimuli. Hence, laboratory-based testing may not adequately represent how children are able to utilize their EFs in the complexity of more naturalistic settings, and questions have been raised about the ecological validity and generalizability of neuropsychological test results (McCue and Pramuka, 1998). Furthermore, assessing EFs using neuropsychological test batteries is also time-consuming and costly. The BRIEF, which is used in this study tries to accommodate this critique aiming to measure EFs abilities needed for everyday adaptive behavior and functioning through teacher completion of the BRIEF rating scale (Gioia et al., 2000a). This together with interviews with participating teachers trying to capture both near and far transfer effects of the intervention.

The first aim of the current study was to examine whether an arts rich intervention constructed to improve children's EFs would yield any effect on a measure on everyday EFs as reported by children's teachers, and as reported in interviews. Based on current knowledge we hypothesized that the intervention group would have a greater improvement overall in everyday EFs than the children in the control group. Our second aim was to delineate whether this intervention program, delivered intensively in schools, will have a differential impact on behavioral self-regulation and MCOG. According to findings reported by Carretti et al. (2014) we hypothesized that the group receiving intervention will show a greater improvement in MCOG than the control group. We did not expect to find greater improvement in behavioral self-regulation in the group receiving intervention compared to the control group.

MATERIALS AND METHODS

Participants

A total of 103 children (49 girls) between 6.1 and 9.3 years (**Table 1**) were recruited from five different public schools in the rural area of Gudbrandsdalen in Norway. Children from three schools (grades 1–2) received the 12-week long AoL intervention and children from the last two schools (grades 1–3, see **Table 2**) served as a control group. Children in the control group worked with their curricula in a traditional manner and received no specific intervention during the trial period. All schools had volunteered to participate in the study. The schools were randomly selected to either intervention or control conditions. At baseline (T1), EFs for all children were assessed by their teachers with the BRIEF-teacher form (Gioia et al., 2000a). The same teachers assessing children's EFs at T1 also reassessed them post-intervention (T2) and after 6 months (T3). Demographic characteristics are presented in **Tables 1**, **2**.

Focus group interviews with teachers were conducted at the intervention schools, as well as individual interviews with one

TABLE 1 | Demographic characteristics.

Variable	Intervention (n = 66)	Control (n = 37)	Group comparisons	
			χ^2/F	p
Sex (male/female)	35/31	19/18	0.27	NS
Age (months)	85.2 (6.1)	88.5 (9.8)	(1,101) 2.12	NS
BRIEF – GEC T1	92.1 (20.9)	87.9 (20.5)	(1,101) 0.96	NS

BRIEF – GEC T1, Behavior Rating Inventory of Executive Function – Global Executive Composite Time 1; NS, not significant.

TABLE 2 | Number of participants in different grades and numbers of interviews conducted in parenthesis.

		Group		Total
		Intervention	Control	
Grade	1,00	30 (3)	17	47
	2,00	36 (3)	13	49
	3,00	0	7	7
Total		66	37	103

teacher at each of these schools. Three focus group interviews and three individual interviews in total. Strategic committees were made by discussing with the principals of two of the schools, which teacher had been active in the project all the way, and who had qualifications to be able to provide good information in the interview. At the third school, only one of the teachers had time to join the interview. Therefore, an accessibility selection was made there. That is to say – the sample was strategically based on the fact that the participant represented properties that were relevant to the problem, and the method for selecting this teacher was based on the teacher being available. All the teachers met up at the agreed time to a 1.5 h per group interview and 1 h per individual interview.

Art of Learning

Art of Learning is an arts rich, creative learning program delivered intensively in schools and aims to have an impact on the development of creative skills, EFs, and attainment in children (Creativity Culture and Education, 2018). AoL is a practice-based program where artists work in partnership with teachers to support planning and implementation of lessons. The program has a duration of 12 weeks and comprises pre-designed creative learning practices from six different artforms (music, theatre/drama, dance, literature/poetry, visual arts, photography/digital) delivered 1 h (60 min) a day 3 days a week (see **Supplementary Data Sheets 1–6** for examples). Each activity is specially designed to address either one or more of the EFs; inhibition, WM, or mental flexibility. The sessions consisted of a selection of 36 predetermined art activities and were translated and adapted to the Norwegian context. They involved a large upheaval of everyday life for the intervention group, while for the control group it meant having teaching as normal. The artists came to the intervention schools and conducted the predetermined arts activities with the children in collaboration with the teachers. The artist and the teacher themselves, designs and deliver a 1-h activity (60 min) each week based on the experiences they gain from the program. The artists' work in one class over a period of 6 weeks and then another artist follows the class for the remaining 6 weeks. The children received a total of 240 min, or 4 h of arts activities each week, through the 12 weeks. The sessions were structured based on the children engaging with activities from the different art forms. Each art form (music, theatre/drama, dance, literature/poetry, visual arts, photography/digital) was devoted to 6 sessions, or 2 weeks.

The sessions were built up according to a fixed structure: warm-up, main activity, and reflection. Each session schedule provided instructions on time usage, materials needed, room setup, guidance on how to conduct the activity, and which EFs the session aimed to train (**Table 3**). It was up to the artists and the teachers to adapt the sessions to the group of children. The artists recorded all changes from the original plans after each session and have since been filed in the project database.

Principals and teachers from the intervention schools, as well as the artists, were trained ahead of the intervention to ensure that they understood and could conduct the practical aspects and the content by being part of the AoL, introducing them to the aims and explaining the different elements of the program (see **Supplementary Appendix 1**). They were also given a comprehensive lecture of EFs and its relation to learning and creativity. Teachers from control schools were not given this information or training, this to ensure they did not alter their pedagogical practices accordingly.

Artists who were to carry out the activities were recruited based on experience from previous, similar activities in schools. They were placed at the various intervention schools on the basis of a desire for continuity. It was stressed that the artists should become acquainted with the children and the teachers and vice versa, based on which arts the artists worked with. Planning time for the artist and teachers at least once a week was provided. How the days were organized, and when time was allocated for planning varied from school to school. The schools were given all the material they needed before the intervention period, except for material they had easy access to at each school. Otherwise, the artists were responsible for ensuring that all material was ready before each session, and for preparing it. During the intervention, the Project Leader visited all the schools to ensure program fidelity.

Measures

The BRIEF rating scale (5–18 years) assesses everyday executive functioning and provides information about cognitive, emotional, and behavioral regulatory processes (Gioia et al., 2000b). BRIEF-teacher form is completed by the child's teacher and contains 86 items measuring different empirically derived aspects of EFs behaviors. These are Inhibit, Shift, Emotional Control, WM, Initiate, Plan/Organize, Organization of Materials, and Monitor. These eight clinical scales form two broad classifications of executive functioning; Behavioral Regulation (BRI) and Metacognition (MI), as well as an overall Global Executive Composite (GEC) score (Gioia et al., 2000a). The current study used the Norwegian version of the teacher form. The teacher form has shown high internal consistency with a Cronbach's α ranging from 0.80 to 0.98, and with test–retest reliability correlations for BRI = 0.92, for MI = 0.91, and for GEC = 0.91. Further, correlational analysis provide evidence for convergent and divergent validity through comparisons with other established scales for behavior (Gioia et al., 2000a). Studies have reported discrepancies comparing European children with the American norm sample in favor of European children scoring better than American norms (Fallmyr and Egeland, 2011; Huizinga and Smidts, 2011; Hovik et al., 2014). Of interest in the current study are the broad measures BRI, MI, and the overall GEC. Raw scores are used in the analyses. Lower raw scores

TABLE 3 | Overview over Art of Learning exercises and aimed executive functions.

Artform	Session	Warm up	IC	WM	CF	Main activity	IC	WM	CF	Reflection	IC	WM	CF
Dance	Week 1 Session 1	Dance warm up	✓			Name dance		✓	✓	Questions			✓
	Week 1 Session 2	Dance warm up 2	✓	✓		Movement symmetry	✓	✓	✓	Mindful breathing	✓		
	Week1 Session 3	Dance warm up 3	✓	✓		The match moves		✓	✓	Questions			✓
	Week 2 Session 1	Brain warm-up and SG	✓		✓	Welcome to the circus	✓		✓	Open circle			✓
	Week 2 Session 2	Alive, once alive, never..			✓	Welcome to the rainforest	✓		✓	Postcard partners		✓	
	Week 2 Session 3	Stop go weather game	✓		✓	It's raining, it's pouring			✓	Think, pair and share	✓		✓
Literature	Week 1 Session 1	Shoulders	✓	✓		This is a haiku		✓	✓	Scale game		✓	
	Week 1 Session 2	This is a. . .			✓	Be very afraid			✓	Step in			✓
	Week 1 Session 3	Poetry clap	✓	✓		Maths poetry		✓	✓	One word		✓	✓
	Week 2 Session 1	Group story with cards		✓	✓	Emotional fiction			✓	Walking emotions			✓
	Week 2 Session 2	Group story with cards 2	✓	✓	✓	Fifty-word story	✓		✓	Walking reflection	✓		
	Week 2 Session 3	Group story with cards 3	✓	✓	✓	Fifty-word story 2	✓		✓	Moving reflection	✓		
Music	Week 1 Session 1	Four beats	✓			Beat games	✓		✓	Questions			✓
	Week 1 Session 2	Don't clap this one back	✓	✓		Louisiana mud slap	✓	✓		High and low reflection			✓
	Week 1 Session 3	Ta ta kidi	✓		✓	Rhythm of my body	✓	✓		Feeling through my body			✓
	Week 2 Session 1	Plasticine person	✓	✓	✓	Beatboxing	✓	✓		Sound reflection			✓
	Week 2 Session 2	Rhyming stamp	✓		✓	Rapping and rhyming			✓	Reflecting on our work			✓
	Week 2 Session 3	The opposite game	✓	✓		Putting on a show		✓	✓	Dartboard reflection			✓
Theatre	Week 1 Session 1	Stop, go, gettingtoknow		✓		Daily routine disco	✓		✓	Questions	✓	✓	✓
	Week 1 Session 2	Yes, let's			✓	The bag part 1		✓	✓	Freeze frame		✓	✓
	Week 1 Session 3	1,2,3	✓	✓	✓	The bag part 2		✓	✓	Scale game	✓	✓	✓
	Week 2 Session 1	Stop go			✓	Mask monologs		✓	✓	Mask monol. on paper	✓	✓	
	Week 2 Session 2	Fast and freeze	✓		✓	What it's like to be. . .			✓	Questions		✓	
	Week 2 Session 3	Speed graffiti		✓	✓	What it's like to be. . . 2			✓	Open-minded reflection			✓
Visual arts	Week 1 Session 1	Big draw	✓			Back to back	✓		✓	Eyes closed	✓	✓	
	Week 1 Session 2	Memory draw		✓		Simon says – collage create	✓	✓	✓	Facial feedback		✓	
	Week 1 Session 3	Question square			✓	Frames of reference	✓		✓	I liked	✓	✓	
	Week 2 Session 1	Count to 20	✓			Picture in my mind	✓	✓		Recalled reflections		✓	
	Week 2 Session 2	Hand squeeze	✓			Drawing through my senses	✓	✓	✓	Post-it feedback			✓
	Week 2 Session 3	Changing spaces	✓	✓		Portrait of change			✓	Scale game			
Digital	Week 1 Session 1	Me-pose	✓		✓	Picture story	✓		✓	Paper-ball free-writing	✓		✓
	Week 1 Session 2	Speed graffiti			✓	Picture an emotion			✓	Emotional questions in pairs	✓		
	Week 1 Session 3	Group story		✓	✓	Sound story of origins		✓	✓	Radio interview			✓
	Week 2 Session 1	Silent walk	✓			School advert 1			✓	Yes/no questions			✓
	Week 2 Session 2	Bouncy warm-up			✓	School advert 2	✓		✓	Bouncy reflection	✓		✓
	Week 2 Session 3	Nod, shrug and shake	✓			School advert 3	✓		✓	Bottle reflection			✓

IC, inhibitory control; WM, working memory; CF, cognitive flexibility.

on the BRIEF indicate better EFs. The teachers completing the BRIEF were the same teachers who led the intervention in the classroom together with the artists.

Information from BRIEF-teacher form was supplemented with a partially structured interview, in which the questions and topics are pre-arranged, but with the opportunity and openness for the informants' experiences as well as room for follow-up questions along the way.

Analysis

SPSS version 24 was used for statistical analysis. Significant results are reported at the $p \leq 0.05$ level. Demographic characteristics are investigated using chi-square test for independence (gender) and independent samples t-test (age). Mixed between-within subjects' ANOVA (mixed ANOVA) were used to investigate possible interaction effects in EFs development across groups (intervention vs. controls, girls vs. boys). Significant interaction effects were followed up with repeated-measures ANOVA for each group. Indications of violations of the assumption of sphericity will be reported together with Greenhouse–Geisser corrected tests of within-subjects' effects. Significant interaction effects from mixed ANOVAs were also followed up with paired samples t-tests to investigate differences within groups between T1−T2 and T2−T3.

The semi-structured interview had eight different topics: aims, the sessions, executive functioning, academic functioning, social functioning, role of the teacher, methods, and improvements. Six teacher interviews with three 1st and three 2nd grade teachers from three schools with a duration of approximately 60–90 min were conducted. All the interviews were recorded using a telephone recorder before being transferred to a computer with anonymous titles. After all the interviews were completed, they were structured for analysis by transcription. All participants became anonymous in the enrolment. The computer program QDA Miner Lite was used for coding and categorization. In this process, several meaningful categories were extracted, and a selection of these was included in this report. The categories are related to statements made by the informants about the phenomena they had experienced along the way and after the intervention. The material was read and reviewed several times.

This study was carried out in accordance with the recommendations of the Norwegian Centre for Research Data with written informed consent from parents of all subjects. All parents gave written informed consent in accordance with the Declaration of Helsinki. The protocol was approved by the Norwegian Centre for Research Data.

RESULTS

Behavior Rating Inventory of Executive Function (BRIEF)

The results from the BRIEF for the intervention group and control group are presented in **Table 4**. The mixed ANOVA for GEC revealed a significant interaction effect of group × time [$F(2,202) = 4.4$, $p = 0.014$, $\eta^2_p = 0.042$] indicating greater improvement on results in favor of the intervention group (**Figure 1**). A repeated measure ANOVA for each group revealed that both had improved scores on GEC over time, intervention group: $F(2,130) = 19.2$, $p < 0.001$, $\eta^2_p = 0.228$. For the control group Mauchly's test indicated a violation of the assumption of sphericity, $\chi^2(2) = 16.3$, $p < 0.001$, results from Greenhouse–Geisser ($\varepsilon = 0.73$)-corrected tests: $F(1.49,52.5) = 4.05$, $p = 0.035$, $\eta^2_p = 0.101$. A paired-samples t-test for the intervention group revealed a significant improvement from T1 to T2 [$t(65) = 3.58$, $p = 0.001$, $d = 0.30$] and from T2 to T3 [$t(65) = 2.56$, $p = 0.013$, $d = 0.26$]. A paired-samples t-test for the control group revealed a significant improvement from T1 to T2 [$t(36) = 2.81$, $p = 0.008$, $d = 0.20$] but not from T2 to T3 [$t(36) = -0.7542$, $p = 0.456$, $d = -0.04$]. There was no significant interaction effect of group × time on the mixed ANOVA for MI (**Figures 2, 4**). A significant effect of time was found for MI [$F(2,202) = 11.9$, $p < 0.001$, $\eta^2_p = 0.105$]. The mixed ANOVA for BRI showed a significant interaction effect of group × time, $F(2,202) = 5.3$, $p = 0.006$, $\eta^2_p = 0.050$ (**Figures 3, 5**). A repeated measures ANOVA shows a significant effect of time for BRI in the intervention group $F(2,130) = 20.3$, $p < 0.001$, $\eta^2_p = 0.237$, but not for the control group $F(2,72) = 1.85$, $p = 0.164$, $\eta^2_p = 0.049$. A paired-samples t-test for the intervention group revealed a significant improvement from T1 to T2 [$t(65) = 3.42$, $p = 0.001$, $d = 0.27$] and from T2 to T3 [$t(65) = 2.96$, $p = 0.004$, $d = 0.30$]. A paired-samples t-test for the control group revealed no significant improvement from T1 to T2 [$t(36) = 1.81$, $p = 0.077$, $d = 0.14$] nor from T2 to T3 [$t(36) = -0.862$, $p = 0.378$, $d = -0.04$].

We found no significant interaction effects between time, group, and gender on GEC, MI, or BRI [GEC, $F(2,198) = 0.28$, $p = 0.755$, $\eta^2_p = 0.003$; MI, $F(2,198) = 0.01$, $p = 0.988$, $\eta^2_p = 0.000$; BRI, $F(2,198) = 1.54$, $p = 0.216$, $\eta^2_p = 0.015$]. Neither did we find any interaction effects between time and gender.

Semi-Structural Interviews With Teachers

The coding and categorization process extracted the following categories relevant for the aims of this article.

Collaboration

The teachers from all three schools described that the project gave the children new tools to succeed in cooperation with others. The students had to discuss solutions, give and take, individualists had to open to others' views and ideas. The teachers believed that intervening with classroom dynamics provided a better school environment.

Conflict Management

The teachers all report that the children's abilities to resolve conflicts improved because of the intervention. At one school, the teachers report that both children and teachers have a new approach in conflicts, as the children have learned new concepts and tools to resolve conflicts, and the teachers have become better at challenging the children to reflect upon difficult situations. In another school, the teachers report improved generosity in the

TABLE 4 | Results on BRIEF-teacher form (raw scores) at T1, T2, and T3: means and standard deviations within the intervention and control groups, and results from mixed model ANOVA.

Variable	Intervention (*n* = 66)			Control (*n* = 37)			Group		Time		Time × group		
	T1	T2	T3	T1	T2	T3	*F*	*p*	*F*	*p*	*F*	*p*	η_p^2
GEC	92.1 (20.9)	86.0 (18.6)	81.8 (13.7)	87.9 (20.5)	84.1 (19.6)	84.8 (21.7)	(1,101) 0.082	NS	15.8	>0.001	4.37	0.014	0.042
MI	55.3 (13.7)	51.8 (11.1)	49.7 (10.2)	52.4 (10.8)	49.9 (10.7)	50.2 (10.7)	(1,101) 0.504	NS	11.9	>0.001	2.24	NS	0.022
BRI	36.5 (8.31)	34.2 (8.61)	32.1 (5.00)	35.6 (11.8)	34.1 (10.1)	34.6 (11.8)	(1,101) 0.083	NS	12.6	>0.001	5.30	0.006	0.050

BRIEF, Behavior Rating Inventory of Executive Function; GEC, global executive composite; MI, metacognition index; BRI, behavioral rating index; NS, not significant.

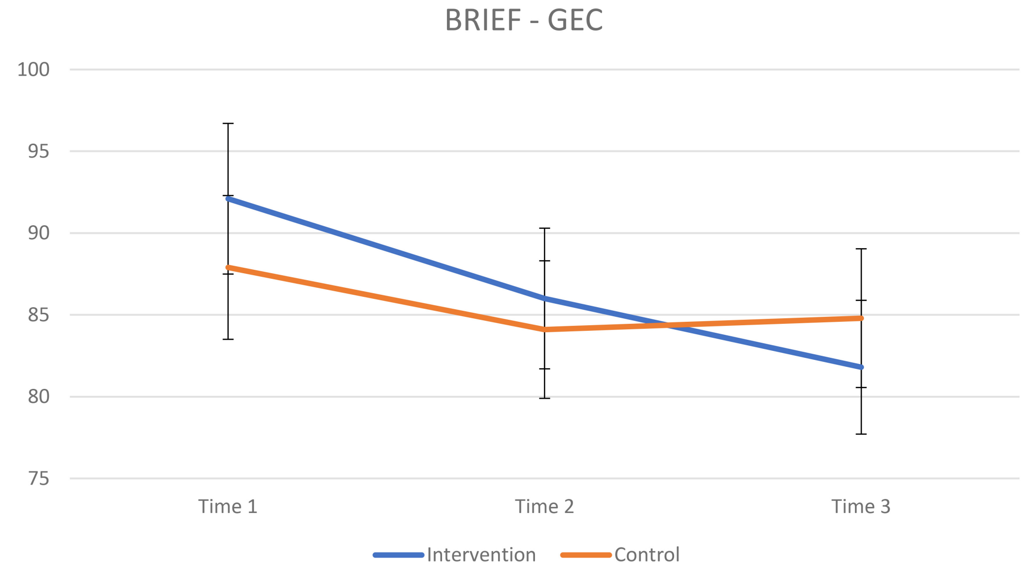

FIGURE 1 | Raw scores, lower scores indicating better results. Vertical bars denote 95% confidence intervals.

group, the children accept each other in a new way, and no one is laughing at each other.

Inclusion

In the interviews, the teachers emphasize the effect the project has had for inclusion. Some describes how the children, through collaborating with several, not just the best friends, create a better school environment. They see that children who were previously left out are included – that everyone is included in a different way than before. The established groups were dissolved, and the children expanded their circle of friends.

Vocabulary

The teachers all report that the children have expanded their vocabulary. They describe, respectively, how the children have acquired a richer language, learned new concepts, and have become more reflective. One teacher describes how the children gained a larger conceptual apparatus and thus were able to verbalize how they experienced the sessions. That children who initially just didn't want to be involved at the end were able to verbalize their own internal conflicts and how they could solve it. Furthermore, teachers describe how children's ability to take conversational turns also had improved.

Confidence

All schools describe that the children have become more confident in expressing their own opinions, and in taking responsibility for group achievements. Teachers from all schools believe the intervention has given the children mastery and a sense of increased self-confidence.

DISCUSSION

The results reveal that both groups improve their EFs, as measured with BRIEF, over time on the GEC score, the MI and on BRI. However, the group receiving the intervention had a significantly greater improvement than the control group on GEC and BRI. The teacher interviews reveal several effects of the project. They report positive effects for the children when it comes to; collaboration, conflict management, inclusion, vocabulary, and confidence. The results revealed no gender differences regarding development of EFs throughout the study period.

Global Executive Composite

The first aim of the current study was to examine whether an arts rich intervention constructed to improve children's EFs would

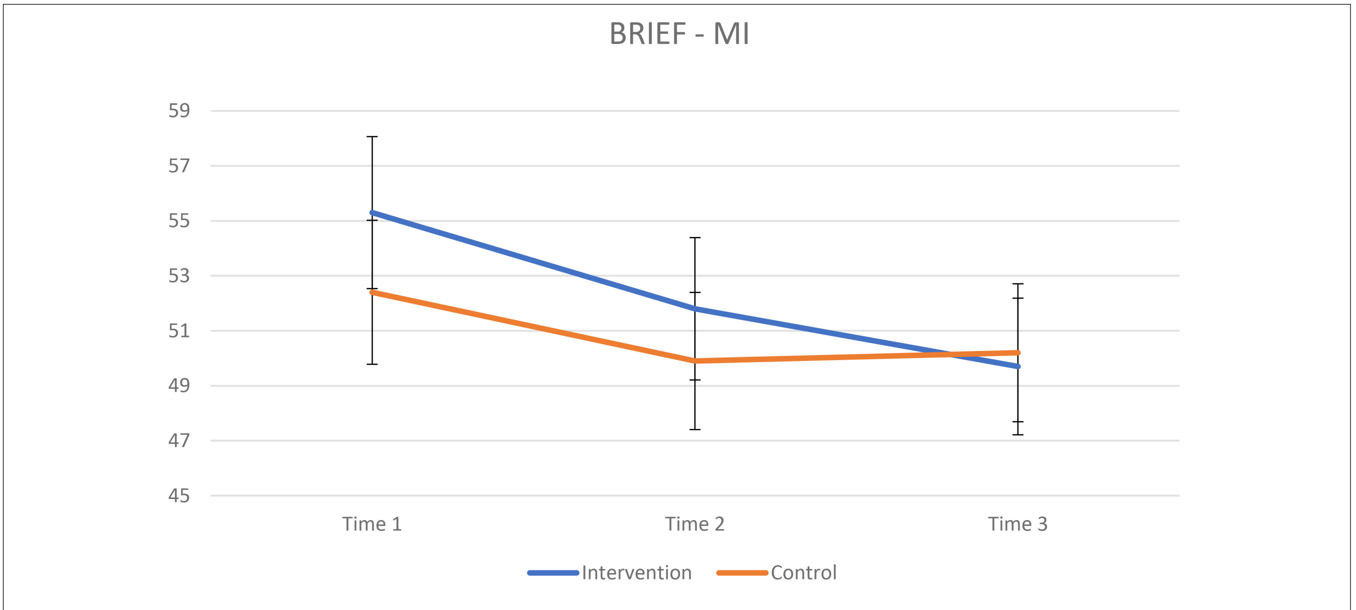

FIGURE 2 | Raw scores, lower scores indicating better results. Vertical bars denote 95% confidence intervals.

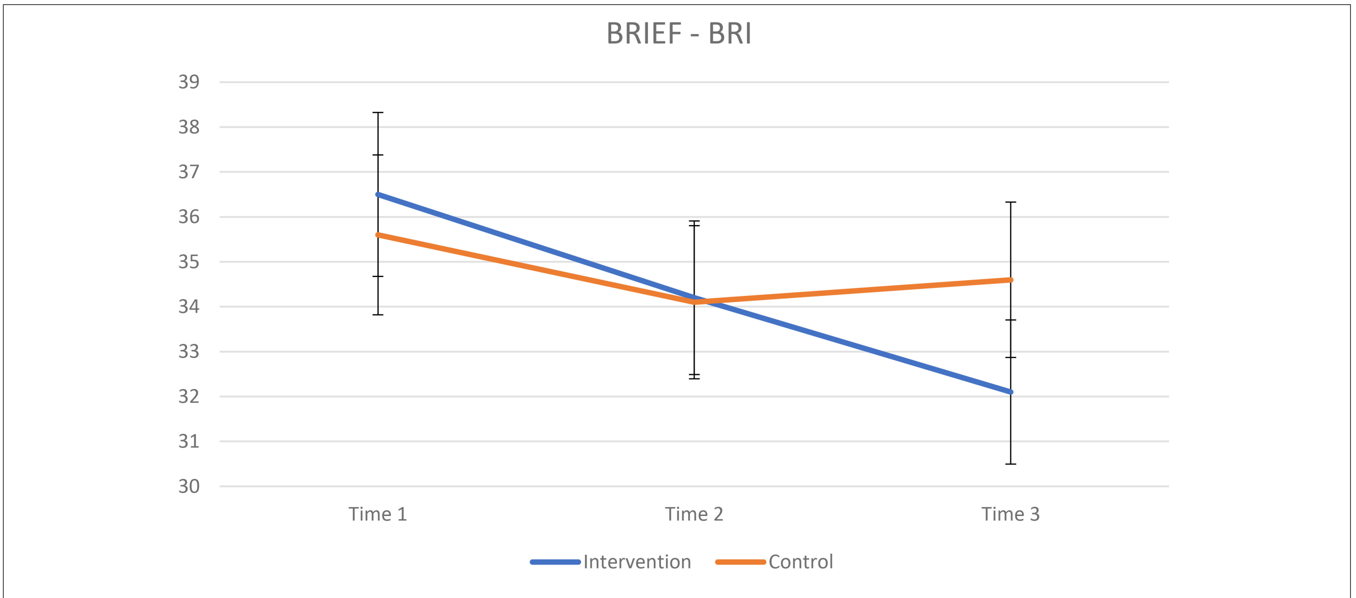

FIGURE 3 | Raw scores, lower scores indicating better results. Vertical bars denote 95% confidence intervals.

yield any effect on a measure on everyday EFs, as reported by children's teachers. Based on current knowledge we hypothesized that the intervention group would have a greater improvement overall in everyday EFs than the children in the control group. As expected, the intervention group displayed greater improvement overall with more than twice as large effect sizes, on a measure on everyday executive function (GEC) as reported by children's teachers, compared to the control group.

These results indicating a global effect of AoL are consistent with previous research showing a significant transfer effect of school curricula aiming to enhance EFs (Diamond and Lee, 2011). These findings are also corroborated by the reports from the teachers involved in the intervention and their reflections upon the effects it had on the participants when it comes to social competence, verbal abilities, and self-assurance. One potential explanation for this wide transfer effect of school curricula programs such as AoL may be the emphasis on dynamic EFs training in all activities, across different situations that may stay in contrast to more specialized EFs programs showing less generalized effect (Lillard and Else-Quest, 2006; Riggs et al., 2006; Diamond, 2007). As can be seen from **Figure 1**, GEC improvement in the intervention group and the control group divert from each other from the timepoint that the intervention was discontinued and until follow-up after 6 months. However,

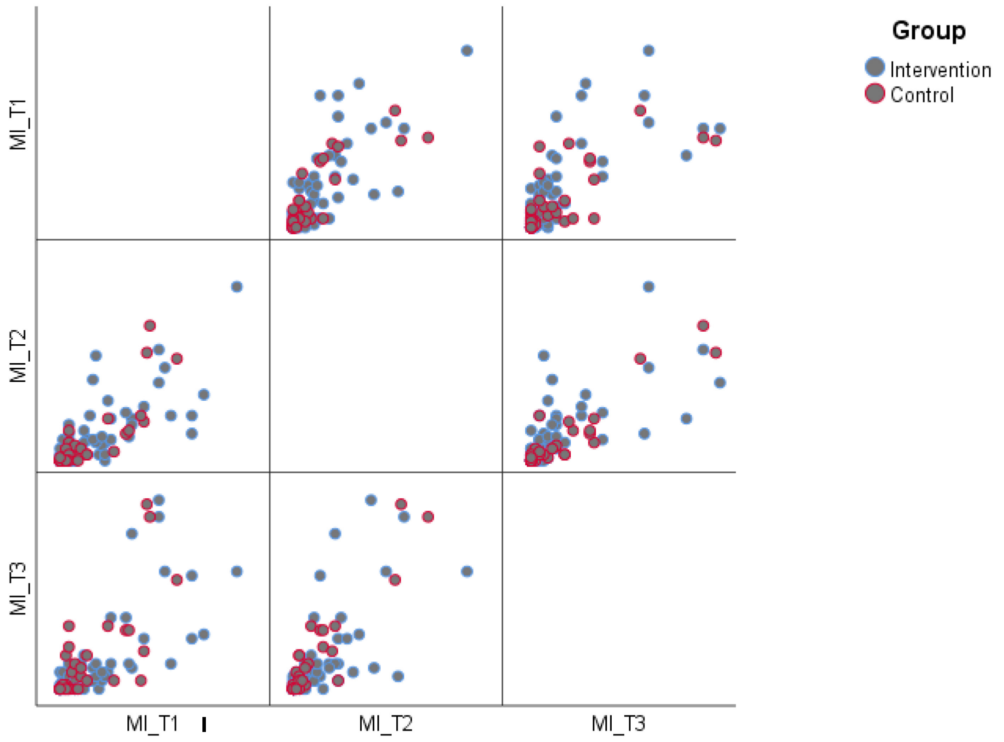

FIGURE 4 | Scatterplot matrix metacognition index time 1, 2, and 3.

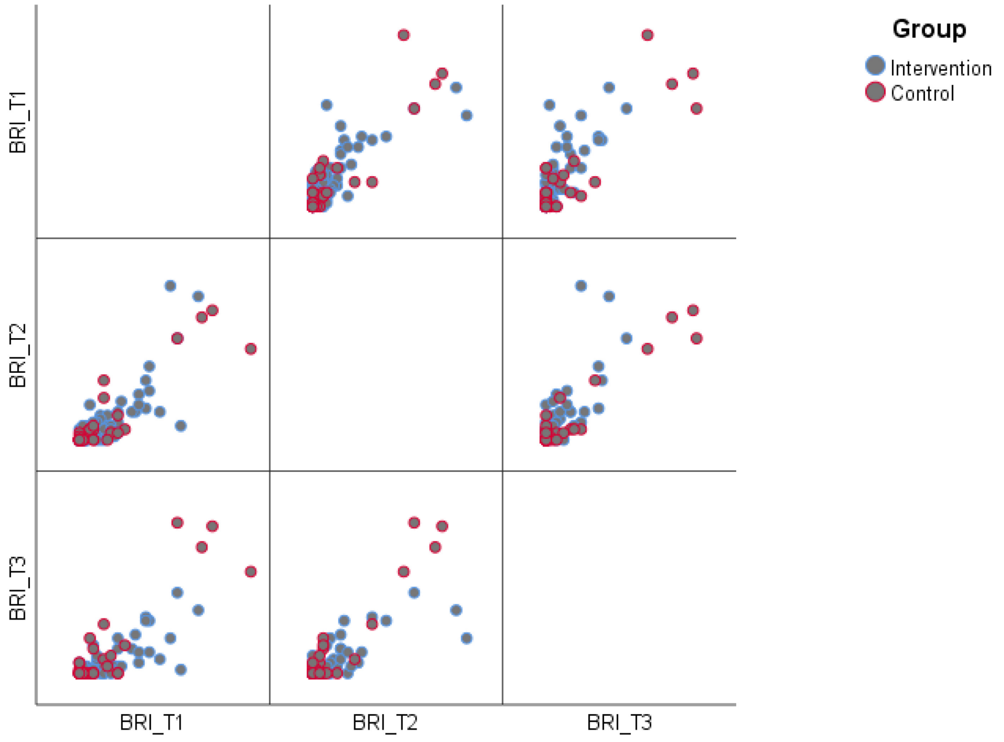

FIGURE 5 | Scatterplot matrix behavioral regulation index time 1, 2, and 3.

it must be noted that this global effect on improved EFs in the intervention group compared to the control group may primarily be driven by improved BRI in the intervention group. As a main difference between groups across time was found for the BRI, improved BRI scores in the intervention group attributes to most of the overall GEC score based on both MI and BRI. There is a possibility that the teachers involved in the intervention gradually altered their pedagogical practices to be more in accordance with AoL, so the prolonged effect may be directly related to the intervention. Such learning gains for teachers have also been reported from previous evaluations of other creative, arts and culture rich school curricula (Thomson et al., 2015).

Behavioral Self-Regulation

Our second aim was to delineate whether this intervention program, delivered intensively in schools, will have a differential impact on behavioral self-regulation and MCOG. According to findings reported by Carretti et al. (2014) we hypothesized that the group receiving intervention will show a significantly greater improvement in MCOG than the control group. We did not expect to find significantly greater improvement in behavioral self-regulation in the group receiving intervention compared to the control group. Contrary to our expectations, we did not find support for greater improvement in MCOG for the intervention group, compared to the control group. Surprisingly, the intervention group displayed a greater improvement in behavioral regulation with four times as large effect sizes compared to the control group. Thus, findings from the current study did not support our hypothesis that an arts rich intervention, constructed to improve children's EFs would yield a particular effect on EFs sub-functions shown to be crucial for school performance (Carretti et al., 2014). Where the MI reflect the child's ability to get engaged in planful and organized problem-solving, as well as, updating and shifting of information needed, the BRI to a higher extent comprises subscales reflecting the child's ability to initiate, inhibit, and modulate behavior, emotions, and activities (Gioia et al., 2000b).

Interestingly, results from our study showing improved behavioral regulation are consistent with findings by Bierman et al. (2008a) reporting better emotion-regulation and social problem-solving skills in pre-kindergarten children after being enrolled in PATHS curricula. Along the same lines, the reduction in problem behavior (d = 0.53−0.89) was the main finding in one "CRSP" – RCT of 609 preschool children, showing more moderate improvements in academic skills (d = 0.20−0.63) (Raver et al., 2009, 2011).

A similar main effect on improved behavioral outcome is evident in our study. When inspecting paired-samples t-tests for the intervention group, the global effect of AoL from T1 to T2 (GEC: d = 0.30) and from T2 to T3 (GEC: d = 0.26) is mainly driven by improved BRI (T1−T2: d = 0.27; T2−T3: d = 0.30). The effect sizes of t-tests from T1 to T2 and T2 to T3 are also small, below, or in line with comparable studies mentioned above. However, the effect sizes from the mixed measures ANOVA's are larger (η_p^2 = 0.237) and indicate that these children continue to improve their EFs more than controls from T1 to T3, although improvements are small to moderate. Albeit the findings from the RCTs by Bierman et al. (2008a), and Raver et al. (2009, 2011) are based on preschool children from low-income families, our findings corroborate previous results elucidating the centrality of improved emotional–behavioral regulation when aiming to improve EFs through different intervention programs.

Furthermore, as previous research has reported behavior regulation to be closely linked to social function (Kenworthy et al., 2009), and metacognitive competences of more importance for school performance (Carretti et al., 2014), our findings from both BRIEF and teacher interviews may indicate that the main advantage of such intervention programs will be related to children's social function, rather than on academic outcome. However, improved social function may boost academic outcome, in the long run, as improved social competencies enhance cooperation needed for solving many of the tasks given in school settings. Egeland and Fallmyr (2010) have speculated that the BRIEF's emotional regulation scale (a subscale of BRI) reflects the emotional and motivational aspects in EFs (i.e., hot EFs), in contrast to the less emotional items constituting the remaining scales in the BRIEF. In line with the interpretation by Egeland and Fallmyr (2010), improved BRI may reflect the necessities identified by Diamond (2014), that effective EFs training programs also help children to reduce stress, increase joy, make children feel they belong and improve physical fitness, i.e., in sum programs that not only will improve EFs and physical health, but also the children's mental health (Diamond, 2014). This assumption coincides with the conclusions from a critical review of a similar creative arts/culture-based curricula interventions, highlighting the benefits for well-being, citizenship, work-related skills, and habits (Thomson et al., 2015). Thus, improved BRI in the intervention group may not only reflect less problems with behavioral regulation, but also, according to Egeland and Fallmyr (2010) improved emotional regulation skills, and better mental health.

Metacognition

One potential interpretation of our results showing no greater improvement on MI in the intervention group, compared to the control group may be that potential improvements related to academic problem-solving activities (MI) may be more easily overlooked by teachers than the more overt behavior regulation competencies incorporated in the BRI. Previous research with clinical samples has shown that parents and teachers often report more behavioral symptoms, while children often report more symptoms about themselves than parents and teachers do regarding anxiety and depression (Faraone et al., 1995; Grills and Ollendick, 2002; Sciutto et al., 2004; Rothen et al., 2009; Skogli et al., 2013). Consequently, teacher ratings may be informative regarding behavioral regulation, but less sensitive regarding metacognitive competencies in children at school.

Strengths and Limitations of the Study

Strengths of the current study is a global intervention specifically aimed at improving executive functioning and the use of an everyday EFs measure pre, post, and 6 months after intervention.

Living in a society with low socio-economic differences and very high attendance to public schools, the study comprises a relatively representative group of pupils. The randomized controlled trial design and the implementation of both qualitative and quantitative data are also regarded as a strength. As the interventions were governed by teachers and artists in classrooms there is a possibility that interventions diverted slightly from how it was originally planned. The project manager visited each school to observe the sessions in order to check fidelity; however, no checklists or other means of checking fidelity were applied. A major limitation is using only teacher reports as outcome measure. This may cause some difficulties regarding a potential teacher–child disagreement. Due to this potential informant variance, it may be stated that what we actually measure is the teacher's apprehension of the child and not the child's capabilities. Therefore, improved EFs may more precisely reflect the teachers altered apprehension of the child. Teachers investment of time and energy to make the intervention work may also reflect how they rate their children after the intervention. However, as the effect was more visible after 6 months this is less likely. Other difficulties with the study are a relatively low *n*, and little control over confounding factors.

CONCLUSION

In conclusion, the AoL program shows promising effects on behavioral self-regulation (BRI) improvement in children aged 6–9 years as reported both from teacher rating scales and interviews. The executive subfunctions underpinning social competencies rather than academic outcome seem to be most affected by the intervention. It remains to be seen if this in turn will improve academic functioning as well.

DATA AVAILABILITY

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of the Norwegian Centre for Research Data with written informed consent from parents of all subjects. All parents gave written informed consent in accordance with the Declaration of Helsinki. The protocol was approved by the Norwegian Centre for Research Data.

AUTHOR CONTRIBUTIONS

PA collected the quantitative data material, did the statistical analyses, and made the first draft of the manuscript. MK did the interviews and the qualitative analyses. ES wrote parts of the manuscript. All authors contributed to the interpretation of both statistical and qualitative analyses, proofread and revised the manuscript, and gave approval to the publication.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.01769/full#supplementary-material

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ORIGINAL RESEARCH
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Program for the Neuropsychological Stimulation of Cognition in Students: Impact, Effectiveness, and Transfer Effects on Student Cognitive Performance

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Despite the crucial role played by the executive functions (EF) to cognitive, emotional, and social development of children before and during school years, little attention has been given to construct and analyze the efficacy of programs that intend to develop them. The program of neuropsychological stimulation of cognition in students: emphasis on EF, or PENcE (an acronym from its original name in Portuguese, *Programa de Estimulação Neuropsicológica da Cognição em Escolares: ênfase nas Funções Executivas*), is an early and preventive intervention program for school-aged children, and implemented at school three times a week for 5 months. The PENcE was structured in four modules, each focusing on a different executive component: organization and planning, inhibitory control, working memory, and cognitive flexibility. The objectives of this study were to verify the effectiveness of the PENcE among elementary school children and to investigate whether there are transfer effects to other executive, cognitive, and academic abilities. The sample consisted of 113 children attending 3rd or 4th grade at two public elementary schools. Eight classes participated in the study, divided into two groups: an experimental group (EG) (four classes; n = 64), which received the intervention, and a control group (CG) (four classes; n = 49), which continued their regular school activities. The EF and academic skills of both participant groups were evaluated before and after the intervention. The EG showed significantly greater improvements in inhibitory control, working memory, and abstract planning relative to the CG, with a small to medium effect size. There were transfer effects to other cognitive and academic abilities. These findings suggest the PENcE may be a useful method of improving EF and could benefit both school-aged children and education professionals.

Keywords: executive functions, cognitive development, cognitive stimulation, neuropsychological intervention, prevention

INTRODUCTION

Studies show that both academic and professional success depend largely on executive functions (EF) (Carlson et al., 2004; Prince et al., 2007). These abilities help individuals regulate and control their thoughts, behaviors, and emotions, allowing them to match behaviors to goals. EF can be understood in terms of three interconnected skills: working memory (the ability to hold and mentally manipulate information in order to perform more than one task at a time), inhibitory control (the ability to resist impulses and control automatic responses), and cognitive flexibility (the ability to change perspective or attentional focus) (Miyake et al., 2000; Diamond, 2013). The interactions between these abilities contributes to the emergence of more complex or higher-level functions, such as reasoning, problem solving, and planning (Diamond, 2013).

Metacognition is a skill that is closely related to EF. It concerns, among other aspects, the understanding of one's own knowledge and thoughts (Flavell, 1987; Dantas and Rodrigues, 2013). The development of EF begins very early [from 4 to 10 or 12 months of age, according to different authors (Diamond, 2013; Hendry et al., 2016)] and extends into adolescence or early adulthood (Best and Miller, 2010; Diamond, 2013). In fact, the development of these cognitive skills depends on both brain development and experience or environmental factors (Center on the Developing Child at Harvard University, 2011; Diamond, 2013). In Brazil, for example, in the current educational model, little instruction is given to students on how to enhance their EF. Most of the time, the school focuses on specific subjects, as well as competencies such as reading, writing, and mathematics. Even though students are increasingly required to complete projects, remember the dates of tests and assignments, and concentrate despite the presence of multiple distractions (Meltzer, 2010; Cardoso et al., 2016), they are hardly ever taught how to reflect about what they think and learn (metacognition) in a systematic way (Meltzer et al., 2007). Furthermore, students are seldom taught how to solve problems in a more flexible way (problem solving and mental flexibility) or control their impulses (inhibitory control). Many educators are interested in going beyond the school curriculum and providing opportunities for students to develop their cognitive abilities. However, they have no training or education on how to help students in this way. A study by León (2018) examined the content of pedagogy courses in the city of São Paulo, Brazil, and found that only 4.7% of institutions offered classes on the neurobiology or neuropsychology of learning. The result is an ever-widening gap between traditional teaching approaches and the real-world challenges facing students and teachers (Lopez-Rosenfeld et al., 2013).

To provide support to teachers and students and contribute to educational improvement, scientists, educators, and psychologists have become increasingly focused on understanding the methods and approaches that can be used to stimulate the development of EF in the school environment (Barnett et al., 2008; Bierman et al., 2008; Dias and Seabra, 2013). Studies show that early interventions to promote the development of such abilities can produce direct long-term benefits to school performance, minimizing academic difficulties and contributing to the reduction and prevention of social, and mental health issues (Bull et al., 2008; Thorell et al., 2009; Roebers et al., 2011).

The efficacy and effectiveness of existing programs aimed at stimulating the EF in children were analyzed in a recent systematic literature review, which examined 19 studies, mostly involving preschool students (Cardoso et al., 2016). The authors found that the interventions were successful in stimulating the EF of healthy children. The majority of programs described in the literature were computer based. Though the interventions led to improvements in targeted skills, the presence of transfer effects to other areas (cognitive abilities and everyday activities) has not been established. In addition to computer-based training, some studies have proposed a curriculum-integrated approach, with activities included in the regular school curriculum. This strategy seems to have broader and more generalizable effects, since it stimulates several cognitive components simultaneously, and tends to be more intensive than interventions outside the classroom setting. However, the review also identified significant heterogeneity in sample characteristics and in the instruments used for pre- and post-intervention assessments, which interfered with the comparison of results across studies (Cardoso et al., 2016). In the school setting, the following programs stand out: Tools of Mind (Bodrova and Leong, 2007; Diamond et al., 2007; Barnett et al., 2008); PATHS (Promoting Alternative Thinking Strategies) (Riggs et al., 2006); and the Program of Intervention and Self-Regulation and EF, or PIAFEx, an acronym for its original name in Portuguese (*Programa de Intervenção em Autorregulação e Funções Executivas)* (Dias and Seabra, 2013). The Tools of Mind is an American program based on Vygosky's theory of cognitive development. It was designed to be implemented as part of the school curriculum in early childhood education and instructs teachers on how to assist in the promotion of students' EF as part of their everyday practice. The program involves 40 activities designed to promote sociodramatic play, encourage the use of private speech, and teach students to use external resources to stimulate self-regulation (Bodrova and Leong, 2007). The PATHS program focuses primarily on emotional and social skills in school-age children and was developed in the United Kingdom. The program was designed as a preventive intervention to be used by educators in the classroom. The PATHS provides teachers with the materials and instructions to teach children about emotions, self-control, social competence, and interpersonal problem-solving skills (Riggs et al., 2006). Last, the PIAFEx is a Brazilian program focused on the stimulation of EF in early childhood education and the 1st year of elementary school. It contains 43 activities and is implemented by teachers in the classroom settings. The activities are divided into 10 basic modules and one complementary section. The activities combine physical/motor activities, rule-based games, strategy learning, organization, as well as time, and goal management with the aim of enhancing the EF (Dias and Seabra, 2013). These interventions have led to improvements in cognitive flexibility and working memory (Diamond et al., 2007), inhibitory control (Röthlisberger et al., 2012; Dias and Seabra, 2015a,b), and social behavior (Barnett et al., 2008). However, most of these investigations focused on preschoolers or first-year elementary students. Very few programs have been developed for children in second grade and beyond (e.g., Rosário et al., 2007). In several countries, children are guaranteed the right to attend kindergarten, and preschool. However, in some South American countries such as Brazil, approximately 20% of children are not enrolled in preschool, despite having the right to do so (Brasil, 2013). This means that many children do not have the opportunity to enhance their executive functioning and benefit from interventions carried out before elementary school (Dias and Seabra, 2016).

In light of this shortcoming, a new program has been developed to stimulate EF of school-aged children, entitled Program for the Neuropsychological Stimulation of Cognition in Students: emphasis on EF, or PENcE (an acronym from its original name in Portuguese, *Programa de Estimulação Neuropsicológica da Cognição em Escolares: ênfase nas Funções Executivas*) (Cardoso and Fonseca, 2016). The program seeks to potentiate and optimize the development of EF and related cognitive processes through play, cognitive activities, and teaching of systematic strategies in the school setting. The purpose of this study was to investigate the efficacy of PENcE in elementary school students (grades 3–4). Furthermore, we sought to verify whether the program would have any transfer effects to academic performance, other cognitive components, and behavior. For this, different measures were used to investigate several components of EF.

MATERIALS AND METHODS

Participants

The initial sample for the present study consisted of n = 160 elementary students in grades 3 and 4, recruited from two public schools in the city of Porto Alegre, Brazil. Eight teachers also took part in the study. The schools were chosen by convenience after their principals agreed to participate in the study. Both schools are in the same geographical area within the city of Porto Alegre, Brazil. The choice of two nearby schools was made in an attempt to control for demographic and socioeconomic variables. Since children in the experimental and control groups (CGs) attended the same schools, students and teachers were instructed not to discuss the intervention with one another. The importance of maintaining the confidentiality of intervention sessions was discussed with every participating teacher, who was also specifically instructed not to share or discuss with their colleagues any of the materials used in the intervention. Written informed consent was obtained from all parents, and assent forms were signed by every participating student.

The following exclusion criteria were applied: intellectual disability (25th percentile or lower on the Raven colored matrices test – Raven, 1938; adapted to Brazilian Portuguese by Angelini et al., 1999) (n = 13 children excluded); uncorrected sensory impairment (n = 0); genetic, psychiatric or neurological medical conditions (as reported by parents and teachers) (n = 10: n = 1 cerebral palsy, n = 1 major depression, n = 1 bipolar disorder, n = 7 attention deficit hyperactivity disorder); school absence rates of 25% or more during the execution of the program (n = 6); and age over 11 years and 11 months (n = 6). An additional n = 11 children transferred schools during the study and did not participate in the postintervention assessment, and n = 1 child was expelled from school during the postintervention assessment. Therefore, a total of n = 47 children were excluded from this study. **Table 1** shows the characteristics of the children in each classroom, the condition to which they were assigned, the number of students with parental consent to participate, the number of participants excluded, and the final sample.

As shown in **Table 1**, the vast majority (82.5%) of children agreed to participate in the study. The number of children excluded and the final sample size were similar across different schools. Cluster random sampling was used to assign each class to a different condition, so that some classrooms were randomly allocated to the experimental group (EG) and others to the CG. Children and teachers in the EG participated in the PENcE, while children in the CG continued their regular school curriculum. Two classes in each school were assigned to the EG (one in 3rd grade and one in 4th grade), while two were assigned to the CG (one in 3rd grade and one in 4th grade), for a total of 194 children (EG n = 103; CG n = 91). A total of 160 children (82.4%) received parental consent to participate in this study (EG n = 85, corresponding to 82.5%; CG n = 75, corresponding to 82.4%). A total of 24.7% of children in the EG (n = 21) and 36% in the CG (n = 26) were excluded from participation. As such, the final sample consisted of n = 64 children in the EG and n = 49 in the CG. The sociodemographic characteristics of the final sample are shown in **Table 2**. A total of eight public school teachers participated in the study, all of whom were female. Though all had a background in pedagogy, only five had postgraduate degrees (EG n = 3; CG n = 2). The average age of teachers in the EG was 41.25 years (SD = 8.26), while the average age in the CG was 46.25 years (SD = 7.41). Those in the EG had been working as teachers for 15 years on average (SD = 8.99), whereas those in the CG worked for a mean of 16.75 years (SD = 8.54). Teachers in the EG had been in their current jobs for an average of 8.50 years (SD = 3.87), and those in the control condition for 7.00 years (SD = 5.83). Teachers in both groups rated their professional performance as good to very good.

Materials

The PENcE was structured in four modules, each focusing on a different executive component: (1) organization and planning, (2) inhibitory control, (3) working memory, and (4) cognitive flexibility. To make the program more engaging and fun, students watched the movie *A Bug's Life*. From that point onward, every module in the program was presented by a different "ant" character. The "ants" and the "League of Mind Training Ants" were developed to accompany the program and improve the learning and consolidation of EF strategies. "Ant Beatrix" presents module 1 – organization and planning; "Ant Pedro" presents module 2 – inhibitory control; "Ant Patrícia" presents module 3 – working memory; and "Ant Fabio" presents module 4 – cognitive flexibility. The "League of Mind Training Ants," on

TABLE 1 | Characterization of the participants in each classroom, the condition to which they were assigned, the number of students with parental consent to participate, the number of participants excluded, and the final sample.

School	Class	Group	Children enrolled	Children with parental consent to participate in the study (%)	Children unable to participate in the study (%), considering the exclusion criteria	Final sample
School 1	3°-32	EG	25	24 (96)	5 (20.8)	19
	3°-33	CG	18	15 (83.3)	4 (26.6)	11
	4°-41	EG	23	21 (91.3)	6 (28.5)	15
	4°-42	CG	26	23 (88.5)	10 (43.4)	13
School 2	3°-A	CG	27	18 (66.6)	5 (27.7)	13
	3°-B	EG	29	22 (75.9)	4 (18.1)	18
	4°-A	EG	23	18 (78.3)	6 (33.3)	12
	4°-B	CG	23	19 (82.60)	7 (36.8)	12
Total				160 (82.5)	47 (29.3)	113

TABLE 2 | Characteristics of the final sample.

Sample characteristics		EG (*n* = 64)	CG (*n* = 49)	
		M (SD)	M (SD)	*p*-value
Age		8.64 (0.70)	8.86 (0.84)	0.138[a]
Age at school entry		5.80 (0.98)	6.02 (0.91)	0.238[a]
Socioeconomic score		19.12 (4.99)	20.23 (5.23)	0.275[a]
		f (%)	f (%)	
Gender	Male	31 (48.4%)	21 (42.9%)	0.555[b]
	Female	33 (51.6%)	28 (57.1%)	
Preschool	Yes	51 (82.3%)	38 (79.2%)	0.682[b]
	No	11 (17.7%)	10 (20.8%)	
Grade repetition	Yes	05 (7.8%)	08 (16.7%)	0.169[b]
	No	59 (92.2%)	39 (81.3%)	
Maternal educational level Illiterate		01 (1.6%)	01 (2.0%)	0.166[b]
Basic education		13 (20.3%)	20 (40.8%)	
High school		36 (56.3%)	22 (44.9%)	
College		09 (14.1%)	03 (6.1%)	
No information		05 (7.8%)	03 (6.1%)	
Paternal educational level Illiterate		00 (0%)	01 (2.0%)	0.093[b]
Basic education		22 (34.4%)	24 (49.0%)	
High school		27 (42.2%)	09 (18.4%)	
College		07 (10.9%)	07 (14.3%)	
No information		08 (12.5%)	08 (16.3%)	

[a]*Variables compared between groups using Student's t-tests.* [b]*Variables compared between groups using chi-square tests.*

the other hand, was introduced as a group of more experienced ants who are called in to help whenever the other ants need assistance. Throughout the program, the "League of Ants" teaches children the strategies and activities used to help the other ants, encouraging them to learn, and participate in the activities. In addition to the games and activities offered in the program, teachers are encouraged to integrate EF strategies into school activities in subjects such as mathematics, Portuguese, and Science. Each module, in turn, was divided into three stages:

Stage 1 – Strategy: Psychoeducation and modeling. Students are taught what, where, when, and how to use a strategy associated with EF discussed in that module. After explaining each strategy, the teacher provided examples and activities to illustrate how and when it could be implemented, in addition to modeling the strategies themselves.

Stage 2 – Learning and strategy consolidation. In the second stage, students are encouraged to actively implement the strategies through games, cognitive tasks, and school activities. Participants in the program completed a total of 38 cognitive activities.

Stage 3 – Reflection and transfer to daily life and school activities. The teacher encouraged students to reflect on how they could apply what they had learned to everyday situations and school activities. While these ideas are presented, the teacher encourages discussion and reflection, providing feedback to students throughout the process.

As an example, an activity developed in each module will be presented. Additional details on the names and procedures of different tasks in the PENcE are available in Appendix 1, as well as the recent book by Cardoso and Fonseca (2016).

Module 1: Organization and Planning, Activities: Looking for the Diamond

In this task, students must find a way to get to a diamond on a game board. In addition to the board, each pair of students receives a puppet, which they must place in a specific location. Then, the students are asked to find the best way to get the puppet to the diamond. Before making any moves, they must write down the planned path on a piece of paper using arrows to show the direction of each movement and stating the number of total steps required to get to the diamond. Only then can they move the puppet as planned.

Module 2: Inhibitory Control, Activities: Opposites Game

In this activity, the students must first name a series of pictures shown by their teacher. Then, they are shown a second set of pictures but are asked to say the opposite of what each picture shows.

Module 3: Working Memory, Activities: Sequencing

In this activity, students are shown a sequence of pictures of fruit and stationery. After the students see the sequence, the pictures are shuffled, and students are asked to put them back in their original order, organizing the fruits first and then the stationery items.

Module 4: Cognitive Flexibility, Activities: A New Ending for the Movie

After watching a movie, the teacher asks the students to imagine different endings for the film, and encouraging them to consider new possibilities and think in different ways. The teacher writes down all the ideas on the blackboard.

Procedures

This study was conducted as part of a larger project, approved by the Ethics Committee of the Pontifical Catholic University of Rio Grande do Sul (PUCRS) (project number 1.035.498). After the study was approved by the committee, we contacted the schools and requested authorization to carry out the investigation. Informed consent was obtained from the legal guardians of all participants prior to the beginning of the study. During the preintervention assessment, the children signed a Term of Assent. The study was conducted in three stages: (1) preintervention assessment, (2) program implementation, and (3) postintervention assessment. Each stage is explained in detail below. The assessments and the intervention were performed during the school year, in the school setting, in bright and airy rooms.

STAGE 1: Preintervention Neuropsychological Assessment

All students underwent clinical and neuropsychological evaluations prior to the intervention. All instruments were administered individually, except for the "single word writing test" and the "arithmetic subtest of the school achievement test (SAT), 4th grade," which were administered collectively. The assessment took place in a suitable setting, during regular school hours, with sessions lasting approximately 1 h and 30 min.

STAGE 2: Program Implementation

Prior to the intervention, each teacher in the EG took part in three individual training sessions. The teachers received printed material with key information on the PENcE and a proposed implementation schedule. Teachers also had weekly meetings with one of the cotherapists participating in the program, where they would discuss the activities performed as part of the intervention, clarify any questions, and present the tasks for the following week. These meetings lasted for 20–30 min and happened during school breaks or whenever the children were involved in activities outside the classroom.

The program was implemented by two neuropsychologists and a teacher from the EG. Group sessions were carried out in the children's regular classroom, three times a week for 5 months. Each session lasted approximately 50–60 min. The teachers conducted the program activities while the neuropsychologists acted as cotherapists, assisting the teachers and participating in two of the weekly intervention sessions The cotherapists were two neuropsychologists who split their time between the four classrooms of the EG according to a predetermined schedule (for more information, see Cardoso and Fonseca, 2016).

STAGE 3: Postintervention Assessment

Shortly after the completion of the program, clinical, and neuropsychological assessments were carried out for all students, using the same instruments as the preintervention assessment. The evaluation was performed by members of the research group who did not participate in the intervention and were blind to participant group.

Instruments Used in Pre- and Postintervention Assessments

Questionnaires Answered by Parents or Guardians:

(1) Sociodemographic and health questionnaires. These instruments were used to screen for medical issues and investigate the child's developmental history, as well as parental education levels (socioeconomic status). This questionnaire was given to parents so they could provide additional information about their children, including age, education level, date of birth, socioeconomic status, history of grade retention, diagnosed physical or psychological illnesses, current medication use, previous hospitalizations, and current medical treatments. This information was used for sample characterization purposes.

Assessment of Intellectual Functioning

Cognitive functioning was evaluated using several different instruments in order to evaluate all the components of the EF. All the instruments used have been adapted for the Brazilian population, and national normative data are available in all cases. In addition, all instruments have evidence of validity and reliability.

(1) Raven colored matrices test [Raven, 1938; adapted to Brazilian Portuguese by Angelini et al. (1999)]. This is a measure of non-verbal and fluid intelligence. It contains 36 items divided into three groups of 12 items each, distributed in ascending order of difficulty. Correct answers are summed to provide a total score (range of scores: 0 – 36 points).

Assessment of EF

(1) Hayling test [(Burgess and Shallice, 1997; Fonseca et al., 2010); adapted for use in Brazilian children by Siqueira et al. (2016)]. This instrument evaluates the following executive components: inhibition, initiation, cognitive flexibility, and processing speed. The test contains 20 sentences, divided into two parts (A and B) of 10 sentences each. In part A, the child must complete each sentence with a context-compatible word. In part B, the child must complete the sentences with a word that is not related to the general meaning of the statement. The variables measured are total reaction time until an answer is given (total time part A and total time part B), number of errors (total errors part A

and total errors part B/10) (range of scores: 0 – 10 points), number of errors in part B divided by 30 (total errors part B/30) (range of scores: 0 – 30 points), and ratio of the time taken to complete parts A and B (time B/time A).

(2) Go/No-Go Task from the Child Brief Neuropsychological Assessment Battery NEUPSILIN-Inf (Salles et al., 2016). This instrument primarily measures cognitive inhibition. An audio recording with 60 random numbers is played. The child is instructed to say "yes" every time he or she hears a number, but keeps silent when he or she hears the number 8. The total number of correct answers and omission and commission errors was calculated for each child (range of scores: 0 – 60 points).

(3) Unconstrained, letter, and category fluency (Jacobsen et al., 2016). These task involve several executive components, as well as lexical and semantic memory and linguistic abilities. In the unconstrained fluency test, the child is given 2 min and 30 s to say as many words as possible. In the letter fluency test, the child is given 2 min to elicit words that begin with the letter "p." Last, in the category fluency test, the child is given an additional 2 min to name as many clothing items as they can. The total number of correct responses was obtained for each fluency test.

(4) Digit Span Subtest from the Wechsler Intelligence Scale, 3rd version [(Wechsler, 1999), adapted by Figueiredo, 2002]. This subtest examines attention and auditory working memory. Numbers are presented in direct and reverse orders. In the first case, also known as forward digit span, the child must repeat the numbers listed by the examiner in the same order they were presented. The backward digit span portion is similar to the first, except the child must repeat the numbers in reverse order of presentation. The number of correct responses on the forward and backward digit span tasks was calculated separately, and then added up to yield a total score. With each hit, the child gets a point: the forward digit span tasks range of scores, 0 – 16 points; the forward and backward digit span tasks range of scores, 0 – 14 points; total score range of scores, 0 – 30 points.

(5) Wisconsin card sorting test (WCST)–short version (Kongs et al., 2000). This test evaluates reasoning, abstract planning, cognitive flexibility, and rule maintenance. The task has 64 cards, which the participant must match to four stimulus cards, according to a rule set by the examiner. The children are given feedback on their response after every attempt. The cards can be matched by either color, shape, or number. The variables collected for this test were the total number of trials (maximum score 64), number of completed categories (range of scores: 0 – 3), number of errors (range of scores: 0 – 64), number of perseverative errors (range of scores: 0 – 63), and failure to maintain set.

Discourse Analysis

(1) Oral Narrative Discourse (OND) (Prando et al., 2016). In this test, the children must retell a story they were previously presented. The task has three stages: (a) partial retelling of the story; (b) complete retelling of the story; and (c) comprehension assessment, including 11 questions about the text. Throughout the test, the examiner must also determine whether the participant has understood the moral of the story. In this activity, the following scores were calculated: number of essential information items included in the partial retelling (range of scores: 0 – 18 points), total number of information items in the complete retelling (range of scores: 0 – 13 points), and comprehension (range of scores: 0 – 11 points).

Evaluation of Strategies and Academic Performance

(1) Arithmetic Subtest of the SATs (Viapiana et al., 2016a). This test evaluates basic arithmetic skills. Items are arranged according to their level of difficulty. Two different versions were used in the present study: one for 3rd grade children and another for 4th grade children. The overall number of correct responses was calculated for each child (3th grade children: range of scores, 0 – 47 points; 4th grade children: range of scores, 0 – 54 points).

(2) Single word writing test (Smythe and Everatt, 2000; Capovilla et al., 2001). Two single word writing tasks were used, one of which was drawn from the International dyslexia test (IDT). The instrument consists of a dictation test with 40 stimuli: 30 real words and 10 pseudowords. The examiner reads each word alone, then uses it in a sentence, and repeats the word again. The number of correctly written words (total: range of scores, 0 – 40 points; real words: range of scores, 0 – 30 points; pseudowords: range of scores, 0 – 10 points) was calculated for every participant.

(3) Decoding of words and pseudowords [developed by Moojen and Costa (2007)]. This task consists of a list of 40 regular and irregular words, plus 10 pseudowords. Through quantitative (number of correct and incorrect responses: range of scores, 0 – 50 points) and qualitative (types of errors) analyses, we identified the reading routes used to complete the task.

Data Analysis

Data were analyzed descriptively and inferentially. Sociodemographic characteristics were compared between groups using chi-square and Student's *t*-tests for categorical and continuous variables, respectively. We then tested for significant differences between the EG and CG on the preintervention assessment using Student's *t*-tests. The presence and magnitude of intervention effects were determined using effect sizes (*d*), calculated as follows: $d = \Delta 1 - \Delta 2/S_{pooled}$, where Δj = Xpos – Xpre and S_{pooled} = [QSIImage]. These analyses were conducted using the Wilson's effect size calculator. We first computed the difference between group means for pre- and postintervention assessments ($\Delta 1$ and $\Delta 2$), before pooling the standard deviations of the four scores (EG pre- and postintervention, and CG pre- and postintervention). The correlation between measures in each group was also included in the calculation (Wilson, 2016). Lastly, the efficacy of the intervention was evaluated based on change scores, calculated as the difference between post- and preintervention assessments. Effect sizes were interpreted as described by Cohen (1988), with $d = 0.20$ suggesting a small effect, d near 0.50 representing a medium-sized effect, and d > 0.80 indicating a large effect size. A 95% confidence interval (CI) was also calculated for each effect size. Lastly, after calculating the difference between the mean values of each variable, a *t*-test for independent samples was used to analyze whether these values differed between participant groups. Results were considered significant at $p \leq 0.05$.

RESULTS

Group Comparisons of Preintervention Results (Baseline)

In **Table 2** the sociodemographic characteristics of the final sample are shown.

The groups did not differ with regard to gender, age, or socioeconomic status. The mean socioeconomic status of both groups was classified as C1 (low socioeconomic status, scores 23 – 28, mean family income of R$ 2,409.01/month), according to the Brazilian Criteria for Economic Classification, developed by the Brazilian Association of Research Companies (ABEP, 2014). **Table 3** shows the comparison between the two groups (experimental vs. control) on the preintervention assessment. The groups did not significantly differ on any cognitive or behavioral measures.

Cognitive Measures: Group Comparison of Differences Between Post- and Preintervention Assessments

Table 4 presents the mean and standard deviation for each cognitive measure, as analyzed before and after the intervention. Effect sizes (d), CIs, and *p* values are also shown. The number of participants is not the same across all tests. This occurred because some children and parents refused to complete certain instruments and, in a few cases, because some participants were unable to complete some of the tasks.

The groups differed significantly on some of the variables analyzed. Our measure of fluid reasoning (Raven's Colored Progressive Matrices), for instance, showed a small to medium effect size between groups. Improvements in inhibitory control (total correct responses on the Go/No-Go test and total errors part B/30 on the Hayling test) were also significantly greater in the EG relative to the CG, with an effect size in the small to medium range. Students in the EG took more time to complete tasks involving inhibitory control relative to their counterparts in the CG. This finding suggests that participants in the EG were less impulsive and put more thought into complex tasks (time B/time A on the Hayling test) than children in the CG. Furthermore, a significant group effect was observed on a measure of initiation and processing speed (total time part A in the Hayling test), where the EG outperformed the CG with a moderate effect size. The EG also obtained higher scores than the CG on measures of auditory attention and short-term auditory memory (total correct responses–digit span forward and total score–digit span–WISC-III). However, the groups did not differ in terms of their working memory (total correct responses–digit span backward). Students in the EG also showed improvements on the complete retelling score of the OND task, which evaluates episodic memory, working memory, linguistic expression, synthetic reasoning, and planning. The results of the WCST also revealed greater improvements in the EG relative to the CG on abstract planning (number of completed categories and total number of errors). No group effects were observed on any of the verbal fluency tests, though postintervention scores did improve relative to the preintervention assessment.

Measures of Academic Ability: Group Comparison of Differences Between Post- and Preintervention Assessments

Table 5 shows the results obtained by each group on measures of mathematical ability (Arithmetic Subtest for 3rd and 4th grades), reading (Decoding), and writing (single word writing).

Children in the EG outperformed the CG on all variables obtained from the single word writing test. Among third graders, significant differences between the EG and CG were also observed on the arithmetic subtest from the SAT. Among fourth graders however, no differences were noted either in the SAT or the decoding test.

DISCUSSION

This study was designed to examine the effectiveness of an early preventive intervention to stimulate EF in the school setting. The program was aimed at school-aged children in elementary grades 3 and 4. First, we sought to verify whether children who completed the program showed improvements in executive abilities relative to CG counterparts. Afterward, we investigated the presence of transfer effects to other cognitive (e.g., attention, fluid reasoning, and processing speed) and academic abilities (mathematics, word reading, and single word writing).

Our findings revealed significant differences between the EG and CG on several measures of EF, with improvements in the following executive components: inhibitory control, abstract planning, and complex verbal working memory. The effect size of these differences ranged from low to moderate. The results are aligned with previous studies, which found that executive components can be improved by school-based interventions (Lizarraga et al., 2003; Diamond et al., 2007; Barnett et al., 2008; Röthlisberger et al., 2012; Dias and Seabra, 2015a, 2016; Traverso et al., 2015). Furthermore, we observed transfer effects to attention, fluid reasoning, academic abilities, and behavior. These and other benefits of the PENcE will be discussed in more detail below. It is important to note that outcomes were evaluated through both formal methods (i.e., performance tests) as well as functional and ecological measures.

With respect to inhibitory control, we found that children in the EG had better impulse control than their CG counterparts. This was deduced from the fact that children in the experimental condition obtained significantly better scores than children in the control condition on the following measures: Total correct responses on the Go/No-Go test and total number

TABLE 3 | Comparison of preintervention assessment results between the experimental and CGs.

Variables	EG M (SD)	CG M (SD)	*p*
Raven – total correct responses	23.32 (4.23)	23.59 (4.96)	0.753
Verbal fluency – correct responses UVF	26.57 (12.21)	24.60 (14.19)	0.406
Verbal fluency – correct responses CVF	9.30 (4.82)	9.91 (3.80)	0.376
Verbal fluency – correct responses LVF	10.98 (4.22)	10.85 (4.02)	0.790
Go/No-Go – total correct responses	52.29 (5.70)	51.70 (5.93)	0.593
Go/No-Go – total omissions	4.30 (4.78)	4.75 (4.99)	0.619
Go/No-Go – total number of errors	3.46 (2.56)	3.52 (3.57)	0.937
OND – partial retelling EI	9.97 (4.25)	10.12 (4.02)	0.942
OND – partial retelling PI	12.54 (5.39)	15.66 (3.84)	0.889
OND – complete retelling	6.77 (3.83)	7.27 (3.22)	0.457
OND – text comprehension	8.03 (2.42)	7.71 (2.38)	0.419
Hayling test – total time part A	27.05 (15.68)	24.34 (14.29)	0.414
Hayling test – total errors part A	0.65 (1.03)	0.68 (0.88)	0.660
Hayling test – total time part B	48.33 (23.11)	40.49 (24.38)	0.565
Hayling test – total errors part B/10	5.78 (2.36)	5.37 (2.27)	0.563
Hayling test – total errors part B/30	14.97 (7.61)	13.72 (6.49)	0.595
Hayling test – time B/time A	2.04 (1.08)	2.05 (1.21)	0.885
Digit span fwd WISC-III	6.50 (1.46)	6.25 (1.61)	0.471
Digit span bwd WISC-III	3.29 (1.20)	2.91 (1.39)	0.092
Digits span fwd + Bwd WISC-III	9.81 (2.22)	9.18 (2.35)	0.152
Digit span fwd - Bwd WISC-III	3.21 (1.49)	3.33 (1.89)	0.521
WCST – number of trials	60.06 (7.43)	59.27 (7.51)	0.547
WCST – total errors	28.20 (12.35)	25.93 (13.76)	0.345
WCST – total perseverative errors	16.45 (11.66)	17.79 (13.39)	0.624
WCST – number of categories	1.85 (1.04)	1.96 (1.30)	0.760
WCST – conceptual-level responses	24.19 (11.69)	24.94 (12.96)	0.575
WCST – trials: First category	26.90 (20.31)	26.29 (19.67)	0.797
WCST – failure to maintain set	0.31 (0.65)	0.50 (0.85)	0.732
Arithmetic subtest–3rd grade	22.79 (5.78)	20.13 (5.89)	0.202
Arithmetic subtest–4th grade	17.27 (6.94)	16.31 (4.21)	0.260
Single word writing test – total correct responses	23.82 (6.34)	22.00 (7.58)	0.214
Single word writing test – total correct responses: pseudowords	5.42 (1.74)	4.95 (2.09)	0.279
Single word writing test – total correct responses: real words	18.40 (5.24)	17.04 (5.86)	0.232
Decoding – total correct responses	43.53 (8.73)	44.15 (6.69)	0.654
Decoding – real words	35.35 (7.20)	37.53 (3.53)	0.532
Decoding – pseudowords	8.18 (2.28)	8.42 (1.83)	0.863

Raven, Raven's colored progressive matrices; UVL, unconstrained verbal fluency; LVF, letter fluency; CVF, category fluency; EI, essential information; Fwd, forward; Bwd, backward; M, mean; SD, standard deviation.

of errors/30 on the Hayling test. Previous studies have found similar results among preschoolers (Dias and Seabra, 2015a; Traverso et al., 2015) and first graders (Röthlisberger et al., 2012; Dias and Seabra, 2015b). Additionally, as suggested by a marginally significant group difference on time B/time A of the Hayling test, the EG appeared to take longer than the CG to respond to complex situations involving impulse control. At first glance, this result may create the false impression that participants exposed to the intervention have become less flexible. However, we believe this finding can be better explained by the fact that children in the EG may have attempted to improve their accuracy by slowing down task execution, which indicates a decrease in impulsivity. Dias and Seabra (2015a) also found that children who participated in a cognitive intervention program showed an increase in reaction time when responding to a complex situation, indicating they took some time to think before providing a response.

This study also showed that children in the EG demonstrated improvements in initiation and processing speed (as measured by total time on part A of the Hayling test). This result indicates an enhancement in automatic skills. In other words, in more automatic situations, participants in the EG were faster to respond. Therefore, the present findings suggest that school-based interventions can lead to improvements in inhibitory control, processing speed, and initiation in typically developing children. Although not all measures showed significant differences in the improvement of CG and EG

TABLE 4 | Cognitive measures: descriptive and inferential data regarding the comparisons between preintervention, postintervention, and change scores for the EG and CG.

Variables	Group	N	M pre-	SD pre-	M post-	SD post-	r	Difference of means	d	CI	p
Raven's colored progressive matrices											
Total correct responses	EG	62	23.26	4.23	26.15	3.75	0.44*	2.89	**0.39**	**0.04/0.74**	**0.038**
	CG	48	23.75	4.88	25.04	3.60	0.69*	1.29			
Go/No-Go											
Total correct responses	EG	62	52.29	5.70	56.85	2.81	0.43**	4.56	**0.46**	**0.03/0.89**	**0.044**
	CG	48	51.70	5.93	54.10	3.92	0.31*	2.40			
Omission errors	EG	62	4.30	4.78	1.67	2.24	0.34**	2.63	0.33	−0.11/0.77	0.163
	CG	48	4.75	4.99	3.41	3.20	0.29*	1.34			
Commission errors	EG	62	3.46	2.56	1.41	1.24	0.11	2.05	0.40	−0.08/0.90	0.118
	CG	48	3.52	3.57	2.47	2.05	0.20	1.05			
Hayling test											
Time part A	EG	59	27.05	15.68	16.50	8.02	0.32**	10.55	**0.53**	**0.09/0.97**	**0.035**
	CG	46	24.34	14.29	20.85	14.80	0.40**	3.49			
Errors part A	EG	60	0.65	1.03	0.62	0.82	0.28*	0.03	0.08	−0.35/0.52	0.656
	CG	47	0.68	0.88	0.55	0.93	0.38**	0.13			
Time part B	EG	56	48.33	23.11	34.68	12.26	0.31**	13.65	0.37	−0.07/0.82	0.352
	CG	41	40.49	24.38	34.06	15.62	0.45**	6.43			
Errors part B/10	EG	60	5.78	2.36	4.80	1.81	0.40**	0.98	0.30	−0.13/0.74	0.166
	CG	46	5.37	2.27	5.04	2.05	0.33*	0.33			
Errors part B/30	EG	59	14.97	7.61	10.33	5.01	0.44**	4.64	**0.45**	**0.03/0.87**	**0.044**
	CG	46	13.72	6.49	11.85	5.05	0.40**	1.87			
Time B/time A	EG	57	2.04	1.08	2.48	1.31	0.48**	−0.44	**−0.41**	**−0.83/0.03**	**0.069**
	CG	41	2.05	1.21	2.01	1.11	0.40**	0.04			
Digits WISC-III											
Digit span fwd	EG	62	6.50	1.46	7.48	1.70	0.48**	0.98	**0.28**	**0.03/0.74**	**0.042**
	CG	48	6.25	1.61	6.62	1.56	0.61**	0.37			
Digits span bwd	EG	62	3.29	1.20	4.16	1.04	0.32*	0.87	0.25	−0.16/0.67	0.244
	CG	48	2.91	1.40	3.48	1.11	0.44**	0.57			
Digit span fwd + bwd	EG	62	9.81	2.24	11.61	2.14	0.52**	1.80	**0.41**	**0.06/0.76**	**0.034**
	CG	48	9.19	2.37	10.08	2.04	0.62**	0.89			
Digit span fwd - bwd	EG	62	3.20	1.49	3.32	1.78	0.38**	0.12	0.17	−0.23/0.59	0.410
	CG	48	3.33	1.89	3.14	1.76	0.45**	−0.19			
Verbal fluency											
Total correct responses (UVF)	EG	60	26.57	12.21	33.00	11.33	0.54**	6.43	0.01	−0.33/0.35	0.943
	CG	48	24.60	14.19	30.88	14.20	0.62**	6.28			
Total correct responses (LVF)	EG	60	9.30	4.82	11.02	3.58	0.35**	1.72	0.30	−0.11/0.72	0.161
	CG	47	9.91	3.80	10.36	4.30	0.42**	0.45			
Total correct responses (CVF)	EG	60	10.98	4.22	12.18	3.87	0.46**	1.20	0.07	−0.31/0.46	0.714
	CG	47	10.85	4.02	11.74	4.54	0.49**	0.89			
WCST											
Number of trials	EG	60	60.06	7.43	53.10	10.73	0.41**	6.96	0.15	−0.28/0.57	0.503
	CG	48	59.27	7.51	53.70	11.70	0.35*	5.57			
Total errors	EG	58	28.20	12.35	17.13	10.83	0.29*	11.07	**0.44**	**0.01/0.88**	**0.050**
	CG	46	25.93	13.76	20.22	11.49	0.43**	5.71			
Perseverative errors	EG	58	16.45	11.66	8.61	6.68	0.20	7.84	0.04	-0.42/0.49	0.994
	CG	46	17.79	13.39	10.43	9.92	0.43**	7.37			
Number of categories	EG	60	1.85	1.04	2.55	0.59	0.35**	0.70	**0.48**	**0.08/0.88**	**0.020**
	CG	58	1.96	1.30	2.19	0.89	0.45**	0.23			
Conceptual level	EG	60	24.19	11.69	31.68	5.92	0.18	7.49	0.42	−0.09/0.92	0.123
	CG	48	24.94	12.96	28.21	9.01	0.05	3.27			
Trials to complete first category	EG	60	26.90	20.31	16.17	10.24	0.36**	10.73	0.22	−0.23/0.68	0.380
	CG	48	26.29	19.67	19.37	16.20	0.20	6.92			
FMS	EG	60	0.31	0.65	0.25	0.54	0.03	0.06	−0.18	−0.70/0.33	0.457
	CG	48	0.50	0.85	0.29	0.61	0.12	0.25			
OND											
Partial retelling EI	EG	61	9.97	4.25	13.38	3.02	0.48**	3.41	0.09	−0.27/0.46	0.289
	CG	49	10.12	4.02	12.76	3.83	0.55**	2.64			
Partial retelling PI	EG	61	12.54	5.39	15.66	3.84	0.50**	3.12	0.22	−0.14/0.58	0.247
	CG	49	12.76	5.21	14.00	4.95	0.55**	1.24			
Complete retelling	EG	57	6.77	3.83	8.86	2.34	0.49**	2.09	**0.42**	**0.03/0.82**	**0.042**
	CG	49	7.27	3.22	8.04	2.87	0.47**	0.77			
Comprehension	EG	60	8.03	2.42	9.10	1.92	0.58**	1.07	0.14	−0.21/0.49	0.446
	CG	48	7.71	2.38	8.46	2.25	0.55**	0.75			

*Raven, Raven's colored progressive matrices; UVL, unconstrained verbal fluency; LVF, letter fluency; CVF, category fluency; EI, essential information; Fwd, forward; Bwd, backward; M, mean; SD, standard deviation; FMS, failure to maintain set. Bold values - there was a significant difference between the groups in those items. The asterisks represent significant at *$p < 0.05$ and **$p < 0.001$.*

TABLE 5 | Measures of academic ability: descriptive and inferential data regarding of the comparisons between preintervention, postintervention, and change scores for the EG and CG.

Variables	Group	*N*	M pre-	SD pre-	M post-	SD post-	*r*	Difference of means	*d*	CI	*p*
Arithmetic subtest of the SAT											
SAT 3rd grade	EG	34	22.79	5.78	29.91	5.21	0.42**	7.12	**0.57**	**0.04/1.10**	**0.041**
	CG	22	20.13	5.89	23.90	6.71	0.60**	3.77			
SAT 4th grade	EG	22	17.27	6.94	23.59	6.34	0.40*	6.32	0.38	−0.21/0.99	0.950
	CG	23	16.31	4.21	20.21	6.40	0.55**	3.90			
Single word writing test											
Total correct responses	EG	47	23.82	6.34	28.85	5.52	0.85**	5.03	**0.45**	**0.22/0.69**	**<0.001**
	CG	41	22.00	7.58	23.92	7.96	0.86**	1.92			
Pseudowords	EG	47	5.42	1.74	6.70	1.58	0.38**	1.28	**0.78**	**0.36/1.19**	**<0.001**
	CG	41	4.95	2.09	4.70	2.44	0.69**	−0.25			
Real words	EG	47	18.40	5.24	22.12	4.46	0.83**	3.72	**0.26**	**0.09/0.52**	**0.046**
	CG	41	17.04	5.86	19.31	6.40	0.81**	2.27			
Word decoding											
Total correct responses	EG	40	43.53	8.73	46.10	4.76	0.50**	2.57	0.22	−0.22/0.66	0.363
	CG	33	44.15	6.69	45.27	5.01	0.58**	1.12			
Real words	CG	40	35.35	7.20	37.53	3.53	0.55**	2.18	0.18	−0.24/0.61	0.598
	EG	33	35.70	5.52	37.24	3.70	0.70**	1.54			
Pseudowords	CG	40	8.18	2.28	8.58	1.77	0.49*	0.40	0.40	−0.06/0.86	0.195
	CG	33	8.42	1.83	8.03	1.98	0.52**	−0.39			

M, mean; SD, standard deviation; d, effect size. Bold values - there was a significant difference between the groups in those items. The asterisks represent significant at $^*p < 0.05$ *and* $^{**}p < 0.001$.

participants over time, all significant differences favored the EG, that is, in no case did the CG present greater gains than the EG.

With regard to working memory, though the groups did not differ on the backward digit span (WISC-III), significant differences were identified on the complete retelling variable from the OND task. This may be attributed to improvements in episodic memory skills and complex verbal working memory in EG participants. Unlike the Backward Digit Span, the OND task evaluates cognition in a contextualized situation (narrative), which places additional demands on linguistic expression, synthetic reasoning, and planning. Indirectly, this task also recruits working memory processes, since the individual must retain the information from previous paragraphs and integrate it with more recent information in order to understand and retell the story. Previous studies involving school-based intervention programs have produced inconsistent findings in this regard, with some identifying significant group differences (Lizarraga et al., 2003) and others failing to do so (Röthlisberger et al., 2012; Dias and Seabra, 2015a,b). However, there is an important difference between these studies: the program developed by Lizarraga et al. (2003) was aimed at private school students with an average age of 13 years. The present investigation, along with other related studies (Röthlisberger et al., 2012; Dias and Seabra, 2015a,b) focused on preschoolers and early primary school children. The PENcE also appeared to have an impact on planning skills, as evidenced by moderate group differences on the number of completed categories on the WCST.

With respect to cognitive flexibility, although the EG showed improvements relative to its preintervention assessment, there were no differences between groups on the total number of perseverative errors on the WCST. Similar results were found by Dias and Seabra (2015a) in preschoolers and by Röthlisberger et al. (2012) in school-aged children. Other studies, however, found improvements in cognitive flexibility among participants in the EG (Lizarraga et al., 2003; Diamond et al., 2007; Dias and Seabra, 2015b). One possible explanation is the format of the tasks used to evaluate cognitive flexibility. Instruments such as the trial making test and Flanker test require that the individual respond to a set of stimuli in a given manner, until they are instructed by the examiner to change the type of response provided. Other tasks, like the WCST, also involve changing response patterns; however, in this case, the examiner does not explicitly inform the participant when they must change their response. The participant must infer the need to adopt a new response pattern based on feedback and observation, which requires significantly more abstract reasoning.

Another possible explanation for these findings is that attention and inhibition begin to develop in early childhood, while working memory and flexibility are more complex and begin to develop later (Karbach and Kray, 2009; Dawson and Guare, 2010; Diamond, 2013; Dias and Seabra, 2015a). It is also possible that these abilities can only be affected by longer interventions, as proposed in programs with an estimated duration of 1–2 years (Lizarraga et al., 2003; Diamond et al., 2007; Barnett et al., 2008). As such, we recommend that the working memory and cognitive flexibility modules be extended and complemented by additional activities. This must also be accompanied by an increase in the length of teacher training periods. We might also consider the structure of the program, in which the working memory and cognitive flexibility modules were the last to be presented. Thus, they are stimulated for less time than components introduced earlier in the program, such as planning and inhibitory control. Another hypothesis is that the benefits of the program may only become evident later (Diamond and Ling, 2015). Some authors have not identified improvements in EF immediately after an intervention but did identify group differences on follow-up assessments (Hermida et al., 2015; Dias and Seabra, 2016).

In addition to initiation and processing speed, there was evidence of transfer effects to attention and short-term memory, as measured by the Forward Digit Span (WISC-III). There also appeared to be transfer effects to fluid reasoning/intelligence, as measured by Raven's colored progressive matrices. In the digit span forward, children from the EG showed greater gains than their CG counterparts. This result supports the hypothesis that EG participants showed improvements in automatic abilities. The relationship between fluid reasoning and EF has been widely researched, and many authors have identified a close association between these two constructs, especially during childhood (Friedman et al., 2006; Brydges et al., 2012; Diamond, 2013). Furthermore, in the past few years, several studies have shown that certain interventions on EF have positive impacts on fluid intelligence (Klingberg et al., 2002, 2005; Lizarraga et al., 2003; Jaeggi et al., 2008; Klingberg, 2010; Bergman Nutley et al., 2011). For instance, studies where a computer program was used to stimulate working memory in children with ADHD showed that participants also experienced significant gains in fluid intelligence, also measured by the Raven test (Klingberg et al., 2002, 2005). On the other hand, when this protocol was administered to healthy preschoolers in a different study, no improvements on the Wechsler Intelligence Scale for Preschoolers were identified in children exposed to the intervention (Thorell et al., 2009). Therefore, the literature is not unanimous with regard to the transfer effects of cognitive training programs to fluid intelligence.

The PENcE also had a positive impact on academic abilities, namely, mathematics and single word writing. There is a strong relationship between EF skills (especially working memory) and mathematical ability. In fact, some studies consider EF a predictor of academic ability (Blair and Razza, 2007; Raghubar et al., 2010; Cragg and Gilmore, 2014). Third graders in the present study showed significant improvements in mathematical ability relative to the CG, who maintained their regular school activities. However, these differences were not observed among fourth graders. The test is more demanding for third graders, which may be why the effects were more evident in this population (Viapiana et al., 2016b). In the single word writing test, the EG showed significantly better performance than the CG for both real words and pseudowords. Previous studies have also shown that interventions to stimulate EF in typically developing children can have a positive impact on academic skills such as reading (Loosli et al., 2012; Karbach et al., 2015), mathematics (Söderqvist and Bergman Nutley, 2015; Dias and Seabra, 2016), and writing (reduced errors in syntax and orthography) (Hooper et al., 2006). Despite improvements in some academic abilities, the EG did not show significant differences in word decoding or school performance (as graded by their teachers). In the study conducted by Rosário et al. (2010), the authors found that participants in the EG improved their knowledge of learning strategies but did not show significant improvements in school performance in mathematics or Portuguese.

Some limitations of the present study must be taken into consideration. This program worked exclusively with teachers and students and did not involve parents. Additionally, our CG did not actively participate in a cognitive training program. Moreover, the use of mixed outcome measures may have made it more challenging to discuss the present findings. We recommend that future studies work on adapting the PENcE to high school students and different clinical groups (e.g., children with ADHD or learning disorders), so that the program can be used in different contexts. The PENcE may also be implemented in the public schools of developing countries as a public policy initiative. Additionally, we recommend a follow-up study to evaluate whether the results change over time. The program may also be complemented by meetings with parents and guardians to raise awareness and provide guidance on how EF can be stimulated at home and in daily life activities. Parents' understanding of executive functioning can help maintain the effects of the intervention in everyday life (Volckaert and Nöel, 2015). We also suggest that the program be amplified to include a module focused on "hot" EF and tasks used to evaluate them. "Hot" EF are related to emotional processes and include motivation, decision-making, emotion regulation, and responses to reward and punishment. "Cold" EF, on the other hand, are more closely related to logical and cognitive processes, such as logical and abstract reasoning, planning, problem solving, and working memory (Zelazo et al., 2005). The PENcE focused on cold EF, and as such, it may benefit from the inclusion of an additional module that deals with emotion regulation. Last, another limitation of this study is that systematic assessments of fidelity were not carried out. Future studies may complement the measures used in the present investigation with records of the number of children who implemented the strategies and used them throughout the intervention (performance records) or in their daily lives.

This study demonstrated the efficacy of the PENcE and showed that it is possible to stimulate EF in school settings with an early preventive intervention for children in elementary school grades 3 and 4, even in poor socioeconomic conditions. Children who participated in the EG outperformed their CG counterparts in several outcome measures. We believe that the ecological setting of the program, the use of a children's story to set up the intervention, and the inclusion of cognitive activities and games were highly motivational, improving engagement and the establishment of mnemonic, and emotional connections among participants. This structure provided the opportunity for exploration, active learning, and the use of visual stimuli, all of which are known to be beneficial for students (Marzano, 2003). Children seldom refused to participate in the program or specific activities. Another positive aspect of the intervention was that it took place in children's school, complementing the regular curriculum. This program was unique in the sense that teachers were encouraged to include EF strategies in other classroom activities, which may have increased transfer effects. Finally, this program encouraged the use of explicit and systematic strategies, as well as reflection, which plays a fundamental role in the development of EF (Espinet et al., 2013).

DATA AVAILABILITY

All datasets generated for this study are included in the manuscript and/or the supplementary files.

ETHICS STATEMENT

This study was conducted as part of a larger project, approved by the Ethics Committee of the Pontifical Catholic University of Rio Grande do Sul (PUCRS) (Project No. 1.035.498). After the study was approved by the committee, we contacted the schools and requested authorization to carry out the investigation. Informed consent was obtained from the legal guardians of all participants prior to the beginning of the study.

AUTHOR CONTRIBUTIONS

CdC wrote the manuscript, analyzed the data, and implemented the intervention in schools. AS assisted in the writing of the manuscript, and reviewed the results and discussion. CG made and assisted the statistical analyses. RF guided the study and reviewed the entire manuscript.

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APPENDIX

Structure of the PENcE (Cardoso and Fonseca, 2016)

INTRODUCTION

Presentation of the program and movie ("Bug's Life")

MODULE 1: ORGANIZATION AND PLANNING

Strategy: Three steps: planning (taking the time to think before starting a task); execution (thinking while doing the task); and assessment (reflect and assess whether the goals of the task were achieved)

Stage 1: Strategy acquisition: Psychoeducation and modeling

Psychoeducation: Introduction of "Ant Beatrix," a ballerina who has trouble with planning, and gets confused when she has many things to do

Modeling: Activities: Packing your backpack and Creating a notebook cover

Stage 2: Learning and strategy consolidation

The following activities were developed as part of this section:

- Dot game
- Looking for the diamond
- Logical sequence
- Building a bug
- Cooking
- School activities

Stage 3: Reflection and transfer to daily life and school activities

Recap of the section and strategies learned; opportunity to discuss and reflect

RECAP OF PREVIOUS MODULES

Writing a text

MODULE 2: INHIBITORY CONTROL

Participants are taught the "Stop, Think, and then Go" strategy"

Stage 1: Strategy acquisition: Psychoeducation and modeling

Psychoeducation: Introduction of "Ant Pedro," who loves playing soccer, but is very impulsive and has trouble waiting his turn

Modeling: Activities: Opposites game and looking for the target

Stage 2: Learning and strategy consolidation

The following activities were developed as part of this section:

- Dancing
- Looking for the target
- Willpower
- Simon says
- Card game: Snap
- School activities

Stage 3: Reflection and transfer to daily life and school activities

Recap of the section and strategies learned; opportunity to discuss and reflect

RECAP OF PREVIOUS MODULES

- Birthday party
- Building an object: a closed mouth catches no flies

MODULE 3: WORKING MEMORY

Strategy – Four steps are suggested: (1) paying attention to the stimulus/instruction; (2) memorizing new information – use of mental repetition and visualization; (3) mental organization of information; and (4) performing activities slowly, focusing on quality rather than speed

Stage 1: Strategy acquisition: Psychoeducation and modeling

Psychoeducation: Introduction of "Ant Patricia," who loves fashion and wants to be a model; but is very forgetful, and can't keep track of multiple items of information or instructions

Modeling; activities: Image sequencing; body parts; and numbering the sequence

Stage 2: Learning and strategy consolidation

The following activities were developed as part of this section:

- Sequencing
- Differences game

- The missing one
- Completing sentences
- Numbering the sequence
- School Activities

Stage 3: Reflection and transfer to daily life and school activities

Recap of the section and strategies learned; opportunity to discuss and reflect

RECAP OF PREVIOUS MODULES

- Following instructions
- Crazy sentences

MODULE 4: COGNITIVE FLEXIBILITYS

Strategy: When something unexpected happens or a problem arises, we need to think of multiple alternatives

Stage 1: Strategy acquisition: Psychoeducation and modeling

Psychoeducation: Introduction of "Ant Fabio," who sings in a band with his classmates. When he comes across a new situation or his plans fall through, he has trouble thinking of different ways to resolve the situation

Modeling: activities: A new ending for the movie and group drawing

Stage 2: Learning and strategy consolidation

The following activities were developed as part of this section: - Taking a new perspective - Switching game - Matching cards - Crack the code - A new ending - School activities

Stage 3: Reflection and transfer to daily life and school activities

Recap of the section and strategies learned; opportunity to discuss and reflect

RECAP OF PREVIOUS MODULES

Complete all modules Activities:

- A new ending for the "Three Little Pigs"
- Building a different tower
- Picnic

frontiers in Psychology

ORIGINAL RESEARCH
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Sustained Effect of Music Training on the Enhancement of Executive Function in Preschool Children

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Musical training is an enrichment activity involving multiple senses, including auditory, visual, somatosensorial, attention, memory, and executive function (EF), all of which are related to cognition. This study examined whether musical training enhances EF in preschool children who had not undergone previous systematic music learning. This study also explored the after-effects 12 weeks after cessation of musical training. Participants were 61 preschool children from a university-affiliated kindergarten in North China. The experimental group underwent 12 weeks of integrated musical training (i.e., music theory, singing, dancing, and role-playing), while the control group performed typical daily classroom activities. The three components (inhibitory control, working memory, cognitive flexibility) of executive functions were evaluated using the Day/Night Stroop, Dimensional Change Card Sort, Dot Matrix Test, and Backward Digit Span Task. In Experiment 1, EFs were tested twice-before (T1) and after (T2) the music training. The results showed that children's EFs could be promoted by musical training. In addition, EFs were tested again 12 weeks later after the end of the intervention (T3) in Experiment 2. We discovered that integrated musical training demonstrated a sustained promotion effect.

Keywords: music, training, executive function, preschool children, sustained effect

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INTRODUCTION

Executive Function and Training

Executive Function (EF) refers to a family of top-down mental processes necessary for concentration, specifically when relying on instinct, intuition, or automatic processing would be ill-advised, insufficient, or impossible (Miller and Cohen, 2001; Espy, 2004; Burgess and Simons, 2005). The division of EF dimensions by various researchers is still controversial. For instance, Miyake et al. (2000) focused on the shifting of mental sets, monitoring/updating of working memory representations, and inhibition of prepotent responses as the three subcomponents of EF; while Garon et al. (2008) labeled EF as inhibition, shifting, and working memory. However, the current study follows the definitions proposed by Diamond (2013), who considered EF to consist of inhibitory control, working memory, and cognitive flexibility. Specifically, these three components were defined as (1) Inhibitory control: the aspect of inhibitory control that involves resisting temptations and not acting impulsively or prematurely; (2) Working memory (WM): holding information in mind and mentally working with it (e.g., relating one thing to another, using information to solve a problem); and (3) Cognitive flexibility: changing perspectives or approaches to a problem, flexibly adjusting to new demands, rules, or priorities (as in switching between tasks) (Diamond, 2013, p. 137).

Executive Function efficiency is an important factor in ensuring physical/mental health, a key predictor of academic/career achievements, and also it plays a vital role in cognitive, social, and psychological development (Baler and Volkow, 2006; Brown and Landgraf, 2010; Morrison et al., 2010; Miller, 2011). EF is incredibly plastic, which can be improved throughout the lifespan. However, the plasticity of EF tends to show a gradual downward trend with aging (Fernández-Ballesteros et al., 2003; Lustig et al., 2009). Therefore, in the early stages of child development, targeted training of EF can allow cognitive ability, as well as physical and mental development, to reach a higher level.

To date, researchers have used interventions such as sports, meditation, and gaming to promote children's EF development (Lakes and Hoyt, 2004; Winsler et al., 2011; Becker et al., 2014; Razza et al., 2015) (**Table 1**). For instance, Lakes and Hoyt (2004) randomly divided 207 children into experimental and control groups. Experimental group underwent 3 months of martial arts training, while the control group underwent 3 months of traditional sports training. Following training, children in the experimental group exhibited improved cognitive self-regulation, affective self-regulation, prosocial behavior, classroom conduct, and performance on a mental math test than children of the control group. Additionally, Razza et al. (2015) divided 29 children, aged three to five, into experimental and control groups, and then trained the experimental group in yoga based meditation. Children were assessed via behavior questionnaire, the toy wait task, and the pencil-tapping task, both before and after training. Results showed a remarkable increase in the experimental group's inhibition ability. Further, Becker et al. (2014) used brief sessions to develop EF of children, aged four to six. Following intervention, children's inhibition ability was generally increased, as well as their ability in reading and mathematics. Winsler et al. (2011) conducted a combination of sound and behavioral musical training for 89 children, between the ages of three and five. Using the gift delay task, dragon/bear game, straight-line task, and other behavioral inhibition experiments, the researchers examined whether the experimental group could suppress its dominant response after musical training. Results showed that the scores of the dominant response of the children who had undergone musical training were significantly higher than those of the control group, and the children who had undergone musical training demonstrated a significant increase in self-speaking in the selective attention task.

TABLE 1 | A synthetic table of EFs.

The type of training	The effects on the specific abilities of EFs	References
Computerized training	Working memory	Klingberg et al., 2005; Holmes et al., 2009; Johnstone et al., 2010; Bergman Nutley et al., 2011
Arts training (e.g., martial arts, mindfulness practices, yoga)	Inhibitory control Working memory	Manjunath and Telles, 2001; Lakes and Hoyt, 2004; Flook et al., 2010; Zelazo and Lyons, 2012; Razza et al., 2015
Sports	Cognitive flexibility, Working memory, Inhibitory control	Tuckman and Hinkle, 1986; Sarnthein et al., 1997; Lakes and Hoyt, 2004; Bergman Nutley et al., 2011; Davis et al., 2011; Kamijo et al., 2011
Music training	Cognitive flexibility, Working memory, Inhibitory control	Degé et al., 2011; Moreno et al., 2011; Winsler et al., 2011
Task training (e.g., the delay of gratification task: flanker, go/no-go)	Inhibitory control	Binder et al., 2000; Traverso et al., 2015
Add-Ons to Classroom Curricula (e.g., Promoting Alternative Thinking Strategies, the Chicago School Readiness Project)	Inhibitory control Cognitive flexibility	Kusché et al., 1993; Webster-Stratton and Reid, 2004; Riggs et al., 2006; Raver et al., 2008; Zhai et al., 2011

According to a comprehensive meta-analysis of EF training programs (Diamond and Ling, 2016), there are several ways to improve EF. These include computerized cognitive training, Montessori-based school curricula, martial arts, and yoga. To be successful, key elements, such as high-quality activity presentation, adequate practice time, and constantly challenged EF should be included in the training programs (Diamond and Ling, 2016). Diamond and Lee (2011) concluded that the best approaches to improve EF and school outcomes would likely be those that (i) engage students' passionate interests, bringing them joy and pride; (ii) address stressors in students' lives, attempting to resolve external causes, and to strengthen calmer, healthier responses; (iii) have students vigorously exercise; and (iv) give students a sense of belonging and social acceptance, in addition to giving students opportunities to repeatedly practice EF at progressively advancing levels.

Musical Training

At present, there are many training methods to improve EF, but musical training has characteristics of a wide transfer effect, challenging training content, and time-consuming practice. In musical training, children train independently, showing interest, motivation, and pleasure in training. This makes musical training an appropriate method for promoting children's EF. Compared to previous studies, musical training is more accordant with the characteristics of promoting EF development proposed by Diamond and Ling (2016). During the process of musical training, individuals need to pay appropriate attention to information from each sensory channel, switch between different sensory simulations in real time, integrate information from multiple sensory channels, and save this information to working memory so that it available for recall at any time, all while restraining interference of other external competitive stimuli (Moradzadeh et al., 2014; Sato et al., 2015; Slevc et al., 2016). Furthermore, not only is musical training a comprehensive type of training, which is more complex than other types of general cognitive training, but it is also typically considered more interesting and attractive than other types of training. Additionally, if the individual is committed to training, it makes him/her less sensitive to the cognitive load, and the direct benefits gained from training further enhances the individual's intrinsic motivation to learn (Okada, 2016). Therefore, long-term, intensive musical training could improve EF, both comprehensively and effectively (Seinfeld et al., 2013; Slevc et al., 2016).

Investigation of differences in brain structure and function between musicians and non-musicians has become an effective way to explore brain plasticity (Schlaug, 2003; Strait and Kraus, 2014). The journal *Nature* reported that the spatial reasoning of college students improved when preceded by 10 min of listening to Mozart's Sonata for Two Pianos in D major, K. 488 (Rauscher et al., 1993). The "Mozart Effect" not only triggered interest in musical training, but also received great attention from the public. Increasing numbers of children and adolescents started learning music. With deepening research, the transfer effect of musical training has been verified. For example, musical training can improve children's intelligence quotient (IQ), self-control, reading ability, mathematics ability, and memory (Schellenberg, 2005).

It is not clear which mechanisms of musical training affect cognitive ability, but many researchers believe that the transfer effect of musical training involves EF (Hannon and Trainor, 2007; Schellenberg et al., 2008; Jäncke, 2009; Moreno et al., 2014; Moreno and Farzan, 2015; Saarikivi et al., 2016; Sala and Gobet, 2017). Early researchers argued that EF played a mediating role in IQ improvement; however, this mediating role was controversial (Degé et al., 2011; Schellenberg and Winner, 2011). Currently, researchers explain the relationship between musical training and EF from two viewpoints. Some researchers believe that the improvement in EF is the far transfer effect of musical training. For instance, Miendlarzewska and Trost (2014) conducted a meta-analysis of the far- and near-transfer effects of musical training. They concluded that factors affecting musical training include genetics, the time when musical training begins, the motivation to learn music, parents, teachers, the process of social development, and the emotional experience brought by music. The near-transfer effects of musical training are reflected in auditory skills, motor skills, and time perception ability, while the far-transfer effects of music are reflected in EF, intelligence, auditory perception, reading, verbal memory, and social interaction ability. Moreno and Bidelman (2014) proposed that the cognitive transfer effects of musical training can be described as a multidimensional continuum. They used the two dimensions of "near/far" and "sensory/cognition" to explain the transfer effects of musical training. For example, the improvement of auditory perception by musical training is a "near/sensory" transfer, the improvement of complex sound processing ability by musical training is a "near/cognitive" transfer, the improvement of speech and language coding ability in musical training is "far/sensory" transfer, and the effects on auditory recognition of patterns and phonological awareness are "far/cognitive" transfer. The two-dimensional transfer model is based on the hypothesis that the uniqueness of musical training itself can promote improvement of the musician's EF, and this EF improvement is the basis of other transfer effects of musical training.

In the process of learning music, it is necessary to maintain a high degree of self-control, attention, and memory (Moreno et al., 2011). Moreover, musicians are constantly monitoring and regulating their behaviors. This requires them to sustain attention for long periods of time, ultimately resulting in improvement of their listening and speech skills. According to the OPERA hypothesis (Patel, 2011, 2012), music enhances auditory processing in ways that are relevant to speech when five conditions are met; specifically, overlap, precision, emotion, repetition, and attention. Patel (2014) also considered that music and speech shared perceptual and cognitive processes, which was anatomical overlap in brain networks (e.g., waveform periodicity and amplitude envelope). Speech processing benefits by music learning, which naturally improves due to its more precise requirement for sound representation, stronger emotion, repetition, and high concentration of attention.

In other words, the transfer effect is determined by the extent to which musical training contributes to EF (White et al., 2013). Researchers holding either perspective believe that musical training can improve EF. The mechanism responsible for the musical training transfer effect can be explained to a certain extent by the complementary dimensions expressed by Moreno, while the musical training transfer effect model emphasizes the phenomenon of the "near-far" transfer effect of musical training.

Musical Training and EF in Developmental Research

The developmental time point in which a person begins receiving musical training is also a key factor in how music affects individuals. Research suggests that better results are achieved if musical training begins in childhood, rather than adulthood; a finding that has been unanimously recognized (Schlaug et al., 1995; Baharloo et al., 1998; Lee et al., 2003). For instance, Baharloo et al. (1998) performed absolute pitch tests in 691 adult musicians and found that 92 showed excellent absolute pitch ability. Of these, 78% began learning music before the age of six.

In 1995, Schlaug et al. studied the neuroanatomical differences between musicians and non-musicians. They found that musicians' corpora callosa were larger than those of the non-musicians. The corpus callosum is a transverse nerve fiber bundle that connects the two hemispheres of the brain. Maturity of the corpus callosum's structure and function likely occurs in late childhood to early adolescence; this period corresponds with the development of motor control and coordinated motion (Schlaug, 2003). A study by Lee et al. (2003) reported that the corpus callosum of males who performed rigorous musical training (piano and string practice) in early childhood were larger than those of non-musical trainers. Such evidence was only found in male participants who studied music before the age of seven. There are two reasons why the corpus callosum of a musician is larger. First of all, no matter which instrument you are learning, you need to coordinate the right and left hands. This makes the movement areas of the left and right brains more developed. Furthermore, long-term musical training can promote the exchange of information between the two hemispheres of the brain, enabling more cooperation between them. Second, early musical training is carried out during a period of rapid development of the corpus callosum; in other words, early initiation of musical training plays an important role in promoting the development and maturation of the corpus callosum. Watanabe et al. (2006) found that adult musicians who began to receive musical training before the age of seven performed significantly better in time series tasks than adult musicians who began to receive musical training after the age of seven. Therefore, it was concluded that in early life there is a critical period during which music promotes the development of brain-related functions. Other researchers have shown that the improvement observed in the auditory cortex and neurophysiological function of musicians is positively correlated with the time of continuous training and negatively correlated with the age at which musical training begins (Zendel and Alain, 2013). That is, the longer one has practiced music, and the earlier musical training begins, the greater the likelihood that the cerebral cortex and cognition system will change in response to musical training.

Although there is a dearth of pre-/post-test experiments, a large body of evidence exists suggesting that children's EF can be improved after a certain period of musical training. For example, Moreno et al. (2011) conducted a four-week structured musical training for 32 children aged four to six; the training included information regarding rhythm, beat, melody, sound, and basic music theory. Results showed that after the 4 weeks of musical training, the experimental group performed better on the control task than the control group. Bowmer et al. (2018) used a two-phase experimental design to investigate the effect of weekly musical training on the EF abilities of children aged three to four. Participants were divided into groups A, B, and C. In Phase 1, Group A took part in eight weekly music lessons, which were provided by a specialized music teacher. While Groups B and C engaged in free play. Results of this Phase showed that Group A's planning and inhibition skills were improved. In Phase 2, Group A continued eight additional weeks of music curricula, and Group B attended the same eight-week music curricula attended by Group A in Phase 1. Conversely, Group C took part in an art intervention. The result showed that, at the end of the two experimental phases, the children who participated in musical training demonstrated significant improvement in EF. A separate study examined the effects of 6 weeks of musical training or Lego® construction in 34 randomly assigned preschool children, aged four to five. All the participants attended 45 min of training twice a week. The music program was focused on bimanual gross motor behavior, creativity, and vocal development of inhibition ability. Results showed the music group demonstrated fewer errors on a visual-motor inhibition task following training when compared to the Lego® group, despite between group differences not being observed (Bugos and DeMarie, 2017).

In the short-term, simply listening to music and structured musical training are representative of interventions studied in the field. Structured musical training generally includes the learning of musical knowledge (e.g., identifying notes, rhythm and beats) and the learning of musical skills (e.g., vocal and keyboard skills; Moreno et al., 2011; Winsler et al., 2011). Winsler et al. (2011) pointed out that structured musical training has a larger impact on subjects. Moreno et al. (2011) conducted musical training with young children, ranging from one month to one year old. The researchers found that musical training resulted in positive changes in children's brain structure, inhibitory control, increased attention, and enhanced creativity (Fujioka et al., 2006; Schellenberg et al., 2007; Moreno et al., 2011). Other researchers conducted a five-day piano exercise for individuals with no prior formal music learning experience. After the exercise, participants' motor cortex, finger flexors, and extensors had increased in size (Pascual-Leone et al., 1995). While a large number of studies have shown effects of musical training, regardless of training duration, these effects appear to be short lived, and have not been well-studied.

In the present study, we designed two experiments, based on the conceptualizations of EF proposed by Diamond (2013), to explore the impact of musical training on children's EF. Experiment 1 used integrated musical training to conduct a 12-week program for children who had not received any prior musical training (the mean age was four). We explored the promotion of musical training on three major subcomponents of children's EF: inhibitory control, working memory, and cognitive flexibility. It was necessary to comprehensively investigate the influence of musical training on all three of these subcomponents. The EFs were tested at two points: before the music training (T1), immediately after the end of the training (T2). In Experiment 2, in order to explore the after-effects of integrated musical training, the children in the musical training and control groups were assessed 12 weeks after the experiment (T3). We hypothesized that (1) inhibitory control, working memory, and cognitive flexibility would be enhanced in preschoolers by integrated musical training (i.e., music theory, singing, dancing, and role-playing); and (2) 12 weeks after cessation of training, the after-effects of integrated musical training on inhibitory control, working memory, and cognitive flexibility would persist.

This study is different from previous studies in several ways. (1) In order to understand the level of musical development and preferences of children, aged three to six, we interviewed professional music teachers who worked in kindergartens. We also referred to previous research and designed musical training curricula (e.g., rhythm, pitch, melody, voice, and basic musical concepts) suitable for 4-year-old children. (2) Although the structure of EF is still debated, this study was based on the view put forth by Diamond (2013). Furthermore, previous studies have primarily focused on one component of EF (e.g., Moreno et al., 2011). The current study examined three components of EF. (3) According to Diamond and Ling (2016), effective training of EF requires cognitive components. We applied cognitive

TABLE 2 | Mean age and gender of participant groups.

	Total number of participants	Male	Female	Average age (months)	Standard deviation
Music training group	30	20	10	51.39	4.27
Control group	31	18	13	50.35	3.38

components within the contents of musical training protocol (e.g., children needed to understand the rhythm rules to correctly stay in time with the music). (4) The contents of the musical training protocol designed within this study was closely related to the three components of EF. It also has a clear training purpose and is easily operated. (5) Compared to previous research, we examined the after-effects of the training curricula 12 weeks later.

EXPERIMENT 1

Materials and Methods

Participants

The effect of music training is normally influenced by some variables, such as social background of participants. In order to maintain the homogeneity of the variables (kindergarten living environment, daily schedule, daily activities of kindergartens, etc.), we selected two classes of children (average age of 4) in the same university-affiliated kindergarten in northern China: one for the music training group and the other for the control group (**Table 2**). This kindergarten is a public kindergarten and nursery fee is 1200RMB per month, and the enrollment is citywide. Even it is affiliated to the university, it is as same as other public kindergartens in this city. The experiment was divided into two groups. Three measurements were made. The number of participates was 29 in each group, which met the criterion of G-power test. There are 30–35 children in every class of public kindergarten in this city. In order to ensure ecological validity and control the interference of irrelevant variables, two natural classes were selected.

The age difference between the music training group and the control group was not significant $F = 3.799$ ($p > 0.05$). All participants were healthy, well-being, and had no formal music learning experience. Parents did not have a background in music-related occupations. The average annual household income was 120,000–180,000 yuan (RMB). Which was middle-income family compared to that in Liaoning Province. This study was approved by the local ethics committees of Liaoning Normal University. Written informed consent had been obtained from the parents/legal guardians of all participants. All preschool children participants were volunteered to join the experiments, and informed consents were signed by their legal guardians.

Training Curricula

The children engaged in the training programs in one team of 45 min each (10 min for organization and 35 min of training), 5 days a week, for 12 weeks (150 min per week). The music training was based on a combination of motor, perceptual, and cognitive tasks, including training in rhythm, pitch, melody, voice, and basic musical concepts.

For short-term music training participants, the following two methods are more representative. One is to sit and listen to music and experience the Mozart Effect; this could include letting college students listen to Mozart's double piano sonatas. The other method allows participants to perform structured music training, which generally includes the learning of music knowledge (identifying notes, rhythm, beats, etc.) and the learning of musical skills, such as vocal or keyboard skills, conducted a 4-week structured music training for 32 children aged 4 to 6 years; the training included topics on rhythm, beat, melody, sound, and basic music theory. The research results showed that after the 4 weeks of music training, the experimental group performed better on the control task than the control group (Moreno et al., 2011).

The selected songs in this experiment are from the *John Thomson's Modern Course for the Piano* (WILLIS, Shanghai Music Publishing House), and the researchers created their own tracks based on the teaching content. To reduce the cognitive load of children, the music training tracks were used in a multi-purpose way. In other words, we could use one track to train participants in singing, dancing, role-playing, and so on. The music training program of this research included two sections (1–4 weeks; 5–12 weeks). We used the second- (**Table 3**) and tenth-week (**Table 4**) training programs to illustrate the relationship between executive function and the content of training in different stages.

The time of effective music training for children was 35 min every day. The order of each music activity was fixed. The melody was active and lively. The difficulty of weekly training is from simple to complex. It gradually increased the difficulty and the training purpose was clear. The purpose of the selected track was clear, the difficulty of music rules gradually increased, the melody was active and lively, the music was mainly about animals and daily life (themes that the children loved), and the rhythm was selected as 2/4 beats and 3/4 beats, emphasizing the enthusiasm, regularity, integration, cheerfulness, and playfulness

TABLE 3 | Examples of music activities included in the intervention and associated areas of EFs (Second week).

	Example musical training (Policeman)	Associated area of EFs
Day 1	Clef and Scale: Identify treble and C major, a minor scale	Working memory, cognitive flexibility
Day 2	Time signature: Listen to 3/4 beats, and be able to follow them	Working memory, cognitive flexibility
Day 3	Termination mark: Identify the termination token, and stop when you see the termination token	Working memory, inhibitory control
Day 4	Strong and weak symbol: Identify strong and weak marks(F/P), which can control sound according to strong and weak marks	Working memory, cognitive flexibility
Day 5	Repeated mark: Identifying repeated marks, and repeat then according to repeated mark indications	Working memory, inhibitory control, cognitive flexibility

TABLE 4 | Examples of music activities included in the intervention and associated areas of EFs (Tenth week).

	Example musical training (Frog chorus)	Associated area of EFs
Day 1	Solo: A young children sings alone, keeping the pitch and rhythm correct	Working memory, inhibitory control, Cognitive flexibility
Day 2	Rotate in turn: Different children rotate and alternately sing the same song	Working memory, inhibitory control, cognitive flexibility
Day 3	Sing in silent: Sing without sound	Working memory, inhibitory control
Day 4	Role performance: Rhythms was divided into two parts (young frog and old frog) according to pitch, the children who acted as young frog started to sing when the young frog rhythms appeared, the others acting as the old frog should wait quietly, and vice versa.	Working memory, inhibitory control
Day 5	Dance: Rhythmic action and action combinations, including clapping, nodding, stamping feet, and so on.	Working memory, Inhibitory control, cognitive flexibility

of the music training. The content was designed to encourage the children to actively participate and experience pleasure in participating. The goal was for children to then follow the rules of music, suppress impulsive behavior, recognize and memorize music symbols, and flexibly use music symbols. All the activities of this music training program were carried out by the same Master of Musicology. This person had a solid theoretical foundation of music teaching, practical experience in early childhood music teaching, relevant knowledge of development and educational psychology, and experimental research experience in kindergarten settings. Furthermore, they could better implement the guiding ideology of music training activities and mobilize the enthusiasm of young children to participate in music training than the experimenter, who only had a psychological background.

The musical training consisted of two parts (see **Tables 3**, **4**):

- Weeks 1–4: musical theory
- Weeks 5–12: singing, dancing, and role-playing

Stimuli and Procedures

The executive functions of the children from all groups were assessed twice-before (T1) and after (T2) the musical training.

Day/Night Stroop

The task was based on study Gerstadt et al. (1994). The experiment used 16 test cards, 20 cm long and 13 cm wide. Half of the cards were painted with a white sun and half with a black moon and stars. The experimental task was divided into two phases. During the practice phase, the experimenter first presented a white card with a bright sun to the child and told the child to say "day" when the child sees the white card; then the experimenter presented a black card with the moon and stars to the child and asked the child to say "night" when the child sees the black card. Then, the experimenter showed the subject a white card. If the subject responded correctly, the experimenter praised the child and proceeded to a practical trial with the black card. If the subject responded correctly to the black card, the experimenter praised the child. If the subject responded incorrectly or did not respond at all on either of these trials, the experimenter immediately reminded the subjected of both rules beginning with the card that the child had identified incorrectly.

During the formal experiment, the experimenter presented the opposite condition to the child, this time no feedback was given. The experimenter presented a white card to the child and told the child to say "night" when the child sees the white card. Then the experimenter presented a black card to the child and asked the child to say "day" when the child sees the black card.

The experiment was performed 32 times, and the cards were presented according to a pseudo-random sequence. We recorded the number of times the participant gave the correct "day" or "night" response. In this task, the Cronbach's Alpha was 0.60.

Dimensional Change Card Sort

Before the formal experiment, we conducted a pre-experiment on 3–5-year-old children in other classes of the kindergarten. The pre-experiment results showed that the three-stage experiment was difficult, the cognitive load of the child was too heavy, and the experiment time was long. Therefore, we only carried out the two-stage experiment task, and in the formal experiment, the two-stage experiment task did not reach the ceiling-effect.

The experiment used 16 cards and 2 wooden plates. The cards were 20 cm long and 13 cm wide, each wooden plate is 11.5 cm long, 9.5 cm wide and 2 cm deep. Children had to sort the cards according to a rule involving either color or shape. They were shown cards with boats or rabbits on them, either blue or red in color. The target cards were fixed to the back of each wooden plate, one showing the image of a blue rabbit, and the other a red boat. The experimenter pointed and verbally named the two target cards. In the pre-switch phase, children were asked to sort six cards according to their color, after two demonstrations given by the experimenter. Cards were presented to the child in a pseudo-random order. In the post-switch phase, children were asked to sort the cards by shape. The test was scored according to the number of correct cards. Both the pre-switch phase and post-switch phase tasks were each scored once (Zelazo et al., 1996; Zelazo, 2006). In this task, the Cronbach's Alpha was 0.61.

Dot Matrix Test

The experimental materials were 16 test cards with red, green, and blue dots. The cards were 20 cm long and 13 cm wide. The dots on the cards were randomly arranged. During the test, children were instructed to count the number of red spots on the card presented. After an initial practice session, children were presented with two cards that were facedown on the table. The experimenter then turned the first card faceup; after the child counted the red spots, this card was turned facedown and the second card was turned faceup. After counting, this card was turned facedown. The experimenter pointed to the first card and then the second, asking the child to recall the number of spots counted on each card. Administration of the test continued until the child made errors on both attempts at a particular span length. This span was recorded as the maximum number of counts recalled in the correct serial order (Towse and Hitch, 1995; Bull and Scerif, 2001). In this task, the Cronbach's Alpha was 0.86.

Backward Digit Span Task

Before the formal experiment, we conducted a pre-experiment on 3–5-year-old children in other classes of the kindergarten, and finally selected 1–4 digits as the numerical range of the Backward digit span task.

The experimental materials for this task were the numbers 0–9. The experiment was divided into two phases. In the practice phase, the experimenter said "1, 2" and told the child to say "2, 1," i.e., reciting the numbers backward. In the formal experiment, the experimenter randomly selected two numbers from 0 to 9, and then let the child say the numbers backward. If the child failed, they scored 1 point. If the child was successful, they scored 2 points, and the experimenter continued on, saying 3 digits. If the child successfully recited the 3 digits backward, they scored 3 points, and then the experimenter moved up to 4 digits. The maximum number of digits used was 4 (Carlson et al., 2002). In this task, the Cronbach's Alpha was 0.79.

Statistical Analysis

In this experiment, the scores of the 4 tasks were the dependent variables, and the time points (pre-test vs. post-test) and the groups (the experimental group vs. the control group) were independent variables. The experimental design was a 2 (time points: pre-test vs. post-test) × 2 (groups: the experimental group vs. the control group) two-way repeated measures ANOVA, in which the time points were the intra-group variables, and the groups were the inter-group variables. The analysis of variance mainly examined the interaction between time points and groups. In the control of unrelated variables, we took the following measures. First, we conducted a survey of two classes of children during the pre-test to ensure that there were no additional music training activities outside the kindergarten environment. Second, we applied a homogeneity test on the pre-test group to ensure both groups' developmental level of executive function. While the experimental group underwent music training, the children in the control group engaged in free play. In addition, the daily activities were the same. Uniform requirements were imposed on all teachers, and teachers were not allowed to impose additional activities on the children. Fourth, we informed parents to control additional music training activities.

Results

The scores of children's executive function tasks before and after music training are shown in **Table 5**.

In order to better control the experimental variables, we performed statistics on the pre-test results. The results showed that there was no significant difference in the scores of the 4 tasks [Day/Night Stroop, Dimensional Change Card Sort (DCCS), Dot Matrix Test, Backward Digit Span Task] between the experimental group and the control group ($t(59) = 0.697$, –0.67, 1.390, 0.247, $p > 0.05$), thus indicating that the two groups of children were homogeneous in levels of executive function.

The results of the 2 (time points: T1 vs. T2) × 2 (groups: the experimental group vs. the control group) two-way repeated measures ANOVAs are shown in **Table 6**.

In the Day/Night Stroop, the interaction between the time points and groups was significant [$F(1,60) = 6.296$, $p < 0.01$, $\eta^2 = 0.096$]. In the *post hoc* test, the difference between the experimental and control groups was significant ($t = 5.19$, $p < 0.001$). The difference between the T1 and T2 results of the experimental group was significant ($t = -11.45$, $p < 0.001$), and the difference between the T1 and T2 results of the control group was significant ($t = -5.77$, $p < 0.001$).

In DCCS, the interaction between time points and groups was significant [$F(1,60) = 7.543$, $p < 0.01$, $\eta^2 = 0.113$]. In the *post hoc* test, the difference between the experimental and the control groups was significant ($t = 3.67$, $p < 0.001$). The difference between the T1 and T2 results of the experimental group was significant ($t = -5.56$, $p < 0.001$), and the difference between the T1 and T2 results of the control group was not significant ($t = -1.75$, $p > 0.05$).

In the Dot Matrix Test, the interaction between time points and groups was significant [$F(1,60) = 6.519$, $p < 0.01$, $\eta^2 = 0.099$]. In the *post hoc* test, the difference between the experimental and the control groups was significant ($t = 3.75$, $p < 0.001$). The difference between the T1 and T2 results of the experimental

TABLE 5 | The executive function task data of the experimental group and the control group.

	Music Training Group (*n* = 30)		Control Group (*n* = 31)	
	T1 (*M SD*)	**T2 (*M SD*)**	**T1 (*M SD*)**	**T2 (*M SD*)**
Day/Night Stroop	12.97(4.62)	23.10(1.16)	12.00(6.08)	18.52(4.70)
DCCS	12.50(2.93)	15.53(1.814)	12.55(2.71)	13.48(2.49)
Dot Matrix Test	0.83(0.87)	1.83(0.75)	0.77(0.99)	0.84(0.86)
Backward Digit Span Task	7.30(2.09)	8.77(1.83)	6.52(2.31)	6.90(2.31)

TABLE 6 | Analysis of variance analysis before and after music training.

Task	Source	*df*	*MS*	*F*	η^2_p
Day/Night Stroop	Time	1	2113.117	133.398***	0.693
	Group	1	234.851	9.257**	0.136
	Time × Group	1	99.740	6.296**	0.096
DCCS	Time	1	120.73	26.996***	0.314
	Group	1	30.525	3.691$^{\Delta}$	0.59
	Time × Group	1	33.548	7.543**	0.113
Dot Matrix Test	Time	1	26.196	19.221***	0.246
	Group	1	53.424	7.370**	0.111
	Time × Group	1	8.884	6.519**	0.099
Backward Digit Span Task	Time	1	8.638	23.234***	0.283.
	Group	1	8.465	7.343**	0.111
	Time × Group	1	6.671	17.943***	0.233

group was significant ($t = -4.52$, $p < 0.001$), and the difference between the T1 and T2 results of the control group was not significant ($t = -1.42$, $p > 0.05$).

In the Backward Digit Span Task, the interaction between the time points and groups was significant [$F(1,60) = 17.943$, $p < 0.001$, $\eta^2 = 0.233$]. In the *post hoc* test, the difference between the experimental and the control groups was significant ($t = 4.82$, $p < 0.001$). The difference between the T1 and T2 results of the experimental group was significant ($t = -5.79$, $p < 0.001$), and the difference between the T1 and T2 results of the control group was not significant ($t = -0.47$, $p > 0.05$).

In order to investigate if there were any difference between the gains of experimental group and control group before and after music training, we took post-assessment scores T2 to minus pre-assessment scores T1, and did independent sample *T*-test to control the impact of T1 on experiments results. The results were shown in **Table 7**. The results indicated that the gains from four executive function experiments had significant differences between the two groups, which demonstrated great impact of music training on experimental group.

Discussion

The results of Experiment 1 showed that 12 weeks of integrated musical training could promote the development of children's EF, a finding that was consistent with the results of previous research (Moreno et al., 2011; Winsler et al., 2011). This experiment was a classic design, in which we randomly chose two classes, with roughly the same number of students, to participate (i.e., experimental and control groups). In addition to the daily musical training, the experimental group still participated in everyday activities typically performed in kindergarten. The musical training duration fit within a natural semester, which was slightly different from what has been reported in previous research. In studies with random recruitment, participants' interest in musical training was less likely (Corrigall et al., 2013). Furthermore, with a long duration of musical training, participants had a halfway point from which they could exit. For example, Schellenberg (2004) conducted a one-year musical training protocol for 144 children; of which, 12 participants withdrew. The kindergartens selected in the present study were university-affiliated kindergartens. The children's parents had a high degree of matching in terms of education level and family annual income. No children withdrew throughout the 12-week musical training program. The musical training protocol utilized in the current study was closer to the daily teaching activities of young children, thus laying the foundation for the promotion of musical training.

A large number of related studies have shown that short-term or long-term musical training can affect the brain structure, function, and cognitive level of those involved in the training (Rauscher et al., 1993; Schellenberg, 2006; Moreno et al., 2011; Schellenberg and Winner, 2011). However, most previous studies did not track the effect of musical training. Thus, it is still not clear whether musical training can have long-term effects in children. In Experiment 2, the children in the musical training experimental group and the control group were followed up at 12 weeks following cessation of the musical training program. Thus, the current study examined both the development of EF of the two groups of children and explored the duration of the musical training transfer effect.

TABLE 7 | *T*-test analysis of the gain (T2-T1).

	Groups	*N*	*M*	*SD*	*t*	*df*
Day/Night Stroop	Experimental group	30	10.133	4.84756	2.509*	59
	Control group	31	6.516	6.29217		
DCCS	Experimental group	30	3.033	2.98829	2.746**	59
	Control group	31	0.935	2.97697		
Dot Matrix Test	Experimental group	30	1.466	1.77596	2.553*	59
	Control group	31	0.387	1.52047		
Backward digit span task	Experimental group	30	1.000	0.94686	4.236***	59
	Control group	31	0.064	0.77182		

EXPERIMENT 2

Materials and Methods

Participants

The participants were the same as those in Experiment 1.

Stimuli and Procedures

The stimuli were the same as those in Experiment 1.

In Experiment 2, we used the same performance test materials to conduct after-effects tests on the children in the music training experimental group and the control group at T3 (12 weeks after Experiment 1). Leading up to this period, the researchers asked the parents of the participating children to ensure their children did not have any in-school or extra-curricular music training activities.

Statistical Analysis

In this experiment, the scores of the 4 tasks were the dependent variables, and the time points (T2 vs. T3) and the groups (the experimental group vs. the control group) were independent variables. The experimental design was a 2 (time points: T2 vs. T3) × 2 (groups: the experimental group vs. the control group) two-way repeated measures ANOVAs, in which the time points were the intra-group variables and the groups were the inter-group variables. The analysis of variance mainly examined the interaction between time points and groups.

Results

The results of the after-effect of executive function tasks of each group of children in Experiment 2 at T3 are shown in **Table 8**.

We used the 4 experimental scores as the dependent variables. The time points (T2 vs. T3) and the groups (the experimental group vs. the control group) were independent variables. The results of the 2 time points (T2 vs. T3) × 2 groups (the

TABLE 8 | After-effect description statistics at T3.

Task	Experimental group (n = 30)		Control group (n = 31)	
	M	*SD*	*M*	*SD*
Day/Night Stroop	21.73	1.143	19.19	2.315
DCCS	15.37	1.474	14.42	1.432
Dot Matrix Test	8.87	2.063	7.84	1.934
Backward Digit Span Task	1.63	0.718	1.10	0.597

TABLE 9 | Music training after-effect repeated measurement analysis of variance.

Task	Source	*df*	*MS*	*F*	η^2_p
Day/Night Stroop	Time	1	3.621	1.150	0.019
	Group	1	386.837	31.908***	0.351
	Time × Group	1	31.851	10.110**	0.146
DCCS	Time	1	4.506	2.556	0.042
	Group	1	68.459	13.388**	0.185
	Time × Group	1	9.260	5.252*	0.082
Dot Matrix Test	Time	1	8.174	6.671*	0.102
	Group	1	63.729	9.755**	0.142
	Time × Group	1	5.321	4.343*	0.069
Backward Digit Span Task	Time	1	0.026	0.062	0.001
	Group	1	17.872	26.582***	0.311
	Time × Group	1	1.599	3.873^{Δ}	0.062

*PS: Time refers to the first measurement and second measurement; Group refers to the experimental group and the control group; *p < 0.05, **p < 0.01, ***p < 0.001, $^{\Delta}p$ < 0.1.*

experimental group vs. the control group) two-way repeated-measure ANOVAs are shown in **Table 9**.

In the after-effects test of the Day/Night Stroop, the interaction between the time points and the groups was significant [$F_{(1,60)}$ = 10.110, $p < 0.01$, $\eta^2 = 0.146$]. The *post hoc* test showed that the results of the post-effects of the experimental group and the control group were significantly different (t = 5.404, $p < 0.001$), the difference between the two time points in the experimental group was significant (t = 5.646, $p < 0.001$), and the difference between the two time points in the control group was not significant (t = –1.153, $p > 0.05$).

In the after-effects test of the DCCS, the interaction between the time points and the groups was significant [$F(1,60) = 5.252$, $p < 0.05$, $\eta^2 = 0.082$]. The *post hoc* test showed that the results of the post-effects of the experimental group and the control group were significantly different (t = 2.546, $p < 0.05$), the difference between the two time points in the experimental group was not significant (t = 0.556, $p > 0.05$), and the difference between the two time points in the control group was significant (t = –2.503, $p < 0.05$).

In the after-effects test of the Dot Matrix Test, the interaction between the time points and the groups was significant [$F(1,60) = 4.343$, $p < 0.05$, $\eta^2 = 0.069$]. The *post hoc* test showed that the results of the post-effects of the experimental group and the control group were significantly different (t = 2.008, $p < 0.05$), the difference between the two time points in the experimental group was not significant (t = –0.356, $p > 0.05$), and the difference between the two time points in the control group was significant (t = –3.275, $p < 0.001$).

In the after-effects test of the Backward Digit Span Task, the interaction between the time points and the groups was significant [$F(1,60) = 3.873$, $p < 0.1$, $\eta^2 = 0.062$]. The *post hoc* test showed that the results of the post-effects of the experimental group and the control group were significantly different (t = 3.176, $p < 0.01$), the difference between the two time points in the experimental group was not significant (t = 1.140, $p > 0.05$), and the difference between the two time points in the control group was not significant (t = –1.680, $p > 0.05$).

Discussion

Twelve weeks following the cessation of musical training, we again tested the EF of the two groups of children and explored the duration of the transfer effect of musical training. Leading up to this period, the parents of the children who participated in the experiment were asked to ensure that their child avoided any additional musical training. Our results showed that in the absence of additional musical training in both groups, the scores of the EF tasks in the experimental group remained significantly higher than those in the control group. While scores on the Day/Night Stroop decreased significantly, scores on the other three tasks did not; thus, the effect of musical training had a sustained effect. Ling et al. (2016) claimed that the Day/Night Stroop involves the inhibition of dominant responses, which is different from other cognitive inhibition tasks. Especially, the aim of the Day/Night Stroop paradigm is focused on preschooler's control over his/her daily lives (say "sun" to moon/star and "moon/star" to sun). Children were taught everyday knowledge in kindergartens, however, the results of Day/Night Stroop declined 12 weeks after musical training cessation.

Scores on the DCCS and the Dot Matrix Test in the control group increased significantly with age, while scores on the Day/Night Stroop and Digit Span Task did not. While this shows that EF improved due merely to the development of age and other factors, the effect of this natural improvement was still not as pronounced as that seen in the musical training group. The results of Experiment 2 showed that the transfer effect continues to play a role after cessation of musical training.

GENERAL DISCUSSION

As the number of EF intervention studies increase, it is progressively more important to explore the most appropriate method of increasing EF. According to Diamond and Ling (2016) meta-analysis of EF interventions, efficient intervention programs should have high-quality activities, adequate duration of practice, challenging content, involve cognitive components, and be able to be widely transferred. We referred to these opinions and designed an integrated musical training program. This research adopted the integrated musical training method, which utilizes daily music education and teaching activities. This approach not only enables children to recognize, memorize, and use music rules and symbols through the study of music theory, but also integrates music rules, symbols recognition, memory, and application through singing, rhythmic activities, role playing, and music appreciation.

In musical training, whether children can understand music rules, memorize, recognize music symbols, sing, and/or tap a beat according to music rules and music symbols is the key to exhibiting melody. A musical melody is composed of notes according to the rules of music writing and using music symbols. To accomplish this, children need to understand the rules of music, including the symbols, and must be able to sing or play musical melodies according to these rules. Moreover, carrying out musical training requires cooperation from many people, and involves, for example, alternate singing, a chorus, and part singing. Therefore, children need to conform to singing order, detect the singing order of other children, and supervise/regulate their performance appropriately. This process requires a high degree of restraint, control, working memory, and cognitive flexibility. For example, in the musical training called "Finding Notes," children need to quickly and accurately recognize different types of notes according to rules and test instructions. With understanding of the rules of notes, children not only can quickly and accurately find the corresponding notes, but also point out the mistakes of others.

In musical training, it is also important to be able to suppress and adjust behavior according to changes in musical symbols. Silent singing means singing without sound. We used this form of "singing" to train the inhibitory control of young children. In the early stage of musical training, it was difficult for children to sing without sound, while with the understanding of "silent singing" rules, young children could gradually suppress their impulse to sing out loud. For example, when learning the basics of music, the child would learn to terminate singing at a particular mark. When this mark appeared in the music, the child could suppress their urge to continue singing, and stop singing. In the case of beat practice, the test would add a "decrescendo" or "crescendo" symbol to the exercise according to the change rule of the beat. The child must then suppress their dominant reaction and produce either fortissimo or pianissimo beats.

In addition, musical training activities, such as turn singing, choral singing, and voice-singing have numerous rules. We created a situation for young children to perform a role, which allowed the children to become interested in our training, and ultimately, the constraints of music rules. Improving EF can also be promoted. For example, in the musical training called "Frog Chorus," children can freely choose to role-play as a small frog or an old frog. Different characters sing a different melody. When the little frog sings, the old frog wants to listen quietly. When the old frog sings, the little frog wants to listen quietly. After the little frog and the old frog sing, all the frogs sing together. In the course of this training, the children are very active. After practicing a few times, most of the children can follow the order of the characters singing. When they are not singing the melody, they wait quietly and pay attention. Over time, musical training with clear rules and full of gameplay gradually improves performance.

Intensity is an important factor in musical training. For the auditory cortex, the intensity of musical training is positively correlated with left transverse temporal gyrus volume (Gaser and Schlaug, 2003). Even when age, sex, and Raven's reasoning test scores were matched, the density of the left transverse temporal gyrus increased with the increase in musical training intensity (James et al., 2014). This integrated musical training totaled 60 days. The average weekly training time was 150 min, and the training intensity was high. Regarding training the EF of infants, Diamond and Lee (2011) believe that EF training should be regular; carried out under the guidance of teachers; include a wide range of transfer functions; include universal, convenient operation; and involve repetitive exercises. Compared with other training methods, musical training has the characteristics of regularity, interest, a wide transfer effect, and repetition (Miendlarzewska and Trost, 2014). Diamond and Ling (2016) also believes that EF must be constantly challenged, activity presentation must be of high-quality, and participants must spend an adequate length of time practicing. Integrative musical training is complex, but music itself is artistic and interesting, which makes it attractive to children. During training, children are not aware of the cognitive load under which they are placed. At the same time, they benefit from the aesthetic and interesting qualities of music, which enhances intrinsic motivation. Although there are many training methods to improve children's EF, the interestingness and regularity of musical training gives it unique advantages in promoting the development of children's EF.

Although the role of musical training in promoting EF has been supported by empirical research, most of the previous studies on the subject have not tracked the effects of musical training; thus it is not clear how long the effects last. To address this gap in the research, we tracked the children who participated in Experiment 1. 12 weeks after the end of musical training (T3), the EF level of the two groups of children was tested to explore the duration of the transfer effect of musical training. The results showed that scores in three major subcomponents of EF in the control group showed significant improvement, while the scores of the children in the musical training group slightly decreased; however, the level of EF in children in the musical training group was still significantly higher than that of children in the control group. This result shows that after musical training (T3), the transfer effect still plays a role. In a return visit to the teachers and parents of the children tested, we found that the children in the musical training group always thoroughly enjoyed music. These teachers and parents stated that many of the children practiced the songs learned in musical training independently in the kindergartens or at home. When the children saw some music symbols, they would also actively explain the meaning of the symbols to their parents. Music exercises spontaneously carried out by children were very frequent, and parents paid special attention to the music that appeared in their daily life. Miendlarzewska and Trost (2014) conducted a meta-analysis of the influencing factors of musical training, and discovered that genetics, age of musical training onset, motivation to learn music, encouragement from parents/teachers, social development, and the emotional experiences brought about by music all play an important role in the transfer effect of musical training. Children acquire positive emotional experience through musical training, which increases the frequency of spontaneous and independent musical training. This may be one of the reasons why musical training can continue to play a role after it has formally concluded.

In the Digit Span Task, the interaction between measurement time points and groups was significant. The reason for this result may be related to the characteristics of the task itself. Although both the Dot Matrix Test and the Digit Span Task are working memory tasks, the Dot Matrix Test is more of a spatial memory task. Some researchers believe that there is a correlation between music processing and spatial processing. For example, Sluming et al. (2007) examined the behavior and fMRI images of 10 male Orchestra members and 10 matched control subjects while completing a three-dimensional graphic mental rotation task. The results showed that, with the increase in pattern rotation angle (0°, 45°, 90°, 135°, and 180°), the response time of musicians did not change significantly, while that of the control group gradually increased. Further, the correct response rate of musicians in the three-dimensional graphics rotation task was higher than that of participants in the control group. Sluming and other researchers believe that musicians have a stronger ability to sight-play. Sight-playing and spatial processing involve common brain regions (Sluming et al., 2007).

Additionally, long-term training in five-line reading may improve the local processing ability of individuals who have been musically trained. Pietsch and Jansen (2012) found that students majoring in music exhibited higher accuracy in mental rotation processing tasks of three-dimensional graphics than students majoring in education. In the process of musical training, notes are arranged in space, according to certain rules. In the face of a complex arrangement of notes in the five-line staff, musicians tend to process several notes as a group. Therefore, long-term musical training can improve processing of spatial relations. In the present study, children were also trained to read five-line music. 12 weeks after musical training (T3), the training experience related to five-line music reading may have played a role in maintaining spatial memory.

Moreover, to ensure ecological validity, this research had chosen natural classes as training and control groups. Thus, training effects observed occurred in natural environments. EF is more sensitive to environmental stimulation. The experimental group participated in 12 weeks of group musical learning in a regulated and structured environment set by researchers. In this group setting, observational learning likely took place, with the subjects possibly being the trainers (i.e., music teachers) or their peers in the same class. This interchangeable nature of observational learning may amplify the effects of musical training, resulting in the sustained effects observed.

Previous studies have preliminarily explored the core subcomponents of musical training that affect EF (Moreno et al., 2011; Winsler et al., 2011); however, these studies often only examined the influence of musical training on only one subcomponent (Puckering et al., 2014). Therefore, the present study investigated the influence of musical training on three major subcomponents of EF. The results of the current study show that integrated musical training can increase the respective levels of these subcomponents.

Limitations

There are three main limitations to this study. First, this study used only behavioral experiments to measure the effect of musical training. The influence of musical training on EF is not reflected by activation intensity of a single brain region, but also may be accompanied by changes in the spatial pattern of EF-related brain region activation, as well as the functional linking pattern of related brain regions. Accordingly, future research should not only use ERP, fMRI, and other technologies, but also use multi-modal brain imaging technology to explore the role of musical training on the neural basis of EF. Additionally, EF-related brain structures and functional changes in musical training transfer effects can also be explored. Second, this study tracked the after-effects of musical training. However, the scope of the tracking was limited and only provided a preliminary explanation of the continuous effect of musical training. Finally, we only chose control and experimental groups in this study. In future studies, we will increase the number of different training groups to examine differences among various interventions.

CONCLUSION

Results showed that musical training can promote children's inhibitory control, working memory, and cognitive flexibility. Furthermore, 12 weeks after the experiment, integrated musical training demonstrated a sustained promotion effect. Ultimately, musical training is an appropriate means to promote the development of children's EF.

DATA AVAILABILITY

The datasets for this manuscript are not publicly available because the topic is not finished. Requests to access the datasets should be directed to corresponding author.

ETHICS STATEMENT

This study was approved by the local ethics committees of Liaoning Normal University. Written informed consent had been obtained from the parents/legal guardians of all participants.

AUTHOR CONTRIBUTIONS

LF and YS designed the experiment. YS, LF, and GL prepared the materials and performed the experiment. YS, LF, YL, and SL analyzed the data and wrote the manuscript.

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Executive Functions Can Be Improved in Preschoolers Through Systematic Playing in Educational Settings: Evidence From a Longitudinal Study

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This study aimed to test the impact of play on the development of executive functions (EFs) in preschoolers. Thirty-two games were designed to be collectively played in groups by 70 children, in their regular classes. The games were specifically designed to promote the development of the three components of EFs: inhibition (behavioral or cognitive), working memory, and cognitive flexibility. The games focused on each function were of three types: playground games, expression games, and classroom games. Sixty 45 min play sessions were held on consecutive days for 3 months, always in the first period. The sessions were guided by two members of the research team, assisted by the four teachers of the participating classes. The intervention was carried out in two highly socially vulnerable schools in the city of Santiago de Chile. Four classes were studied in total: two experimental groups and two controls. The classes were selected using a questionnaire on teacher-student interaction quality and an age homogeneity criterion. EFs were evaluated using the Hearts and Flowers task at three points: before the intervention (T1), immediately after the end of the intervention (T2), and 8 months after the end of the intervention (T3). The results show a significant difference in the growth of EFs by comparing the experimental and control groups ($p = 0.04$) between T1 and T3. They also reveal a strong correlation between EFs measures at T1 and mathematics performance at T3. These results are discussed within the context of the guidelines proposed by Diamond and Ling (2016) and Barnett (2011) regarding what an EFs promotion program needs to be considered effective and high quality. The program presented in this study meets most of the requisites mentioned by the authors, which proves that following these guidelines guarantees a high probability of success.

Keywords: executive functions, intervention program, preschool, play, inhibitory control, working memory, cognitive flexibility

INTRODUCTION

Executive functions are psychological processes that enable us to plan and monitor our actions. They involve our ability to keep our thoughts, actions, and emotions under conscious control (Zelazo and Müller, 2011). Three components of EFs are commonly distinguished: inhibitory control, working memory, and cognitive flexibility (Diamond, 2013; Snyder et al., 2015; Bardikoff and Sabbagh, 2017).

Inhibitory control allows us to consciously direct our attention to stimuli that will enable us to conduct a task. This cognitive function permits us to avoid thoughts, behaviors, or emotions unsuited to the demands of a given situation (Friedman and Miyake, 2004; Diamond, 2013). Specifically, control of one's emotions, thoughts, and affects has been labeled as cognitive inhibition, whereas control exerted over one's actions is known as behavioral inhibition (Lampe et al., 2007).

Working memory means the ability to operate with mental representations, that is, to remember and use information simultaneously. It is a limited capacity that increases with age. Working memory is essential to establishing connections between prior knowledge and new information (Carriedo et al., 2016), generating non-evident associations, and understanding expressions of various types (Diamond, 2012, 2013).

Lastly, cognitive flexibility is an ability that enables us to adjust to the demands posed by the environment in an efficient manner (Miller and Cohen, 2001) by creating alternative ways of solving problems from multiple perspectives (Diamond, 2012), shifting our attention, or changing our strategies according to stimuli (McGowan et al., 2018). Cognitive flexibility is a relevant socio-affective component since it involves not only adopting divergent strategies to solve one's problems but also understanding the approaches used by others. In brief, it is both an affective and a cognitive function that is closely linked to creativity (Diamond, 2014; Santa Cruz and Rosas, 2017).

Development of EFs

Executive functions involve a long developmental process that begins during the perinatal period, sharply increases in the preschool stage, and reaches its apex during adolescence (Shonkoff et al., 2011). This process is supported by the development of the prefrontal cortex (Lezak et al., 2012), a brain area that hosts higher psychological functions, which are key to achieving adequate social and cognitive functioning (Rueda et al., 2011; Wiebe et al., 2011; Posner, 2012).

Although the growth of EFs follows a common trend, it has been proposed that their components do not develop as a unit; rather, each individual EFs follows its own trajectory (Diamond, 2006). Yet authors have suggested that these trajectories operate in tandem, with certain factors forming the basis for the development of others. Inhibitory control has been described as laying the groundwork for the development of EFs, followed by working memory and cognitive flexibility (Anderson et al., 2001). Thus, the development of inhibitory control has been reported to make it possible for working memory to grow, with both enabling individuals to increase their cognitive flexibility skills.

It has been proposed that although all the components of EFs start developing in the first years of life, their individual development trajectories differ. Inhibitory control has been described as having a very steep developmental slope between 3 and 5 years of age, which becomes weaker from age 5 onward, sharply declines after age 8, and becomes stable around age 12. Working memory, for its part, has a more gradual development trajectory, with a linear increase being observed between 4 and 14 years of age and stabilization being reached in adolescence. Lastly, research suggests that cognitive flexibility also gradually develops in childhood and reaches its peak around age 15 (Best et al., 2009; Best and Miller, 2010).

The development of the components of EFs allows reasoning, problem-solving, and planning to manifest themselves (Diamond, 2013, 2016; Baggetta and Alexander, 2016). These higher psychological processes are essential when confronting the demands of school life and those that entail adult life.

Why Play Is Important for the Development of EFs at Preschool Age

As noted above, the components of EFs develop at a much faster rate in the preschool stage. It is precisely at this stage that children are first exposed to schooling, where environmental demands are key to promoting the early development of EFs (Rothbart and Posner, 2006; Garon et al., 2008), which in turn help improve school learning (Rimm-Kaufman et al., 2009).

Preschool education has been described as a space that makes it possible to strengthen the development of skills and knowledge that children require to adequately perform at later stages of school education (Pianta et al., 2009). At this stage, children are expected to develop the skills that lay the groundwork for the acquisition of reading and mathematical skills (Whitehurst and Lonigan, 1998; Espy and Cwik, 2004), which are modulated by the development of EFs. In addition, children are expected to improve their skills needed to develop adaptive behaviors that will enable them to meet the demands of the school system (Blair, 2002). These include self-regulation and social competence, both of which allow students to be motivated, focused, and persevering when dealing with tasks in order to complete them successfully (Kochanska et al., 2000). These skills are also grounded in the development of EFs, inasmuch as they allow thought and behavior to become organized while inhibiting automatic responses to attractive stimuli and privileging more self-regulated behaviors (Kochanska et al., 2001; Bierman et al., 2008).

However, not all educational environments promote the development of EFs equally. There is evidence that shows that stress and poor fitness negatively affect the functioning of the prefrontal cortex, and thus of EFs (Diamond and Lee, 2011). In this context, the educational programs that have proven to be most successful in developing EFs share two key characteristics: (1) they do not expect children to remain seated for long periods since this is not in line with their stage of development, generating tension between teachers and students and increasing children's fear of school, and (2) they tend to reduce stress in the classroom, encouraging enjoyment, self-confidence, and the development of social ties.

Ludic environments could be spaces that foster the development of EFs if they take into account the needs of preschoolers and implement activities that promote the improvement of students' physical condition. Play-based interventions have been shown to be effective when they increase the development of skills associated with divergent thinking, problem-solving, and life satisfaction (Moore and Russ, 2008).

Various types of games can support the development of EFs. There is evidence linking the use of video games designed to foster visual working memory skills (Thorell et al., 2009) and attention (Tahiroglu et al., 2010; Anderson and Bavelier, 2011) with better EFs development in preschoolers. In addition, authors have reported that EFs improve as a consequence of engaging in games based on aerobic exercises (Davis et al., 2011) and sports such as karate (Lakes and Hoyt, 2004). It has also been suggested that role-playing activities are tools that contribute to the development of emotional regulation and language, both of which are regarded as precursors of EFs (Fantuzzo et al., 2004). Other authors have reported that children's performance improves when EFs are evaluated through play (Rosas et al., 2015).

Play makes it possible to reduce anxiety, which increases motivation and provides further chances to try out solutions and practice with no real consequences (Cadavid-Ruiz et al., 2014). Also, given that play is the predominant activity at the preschool stage, it can be regarded as a mediator that promotes children's cognitive development (Vygotsky, 2001). In short, play is considered to be one of the key activities in children's life at the preschool stage (Duncan and Tarulli, 2003).

Successful Play Intervention Programs for the Development of EFs in Preschoolers

The literature describes a variety of successful EFs training initiatives. Authors have also referred to the necessary conditions for EFs interventions to succeed.

Traverso et al. (2015) conducted an intervention focused on the development of working memory, inhibitory control, and cognitive flexibility with 75 children aged 5. Twelve play sessions lasting 30 min each were conducted for over 1 month at the educational center that these children attended. The children were divided into groups of five and performed tasks that required progressive levels of inhibitory control, working memory, and cognitive flexibility. The results indicate that the children who took part in the intervention performed better in tasks involving simple EFs as well as in others requiring complex EFs. To analyze the effectiveness of the intervention, the authors compared the students' performance in the tasks presented. Significant differences were observed in most tasks, controlling for initial performance. The children in the experimental group performed significantly better in inhibition tasks (delay task, gift wrap task time, circle drawing task, preschool matching familiar figure task, arrow flanker task), working memory tasks (backward word span, keep track task), and cognitive flexibility tasks (point accuracy task). This suggests that the children who participated in the training sessions performed better than those in the control group.

Specifically for EFs, Diamond et al. (2007) noted that children trained with "Tools of the Mind", which is a research-based model that implies the implementation of a preschool curriculum focused on the development of cognitive, social-emotional, self-regulatory and foundational academic skills of children, perform better than their untrained peers in overall EFs, with minor effects in tests with low EFs requirements and major effects in tests with greater EFs demands, which benefit from more inhibitory control.

In the same way, Goldin et al. (2014) assessed several aspects of EFs (working memory, inhibitory control, flexibility, and planning) and school grades (language and mathematics), comparing children who used a computer program aligned with the Argentinian school curriculum and designed to train these variables (7 h of training in total over 10 weeks). Children in the experimental group played three adaptive computer games focused on training EFs, and children in the control group played games that require similar motor responses but were less demanding cognitively. All children played during school time, one game per 15-min session. The authors presented evidence that showed that children who received this training exhibited improvements in working memory as measured by the Attention Network Test (Rueda and Posner, 2013) and in inhibition and cognitive flexibility as measured by the Hearts and Flowers task (Davidson et al., 2006).

Another example of a play-based intervention was reported by Hermida et al. (2015), who generated a program that involved a longer training period: twice a week for 16 weeks. These authors carefully designed an intervention in which each activity had to meet the following conditions: (a) must be based on an aspect of the official school curriculum of the city of Buenos Aires; (b) must be structured as a game; (c) must require an increasing level of executive functioning; (d) must have three chronological stages (i.e., teacher-provided planning, execution of the planned activity and discussion of the activity with the children, and integration, with the children evaluating the plan and the strategies needed to implement it); (e) must be novel and different from previously introduced games, and; (f) must target an EFs clearly identified by the teachers, who had to be aware of which specific part of the activity trained EFs selected. They assessed the children in a variety of cognitive tasks at the beginning and after finishing the intervention. Also, they collected the grades of the children of both groups the year after the intervention.

Results for cognitive variables show that only differences in favor of the experimental over the control group exist, in the general measure of the Attention Network Test (Rueda and Posner, 2013) and in the selection of four blocks in the Corsi block-tapping test (Kessels et al., 2010). However, since these represent only two dependent variables out of 20, the authors suggested that the results cannot be attributed to the intervention. However, the experimental group showed significantly better performance in both language and math grades one year after the intervention, when comparing the experimental and control groups. They also compared these results with an external control group with similar demographic characteristics (not part of the study) and found similar results, suggesting a lasting effect of the training over the general school outcomes of the children. The authors noted that the rejection of the main hypothesis (posttest cognitive advantage for the intervention group) could be due to several factors: (1) the use of a test battery that might have been suboptimal for interventions of this type, (2) the time that the intervention lasted and the intensity of the activities (32 weeks, two games per week), and/or (3) the composition of the sample since ethical considerations demanded that an experimental design be avoided: the unit of analysis included whole classes (each with its own dynamics) participating in the intervention program, not individual participants.

Finally, although it is not totally based on play, the intervention program of Röthlisberger et al. (2011) is particularly relevant to the present work because of their strong similarities. The authors developed a small group intervention in EFs for a total of 33 prekindergarten and 30 kindergarten children, for 30 min in consecutive schooldays for a total of 6 weeks. A total of 19 tasks that would promote EFs were designed, specifically for working memory, interference control, and cognitive flexibility. The tasks were presented 2 days a week by a research team member and the remaining 3 days by a regular teacher. Group sizes for both the intervention and the control groups varied between 3 and 11 children. All the sessions, which lasted for about 30 min, included whole group activities, small group ones, and individual ones. Although not all tasks were games, all of them were highly motivating to the children. The three EFs components were assessed separately: interference control, by an adaptation of the Simpler Flanker Task (Roebers and Kauer, 2009); working memory, by an adaptation of the Complex Span Task (Daneman and Carpenter, 1983); and flexibility by an adaptation of the Flanker Task from Diamond et al. (2007).

The results show significant training effects for working memory and flexibility in the prekindergarten group and for interference control only in the kindergarten group.

One important issue that arises from these studies is that they can all demonstrate significant effects over at least one of the EFs components. Nevertheless, none of them give a sound theoretically grounded explanation as to why their particular programs have a specific impact over only some of the EFs components. We believe that these results show that at preschool age, EFs are not so clearly differentiated and thus cannot be reliably measured separately. In the present project, we will therefore use only one global measure of EFs, although we will differentiate the EFs components to be trained in the intervention program.

A Framework for the Design of Successful EFs Enhancement Intervention Programs

Diamond and Ling (2016) analyzed several studies on interventions that successfully improved EFs development, drawing a number of conclusions about the characteristics of these initiatives. The following is a brief description of the authors' conclusions. (1) Although training appears to have a high degree of transference, it tends to be strongly associated with the cognitive function trained. For this reason, to avoid predictability, the authors suggest developing varied tasks that require the use of multiple cognitive skills. (2) Practice time is important, as programs that include more weekly sessions and are applied over a longer period have better outcomes. (3) The way in which the activity is presented and conducted can also influence the program's outcomes: it has been observed that when a program is administered by more committed people, more benefits are observed. (4) EFs must be constantly challenged. (5) Individuals with lower levels of EFs development benefit more from programs of this type, with potential differences being due to age, socioeconomic status (SES), or the presence of disorders. (6) The impact of programs fades over time. (7) Differences that can be attributed to the impact of a program are often observed only in the most cognitively demanding tasks. (8) Physical training without a cognitive component has little impact on EFs development. (9) It is necessary to analyze the largest number of intervening factors possible to determine whether the results obtained are due to the program or to other factors related to it. For instance, benefits may be due to the type of mediation rather than to the cognitive tasks proposed; alternatively, gains could be mediated by the impact of the program on other factors such as stress reduction.

Also, extending the effects of interventions to other cognitive aspects, evidence shows that cognitive gains appear to be small initially, but longitudinal studies indicate that they increase as children grow up (Nix, 2003) and that effective interventions tend to be part of low-scale, high-quality programs (Schweinhart et al., 2005). Thus, program quality should be ensured, considering the aspects that have shown to be key: clarity regarding what the program provides, who its target audience is, and what wider educational, social, and economic contexts it encompasses (Barnett, 2004). These three factors become especially relevant considering that low-quality programs do not produce good results and that significant long-term effects are observed only when programs protect their high quality (Barnett and Masse, 2007). In consequence, authors recommend that interventions be implemented in both developed and developing countries if good quality can be ensured (Barnett, 2011).

In brief, research suggests that intervention programs, both play-based and not play-based, aimed at promoting EFs development in preschoolers must meet certain requirements in order to succeed. The present study was designed considering the main findings derived from interventions that have successfully improved EFs development in preschoolers, based on play activities in a natural context.

MATERIALS AND METHODS

Participants

A total of 70 preschool monolingual Chilean children, out of whom 57% were boys and 43% were girls, participated in the research program. The average age was 68.42 months (SD = 3.48). The experimental group was composed of 37 children (M = 68.24 months; SD = 3.39), and the control group consisted of 33 children (M = 68.61 months; SD = 3.46).

Both groups had the same proportion of boys and girls as the complete group.

The participants were recruited from two schools located in vulnerable areas in the city of Santiago de Chile. All children belonged to middle-low SES families. The SES classification is determined by the Quality Agency of Education of Chile and is constructed by considering the educational level of both parents, the total monthly economic income of the household, and the student vulnerability index. This index is calculated by determining the percentage of school students who are in an extreme poverty situation or who are at risk of school failure. The first three indicators are obtained through a survey given to the parents of the students in a national assessment, while the fourth is obtained from data collected by the National Board of School Aid and Scholarships of Chile. A middle-low SES school category means that its community includes families whose parents on average have 10 years of formal education with an average monthly family income of around US$ 358, and with 72% of the students in a vulnerable situation.

All the children attended the second transition level at the start of the intervention program. This level precedes the first grade of primary education. In Chile, there are six levels of preschool education. The first two levels correspond to nursery (from 84 days old to 2 years old), the next two are middle-age levels (from 2 to 4 years old), and the last ones correspond to transitions levels, including prekindergarten (5 years old) and kindergarten (until 6 years old).

Procedure

Four different classes were selected, one experimental class from each school and two control classes from one of the schools. The classes were randomly assigned to each condition.

One of the schools had four classes in Kindergarten, and the other school had two. We included in the sample three classes from the first school and one from the second because the other classes did not meet the inclusion criteria. The first criterion was age, which was controlled by selecting classes with at least a median age of 68 months. This decision was taken because in a previous analysis we observed that the reliability of the EFs measurement was weak for the youngest part of the sample. The second inclusion criterion was the quality of instructional interactions between educators and children, measured by CLASS Pre-K® (Pianta et al., 2008). This test shows the quality of interaction between educators and children in the classroom through three main indicators (emotional support, class organization, and instructional support). The research team hired a certified professional in CLASS Pre-K. Assessment was made through six different observation periods of 20 min each in three different days. Each observation was qualified on a 7-point scale. The quality of interactions can be high (6 to 7 points), middle (3 to 5 points) or low (1 to 2 points). To be included in the sample, classes needed to exhibit the high or middle quality of interactions in all the domains. One of the classes presented low-quality interactions in the instructional domain of the instrument, which determined its exclusion from the experiment.

The participants had never been included in any other cognitive intervention programs and received no incentives for taking part in the study. The parents signed an informed consent form to authorize their children to participate in the study, and these children gave their verbal assent before the beginning of each evaluation. The study was approved by the Vicerrectoría de Investigación (VRI; Vice President's Office for Research) of the Pontificia Universidad Católica de Chile through the Ethics Committee of the Faculty of Social Sciences of the School of Psychology, thus meeting international norms for social science research.

Games were played with the complete class, but only children who were authorized by their parents and who voluntarily agreed to participate were assessed and included in the research sample. Classes had about 35 children each.

Measures

The EFs of the children from all groups were assessed at three different times. The first assessment was made before the implementation of the program, when the students were starting kindergarten (T1). Then the participants were assessed using the same test after finishing the intervention, when they were in the middle of kindergarten (T2). And then they were assessed 8 months later, when they were starting first grade (T3). Academic performance was assessed at the last evaluation point. **Figure 1** shows the assessment and intervention times.

The Hearts and Flowers task (Wright and Diamond, 2014) was used as a general measure of EFs in all the three measures. Reliability of this test is not reported by the authors, but an adapted version with a Chilean sample, obtained a Cronbachs $\alpha = 0.83$ (Rosas et al., 2019). In this task, participants are required to use a tablet device to respond to congruent and incongruent visual stimuli within a set time limit. The task comprises three phases. The first phase is the congruent phase, in which the child must touch the same part of the screen when a stimulus (heart) appears 12 times. The second phase has an incongruent stimulus, in which the participant must touch the opposite side of the screen when the stimulus (flower) appears also 12 times. The third phase is the mixed phase, in which both congruent and incongruent stimuli are randomly presented 33 times. In all the phases, the stimuli are shown for 750 ms, and then disappear for 1 s (response time), and then another stimulus is presented. The total number of correct answers in phase 3 is used as an indicator of EFs performance. **Figure 2** shows the three phases of the test.

Academic performance in the language area was evaluated through phonological awareness and word reading skills. Phonological awareness was measured using the rhyme detection subtest of the Woodcock-Muñoz battery (Cronbach $\alpha = 0.98$) (Muñoz-Sandoval et al., 2005). In the rhyme test, participants must select the option that ends with the same sound as the target word. Word reading is assessed using the letter and word identification test of the Woodcock-Muñoz battery (Cronbach $\alpha = 0.98$) (Muñoz-Sandoval et al., 2005), in which participants read words and receive a score according to their reading accuracy. The complexity of this test gradually increases based on the syllabic structure, length, and frequency of the words used.

Performance in the mathematics area was assessed using problem-solving and counting skills. Problem-solving skills are assessed using the problem-solving scale of the

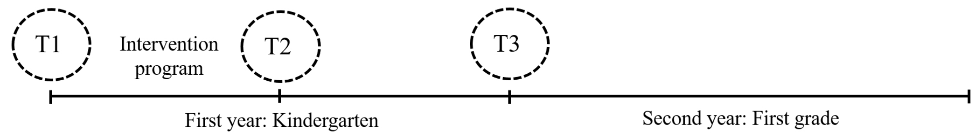

FIGURE 1 | Distribution of time during the research process.

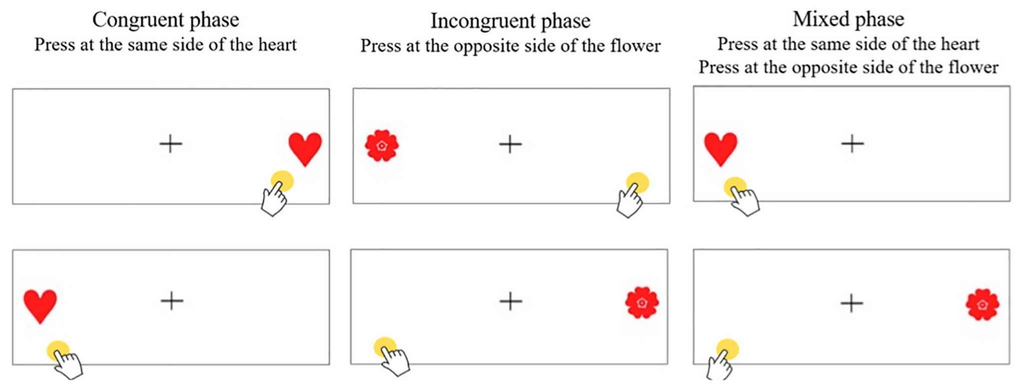

FIGURE 2 | Examples of the Hearts and Flowers test items at different phases.

Woodcock-Muñoz battery (Cronbach α = 0.95) (Muñoz-Sandoval et al., 2005), in which participants must quickly solve addition, subtraction, and multiplication problems within 3 min. Counting skills are assessed through an adaptation of the paradigm proposed by Koponen et al. (2012) (Cronbach α = 0.72). The task has two parts: forward counting (from 1 to 51, from 18 to 25, and from 6 to 13) and backward counting (from 33 to 17, from 23 to 19, from 12 to 7, and from 23 to 1).

It is important to note that because of the extreme SES homogeneity of the Chilean educational system, IQ also tends to be extremely homogeneous (Rosas and Santa Cruz, 2013) and therefore was not considered as a relevant covariable in the present study. As the authors show in the cited works, even small increments in parents' copayment for public school education determine causal differences in the children's cognitive outcomes. There is an almost perfect linear relationship between SES and cognitive outcome in the Chilean educational system (Rosas and Santa Cruz, 2014).

Trained psychologists (different as the game mediators) applied all tests in individual sessions of 30 min each during regular school time in a private office at the same schools that the children attended.

Intervention Program

The intervention program consisted of 1-h play sessions in 60 consecutive school days. Work sessions always comprised three phases (**Table 1**): (a) an initial activity (5 min) focused on activating the participants through singing and dancing, (b) a collective game designed to improve one of the three main EFs components (30 min), and (c) a closing activity (10 min) focused on metacognition that included some of the principles of mindfulness methodology (**Table 2**).

A total of 32 different games (see **Supplementary Appendix 1**) were designed or adapted from existing games by the research team. Every game was specifically designed to enhance one of the three components of EFs, although most of them could also help enhance the other components. The games were gradually implemented during the program implementation, according to their cognitive demands. They were always played during the first period (length: 45 min) and were mediated by two professionals from the Center for the Development of Inclusive Technologies (CEDETi UC), which is part of the Pontificia Universidad Católica de Chile. The four participating teachers were also invited to help with the game coordination, but they

TABLE 1 | Sessions' game structure.

Time	Duration	Content
1	5 min	Activate and positive attitude
2	30 min	Game development
3	10 min	Metacognitive activity based on mindfulness

TABLE 2 | Examples of initial and closing activities.

Initial activities	Closing activities
Frog family: The mediator sings the song of the frog family, making some movements to represented it. Children repeat the song and the movements. The song represents different family members using the characteristic movements of each: dad, mom, son, daughter, and baby.	Balloon inflating: Children stand in front of the mediator. They are asked to stand upright and put their hands on their bellies. Then they are told to imagine that their bellies became balloons and that they will inflate them slowly, inspiring through their noses. They are asked to pay attention to the way their bellies expand when the air enters. Then they deflate the balloon slowly.

devoted their game time mostly to attending to other duties in the classroom.

To homogenize the intervention among the mediators, fact sheets were created by the research team for each game. These sheets referred to formal aspects such as the goal of the game, instructions, duration, spatial arrangement (classroom or playground), number of players, and materials needed, along with didactic aspects such as the mediator's role, scaffolding ideas, possible variations, and specific advice regarding the contents of each game. **Figure 3** presents a sample sheet for one of the games.

Although the focus of each session was on the game designed to develop EFs, the initial and closing activities were also aimed for the intervention program in general. In **Table 2** can be seen some examples of initial and closing activities.

The participating classes had 35 children on average; however, not all parents signed the informed consents, which resulted in different numbers in the data for the experimental and control groups (experimental class 1, $n = 29$; experimental class 2, $n = 8$; control class 1, $n = 22$, control class 2, $n = 11$). Regarding the effective playing time, the experimental groups had on average 81% attendance during the game sessions.

Meanwhile, games were played by the two experimental groups; the children from the control groups received their traditional learning activities. For the traditional Chilean curriculum, this means that children who did not participate in the intervention (control) had personal and social development (i.e., identity and autonomy, coworking and citizenship, corporality and motor aspects), integral communication (i.e., verbal language, artistic language), and finally, interaction and environment comprehension (i.e., wild environment exploration, sociocultural context comprehension, and mathematical thinking).

Analytical Plan

The data analysis consists in two parts. In the first, we analyze the differences between the groups, with the aim to assess the impact of the program over the development of executive functions (EFs). The differences were analyzed through a covariance analysis of the differences in the growth deltas observed in the two groups. In the second part we focus on the effects of EFs development over academic performance. These effects were calculated by doing a regression analysis using the executive function level at time 1 (T1) as a predictor over the academic performance of children in language and math at time 3 (T3).

Results

Differences in EFs performance were measured between T1 and T2 and between T1 and T3 for the experimental and control groups. The total score for phase 3 (mixed congruent and

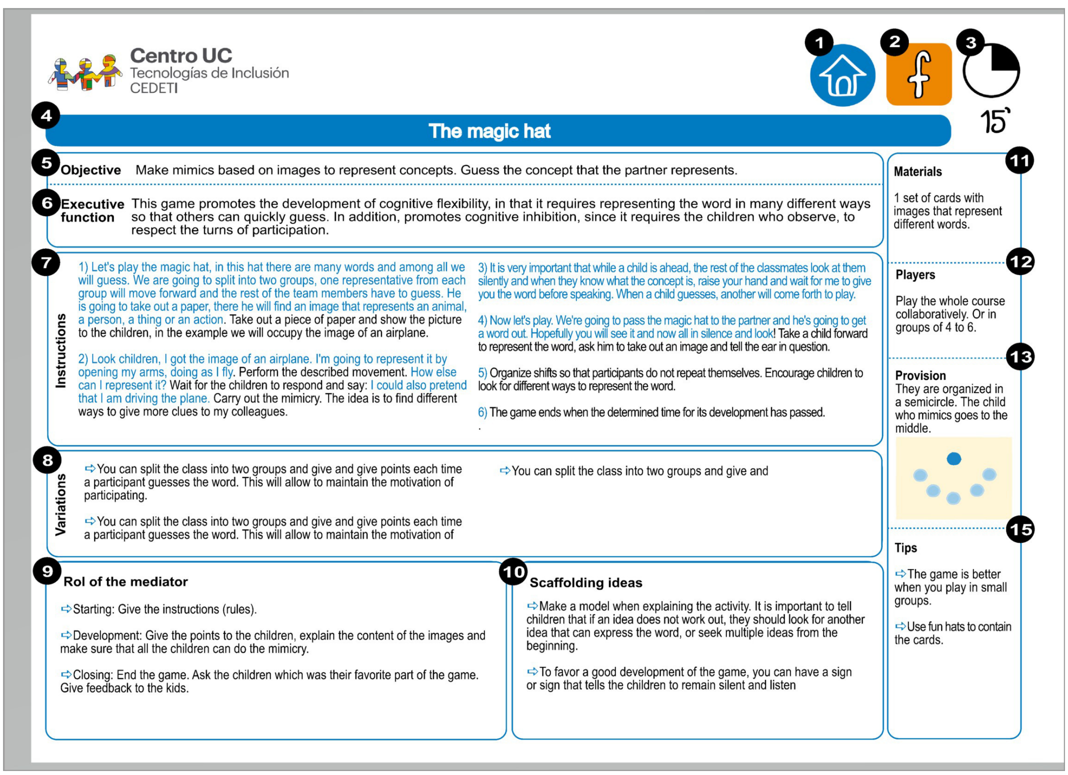

FIGURE 3 | Sample of a homogenization sheet. (1) Type of game: playground, expression, or classroom games. This is a classroom game. (2) Main EFs component developed. (3) Approximate duration of the game. (4) Title of the game. (5) Aim of the game. (6) Way in which executive functions are developed. (7) Instructions. (8) Ways in which the game can be modified. (9) Role of the mediator in each phase of the activity. (10) Scaffolding ideas. (11) Materials needed to conduct the activity. (12) Number of players and organization. (13) Suggested spatial arrangement. (14) Additional suggestions.

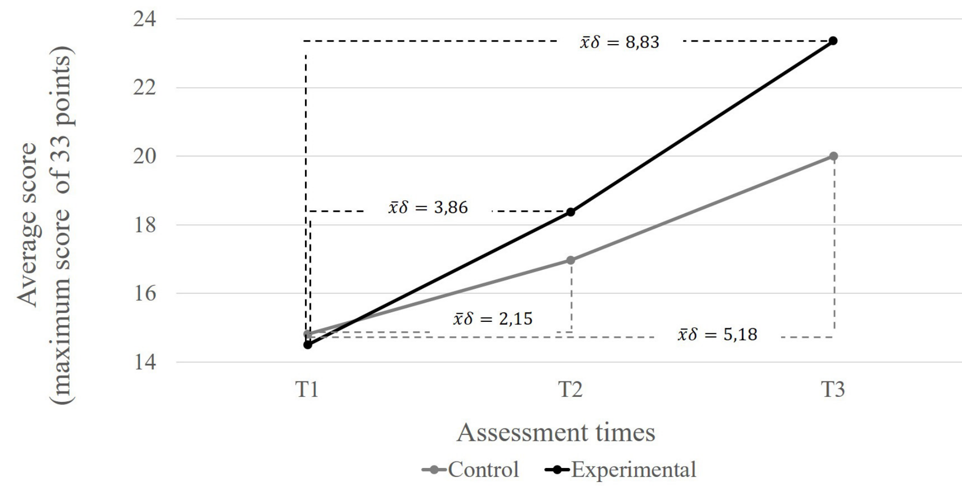

FIGURE 4 | Average growth deltas observed in each group at each assessment time.

incongruent trials) is considered to be an indicator of EFs general performance. The results are shown in **Figure 4** and **Table 3**.

Afterward, two analyses of variance were performed to examine the EFs performance between the experimental and the control group. The first analysis was performed to detect the performance differences between T1 and T2 (Delta), while the second focused on the differences between T1 and T3 (delta), controlling for the participants' age. The results are shown in **Table 4**.

The results of the ANOVA revealed no significant performance differences between T1 and T2 between the experimental and the control group (p = 0.330). However, the differences were significant between T1 and T3 (p = 0.044), in which the experimental group (X = 23.35) performed better than the control group (X = 20). The effect size ($\eta_p{}^2$ = 0.090) was small (Cohen, 1988), and the statistical power was 1–β = 0.71.

TABLE 3 | Medias, standard deviations, and percent correct outcomes of each group at different assessment moments.

	Time 1			Time 2			Time 3		
	M	**SD**	**PC**	**M**	**SD**	**PC**	**M**	**SD**	**PC**
Experimental	14.51	5.63	44.0%	18.38	6.0	55.7%	23.35	5.91	70.5%
Control	14.82	6.67	44.9%	16.97	7.43	51.4%	20.0	7.86	60.6%

M, media on EFs results; SD, standard deviation; PC, percent of correct outcomes on EFs.

TABLE 4 | EFs performance of the experimental and the control groups, compared between T1 and T2 and between T1 and T3.

	Df	F	*P*	$\eta_p{}^2$
T1-T2 performance difference	2	1.127	0.330	0.033
T1-T3 performance difference	2	3.282	0.044*	0.090

Significant at α = 0.05

The differences in mathematics and language performance between the experimental and the control group were compared at T3, controlling for EFs level at T1 (it is impossible to control for language and math outcomes at T1 because there is no formal instruction of these contents in the Chilean preschool system, and therefore, they were not assessed). The results revealed no significant differences in the language area; however, they were significantly different in mathematics, showing a significantly better performance for the experimental group (**Table 5**).

Afterward, to understand the association between EFs and academic performance, we analyzed the predictive power of the Hearts and Flowers score at T1 with regard to mathematics and language performance at T3. Age for experimental and control groups was initially controlled (step 1). Then we included the T1 Hearts and Flowers performance measure (step 2). Separate regressions were generated for the standardized mathematics (**Table 6**) and language scores (**Table 7**).

The results clearly showed that, after controlling for age, the EFs measure significantly predicted the variance in mathematics performance (0.193, p = 0.000) but did not have any predictive value in language performance (0.025, p = 0.233). These results are consistent with the ANCOVA that compared the differences between the experimental and the control group in math and language in T3 after controlling for the performance of EFs (**Table 4**).

Finally, we compared the students' performance in EFs at T3 according to their initial outcomes. The experimental group sample was subdivided into three subgroups according to their

TABLE 5 | Comparison of mathematics and language performance between the experimental and the control group at T3, controlling for EFs performance at T1.

	df	*F*	*p*	$\eta_p{}^2$
Mathematics performance	2	8.252	0.001*	0.222
Language performance	2	0.771	0.467	0.025

Significant at α = 0.001.

TABLE 6 | Stepwise regression for mathematics performance.

Step	Variable	β	ΔR^2	*df*	*t*	*p*
Step 1	Age (months)	0.139	0.003	1	1.08	0.285
Step 2	EFs time 1	0.455	0.193	1	3.863	0.000**

**Significant at $\alpha < 0.001$.

TABLE 7 | Stepwise regression for language performance.

Step	Variable	β	ΔR^2	*df*	*t*	*p*
Step 1	Age (months)	0.098	0.010	1	0.746	0.459
Step 2	EFs time 1	0.160	0.025	1	1.206	0.233

performance in the EFs assessment at T1. We divided the groups at percentiles 33 and 66, thereby forming the three subgroups. Then, through an analysis of variance, we compared the growth deltas of the poorest-performing third (M = 10.33; SD = 6.41) and the best-performing third (M = 5.54; SD = 5.41). Although the results showed no significant differences between the growth deltas of the two groups, they were clearly at the limit (F = 4.1; p = 0.055), which were higher in the group with the poorest initial performance.

DISCUSSION

This study aimed to analyze the impact of a game-based intervention on the development of EFs in preschoolers. As described by other authors (Hermida et al., 2015; Traverso et al., 2015), the implementation of the program had a positive impact on the improvement of the participants' EFs, which provides support for the use of such programs in preschool classrooms.

We will organize our discussion around some of the conclusions advanced by Diamond and Ling (2016) since we consider them to be essential for analyzing the causes of the program's success.

First, regarding transference, we sought to align our program with the authors' views: it includes a variety of games that, apart from involving physical activity, require the combined use of a number of cognitive skills. For instance, ball war not only involves picking up and throwing balls around, as children must also make a cognitive effort to identify the facial expression drawn on each ball and then decide to either throw or keep it. The games used were varied and were repeated only three times at most. This prevented the children from predicting their contents and putting less effort into them. In addition, the types of tasks used for evaluating EFs sharply differ from the games implemented in the intervention, which makes it possible to rule out the effect of direct or excessively specific training of EFs components.

One open question related to transference that was not addressed by our project is whether there can be design-specific EFs component interventions to specific EFs outcomes. As we only took a general measure of EFs, we cannot show any data in this direction, but future research should address the contradictory evidence from almost all of the studies reported regarding these issues.

Second, regarding duration, the present program attempted to greatly surpass the 32 sessions used in the study conducted by Hermida et al. (2015), who found this number to be insufficient. The participants played for 45 min per day over a 3-month period. This resulted in a total of 60 game sessions. Compared with other programs (e.g., Traverso et al., 2015), this implementation time is long; however, it is shorter than that reported for curricular programs such as "Tools of the Mind." Implementing a game-based program such as ours at the curriculum level could have a more lasting impact on students' EFs development. This should be tested in future studies that incorporate games over a longer period and that are able to conduct a longer longitudinal follow-up process. It is interesting to note that a very similar intervention program designed by Röthlisberger et al. (2011) also generated significant training effects in 60 sessions of 30-min activities. But in contrast to that experience, which was implemented in a small-group format, our intervention proved to be possible to implement in a totally natural classroom context, with groups with up to 30 children. This is a huge advantage of our design because it can possibly be transferred as a regular preschool activity, without the need to take groups of children apart.

Related to this, it should be noted that a program such as that proposed here, implemented during regular class hours, shows that it is more effective for EFs development than the "regular" classes attended by the control group. And given the proven association between EFs and mathematics performance 10 months later, it is necessary to consider the importance of conducting activities to promote EFs in the preschool curriculum.

The fact must be highlighted that our interventions were always implemented with the entire class of approximately 35 children, that is, a full group intervention. Some of the games required dividing the class into subgroups, of course. But our methodology, in contrast to other successful programs (e.g., Traverso et al., 2015), is designed to make its implementation possible in natural school settings.

In any case, it is important to highlight that the work of Traverso et al. (2015) shows significant outcomes in many measures of EFs after only twelve 30-min training sessions in a controlled setting, with robust size effects in the majority of them. Although they did not report any long-term effects, it is necessary to investigate more exhaustively whether their results are a consequence of the type of training tasks employed, the training setting, or a combination of the two.

In the same direction, it is important to note, however, that the intervention program's optimal duration remains an open question. Hermida et al. (2015) showed very weak results in EFs after 32 sessions, but very strong results in the long-term effects over math and language outcomes one year later. We obtained similar results in math outcomes, but not in language outcomes. And our program effects over EFs are modest but significant.

Third, this study expressly controlled for the program monitors' commitment and motivation, as suggested by

Diamond and Ling (2016). The monitors were part of the research team and took part in the design of the games and the program. Therefore, they expected the program to have positive results and were committed to the success of the intervention. However, it is necessary to test the efficacy of the program in a more natural context, that is, where the implementation is in charge of the educators who work with the children.

Fourth, this program has a design that constantly challenges children's EFs, at least for 45 min per day for over 3 months. Organizing the sessions around mindfulness activities, games, and a cognitive closing phase in which the participants metacognitively reflect on the games can also allow the children to learn a more general way to approach tasks. In this regard, this program is consistent with others in which activities are designed to permanently challenge children's EFs (Hermida et al., 2015) but extend the intervention compared with brief programs, whose longer-term effects are unknown (Traverso et al., 2015).

Fifth, our study is consistent with what Diamond and Ling (2016) report, as we observed that individuals with lower EFs development levels tend to benefit more from programs of this type.

Although research shows that the effect of these programs fades over time, 8 months after they are finished, our program displayed a better effect than immediately after it ended. This is a promising result since it suggests that game-based strategies promote a more lasting development of EFs.

This project yielded no information about the cognitive load of tasks and their greater influence in programs aimed at developing EFs (Diamond and Ling, 2016) since we only tested EFs with the gold standard for their overall evaluation: the Hearts and Flowers task devised by Wright and Diamond (2014). Likewise, our program did not aim to generate evidence about whether physical activity by itself is a good way to foster EFs, as suggested by Hillman et al. (2018) in their response to Diamond and Ling's (2016) criticism. Still, what we do consider relevant is to incorporate games with a major aerobic component since preschoolers are very open to and motivated by games of this type. Yet in all the games included, our program explicitly sought to develop a given EFs component; thus, we have no information that could shed light on the issue.

Lastly, it cannot be completely ruled out that our program was affected by intervening factors beyond our control. We believe that the main potential issue was that the experimental group had very motivated monitors with lengthy experience in classroom games with small children. In contrast, the control group attended to regular classes with their regular teachers. Although we made sure to select only teachers with good scores on the CLASS Pre-K® scales (Pianta et al., 2008), the novelty and highly interactive nature of the games played by the experimental group could have a strong impact on the motivation of the children. Although this is a possibility, it does not negate the fact that the proposed program, after controlling for all the aspects listed by Diamond and Ling (2016), has a significant effect on the development of EFs in preschoolers, which was measured 8 months after the end of the intervention.

Also, the results of our intervention, despite its modest effect sizes, show that the suggestions laid out by Diamond and Ling (2016) give a good framework to the design and implementation of high-quality (Barnett, 2011) and replicable programs for the enhancement of EFs, with proven, lasting effects.

Future research interventions should include more variables, as IQ or sociodemographic factors that could have an impact over the program results.

AUTHOR'S NOTE

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DATA AVAILABILITY

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

This study was approved by the Vicerrectoría de Investigación (VRI) (Vice-President's Office for Research) of the Pontificia Universidad Católica de Chile through the ethics committee of the Faculty of Social Sciences of the School of Psychology, thus meeting global norms for social science research. The children's parents signed an informed consent form to authorize them to participate in this study, and the children gave their verbal assent before the start of each evaluation.

AUTHOR CONTRIBUTIONS

RR designed the study and wrote the final version of the manuscript. VE coordinated the research, analyzed the data, and wrote the first draft of the theoretical part of the manuscript. FP wrote the method and built the final databases for the manuscript. FC helped with the writing of the discussion.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.02024/full#supplementary-material

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Effectiveness of an Executive Function Training in Italian Preschool Educational Services and Far Transfer Effects to Pre-academic Skills

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In this study we examine the effectiveness and far transfer effects of a training that was found to be effective in promoting Executive Function (EF) in a sample of 5-year-old children (Traverso et al., 2015). By contrast with Traverso et al. (2015), the intervention was administered by regular teachers to verify its ecological validity. Far transfer was assessed by evaluating the training effects on pre-academic skills. 126 children attending the last year of Italian preschool educational services took part in the study (mainly 5-year-old children). Pre- and post-test assessments were conducted using a large EF and pre-academic skill task battery. The results indicate that the experimental group outperformed the control group in an interference suppression composite score. Moreover, significant far transfer effects to pre-academic skills in literacy domain were found. In addition, we found that the improvement in the pre academic skills (in both literacy and math domains) was mediated by the improvement in the interference suppression score. The results suggest the possibility that this intervention, which may be easily implemented in the context of educational services, can promote EF during the preschool period before entry to primary school.

Keywords: executive function, training, pre-academic skills, preschool, intervention

INTRODUCTION

Executive function (EF) refers to a set of self-regulatory cognitive processes that underlie goal-directed behavior and support individuals faced with new or complex situations (Miyake and Friedman, 2012). In recent years, there has been a considerable interest in the early development of EF, particularly because EF measured in early childhood is a significant predictor of several developmental outcomes, including school readiness (Shaul and Schwartz, 2014) and academic achievement (Best et al., 2011). Consequently, promoting EF may constitute a useful strategy to reduce the neurocognitive disparities among children before school entry and to increase the likelihood of positive developmental outcomes (Blair and Raver, 2015). Recently, promising results have been reported in training studies fostering EF (Diamond and Lee, 2011), nevertheless, some open questions emerged from recent reviews including what are the best methods of improving EF and whether training benefits transfer to other domains (Willis and Schaie, 2009; Jolles and Crone, 2012; Melby-Lervåg and Hulme, 2013; Redick et al., 2015; Diamond and Ling, 2016).

Preschool training includes diverse types of training that differ in duration (long- vs. short-term intervention), setting (individual vs. group intervention), and materials. Training that is delivered by teachers allows to extend the opportunity to train EF before starting primary school to a large sample of children. Nevertheless, not all the available trainings are feasible for all the educational services, such as low resource contexts. Moreover, only a few studies investigated whether benefits in EF, attained with short-term preschool training, transfer to pre academic achievement and the results of these studies are mixed.

The current study was designed to ascertain the effectiveness and the far transfer effects of a short-term school-based intervention that was found to be successful in promoting EFs when a trained psychologist administered it to 5-year-old children (Traverso et al., 2015). Specifically, effectiveness was investigated by verifying the training efficacy when regular teachers of preschool services administered the training in a real-world condition; far transfer was investigated by verifying the effect of EF training on pre-academic skills.

Preschool Executive Function Development

The preschool years are considered a crucial period in the development of EF during which a significant increase of performance in tasks supposed to assess different EF abilities takes place (see, for example, Garon et al., 2008; Best and Miller, 2010). During the preschool years, besides a quantitative change in EF, a reorganization and progressive identification of different EF skills occurs; specifically, a two-factor structure, in which inhibition and working memory (WM) are distinct but interrelated factors, emerged between 4 and 6 years of age (Miller et al., 2012; Lee et al., 2013; Usai et al., 2014; Monnette et al., 2015; but see Willoughby et al., 2012).

Individual differences in EF reflect substantial genetic contributions at the level of latent variables (Friedman et al., 2008), nevertheless, in recent research it has been highlighted that EF is sensitive to early experience (Kraybill and Bell, 2013; Müller et al., 2013; Raver et al., 2013; Cuevas et al., 2014). Given the prolonged development of EF, it seems plausible that the environment can affect children's EF, especially when considering environmental factors to which children are extensively exposed to. For example, evidence suggested that factors such as socio-economic status, parenting behaviors and responsive parenting affect the development of EF (Noble et al., 2005, 2007; Farah et al., 2006; Rhoades et al., 2011; Fay-Stammbach et al., 2014). The malleability of EF in response to environmental conditions suggested the possibility of enhancing EF by means of specific stimuli, such as EF training, provided to children in familiar contexts.

Preschool Executive Function Training

In recent years, EF training has received considerable attention (see Diamond and Ling, 2016, for a review) and diverse types of training have been developed and tested even for preschool children.

Some studies investigated the efficacy of short-term training, consisting of individualized computer training sessions to be carried out over periods ranging from 1 week to 1 month and delivered by researchers in lab (Rueda et al., 2005, 2012; Thorell et al., 2009; Bergman Nutley et al., 2011; Blakey and Carroll, 2015). This approach is based on the idea that EF skills can be enhanced with repeated practice sessions of specific EF tasks; consequently, the effects of this kind of training is generally highly specific (Owen et al., 2010). Positive results were observed in short-term computer training although not in all the EF components that were assessed, in particular positive effects were more often shown in WM tasks than in inhibition tasks (Thorell et al., 2009). Concerning transfer effects on academic achievement, in the study by Blakey and Carroll (2015), transfer effects on math were observed, even though math ability was assessed only at follow up.

Other studies focused on long-term programs, generally group-based interventions that correspond to a school curriculum and are provided in educational services over the entire duration of preschool or during the year before the beginning of primary school (e.g., Bierman et al., 2008a,b; Raver et al., 2011). These teacher-led interventions are mainly designed to improve different aspects of children's school readiness (for a review see Bierman and Torres, 2016). In a series of studies, Raver et al. (2008, 2009, 2011) evaluated the efficacy of the Chicago School Readiness Project (CSRP) that was effective providing teachers with better classroom management strategies and had the expected impact on the quality of teacher-child interactions (Raver et al., 2008), on children's aggressive behavior (Raver et al., 2009), on pre-academic skills and on inhibitory control (Raver et al., 2011). Similar results were found for the Head Start REDI program (Bierman et al., 2008b) that showed an impact on children's EF measures (Bierman et al., 2008b). Another example is the Tools of the Mind Program (Bodrova and Leong, 2007) specifically designed to promote the development of self-regulation skills and that was found to be effective in promoting EF (Diamond et al., 2007; Blair and Raver, 2014). These long-term interventions require extensive teacher training and materials for implementation and are comprehensive in nature, in the sense that are aimed at improving several components of school-readiness, such as self-regulation, social skills, early math, and literacy. The rationale for these interventions is that EF skills can be enhanced in early educational settings by improving the quality of teacher-child interactions and providing supportive educational contexts (Bernier et al., 2012).

As Dias and Seabra (2015) pointed out, it must be noted that these types of training are not suitable for all contexts. For example, some schools may lack key resources to provide computer training or educational interventions that require high-trained personnel. Consequently, both efficacy and effectiveness should be evaluated in order to assess, in the first place, whether a given intervention works under controlled circumstances and then under "real word" conditions and practice (Singal et al., 2014).

To our knowledge, the efficacy of short-term EF training delivered in educational services was investigated in few studies (Röthlisberger et al., 2011; Tominey and McClelland, 2011; Dias and Seabra, 2015; Schmitt et al., 2015; Traverso et al., 2015; Duncan et al., 2018), and even fewer investigated the training effectiveness, that is the training effects on EF when regular teachers administered the training in real-world conditions

(Dias and Seabra, 2015; Duncan et al., 2018); finally, only in some short-term training studies, transfer effects on academic performance were examined (Tominey and McClelland, 2011; Schmitt et al., 2015; Duncan et al., 2018). Tominey and McClelland (2011) developed a classroom-based, early childhood intervention that consisted of circle time games implemented in 16 sessions mainly aimed at enhancing behavioral inhibition. *Post hoc* analyses revealed significant effects of the intervention on children with low inhibition scores at pre-test. A second study with children from low-income families showed that the intervention was effective in enhancing self-regulation for the full sample and math skills for English language learners (Schmitt et al., 2015). In both cases, the intervention was administered by the researchers in preschool classrooms. However, in a more recent study (Duncan et al., 2018), the effectiveness of the intervention in improving self-regulation was also demonstrated when it was delivered by teachers as part of an existing kindergarten readiness summer program. No significant effects on early math or literacy skills were found at the end of the program, even though children who took part in the experimental sample showed improved growth in math and literacy during the kindergarten transition period compared with an independent longitudinal sample. However, the results of this study were only partially obtained by a randomized design.

Executive Function and Pre-academic Skills

Pre-academic skills represent the knowledge a child acquires during the preschool years and include domain-specific precursors of later academic achievement, such as phonological awareness, rapid naming, number recognition, magnitude understanding. These skills are highly predictive of subsequent academic achievement (for a meta-analysis, see La Paro and Pianta, 2000) and contribute to young children's school readiness (Willoughby et al., 2017). Even though individual differences in preschool EF were consistently found to predict long term math and literacy achievement (Bull et al., 2011; Clark et al., 2013; Miller et al., 2013; Viterbori et al., 2015; De Franchis et al., 2017; Usai et al., 2018), less is known about the predictive associations between EF skills and pre-academic skills. Given that EFs are a set of abilities that support the individual when faced with novel situations, it is plausible that EF influences the acquisition of new abilities or the management of complex cognitive tasks, such as those typical of early reading or writing skills (Blair and Raver, 2015). Nevertheless, as pointed out by Jacob and Parkinson (2015), to date only few studies explored the nature of the association between EF and achievement, with randomized control trial, in preschool age.

The Current Study

The current study used a randomized design to investigate the effectiveness of a short-term EF preschool training that was previously found to be effective in enhancing EFs when administered by a trained psychologist external to educational service personnel (Traverso et al., 2015); moreover, we aimed to investigate the far transfer effects to pre academic skills.

Specifically, concerning the first aim, whereas efficacy studies, such as Traverso et al. (2015) study, maximizes the likelihood of observing an intervention effect if one exists, effectiveness studies evaluate training under conditions that more closely approach real-world conditions (Singal et al., 2014). In Traverso et al. (2015), the training showed a significant effect on most EF measures, after controlling for pre-test scores. Specifically, the children who took part in the training performed better than the control group in tasks that required delaying a gratification (i.e., Delay Task, adapted from Kochanska et al., 1996), controlling a prepotent behavioral response (i.e., the Circle Drawing Task and Preschool Matching Familiar Figure Task), managing interference (i.e., Flanker Task) and high cognitive conflict (i.e., the Dots task), and in tasks assessing WM (i.e., Backward Word Span and Keep Track). The effect size (Cohen's d) ranged from 0.35 to 0.70 and it was from medium (>0.50) to large (0.80) for the majority of the tasks. In the current study, we were interested in verifying whether the EF gains obtained in the study by Traverso et al. (2015) could be found also when regular teachers, minimally trained, administered the training during the daily school schedule in real-world conditions. As pointed out by Singal et al. (2014), in effectiveness studies, providers may adopt less-standardized protocols and target a more heterogeneous children population. Indeed, differently from Traverso et al. (2015), we decided to include in the study also the children with special needs who in Italy attend regular classes (see Zanobini et al., 2017).

In addition, as regards the second aim, differently from the previous study, the present one was designed to assess whether EF training effects could transfer to pre-academic skills. Specifically, we were interested in verifying whether an increase in EF skills could enable children to benefit more from learning opportunities and consequently enhance their pre-academic skills, even without an intervention directed at these skills. To date the far transfer of short-term EF training delivered by teachers to pre-academic skills in preschoolers has been rarely investigated (Duncan et al., 2018). In addition, as suggested by Bierman and Torres (2016), we employed an analytical approach that allows to control for dependencies associated with influences due to the belonging to different classes.

Similarly, to the intervention used in Duncan et al. (2018), the training involved low-cost and easily available materials (e.g., colored markers, pens, and pencils) and lasted approximately 1 month. Moreover, the activities were designed to be included in the standard preschool curriculum, which in Italy emphasizes learning through play and adopt a small-group approach. Indeed, we were interested in comparing the training condition with usual practice. Differently from Duncan et al. (2018) whose training activities were designed to primarily practice inhibitory control, our training focused on both inhibitory control and WM, and we used a large battery of EF tasks at pre- and post-test.

To summarize, we examined two research questions: (1) whether a short-term training designed to foster EF in children of 5 years of age showed ecological validity, being effective in promoting executive skills when administered by regular teachers with all the children; (2) whether the training produced far transfer effects on pre-academic skills.

MATERIALS AND METHODS

Participants

A total of 137 5-year-old children attending the last year of seven preschool educational services participated in the study. Public preschools in Italy enroll children from 3 to 5 and offer a pre-primary curriculum that promotes social skills, autonomy, and learning. Even though attendance is non-compulsory, more than 95% of target children attend preschool before starting primary school at the age of six. During the last year of preschool, which corresponds to kindergarten level in the US, particular attention is paid to school-readiness and acquisition of pre-academic skills, such as early reading and writing skills, phonological awareness, and number sense.

1The selected preschools serve the same urban area of two large cities in a northern Italian region. In agreement with the school principals and teachers, the study was presented to the parents of the children attending the last year of preschool; the parents who agreed to allow their children to participate filled in the parental informed consent form. This study was carried out in accordance with the recommendations of the Ethical Code of the Italian National Council of Psychologists and the Ethical guidelines of the Italian Association of Psychology.

Eleven children were excluded from the initial sample because they did not take part in the assessment at pre- or post-test evaluation. We were therefore interested in verifying whether the training was effective also when administered in regular classes that may include children with special educational needs. In particular, 21 children with special needs participated, specifically nine children with atypical developmental paths (i.e., born pre term, presenting language delays, or with attention difficulties) (eight in the control group), one child in the care of social services (one in the control group); two minority language children with limited proficiency in Italian (two in the control group), nine children with a score under the 10th percentile in the Raven's colored progressive matrices (three in the control group). Children with special needs were not evenly distributed between the experimental and the control group, since group allocation was according to class.

The final sample included 126 children between the ages of 52 and 78 months (M_{age} = 65.4 months; SD = 4.31; 44% females) who were attending the last year of preschool services before starting primary school: 57 children were in the control group (M_{age} = 66.1; SD = 4.29; 47% females) and 69 children were in the experimental group (M_{age} = 64.9; SD = 4.28; 42% females).

In determining the sample size we referred to previous studies in which short-term training were assessed (i.e., Tominey and McClelland, 2011; Blakey and Carroll, 2015; Dias and Seabra, 2015; Traverso et al., 2015). The children attended 7 preschools and were grouped in 13 classes. Preschools were randomly assigned to the control condition (four preschools, four classes) and to the experimental condition (three preschools, nine classes), in order to have a similar sample size and to ensure that teachers of the control group of children were unaware of the intervention stimuli, and that teachers of the experimental group of children did not transfer the training activities to the control group. We do not include an active control group because children of both the control and experimental group spend the same time with teachers in similar settings, and are normally involved in small-group educational workshops. Specifically, in Italy, the preschool classrooms comprise from 18 to 26 children between 3 and 5 years of age. In each classroom there are two teachers with some hours of co-teaching, during which they usually organize small group activities for children of the same age.

The Training

The training program was the one described in Traverso et al. (2015). It included 12 sessions of approximately 30 min that were administered at school three times a week over approximately 1 month.[1] While in the Traverso et al.'s (2015) study the training was administered to small groups of five children, in the current study the groups ranged from 5 to 8 children. The training aimed to stimulate EF skills through a series of small group game activities that require progressively higher levels of inhibitory control and working memory and require children's active participation. Each child was given a different role with a specific responsibility (i.e., the director, the referee, the player) – for example, the director was in charge of managing the players' behavior. During each session, the roles were exchanged. For example, in the second activity, children must help the Magic Frog become better able to inhibit irrelevant information and control its actions. The director has to regulate attention in naming a series of pictures on a paper, and he asks the players to touch the floor or jump according to what they hear and what they have as assigned pictures. The referee must assign a score only if all the players move correctly. All of the training activities were different from the assessment tasks that were administered to the children before and after the intervention.

In order to help children manage the activities, we use a narrative framework that enables young children to connect and remember the activities from one session to the other and to be more focused and motivated, since the activities are included as a part of the story in which they have to help two little goblin friends. Moreover, each session is structured in the same way. First, an introductory activity helps children to recall the rules they are asked to respect and to bring to mind what happened in the previous session; then, the specific EF activities are presented to children and, in the end children are engaged in a metacognitive activity during which they have to assess their performance and to briefly discuss the strategies they used in managing the activities. We provided concrete aids to help the children develop and practice self-regulation strategies through concrete experiences with physical materials. Finally, the adult that administers the activities is asked to pay special attention to support the children's self-esteem and well-being during the activities, and to praise the children for their efforts during and at the end of each session.

By contrast with Traverso et al. (2015), in which the training was carried out by a trained psychologist, in this study regular teachers administered the training to all the pupils of their class. A training manual (see **Supplementary Material**) and a 12-h in-service course were provided to the teachers that participated in

[1] The training is available at www.autoregolazione.org.

the study. Specifically, the training manual included a general description of the training's aims, the description of the activities, the instructions to administer the activities, and some printed materials to be used during the training. The course took place concurrently with the training and included six 2-h-sessions. The first session focused on EF and its role in early education, and provided a description of the general characteristics of the training. In the second session, the first three training activities were presented to the teachers and in addition, teachers were given all the instructions to prepare the materials. In the following three sessions, the other activities were presented (three at a time) and teachers were encouraged to discuss their experience with the administration of the previous three activities; in addition, the adherence to the program was assessed and discussed with the teachers. Finally, in the last session, teachers were encouraged to discuss their global experience with the training.

Assessment Procedure

The control and the experimental groups were assessed before and after the training. Children were tested individually in a quiet room in three separate sessions, each lasting approximately 20 min. Evaluations were made within 2 weeks before and after training. The tasks were presented in a fixed order (**Table 1**). A fixed order is a standard practice in individual differences research (see Carlson and Moses, 2001). All the tasks described in the following section were administered twice (i.e., pre- and post-training), with the exception of the Coloured Progressive Matrices Test (CPM, Raven, 1954), which was used as a control measure concerning cognitive functioning of the two groups at pre-test. In both pre- and post-training conditions, trained psychologists, blind to the children's group assignment, tested the children individually.

Measures

Fluid Intelligence

The Coloured Progressive Matrices Test (Raven, 1954) was administered to measure fluid intelligence and was used as a control. It is a multiple choice test of abstract reasoning in which the child is required to complete a geometrical figure by choosing the missing piece among six possible drawings; the patterns progressively increase in difficulty during the 36 items presented (CPM, expected range 0–36).

Executive Function Battery

To assess EF, the following tasks were administered.

Circle drawing task

This task (Usai et al., 2017, adapted from Bachorowski and Newman, 1985) was used to evaluate response inhibition, specifically the motor inhibition of an on-going response (Geurts et al., 2005; Marzocchi et al., 2008; Usai et al., 2014). The child must trace with his finger over a 17 cm diameter circle from a starting point to an ending point. The task is administered twice. On the first administration, neutral instructions ("trace the circle") were given, and on the second administration inhibition instructions were given ("trace the circle again but this time as slowly as you can"). Larger time differences indicate better inhibition (slowing down) on the part of the participant in their continuous tracing response. Time in seconds was recorded for each trial. Scores were calculated as the slowdown relative to the total time using the following formula: T2-T1/T2 + T1, where T1 and T2 were the times recorded for the first and second trials, respectively (Circle drawing, expected range negative to positive values-no limit). The test–retest reliability coefficient was calculated on a sample of 43 5-year-olds, who had been assessed twice in a previous study by Traverso et al. (2015). The Pearson correlation coefficient was 0.57.

Preschool matching familiar figure task

This task (Traverso et al., 2016; Usai et al., 2017) measures the child's ability to restrain impulsive responses and to compare the target with all of the pictures by shifting attention from the target to each alternative. The child is asked to select the figure that is identical to the target picture at the top of the page from among different alternatives. In the format adapted for kindergartners, this task involves five alternatives and comprises 14 items. The number of errors was recorded (Matching, expected range 0–56). The Cronbach's alpha calculated in a sample of 174 children (M_{age} = 60.04) was 0.67 (Traverso et al., 2016).

Fish flanker task

The Flanker task (Usai et al., 2017, adapted from Ridderinkhof and van der Molen, 1995) is a well-known paradigm that is used

TABLE 1 | Summary of the assessment battery: the order of tasks for each session and the variable labels used in each task to assess cognitive abilities, EF, and pre-academic skills are reported.

	Task order for each sessions	Variables (score range)	To assess
1° Session	Coloured progressive matrices	CPM, sum of correct item (0–36)	Intelligence
	Backward word span	Backward span, span level (1–9)	WM
	Preschool matching figure task	Matching, errors (0–56)	Response inhibition
	Keep track	Keep track, sum of correct item (0–9)	WM
2° Session	Fish flanker task	Flanker, accuracy (0–16)	Interference suppression
	Circle drawing task	Circle drawing, proportion of slow down	Response inhibition
	Dots task	Dots, accuracy (0–20)	Interference suppression
3° Session	Digit comparison task	Digit comparison, accuracy (0–11)	Early math
	Digit-dots correspondence	Digit correspondence, accuracy (0–9)	Early math
	Rapid automatic naming	Rapid naming, errors (0–no limit)	Rapid naming
	Identifying the rhymes	Rhymes, accuracy (0–19)	Phoneme awareness
	Syllable fusion	Syllable, accuracy (0–18)	Phoneme awareness
	Writing task	Writing task, accuracy (0–6)	Early writing skills

to evaluate the ability to inhibit irrelevant interfering stimuli (Eriksen and Eriksen, 1974). The child is required to respond to a left or right oriented fish that is presented at the center of the computer screen by pressing a left or right response button. Two other fish facing the same (congruent condition, 16 items) or opposite direction (incongruent condition, 16 items) flank the target fish. After a brief training session consisting of four items (two of each condition), thirty-two items are randomly presented (16 items per condition, half left and half right). A warning cross (500 ms in duration) preceded the stimulus. After the response, the screen turned blank for 500 ms. Accuracy in the incongruent condition (Flanker, expected range 0–16) was recorded. Test–retest reliability (Pearsons' r) calculated in a sample of 43 typically developing children (age range 62–75 months, M_{age} = 68.60; SD = 3.5) was 0.42 (Usai et al., 2017).

Dots task

This task (Usai et al., 2017 adapted from Diamond et al., 2007) is a high cognitive conflict task that requires both inhibition and WM (Diamond et al., 2007). In this task, the child has to shift between rules according to the stimulus presented (see Diamond et al., 2007; Diamond and Lee, 2011). A heart or a flower appears on the right or left of a computer screen. The child is told that he must press on the same side as the heart but on the side opposite the flower, which requires inhibiting the tendency to respond on the side where the stimulus appeared. After a brief training session with heart and flower items, the test began, and hearts and flowers were intermixed in the test. The sum of the correct responses (Dots, expected range 0–20) was recorded. Test–retest reliability (Pearson's r) calculated in a sample of 43 typically developing children (age range 62–75 months, M_{age} = 68.60; SD = 3.5) for accuracy was 0.62 (Usai et al., 2017).

Backward word span

This task is a traditional WM task (Carlson, 2005; Alloway et al., 2006). This task requires the child to recall a sequence of spoken words in reverse order. Words were presented approximately once per second. After an illustration trial, the test begins with three trials of two words. The number of words increments by one every three trials until three lists are recalled incorrectly. The maximum list length at which two sequences were correctly recalled was scored (Backward span, expected range 1–9).

Keep track

The Keep track task (Usai et al., 2017 adapted by Van der Ven et al., 2011) is a WM task that is suitable for assessing updating ability in both adults (Miyake et al., 2000) and children (Van der Sluis et al., 2007; Van der Ven et al., 2011). The child was shown pictures, each of which belonged to one of the following five categories: animals (dog, cat, fish, bird), sky (sun, moon, stars, cloud), fruit (strawberry, grape, pear, apple), vehicles (train, bicycle, motorbike, car), and clothes (socks, skirt, t-shirt, shoes). Before each trial, the child was asked to pay special attention to one (first three trials) or two designated categories (last three trials). The pictures were shown in series of six. During the presentation of each series, the child had to name each picture. At the end, the child had to recall the last item in each designated category, which required managing the interference caused by the other named pictures. The number of designated categories increased from one (in the first three series) to two (in the last three series). During the picture presentation, small pictures symbolizing the categories to be remembered were shown at the bottom of the screen to serve as a reminder. One point was given for each correct response, and 0.5 points were given if the child was not able to recall the item and asked to see all the pictures in the requested category again (Keep track, expected range 0–9). Test–retest reliability (Pearson's r) calculated in this sample (typically developing children of the control group) was 0.544.

The Pre-academic Skills Battery

To assess pre-academic skills, the following tasks were administered.

Early math skills

We administered two subtests of the Numerical Intelligence Battery (BIN, Molin et al., 2007), a standardized battery for the assessment of numerical competence in preschool children. In the digit comparison task, children have to choose the larger of two Arabic digits and receive one point for each correct response. The task is composed of eleven trials with digits ranging from 1 to 9 (Digit comparison, expected range 0–11). In the digit-dots correspondence, the children have to match the digit presented with the corresponding set of dots among three visually presented sets. The task is composed of nine trials and children receive one point for each correct response (Digit correspondence, expected range 0–9).

Early literacy skills

We administered two subtests of the PAC-SI (Scalisi et al., 2003) and one of the CMF (Marotta et al., 2008), that are two standardized batteries for the assessment of pre-academic skills in preschool children. In the Rapid automatic naming task (PAC-SI), children must name a series of different objects, which are in different sequences and divided into six rows, as quickly as possible and in order from left to right. Errors (Rapid naming, expected range 0–no limit) were measured. In the Identifying the rhymes task (PAC-SI), children are shown three pictures have to name the pictures aloud and identify the word that does not rhyme with the others. The test includes 19 items. The score (Rhymes) is the number of words correctly identified by the children (expected range 0–19). In the Syllable fusion test (CMF), after listening children had to put syllables into one word and pronounce it. The test includes 18 items (six words with three, four and five syllables). The score (Syllable) is the number of correct words repeated by the children (expected range 0–18).

In addition, children were asked to perform a spontaneous handwriting task (Writing task), in which they had to write the name of four different pictures (a dog, a table, a sun, and an elephant). Based on Ferreiro and Teberosky's (1982) model of writing acquisition, children's performance was scored as follows: writing via drawing or scribbling (1 point), writing via making letters like forms (2 points), writing via reproducing at least one correct letter (3 points), writing via reproducing well-learned units (4 points), writing via invented spelling (5 points) and writing via conventional spelling (6 points). A score ranging from 1 to 6 was assigned to each of the four figures. The final score was given by the mean of the scores obtained in each of the four pictures. Two judges coded the children's performance independently. The correlations between the two judges indicated adequate coding reliability (pre-test, $r = 0.986$; post-test, $r = 0.993$).

Statistical Analyses

Descriptive analyses and pre-test comparisons with Student's T-test and Chi-square were conducted to investigate differences between the control and the experimental groups at baseline in relation to EF task scores, pre-academic skill tasks performance, age, fluid intelligence, level of mother's education, and gender distribution. Zero-order (Pearson) correlations among measures were calculated. Given that EFs are usually low associated (Willoughby et al., 2016), in order to improve precision of measurement, Willoughby et al. (2017) suggest to administer multiple tasks and aggregating performance across these tasks (formative indices). Therefore, to perform the subsequent analyses, the pre- and post-test scores were transformed into z-scores. Each z-score for the post-test was calculated using the mean and the standard deviation derived from the pre-test phase, thus obtaining a z-score gain. Based on the literature, which suggests that two components of inhibition emerge as separate at this age (Gandolfi et al., 2014; Traverso et al., 2018), two inhibitory composite scores were calculated as the mean of the z scores: a response inhibition score with the Circle drawing score and the Preschool matching familiar figure score (multiplied by −1), and an interference suppression score with the Fish flanker and the Dots tasks. Moreover, a composite score for WM abilities was obtained with the Backward word span and the Keep track tasks. The Math and the Literacy composite scores included the Digit comparison and the Digit correspondence scores, and the Rhymes, the Syllable fusion, and the Rapid automatic naming (multiplied by −1) scores, respectively. The composite scores for each participant were calculated when both or two out three values of the original variables were present. Zero-order (Pearson) correlations among composite scores were calculated. Then, for each child the three EF composite scores, the Literacy and the Math composite scores and the spontaneous handwriting score (Writing score) were submitted to a series of repeated measures linear mixed model (LMM) analyses using General Analyses for Linear Model (GAMLj) in a Jamovi package (The Jamovi Project, 2018). The LMM enables taking into the account the dependency among the measures within clusters; in this case, we can consider the dependency effects in the models to be due to the participants' characteristics and the class attended. Moreover, the LMM enables efficient handling of missing values because it does not employ a listwise procedure. Specifically, mixed models uses maximum likelihood, which handles the missing data. In each LMM, the EF composite scores, the Literacy and Math composite scores and the Writing score were modeled as fixed factors; participant and class intercepts were considered as random factors and age as covariate. To investigate the training efficacy the interaction between Time of assessment (pre- and post-test) and Group was included. This analysis was used to test our hypotheses for each dependent variable. To verify the relative magnitude of the training, the d effect size was calculated using Morris (2008) effect size formula for mean differences of groups with unequal sample size within a pre-post-control design.

In order to investigate the relationship between experimental condition, EF and pre-academic skills a mediation analysis was executed with the Bootstrapping method (Preacher and Hayes, 2008), implemented in the MedMod package of Jamovi software. This type of analysis enables verifying whether the relationship between two variables (group condition and pre-academic skill scores) depends on another variable (EF score).

RESULTS

Baseline Level

Descriptive statistics for all the tasks for both the control and the experimental groups at pre- and post-test are reported in **Table 2**. A high percentage of missing values was observed in the Writing task (children refused to perform the task) and in the Dots and Flanker task (due to a computer problem which caused data loss).

At pre-test no difference emerged between the two groups in EF and pre-academic skills. Moreover, no difference emerged between the control and the experimental group in the CPM score (control group mean = 16.75, SD = 4.69, experimental

TABLE 2 | Descriptive statistics for the experimental and the control group in the pre- and in the post-test phase.

		Pre-test			Post-test		
Tasks' variables	**Groups**	***n***	***M***	***SD***	***n***	***M***	***SD***
Circle drawing	Control	54	0.37	0.49	55	0.35	0.48
	Experimental	69	0.36	0.48	68	0.43	0.50
Matching errors	Control	57	11.86	6.93	57	9.56	5.95
	Experimental	69	13.01	5.70	68	9.47	5.37
Flanker accuracy	Control	55	11.86	4.52	52	13.11	4.19
	Experimental	54	12.60	4.31	67	15.20	1.74
Dots accuracy	Control	55	14.00	4.03	56	15.00	4.30
	Experimental	57	13.39	4.15	67	16.37	4.00
Backward span	Control	56	1.95	0.80	56	2.21	0.65
	Experimental	69	1.93	0.80	69	2.22	0.66
Keep track	Control	57	3.72	2.33	57	5.08	2.39
	Experimental	69	3.38	2.04	69	5.13	1.90
Digit comparison	Control	57	8.39	2.56	55	9.26	3.13
	Experimental	69	8.75	2.79	66	9.82	1.82
Digit correspondence	Control	57	6.90	2.15	57	6.75	2.81
	Experimental	69	6.33	2.63	69	7.15	2.40
Syllable	Control	57	11.98	5.29	57	13.72	5.95
	Experimental	69	11.59	5.00	69	14.12	5.41
Rhymes	Control	57	7.98	4.31	57	8.70	5.05
	Experimental	69	8.33	4.21	69	9.49	5.10
Rapid naming	Control	53	0.57	1.03	51	0.98	1.27
	Experimental	67	0.58	1.03	65	0.40	0.08
Writing task	Control	54	2.65	1.58	50	3.02	1.61
	Experimental	63	3.10	1.59	62	3.73	1.73

group mean = 16.33, SD = 3.85), in the level of mother's education (school years; control group mean = 12.5, SD = 3.34, experimental group mean = 13.5, SD = 3.56), and in children's age (all *p*s > 0.05). Zero-order (Pearson) correlations among EF and pre academic skill measures were calculated (**Table 3**). As expected, the EF task scores were not highly related (Willoughby et al., 2016). Moreover, zero-order (Pearson) correlation among composite scores were calculated (**Table 3**).

Training Effects on EF and on Pre-academic Skill Tasks

To test the efficacy of the training a series of repeated measures analyses with the LMM was conducted on the three EF composite scores (response inhibition, interference suppression, and WM), on the Literacy and Math composite scores, and on the Writing score. Variance for the random effect due to participants ranged from 0.44 (for the Response inhibition score) to 0.89 (for the Writing task). Variance for the random effect due to the class attended ranged from 0.01 (for the Math score) to 0.08 (for the Writing task). Considered the aim of this study, only the interaction between Group (experimental and control) and Time (pre- and post-test phases) was considered and the results are shown in **Table 4**. This interaction was significant for the Interference suppression, the Literacy and the Writing task scores. The inspection of simple effects showed that the experimental group (B = 0.303, SE = 0.042, $t = 7.25$, $p < 0.001$) and control group (B = 0.125, SE = 0.042, $t = 2.96$, $p = 0.004$) both presented an increase in performance from time 1 to time 2, but this gain was greater for the experimental group. Age does not show significant effects in any model. Effect sizes for the gains obtained at Time 2 are shown in **Figure 1**.

Mediation Analysis

In order to investigate the relationship between experimental condition, EF and pre-academic skills a mediation analysis was performed considering only the measures that were improved by the training (interference suppression, literacy, and writing). A full mediation effect was observed when we entered Literacy as a dependent variable, group condition as an independent variable and the interference suppression score as a mediator. A significant effect for the indirect path was found ($Z = 2.084$, $p = 0.037$; 57.5% of the total effect), but not for the direct path ($Z = 0.847$, $p = 0.397$). The group condition predicted the interference suppression composite score, specifically the experimental group showed higher levels of interference suppression compared to the control group in the post-training assessment (β = 0.31, SE = 0.14, $Z = 2.264$, $p = 0.024$). Supportive to our mediation hypothesis, when the interference suppression composite score was entered into the model as a mediator, the effect of group condition on the Literacy score turned non-significant (β = 0.09, SE = 0.11, $Z = 0.847$, $p = 0.397$), whereas the effect of the interference

TABLE 3 | Zero-order correlations among EF and pre academic skills tasks (measures scores) and among composite score.

Measures scores												
	1	2	3	4	5	6	7	8	9	10	11	12
Circle	1	0.004	0.133	0.348**	0.162	0.054	0.11	0.194*	0.244**	0.241**	0.046	0.279**
Matching		1	−0.327**	−0.267**	−0.255**	−0.271**	−0.178*	−0.184*	−0.168	−0.226*	0.113	−0.092
Flanker accuracy			1	0.278**	0.320**	0.128	0.282**	0.252**	0.154	0.13	0.102	0.214*
Dots accuracy				1	0.410**	0.148	0.257**	0.435**	0.225*	0.243**	−0.149	0.329**
Backward span				1	0.175	0.373**	0.500**	0.327**	0.241**	−0.153	0.311**	
Keep track					1	0.202*	0.284**	0.211*	0.092	−0.045	0.072	
Digit comparison						1	0.597**	0.289**	0.355**	−0.042	0.314**	
Digit correspondence						1	0.404**	0.414**	−0.268**	0.288**		
Syllable									1	0.386**	−0.059	0.385**
Rhymes										1	−0.071	0.412**
Rapid naming										1	−0.117	
Writing task											1	

Composite scores						
	1	2	3	4	5	6
Response inhibition	1	0.459**	0.360**	0.284**	0.344**	0.317**
Interference suppression	1	0.404**	0.334**	0.216*	0.422**	
WM			1	0.250**	0.235**	0.481**
Literacy			1	0.366**	0.352**	
Writing task			1	0.419**		
Math				1		

*$p < 0.05$; **$p < 0.01$.

TABLE 4 | Composite *z*-scores for the two groups at the pre- and the post-test phase.

		Pre-test			Post-test						
Composite *z*-scores	**Groups**	***n***	***M***	***SD***	***n***	***M***	***SD***	***F***	***p***	$R^2_{marginal}$	$R^2_{conditional}$
Response inhibition	Control	54	0.03	0.72	55	0.18	0.70	2.000	0.160	0.037	0.487
	Exp.	69	−0.05	0.70	67	0.30	0.66				
Interference suppression	Control	54	0.00	0.79	52	0.31	0.79	8.391	0.005	0.101	0.708
	Exp.	54	−0.00	0.83	65	0.67	0.58				
WM	Control	56	0.06	0.82	56	0.55	0.77	0.399	0.529	0.119	0.574
	Exp.	69	−0.04	0.72	69	0.54	0.69				
Math	Control	57	0.03	0.84	55	0.21	1.05	2.684	0.104	0.039	0.671
	Exp.	69	−0.02	0.94	66	0.41	0.65				
Literacy	Control	53	0.06	0.68	51	0.22	0.70	4.14	0.044	0.080	0.655
	Exp.	67	0.04	0.59	65	0.42	0.64				
Writing task	Control	54	−0.15	0.99	50	0.13	1.01	4.470	0.037	0.067	0.841
	Exp.	63	0.08	0.64	62	0.52	1.08				

LMM results for the interaction between group and time controlling for age.

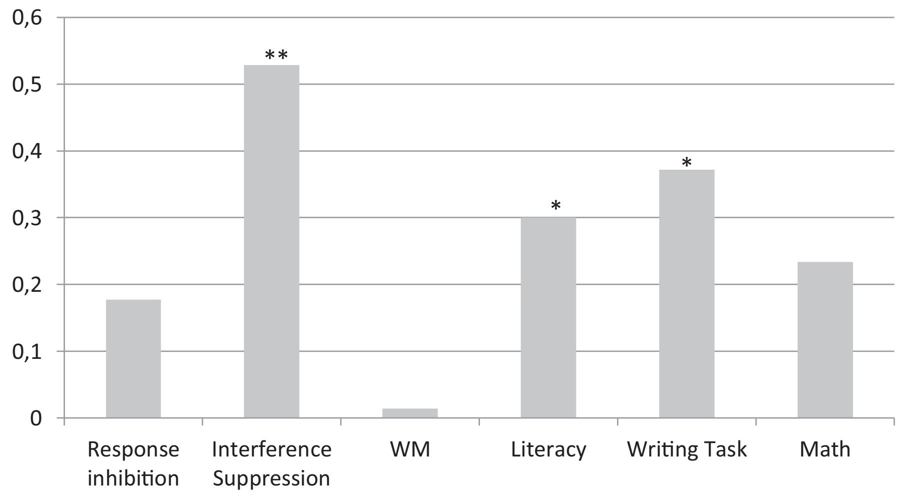

FIGURE 1 | Effect sizes of the gain scores at Time 2. *$p < 0.05$; **$p < 0.001$.

suppression score on the Literacy score was significant (β = 0.40, SE = 0.07, $Z = 5.462$, $p < 0.001$) and also the indirect path from group condition to pre-academic skills through FE improvements was significant, $a \times b = 0.12$, Bootstrap 95% CI [0.02,0.25] (**Figure 2**).

Similarly, when we repeated the analyses entering the Writing task as a dependent variable, a significant effect for the indirect path was found ($Z = 2.16$, $p = 0.031$; 51.6% of the total effect), but not for the direct path ($Z = 1.03$, $p = 0.302$). The experimental group belonging predicted higher levels of interference suppression (β = 0.33, SE = 0.14, $Z = 2.37$, $p = 0.018$). When the interference suppression composite score was entered into the model as mediator, the effect of group condition on the Writing performance turned non-significant (β = 0.20, SE = 0.20, $Z = 1.03$, $p = 0.302$), while the effect of the interference suppression on the Writing score was significant (β = 0.65, SE = 0.12, $Z = 5.34$, $p < 0.001$) and the indirect path from group condition to pre-academic skills through FE improvements was significant, $a \times b = 0.22$, Bootstrap 95% CI [0.05,0.44] (**Figure 2**).

In sum, the experimental group outperformed the control group in the Interference suppression ability represented by the Fish flanker and the Dots task. The experimental group's improvement in the Literacy and in the Writing task was mediated by interference suppression improvement showing that the training produced significant far transfer effects.

Moreover, although total effect was not significant, according to Hayes (2009), we performed a mediation analysis considering the Math composite score as dependent variable. A partial mediation effect was observed when we entered Math as a dependent variable, group condition as an independent variable and the interference suppression score as a mediator. A significant effect for the indirect path was found ($Z = 2.232$, $p = 0.026$; 86.6% of the total

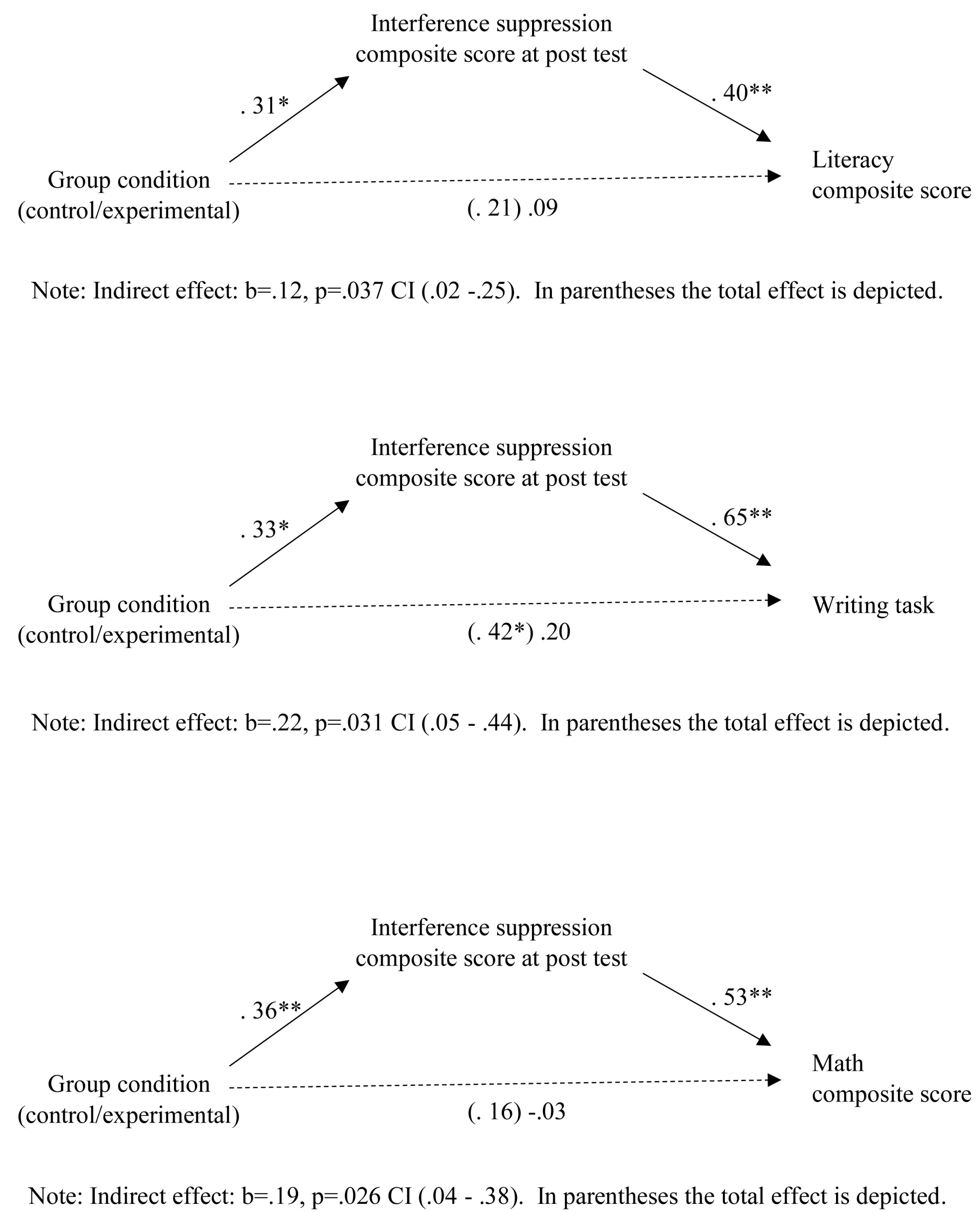

FIGURE 2 | Results of mediation analysis. $^*p < 0.05$; $^{**}p < 0.001$.

effect), but not for the direct path ($Z = -0.222$, $p = 0.824$). The group condition predicted the interference suppression composite score, specifically the experimental group showed higher levels of interference suppression compared to the control group in the post-training assessment ($\beta = 0.36$, SE = 0.13, $Z = 2.690$, $p = 0.007$). Moreover, the effect of the interference suppression score on the Math score was significant ($\beta = 0.53$, SE = 0.12, $Z = 4.598$, $p < 0.001$) and also the indirect path from group condition to pre-academic skills through FE improvements was significant, $a \times b = 0.18$, Bootstrap 95% CI [0.04,0.38].

DISCUSSION

The Training Effectiveness

This study adds to the literature examining the effects of EF training in preschoolers. In particular, the rationale for designing such a study was to test the effectiveness of a short-term intervention that previously proved to be effective in promoting EF (Traverso et al., 2015). Differently from the study by Traverso et al. (2015) in which training efficacy was evaluated when the training was administered in high controlled conditions by a trained psychologist external to the educational service personnel, in the current study, regular teachers, minimally trained, administered the training to all the pupils of their class in real world conditions. Diamond and Ling (2016) suggest that the way in which an activity is presented and conducted may influence the results in terms of gains. Indeed, when the intervention was administered by a trained psychologist who was "committed to it succeeding and believes firmly in its efficacy" (Diamond and Ling, 2016, p. 37), a significant increase in a wide range of EF skills was found (Traverso et al., 2015). The results of the present study indicate that the intervention is still effective in promoting EF abilities even when administered by regular teachers. Specifically, in Traverso et al. (2015) effects were observe in WM, response inhibition and interference suppression tasks, in the current study the intervention still produced an increase in interference suppression abilities with a comparable effect size.

Another important issue concerns the composition of the groups. It should be noted that in Italy children with special needs attend regular classes. Thus, the experimental and the control samples included all the children for whom parents gave their consent to participate, including children with special needs. Even if it was not possible to examine training effects on children with special needs due to the low number of children, results showed that in average the experimental group, in which special needs children were included, outperformed the control group in both EF (interference suppression) and pre-academic skills tasks (literacy domain). This is an important point because these results support the idea that there were no barriers that affect participation of children with special needs, therefore this kind of intervention appears to be suitable for inclusive educational contexts. Moreover, given that inclusive contexts are generally highly challenging, we may assume that this training may be easily administered by teachers in real classes even in educational contexts outside the Italian inclusive system.

The literature on EF interventions recommends the use of intent-to-treat analyses to avoid biases due to intervention drop-out, in addition to a nested design to account for teacher and school influences (e.g., Bierman and Torres, 2016). In this study the dependencies associated with the presence of participants belonging to the same classes were modeled using the LMM that, in addition, enables managing missing data without employing a listwise procedure. The participants' characteristics and the way in which the intervention was implemented may support the generalization of these results to the population.

The narrower training effects as compared to Traverso et al.'s (2015) study were possibly due to fact that the training was administered by teachers instead of a specialized psychologist; nevertheless, the reasons why the training produced positive results in some but not all the EF tasks must be discussed. Specifically, the training group outperformed the control group in the interference suppression ability represented by the Fish flanker task and the Dots task, while response inhibition and WM were not affected by the training. These results can be explained by considering the types of skills we considered and the developmental trajectories of these skills. The ability to suppress a prepotent but inappropriate response to a stimulus (response inhibition) appears early whereas interference suppression, that is the ability to address conflict or interference from complex and misleading features of a task, develop later (Gandolfi et al., 2014). Considering their later development, interference suppression skills could be possibly characterized by a higher plasticity in the age group examined, thus resulting more sensitive to external stimulations. In fact, according to Cragg (2016), performance enhancement in inhibitory tasks during middle childhood may be explained mainly by the improvement in interference suppression rather than in response inhibition ability. Following this line of reasoning, response inhibition and WM increase may require more extensive effort to produce appreciable changes. The present intervention, which is composed of 12 sessions, may not be sufficient to produce a significant improvement in these abilities. As also suggested by Diamond and Ling (2016) EF gains certainly depend on the amount of time spent practicing, but the optimal amount of practice to produce significant results has not yet been ascertained (Bierman and Torres, 2016). Finally, it should be noted that although the training did not increase the experimental group's performance in all the tasks, the dissimilarity between the training activities and the tasks adopted in the assessment leads us to assume that we measured real improvements in EF capacity and not a mere task-training effect.

The Issue of the Far Transfer

This study also examined the far transfer of the training to pre-academic skills. As noted by Bierman and Torres (2016), an issue of great importance for early education and prevention policy is the degree to which the improvement in specific EF tasks extends to learning or behavioral outcomes. Although the predictive relationship between preschool EF and school achievement has been well-established (Viterbori et al., 2015; De Franchis et al., 2017), less is known about the relationship between EF and pre-academic skills and about the possibility of bringing about improvement in pre-academic skills and school readiness through EF training.

For the aim of this study, the question was whether the improvement in interference suppression could promote an enhancement in the level of pre-academic skills.

The results show an improvement in early literacy and in writing skills and suggest the existence of a direct effect of EF on these pre-academic skills. Moreover, our results showed that the training improved the interference suppression composite score, which in turn accounted for Math composite score.

Considering the results of the full mediation in the literacy domain, evidence suggests that early spelling attempts predict subsequent word reading and interventions that improve this ability in the last year of preschool can consequently promote an advantage in reading acquisition (Ouellette and Sénéchal, 2008). Moreover, research suggests that EF skills are strong correlates of young children's emergent literacy skills in kindergarten (e.g., phonemic awareness and letter knowledge) (Blair and Razza, 2007). In particular, Zhang et al. (2017) found that preschoolers with stronger EF skills achieved higher gains in letter-sound knowledge, which, in turn, contributed to children's invented spelling skills. Another explanation is that the improvement in the literacy tasks would be due to the EF resources required in performing the tasks (see also Shaul and Schwartz, 2014). The writing task requires a number of highly synchronized skills such as phonemic awareness, grapheme-phoneme correspondence, visual perception, and grapho-motor skills. For example, learning to write words requires holding the representations of letter-sound correspondence in mind, and at the same time retrieving the shape of the letters while writing; furthermore, children must inhibit one letter over the other, such as when learning the letters "c" and "k" in English or phonetically similar letters such as "d" and "t" in Italian. The synchronization of these multiple skills demands a great involvement of EF.

It may be also possible that the increase in EF, in the trained group, allowed the children to benefit more from the educational activities, by improving their cognitive control and consequently making them more ready to learn. For example, early EF were found to support active and positive involvement in classroom tasks and self-regulated use of learning strategies and to limit inappropriate behaviors (such as off-task and disruptive behaviors) that interfere with adaptive engagement (Nesbitt et al., 2015; Nelson et al., 2017).

Concerning math pre academic skills, the interaction between Group (experimental and control) and Time (pre- and post-test phases) was not significant. It is possible that a ceiling effect in one of the two math tasks (Digit Comparison) may have prevented to detect an improvement. Nevertheless, the mediation analysis revealed a significant indirect effect. The interference suppression composite score, enhanced by the training, accounted for math composite score. According to Hayes (2009) given that the total effect is the sum of many different paths of influence, it is possible to detect a significant indirect effect in absence of the total effect. Indeed, we need to be cautious in assuming that the improvement observed in one pre academic skill domain (literacy vs. math) may be due to the specificity of the domain. Several studies' results support the idea of a domain general association between EF and pre academic skills (e.g., Allan and Lonigan, 2011; Fuhs et al., 2015). Concerning the role of inhibition on math achievement, several studies suggested that inhibition accounts for both pre-academic skills (i.e., Lan et al., 2011; Purpura et al., 2017) and for complex math acquisition such as problem solving (i.e., Passolunghi and Siegel, 2001; Khng and Lee, 2009; Viterbori et al., 2017). Nevertheless, previous studies on pre-academic skills focused mainly on response inhibition (i.e., Purpura et al., 2017), whereas our results revealed a significant association between the ability to suppress interference and the acquisition of Arabic numerals.

Limitations and Future Directions

Finally, the results are promising and indicate that it is possible to foster the development of different aspects of EF with relatively simple interventions. Nevertheless, the current results should be considered in the context of the study limitations. First, in this study we did not evaluate whether the gains in EF evident in the trained group endured over time, or whether they were associated with achievement in Grade 1. Moreover, given that mediator variable (EF skills) was assessed at the same time point as the outcome measure (pre-academic skills), far transfer need to replicated with data measured at distinct time points. Second, although we were interested in verifying if the training by Traverso et al. (2015) enhance children EF more than regular activities that children usually perform, it is not possible to exclude the Rosenthal effect. Moreover, although this type of training, such as the one developed by Tominey and McClelland (2011) aims to target more directly the EF than the long term curricula, such as Tools of the Mind, which are comprehensive in nature, further studies may address which aspects of this type of training accounts for EF improvement. Indeed, although we suppose that the core aspect of the training were the activities that changed every session and required higher level of cognitive control, the training included other elements such as role playing, metacognitive activities and an adult that actively supported children's self esteem, therefore it could be interesting to understand the relevance of these aspects. Finally, it may be particularly helpful to verify the effect of this type of intervention with children at risk, such as children with low EF due to social disadvantage (Farah et al., 2006). It should be noted that children from disadvantaged socio-economic backgrounds are more likely than their peers to have lower EF, which in turn contributes to lower academic achievement in Grade 1 (Nesbitt et al., 2013). Hence developing interventions suitable for educational services attended by this population of children could reduce disparities at school entry level and reduce the negative effects of poor self-regulation. Compared to other kinds of training, the one we described appears to be particularly suitable for this population because of its play-based approach, its low costs and its ease of administration.

In conclusion, this study confirms the effectiveness of a school-based intervention that addressed EF in 5-year-old children and indicates that teachers with minimal training may significantly foster the development of EF. In addition, the study shows promising results concerning the possibility of cross- domain transfer to pre-academic skills. Given the predictive association between EF and later achievement, interventions that begin in the preschool period may lead to better outcomes by increasing school readiness. The development of low-cost EF training feasible for educational settings should be considered a priority for prevention research.

DATA AVAILABILITY

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was provided by the participants' legal guardian/ next of kin.

AUTHOR CONTRIBUTIONS

LT, PV, and MU revised the literature on EF development and EF training, conceived and designed the experiment, and read and approved the final manuscript. LT collected the data and wrote the first draft of the manuscript that was revised by PV and then by MU. LT and MU performed the analysis.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.02053/full#supplementary-material

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Effects of Executive Function Training on Attentional, Behavioral and Emotional Functioning and Self-Perceived Competence in Very Preterm Children: A Randomized Controlled Trial

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Objective: Very preterm children have poorer attentional, behavioral and emotional functioning than term-born children. Problems on these domains have been linked to poorer executive function (EF). This study examined effects of a game-formatted, comprehensive EF training on attentional, behavioral and emotional functioning and self-perceived competence in very preterm children.

Study Design: Eighty-five children participated in a multi-center, double-blind, placebo and waitlist-controlled randomized trial. Children were recruited from neonatal follow-up units of two academic medical centers in The Netherlands. Eligible for inclusion were 8–12 year old children born very preterm (<30 weeks of gestation) and/or with extremely low birthweight (<1000 g) with parent reported attention problems. Children were randomly assigned to one of three treatment arms: EF training, placebo training or waitlist. The EF and placebo training involved a 6 weeks, 25 (30–45 min) sessions training program. Attentional functioning (Attention Network Test), behavioral and emotional functioning (parent and teacher Strengths and Difficulties questionnaire) and self-perceived competence (Self-Perception Profile for Children) were assessed at baseline, at the end of the training program and 5 months after the training was finished. Data analyses involved linear mixed model analyses.

Results: Children in the EF training arm significantly improved on all training tasks over the course of the EF training program. Despite these improvements on the EF training tasks, there were no significant differences over time on any of the outcome measures between the three treatment arms, indicating that this computerized EF training program had no beneficial effects.

Conclusion: Although there were significant improvements in the EF training tasks, there was no generalization of these improvements to any of the outcome measures. Thus, our findings do not support the use of computerized EF training programs. Future research should investigate effectivity of more ecologically valid, real-world like EF training programs.

Keywords: intervention, premature, EF training, computerized, executive functions

INTRODUCTION

Between 0.7 and 1.4% of all live born children in Western countries are born very preterm (gestational age [GA] < 32 weeks) (Delnord et al., 2017). Long-term consequences of very preterm birth have been intensively investigated in the domains of cognitive, academic, behavioral and emotional functioning, with very preterm children showing substantial problems in all of these domains (Bhutta et al., 2002; Anderson et al., 2003; Aarnoudse-Moens et al., 2009; Mulder et al., 2009; Blencowe et al., 2013; Aylward, 2014; Ritchie et al., 2015; Allotey et al., 2017; Twilhaar et al., 2017). For example, executive functions (EF), which is an umbrella term for a set of higher-order cognitive functions allowing for top–down, goal-directed behavior, are adversely affected in very preterm children (Aarnoudse-Moens et al., 2009; Mulder et al., 2009; van Houdt et al., 2019). Deficits in EF have been shown to play an important underlying role in both the academic as well as the behavioral and emotional functioning problems that very preterm children encounter (Nadeau et al., 2001; Taylor et al., 2006; Mulder et al., 2010, 2011; de Kieviet et al., 2012; Loe et al., 2012; Aarnoudse-Moens et al., 2013; Alduncin et al., 2014). For example, EF performance has been shown to predict math performance in very preterm children at primary school (Aarnoudse-Moens et al., 2013) and working memory has been shown to account for academic attainment (Mulder et al., 2010). Furthermore, working memory has been shown to account for attention problems in very preterm children at school-age (Nadeau et al., 2001; Mulder et al., 2011; de Kieviet et al., 2012). Last, poorer EF performance has been shown associated with poorer social competence in very preterm children at preschool age (Alduncin et al., 2014) and school-age (Taylor et al., 2006; Loe et al., 2012).

In the past decade, an increasing number of studies have addressed the efficacy of computerized interventions to improve EF, with Cogmed Working Memory Training (CWMT) (Klingberg et al., 2005) being the most widely studied computerized EF training program. CWMT for school-age children involves gamified verbal and visuospatial working memory training tasks presented on a space-themed interface design. Children's scores are presented on the screen to challenge children to outperform their own scores and difficulty level is automatically adjusted according to the child's performance. CWMT is played five times a week for 30–45 min per session. Studies on CWMT in children with Attention Deficit/Hyperactivity Disorder (ADHD) have shown promising results in improving working memory and also reported some promising transfer effects to untrained functions (Klingberg et al., 2005; Beck et al., 2010; Green et al., 2012; Hovik et al., 2013; Chacko et al., 2014). Compared to a wait-list control group, CWMT was reported to improve verbal and non-verbal working memory storage, visuospatial working memory, verbal working memory, parent-rated working memory and parent-rated inattention symptoms (Beck et al., 2010; Hovik et al., 2013). Furthermore, compared to a placebo control group, CWMT was reported to improve trained working memory tasks and untrained performance on tasks assessing visuospatial working memory, verbal working memory, response inhibition and complex reasoning. Furthermore beneficial effects have been reported on parent-rated inattention and hyperactivity/impulsivity symptoms and on observed behaviors during an academic task (Klingberg et al., 2005; Green et al., 2012; Chacko et al., 2014). There is also some evidence of neural changes following CWMT and associations between these neural changes and improved working memory, both in healthy children and adults (Barnes et al., 2016; Metzler-Baddeley et al., 2016, 2017) and in adolescents with ADHD (Stevens et al., 2016). Three meta-analyses have been conducted investigating near-transfer effects of CWMT on working memory (Shipstead et al., 2012; Melby-Lervåg and Hulme, 2013; Aksayli et al., 2019). Two out of these three meta-analyses concluded that there is evidence that CWMT leads to improved working memory task performance (Melby-Lervåg and Hulme, 2013; Aksayli et al., 2019), with the strength of the improvement depending on the similarity of the tasks to the training tasks (Aksayli et al., 2019). Four meta-analyses have been conducted investigating far-transfer effects of CWMT on untrained functions (Shipstead et al., 2012; Melby-Lervåg and Hulme, 2013; Spencer-Smith and Klingberg, 2016; Aksayli et al., 2019). Of these, three meta-analyses concluded that there is no evidence for improvements of untrained functions after following CWMT (Shipstead et al., 2012; Melby-Lervåg and Hulme, 2013; Aksayli et al., 2019). Only one randomized controlled trial into effects of CWMT in very preterm born children has been conducted and showed no improvements in academic achievement, working memory, attention, daily life EF and general cognitive ability (Anderson et al., 2018). However, CWMT is an EF training program that focuses solely on training working memory, while other core EFs such as inhibition and cognitive flexibility are also affected in children born preterm (Aarnoudse-Moens et al., 2009; Mulder et al., 2009; van Houdt et al., 2019).

Recently, a game-formatted and comprehensive EF training program entitled BrainGame Brian (BGB) was developed, that aimed at training not only working memory, but also inhibition and cognitive flexibility, in children aged 8–12 years (Prins et al., 2013). BrainGame Brian involves a game-world in which training tasks for visuospatial working memory, response inhibition and cognitive flexibility are played to help the main character, Brian. Difficulty level is automatically adjusted according to the child's performance. The training program is played four times a week for 30–45 min per session. The BGB EF training program has been consistently shown to improve working memory in children with ADHD and Autism Spectrum Disorder (ASD) (van der Oord et al., 2014; de Vries et al., 2015; Dovis et al., 2015). However, effects on other EFs or other untrained functions were inconsistent (van der Oord et al., 2014; de Vries et al., 2015; Dovis et al., 2015). Furthermore, one small-sized non-randomized pilot study has been conducted into the feasibility of the BGB EF training program in very preterm children, which showed positive effects on visuospatial working memory task performance (Aarnoudse-Moens et al., 2018). The BGB EF training program may have beneficial effects on various areas of functioning, including attentional, behavioral and emotional functioning and self-perceived competence in very preterm born children. Deficits in EF have been shown to play a crucial role in a range of psychiatric disorders such as ADHD and ASD, and a large body of literature has indicated that executive functioning is strongly related to both behavioral and emotional functioning (Ozonoff et al., 1991; Pennington and Ozonoff, 1996; Nigg, 2000; Sergeant et al., 2002; Oosterlaan et al., 2005; Willcutt et al., 2005; Riggs et al., 2006; Carlson and Wang, 2007). In very preterm children, deficits in EF have been shown to underlie the attentional problems these children encounter as well (Mulder et al., 2011; de Kieviet et al., 2012; Aarnoudse-Moens et al., 2013). Therefore, improving EFs with the BGB EF training program could lead to improvements in attentional, behavioral and emotional functioning as well. If the BGB EF training program leads to improvement in those domains, it may improve children's self-perceived competence as well.

Therefore, the current study aimed to investigate effects of the BGB EF training program on attentional functioning, parent and teacher rated behavioral and emotional functioning and self-perceived competence in a group of very preterm (<30 weeks of gestation) and/or extremely low birthweight (< 1000 g) children with parent-rated attention problems, compared to both a placebo training and waitlist arm. The BGB EF training program uses game elements and strong and immediate reinforcements to optimize the participants' motivational state and compliance with the training, which in turn is supposed to enhance efficacy of the training. The effects of EF training with BGB may therefore be moderated by exposure to gaming before start of the EF training program. More specifically, children with intensive exposure to gaming may show a more blunted response to the reinforcements build in the training than children with little exposure to gaming. Therefore, exploratory analyses also examined effects of the BGB EF training program while correcting for time spent gaming outside school-hours. Also, associations between time spent gaming outside school-hours and baseline measurements were examined.

MATERIALS AND METHODS

Trial Design

This was a multi-center, double-blind, placebo and waitlist-controlled randomized trial conducted in two academic hospitals in The Netherlands (Amsterdam University Medical Centers and University Medical Center Utrecht). The Medical Ethical Committee of the two participating academic hospitals approved the study protocol and the execution of the study procedures was according to the Declaration of Helsinki. The trial was registered in the Dutch Trial Registry (NTR, # NTR5365). CONSORT guidelines were followed.

Participants

The Dutch version of the Child Behavior Checklist 6–18 years (CBCL6-18) (Verhulst and Van der Ende, 2013) was sent to parents of 7–12 year old (chronological age) children born very preterm (<30 weeks of gestation) and/or with extremely low birthweight (birthweight < 1000 g) that participated in the national neonatal follow-up program after being admitted to the Neonatal Intensive Care Unit (NICU) in one of the two participating hospitals. Eligible for this study were children of whom parents reported attention problems on the CBCL6-18 ($T \geq 55$ on the Attention Problems scale, Hudziak et al., 2004), as soon as they reached the chronological age of at least 8 years. Exclusion criteria were an estimated IQ < 80 (in order to assure that the child was able to understand and comply with instructions), motor problems too profound to allow use of a computer and no Dutch language use in the home situation. The inclusion process and participant's flow through the study is depicted in **Figure 1**. Reasons not to return the questionnaire that was used to assess whether children had parent- rated attention problems were no time or no interest. Reasons not to participate were that parents found that incorporation of the training sessions into already busy schedules was too burdensome for the child and/or family or that parents or children had no interest in participating. In short, 85 children were randomized, 29 to the EF training arm, 26 to the placebo training arm and 30 to the waitlist arm. Data of the first follow-up visit were available for 24, 20, and 29 children, respectively, and data of the second follow-up visit were available for 23, 19, and 27 children, respectively. Thus of all children, 81% completed all assessments. Reasons for withdrawal from the study after randomization were not being able to incorporate training sessions into a busy schedule or the child not wanting to complete the training sessions ($n = 9$), no time or willingness to schedule the follow-up visit(s) at the appropriate time-point(s) ($n = 5$) or severe illness discovered ($n = 2$). All available data of participants (also data of participants with missing data) were incorporated in the analyses.

Randomization and Blinding

Children meeting inclusion criteria were randomly assigned to one of three treatment arms: EF training, placebo training or

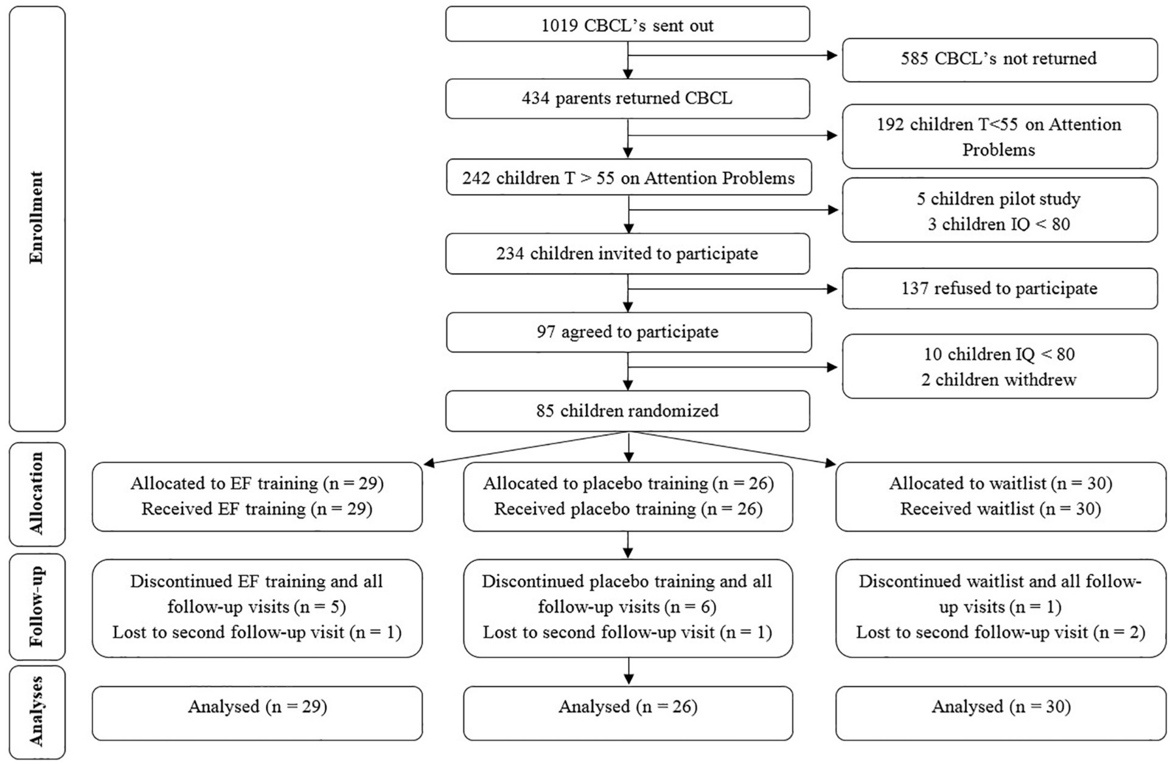

FIGURE 1 | CONSORT Flow diagram. CBCL, Child Behavior CheckList; IQ, Intelligence Quotient. EF, Executive Function.

waitlist. Allocation to treatment arms was stratified by age (below or above 10.5 years of age) and severity of attention problems (Attention Problems T-score below or above 65), with equal proportions of children allocated to each arm within the same stratum. A random number generator was used to generate randomization lists. A researcher not otherwise involved in this study was responsible for randomization and handed the test assistant a sealed envelope with a note stating 'waitlist' or a login and password, which was opened by the child and parents after baseline assessment. To ensure blinding, parents were only informed about whether their child was randomized to either one of two training arms or the waitlist arm, and in case more children from the same family were included in the study, one of those was randomized and the other was put in the same arm. All staff was blinded to EF training or placebo training assignment, including the person involved in randomization. Test assistants that played the first training session with the child were deblinded because of differences in training tasks (see below) between EF training and placebo training and were not involved in follow-up assessments of these children. Parents, children and researchers were aware of children's allocation to the waitlist arm. Data were analyzed by a researcher blinded to treatment allocations.

Intervention

BrainGame Brian Training

The BGB EF training program is a game-formatted, computerized training program (Prins et al., 2013) that is performed by the child at home. The BGB EF training program uses game elements and strong and immediate reinforcements to optimize the participants' motivational state and compliance with the training. The game-world exists of several different villages, in each of which there are characters that face problems and need help of the main character: Brian. During the first sessions, only one of those villages in accessible, with more villages becoming accessible during the course of the training program. To help the characters facing problems, children perform the EF training tasks with Brian. After completion of each block of training tasks, an invention made by Brian will appear in the game-world that helps solving the problem of the character, thereby acting as an immediate reinforcement. These inventions remain visible in the game-world during subsequent sessions. Thus the more sessions children have performed, the more inventions will be visible in the game-world, which enhances motivation. The training consists of 25 sessions, with two blocks of three training tasks, one for each EF, administered in every session. These three training tasks remain the same throughout the 25 sessions, except for the visuospatial working memory task, which was administered in five different versions to increase working memory demands.

EF Training Arm

In the working memory task, children are asked to repeat a sequence of dots on a 4×4 grid. There were five versions of the working memory task, each of which was administered for five consecutive training sessions and increased in difficulty level across training sessions. In the inhibition task, children are asked to press a button in a specific time window (target), but to refrain from pressing that button when a visual stop signal is presented. In the cognitive flexibility task, children are asked to sort objects according to either it's shape or it's color, with the sorting rule changing every three to five trials. Difficulty level of each training task is automatically adjusted to the child's level of performance. The number of trials and therefore also the duration of all three tasks depends on the child's performance. Most children are able to finish the training tasks within 8 min per task. For the first three and last two versions of the working memory task, a total of at least 74 and 62 boxes need to be repeated correctly (with only correctly repeated boxed within correctly repeated sequences adding to this total), respectively, to end the task. For the inhibition task, the task ends after ten blocks of five trials that were all performed correctly. For the cognitive flexibility task, the task ends after 10 blocks of three-to-five trials that were all performed correctly. Difficulty level was adjusted for each task after completion. Difficulty level for the working memory task was adjusted by increasing or decreasing the sequence length. Difficulty level for the inhibition task was adjusted by increasing or decreasing the time between start of the time window in which children needed to respond and presentation of the stop signal. Difficulty for the cognitive flexibility task was adjusted by increasing or decreasing the time children have to sort each presented target.

Placebo Training Arm

The placebo training arm is identical to the actual training arm, however, the specific elements that actually train the EFs are removed from the training tasks. In the working memory task, children are asked to repeat sequences with a span length of two in the same order as presented. In that way, the training task only involves short-term memory and does not tax working memory. In the inhibition task, no stop-signals are presented. In the shifting task, no shifting trials are presented. Furthermore, difficulty level is not adjusted. Thus, children do play the training tasks, but do not train working memory, inhibition or cognitive flexibility in the placebo training arm.

Waitlist Arm

Children in the waitlist arm do not play the training and were instructed to perform the same activities in the waiting period as they do normally.

Measures

Improvement During Training

To validate whether the BGB EF training program actually induced improvement on the trained tasks, we assessed improvement of training performance across all training sessions. For the inhibition and cognitive flexibility tasks, improvement was assessed by comparing the mean difficulty level of day two and day three of training (start level) with the highest achieved difficulty level (highest level). All children start at the same level at day one, but for some children this level is too easy and for some children this level is too difficult. Therefore, taking the mean difficulty level of day two and day three as start level ensures that this is the child's actual level of performance at the beginning of the training. As there were five versions of the working memory task, which were each played in five consecutive training sessions, for each version improvement was assessed by comparing mean difficulty level at day two (start level) with the highest achieved difficulty level (highest level). Again, mean difficulty level at day two was chosen as start level to ensure this was the child's actual level of performance at the start of each new version of the working memory task. Difficulty level at day two and not mean difficulty level of day two and three (as was done for the inhibition and cognitive flexibility tasks) was chosen because each version of the working memory task was only performed in five consecutive training sessions and not 25 as in the inhibition and cognitive flexibility tasks.

Attentional Functioning

The Child version of the Attention Network Test (Child-ANT) (Rueda et al., 2004) was administered to assess efficiency of the three attention networks: (1) the alerting network, (2) the orienting network, and (3) the executive attention network. Each trial of the Child-ANT started with a central fixation cross. The target was one single yellow fish or a horizontally positioned line of five yellow fish, appearing above or below the fixation cross. The child was asked to respond by pressing one of two buttons on the side the central fish pointed to. Trials could be (a) congruent (central fish pointing to same direction as flanking fish), (b) incongruent (central fish pointing to opposite direction as flanking fish) or (c) neutral (only central fish, no flanking fish). Furthermore, each target was preceded by a warning cue condition that comprised one of four options: (a) no cue, (b) center cue (cue presented at the location of the fixation cross), (c) double cue (cues presented above and below the fixation cross), or (d) spatial cue (cue presented at the location of the upcoming target). Outcome measures were efficiency of the alerting, orienting and executive attention networks, calculated by (1) subtracting the median RT for the double cue condition from the median RT for the no cue condition, (2) subtracting the median RT for the spatial cue from the median RT for the central cue and (3) subtracting the median RT for the congruent trials from the median RT for the incongruent trials, respectively. For the alerting and orienting networks, higher values reflect higher network efficiency. For the executive attention network, higher values reflect lower network efficiency.

Behavioral and Emotional Functioning

Behavioral and emotional functioning was measured with the Strengths and Difficulties Questionnaire (SDQ) (van Widenfelt et al., 2003) which contains five subscales: Emotional Problems, Hyperactivity, Conduct Problems, Peer Problems and Prosocial Behavior. Raw scores on these scales were used as outcome measures. Scores may range between 0 and 10, with higher scores reflecting more problems.

Self-Perceived Competence

The Dutch translation of the Self-Perception Profile for Children (CBSK) (Veerman et al., 1997), was used to assess self-perceived competence using six scales: Scholastics, Social Acceptance, Athletics, Physical Appearance, Behavioral Conduct and Global Self-Worth. Raw scores on these scales were used as outcome measures. Scores may range between 6 and 24, with higher scores reflecting higher self-perceived competence.

Gaming at Baseline

Gaming was defined as playing games on any electronic apparatus. At the baseline assessment, parents provided information on the amount of hours per week their children spent gaming outside of school-hours.

Procedure

After written informed consent was obtained from parents and, if applicable, from children aged 12, children completed a baseline neurocognitive assessment including estimated IQ, efficiency of attention networks and self-perceived competence. Parents and teachers were asked to fill out a questionnaire on children's behavioral and emotional functioning (a full description is provided below). Assessments were part of a larger battery of measures administered to study effectiveness of the BGB EF training program. When children were randomized to either the EF training or placebo training arm, a house visit was made to install the BGB EF training program at the home computer or laptop and play the first session. When children were randomized to the waitlist-control arm, no house visit was made. To assess short-term and longer-term efficacy of the BGB EF training program, two follow-up visits were scheduled. The first follow-up assessment (T1) was approximately 2 weeks after the last training session (approximately 2 months after baseline assessment for children in the waitlist condition) and the second follow-up assessment (T2) was approximately 5 months after the first follow-up assessment. Gaming at baseline, demographic characteristics, medical characteristics of the neonatal period and estimated IQ were only assessed at baseline assessment. Attentional functioning, behavioral and emotional functioning and self-perceived competence were assessed at baseline assessment and both follow-up assessments.

Demographic Characteristics, Medical Characteristics of Neonatal Period and IQ

Parents provided information on demographics. Medical data from the neonatal period were obtained from medical records. To estimate IQ, a two subtest short-form (Vocabulary and Block Design) of the Dutch Wechsler Intelligence Scale for Children, Third Edition (WISC-III-NL, Sattler, 1992), was administered during the baseline assessment. Scaled scores for both the Vocabulary and Block Design subtests were computed. Subsequently the estimated full scale IQ equivalent for the sum of scaled scores of these two subtests was taken from the manual. Estimated IQ based on this short-form correlates highly with full scale IQ ($r = 0.90$) (Sattler, 1992).

Statistical Analyses

Sample size calculation was based on a repeated measures design with three time points. To be able to demonstrate a medium-sized intervention effect (Cohen's $d = 0.5$), assuming a within-subject correlation of 0.295 (taken from our BGB EF training pilot study in very preterm, Aarnoudse-Moens et al., 2018), a power of 80% and a significance level of 0.05, 39 children in each intervention arm were needed (Twisk, 2013).

IBM SPSS Statistics version 25 was used for the statistical analyses (IBM, 2017). Outliers were winsorized at three standard deviations (SDs) (Ghosh and Vogt, 2012). For baseline assessment, first follow-up assessment and second follow-up assessment, 4.7, 11, and 10.1% of data was missing for the Child-ANT, respectively, 1.2, 1.4, and 5.8% of data was missing for the parent SDQ, respectively, 14.1, 44.7, and 52.2% of data was missing for the teacher SDQ respectively, and 3.5, 2.7, and 1.4% of data was missing for the CBSK, respectively. Missing data were not imputed.

Data were analyzed on intention-to-treat basis. To assess whether attrition from the study was selective, children that did and did not complete all assessments were compared on all demographic and neonatal medical characteristics and all outcome measures with independent t-tests and chi-square tests. To assess whether demographic and neonatal medical baseline characteristics differ between the treatment arms, one-way analyses of variance (ANOVA's) and chi-square tests were performed. To assess whether children actually improved on the training tasks in the BGB EF training program, their start level was compared to their highest level for the inhibition task, cognitive flexibility task and each of five versions of the working memory task with paired t-tests.

To assess whether there was a differential effect of treatment arm over time on attentional functioning, behavioral and emotional functioning, and self-perceived competence, linear mixed model analyses were run for all outcome measures with a random intercept to account for dependency in the data due to family bonds, and fixed factors for treatment arm, time and the interaction between treatment arm and time. To assess whether differential effects of treatment arm over time existed for younger and older children, linear mixed model analyses were performed on all outcome measures. A random intercept accounted for dependency in the data due to family bonds and the three-way interaction between treatment arm, time and age above or below 10.5 years was added as a fixed factor. To assess whether effects of BGB EF training program depend on time spent gaming before start of the training, the described linear mixed model analyses were also run with time spent gaming outside school-hours at baseline assessment added as a covariate. All available data was used in all linear mixed model analyses. In addition, we explored the association between gaming at baseline and baseline measurements of attentional, behavioral and emotional functioning and self-perceived competence, using Pearson r correlations.

RESULTS

Preliminary Analyses

Attrition analyses showed no differences on any of the demographic or neonatal medical characteristics nor on any of

TABLE 1 | Demographic and neonatal medical characteristics for the three treatment groups.

Measure	EF training (*n* = 29)	Placebo training (*n* = 26)	Waitlist (*n* = 30)	Test statistic (df), *p*-value
Demographic characteristics				
GA (M, SD)	28.2 (1.3)	28.0 (1.0)	27.8 (1.4)	$F(2,82) = 0.67$, $p = 0.52$
BW (M, SD)	1026 (256)	1039 (179)	1049 (267)	$F(2,82) = 0.07$. $p = 0.93$
Age (M, SD)	10.2 (1.2)	10.2 (1.3)	10.3 (1.1)	$F(2,82) = 0.03$, $p = 0.97$
IQ (M, SD)	99.0 (13.6)	96.4 (11.7)	100.8 (11.1)	$F(2,82) = 0.95$, $p = 0.39$
CBCL attention T-score (M, SD)	62.8 (6.9)	64.0 (7.6)	64.4 (7.0)	$F(2,82) = 0.38$, $p = 0.69$
Time spent gaming	5.5 (5.9)	8.0 (6.3)	8.5 (7.0)	$F(2,82) = 1.7$, $p = 0.18$
Boys (n,%)	13 (44%)	16 (62%)	20 (67%)	$\chi^2(2) = 3.1$, $p = 0.21$
Parental education level (n,%)				$\chi^2(4) = 8.9$, $p = 0.06$
Low	6 (21%)	4 (16%)	1 (4%)	
Middle	3 (10%)	5 (20%)	11 (39%)	
High	20 (69%)	16 (54%)	16 (57%)	
Neonatal medical characteristics				
SGA (n,%)	8 (28%)	4 (17%)	4 (14%)	$\chi^2(2) = 1.9$, $p = 0.38$
Ventilator support (n,%)	20 (69%)	17 (65%)	23 (77%)	$\chi^2(2) = 0.9$, $p = 0.64$
BPD at 36 weeks PMA (n,%)	7 (24%)	4 (16%)	6 (21%)	$\chi^2(2) = 0.2$, $p = 0.90$
IVH I or II	9 (31%)	6 (23%)	8 (27%)	$\chi^2(2) = 0.4$, $p = 0.80$
IVH III or IV	0 (0%)	2 (8%)	1 (3%)	$\chi^2(2) = 2.4$, $p = 0.30$
PVL I	1 (3%)	2 (8%)	0 (0%)	$\chi^2(2) = 2.4$, $p = 0.30$
PVL II, III or IV	0 (0%)	0 (0%)	0 (0%)	
Open Ductus Botalli treated	3 (10%)	12 (46%)	13 (43%)	χ^2 $(2) = 10.2$, $p < 0.01$
Sepsis	17 (59%)	16 (62%)	20 (67%)	$\chi^2(2) = 0.4$, $p = 0.81$

GA, Gestational Age; BW, Birth Weight; IQ, Intelligence Quotient; CBCL, Child Behavior CheckList; SGA, Small for Gestational Age; BPD, BronchoPulmonary Dysplasia; PMA, Post Menstrual Age; IVH, IntraVentricular Hemorrhage; PVL, PeriVentricular Leukomalacia; M, mean; SD, standard deviation; n, number.

the outcome measures at baseline between children that did and did not complete all assessments (all t-values < 1.94, all χ^2-values < 0.72, all p-values > 0.06). There were no significant differences on any of the baseline demographics or neonatal medical characteristics between the treatment arms, with one single exception. There was a significant difference between the treatment arms for open ductus botalli that was treated with either medication or surgery [$\chi^2(2) = 10.2$, $p = 0.006$], with less children with a treated open ductus botalli in the EF training arm than in the placebo and waitlist arm. An open ductus botalli is very common in preterm neonates, with an incidence of 50% in infants born with a birthweight below 750 g and 37% in infants born with a birthweight between 750 and 1000 g (Dice and Bhatia, 2007). Treated open ductus botalli has been found to be not associated with neurodevelopmental outcomes (Chorne et al., 2007). See **Table 1** for more detailed information on the demographic and neonatal characteristics of the three treatment groups at baseline. Assessments took place between October 2015 (first baseline measurement) and September 2018 (last second follow-up measurement). Mean number of weeks between baseline assessment and first follow-up assessment was 9.1 weeks ($SD = 2.5$) and mean number of weeks between baseline assessment and second follow-up assessment was 32.7 weeks ($SD = 4.8$). Mean number of months between first and second follow-up assessment was 5.5 months ($SD = 0.8$ months). There were no significant differences in time between baseline and first or second follow-up assessments between the three treatment arms [$F(2,68) = 0.66$, $p = 0.52$; $F(2,60) = 2.0$, $p = 0.15$, respectively].

Improvement During Training

For the inhibition training task, the cognitive flexibility training task and all five versions of the working memory task, significant improvements were found across the training sessions in the EF training arm. Performance significantly increased on all measures between the start level and the highest level achieved of children, indicating that children actually improved on all training tasks over the course of the EF training program. See **Table 2** for more details.

TABLE 2 | Improvement during training on the training tasks.

Training task	Start level *M* (*SD*)	Highest level *M* (*SD*)	Test statistic, *p*-value
Working memory version 1	3.15 (0.42)	3.87 (0.65)	$t(23) = -8.97$, $p < 0.001$*
Working memory version 2	3.25 (0.37)	3.84 (0.71)	$t(23) = -6.87$, $p < 0.001$*
Working memory version 3	3.07 (0.41)	4.03 (0.82)	$t(23) = -8.75$, $p < 0.001$*
Working memory version 4	2.95 (0.44)	3.55 (0.77)	$t(23) = -7.56$, $p < 0.001$*
Working memory version 5	2.98 (0.53)	3.74 (0.96)	$t(22) = -6.89$, $p < 0.001$*
Inhibition	3.70 (1.30)	11.42 (2.08)	$t(23) = -18.39$, $p < 0.001$*
Cognitive Flexibility	1.28 (0.51)	8.63 (4.14)	$t(23) = -8.44$, $p < 0.001$*

Significant at $\alpha = 0.05$. M, mean; SD, standard deviation.

Effects of the EF Training Program on Attentional, Behavioral and Emotional Functioning and Self-Perceived Competence

There was no significant difference over time between the three treatment arms for efficiency of the orienting and executive attention networks. The difference over time between the three treatment arms for the alerting network approached significance [$F(4,133) = 2.40$, $p = 0.053$]. *Post hoc* mixed model analyses indicated larger improvement of alerting network efficiency in the waitlist arm than in the EF training arm between baseline and first follow-up assessment, but larger improvement in EF training arm than in the waitlist arm between first and second follow-up assessment. There were significant main effects of time for efficiency of the executive network [$F(2,139) = 9.34$, $p < 0.001$] and the alerting network [$F(2,133) = 7.51$, $p = 0.001$], indicating efficiency improved over time. See **Table 3**.

There was no significant difference over time between the three treatment arms for any of the subscales of parent or teacher Strengths and Difficulties questionnaire. There was a significant main effect of treatment arm for the teacher Peer Problems subscale, indicating less peer problems in the EF training arm than in the waitlist arm [$F(2,77) = 3.65$, $p = 0.03$]. See **Table 4**.

There was no significant difference over time between the three treatment arms and time for any of the subscales of the self-perceived competence questionnaire for children. There were significant main effects of time for self-perceived competence in Scholastics [$F(2,144) = 6.04$, $p = 0.003$] and Athletic Competence [$F(2,142) = 3.42$, $p = 0.04$], both suggesting improved self-perceived competence over time. The main effect of time for self-perceived Behavioral Conduct approached significance [$F(2,145) = 2.95$, $p = 0.06$], suggesting improved self-perceived competence over time. See **Table 5**.

Significant three-way interactions between treatment arm, time, and age (above or below 10.5 years) were found for the alerting and executive attention networks [$F(17,121) = 1.89$, $p = 0.03$; $F(17,128) = 2.14$, $p = 0.009$, respectively]. However, *post hoc* analyses did not indicate more improvement for children in the BGB EF training arm than for children in the placebo or waitlist arm, either for children above or for children below 10.5 years of age.

Effect of the EF Training Program, Corrected for Gaming

Adding hours spent gaming outside school-hours to the mixed model analyses as a covariate showed that a significant interaction effect between treatment arm and time was now found for efficiency of the alerting network [$F(4,129) = 8.85$, $p = 0.03$]. *Post hoc* mixed model analyses showed larger improvement of efficiency of the alerting network for the placebo training arm than the EF training arm between baseline and first follow-up assessment. In addition, with time spent gaming in the model, a significant main effect of time was now found for the parent Emotional Symptoms scale of the SDQ [$F(2,135) = 3.41$, $p = 0.04$], suggesting less emotional problems over time. Furthermore, a significant main effect of time was found for self-perceived Behavioral Conduct [$F(2,138) = 3.08$, $p = 0.049$], indicating a reduction in behavioral problems over time. All other outcomes remained unchanged.

Associations Between Gaming and Baseline Attentional, Behavioral and Emotional Functioning and Self-Perceived Competence

Hours spent gaming outside school-hours was significantly and inversely related to scores on both parent and teacher rated Prosocial Behavior on the SDQ, indicating that the more hours children spent gaming outside of school-hours, the less prosocial behavior parents and teachers reported ($r = -0.23$, $p = 0.04$; $r = -0.25$, $p = 0.04$, respectively). Furthermore,

TABLE 3 | Baseline and follow-up data on the Attention Network Test for Children for the three treatment groups.

Outcome measure	T0 *M* (*SE*; 95% CI) *N* = 85	T1 *M* (*SE*; 95% CI) *N* = 73	T2 *M* (*SE*; 95% CI) *N* = 69	*p*-value
Attention Network Test				
Orienting Network				
EF training	26.15 (9.29; 7.83 – 44.47)	22.29 (10.68; 1.22 – 43.36)	21.08 (11.23; −1.06 – 43.22)	Group: 0.18
Placebo training	52.45 (9.77; 33.18 – 71.72)	38.54 (12.58; 13.72 – 3.36)	22.79 (11.83; −0.54 – 46.11)	Time: 0.22
Waitlist	25.19 (9.25; 6.94 – 43.44)	21.07 (9.10; 3.14 – 39.01)	18.42 (9.60; −0.51 – 37.36)	Group × Time: 0.77
Alerting Network				
EF training	74.57 (8.63; 57.54 – 91.60)	50.22 (9.86; 30.78 – 69.66)	90.90 (10.34; 70.51 – 111.28)	Group:0.58
Placebo training	53.46 (9.03; 35.64 – 71.28)	64.45 (11.54; 41.70 – 87.20)	79.18 (10.87; 57.74 – 100.61)	Time: 0.001
Waitlist	55.35 (8.56; 38.47 – 72.23)	79.45 (8.42; 62.84 – 96.07)	90.70 (8.87; 73.21 – 108.18)	Group × Time: 0.053
Executive Network				
EF training	85.90 (9.60; 66.95 – 104.83)	57.12 (10.98; 35.47 – 78.77)	58.04 (11.52; 35.32 – 80.76)	Group:0.25
Placebo training	97.76 (10.05; 77.93 – 117.59)	65.69 (12.86; 40.33 – 91.06)	61.26 (12.11; 37.37 – 85.15)	Time: <0.001*
Waitlist	73.86 (9.53; 55.07 – 92.65)	45.58 (9.37; 27.09 – 64.07)	55.38 (9.87; 35.91 – 74.85)	Group × Time: 0.91

Significant at $\alpha = 0.05$. Depicted are estimated marginal Means (M) and Standard Errors (SE). CI, Confidence Interval; N, total number of participants; T0, Time-point 0, i.e., baseline; T1, Time-point 1, i.e., first follow-up visit; T2, Time-point 2, i.e., second follow-up visit. See **Figure 1 for number of participants in each group at each time-point.*

TABLE 4 | Baseline and follow-up data on the Strengths and Difficulties Questionnaire according to parents and teachers for the three treatment groups.

Outcome measure	T0 *M* (*SE*; 95% CI) *N* = 85	T1 *M* (*SE*; 95% CI) *N* = 73	T2 *M* (*SE*; 95% CI) *N* = 69	*p*-values
Parent SDQ				
Emotional Symptoms				
EF training	2.79 (0.45; 1.90 – 3.68)	2.35 (0.47; 1.42 – 3.28)	2.67 (0.48; 1.72 – 3.61)	Group: 0.19
Placebo training	3.46 (0.45; 2.56 – 4.36)	2.70 (0.49; 1.72 – 3.67)	2.90 (0.51; 1.90 – 3.90)	Time: 0.07
Waitlist	2.23 (0.42; 1.39 – 3.06)	1.92 (0.43; 1.07 – 2.77)	1.86 (0.44; 0.98 – 2.73)	Group × Time:0.88
Conduct Problems				
EF training	1.03 (0.36; 0.31 – 1.75)	0.72 (0.38; −0.02 – 1.47)	0.93 (0.38; 0.18 – 1.69)	Group: 0.13
Placebo training	1.68 (0.37; 0.95 – 2.40)	1.80 (0.39; 1.03 – 2.58)	1.84 (0.41; 1.03 – 2.65)	Time: 0.92
Waitlist	1.55 (0.34; 0.87 – 2.23)	1.81 (0.35; 1.12 – 2.50)	1.69 (0.35; 0.99 – 2.39)	Group × Time:0.68
Peer Problems				
EF training	1.51 (0.39; 0.74 – 2.28)	1.24 (0.40; 0.44 – 2.03)	1.05 (0.41; 0.25 – 1.86)	Group: 0.18
Placebo training	2.07 (0.39; 1.29 – 2.84)	1.50 (0.42; 0.67 – 0.33)	1.97 (0.44; 1.11 – 2.83)	Time: 0.13
Waitlist	2.33 (0.36; 1.61 – 3.05)	2.24 (0.37; 1.51 – 2.98)	1.93 (0.38; 1.19 – 2.67)	Group × Time: 0.50
Prosocial Behavior				
EF training	8.76 (0.36; 8.04 – 9.48)	8.41 (0.38; 7.66 – 9.16)	8.54 (0.39; 7.77 – 9.30)	Group: 0.35
Placebo training	8.20 (0.37; 7.47 – 8.93)	7.85 (0.40; 7.06 – 8.65)	7.68 (0.42; 6.86 – 8.50)	Time: 0.32
Waitlist	8.14 (0.34; 7.46 – 8.81)	8.01 (0.35; 7.32 – 8.70)	8.19 (0.36; 7.49 – 8.90)	Group × Time: 0.83
Hyperactivity				
EF training	5.26 (0.45; 4.37 – 6.15)	4.76 (0.47; 3.83 – 5.69)	4.67 (0.48; 3.71 – 5.62)	Group: 0.04*
Placebo training	6.44 (0.46; 5.53 – 7.35)	6.37 (0.50; 5.38 – 7.36)	5.56 (0.52; 4.54 – 6.58)	Time: 0.10
Waitlist	6.24 (0.42; 5.40 – 7.07)	6.15 (0.43; 5.29 – 7.00)	6.01 (0.44; 5.14 – 6.89)	Group × Time: 0.73
Teacher SDQ				
Emotional Symptoms				
EF training	1.90 (0.40; 1.10 – 2.70)	1.66 (0.43; 0.80 – 2.52)	1.73 (0.45; 0.84 – 2.62)	Group: 0.62
Placebo training	1.51 (0.43; 0.65 – 2.37)	1.58 (0.49; 0.61 – 2.55)	1.59 (0.61; 0.40 – 2.79)	Time: 0.83
Waitlist	1.38 (0.39; 0.60 – 2.16)	1.23 (0.43; 0.38 – 2.08)	1.12 (0.47; 0.20 – 2.04)	Group × Time: 0.97
Conduct Problems				
EF training	0.66 (0.27; 0.13 – 1.18)	0.41 (0.30; −0.18 – 1.01)	0.40 (0.32; −0.23 – 1.03)	Group: 0.53
Placebo training	0.76 (0.30; 0.17 – 1.35)	0.99 (0.35; 0.29 – 1.69)	0.75 (0.47; −0.18 – 1.67)	Time: 0.56
Waitlist	1.01 (0.26; 0.50 – 1.52)	0.89 (0.29; 0.31 – 1.47)	0.59 (0.34; −0.09 – 1.26)	Group × Time:0.82
Peer Problems				
EF training	1.15 (0.39; 0.38 – 1.92)	0.61 (0.43; −0.25 – 1.47)	0.85 (0.47; −0.08 – 1.78)	Group: 0.03*
Placebo training	2.05 (0.43; 1.20 – 2.91)	1.97 (0.51; 0.97 – 2.98)	1.54 (0.67; 0.22 – 2.85)	Time: 0.24
Waitlist	2.43 (0.38; 1.69 – 3.18)	1.97 (0.43; 1.13 – 2.81)	2.11 (0.49; 1.14 – 3.07)	Group × Time: 0.93
Prosocial Behavior				
EF training	7.94 (0.48; 6.99 – 8.89)	8.34 (0.52; 7.31 – 9.37)	7.57 (0.55; 6.49 – 8.65)	Group: 0.42
Placebo training	7.83 (0.51; 6.81 – 8.85)	7.13 (0.60; 5.95 – 8.31)	7.46 (0.76; 5.97 – 8.96)	Time: 0.23
Waitlist	7.58 (0.46; 6.66 – 8.50)	6.93 (0.51; 5.92 – 7.93)	6.85 (0.57; 5.73 – 7.98)	Group × Time: 0.35
Hyperactivity				
EF training	4.39 (0.60; 3.21 – 5.57)	3.90 (0.65; 2.60 – 5.19)	4.14 (0.69; 2.78 – 5.50)	Group: 0.70
Placebo training	5.51 (0.66; 4.20 – 6.82)	5.22 (0.76; 3.72 – 6.73)	2.64 (0.97; 0.72 – 4.56)	Time: 0.02*
Waitlist	5.09 (0.58; 3.94 – 6.23)	4.71 (0.64; 3.44 – 5.98)	4.61 (0.74; 3.15 – 6.08)	Group × Time: 0.14

*Significant at $\alpha = 0.05$. Depicted are estimated marginal means (M) and standard errors (SD). CI, Confidence Interval; N, total number of participants; SDQ, Strengths and Difficulties Questionnaire; T0, Time-point 0, i.e., baseline; T1, Time-point 1, i.e., first follow-up visit; T2, Time-point 2, i.e., second follow-up visit. See **Figure 1** for number of participants in each group at each time-point.*

hours spent gaming outside of school-hours was significantly and positively related to scores on parent rated Hyperactivity on the SDQ ($r = 0.23$, $p = 0.04$), indicating that the more hours children spent gaming outside of school-hours, the more hyperactive behavior they showed. There were no other significant associations between gaming and any of the other baseline measures.

DISCUSSION

This study examined the effects of a computerized, game-formatted EF training program (BGB EF training program) on attentional, behavioral and emotional functioning and self-perceived competence of very preterm children in a double-blind, placebo and waitlist-controlled randomized trial. We first

TABLE 5 | Baseline and follow-up data on self-perceived competence for the three treatment groups.

Domain	T0 *M* (*SE*; 95% CI) *N* = 85	T1 *M* (*SE*; 95% CI) *N* = 73	T2 *M* (*SE*; 95% CI) *N* = 69	*p*-value
Scholastics				
EF training	15.12 (0.70; 13.74 – 16.50)	16.01 (0.74; 14.55 – 17.47)	14.56 (0.75; 13.08 – 16.04)	Group: 0.52
Placebo training	15.37 (0.73; 13.93 – 16.81)	17.15 (0.79; 15.59 – 18.72)	15.72 (0.79; 14.16 – 17.29)	Time: 0.003*
Waitlist	15.50 (0.66; 14.21 – 16.80)	16.59 (0.66; 15.28 – 17.90)	16.18 (0.68; 14.84 – 17.51)	Group × Time: 0.58
Social Acceptance				
EF training	18.54 (0.85; 16.86 – 20.21)	18.18 (0.89; 16.43 – 19.93)	17.79 (0.90; 16.02 – 19.57)	Group: 0.08
Placebo training	16.68 (0.88; 14.94 – 18.41)	17.30 (0.94; 15.45 – 19.16)	16.29 (0.94; 14.43 – 18.15)	Time: 0.31
Waitlist	19.19 (0.79; 17.62 – 20.75)	19.43 (0.80; 17.85 – 21.01)	18.95 (0.81; 17.34 – 20.56)	Group × Time: 0.90
Athletic Competence				
EF training	17.34 (0.71; 15.93 – 18.75)	17.35 (0.75; 15.86 – 18.84)	17.98 (0.76; 16.47 – 19.49)	Group: 0.38
Placebo training	17.63 (0.74; 16.16 – 19.10)	18.04 (0.80; 16.45 – 19.63)	18.50 (0.80; 16.92 – 20.09)	Time: 0.04*
Waitlist	17.68 (0.67; 16.35 – 19.00)	19.55 (0.68; 18.21 – 20.89)	19.02 (0.69; 17.66 – 20.39)	Group × Time: 0.29
Physical Appearance				
EF training	19.19 (0.82; 17.56 – 20.81)	18.89 (0.85; 17.20 – 20.58)	18.82 (0.86; 17.12 – 20.53)	Group: 0.07
Placebo training	19.54 (0.85; 17.86 – 21.22)	19.32 (0.90; 17.54 – 21.10)	19.44 (0.90; 17.66 – 21.22)	Time: 0.83
Waitlist	20.56 (0.77; 19.03 – 22.08)	21.53 (0.77; 20.00 – 23.07)	21.65 (0.78; 20.09 – 23.20)	Group × Time: 0.36
Behavioral Conduct				
EF training	17.63 (0.72; 16.20 – 19.06)	18.34 (0.77; 16.82 – 19.85)	17.65 (0.78; 16.11 – 19.19)	Group: 0.78
Placebo training	17.26 (0.76; 15.76 – 18.75)	18.46 (0.82; 16.83 – 20.09)	17.42 (0.82; 15.79 – 19.05)	Time: 0.06
Waitlist	18.06 (0.68; 16.71 – 19.40)	18.89 (0.69; 17.53 – 20.25)	17.94 (0.70; 16.55 – 19.33)	Group × Time: 0.99
Global Self-Worth				
EF training	20.07 (0.65; 18.78 – 21.37)	19.97 (0.69; 18.61 – 21.33)	20.60 (0.70; 19.23 – 21.98)	Group: 0.12
Placebo training	19.97 (0.68; 18.62 – 21.32)	20.55 (0.73; 19.11 – 22.00)	20.60 (0.73; 19.16 – 22.05)	Time: 0.27
Waitlist	21.35 (0.61; 20.14 – 22.57)	22.11 (0.62; 20.89 – 23.34)	21.69 (0.63; 20.45 – 22.94)	Group × Time: 0.70

Significant at α = 0.05. Depicted are estimated marginal means (M) and standard errors (SD). CI, Confidence Interval; N, total number of participants; T0, Time-point 0, i.e., baseline; T1, Time-point 1, i.e., first follow-up visit; T2, Time-point 2, i.e., second follow-up visit. See* ***Figure 1* *for number of participants in each group at each time-point.*

analyzed whether or not the intervention group showed improvements on the working memory, cognitive flexibility and inhibition tasks they trained during 12 weeks. Significant training effects were indeed found. Despite of this, results showed no positive effects of the BGB EF training program on any of the dependent measures.

In children with ADHD, promising effects of EF training programs on working memory were reported (Klingberg et al., 2005; Beck et al., 2010; Green et al., 2012; Hovik et al., 2013; Chacko et al., 2014; van der Oord et al., 2014; Dovis et al., 2015). However, in all of these studies, either a placebo or a waitlist-control group was included, but not both. Including a placebo condition enables to entangle specific and a-specific training effects, while including a waitlist-control group enables to entangle training effects (either specific or a-specific) from developmental effects and test-retest effects. In very preterm born adolescents aged 14–15 years, CWMT was shown to have positive effects on working memory and verbal learning (Lohaugen et al., 2011), however again only a non-intervention control group was included in that study, and no placebo control group, and the positive effects could thus reflect developmental or test–retest effects instead of effects of CWMT. Our results, without any beneficial effect of a computerized EF training program in very preterm children, are in line with the first randomized controlled trial on CWMT in very preterm children that did include a placebo control group, reporting no positive effects (Anderson et al., 2018). Literature on the effects of EF training programs is inconsistent at least and there is much debate on what effects EF training programs, including CWMT, actually have. Regarding the effects of working memory training on working memory performance, three meta-analyses have been performed, of which two conclude that EF training programs produce reliable improvements in both verbal and visuospatial working memory, with some evidence that the improvements in visuospatial working memory are maintained (Melby-Lervåg and Hulme, 2013; Aksayli et al., 2019). However, the third has theoretical arguments why simple span tasks are not a good measure for working memory improvement following CWMT and concludes that some studies using complex span tasks do and some studies do not find working memory improvements following CWMT (Shipstead et al., 2012). Regarding the effects of working memory training on other, untrained functions, these meta-analyses all three concluded that there was no evidence for generalization of working memory improvement to other domains (Shipstead et al., 2012; Melby-Lervåg and Hulme, 2013; Aksayli et al., 2019). Only one meta-analysis, performed by the research group involved in the development of CWMT (Spencer-Smith and Klingberg, 2016), concluded that CWMT has significant positive effects on inattention in daily life. However, comments on this study by Dovis et al. (2015a,b), have made arguments as to why these conclusions are controversial. In short, they state that: (1) there were coding errors in the initial meta-analysis, and after correction of these coding errors, effects of CWMT were no longer significant for several subgroup analyses, including for studies using an active or non-adaptive control group and for studies using a specific measure of inattention in daily life, (2) that differences between CWMT and control groups were analyzed without taking into account pre-test ratings of inattention, thus making it impossible to interpret which group benefits or improves most, or if there is any benefit or improvement at all and (3) that with correction for publication bias, the overall effect of CWMT on inattention was no longer significant, and that the reasons the authors of the meta-analysis provide for not correcting for publication bias are not supported by the literature.

The current study did not find positive effects of the BGB EF training program on attentional, behavioral and emotional functioning and self-perceived competence. Furthermore, meta-analyses have indicated no positive effects of the CWMT program for untrained functions. These results may be interpreted as game-based EF training being inadequate. However, as reported in the most recent meta-analysis on CWMT studies, this training induces moderate improvements in performance on memory tasks that are not included in the training or related to the trained tasks. This suggests that game-based EF training programs actually are able to improve working memory task performance, but that this improvement does not generalize to other functions. This could suggest that the game-based EF training programs need adjustments before they are capable to induce generalization of the trained functions to untrained functions. It could also suggest that the associations between EF deficits and problems in attentional, behavioral and emotional functioning that are commonly found (Nadeau et al., 2001; Taylor et al., 2006; Mulder et al., 2010, 2011; de Kieviet et al., 2012; Loe et al., 2012; Aarnoudse-Moens et al., 2013; Alduncin et al., 2014) are very complex, and that improvements in EFs alone do not directly lead to improvements in attentional, behavioral and emotional functioning. Furthermore, there may be limits to the plasticity of the brain of very preterm children, which may influence the extent to which game-based EF training leads to improvements in trained and untrained functions. Last, very preterm birth does not just influence the development of the child itself, but also has an impact on family functioning and parents' functioning (Treyvaud, 2014) and subsequently parent-child interactions (Potharst et al., 2012). In 5-year-olds, mothers of very preterm children were less supportive of their children's autonomy and interfered more often with their children's autonomy than mothers of term born children (Potharst et al., 2012). In the setting of game-based EF training, this may lead to more negative interactions with the child about planning or execution of the training sessions, which in turn could lead to children being less motivated about the training. This may have negatively affected the extent to which children profit from the training.

The current study included children with a wide age range, including both children and adolescents (ages 8 years up to and including 12 years). As adolescence is a time in which significant neural, cognitive, behavioral and emotional changes take place (Spear, 2000; Yurgelun-Todd, 2007; Casey et al., 2008), effects of the BGB EF training program may differ depending on the ages studied. However, our analyses involving three-way interactions between treatment arm, time and age (above or below 10.5 years) showed that for almost all outcome measures, there was no differential effect of treatment arm over time between children above and below 10.5 years of age. Furthermore, for the two outcome measures for which there was a significant three-way interaction, there were no indications that the BGB EF training induced more improvement in either children above or below 10.5 years of age when compared to the placebo training and waitlist arm.

The interaction-effect for alerting network efficiency approached significance, and after time spent gaming before the intervention was taken into account, this interaction-effect became significant. However, for both, *post hoc* analyses showed that these interaction-effects were not indicative of larger improvements of alerting network efficiency in the EF training arm.

Significant improvements over time, regardless of treatment arm, were found for efficiency of the alerting and executive attention networks and for self-perceived competence in the domains of scholastics and athletics. After correction for time spent gaming before the intervention, there were also significant improvements over time for self-perceived behavioral conduct and parent-rated emotional symptoms. No negative changes over time were found. These improvements over time could be a sign of spontaneous recovery or regression to the mean. We also cannot exclude the explanation that this may be a Hawthorne effect, in which the effect of participating in research is reflected in a decrease in problems.

Our exploratory analyses revealed no large differences in outcomes of the analyses when these were adjusted for the time spent gaming outside school-hours. The small differences in outcomes when time spent gaming is adjusted for, may suggest that exposure to gaming at forehand does not influence the degree to which an EF training program as BGB may be effective.

Further analyses revealed that more time spent gaming outside school-hours at baseline assessment, was associated with more parent-rated hyperactive behavior and less prosocial behavioral according to both parents and teachers. Correlation obviously does not imply causation. Either way, our findings may suggest that if a computerized intervention is prescribed, it must be done in a healthy way, explaining child and parents that restrictions in time must be taken into account. For example, the American Academy of Pediatrics recommends that children have 2 h or less of sedentary screen time daily and that media-free times with the family and media-free locations in homes should be designated (Council on Communications and Media, 2016).

Is there still a future for EF training programs, or should focus shift away and focus on other promising interventions? The fact that improvements on the training tasks within the BGB EF training program took place, but no effects on the same EFs measured at follow-up assessments was found, suggests that improvement in the EFs was not just EF-specific, but also task-specific. From the skill learning field, it is known that transfer of learning from a trained task to even highly similar untrained tasks is generally the exception rather than the rule (Green and Bavelier, 2008). Training paradigms where more general learning has been established, are typically more complex and more ecologically valid, corresponding to real-life experiences (Green and Bavelier, 2008). One of the key factors in ensuring more general learning is variability in tasks and input (Green and Bavelier, 2008). In the BGB EF training program, only one EF is trained at a time and there is little correspondence to real-life experiences. For working memory, there is variability in task instructions and difficulty level, but not in the context in which the training task is performed or in what kind of working memory is trained (only visuospatial working memory, not verbal working memory). For inhibition and cognitive flexibility training, there is variability in difficulty level, but not in task instructions, context in which the training is performed or in the manner in which inhibition or cognitive flexibility is trained. Furthermore, for inhibition, only response inhibition is trained, while there are several other kinds of inhibition as well (Nigg, 2000). For CWMT, most of these arguments also apply; although several different working memory tasks are trained, there is little correspondence to real-life experiences and only one EF is trained at a time. Before abandoning the field of EF training programs, more ecologically valid EF training programs should be investigated for effectivity in improving EF and generalization of EF improvements to other functions such as attention. Focus could also shift to other promising interventions. Several activities seem to improve EFs in children in the general population, including traditional martial arts, aerobics, yoga, mindfulness, and several school curricula (Diamond, 2012). It has been suggested that especially interventions that address both EFs and children's emotional, social and character development are effective (Diamond, 2012). Furthermore, two meta-analyses have shown that acute and longitudinal physical activity has positive effects on EF, attention and academic performance in children in the general population (Verburgh et al., 2014; de Greeff et al., 2018). Interventions as mentioned above have not yet been investigated in the very preterm population and thus should be subject of further research.

Strengths and Limitations

Strengths of the current study are the incorporation of both a placebo training- and a waitlist-control arm, the use of intention-to-treat analyses, the objective measure of attentional functioning (efficiency of attention networks), the comprehensive assessment of behavioral and emotional functioning by both parents and teachers, and the assessment of both direct and longer-term effects. A limitation is that we failed to achieve our calculated sample, however, differences over time between groups were small and not clinically meaningful. Another limitation is the relatively high number of missing teacher SDQ questionnaires, however, as results on these measures are highly similar to results on the other outcome measures, we expect that a lower number of missing questionnaires would not have led to different results. As also in other studies using questionnaires (Simons et al., 2019), response rate on the CBCL in our study was low and possibly biased toward families of higher socio-economic status. Last, children with severe neonatal complications (IVH grade III or IV) were not excluded if they met inclusion criteria, which could have increased variability within the sample. However, sensitivity analyses including only children without severe neonatal complications were performed and results remained essentially unchanged.

CONCLUSION

A computerized, game-formatted EF training program does not improve performance measures of attention, parent- or teacher rated behavioral and emotional functioning or self-perceived competence in very preterm children.

DATA AVAILABILITY

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

This study was approved by the Medical Ethical Committee of Amsterdam University Medical Centers and University Medical Center Utrecht. Written informed consent was obtained from the parents of all participants. Written informed consent was also obtained from participants aged >11 years.

AUTHOR CONTRIBUTIONS

CH contributed to the conceptualization, design, and methodology of the study, responsible for the outcome assessments and data collection, carried out the data analyses and interpretation, and wrote the manuscript. CA-M contributed to the conceptualization and design of the study, funding acquisition, data analysis methodology and data interpretation, overall supervision, and reviewed and revised the manuscript. AW-L contributed to the conceptualization and design of the study, funding acquisition, data interpretation, overall supervision, and reviewed and revised the manuscript. AL and CK-E contributed to the resources (participants), supervision in one of the Medical Centers, and reviewed and revised the manuscript. AK contributed to the conceptualization, design, and methodology of the study, data interpretation, overall supervision, and reviewed and revised the manuscript. JO contributed to the conceptualization, design, and methodology of the study, funding acquisition, data analysis methodology and data interpretation, overall supervision, and reviewed and revised the manuscript.

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Schoolchildren's Compensatory Strategies and Skills in Relation to Attention and Executive Function App Training

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Background: Given the importance of attention and executive functions (EF) in children's behavior, programs aimed at improving these processes are of special interest. Nexxo-training combines the use of the Nexxo touchscreen application (inhibition and vigilance tasks) with procedural metacognitive strategies (imparted by an instructor) for all the individuals using the app, regardless of their level of ability, plus compensatory strategies based on individual child performance. This study presents an analysis of the compensatory strategies that schoolchildren (aged 6–8 years old) receive when experiencing difficulties with EF tasks, in addition to an analysis of the developmental factors and cognitive skills that may modulate EF task performance.

Methods: For this study, we use data from a previous randomized active-controlled study (under review), in which forty-six typically developing children aged between 6 and 8 years old (24 girls/22 boys) were enrolled in the training group. The selected children were in the 1st grade ($n = 28$, $\bar{x} = 78.32 \pm 4.037$ months) and 3rd grade of primary education ($n = 18$, $\bar{x} = 102.11 \pm 3.445$). We collected data on EF training performance, compensatory strategies needed and neuropsychological assessments.

Results: A total of 80.43% participants required some form of compensatory strategy during training. Regarding required compensatory strategies, those who had lower scores in EF training needed more compensatory strategies, in particular, instructional comprehension ($r = -0.561$, $p < 0.001$ for inhibition-tasks; $r = -0.342$, $p < 0.001$ for vigilance-tasks). Concerning developmental factors, age significantly predicted better performance in both EF tasks ($\beta = 0.613$, $p < 0.001$ for inhibition; $\beta = 0.706$, $p < 0.001$ for attention). As regards task performance, those with better performance in inhibition tasks also had better performance in vigilance tasks ($r = 0.72$, $p < 0.001$). Finally, regarding cognitive skills, participants with higher performance in fluid intelligence (Q1, $n = 12$) had higher scores ($U = 14.5$, $p < 0.05$) than the group with the lowest performance (Q4, $n = 11$) in vigilance.

Conclusion: As previous literature suggests, inhibition is one of the core processes of EF. Therefore, we should focus training on the core EF processes. Inhibition and vigilance are closely related processes. In terms of the use of compensatory strategies, these are more needed for participants with lower levels of performance in inhibition or vigilance. Regarding strategy analysis, instructional comprehension and self-instruction (goal setting and planning) seem to be the most useful strategies for those with difficulties in inhibitory and vigilance task performance. Regarding development, as expected, age moderates task performance in inhibition and attention. Finally, cognitive skills, such as fluid intelligence and cognitive flexibility, predicted better results in attention. EF training using not only an app, but also compensatory strategies based on user performance, is a new research direction offering more opportunities to generalize EF training in everyday life.

Keywords: inhibition, vigilance, procedural metacognition, application, children, attention, executive functions, cognitive training

INTRODUCTION

Executive Functions (EF) can be understood as a variety of interrelated processes that help to direct and control mental abilities to accomplish a task or goal (Reck and Hund, 2011). Miyake et al. (2000) propose a hierarchical model in which EF is considered as a unitary construct with three main components: (1) inhibition, (2) updating, and (3) shifting. Inhibition is the ability to suppress one automatic or prepotent response in favor of another, or to suppress the response altogether, known as response inhibition. Another aspect of inhibition is interference control, which is required to select relevant stimuli when a distractor appears (Miyake et al., 2000; Diamond, 2013; van der Ven et al., 2013; Tamm and Nakonezny, 2015). This process is one of the first stages to develop and is thought to be responsible for changes in other EF components (Dempster, 1992; Gandolfi et al., 2014). Updating is the ability to retain and manipulate information during a short period of time (Miyake et al., 2000; Klingberg et al., 2002). This ability is essential for learning (Conway et al., 2003). Finally, shifting is the ability to change from "one mental set" to another (Miyake et al., 2000). These components are involved in several everyday activities (Diamond, 2013).

Previous studies have found a relation between EF and intelligence (Andersson, 2008; Molfese et al., 2010; Karbach and Unger, 2014); however, EF is even more predictive of academic success than IQ (Gathercole et al., 2004; Blair and Razza, 2007). Apart from academic success, EF also seems to have an impact on social adjustment (Bryck and Fisher, 2012). "Social adjustment is defined as the degree to which children get along with their peers; the degree to which they engage in adaptive, competent social behavior; and the extent to which they inhibit aversive, incompetent behavior" (Crick and Dodge, 1994, p.82). Difficulties in EF are present in social maladjustment (Olson, 1989; Blair and Razza, 2007). EF components are impaired in various childhood disorders (Barkley, 1997), such as ADHD (Rebollo and Montiel, 2006; Gau et al., 2010), autism (Ciesielski and Harris, 1997), obsessive-compulsive disorder (Enright and Beech, 1993), and behavioral disorders (Rebollo and Montiel, 2006). For these reasons, studies on EF interventions in children and the mechanisms involved in their development are relevant. This knowledge can be applied to EF programs aimed at school settings for typically developing children as a protective factor or in clinical contexts for those with EF difficulties as part of the intervention.

If inhibition is one the core components of EF, the intensity domain of attention is the core component of attention (Sturm, 2008). The intensity domain involves alertness, sustained attention and vigilance as the basis of attention (Hauke et al., 2011). Tonic alertness is thought of as a top-down control function of the arousal system without the influence of external stimuli, whereas phasic alertness is the capability to respond following a warning stimulus (Sturm and Willmes, 2001). Sustained attention involves the detection of changes over a long period with a high rate of relevant stimuli. In contrast, vigilance, a state of sustained alertness, involves the detection of changes when only a low rate of relevant stimuli exists (Hauke et al., 2011). Some aspects of attention overlap with certain components of EF (Rueda et al., 2012), which explains the high degree of interaction between attention and EF. The core processes of attention and EF are related; for instance, inhibition is fundamental for attentional maintenance (Pontifex et al., 2012). Furthermore, previous research has found that children with higher levels of sustained attention present high levels of inhibitory control (Reck and Hund, 2011). Sustained attention and behavioral inhibition interact throughout child development. A longitudinal study (testing attention at 9 months and studying behavioral inhibition until adolescence) demonstrated that sustained attention is related to inhibitory control. Individuals with lower levels of sustained attention presented increased levels of behavioral inhibition during childhood and social discomfort during adolescence (Pérez-Edgar et al., 2010). Apart from sustained attention, vigilance and inhibitory control are closely related (Lovejoy and Rasmussen, 1990).

Studying the attentional element involved in EF tasks, procedural metacognitive strategies (including self-regulatory strategies) and related skills may help us to design EF training strategies and interventions based on scientific data. Attention is strongly needed in EF tasks, and EF and self-regulation share resources (Kaplan and Berman, 2010). Some attention training has shown benefits in EF tasks. One study demonstrated how attention training in children with ADHD not only reduced symptoms of inattentiveness, but also enhanced EF, specifically, by shifting attention (La Marca and O'Connor, 2016). Studies on attention span and working memory have shown how training benefits participants with ADHD with regard to EF (Klingberg et al., 2002, 2005; Beck et al., 2010). In our view, due to the interaction between attention, EF and self-regulation, training that combines these processes may produce more transfer effects than just training EF alone. Following this hypothesis, our team developed Nexxo-training, which aims to improve vigilance, inhibition and procedural metacognitive strategies in typically developing children.

Most cognitive training can be classified into two categories: process-based training and strategy-based training (Morrison and Chein, 2011; Jolles and Crone, 2012). Both approaches involve practice or intentional instruction to improve cognitive skills. The main difference is that strategy-based training uses more explicit task instructions than process-based training (Jolles and Crone, 2012). Regarding attention and EF training, a few process-based training methods have shown positive effects in typically developing children, either in terms of attention (Thorell et al., 2009) executive attention (Rueda et al., 2005), fluid intelligence (Klingberg et al., 2005; Liu et al., 2015), or academic performance (Dahlin, 2011, 2013; Holmes and Gathercole, 2014). Nevertheless, the limitations of process-based training have been found in the far transfer or generalization of the training in the user's everyday life. Similarly, limitations have been found in long-term effects (Rossignoli-Palomeque et al., 2018). The aim of EF training should be the generalization of the training in children's daily life, in cognitive skills, academic performance, and social adjustment, which are considered "far transfer." A significant number of previous studies on EF training efficacy fail to find or examine these types of transfer results (Rossignoli-Palomeque et al., 2018). To overcome this limitation of traditional process-based training, strategy-based training provides guidance with the tasks which help users to identify the strategies needed to perform those tasks. An example of this kind of guidance is scaffolding, or metacognitive strategies, designed in combination with the training (Pozuelos et al., 2018). Indeed, strategy-based training has yielded positive results. Pozuelos et al. (2018) compared two groups with executive attention training in typically developing children with an active control group. One of the training groups followed traditional attention and EF protocol, whereas the other underwent metacognitive strategies. The children in the metacognitive group showed not only greater gains in intelligence, but also significant increases in conflict processing, measured through electrophysiological techniques. In addition, changes in brain activity regarding conflict processing predicted gains in intelligence in this group. The EF and attention intervention program that we analyze, called Nexxo-training, combines inhibition and vigilance training through a touchscreen application with strategies of "procedural metacognition" directed by a single instructor. This strategy-based training consists of repeating a task in combination with strategies to improve performance tasks. The unique feature of this specific strategy-based training is that the training provides not only procedural metacognitive strategies (i.e., general strategies for the whole group), but also compensatory strategies for participants who experience greater difficulty during the training. In this way, the developmental processes involved in the attention and EF training task can be easily improved and generalized. A previous study of Nexxo-training, a randomized-controlled study, showed far transfer after training in supervision, attention and EF as reported by parents (Rossignoli-Palomeque et al., submitted). Far transfer occurs when training effects are produced in tasks or constructs that have not been directly trained. By contrast, near transfer occurs when the effects are reflected in similar tasks to those that have been directly trained (Karbach and Unger, 2014). Further research on this type of training is crucial as it offers a new direction for cognitive training interventions.

In addition, to plan any form of attention and EF intervention, developmental factors must also be considered. In general, the initial manifestations of EF occur during the 1st year of life, with accelerated development in childhood (Carlson and White, 2013). EF development may be a pyramidal process. Certain basic components, such as inhibition, will later support the development of other more complex processes, such as flexibility (Flores-Lázaro et al., 2014). Nevertheless, other components, such as planning, do not reach adult levels until approximately the age of 12 years old while others, such as abstraction, will continue to develop into adulthood (Zelazo and Müller, 2002) reaching peak performance at around 20–30 years of age (Blakemore and Choudhury, 2006). Regarding attention, conscious control of attention increases between 2 and 6 years of age (Rothbart and Posner, 2001; Diamond et al., 2007). There is a second significant improvement in cognitive control of attention at around 9–12 years of age (Pozuelos et al., 2014). Meanwhile, sustained attention improves significantly between the ages of 3 and 5 years old (Garon et al., 2008) and continues to develop progressively throughout a child's school years. There are significant changes in sustained attention from 6 to 7 years of age in comparison with 10- to 11-year-olds (Lewis et al., 2017b). Inhibition and attention are relevant cognitive abilities. In terms of development, go/no-go tasks have demonstrated a significant improvement in response inhibition and sustained attention between the ages of 6 and 8 years old, while these changes are more subtle from 8 to 11 years of age (Lewis et al., 2017a). Previous studies, using go/no-go tasks for assessment, support the same idea that there is an improvement in response inhibition abilities between the ages of 6 and 8 years (Becker et al., 1987). Inhibition is a process that develops particularly between the ages of 5 and 10 years (Urben et al., 2011).

Apart from the relation between attention, EF and developmental factors, it is also worth considering what other skills and strategies may be involved in performing attention and EF tasks successfully. Previous studies have shown that inhibition training in preschoolers produced a trend-level improvement in reasoning and neural changes in the experimental group

(Liu et al., 2015). Other authors suggest that students with a high IQ also perform well in EF tasks, specifically in inhibition and flexibility (Sastre-Riba and Viana-Sáenz, 2016). On the other hand, lower vigilance performance has been linked to a lower IQ in children who are at risk of learning disabilities (Swanson and Cooney, 1989). Therefore, if attention, EF and intelligence are related, which specific cognitive abilities are involved, and which are better at predicting attention and EF performance? These crucial questions must be addressed by attention and EF training developers.

Regarding schoolchildren's use of procedural metacognitive strategies in inhibitory tasks, it seems that verbal strategies (e.g., verbalizations of what to do/not do) and motor strategies (e.g., moving away, shaking their heads, covering their mouths, etc.) are used by preschoolers to inhibit themselves (Fatzer and Roebers, 2013). The combination of both types of strategies seems to produce better inhibitory results (Manfra et al., 2014). The development of these strategies depends on the child's age. For instance, verbalizations and inner speech evolve between 2 and 8 years of age, from irrelevant speech to self-directed verbalizations, both of which are relevant to the task (Winsler et al., 2009). Another type of strategy, which seems to promote better results in EF tasks in older students and adults, are self-instructions (e.g., saying out loud what to do, how to do it, etc.) (Karbach and Kray, 2009). The development of these strategies varies throughout child development (Vygotsky et al., 1978; Bjorklund and Harnishfeger, 1990) and is also based on the level of task difficulty (Fernyhough and Fradley, 2005). Nexxo-training strategies consist of procedural metacognitive strategies. These strategies involve self-regulation (motor and verbal strategies), instructional comprehension, and self-instruction strategies, according to the participant's development. Self-instruction and instructional comprehension involve three phases: (1) forethought (establish goals, "what do I have to do?"), (2) performance/volitional control (planning, monitoring and controlling cognition, "how am I going to do it?") and, (3) self-reflection (self-evaluation and cognitive flexibility to make adjustments if required). These three phases are metacognitive strategies that can be applied in self-regulated learning (Dina and Efklides, 2009). EF and procedural metacognition (such as the strategies mentioned above) share common theoretical characteristics, developmental paths, and even brain regions. Therefore, the student's control of their own learning is crucial (Roebers and Feurer, 2016). To our knowledge, this is the first EF training that offers these strategies for school-aged students. The primary focus of this study was to analyze the strategies that students (aged 6–8 years old) use when confronted with challenging strategy-based EF and attention training ("Nexxo-training"). This training, delivered through an online application, combines inhibition and vigilance training with procedural metacognitive strategies. The study also analyzes the cognitive skills and developmental factors that may modulate task performance.

The study objectives are as follows: (1) to determine whether procedural metacognitive strategies have an impact on task performance and which ones are relevant; (2) to ascertain whether age moderates the use of strategies and task performance; (3) to identify which cognitive skills are related to task performance as possible predictors; and (4) if cognitive skills are predictive of task performance, the final objective is to test whether this relation is sustainable when the lowest and highest levels of performance are compared.

This information is crucial to the scientific development of new training technologies for EF and attention interventions.

MATERIALS AND METHODS

Ethics Statement

In accordance with the Declaration of Helsinki, written informed consent was obtained from each parent's participant. This study was approved by the ethics committee of the San Carlos Hospital (n° 15/315-E) in June 2015.

Participants

The study participants were recruited from two schools after receiving their parents' consent. Forty-six typically developing children aged between 6 and 8 years old (24 girls and 22 boys) participated in the study. The selected children were in the 1st grade (n = 28, $\bar{x}$ = 78.32 ± 4.037 months) or 3rd grade of primary education (n = 18, $\bar{x}$ = 102.11 ± 3.445). The parents' average professional range was $\bar{x}$ = 2.59 ± 0.53 (0 = low level, 1 = medium-low, 2 = medium, 3 = medium-high, and 4 = high) according to the "National Institute of Professional Range" (Spain). The inclusion criteria were as follows: (1) between the ages of 5–7 and 8–9 years; (2) no previous diagnosis of diseases or disorders related to developmental delays; (3) no psychological or speech therapy treatment required at the time of the study or earlier; (4) Spanish-speaking (monolingual); and (5) no diagnosis of learning difficulties or repetition of school year. Criteria 1–5 were obtained through a parents' questionnaire. **Table 1** shows the sociodemographic description of the participants.

Assessments

Standardized Tests Were Used to Assess the Following Dimensions:

Cognitive skills through individual cognitive assessments (40–45 min): attention using the DIVISA-R "Trees Simple Visual Discrimination Test – Revised" (Santacreu et al., 2010), intelligence using the Reynolds Intellectual Screening Test (RIST) (Reynolds and Kamphaus, 2003), the Five Digit Test (FDT) (Sedó, 2007) to measure inhibition and cognitive flexibility, and,

TABLE 1 | Sociodemographic description of participants.

	Female (n = 24)				Male (n = 22)				Total (n = 46)			
	Mean	*SD*	Min	Max	Mean	*SD*	Min	Max	Mean	*SD*	Min	Max
Age	7.04	1.06	6	9	6.62	0.973	5	8	6.85	1.03	5	9
IQ	104	13.9	79	131	106	16.1	78	130	105	14.8	78	131

SD = standard deviation; IQ = intelligence quotient measured by Reynold Intellectual Screening Test (RIST); Min = minimum; Max = maximum.

processing speed assessment through the Wechsler Intelligence Scale for Children-fourth edition (WISC-IV) (Wechsler, 2005).

The DIVISA-R (Santacreu et al., 2010) is a computer-based test in which the participant is required to tap the same trees as the model as quickly as possible. It takes approximately 15 min and is suitable for children aged 6–12 years. It provides five main indexes: distraction-precipitation, commission errors, omission errors, processing speed, and a global attention score. The reliability is based on Cronbach's alpha ≥0.77 for all scales.

The RIST (Reynolds and Kamphaus, 2003) is a screening intelligence test. It contains two subscales: "guess what," to assess verbal intelligence, and "odd-item-out," to assess non-verbal intelligence. The sum of both subscales determines a general index of intelligence ($\bar{x}$ 100 ± 15). The reliability based on Cronbach's alpha is 0.91.

The FDT (Sedó, 2007) is a test to measure certain aspects of EF (inhibition and cognitive flexibility). It contains four subscales: decoding, counting, election and alternative. It provides measures of inhibition and flexibility. In the inhibition subscale, the participant is required to count the numbers in a box instead of reading the numbers (automatic response). In the flexibility subscale, the participant must change strategy (from counting the numbers in a box to reading the number seen in the box), indicated by boxes in a blue frame. The Spearman-Brown coefficient ranges between 0.92 and 0.95.

The WISC-IV (Wechsler, 2005) implemented in this study included the Index of processing speed PSI (Coding and symbols searching). In coding, the participant is required to transcribe a digit-symbol code as quickly as possible for 2 min. In symbol searching, the participant is asked to decide whether target symbols appear in a row of symbols or not. These subscales were used to assess processing speed. The average internal consistency coefficient for PSI is 0.88.

Inhibition and vigilance through go/no-go and stop signal task performance: the Nexxo application provides a score of task performance for inhibition and vigilance for each session according to the number of errors (omissions and commissions) and successes. At the end of the training, the scores for each session in the different blocks are added up to obtain an overall score for the intervention, which is used to as a measure of task performance in inhibition and vigilance for each participant.

Task

Go/No-Go and Stop Signal Tasks

The Nexxo application is based on neuropsychological models known as "go/no-go" and "stop signal" tasks (Shiffrin and Schneider, 1977; Logan, 1994), which involve a suppression of an ongoing response (inhibition), "n-back," a typical task involving the temporary storage, manipulation, and selection of information (Tsujimoto et al., 2007) by deciding whether to make a response or not depending on whether a sequence is fulfilled (working memory), and, vigilance, in which changes are to be detected when only a low rate of relevant stimuli are presented (Sturm, 2008). As there is a low presence of these types of games (n-back) in level 1 of the Nexxo app (i.e., the one used in the study), we excluded them to focus on inhibition and vigilance processes. The game had two different blocks: vigilance vs. inhibition. In the vigilance block, the user had to tap the screen sporadically (differentiating between possible distractors and thus maintaining a state of alertness, also known as "vigilance"), whereas in the inhibition block, the user had to tap very frequently (holding back an automatic response, which is known as "inhibition or self-control"). The mechanics of the game included requirements to touch the screen when a specific stimulus was present, for example: "tap when you see that the figures on the screen are the same." The screen turned green when the user tapped correctly and red when the user tapped incorrectly. The instructor applied compensatory strategies if the user displayed difficulties in carrying out the task.

Figure 1 shows an example of a Nexxo activity.

Each game has a different command and stimulus presentation. In the vigilance block, the rate of target presence was less than 30% (70% no-go probability), whereas in the inhibition block the rate of target presence was over 70% (30% no-go probability). After each game, the participants were shown on the screen how many stars they had received as a reinforcement (0–3 depending on the level of performance). The participants played 30 games divided into two different blocks (15 vigilance games and 15 inhibition games) in the first level. There were 15 session in total (three games per session/each game was done twice) with each session lasting approximately 15 min. Additionally, Nexxo was developed to train processing speed (as the screen transition was set at one second, stimulus processing and the decision to tap or not tap required perceptual-motor agility). The Nexxo application also requires visual and auditory discrimination skills due to the presence of both types of stimuli in the form of targets and distractors (e.g., game V7 level 1 instruction: "tap each time you see a yellow circle with this sound"). Finally, Nexxo records the types of errors committed by the user: commission errors (the user tapped the screen when a response should have been withheld) and omission errors (the user did not tap when a response was required).

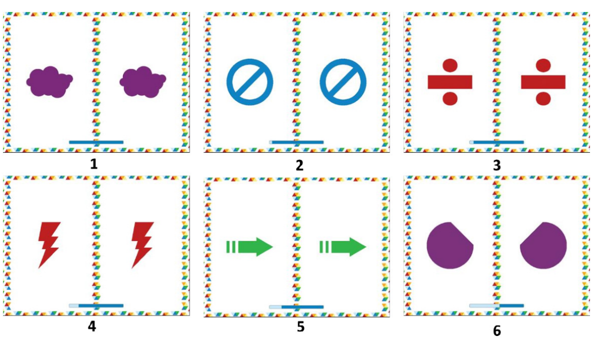

FIGURE 1 | Nexxo activity example. **(2)** Screenshots of inhibition block. Instruction: "tap when you see that the figures on the screen are the same." The user must tap all the screens except the last, where the hold response is required. Transitions between stimulus: 1000 ms. Nexxo 2016. Reproduced with permission of tapp-mobile. Number correspond with the order of stimulus appereance.

Procedural Metacognitive Strategies

The training also involved self-regulatory and self-monitoring strategies inspired by Perez-Hernandez and Capilla (2008), which were directed by the instructor and recorded for each participant in each session, as follows: (1) general instructions (for all participants): an instruction to get ready for the session (the participants had to put their hands over two fixed stickers when they heard "in position" and wait for the instructor to give further instructions), "visual self-instruction" (wait-see-tap), a visual reminder of how to perform the games in order to foster self-control, and verbal self-instructions: "I am a good observer, I do not fall into traps," instructional comprehension/self-instruction (goal setting and planning): the instructor reads the instructions of the game out loud and asks the participants to say when and how they have to tap in each game though fixed questions (e.g., "when do we have to tap?" (the instructor) "we have to tap when..." (the participants) "how are we going to do it?" (the instructor) "we have to wait, see and tap"), and, verbal reinforcement after the games (e.g., "very good"); and (2) compensatory strategies (for participants who presented difficulties while performing the task): individual reinforcement if required (repeating the instruction to get ready, repeating self-instruction, repeating instructions, child verbalizations during the game (saying out loud what appears on the screen), or, in the latter case, instructor verbalizations (saying out loud what appears on the screen), and positive reinforcement through gestures (saying "well done" out loud).

More information about strategies applied can be seen in **Supplementary Material**.

Procedures

The Nexxo-training intervention combines the repetition of EF and attentional tasks in addition to strategies to enhance the tasks. We refer to these strategies as "procedural metacognitive strategies." In addition to general strategies aimed at the whole group, Nexxo-training provides compensatory strategies to individual participants who experience greater difficulties during training. The Nexxo application (go/no-go and stop signal tasks) was designed between 2012 and 2014, and a pilot version was developed for the study in October 2015 (Tapp-Mobile, 2015). Written informed parental consent was obtained from each participant. The participants underwent a neuropsychological assessment conducted by an examiner, which included individual tests to measure intelligence, attention, inhibition and flexibility, working memory, and processing speed. The examiners were trained psychologist who participated in the data collection. The group received a 5-week intervention conducted by a psychologist (groups of eight participants) using a special training script provided by each instructor. The Nexxo intervention was carried out over a 5-week intervention period (two sessions per week/15 min each/three games repeated twice in each session). Regarding inhibition training, a previous study of a go/no go task using a touchscreen application with preschoolers showed a trend-level improvement in reasoning and neural changes in the experimental group after 3 h of training (Liu et al., 2015). This is the reason why we decided to set the Nexxo-training duration at 3 h. The complementary strategies aimed at procedural metacognitive strategies were inspired by Perez-Hernandez and Capilla (2008). The complementary strategies were implemented by an instructor and recorded for each participant. **Figure 2** shows a description of the Nexxo-training.

Data Analysis

Statistical analyses were performed using IBM SPSS Statistics 23. **Table 2** shows the frequency of participants with whom compensatory strategies were used at some point during the

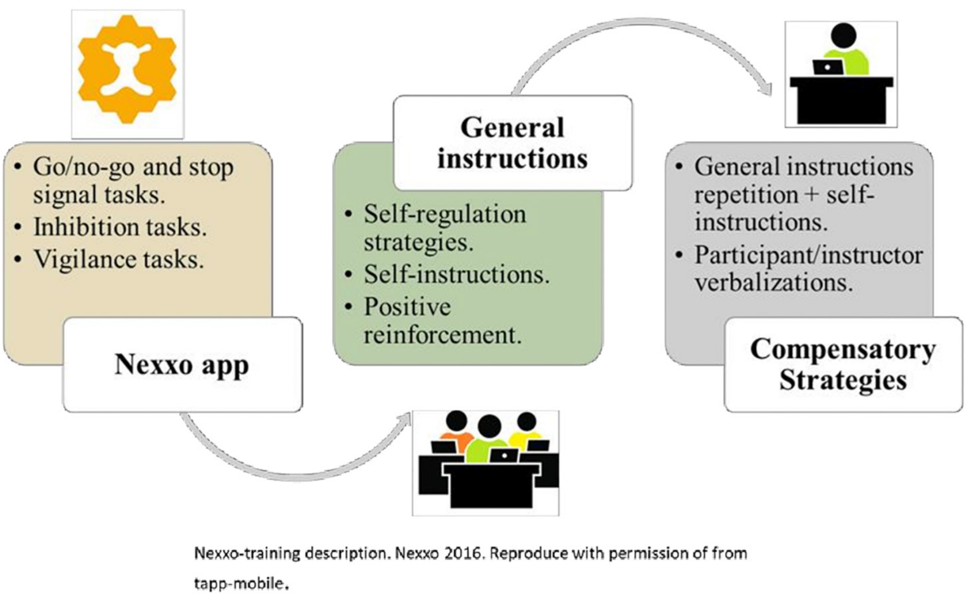

FIGURE 2 | Nexxo-training.

TABLE 2 | Frequency of participants with whom compensatory strategies were used at some point during the training.

	Total *N* (%)	1st grade *n* (%)	3rd grade *n* (%)
Repeat warning to get ready	21 (45.65)	19 (67.86)	2 (11.11)
Repeat self-instructions	13 (28.26)	12 (42.86)	1 (5.56)
Instructional comprehension	35 (76.09)	25 (89.29)	10 (55.56)
Positive reinforcement	2 (4.35)	2 (7.14)	0 (0)
Child verbalizations	26 (56.52)	19 (67.86)	7 (38.89)
Instructor verbalizations	16 (34.78)	11 (39.29)	5 (27.78)
Total set of compensatory strategies	37 (80.43)	26 (92.86)	11 (61.11)

% = percentage.

training. The "positive reinforcement" strategy was excluded from the following analyses because only two used it once.

Table 3 shows the scores in inhibition and vigilance tasks recorded by the Nexxo App, the number of total compensatory strategies applied and recorded by the instructor for children who experienced difficulties during the tasks, and the number of strategies applied of each subtype. These scores were reported for the total sample and, also, separately for the 1st and 3rd grade groups.

For cognitive skills, we used T-scores provided by the instruments, with the exception of FDT since part of our sample was younger than the norm-based scores provided by the instrument. In this case, we calculated T-scores for our sample (1st graders and 3rd graders, separately); the higher the T-score, the lower the FDT performance.

For all the statistical analyses, the significance threshold was set at 0.05. In linear regressions, standardized β and adjusted R^2 are reported.

TABLE 3 | Indicators of performance in inhibition and vigilance, and compensatory strategies.

	Mean	*SD*	Minimum	Maximum
Inhibition				
Total	92.5	5.93	79	100
1st grade	89.82	5.88	79	100
3rd grade	96.78	2.67	91	100
Vigilance				
Total	69.7	14.3	38	97
1st grade	61.79	10.73	38	85
3rd grade	82.11	9.45	60	97
Repeat warning to get ready				
Total	0.674	0.871	0	3
1st grade	1	0.9	0	3
3rd grade	0.17	0.51	0	2
Repeat self-instructions				
Total	0.609	1.42	0	8
1st grade	0.96	1.73	0	7
3rd grade	0.06	0.24	0	1
Instructional comprehension				
Total	2.59	2.29	0	7
1st grade	3.43	2.33	0	8
3rd grade	1.28	1.49	0	4
Child verbalizations				
Total	0.891	1.1	0	5
1st grade	1.18	1.25	0	5
3rd grade	0.44	0.62	0	2
Instructor verbalizations				
Total	0.609	1.11	0	5
1st grade	0.79	1.32	0	5
3rd grade	0.33	0.59	0	2
Total set of compensatory strategies				
Total	5.43	5.39	0	26
1st grade	7.46	5.81	0	26
3rd grade	2.28	2.42	0	8

SD = standard deviation.

RESULTS

Compensatory Strategies and Task Performance

We used partial correlation analysis to detect the possible relation between performance and compensatory strategies, controlling for age (in months) to eliminate possible moderation due to development. After controlling for age, there was a significant correlation between inhibition and vigilance performance: the participants with a higher level of performance in inhibition games also demonstrated a higher level in vigilance games ($r = 0.517$, $p < 0.001$).

The correlations between performance in both types of tasks and compensatory strategies were significantly negative for "repeat self-instructions" and "instructional comprehension" (see **Table 4**), meanwhile they were marginally significant between performance in "vigilance" and "instructor verbalizations" ($r = -0.29$, $p = 0.053$). Those who obtained lower scores in the tasks (either inhibition or vigilance) required more compensatory strategies. **Table 4** shows the correlations between inhibition and vigilance performance and compensatory strategies.

Compensatory Strategies and Task Performance in Relation to Age

Using the participants' age in months as an independent variable in a linear regression showed that age predicts better performance in both inhibition (β = 0.613, $p < 0.001$, adjusted $R^2 = 0.361$) and vigilance (β = 0.706, $p < 0.001$, adjusted $R^2 = 0.487$), with a steeper slope for vigilance: older participants have better results (see **Figure 3**).

Regarding the relation between age (in months) and compensatory strategies, statistically negative correlations were found with the total set of compensatory strategies, and the subtypes "repeat the warning for starting," "instructional comprehension," and "child verbalization" (see **Table 5**).

Cognitive Skills and Task Performance

Stepwise multiple linear regression analysis was used to identify which cognitive skills scales (DIVISA, RIST, WISC and FDT indexes) (independent variables) better predict performance

TABLE 4 | Partial correlation, controlling for age in months, between performance in inhibition and vigilance, and compensatory strategies.

		Repeat warning to get ready	Repeat self-instructions	Instructional comprehension	Child verbalizations	Instructor verbalizations	Total set of compensatory strategies
Inhibition	Pearson's r	−0.229	−0.354*	−0.561***	−0.110	−0.256	−0.475**
	p-value	0.130	0.017	<0.001	0.472	0.090	0.001
Vigilance	Pearson's r	−0.196	−0.362*	−0.342*	−0.073	−0.290	−0.387**
	p-value	0.197	0.014	0.022	0.635	0.053	0.009

*$p < 0.05$, **$p < 0.01$, and ***$p < 0.001$.

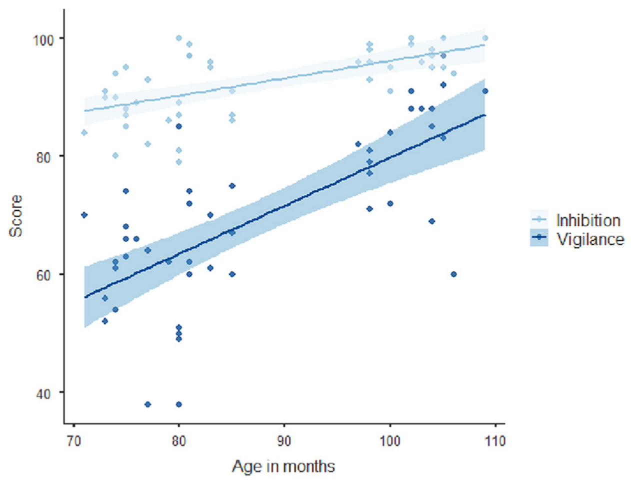

FIGURE 3 | Performance in inhibition and vigilance throughout child development.

in inhibition and vigilance tasks (dependent variables). For inhibition tasks, all the independent variables were non-significant. For vigilance tasks, the results showed that higher scores in odd-item-out from RIST (β = 0.389, p = 0.002) and lower scores in omissions from DIVISA (β = −0.479, p < 0.001) and flexibility from FDT (β = −0.279, p = 0.02) predicted better performance. **Table 6** shows the complete regression model.

To ascertain if this relation is present when comparing children with low and high performance in inhibition and vigilance tasks, the sample was divided into four groups using quartiles. The groups with the best performance (Q1, superior quartile) and worst performance (Q4, inferior quartile) for each task were selected for the analysis (see data in **Table 7**).

Because the sample size of the groups was small, and the normality assumption was not met, a non-parametric Mann–Whitney U test was carried out to compare the differences between the Q1 and Q4 groups. **Tables 8**, **9** show the results for Inhibition and Vigilance, respectively.

Concerning inhibition tasks, no differences were found between the Q1 and Q4 groups in any of the skills assessed. Nevertheless, for vigilance tasks, the scores were significantly higher for Q1 in distraction from DIVISA (U = 18, p = 0.008), odd-item-out subtest (U = 14.5, p = 0.002) and general index (U = 29.5, p = 0.024) from RIST, and lower in omissions from DIVISA (U = 22.5, p = 0.021) and flexibility from FDT (U = 33, p = 0.042).

DISCUSSION

Nexxo-training is an innovative strategy-based training for attention and EF. Strategy-based training combines the repetition of a task with strategies (e.g., scaffolding or metacognitive strategies) to improve performance (Morrison and Chein, 2011; Jolles and Crone, 2012). In this study, the Nexxo-training involved computer-based training through "go/no-go" and "stop signal" tasks, in combination with procedural metacognitive strategies for the whole group, adapted to the participants' developmental stage, as well as compensatory strategies for those who presented greater difficulties during the training. The tasks were developed using an application ("Nexxo" iPad application). As touchscreens and applications are appealing to children (Lai et al., 2013), this approach can motivate them to participate in the training. This new training approach has demonstrated positive results in school-age students in terms of attention and EF (Rossignoli-Palomeque et al., unpublished). To our knowledge, this is the first (strategy-based) cognitive training that provides, compensatory strategies for participants who experience greater difficulties. Considering the proportion of participants who required compensatory strategies at some point in the training period (80.43%), it seems that compensatory strategies are relevant over the course of the training process. The most commonly used compensatory strategy was instructional comprehension (76.05%), followed by child verbalizations (56.52%), repeating warning for starting (45.65%), instructor verbalizations (34.78%), repeating of self-instructions (28.26%), and gestures reinforcement (4.35%). Instructional comprehension (i.e., verbalizations of what to do) was the strategy most commonly required by both 1st-grade and 3rd-grade participants. This strategy is fundamental in self-regulated learning (Dina and Efklides, 2009). As shown in **Table 2**, the younger participants displayed a greater need for repeating instructions to get ready (67.86% in 1st grade vs. 11.11% in 3rd grade), child verbalizations (67.86% in 1st grade vs. 38.89% in 3rd grade), and self-instructions (42.86% in 1st grade vs. 5.56% in 3rd grade). These results may be due to a greater development of attentional control and inner speech around the 3rd grade. As suggested by Winsler et al. (2009), inner speech evolves from irrelevant speech to self-directed verbalizations

TABLE 5 | Correlations between age in months and compensatory strategies.

		Repeat warning to get ready	Repeat self-instructions	Instructional comprehension	Child verbalizations	Instructor verbalizations	Total set of compensatory strategies
Age (in months)	Pearson's r	−0.510***	−0.276	−0.484***	−0.329*	−0.174	−0.473***
	p-value	<0.001	0.063	<0.001	0.026	0.248	<0.001

**p < 0.05, **p < 0.01, and ***p < 0.001.*

TABLE 6 | Regression model predicting performance in vigilance.

	Unstandardized coefficients		Standardized coefficient	
	B	**SE**	**β**	***t***
Intercept	79.367	11.072	–	7.168***
DIVISA-R: omissions	−0.199	0.048	−0.479	−4.417***
RIST: odd-item-out	0.46	0.137	0.389	3.356**
FDT flexibility	−0.407	0.167	−0.279	−2.431*
$F(3,38) = 13.11$***, adjusted $R^2 = 0.47$				

**p < 0.05, **p < 0.01, and ***p < 0.001. DIVISA-R = test of simple visual discrimination of trees – revised; RIST = reynold intellectual screening test; FDT = five digit test.*

TABLE 7 | Data from Q1 and Q4 groups for Inhibition and Vigilance performance.

		n	Mean age (months)	SD age (months)	Score	Mean score	*SD* score
Inhibition	Q1	14 (7 M;7 F)	95.07	11.38	≥97	98.6	1.28
	Q4	11 (5 M; 6 F)	78.27	4.41	≤87	84	3
Vigilance	Q1	12 (6 M; 6 F)	101.33	7.34	≥82	87.8	4.37
	Q4	11 (4 M; 7 F)	80.82	9.15	≤60	51.6	7.85

M = Males; F = Females; SD = standard deviation.

that are relevant for the task. Strategy-based attention and EF training with compensatory strategies is a new direction, and further research on attention and EF training should focus on strategies that are more likely to improve task performance and far transfer. Indeed, it is crucial to conduct this type of training research on strategies used by students while performing attention and EF tasks.

Cognitive training should be designed based on neuropsychological models. The Nexxo application is founded on well-known attention and EF paradigms (Shiffrin and Schneider, 1977; Logan, 1994). In addition, the strategies, self-regulation strategies (motor and verbal strategies), instructional comprehension, and self-instruction have been designed considering developmental factors (Vygotsky et al., 1978; Bjorklund and Harnishfeger, 1990). As reviewed in scientific literature, verbal and motor strategies are used by preschoolers to inhibit themselves (Fatzer and Roebers, 2013; Manfra et al., 2014), and internal verbalizations evolve from irrelevant speech (at 2 years of age) to self-directed instructions that are relevant to the tasks (at 8 years of age) (Winsler et al., 2009). Thus, it seems reasonable to use self-directed instructions as a verbal strategy in school-age students in combination with motor strategies for self-control. Finally, Nexxo-training also involves procedural metacognitive strategies, such as self-instruction and instructional comprehension strategies, to promote self-control and attention. As cognition and self-regulation are viewed as an integral unit (Vygotsky et al., 1978), by combining computer-based training in attention and EF with procedural metacognitive strategies selected for the appropriate developmental period, the training will help to improve these processes as they develop naturally. This should be the criteria when selecting the training strategies. Teaching children to control their own behavior can lead to more durable behavioral changes and less dependency on adult supervision (O'Leary and Dubey, 1979). The student's use of procedural metacognitive strategies, such as selection, monitoring, and control of their learning activities, is crucial for their achievement in all learning situations (Zimmerman, 2011). This can be justified by the theoretical overlap between EF and procedural metacognition (Roebers and Feurer, 2016). For this reason, we consider that analyzing strategy-based training is relevant for the increased likelihood of transference and long-term effects. Finally, cognitive training researchers should consider studying strategies that can be applied in attention and EF training at different developmental stages.

In this study, we analyzed the compensatory strategies used by participants experiencing difficulties in EF and attention tasks. In addition, we analyzed the developmental factors and cognitive skills that may modulate EF and attention task performance. This is relevant for the future of attention and EF cognitive training design. First, we found a positive correlation between inhibition and vigilance. This result is supported by previous findings suggesting a relation between the two elements (Lovejoy and Rasmussen, 1990; Corbetta and Shulman, 2002; Friedman and Miyake, 2004; Rebollo and Montiel, 2006; Tirapu Ustárroz, 2012). As inhibition is central to EF (Dempster, 1992), and vigilance is central to attention (Hauke et al., 2011), we believe that the combination of both processes may help to improve more complex subcomponents of attention and EF. The results are consistent with previous findings that connect attention and EF (Lovejoy and Rasmussen, 1990; Pérez-Edgar et al., 2010).

Regarding the procedural metacognitive strategies used during task performance, our analysis showed that those who obtained lower scores in task performance (either inhibition or vigilance) required more compensatory strategies. Compensatory strategies provide a way for participants to adapt to the training. Specifically, the participants with lower inhibition and

TABLE 8 | Mann–Whitney U test in inhibition.

	Q1 Mdn	Q4 Mdn	Mann–Whitney U	*p*-Value
DIVISA-R				
General attention index	3	5	44.5	0.345
Commissions	85	75	55.5	0.841
Omissions	45	85	43	0.299
Organization	50	25	49	0.523
Distraction	15	10	36.5	0.131
RIST				
Guess what	55.5	53	51	0.153
Odd-item-out	54.5	51	70.5	0.721
General intelligence index	107.5	100	62.5	0.427
WISC-IV				
Symbol search	10.5	11	67	0.579
Coding	9.5	10	72.5	0.8
Digit span	12	10	54	0.201
Digit forward	11	11	56	0.229
Digit backward	12.5	12	68.5	0.639
Processing speed index	104.5	104	67.5	0.602
FDT				
Inhibition	45.17	53.30	52	0.171
Flexibility	45.61	50.96	49	0.134

**p < 0.05, **p < 0.01, and ***p < 0.001. Mnd = median; DIVISA-R = test of simple visual discrimination of trees – revised; RIST = reynold intellectual screening test; WISC-IV = wechsler intelligence scale IV; FDT = five digit test.*

TABLE 9 | Mann–Whitney U test in vigilance.

	Q1 Mdn	Q4 Mdn	Mann–Whitney U	*p*-Value
DIVISA-R				
General attention index	10	2.5	28.5	0.058
Commissions	85	88	50	0.723
Omissions	20	89	22.5	0.021*
Organization	35	35	46.5	0.547
Distraction	15	5	18	0.008**
RIST				
Guess what	53	50	57	0.578
Odd-item-out	60	41	14.5	0.002**
General intelligence index	113.5	91	29.5	0.024*
WISC-IV				
Symbol search	10	8	45.5	0.201
Coding	9.5	9	49	0.283
Digit span	12	10	51	0.350
Digit forward	11	11	63	0.847
Digit backward	13	12	46.5	0.226
Processing speed index	106	96	38.5	0.09
FDT				
Inhibition	45.57	54.97	40	0.109
Flexibility	44.49	50.96	33	0.042*

**p < 0.05, **p < 0.01, and ***p < 0.001. Mnd = median; DIVISA-R = test of simple visual discrimination of trees – revised; RIST = reynold intellectual screening test; WISC-IV = wechsler intelligence scale IV; FDT = five digit test.*

vigilance scores in the application required more instructional comprehension as a compensatory strategy. Similarly, those with lower task performance and a higher number of omissions in the DIVISA-R test (Santacreu et al., 2010), which is related to inattention, depended more on the instructional comprehension strategy. As mentioned above, instructional comprehension and self-instruction strategy can help participants to establish a goal, plan and monitor task performance (Dina and Efklides, 2009). Moreover, repeating instructions helps to overcome difficulties in working memory (Baddeley, 1992). This finding is robust considering the effectiveness that self-instruction has shown in students with difficulties in attention and EF, such as ADHD (Harris et al., 2004; Gawrilow and Gollwitzer, 2008). For these participants, repeating instructions using self-instruction and goal setting was fundamental. Future strategy-based training designs for attention and EF should consider these findings.

One of the objectives of the study was to analyze the influence of age in task performance in order to identify the appropriate age for Nexxo-training. As hypothesized, the older participants obtained better results in inhibition and vigilance tasks; therefore, age moderates task performance. This may be due to neuropsychological changes that occur during child development (Duncan and Owen, 2000; Collette et al., 2005). In terms of inhibition performance using go/no-go tasks for assessment, it seems that there is an improvement in response inhibition abilities moderated by age (Becker et al., 1987; Lewis et al., 2017a), which makes this period relevant. In this regard, our finding is consistent with previous scientific literature. Furthermore, age moderates the use of strategies, as statically negative correlations were found with the total set of compensatory strategies, and the subtypes ("repeat the warning for starting," "comprehension instructions," and "child verbalization"). This finding is consistent with the progressive development of verbal strategies and self-instruction (Vygotsky et al., 1978; Bjorklund and Harnishfeger, 1990). According to these findings, and, consistent with our results, using this type of training with children up to the age of 8 years old seems ideal.

Regarding cognitive skills and task performance, our results shows that higher scores in RIST odd-item-out (fluid intelligence), and lower levels of Omissions in DIVISA (attention test) and in FDT flexibility (cognitive flexibility) predicts better results in vigilance tasks. Recent research shows that working memory, inhibition and shifting, the main components of EF, contribute substantially to general intellectual ability, especially fluid intelligence (Chen et al., 2019). Meanwhile, the parietal and frontal areas involved in EF have also been related to fluid intelligence (Tschentscher et al., 2017; Yoon et al., 2017). Consequently, based on this idea, we analyzed the relation between inhibition and vigilance task performance with fluid intelligence. Our results show that fluid intelligence predicts better results in vigilance. Vigilance tasks require attentional control which is related to inhibitory control. We also found that participants with higher levels of performance in vigilance also obtained higher scores in fluid intelligence. Previous findings have suggested a relation between vigilance and intelligence in children at risk of learning disabilities (Swanson and Cooney, 1989). In this sense, we must add that intelligence benefits vigilance performance. In terms of attention, our results show that the participants with fewer omissions and a lower level of distractibility in neuropsychological tests had better results in vigilance task (after training). As demonstrated in previous studies, omissions and distractibility can be predictors of go/no-go performance (Lewis et al., 2017b). In our view, the fact that lower levels of omissions in the DIVISA-R test is related to better performance in vigilance, is a result which provides validity to the training. Finally, as regards the relation between cognitive flexibility and attention, we consider that cognitive flexibility has a positive influence on vigilance tasks as the instructions change for each game. The transition from one rule (e.g., "tap each time a bear appears on the screen) to another (e.g., "tap when you see the number 5") involves not only an alteration in the type of instructions (target and distractors) but also a change from vigilance tasks to inhibition tasks, as both types of games are played in each session. We hypothesize that individuals with higher cognitive flexibility may better adjust their cognitive resources to these changes. A previous study suggested that cognitive flexibility may become a useful tool for vigilance training strategies, as individual differences in cognitive flexibility predicts better results in vigilance tasks (Figueroa and Youmans, 2012). Another possible explanation refers to the idea of flexibility as a predictor of response speed (Deák and Wiseheart, 2015). Go/no-go tasks involve response speed, i.e., a participant with a low response speed may produce a high number of omissions in the task and, as a result, obtain lower levels of vigilance performance. All these examples demonstrate how cognitive processes are interrelated, and, therefore, how training may have a simultaneous impact on multiple processes.

This study has several key strengths. Firstly, it examines a type of strategy-based training in attention and EF functions that provides compensatory strategies adapted to the participant's needs. This is an innovative approach for cognitive training with potential for further research. Secondly, the cognitive training tasks presented in the Nexxo app are based on neuropsychological models (Shiffrin and Schneider, 1977; Logan, 1994). Furthermore, the implemented strategies are based on previous research and have been designed according to the developmental stage at which the training is applied. In this regard, it is important for future strategy-based training designs to consider child developmental factors. In our view, this approach can overcome the limitations of previous cognitive training designs in attention and EF, in terms of generalization and long-term effects (Rossignoli-Palomeque et al., 2018). Thirdly, this analysis has helped to clarify the relevance of instructional comprehension and self-instruction as compensatory strategies. This finding should also be taken into consideration for future training designs. This study reveals that child development moderates inhibition and vigilance performance. In addition, this paper demonstrates that there is a relation between fluid intelligence and vigilance. This finding raises the question of whether intelligence can be improved by training vigilance. However, further research is needed in this area. In addition, our paper shows a relation between inhibition and vigilance. Nevertheless, this study also had certain limitations. For example, as the study did not involve groups of older participants, we could not analyze the feasibility of the strategies in different age groups. In addition, due to a technical limitation, we were unable to include processing speed as a variable in our analysis. Therefore, it would be advantageous to include this variable in future training designs.

Finally, we focused on Nexxo-training with typically developing children. Further research on Nexxo-training should focus on atypically developing children in terms of attention and EF, such as ADHD.

CONCLUSION

Nexxo-training is a specific form of strategy-based training that provides not only general procedural metacognitive strategies for the whole group, but also compensatory strategies for individual participants who experience greater difficulties during the training. Considering the proportion of participants who required compensatory strategies at some point in the training period (80.43%), it seems that compensatory strategies are relevant over the course of the training process. Regarding strategy analysis, instructional comprehension and self-instruction (e.g., goal setting and planning) seem to be the most useful strategies for participants with difficulties in inhibitory and vigilance task performance. Finally, developmental factors moderate task performance, while fluid intelligence and cognitive flexibility is related to vigilance performance.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the manuscript/**Supplementary Files**.

ETHICS STATEMENT

In accordance with the Declaration of Helsinki, written informed parental consent was obtained from each participant. This study was approved by the Ethics Committee of the San Carlos Hospital (*n*°186; 15/315-E) in June 2015.

AUTHOR CONTRIBUTIONS

TR-P conceived the application. TR-P, EP-H, and JG-M conceived, design, and coordinated the experiment. MQ-G involved in the data analysis. TR-P and MQ-G wrote the manuscript. EP-H reviewed the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.02332/full#supplementary-material

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Conflict of Interest: TR-P owns the original idea for the Nexxo application and participated in the design of the Nexxo games. The Nexxo application for iPad is a commercially available app (a free-to-install app with in-app purchases). TR-P is part of the development team for the Nexxo application for iPad.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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BRIEF RESEARCH REPORT
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The Planning of Difficulty Curves in an Exergame for Inhibitory Control Stimulation in a School Intervention Program: A Pilot Study

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Apollo & Rosetta is an Exergame developed for Inhibitory Control stimulation in Elementary School children. This works' goal has been to demonstrate the behavior of the difficulty curves planned for seven activities (minigames) ingame, as well as their correspondence with the variables collected during a pilot neuropsychological intervention. Seven students participated in the study and played the minigames 1528 times during the 3-month intervention. Each of the minigames had a difficulty curve computed with the goal of keeping the players in the state of Flow. The curves were designed in cycles which grow throughout levels (Normal Level) to a peak (Peak Level), followed by a rest period (Rest Level). The pilot study encompassed three different analyses: (1) Exploratory performance analysis with Spearman correlation, which indicated a positive and significant general correlation between performance and level difficulty; (2) Success exploratory analysis, which showed that as the stages progressed, the success rate increased, even if the level difficulty also increased; (3) Analysis of the factors which influenced performance, through Mixed Effects Logistic Regression and the Backward method. This analysis demonstrated that the odds ratio for overcoming challenges between Normal levels was 0.71 [0.59;0.86] times lower than Rest Level (p-value = 0.000), whereas in Peak levels it was 0.62 [0.47;0.83] times lower than Rest level values (p-value = 0.001). These data confirm the overall planned behavior of the difficulty curves.

Keywords: digital games, difficulty curve, Inhibitory Control, exergames, Apollo & Rosetta

INTRODUCTION

Executive Functions are the most complex cognitive abilities that manage control-demanding tasks and are essential for thoughts and behavior regulation in order to achieve goals (Friedman and Miyake, 2017). Inhibitory Control (IC), one of the components of Executive Functions, is the ability to perform behavior control, and also to stop inappropriate actions/behaviors. It allows a person to choose how to react and behave in a given situation (Miyake et al., 2000; Carlson and Wang, 2007; Diamond, 2013, 2015). Self-control (Zelazo, 2015) and emotional understanding of oneself and of others are also associated with IC (Rueda and Paz-Alonzo, 2013). IC is also known to be related to students' academic performance (Brock et al., 2009; Visu-Petra et al., 2011). Furthermore, children with Attention Deficit Hyperactivity Disorder (ADHD) have impairments concerning IC (Salum et al., 2014). Currently, difficulties have been found in the reproduction of research results related to the use of computer programs, such as digital games, for IC stimulation. This demonstrates the need for further evidence-based investigation (Diamond and Lee, 2011; Diamond and Ling, 2016).

This article presents a study about the computation of difficulty curves (DC) for an exergame designed for IC stimulation. Exergames are computer programs in which the body is the element of interaction between the player and the game (Staiano and Calvert, 2011). Our goal here has been to design DCs that would keep the players in the state of Flow (Csikszentmihalyi, 2014), a condition achieved when people are fully focused on their activities.

The exergame, called *The Incredible Adventures of Apollo & Rosetta in Space* (A&R) (Mossmann et al., 2017), is tailored to Elementary School children. Seven different activities (minigames) in the game allow the player to deal with different IC stimulation events. Each activity presents a specific DC designed to generate a gradual increase in executive difficulties. It also presents challenges in order to balance cognitive stimulation, fun, engagement, and physical fatigue.

This article explains the design and implementation of a model for the computation of the exergame's DCs. It also presents the results of a pilot neuropsychological intervention that took place in a school environment.

APOLLO & ROSETTA (A&R)

Apollo & Rosetta was designed as an exergame for the IC stimulation, conceived and developed by a multidisciplinary team and evaluated by specialists from the EF field. The ludic narrative developed in the game has a space fiction theme designed for Elementary schoolchildren. Each of the seven activities in the game, structured as minigames, was created to perform different types of IC stimulation, as detailed in Mossmann et al. (2017). The activities were divided into three groups:

> *Seriated activities:* (1) **Jumping Asteroids** is a game in which the player sees four asteroids and must jump over a colored pair, which changes color in each round. If the color matches those in a list, the player must not step on the colored pair anymore. (2) **Deciphering codes** is a game in which the player must place his/her hands or feet on the specified places. However, a character may occasionally say a word, which is a determinant of whether the player should keep doing the same or perform another movement.
>
> *Activities with distractors:* (3) **Explorer**, a game in which the player must move laterally to guide the character in a path, and collect what is indicated in a list while collectible items and distractors, that must be dodged, arise; (4) **Stellar Laboratory** is a game in which, using one's feet and hands, one must collect colored and numbered items that match the corresponding colored and numbered buttons on the screen; (5) **Challenge of the Opposites** is a game in which the player must collect items using his/her hands or feet. The player is guided by sound instructions and, at any given moment, he/she must do the opposite of what is instructed.
>
> *Prepotent motor response inhibition activities:* (6) **Particle Accelerator Tunnel**, in which the player must move laterally to dodge obstacles and, at any given moment, move in a direction that is contrary to the usual; and (7) **Galactic Art**, in which the player must hit colored flying balls with his/her hand, and refrain from action when they are white/black. In addition, the player must attempt to scare away space flies that occasionally invade the screen.

Development and Quantification of the Difficulty Curves

Apollo & Rosetta was developed according to the Flow model (Csikszentmihalyi, 2014) to increase children's fun and consequently their engagement in the game. The Flow state is reached when people are fully focused on their current activity, enabling them to achieve their top performance level. For this state to be achieved there needs to be a balance between the challenge and the person's ability to carry out the given activity. In the context of games, this theory has been used by game designers in an attempt to create engaging games (Cowley et al., 2008).

Among the existing techniques to develop a game with a balanced DC, Schell (2008) states that the difficulty must be increased progressively each time the player performs a successful action. A&R employed a variation of a methodology commonly used in the digital game industry (Schell, 2008; McMillan, 2013), which consists of assigning numerical variables related to the difficulty level and the quantification of the execution of the existing game mechanics[1] (GM).

During the development of the A&R game, evaluation steps were carried out to evaluate its gameplay and usability (Mossmann et al., 2017), in which the priority was to collect information based on the assumptions of the Flow model. The data collected in the sessions indicated aspects that could control as well as contribute to a balanced experience between the challenges presented and the individual's ability (Cowley et al., 2008). Cycles of nine levels were designed for the functioning of the curve, as detailed in section "Model Application."

The operation of the DC has been based on a numerical scale varying from 0 to 10. On this scale, each GM received a value related to its difficulty, respecting the fact that the sum of the values assigned to all the GM had to be 10. Thus, the recurrence of each GM and the effort required to overcome each challenge is what varies among the levels, so that the game designer may compute, manipulate, and extend the DC as much as desirable.

[1] Game Mechanics (GM): possibilities, behaviors, and elements for the player to interact and overcome challenges in a determined game (Hunicke et al., 2004), e.g., in a car racing game, the player can accelerate, brake, and orientate the car. Each of these are the fundamental GM for the player to drive. However, other GM could add difficulty, such as rainy or desert races.

Therefore, a different weight was attributed to each GM related to the activity. Then, to design the difficulty of a level, a value was assigned to each GM, according to the following equation:

$$d = w * y$$

$$TD = d1 + d2 + \ldots + dn$$

while d is the difficulty of a given GM, w is the representative weight of that difficulty, and y is the intensity in which the GM will be present at the game level. In this context, the level of a game is composed of a sequence of GM. Therefore, the difficulty must be the sum of all the GM (d) that make up a certain level, while the Total Difficulty (TD) is the result of this sum.

Model Application

To explain the model of difficulty quantification, the minigame *Particle Accelerator Tunnel* is used as an example. The purpose of this activity is to guide (1) the character through a tunnel, as the player moves his/her body to the right or to the left. Throughout the tunnel, there are obstacles that the player must dodge (2). Thus, the player must guide the character, preventing his collision with the obstacles on the way. There are two view modes ingame: In the first one, the game character appears on his back, so the player's laterality coincides with that of the character's. In the second one, the camera rotates, giving the player a frontal view (3) of the character for a few seconds. Therefore, the player must guide (4) the character having as reference his/her laterality (the player's left side is the character's right side, and the player's right side is the character's left side), inhibiting the tendency to move in the usual way to avoid obstacles (Mossmann et al., 2017). These GM were separated as follows:

- Speed (1): Character's speed.
- Obstacle Quantity (2): the number of dodgeable obstacles generated in the level.
- Inverted Camera Distance (3): the distance between the camera and the character, which increases according to his/her speed.
- Reverse obstacle quantity (4): the number of obstacles generated during the camera inversion.

Figure 1 shows how the values were distributed in each level type: Normal (1, 2, 3, 4, and 5), Peak (6), and Rest (7, 8, and 9). The last type has a TD value that is lower than those of the Peak type to provide a moment of rest for the player, keeping him as close as possible to the Flow state. Thus, it was crucial to plan the difficulty values according to this tension relief context. **Figure 1** also presents the first cycle of the DC of this minigame. The TD column is computed by multiplying the value of the GM by its weight and adding each result, as in the Level 1 $(1.1 \times 4) + (5 \times 1) + (0.9 \times 2) + (1 \times 3) = 14.2$ (**Supplementary Table 1**), followed by the evolution of the difficulty of the first cycle, demonstrating the peak and the rest levels.

To define the changes in the subsequent cycles, the values from the next cycle (level 10 – the first level of the second cycle) are increased, so that it has a TD greater than or equal to level 6 (the peak of the previous cycle). These relationships were created to standardize the curve's behavior.

MATERIALS AND METHODS

The design of the A&R school intervention as a pilot study followed a cross-sectional approach (Shaughnessy et al., 2012). The pilot study was carried out in a private school located in Novo Hamburgo (Rio Grande do Sul, Brazil), both school and participants were selected by convenience sampling. The game activities were conducted out of the class hours so as not to interfere with the students' curricular activities. The exergame was used by elementary school children. A total of seven participants joined the study and played a total of 1528 rounds ($n = 1528$) of the game. The school intervention program was carried out in 25 sessions of 20 min, three times a week for 3 months. While using the game, some variables were collected and stored by the game itself.

The application setup was composed of an individually prepared room for each participant, with Kinect 360 for Windows® connected to a Windows 7 laptop, and the A&R exergame pre-installed. The game was displayed through a projector on a big screen. A research assistant was available to help the participants in every session.

Participants

The inclusion criteria for participants were: absence of genetic, psychiatric or neurological disorders; absence of uncorrected sensory disabilities; hadn't scored below the 25th percentile in the Raven Colored Progressive Matrices test (Portuguese translated version – Angelini et al., 1999).

Only students who attended more than 70% of the game sessions had their data collected and taken for analysis. According to this rule, no child was excluded from the sample. Ethical aspects were also considered in the project, which was submitted and approved by the university's ethics committee. The children's parents also authorized their participation in the research. The participants were composed of five boys and two girls with a mean age of 7.86 (1.46) years old. The average socioeconomic status of the participants was classified as B1 (ABEP, 2014). Three children were in their first year of primary school, whereas two were in their third year of primary school. The other two were in the fourth year of primary school.

Instruments

The following data from the participants were stored during the pilot study: Name, sex, age, and school year. Moreover, data related to the game use were collected, namely: activity, timestamp, level type, and performance. All variables were considered in the analyses.

To evaluate the association of quantitative variables with performance, Spearman's correlation (Hollander and Wolfe, 1999) was used, and Mixed Effects Logistic Regression (Fitzmaurice et al., 2011) was employed to identify aspects that influenced performance, with the subsequent use of the Backward method (Efroymson, 1960) for the selection of the significant variables. The analyses based on the data were the following:

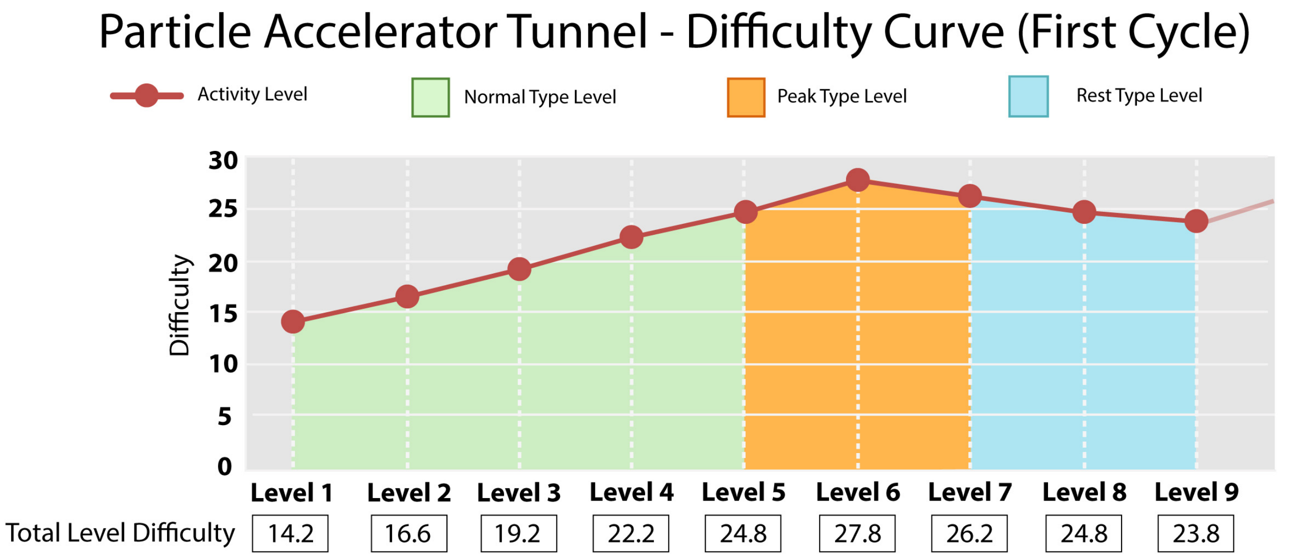

FIGURE 1 | Graph representing the evolution of difficulty of the first cycle (nine levels) of the Particle Accelerator Tunnel minigame. Activity levels and DCs are represented in a reddish color. The graph starts at "14.2" due to the sum of the player's required GM at the given level, considering level 1 as the minimum and initial value of a DC. Normal level types, on which the difficulty has a gradual increase, are pictured in the green range for five levels. The peak level type is represented in the orange range at the sixth level and always follows the growth interval and precedes the rest interval. The resting level types are characterized by the gradual decrease of the difficulty of the three levels – represented in the blue interval – after the maximum difficulty of that cycle and precede the next cycle, which maintains the growth pattern of the DC detailed here.

1. Exploratory analysis of students' performance, which aims at evaluating the performance of the participants in the activities, as well as the average performance in each minigame and each level type.
2. Exploratory analysis of success, which aims at identifying the chances of participants to succeed in each level type based on descriptive analysis.
3. Analysis of the influencing factors on student's performances during the activities, using Mixed Effects Logistic Regression to verify the dependent variables and random effects, applying the Backward method to select the significant variables.

ANALYSES AND RESULTS

Within the exploratory analyses of the variables of interest, the performance of the students is considered to have a number between 0 and 1, with 0 being the lowest value and 1 the highest. Therefore, a performance of 0.90 indicates the overcoming of 90% of the challenges in a certain level of the game.

Exploratory Performance and Success Probability Analysis

For the exploratory performance analysis of the seven participants in the 1528 rounds played, Spearman's correlation between performance and difficulty levels for each activity was: **Galactic Art** (**Figure 2A**) (n = 144) (r = 0.25, p-value = 0.002); **Challenge of the Cosmic Opposites** (**Figure 2C**) (n = 171) (r = 0.15, p-value = 0.051); **Explorer** (**Figure 2D**) (n = 283) (r = 0.17, p-value = 0.003); **Stellar Laboratory** (**Figure 2E**) (n = 280) (r = 0.33, p-value = 0.000); **Jumping Asteroids** (**Figure 2F**) (n = 214) (r = 0.56, p-value = 0.000); **Particle Accelerator Tunnel** (**Figure 2G**) (n = 250) (r = 0.19, p-value = 0.003); and **Deciphering Codes** (**Figure 2B**) (n = 186) (r = 0.11, p-value = 0.148).

In general, the correlation between performance and difficulty was significant and positive, which means that the greater the difficulty, the greater the performance of the player. It is important to emphasize that the first stages, from levels 1 to 9 in **Figure 2**, presented some below-average performance values, which may have been produced because the children were learning to play a new game.

An exploratory analysis of the variables of interest concerning the students' probability of success in the activities was also carried out. In this context, whenever the player reached the performance of at least 70% in a certain level, he would win. Hence, each level had an associated difficulty, for which success was a binary information (value = 1[successful]; value = 0[unsuccessful]). **Figure 3** shows that in most activities it was possible to observe that the initial levels had a low success rate and, as the player advanced in the stages, the success rate increased, even if the difficulty level also increased. Thus, one can infer that the player was progressively learning to overcome the challenges presented in the minigame.

Analysis of the Factors That Influenced the Player's Performance

Mixed Effects Logistic Regression (Fitzmaurice et al., 2011) was used to identify variables that influenced performance of

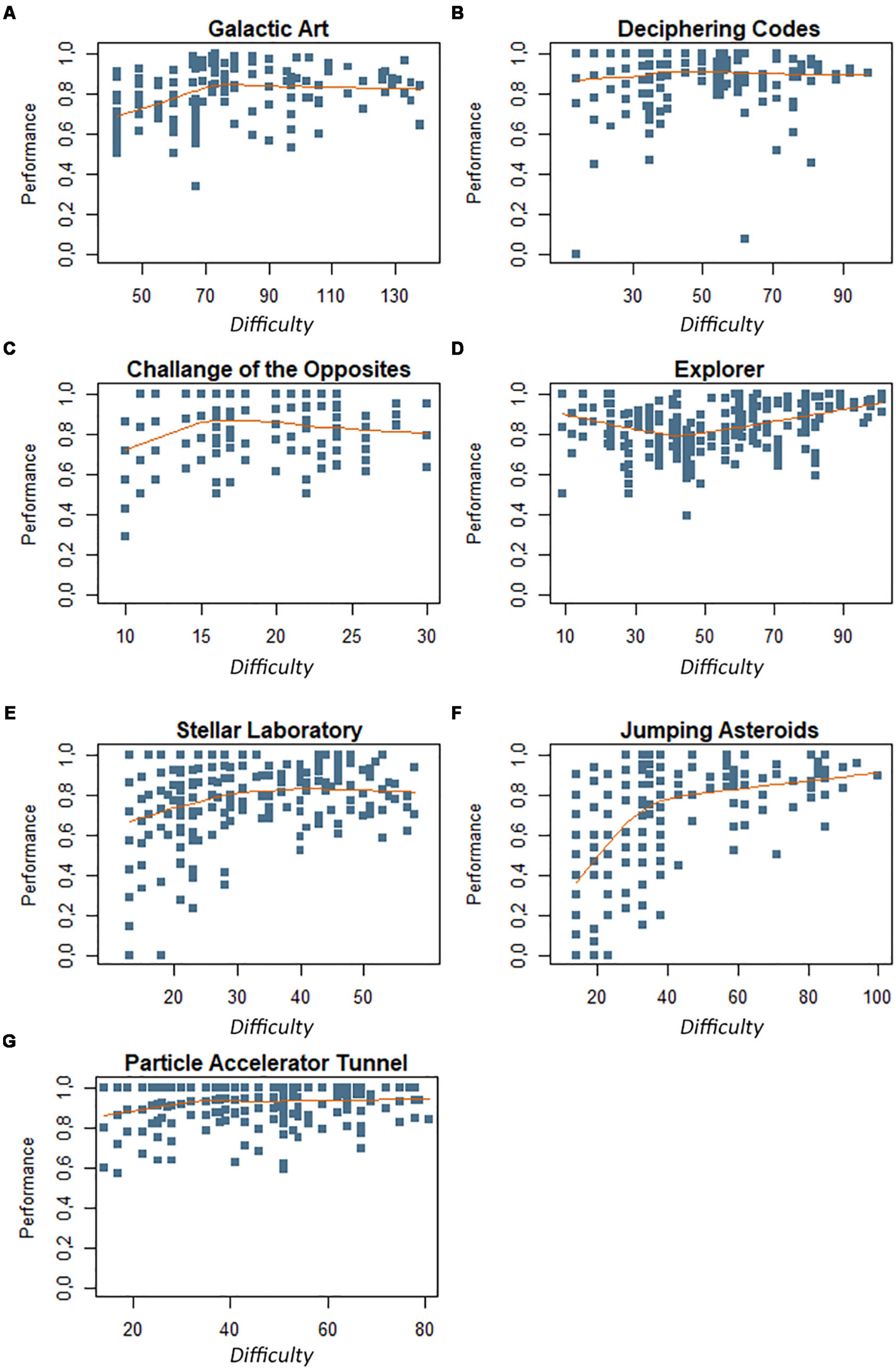

FIGURE 2 | (A–G) Performance concerning the difficulty of the activities. The participant's performance registered by the game is depicted in the orange range. Each activity level is represented by its inherent difficulty in the lower row, e.g., Level 1 of the Particle Accelerator Tunnel activity has a total of 14.2 difficulties, hence all the blue squares in that column represent the performance of the participants in that level. The orange line represents the average participant's performance. It is noteworthy that more than one participant performance is registered in a single blue square.

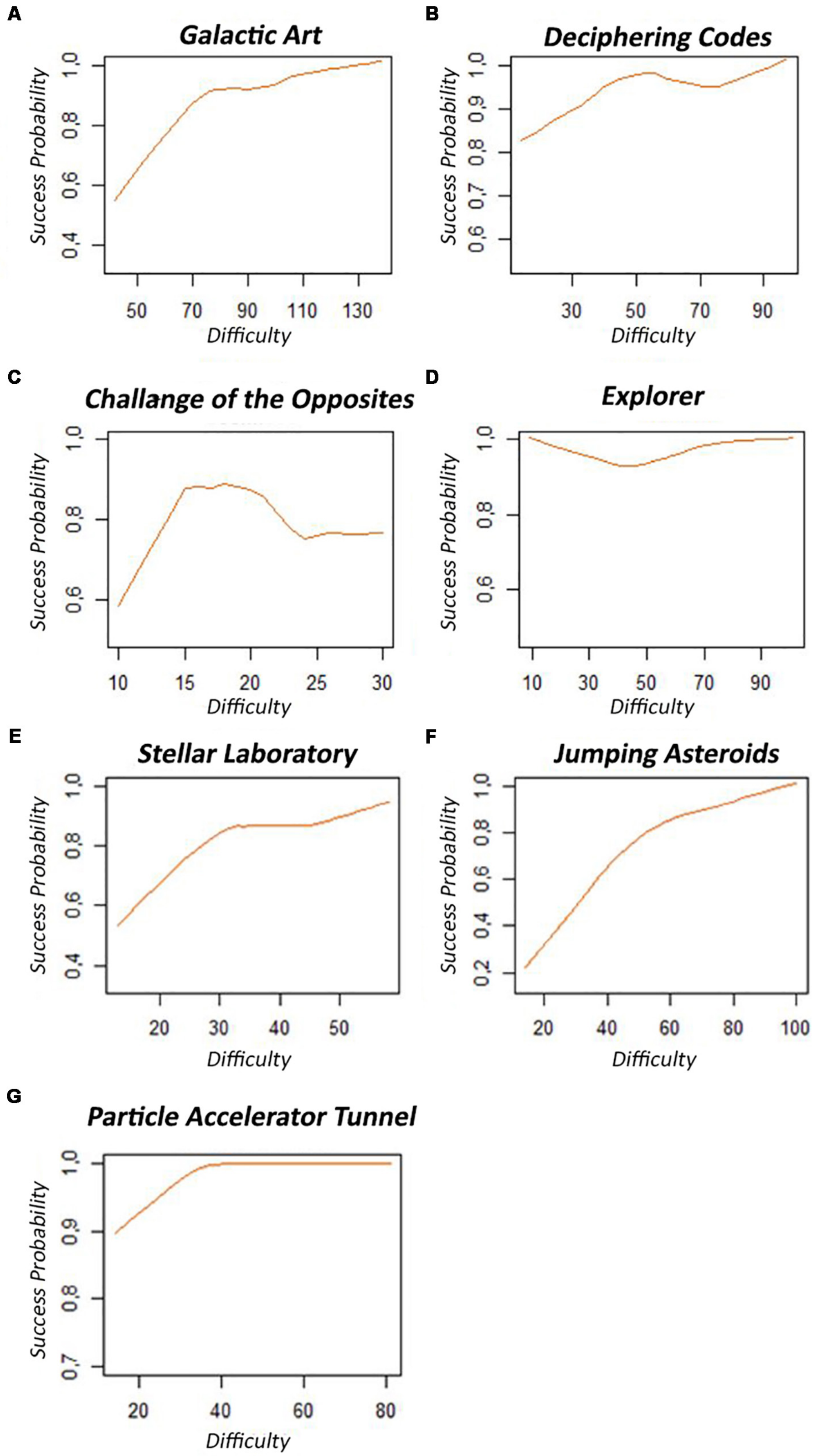

FIGURE 3 | (A–G) Difficulty related to the probability of success for each minigame. Each activity level is represented by its inherent difficulty in the lower row, and the success probability in that difficulty is depicted as the orange line until the last player entry registered in the game.

the seven participants in the 1528 rounds played, considering student data (age, sex, school year), game level, and the difficulty associated with each level of the minigames. Subsequently, the Backward method was applied (Efroymson, 1960), which identified as significantly influential in the performance the following: school year and game level, as shown in **Table 1**. A 5% significance level was adopted for the Backward method. R software was used.

Table 1 shows that there was a significant difference (p-value = 0.001) between the **Peak** level type compared to the **Rest** level type, considering students with similar capacity who played the same game at the same level. The performances in the **Peak** level type were lower when compared to the **Rest** level type since the students who were in the **Peak** level type had a chance 0.62 times lower to match the challenge predicted in the level type than the students who were in the **Rest** level type (0.47;0.83). The **Normal** level type differed significantly (p-value = 0.000) from the **Rest** type. Students who played the **Normal** level type had a 0.71 times lower chance to succeed in predicted challenges than the students who played the **Rest** level type (0.59;0.86). Therefore, the performance in the **Normal** level type was lower when compared to the **Rest** level type.

These findings confirm the planned behavior of the DCs depicted in **Figure 1**. The controlled difference of the difficulties allowed the presentation and regulation of the type and number of challenges that the student had to face in each level of the activities. Thus, the alternation between the level types (Normal/Peak/Rest) helped the players to avoid the comfort zone. This can be observed in **Table 1** Chance Ratio of accomplishing tasks in the Rest type levels, which were higher when compared to the Normal and Peak level types.

DISCUSSION

As presented in section "Development and Quantification of the Difficulty Curves," different criteria had been established to model the DC and make the game more attractive, engaging, and fun, proposing challenges that matched the players' skills. It is important to highlight the relevance of computing the DCs during the game development process as the difficulties must be assessed and their weights assigned according to the GM (Schell, 2008; McMillan, 2013). Thus, considering that the GM and their complexities change from game to game, the definition and assignment of values for the curves must be tested by game designers, specialists and more importantly, the target audience, to validate the GM's weights. The evaluation stage mentioned in section "Development and Quantification of the Difficulty Curves" (Mossmann et al., 2017) also contributed to present the player with new and more complex challenges considering his/her previous learning, thus, producing a cyclic (periodic) balance between challenge and skills (Cowley et al., 2008). As indicated by the pilot study results, most of the DCs showed a significant and positive Spearman correlation between the difficulty levels and the participants' performance. Therefore, the minigames in A&R may produce an environment that favors the player to reach the Flow state, which is desirable in games for IC stimulation designed for children.

The minigames were composed of different challenges and difficulties lined by rules so that it presented the player with challenges that they were able to overcome. This feature for conducting the player to the Flow state was described by Cowley et al. (2008) and was implemented here according to the details presented in section "Model Application."

Furthermore, there must be a balance between the challenges presented in the game and the person's ability to overcome these challenges (Schell, 2008). The players are expected to practice and exercise the tasks in the game throughout the game levels, thereby perfecting their skills and learning to overcome challenges (McMillan, 2013). Thus, while going through each game level, the students improved their abilities. As the level difficulties increased, the players' performances also improved, according to the general positive Spearman's correlation computed.

Cowley et al. (2008) indicated that the DC of a game must establish a link between the player's (intrinsic) ability and the external challenges inherent to the game (extrinsic to the player). Besides, the player must be (intrinsically) interested, willing and able to learn and improve his skills. This must match the game system, which must be designed to identify the player's skills, presenting challenges that are consonant to each player (Schell, 2008). To offer the children appropriate challenges, the minigames developed in this research were planned to have increasing difficulty levels and no final stage. Thus, if the player demonstrated abilities greater than the challenge, he could quickly go through the easier levels and find the appropriate challenges at advanced levels. According to the data in **Table 1**, students in higher school years were able to overcome the initial challenges more quickly and could face challenges consistent with their skills at advanced levels, since the DCs presented increasingly difficult challenges.

TABLE 1 | Mixed effects logistic regression for performance.

Variables	Final model		
	p-value	OR	CI – 95%
Age	–	–	–
Sex: Girls	–	–	–
Sex: Boys	–	–	–
School grade: first grade	–	1	–
School grade: third grade	0.078	1.46	[0.96;2.21]
School grade: fourth grade	0.000	2.39	[1.57;3.63]
Type: Rest	–	1	–
Type: Normal	0.000	0.71	[0.59;0.86]
Type: Peak	0.001	0.62	[0.47;0.83]

The OR columns stand for Chance Ratio, that is, the ratio between the possibility of an event to occur in one group and the possibility of the same event to occur in another group. The CI – 95% column (95% Confidence Interval) ensures that the estimated parameter is within this range in other samples from the same population.

Nevertheless, further experimental investigations are needed to estimate if the DCs planned in this study can be adapted considering the results obtained according to the players' school year (**Table 1**).

Furthermore, the graphs in **Figure 3** illustrated the success probability of a minigame. They show that, in general, the greater the difficulty, the greater the expectation of success. Therefore, the students improved their abilities by playing through subsequent game levels, which increased their chances of success. The same result was found in Spearman's correlation of performance data, shown in **Figure 2**. Accordingly, the challenges were relevant to the improvement of the player's ability.

The DCs planned for the minigames worked as expected in general, enabling the selection of more complex challenges considering the player's previous learning phase. This made it possible to keep a balance between the challenges and the children's abilities shown in varying level types (Normal/Peak/Rest) as explained in **Figure 1**. The model presented in **Table 1** shows that the players had a worse performance in the Peak level when compared to the Rest level, as the chance ratio to succeed the challenges in the Peak levels was smaller than in the Rest stages. Furthermore, the Normal levels also presented lower chance ratios to succeed in the challenges when compared to the Rest levels.

Ultimately, the DCs of the game achieved satisfactory results in terms of players' performance and success based on the previous game evaluation. That demonstrates the children's understanding of the activities and their evolution in the cognitive stimulation activities, previously approved by neuropsychology experts. The performance of the DCs in the activities allowed the players to engage in the game, which shows the potential of the proposed approach for the development of digital games tailored to IC stimulation in the future.

To enhance their cognitive stimulation, players must perform tasks that demand and train their executive skills according to their abilities (Cowley et al., 2008). The DCs in a stimulation game require the tasks to be planned in a way that enables the players to continue to have a game experience that does not tend to indifference or anguish, according to the Flow model. Therefore, the main contribution of this work is in the field of game development for cognitive stimulation.

The most important aspects of this research are the following: (a) It contributes to the development of games directed to IC stimulation, with emphasis on the use of the Flow model as a paradigm to influence people's participation in given activities; (b) The study points to an intersection among fields such as neuropsychology, computer science, education, and digital games.

Nevertheless, we are aware that our research may have three limitations: (a) The scope of this article does not address the impacts of pre/post neuropsychological tests performed by the participants, results that will be published in future papers; (b) DCs weren't meant to fit each player, causing a more skilfull player to take longer to reach a challenging level. Concerning the school years, a curve should be considered for each school year in future works to optimize a possible gain in IC; (c) This was a pilot study that involved only seven participants of three different school grades. Future research should focus on different school grades separately, also involving a higher number of participants.

This research was conducted with the aim to contribute to discussions in the field of IC stimulation with digital games, by approaching game design techniques as one of the parameters for the development of stimulation activities. In doing so, the use of the model for the definition of the A&R DCs produced overall satisfactory results in the performance and probability of success with the target audience. Besides, our findings highlight the relevance of games' DCs as cognitive enhancement outcomes in neuropsychological and educational interventions, in addition to standardized neuropsychological tools. Finally, we expect that the development of cognitive stimulation digital games, through the Flow-oriented difficulty computation parameter, makes them more fun, interesting and engaging for their users.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of Resolution CNS 466/12, under the CAAE no. 58350416.0.0000.5336, Research Ethics Committee of the Pontifical Catholic University of Rio Grande do Sul with written informed consent from all subjects and their parents. All subjects gave written informed consent in accordance with the Declaration of Helsinki. The protocol was approved by the Research Ethics Committee of the Pontifical Catholic University of Rio Grande do Sul.

AUTHOR CONTRIBUTIONS

JM, ER, and RF designed the study. JM and RF prepared the experimental materials. JM, RF, ER, and BC carried out the data collection and the statistical analyses. BC wrote the first and second draft of the manuscript. DB, JM, RF, and ER provided revisions and approved the final version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.02271/full#supplementary-material

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Check for updates

Red Light, Purple Light! Results of an Intervention to Promote School Readiness for Children From Low-Income Backgrounds

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Considerable research has examined interventions that facilitate school readiness skills in young children. One intervention, *Red Light, Purple Light Circle Time Games* (RLPL; Tominey and McClelland, 2011; Schmitt et al., 2015), includes music and movement games that aim to foster self-regulation skills. The present study ($N = 157$) focused on children from families with low-income and compared the RLPL intervention (SR) to a revised version of RLPL that included literacy and math content (SR+) and a Business-As-Usual (BAU) control group. In both versions of the intervention, teachers were trained to administer the self-regulation intervention in preschool classrooms with coaching support. Although not statistically significant, children receiving either version of the intervention gained more in self-regulation on the Head-Toes-Knees-Shoulders (HTKS) over the preschool year compared to the BAU group ($\beta = 0.09$, $p = 0.082$, Cohen's $d = 0.31$). Effect sizes were similar to previous studies (Schmitt et al., 2015; Duncan et al., 2018) and translated to a 21% difference in self-regulation over and above the BAU group at post-test. Furthermore, children participating in either version of the intervention gained significantly more in math across the school year compared to children in the BAU group ($\beta = 0.14$; $p = 0.003$, Cohen's $d = 0.38$), which translated to a 24% difference in math over and above the BAU group at post-test. Results were somewhat stronger for the SR+ version, although effect sizes across intervention conditions were comparable. There were no statistically significant differences across groups for literacy skills. Results extend previous research and suggest that the RLPL intervention, which includes an explicit focus on self-regulation through music and movement games, may improve children's self-regulation and math scores over the preschool year.

Keywords: self-regulation, executive function, intervention, school readiness, academic achievement

INTRODUCTION

A disproportionate number of children with low self-regulation and academic skills at kindergarten entry are from families experiencing socioeconomic disadvantage (Evans and Rosenbaum, 2008; Wanless et al., 2011; Blair and Raver, 2015). Given existing school readiness gaps, it is critical to design programs that promote the development of self-regulation skills for children from diverse backgrounds. In recent years, numerous interventions have emerged that include self-regulation as part of more comprehensive programs, many that also include academic skills (e.g., PATHS, Tools of the Mind; Diamond et al., 2007; Domitrovich et al., 2007). Although many of these interventions have shown significant effects in improving aspects of children's self-regulation, few have demonstrated substantive effects on self-regulation and early academic skills (Bierman et al., 2008; Raver et al., 2011), and others demonstrate no effects on self-regulation or academic outcomes (Farran et al., 2013; Morris et al., 2014). Moreover, comprehensive curricula require extensive training to implement with fidelity, which may help explain null, small, and moderate effect sizes. Although aligned with best practices for early childhood, the comprehensive approach to intervention can make it challenging, if not impossible, to determine what part of each program is most effective. In order to accommodate early childhood education programs that are likely to have limited resources and time to commit to professional development, it is critical to develop interventions where the impact of specific components can be tested in order to identify core elements that could be integrated with little time and at low-cost into existing comprehensive early childhood curricula.

The present study evaluated and compared the effectiveness of two versions of a teacher-implemented school readiness intervention called *Red Light, Purple Light Circle Time Games* (RLPL; McClelland and Tominey, 2015). One version of the program was a self-regulation only version (SR), and the other was a self-regulation plus math and reading version (SR+), which was informed by best practices to support reading and math development. Both were designed for teachers to administer in preschool classroom settings. Given the targeted nature of the intervention and that RLPL requires few resources to implement (e.g., materials found in typical early childhood classrooms, half day of professional development), the intervention can feasibly be implemented in classrooms to benefit self-regulation and early academic achievement.

The Development of School Readiness

Self-Regulation

Self-regulation has been conceptualized across disciplines in many ways; however, it is commonly recognized as a multidimensional concept that incorporates emotion, cognition, and behavior (McClelland et al., 2010). The present study focuses on the aspects of self-regulation most relevant in classroom contexts, which are related to three underlying executive function (EF) cognitive processes: working memory, attentional or cognitive flexibility, and inhibitory control (Cameron Ponitz et al., 2009). Working memory refers to the ability to maintain and manipulate information (Gathercole, 2008); attentional or cognitive flexibility is the ability to sustain focus and adapt to changing goals (Rothbart and Posner, 2005); and inhibitory control includes stopping a dominant response in favor of a more appropriate one (Blair, 2003). Although each aspect of EF contributes to academic outcomes, evidence suggests that the integration of working memory, attentional or cognitive flexibility, and inhibitory control in children's overt behavior is important for their success in early classroom contexts (McClelland and Cameron, 2012; Blair and Raver, 2015). In this study, we refer to *self-regulation* to capture children's EF processes in real-world settings. Self-regulation emerges in early childhood and during this period, acquisition of these skills involves various environmental and developmental processes (Blair and Raver, 2015; McClelland et al., 2015). In addition, self-regulation has been shown to be a malleable set of skills that mediate the relation between early risk and academic success (Sektnan et al., 2010). Thus, targeting self-regulation prior to formal schooling may be one way to improve children's school readiness.

Early Math Skills

Early math consists of skills and concepts that build upon one another and include domains such as numeracy (National Mathematics Advisory Panel, 2008; National Research Council [NRC], 2009). Early numeracy is comprised of skills related to counting and cardinality, quantity comparison, numeral knowledge, and more advanced mathematical (or arithmetic) operations (National Mathematics Advisory Panel, 2008; Purpura and Lonigan, 2013). These aspects of numeracy are critical for later mathematics skills according to many international benchmarks (Common Core State Standards Initiative, 2002; National Council of Teachers of Mathematics, 2006; Australia Curriculum Assessment Reporting Authority, 2013; Curriculum Development Council, 2017). Moreover, deficits in early mathematics skills are likely to lead to long-term difficulties (Aunola et al., 2004; Every Child a Chance Trust and KPMG, 2008; National Research Council [NRC], 2009).

Emergent Literacy Skills

Three components of emergent literacy measured in preschool are believed to form the foundation for the acquisition of literacy skills: oral language, phonological awareness, and print knowledge. Oral language is comprised of skills such as word knowledge, vocabulary, and understanding grammatical rules and word order (Storch and Whitehurst, 2002). Phonological awareness refers to children's ability to detect and manipulate language through blending, matching, or removing parts of words (Wagner and Torgesen, 1987). Print knowledge includes children's awareness of basic print conventions (i.e., letter names and sounds; Whitehurst and Lonigan, 1998). Children who enter school with difficulties in emergent literacy skills are likely to experience reading difficulties that persist over time (Storch and Whitehurst, 2002). Moreover, children with low levels of early reading skills are at elevated risk for needing special education services (Lentz, 1988).

Connections Between Self-Regulation and Academic Skills

A large body of research indicates that self-regulation is an important part of academic success in childhood, adolescence, and into adulthood (McClelland et al., 2006, 2007, 2013; Duckworth et al., 2010; Blair and Raver, 2015). In addition to empirical evidence indicating a strong predictive relation between self-regulation and academic achievement, interventions that aim to improve self-regulation have also shown significant effects on children's math and literacy (Tominey and McClelland, 2011; Blair and Raver, 2014; Schmitt et al., 2015; Pandey et al., 2018) suggesting that self-regulation may be an important precursor for early achievement. In addition, children's self-regulation has been found to be especially predictive of early math skills where children have to focus and pay attention, remember and execute step-by-step instructions, and demonstrate self-control, all of which are important for learning math (McClelland et al., 2014; Blair et al., 2015; Purpura et al., 2017). In addition, research suggests that relations between self-regulation and mathematics and literacy may be bidirectional and more complex than previously thought (Fuhs et al., 2014; Schmitt et al., 2017). The bidirectional connections between self-regulation, math, and literacy suggest the promise of an intervention that targets the integration of these skills.

The Role of Socio-Demographic Risk for Self-Regulation, Math, and Literacy

A large body of research documents negative relations between children's socioeconomic risk and children's academic outcomes (e.g., Duncan and Magnuson, 2005). Children from low-income households typically experience more difficulty with the development of math and literacy skills than children from middle-income families (Jordan et al., 1992). Recent work also documents the negative effects on children's self-regulation (e.g., Wanless et al., 2011; Raver et al., 2012). In the United States, ethnic minorities, and particularly Spanish-speaking English language learners (ELLs) are more likely to experience elevated risks, such as poverty and low parent education levels (U. S. Census Bureau, 2011), which may negatively impact children's outcomes. However, research suggests that self-regulation may be an important protective factor for children growing up from disadvantaged backgrounds (Obradovic, 2010; Sektnan et al., 2010). This suggests that promoting self-regulation for children at socio-demographic risk is important for successful learning outcomes in school.

Existing School Readiness Interventions

A number of classroom-based interventions that specifically target self-regulation and early academic skills have demonstrated effectiveness. Examples of interventions include the preschool Promoting Alternative Thinking Strategies (PATHS) curriculum, which focuses on children's problem solving skills, emotional awareness, social-emotional skills and self-control (Greenberg and Kusche, 1993; Kam et al., 2003; Domitrovich et al., 2007). There are also interventions that focus explicitly on improving preschoolers' early math that have been shown to be effective such as Pre-K Mathematics (Starkey et al., 2004; Thomas et al., 2018) and Building Blocks (Clements and Sarama, 2007; Clements and Sarama, 2011). Finally, interventions designed to promote preschoolers' emergent literacy have shown positive effects (Justice and Pullen, 2003; Farver et al., 2009; Justice et al., 2009).

Although these interventions have shown to be successful at improving children's outcomes, they typically require in-depth training, time (for planning/professional development as well as for implementation), materials, and significant expense. Furthermore, many interventions target a range of skills, making it difficult to determine the specific mechanisms that are responsible for observed changes in self-regulation and academic achievement. For example, Head Start REDI (Research-Based, Developmentally Informed), emphasizes literacy, language and social-emotional skills and has been shown to be effective at improving children's self-regulation and academic outcomes (Bierman et al., 2014; Sasser et al., 2017). Another program, Tools of the Mind, also focuses on early literacy and self-regulation with mixed results of its effectiveness (Farran et al., 2013; Blair and Raver, 2014). It is difficult, however, to identify which aspects of these interventions are most effective and none of the interventions reviewed target self-regulation *and* early math and emergent literacy.

Red Light, Purple Light (RLPL) Intervention

The Red Light, Purple Light Intervention (RLPL) is a classroom-based, self-regulation intervention consisting of circle time, music and movement games that have been designed to systematically increase in cognitive complexity over 16 sessions (delivered twice a week for 8 weeks). The games are delivered in a large-group format in 15–20 min sessions (Tominey and McClelland, 2011; McClelland and Tominey, 2015; Schmitt et al., 2015). The games focus on the three aspects of EF (i.e., working memory, attentional or cognitive flexibility, and inhibitory control) and enable children to practice self-regulation in a classroom setting (i.e., children play the games in a large group, such as during circle time).

The intervention consists of five games (one played per session), which are repeated multiple times over the course of the intervention, but with increasing levels of complexity in the variation of the game that is reintroduced. An example of one of the intervention games is *Red Light, Purple Light*, which is a variation of the childhood game Red Light, Green Light. In this game, the teacher acts as a stoplight and holds up different colors of construction paper circles that represent stop and go. The first time the game is introduced, the teacher asks children to respond to green ("go") and red ("stop") circles, with children performing different actions when the teacher holds up green (e.g., stomp, clap, hop) and stopping or freezing when the teacher holds up red. The game increases in complexity where the teacher adds colors (e.g., orange and purple) and children are asked to respond to opposite cues. Children are also given the opportunity to lead, choosing colors and actions for their classmates to respond to.

In the SR+ version of the games, literacy (print knowledge and phonological awareness) and math (counting and cardinality and numerical knowledge) content is embedded into the cues children are asked to respond to. For example, when playing *Red Light, Purple Light*, instead of responding to colors, children are shown a circle with a number written on it. In addition to responding to the color (e.g., clapping when they see blue, stomping when they see orange), children are shown a number card and asked to perform the action as many times as represented on the card (e.g., if teacher holds up a number 4, children clap 4 times, counting from 1–4 together as they clap). When playing the *Sleeping Game*, children pretend to go to sleep when the teacher sings the "Sleeping Song" and then wake up and act out the animal named by the teacher. In the SR+ version of the game, the teacher emphasizes print knowledge and phonological awareness (e.g., "When you wake up, pretend to be the first animal that I say that starts with an 'm.' Snake! Does that start with an 'm?' Mouse!"). In another, teachers show a picture of the animal with the printed word underneath (teachers use pictures in the SR version, but without words). A detailed manual with information about the games and sessions is also given to teachers (see section Materials and Methods).

Like each of the RLPL games, Red Light, Purple Light targets children's EF skills where children have to listen and remember instructions (i.e., working memory), successfully move from one rule to another (i.e., attentional flexibility), and do the opposite as part of a game (i.e., inhibitory control). As the intervention progresses, new games are introduced and games are repeated with additional rules introduced to increase cognitive complexity. In each game, children respond to visual and/or oral cues and are often asked to respond to opposite cues. In the SR+ version of the intervention, the cues children are asked to respond to before choosing their actions relate specifically to literacy or math.

The self-regulation-only (SR) version of the RLPL intervention has been evaluated in two randomized controlled trials (RCTs) administered by researchers in preschool classrooms and one RCT where the games were delivered by teachers (Tominey and McClelland, 2011; Schmitt et al., 2015; Duncan et al., 2018). In one study, participation in the intervention was associated with improvement in self-regulation for children with low initial scores on self-regulation [e.g., a score of zero on the Head-Toes-Knees-Shoulders (HTKS) measure], and gains in literacy for the overall sample in comparison with a control group (Tominey and McClelland, 2011). Results from a larger study with children from disadvantaged backgrounds (i.e., enrolled in Head Start) found that participation in the intervention was significantly related to gains in self-regulation for the overall sample and gains in math for English language learners (Schmitt et al., 2015). In each of these studies, researchers with previous classroom experience led the games in early childhood classroom settings. A recent study examined the RLPL games delivered by teachers and included as part of a summer school readiness program (Duncan et al., 2018). In the RCT part of the study, children who participated in the summer program with RLPL games experienced significant improvement in self-regulation compared to children who participated in the summer program without exposure to RLPL games. There were no significant effects of intervention participation on math or literacy at the end of the program. However, when children were followed into the fall of kindergarten, participation in the summer program with the RLPL intervention was related to greater change in self-regulation, math, and literacy scores from the beginning of the intervention to the fall of kindergarten compared with children's expected development using a separate longitudinal sample.

An important aspect of the RLPL intervention is the focus on ease-of-use and feasibility: the games require little training to implement, few materials (those readily available in early childhood classroom settings), and have been reported to be engaging for children with a range of developmental levels and needs (Tominey and McClelland, 2013). Moreover, the games were developed to be implemented as part of daily activities (i.e., large group time) and embedded in existing classroom curricula.

Theory of Change

Preschool is an ideal time to implement a self-regulation intervention because of the rapid development in the prefrontal cortex, an area associated with self-regulation and EF skills (Blair, 2002). For most children, the preschool classroom is the first early learning environment in which they are asked to demonstrate self-regulation skills. Moreover, preschool is an important time for developing the early math and emergent literacy skills that are related to academic achievement in later elementary and high school (Duncan et al., 2007; Clements and Sarama, 2011).

Conceptually, our theory of change hypothesizes that promoting self-regulation would help children develop skills required to effectively take advantage of learning opportunities, including those that focus on math and literacy. With the added version of the intervention (SR+), the present study tested the idea that embedding academic content would not only help children develop the self-regulation skills needed to benefit from these learning opportunities, but also to extend that learning to those specific learning contexts. The self-regulation games require children to pay attention to, remember, and follow increasingly complex sets of rules through multiple exposure and repeated practice.

In addition to teaching and practicing self-regulation, the SR+ components of the classroom games provide additional complexity and were hypothesized to impact self-regulation more strongly than the SR components alone. For example, given the strong relations between self-regulation and early academic skills, it is possible that targeting these skills together would have the greatest benefit on self-regulation (Duncan et al., 2007). We focused on aspects of early math (counting, cardinality, and numeral knowledge) and emergent literacy (phonological awareness and print knowledge) that are most strongly related to early self-regulation (Purpura et al., 2017). Previous evidence has supported the effectiveness of the intervention on self-regulation and academic outcomes, especially math, in young children (e.g., Tominey and McClelland, 2011; Schmitt et al., 2015). Thus, we anticipated that the self-regulation games would result in significant positive impacts on self-regulation and academic outcomes, particularly math, compared to the BAU delayed intervention group.

The Present Study

The present study evaluated an intervention that explicitly focuses on self-regulation (attentional flexibility, working memory, and inhibitory control) and compared the core curriculum with an enhanced version of the curriculum with embedded early math (counting, cardinality and numeral knowledge) and literacy (phonological awareness and print knowledge) components, given that these skills are foundational for academic success.

In summary, the specific aims of this study were to:

(1) Examine if there are significant effects of the self-regulation intervention (testing for effects of each version of the intervention: SR and SR+) on self-regulation over the preschool year in children from low-income backgrounds.
(2) Examine if there are significant effects of the self-regulation intervention (SR and SR+ versions) on children's academic achievement (early literacy and math skills) over the preschool year.

We compared two versions of the intervention (SR and SR+) with a Business-As-Usual (BAU) delayed intervention group on children's school readiness skills (self-regulation and academic achievement) over the preschool year. One version included the self-regulation games from our previous research (e.g., Tominey and McClelland, 2011; McClelland and Tominey, 2015; Schmitt et al., 2015; SR), and one version (SR+) included enhanced early math and literacy components added to the original self-regulation games. Given the strong relations between early self-regulation and academic achievement (and math in particular), it was possible that targeting these skills together would have the greatest benefit on self-regulation (Duncan et al., 2007). We anticipated that both versions of the intervention would result in significant positive impacts on self-regulation and academic skills, especially math, compared to the BAU delayed intervention group. Further, the SR+ version was expected to lead to stronger effects than the BAU condition or the SR-only intervention on early math and literacy skills because this version explicitly aimed to incorporate mathematical thinking and emergent literacy into the self-regulation games.

MATERIALS AND METHODS

Participants

Children, parents, and teachers for the current study were from a study focused on developing, refining, and testing the promise of a self-regulation intervention. The initial sample consisted of 188 children (52% female) from low-income families who were participating in Head Start, a U.S. preschool program for low-income families. Children were recruited from 13 Head Start classrooms across nine sites in the Pacific Northwest of the United States. Children and families were recruited through consent forms distributed in enrollment packets during the summer prior to the start of preschool.

In the fall of the preschool year (time 1), a total of 188 children were eligible to participate. At time 2 in the spring of the preschool year, 157 children from the initial sample participated. This was an attrition rate of 17%. Children who did not participate in the post-test did not significantly differ from the other children who completed the study in terms of gender, maternal education, English language learner (ELL) status or on any of the measures described below at pre-test ($p > 0.05$), but did differ in terms of age. Children who did not participate in the post-test session were more likely to be younger than children who did participate, $t(184) = 3.10$, $p = 0.002$. All of the analyses described below were conducted using the data from the 157 children who contributed at least partial data at both pre-test and post-test.

Parents' education level ranged from 2 to 17 years ($M = 11.27$, $SD = 2.30$). Children were eligible to participate in the study if they were between the ages of 3–5 and attending, or planning to attend, one of the 13 target classrooms. At pre-test, children had an average age of 51 months (range = 38–62 months, $N = 41$ 3-year-olds, 99 4-year-olds, 17 5-year-olds), and at post-test had an average age of 58 months (range = 44 – 68 months, $N = 12$ 3-year-olds, 80 4-year-olds, 65 5-year-olds).

More than half of the sample of children and families identified as Latino (58%), 26% identified as White, 7% Pacific Islander, 6% African American, and 2% reported other for ethnicity. Information from the consent form (child's home language) identified 62 children (33%) as ELLs. Spanish-speaking research assistants administered the Pre Language Assessment System (preLAS) at pre-test and post-test to determine whether a child should receive direct assessments in English or Spanish (Duncan and De Avila, 1985–1987). If children did not pass the preLAS, and their home language was not Spanish, they were not administered any assessments at that time point ($n = 2$). Eight teachers (all female) across 13 classrooms and seven sites consented to participate. Five teachers had separate morning and afternoon classrooms ($n = 10$ classrooms); three teachers taught in either morning or afternoon ($n = 3$ classrooms).

Procedure

In the fall (pre-test) and spring (post-test) of the preschool year, all direct assessments were administered using trained research assistants. Assessments were given in 10–15 min sessions inside the classroom in a quiet area or in a hallway. All assessments were completed in 2–3 classroom visits, depending on child absences, and the order of assessments was counterbalanced. Children identified as ELL's were assessed by Spanish-speaking research assistants at pre and post-test, whether or not children passed the preLAS. Parents and teachers completed demographic questionnaires.

Pre-test

Direct assessments of self-regulation and early academic achievement were administered to children in the fall of the preschool year.

Intervention

To prevent contamination, block randomization occurred at the teacher level in the winter so that teachers leading more than one classroom (i.e., teachers with a morning and an afternoon class) delivered the same condition in each classroom. Eight teachers were included in the study who were supporting a total of 13 classrooms (half-day classrooms). Five teachers taught across a full day (one morning session; one afternoon session) and three teachers taught half-day only (one morning session or one afternoon session). Of the five full-day teachers, two were randomly assigned to the SR group (2 teachers; 2 classrooms each = 4 classrooms total), two were randomly assigned to the SR+ group (2 teachers; 2 classrooms each = 4 classrooms total), and one was randomly assigned to the control group (1 teacher; 2 classrooms). Of the three half-day teachers, each was randomly assigned to one of the conditions (SR, SR+, and control). In total, five classrooms were assigned to each intervention condition (SR or SR+) and three were randomly assigned to the control. Of the three sites with intervention classrooms, only one site had all classrooms receiving the same condition of the intervention (SR+).

The training of the intervention was consistent aside from the difference in content that included either self-regulation content (SR) or self-regulation with embedded literacy and math content (SR+). Learning goals were created for each of the sessions to demonstrate how session content related to the specific SR or SR+ intervention condition. The SR condition did not include any explicit instruction related to early math or literacy skills so learning goals only related to the three aspects of self-regulation (inhibitory control, attentional flexibility, and working memory). In the SR+ condition learning goals related to those same three components of self-regulation, but also included an explicit focus on emergent literacy skills (e.g., embedding dialogue related to early literacy into game play) and early math skills (e.g., counting together the number of intervention sessions 1 to 16; emphasizing the number of times actions were performed and using spoken numbers to cue children). During the intervention half-day training, teachers were asked not to share information across classrooms or with other teachers.

Teacher training

Intervention classroom teachers (n = 6) attended a half-day training led by two master trainers, one training for SR classrooms, and one for SR+ classrooms held in separate locations. Teachers participating in the SR training learned about the importance of self-regulation in the classroom along with the core elements of the self-regulation intervention and had an opportunity to use their training manual and materials. Teachers participating in the SR+ training received a similar training to the SR classroom, but also received information on embedding math and literacy content into the intervention games.

Intervention implementation

Through an iterative development process working with a set of master teachers, the research team refined the RLPL training materials and classroom kits prior to implementation, including detailed session plans and refinement of fidelity of implementation surveys (i.e., surveys teachers were asked to complete following each session related to implementation). Teachers participating in this RCT received a comprehensive intervention training manual and classroom kit at training. For some classrooms, both lead and assistant teachers were present, however, only lead teachers (unless absent) implemented intervention sessions in the classroom. Following the training, 100% of teachers reported on training evaluation surveys that they agreed or strongly agreed they felt prepared to play the games in their classrooms. Implementation began 1 week after the training, during winter of the preschool year. Teachers implemented the RLPL intervention in their classrooms, twice a week over 8 weeks for 15–20 min during large group circle time. Children in the control classrooms engaged in the daily routines and curricula activities that came before study participation (business-as-usual).

Dosage, Fidelity, and Feasibility of Implementation

To capture dosage of the intervention, teachers completed an attendance sheet after each session (2x a week). Fidelity of implementation was monitored each week through teacher reported daily logs completed at the end of each session. To assess, feasibility, teachers were asked to rate their own and their students' enjoyment of the games played in each session, if the manual and materials were helpful, and overall length, difficulty, and prep time for each session. In addition, all intervention classroom teachers (n = 6) received coaching support and met six times with their coach throughout the intervention implementation. Teachers were coached on three dimensions of implementation fidelity- adherence, quality, and responsiveness. As part of the coaching process, teachers recorded intervention sessions to be reviewed during their one-on-one coaching session the following week. Additionally, over the course of the intervention, 43 videos were collected from intervention and BAU classrooms for the research team to use and code for fidelity. The video coding team attended a 3-h training on video coding processes (i.e., the importance of objectivity) and the coding rubric created by the coaching development team. Coders attended weekly meetings and provided codes on a series of master coded videos to obtain reliability. Once group reliability was achieved, all intervention videos were double coded and consensus codes were used to assess fidelity. These videos were also used to explore the presence of similar self-regulation games in BAU classrooms as well as to code for fidelity of implementation – adherence, quality, and responsiveness across all intervention classrooms.

Post-test

In the spring of the preschool year, the same direct assessments on self-regulation and academic achievement were administered to children. All research assistants were blind to children's treatment and control group participation.

Measures

Parent Demographic Questionnaire

Parents completed a survey in English or Spanish with questions about children's age, gender, child care experiences, health, and parent and family characteristics such as years of education completed, work status, and household size.

Language Screener

The Simon Says and Art Show subtests of the preLAS were used to determine language of assessment. Simon Says is a measure of receptive language and Art Show is a measure of expressive language assessing naming and descriptive vocabulary. These two subtests of the preLAS have been demonstrated to have strong reliability and validity in Spanish-speaking preschool aged children (Rainelli et al., 2017). If children did not pass the preLAS, and parent identified as Spanish-speaking, they were assessed in Spanish.

Direct Measures of Self-Regulation

The Head-Toes-Knees-Shoulders-Revised (HTKS-R) task was used to assess children's self-regulation and taps aspects of attention, working memory, and inhibitory control (McClelland et al., 2014). The task has four sections and is a complex version of the HTKS (McClelland et al., 2014) for children ages 3–8. In the first section, children are asked to say the opposite of what is instructed. In the next section, children are told to touch their head (or toes) when asked to touch their toes (or head). Then, in the following section, both rules are included (head/toes opposite and knees/shoulders opposite). In the last section, children are still doing the opposite, but the rules are switched with different pairings. There were a total of 58 items across the 4 sections. Items are scored 0 for an incorrect response, 1 for a self-corrected response, and 2 for a correct response and overall scores range from 0 to 116. The HTKS-R and HTKS have demonstrated strong reliability and validity in diverse samples around the world including significant relations to other tasks measuring aspects of self-regulation and EF (e.g., Wanless et al., 2011; McClelland et al., 2014). The measure has also been sensitive to intervention effects, showing significant change in response to participation in self-regulation interventions when compared with children in a control group (Tominey and McClelland, 2011; Schmitt et al., 2015; Duncan et al., 2018; Landis et al., 2018; Upshur et al., 2019). In the current sample, the HTKS-R demonstrated adequate to strong internal reliability (Cronbach's $\alpha = 0.96$ at pre-test and 0.97 at post-test).

Children's inhibitory control was assessed using the Day-Night Stroop task (Gerstadt et al., 1994). Children are presented with 16 cards with pictures of a sun or moon and asked to say the opposite (e.g., "day" for a moon and "night" for a sun). The measure has demonstrated strong reliability in research (Rhoades et al., 2009; McClelland et al., 2014). In the current sample, the Day-Night Stroop task demonstrated strong internal reliability (Cronbach's $\alpha = 0.90$ at pre-test and 0.91 at post-test).

Academic Outcomes

Emergent Literacy Skills

The Letter-Word Identification subtest of the Woodcock Johnson Tests of Achievement (Woodcock et al., 2001) or The Batería III Woodcock- Muñoz (Muñoz-Sandoval et al., 2005) was used to assess emergent literacy. Research has shown high reliability and validity ($\alpha > 0.80$) for all of the subtests (Woodcock and Mather, 2000; Schrank et al., 2005). In the present study, *W* scores were used in the analyses, which are standardized based on the average performance for a child at a particular age (Jaffe, 2009). *W* scores are appropriate for emergent literacy skills. The Letter-Word Identification subtest measures children's letter skills and developing word-decoding skills with strong reliability and validity. Reliability for English-speaking preschool children ranges between 0.98–0.99 and 0.84-0.98 for Spanish-speaking children.

Early Math Skills

Children's early math skills were assessed using the Preschool Early Numeracy Skills Screener (PENS; Purpura et al., 2015). This numeracy task consists of 24 items that are ordered by difficulty, progressing from the easiest items to the most difficult. The PENS assesses aspects of numeracy including set comparisons, numeral comparisons, one-to-one correspondences, number order, numeral identification, ordinality, and number combinations. Children receive 1 point for each correct answer. If a child responds incorrectly to three items in a row, the assessment ends. The assessment takes approximately 5 min to administer. In the current sample, the PENS demonstrated adequate internal reliability (Cronbach's $\alpha = 0.91$ at pre-test and 0.92 at post-test).

Control Variables

Children's age in months, gender, parent education in years, ELL status, and baseline self-regulation or academic achievement scores were used as control variables in models. Previous research has shown these variables to be related to children's self-regulation and early academic achievement (Cameron Ponitz et al., 2009; Wanless et al., 2011).

RESULTS

Analytic Strategy

All analyses were conducted using Stata 15.1 (StataCorp, 2017). Due to the hierarchical structure of the data with children nested within different classrooms, we first evaluated whether a multilevel framework was necessary to accurately test the effects of the two versions of the intervention in comparison with a BAU control. The ICCs from the intercept-only models for both the self-regulation outcomes (ICC range:0.02 – 0.05) and the academic outcomes (ICC range: <0.001 – 0.001) were small, but were within a range where accounting for the nested structure of the data is appropriate (Hox et al., 2010). Thus, we utilized clustered robust standard errors for all analyses described below which adjust standard errors for the nested structure of the data.

We ran separate, but parallel analyses for each of the self-regulation and academic outcomes. All models included children's performance at pre-test on the outcome variable, their age, gender, ELL status, and parent level of education when evaluating the effect of the different interventions. For each model, we also utilized an intent to treat (ITT) analysis (Fisher et al., 1990) where children's scores were analyzed as part of their assigned intervention group regardless of whether or not they were present for all aspects of their assigned intervention group. To calculate the estimated effect sizes of the interventions on the outcome variables, the estimated mean differences over and above the control group from each of the final models were divided by overall standard deviation of the outcome variable at pre-test (Feingold, 2009).

Missing Data

For the 157 children in the analyses, data were missing for a small percentage of children on the HTKS-R at pre-test (8%) and post-test (10%), Day-night at pre-test (3%) and post-test (6%) WJ-Letter-word at pre-test (3%) and post-test (8%) and on PENS at pre-test (3%) and post-test (11%). Data on individual measures were typically missing due to child absences at one of the testing sessions or other extraneous factors. For all of the analyses described below, these data were assumed to be missing at random (MAR; Little and Rubin, 2002). Although there are no definitive tests of the MAR assumption (Baraldi and Enders, 2010), we assessed whether missingness on any of the variables was due to any auxiliary variables available in the dataset using logistic regression and no significant predictors emerged. Thus, we concluded an MAR assumption was valid (Acock, 2012).

To account for MAR data in our analyses, we ran path models with a full information maximum likelihood (FIML) estimator in Stata 15.1 (Muthén and Muthén, 2012; StataCorp, 2017) for all of the final models described below. A FIML estimator utilizes all available data in the analysis and provides more unbiased estimates compared to traditional missing data techniques such as pairwise or listwise deletion (Enders and Bandalos, 2001).

Fidelity of Implementation

On average, participating children attended 14 sessions across both intervention groups and 95% of participating children attended at least 10 intervention sessions. As noted above, 43 videos were collected from intervention and BAU classrooms and coded for fidelity (adherence, quality, and responsiveness). All participating teachers delivered 100% of the intervention sessions, in order, and on the dates scheduled (two times per week for 8 weeks). Videos of intervention classrooms indicated that teachers implemented the intervention effectively (e.g., played the correct games, modeled appropriate behaviors) and adhered to the condition of the intervention they were trained in. Coders did not observe any deviations from the session guides and learning objectives included in the training manual. All participating classrooms (BAU and intervention classrooms) used Creative Curriculum. A review of the curricula and lesson plans used by BAU classrooms along with video observations also confirmed that teachers in BAU classrooms were not playing self-regulation games of a similar nature to those in either version of the intervention as part of their typical practice.

Descriptive Statistics

Bivariate correlations between all these variables are also presented in **Table 1**. Descriptive statistics for all direct assessments at pre-test and post-test and all control variables are presented in **Table 2**. Two-sample t-tests (**Table 1**) were conducted to assess for any differences at pre-test between children assigned to the BAU control group and children assigned to either of the intervention conditions. Although random assignment was utilized, significant baseline differences were found on children's performance on the HTKS-R and on the PENS at pre-test and marginally significant differences were found on children's performance on Day-Night at pre-test. There were also significant differences in the proportion of ELL children in the BAU control group and the two intervention groups. Specifically, children in classrooms with teachers randomly assigned to the control group had higher baseline scores on each of these measures than children in classrooms with teachers randomly assigned to treatment groups. Thus, fall baseline scores on the HTKS-R, Day-Night, or PENS were included as control variables in models predicting these corresponding outcomes in the spring. In addition, ELL status was included as a control variable in all models.

Hypothesis Testing

Parallel path models utilizing all available data at post-test were conducted for each of the outcome variables which are presented below. Estimated effects of treatment condition and all other covariates in the final models are included in **Table 3**.

Self-Regulation Outcomes

We first tested whether there were any effects of either condition of the intervention (SR and SR+ versions combined) on children's self-regulation over the preschool year, given that both conditions included the same underlying self-regulation components. As shown at the top of **Table 3**, children receiving either version of the intervention demonstrated higher self-regulation on the HTKS-R at post-test compared to the business as usual group. Although results were not statistically significant, they indicated a significant trend ($\beta = 0.09$, $p = 0.082$). In addition, the estimated mean difference of children's self-regulation at post-test over and above the BAU group (M = 6.81 points, Cohen's d = 0.31, 95% CI: −0.10 – 0.72) were similar to gains made on the HTKS in previous intervention studies (Schmitt et al., 2015; Duncan et al., 2018) and consisted of a 21% difference over and above the BAU group at post-test.

When evaluating the individual intervention types as shown at the bottom of **Table 3**, gains in self-regulation for the SR+ group over the BAU group were larger (M = 6.93 points, Cohen's d = 0.32, 95% CI: −0.26 – 0.76) with a trend for a significant difference over and above the BAU group (β = 0.11, p = 0.066), whereas estimated gains on the HTKS-R in the SR group were smaller (M = 5.41 points, Cohen's d = 0.25, 95% CI: −0.11 – 0.75), and were not significantly different from the BAU group (β = 0.09, p = 0.168). Although there was a trend for the effect of the SR+ version to be larger than the SR version, the difference between the two intervention groups was not statistically significant (p = 0.394, d = 0.07, 95% CI: −0.44 – 0.58). Children's estimated mean performance on the HTKS-R at post-test is illustrated in **Figure 1A**. Differences in children's performance on the Day-Night task at post-test were not significantly different between children in either of the intervention groups and the BAU control group.

Academic Achievement Outcomes

Second, we tested whether there were any significant effects of either version of the intervention (SR and SR+) on

TABLE 1 | Pairwise correlations of variables.

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13
(1) Age	–												
(2) Gender	0.18*	–											
(3) Fall ELL Status	−0.11	−0.04	–										
(4) Parent Edu	−0.13	0.12	−0.37**	–									
5. Fall HTKS	0.33***	0.00	−0.37***	0.15	–								
(6) Spring HTKS	0.46***	0.04	−0.33***	0.23	0.56***	–							
(7) Fall Day-Night	0.08	−0.10	0.10	−0.15	0.17*	0.10	–						
(8) Spring Day-Night	0.09	−0.07	−0.03	−0.05	0.24**	0.22*	0.30***	–					
(9) Fall Letter-word	0.40***	−0.04	0.12	−0.11	0.27**	0.33***	0.19*	0.12	–				
(10) Spring Letter-word	0.30***	−0.03	−0.07	−0.07	0.38***	0.36***	0.21*	0.15	0.64***	–			
(11) Fall PENS	0.54***	0.03	−0.33***	0.20	0.62***	0.62***	0.16*	0.18*	0.48***	0.56***	–		
(12) Spring PENS	0.51***	0.10	−0.41***	0.04	0.52***	0.68***	0.15	0.29***	0.48***	0.56***	0.72***	–	
(13) SR Treatment	0.12	0.02	0.17*	−0.36**	−0.06	−0.04	0.06	−0.03	0.12	0.14	−0.09	0.00	–
(14) SR + Treatment	−0.11	−0.11	0.06	0.12	−0.09	−0.01	0.06	0.08	−0.19*	−0.19*	−0.07	−0.01	−0.62***

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.*

TABLE 2 | Means (SD) of each variable by intervention condition.

	Overall sample (*N* = 157)				Difference tests[b]	
	BAU (*N* = 37)	**SR (*N* = 59)**	**SR+ (*N* = 61)**	**Any treatment (*N* = 120)**	***t***	***g***
Age	51.73 (6.90)	52.84 (5.49)	51.04 (6.45)	51.92 (6.04)	$t(155) = 0.17$	0.03
Gender	0.59	0.51	0.43	0.47	$\chi^2(1) = 2.66$	
Fall ELL-Status	0.05	0.36	0.30	0.33	$\chi^2(1) = 10.76$***	
Parent Education	12.26 (1.43)	10.13 (3.23)	11.62 (1.31)	10.83 (2.61)	$t(68) = 2.26$*	0.60
Fall HTKS	29.84 (23.80)	21.36 (23.92)	20.30 (17.13)	20.83 (20.72)	$t(142) = 2.10$*	0.42
Spring HTKS	41.52 (27.61)	36.74 (31.22)	38.05 (32.54)	37.43 (31.79)	$t(145) = 0.67$	0.13
Fall Day-Night	15.63 (11.44)	18.72 (9.31)	18.73 (9.68)	18.73 (9.46)	$t(151) = 1.62^{\dagger}$	0.31
Spring Day-Night	21.6 (10.34)	22.09 (9.45)	23.38 (8.85)	22.75 (9.13)	$t(146) = 0.63$	0.12
Fall Letter-Word	314.94 (28.9)	315.5 (25.98)	305.65 (21.11)	310.49 (24.04)	$t(151) = 0.92$	0.18
Spring Letter-Word	331.09 (25.83)	333.29 (22.72)	323.33 (22.13)	328.08 (22.86)	$t(142) = 0.65$	0.13
Fall PENS	6.71 (5.26)	4.59 (4.32)	4.69 (4.31)	4.64 (4.29)	$t(151) = 2.35$**	0.46
Spring PENS	8.94 (5.69)	8.75 (5.87)	8.69 (5.20)	8.72 (5.51)	$t(139) = 0.20$	0.04

*[b]Difference tests (Hedge's g) calculated between the BAU group and both treatment groups combined (Any Treatment). $^{\dagger}p < 0.10$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.*

children's academic achievement (early literacy and math skills) over the preschool year. As shown on **Table 3**, children receiving either intervention demonstrated significantly higher math scores on the PENS at post-test compared to children in the BAU group ($\beta = 0.14$; $p = 0.003$). The estimated mean difference in children's math ability on the PENS ($M = 1.75$ points, Cohen's $d = 0.38$, 95% CI:0.15 – 0.61) was equivalent to a 24% difference over and above the BAU group.

Children in the SR+ version of the intervention demonstrated significantly higher math scores on the PENS at post-test ($\beta = 0.17$, $p = 0.003$) compared to children in the BAU group ($M = 1.76$ points, Cohen's $d = 0.38$, 95% CI:0.15 – 0.61) with a similar significant difference ($\beta = 0.14$, $p = 0.016$) for children in the SR version of the intervention ($M = 1.57$; Cohen's $d = 0.34$, 95% CI:0.07 – 0.62). Estimated mean differences in children's math ability on the PENS did not differ significantly from the SR intervention group or SR+ intervention group versions of the intervention, $p = 0.698$, Cohen's $d = 0.03$, 95% CI: −0.26 – 0.40. Children's estimated mean performance on the PENS at post-test is illustrated in **Figure 1B**.

Finally, we tested whether either version of the intervention demonstrated any significant effects on children's early literacy skills. As shown on the top of **Table 3**, children receiving either version of the intervention did not demonstrate any significant difference in their early literacy skills compared to the BAU group at post-test ($\beta = 0.01$, $p = 0.924$). As shown in **Figure 1C**, when examining the intervention groups individually, neither the SR intervention ($\beta = 0.06$, $p = 0.108$) nor the SR+ intervention ($\beta = -0.02$, $p = 0.609$) demonstrated any significant difference compared to the BAU group.

Exploratory Analyses

We also conducted a series of exploratory analyses to assess whether there were any significant effects of the interventions (SR and SR+ versions) on children's self-regulation (measured on the HTKS) over the preschool year for children who

TABLE 3 | Estimated effects for intervention conditions vs. BAU control on self-regulation, mathematics, and literacy at post-test (*N* = 157).

Variable	Self-regulation				Math				Literacy			
	β	*SE*	*P-value*	*Cohen's d*	β	*SE*	*P-value*	*Cohen's d*	β	*SE*	*P-value*	*Cohen's d*
BAU versus Any Treatment												
Pre-test Score	0.40	0.06	<0.001		0.59	0.07	<0.001		0.64	0.07	<0.001	
Age	0.35	0.05	<0.001		0.15	0.05	0.004		0.06	0.10	0.534	
ELL- Status	−0.09	0.08	0.246		−0.22	0.04	<0.001		−0.13	0.09	0.172	
Gender	−0.03	0.06	0.680		0.03	0.07	0.676		0.02	0.07	0.791	
Parent Education	0.22	0.06	<0.001		−0.05	0.05	0.374		0.01	0.13	0.924	
Intervention [a]	0.09	0.07	0.082	0.31	0.14	0.05	0.003	0.38	0.01	0.05	0.401	0.03
BAU versus SR and SR+												
Pre-test Score	0.39	0.07	<0.001		0.60	0.06	<0.001		0.62	0.07	<0.001	
Age	0.34	0.05	<0.001		0.15	0.05	0.002		0.06	0.10	0.524	
ELL-Status	−0.10	0.07	0.158		−0.22	0.04	<0.001		−0.13	0.09	0.171	
Gender	−0.02	0.06	0.695		0.03	0.07	0.657		−0.03	0.07	0.722	
Parent Education	0.18	0.08	0.023		−0.07	0.05	0.215		0.03	0.13	0.816	
Intervention												
SR[a]	0.09	0.09	0.168	0.25	0.14	0.06	0.016	0.34	0.06	0.05	0.108	0.12
SR+[a]	0.11	0.07	0.066	0.32	0.17	0.06	0.004	0.38	−0.02	0.08	0.609	0.03

All estimates are from a path model accounting for missing data (estimator = FIML) and the nested data structure (robust clustered standard errors). [a]P-values for Intervention effects are one-tailed tests.

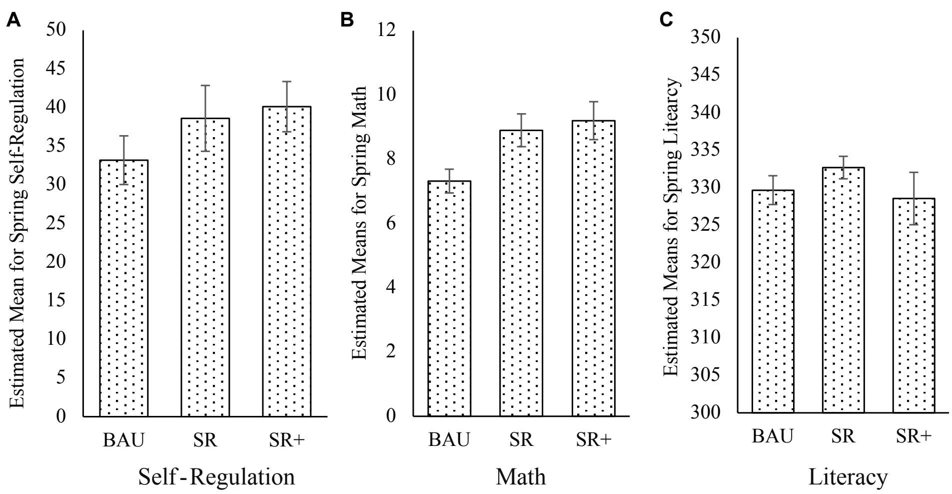

FIGURE 1 | Estimated means at post-test in **(A)** Self-Regulation, **(B)** Math, **(C)** Literacy (±SE) the BAU, SR, and SR+ groups controlling for initial scores at pre-test, age, ELL-status, gender and parental education.

started out with initially low levels of self-regulation on the HTKS as in previous studies (e.g., Tominey and McClelland, 2011). First, we tested for an interaction between the effect of the intervention and whether children started with low initial levels of self-regulation, and then conducted a subgroup analysis examining the effect of the intervention for children with low self-regulation. However, given the available sample size in the current study, results reported below should be interpreted with caution.

In a previous study (e.g., Tominey and McClelland, 2011), children were determined to have low levels of self-regulation if they initially received a zero on the HTKS. The HTKS-R contains all the same components of the HTKS but adds a downward extension to capture more variability in children with low self-regulation. To capture the limited variability of children with low-levels of self-regulation on the HTKS-R and align with previous studies, we coded children as having low self-regulation if they did not get at least 4 out of the 6 possible points on the initial practice questions for Part 1 of the measure. At pre-test, 74% of children (n = 116) did not meet the initial threshold on the HTKS-R.

We tested an interaction between the effect of intervention type (BAU, SR, or SR+) and children with low levels of self-regulation at pre-test. Results indicated a significant interaction

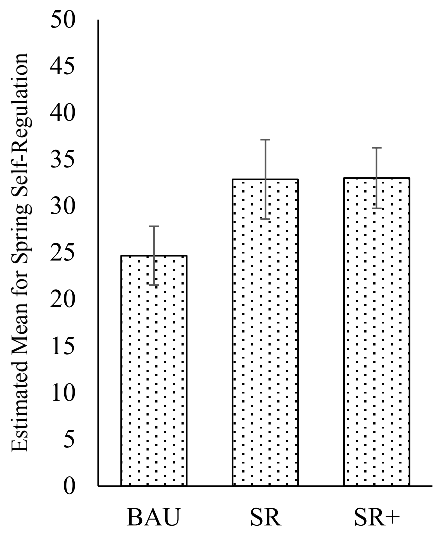

FIGURE 2 | Estimated means at post-test (±SE) for self-regulation in children with low initial levels of self-regulation.

between the intervention groups and children's low self-regulation status. Children with low self-regulation children in the SR group showed an additional benefit of the intervention compared to children with high self-regulation, $\beta = 0.35$, $p = 0.037$. In contrast to the analyses with the overall sample (**Figure 1A**), for children with low initial HTKS-R scores at pre-test, children in the SR and SR+ intervention groups showed significant gains in self-regulation over and above the BAU group at post-test. This subgroup analysis for the interaction is shown in **Figure 2**.

DISCUSSION

The goal of this study was to examine a self-regulation intervention that explicitly focused on self-regulation (attentional flexibility, working memory, and inhibitory control) and to compare the self-regulation-only version of the intervention (self-regulation; SR) with an enhanced version that included emphasis on best practices to support early math (counting and cardinality and numeral knowledge), and literacy (phonological awareness and print knowledge; SR+). We examined if there were significant effects of the self-regulation intervention (SR and SR+ versions) on children's self-regulation and academic outcomes (early literacy and math skills) over the preschool year.

Results indicated that although not statistically significant, there was a trend for children receiving either version of the intervention to show greater improvement on a measure of self-regulation, and results for the SR+ version also demonstrated a trend toward significant improvements in self-regulation. Children receiving either version of the intervention gained significantly more in math over the preschool year compared to children in the BAU group, but there were no differences between groups on literacy performance.

Effects of the Intervention on Self-Regulation Outcomes

The present study demonstrated that children receiving either intervention version demonstrated higher self-regulation on the HTKS-R at post-test compared to the BAU group, based on measures of effect size, but results were not statistically significant. Gains on the HTKS-R for either version and for the SR+ version over the BAU group were larger and approached significance ($d = 0.31$ and $d = 0.32$ respectively), whereas gains on the HTKS in the SR version were smaller ($d = 0.25$). Despite the small sample size, effects from either version of the intervention ($d = 0.31$) were similar to effect sizes in previous studies, which were ($d = 0.32$) in Schmitt et al. (2015) and ($d = 0.33$) in Duncan et al. (2018). The lack of significant effects may be in part due to limited power and the small sample size in the present study, but the consistency in effect sizes across studies suggests the promise of a robust intervention effect (Cumming, 2014). This research also aligns with other similar interventions documenting improvements in children's self-regulation (Blair and Raver, 2014) and recent meta-analyses of self-regulation interventions (Pandey et al., 2018), which supports the substantive and practical significance for effects of this size (Hill et al., 2008).

Effects of the Intervention on Early Academic Outcomes

Effects on Math

Children receiving either version of the self-regulation intervention had significantly higher math scores at post-test compared to children in the BAU group, which was equivalent to a 24% difference in math at the end of the preschool year. Children in the SR+ version of the intervention had significantly higher math scores at post-test compared to children in the BAU group and children in the SR version showed a similar pattern. Effect sizes for either version of the intervention (0.38) and for the two versions of the intervention were substantive (0.38 and 0.34, respectively). The size of the effects did not significantly differ by intervention version (SR+ and SR), which suggests that there is something about the cognitive complexity in the self-regulation games that promotes early math skills especially in children from low-income backgrounds (as defined by Head Start enrollment in the U.S.) rather than the addition of the math and literacy components. These results support other research on self-regulation interventions (e.g., Blair and Raver, 2014; Schmitt et al., 2015), which have found significant effects on children's early math skills. This is also supported by research finding bidirectional relations between early math and self-regulation skills in early childhood (Schmitt et al., 2017; Cameron et al., 2019; McClelland and Cameron, 2019). The nature of the intervention games required children to pay attention to, remember, and follow increasingly complex sets of rules, which are especially important for children's early math development (McClelland et al., 2014; Purpura et al., 2017). Overall, results from the present study suggest that self-regulation interventions can improve early math skills in children from low-income families.

Effects on Literacy

Differences in children's early literacy at post-test were not statistically different between the intervention groups and the BAU group. Previous research has shown mixed effects; one study on the RLPL intervention showed an overall intervention effect on improved early literacy skills with a diverse sample of children from a range of socioeconomic backgrounds (Tominey and McClelland, 2011), but a study with a low-income sample did not find significant effects of the intervention on children's literacy skills (Schmitt et al., 2015). It is possible that effects are present in more diverse samples of children. Another possibility is that relations between early literacy and self-regulation are weaker than relations between math and self-regulation and math in early childhood (Blair et al., 2015). In older children, however, stronger reciprocal relations have been found between complex aspects of literacy such as comprehension and self-regulation (Connor et al., 2016). The results of the present study do not clearly indicate if self-regulation interventions can improve children's early literacy skills and more research is needed.

Differential Intervention Effects

Previous research has pointed to the importance of examining differential intervention effects on children with low initial self-regulation and children from low-income families (McClelland et al., 2017). Results from the current study indicated that children in the intervention with low baseline levels of self-regulation measured at the fall of preschool (pre-test) made significantly greater gains in self-regulation compared to children in the BAU control group with higher self-regulation measured at pre-test. This supports other research demonstrating that children with low initial self-regulation may show stronger self-regulation gains in the RLPL intervention and other self-regulation interventions compared to children with higher baseline levels of self-regulation (Tominey and McClelland, 2011; Sasser et al., 2017). It may be that children with low initial levels of self-regulation demonstrate greater risk (e.g., have exposure to greater stress and are at risk from coming from chaotic backgrounds (Blair and Raver, 2012) and have more room to improve when participating in interventions. This idea has been called the compensatory hypothesis and suggests that targeting children with low self-regulation may be one way to support school readiness in young children from low-income families. One hypothesized explanation could be that children who showed significant gains with low scores at the beginning of the year were simply demonstrating regression to the mean. Given the use of classroom randomization, however, regression to the mean is unlikely because children in the BAU control classrooms did not show the same level of improvement over the year (Diamond and Ling, 2016). Overall, however, more research is needed to investigate and replicate these findings, especially in larger and more diverse samples of children.

Limitations and Future Directions

Results from the present study provide additional information about the effectiveness of a self-regulation intervention on school readiness in children from low-income families, but there were limitations. First, although the study specifically focused on the iterative development of the intervention and included an RCT to evaluate the promise of the intervention, the study sample was small and had limited power given that results were clustered at the (teacher) level. Future research needs to examine effects with a larger sample. Second, the sample focused on children from families with low incomes based on research indicating that these children may especially benefit from the RLPL intervention (e.g., Schmitt et al., 2015). However, this limited our ability to generalize findings beyond children from low-income families in the U.S. and future research needs to include more diverse samples of children. Third, although random assignment was used to assign teachers (and thus classroom children) to intervention and control groups, there were baseline differences on several of the variables of interest. All models included baseline skills, but our ability to make causal inferences was limited. Although results of the present study supported previous RCT evaluations of the RLPL intervention (Tominey and McClelland, 2011; Schmitt et al., 2015; Duncan et al., 2018) more research is needed. Fourth, although we used two measures of self-regulation, we largely treated self-regulation as a unidimensional construct. Future studies need to include additional measures that explicitly tap into other aspects of EF (e.g., cognitive flexibility) to better understand generalizability of our findings to other domains of self-regulation. Expanding the number of self-regulation measures would also enable the use of latent variable approaches allowing for a more nuanced understanding of the self-regulation construct. In addition, although the literacy aspect of the intervention was focused on print knowledge and phonological awareness, the outcome measure was a more general literacy measure that broadly captured letter knowledge and decoding. Thus, there may have been more targeted intervention effects on specific aspects of literacy that were not captured by the outcome measure. Future work should consider the use of measures of each of the individual targeted components of literacy to best evaluate potential intervention effects.

Finally, the study focused on two versions of a self-regulation intervention (SR and SR+), which did not vary significantly in their impact on child outcomes. The primary difference was an enhanced emphasis on best practices to promote early math and emergent literacy skills in the SR+ version of the intervention. As Head Start centers, the early childhood programs where the RCT was conducted had significant support and emphasis on embedding best practices to support emergent literacy and early math into their daily routines. Given the existing emphasis on these skills, the difference in intervention conditions may not have been as great as it would have been in settings where there was less support to integrate these skills into daily practice.

Despite these limitations, there are a number of practical implications based on the present study. First, results of the present study largely replicated previous research on the RLPL intervention including three RCTs (Tominey and McClelland, 2011; Schmitt et al., 2015; Duncan et al., 2018). Together, results from these studies suggest that the games included in the RLPL intervention are cognitively complex and can improve children's self-regulation and early academic outcomes. Although results were largely consistent between the SR and

SR+ versions of the intervention in the present study, there was some indication that adding math and literacy components to the intervention resulted in stronger outcomes than the SR version. This possibility needs to be more rigorously tested in a larger scale study with a more diverse sample of children. These findings also point to the importance of promoting self-regulation, math, and literacy as a way to support children's school readiness, especially in children from low-income families.

Second, results suggest that the RLPL intervention, as an example of a short-term, low-cost, and feasible intervention, can produce substantive improvements in children's math skills, with some indication of improvements in self-regulation. The RLPL intervention required minimal training (one 3-h workshop) and materials were low-cost and readily available in most early childhood classrooms (e.g., construction paper). Moreover, the games could be embedded in teachers' everyday curricular practice (e.g., circle times), which increased the feasibility of the intervention. These factors point to the scalability and feasibility of the intervention although more work is needed to further assess these potential benefits. Overall, the present study provides additional evidence that the RLPL intervention and similar interventions focused on self-regulation may be an effective and feasible way to improve low-income children's school readiness skills.

CONCLUSION

Results extend previous research and suggest that the RLPL intervention, which includes music and movement games, can improve children's math scores over the preschool year. There was also evidence that the intervention resulted in gains in children's self-regulation, especially for children with low self-regulation scores at baseline. These findings suggest that low-cost interventions, which are engaging and developmentally appropriate for young children, can improve school readiness with the potential to be scalable and practical for early childhood teachers. Interventions that focus on supporting self-regulation and school readiness can help ensure that children from low-income backgrounds enter school with the skills they need to be successful.

DATA AVAILABILITY STATEMENT

The datasets for this study will not be made publicly available because we are not allowed to share data outside the key personnel for the grant by our IRB. Requests to access the datasets should be directed to the corresponding author.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of the Internal Review Board (IRB) at Oregon State University with written informed consent from parents and verbal assent from children. Parents gave written consent and children gave verbal assent in accordance with the Declaration of Helsinki. The protocol was approved by the IRB at Oregon State University.

AUTHOR CONTRIBUTIONS

MM, ST, SS, BH, DP, CG, and AT contributed to the conceptualization and design of the study. MM, ST, SS, DP, and CG contributed to the data analysis and results. All authors contributed to the writing of the manuscript.

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Enhancing Executive Functions Through Social Interactions: Causal Evidence Using a Cross-Species Model

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It has long been theorized that humans develop higher mental functions, such as executive functions (EFs), within the context of interpersonal interactions and social relationships. Various components of social interactions, such as interpersonal communication, perspective taking, and conforming/adhering to social rules, may create important (and perhaps even necessary) opportunities for the acquisition and continued practice of EF skills. Furthermore, positive and stable relationships facilitate the development and maintenance of EFs across the lifespan. However, experimental studies investigating the extent to which social experiences contribute causally to the development of EFs are lacking. Here, we present experimental evidence that social experiences and the acquisition of social skills influence the development of EFs. Specifically, using a rat model, we demonstrate that following exposure to early-life adversity, a socialization intervention causally improves working memory in peri-adolescence. Our findings combined with the broader literature promote the importance of cultivating social skills in support of EF development and maintenance across the lifespan. Additionally, cross-species research will provide insight into causal mechanisms by which social experiences influence cognitive development and contribute to the development of biologically sensitive interventions.

Keywords: executive function, social competence, early-life adversity, poverty, social skills, social behavior, development, longitudinal

INTRODUCTION

The cognitive control abilities that enable holding and manipulating information in mind, the flexible shifting of attention between tasks, and inhibiting impulses and responses to stimuli are critical thinking skills that assist reasoning, planning, self-regulation, and management of one's life. These higher-order cognitive abilities—called executive functions (EFs)—develop across the lifespan and are enhanced or diminished by a variety of experiential factors, especially early in life, such as environmental stimulation or stress/adversity (Perry et al., 2018b), and even physical fitness (e.g., body mass index, physical exercise) (Verburgh et al., 2014; Blair et al., 2019). Prior studies have demonstrated that these experiential factors can be successfully leveraged as points of intervention, with EF skills improving following interventions promoting stress reduction (Zelazo and Lyons, 2012) or physical exercise (Verburgh et al., 2014). However, a lesser acknowledged factor by which EF skills may also be promoted is through interpersonal experiences. This is despite strong evidence from developmental research and longstanding theory that cognitive development occurs within the context of positive social interactions and relationships (Vygotsky, 1978; Carlson, 2009; Lewis and Carpendale, 2009; Moriguchi, 2014; van Lier and Deater-Deckard, 2016).

While EF and social development are traditionally considered to be distinct domains of development, they are increasingly understood to be functionally connected. The majority of research regarding the social origins of EFs has focused on caregiver scaffolding of EF development through social interactions with their infants (e.g., Landry et al., 2002; Bibok et al., 2009; Hughes and Ensor, 2009; Roskam et al., 2014). This large body of research provides strong support that sensitive caregiving facilitates EF development. Furthermore, increasing evidence suggests that social processes influence EF development not only in infancy, but also across later development as peers become more central in youth's lives. For example, in preschool, engaging in pretend play with peers is associated with improved self-regulation (Lindsey and Colwell, 2003). Playful interactions with peers are also associated with EF development, including cognitive flexibility (Bateson, 2005) and inhibitory control (Peterson and Flanders, 2005). Even in adolescence and adulthood, peer problems, such as peer victimization, rejection, and social exclusion, have been associated with impaired EF skills (Baumeister et al., 2002, 2005; Holmes et al., 2016). Despite these findings, the extent to which social interactions with peers may function as causal mechanisms supporting EFs is not understood.

The attainment of appropriate social skills through social interactions with peers (in addition to caregivers) may be an important driving component of EF development. In line with this idea, we recently reported findings of a novel developmental pathway whereby social competence through EF longitudinally mediated the impact of cumulative poverty-related adversities on academic achievement across the early school years (Perry et al., 2018a). Specifically, social competence in Kindergarten through EFs at Grade 1 longitudinally mediated a negative association between early-life poverty-related cumulative risk exposure and academic skills at Grade 2. These findings are in line with a growing literature that suggests that the development of social competence may be functionally linked with the development of EFs (e.g., Riggs et al., 2006; Carlson, 2009; Lewis and Carpendale, 2009; Moriguchi, 2014; van Lier and Deater-Deckard, 2016). Additionally, these results indicate that social competence may be a key mechanism by which early-life adversity impacts EF development.

Taken together, our findings paired with a broader body of literature and longstanding theory suggest that higher-order cognitive development might be facilitated, at least in part, by targeting the improvement of social skills and social interactions with caregivers and peers. Moreover, this developmental relation may be especially important for children reared in adverse environments. Indeed, a few randomized controlled trials (RCTs) provide further support for this idea. For example, interventional school curricula, such as Tools of the Mind, have incorporated Vygotskian principles into their design by not only directly scaffolding EF development, but also incorporating social pretend play to positively impact EF development (Bodrova and Leong, 1996; Diamond et al., 2007; Blair and Raver, 2014; Sasser et al., 2017). However, looking beyond the earliest school years, there is a paucity of RCTs experimentally testing if interventions that target social processes positively impact EF development. This gap in the literature persists despite well-established evidence that EF development is protracted and remains amenable to experiential input well into adolescence and adulthood (Perry et al., 2018b). Furthermore, the field is currently limited in its understanding of the causal mechanisms by which social processes operate to influence EF development, which would ultimately inform design and implementation (e.g., developmental timing) aspects of interventions to maximize effect sizes.

These gaps in the literature are likely due to normal limitations that human developmental researchers face. While prior research, including our own, has benefited from longitudinal data to begin to understand how social processes influence EF development, most studies are based on non-experimental, correlational data which limits our inferences regarding causal relations. Furthermore, we face difficulties in readily discerning cause–effect relations between social processes and EF development due to lack of experimental control within research designs involving humans. Thus, in the present study, we expanded upon our prior human findings (Perry et al., 2018a) by leveraging a rodent model with high internal validity to experimentally test our overarching hypothesis that EF development can be enhanced by targeting the improvement of social skills through facilitated social interactions. We focus specifically on the functional interplay between social development and working memory, a core EF which involves the ability to hold in mind, manipulate, and update information in one's memory (Diamond, 2013). Working memory can be readily assessed in rodent models by using a widely used spontaneous alternation task, which is based on the tendency of rodents to explore a prior unexplored arm of a maze, and thus requires that the rodent remember which maze arms were most frequently visited (e.g., Lalonde, 2002; Hughes, 2004; Liet et al., 2015; Kraeuter et al., 2019). Importantly, spontaneous alternation also occurs in humans and has been demonstrated as early as 18 months of age (Vecera et al., 1991). Working memory is an important component of social competence as it is essential for organizing, inhibiting, and executing behavior (Riggs et al., 2006). Indeed, working memory has been associated with the facilitation of social development (Riggs et al., 2006). Furthermore, working memory develops into young adulthood and remains malleable (especially in childhood), such that working memory skills can be influenced by training (Klingberg et al., 2002, 2005) and social experiences (Perry et al., 2018b).

Thus, we employed a rodent model of early-life scarcity–adversity, which induces atypical mother–infant interactions (Perry et al., 2019) and altered social behavior across development (Raineki et al., 2012, 2015; Rincón-Cortés and Sullivan, 2016), to experimentally test if a peer socialization intervention could improve working memory in peri-adolescence. Based upon Vygotskian theory linking cognitive development to social processes, as well as prior findings that our rodent model of early-life scarcity–adversity causes social behavior problems in later life, we hypothesized that scarcity–adversity rearing would also produce cognitive development problems, as assessed via working memory performance in peri-adolescence. We additionally sought to replicate and expand upon previous results demonstrating that early-life scarcity–adversity would cause social behavior problems in juvenile and adolescent rats (Raineki et al., 2012, 2015; Rincón-Cortés and Sullivan, 2016). Furthermore, drawing from our prior human research findings suggesting that social development influences EF development (Perry et al., 2018a), we hypothesized that socializing a scarcity–adversity reared subject with a control reared rat (via co-housing) would improve the scarcity–adversity reared subject's social behavior and working memory performance. We tested this using a peer socialization intervention spanning from time of weaning until time of testing in peri-adolescence, a developmental period which encompasses the maturation of social behavior and is increasingly thought of as a period in which neurodevelopment is sensitive to social experiences (Sisk and Foster, 2004; Schulz et al., 2009; Wei et al., 2011; Fuhrmann et al., 2015). While this rodent model is not meant to supersede the need for future human RCTs examining the efficacy of peer socialization interventions for the improvement of EFs, it serves as a valuable tool with which we can efficiently test our research questions using a tightly controlled experimental design. Furthermore, our rodent model welcomes future experiments for the assessment of specific behavioral and neurobiological mechanisms by which social interactions influence cognitive development, which would provide valuable insight into the design of mechanism-based, developmentally sensitive, biologically informed interventions.

MATERIALS AND METHODS

Subjects

Male and female Long Evans rats were bred and raised in a temperature (20 ± 1°C)- and light (12-h light/dark cycle)-controlled room in an animal facility to provide a controlled rearing environment for all subjects. Subjects were born on postnatal day (PN) 0 and culled to 12 pups (six males, six females) on PN1. With the exception of our scarcity–adversity reared subjects (described in methods below), animals were housed with their mother in polypropylene cages (34 × 29 × 17 cm) with *ad libitum* food (Purina LabDiet #5001) and water, as well as ample wood shavings materials for nest building. Animals were weaned from their mother at PN23 and housed with one age- and sex-matched cage mate in a polypropylene cage (34 × 29 × 17 cm) with access to ample wood shavings and *ad libitum* food (Purina LabDiet #5001) and water. Animals were tested once in peri-adolescence (PN37-47, the time immediately prior to and during the onset of puberty) and each subject was only used once, with one male and one female used per litter per experimental group. All procedures were approved by New York University and Nathan Kline Institute's Animal Care and Use Committee, in accordance with National Institutes of Health's guidelines for the care and use of laboratory animals.

Procedures

Scarcity–Adversity Rearing

On PN8, litters were randomly assigned into scarcity–adversity or control rearing conditions. In scarcity–adversity conditions the mother was provided with insufficient wood shavings materials (100 ml) for nest building in polypropylene cages (34 × 29 × 17 cm), so that she could not build a proper nest for her pups. This procedure has previously been demonstrated to negatively disrupt mother–infant interactions (Perry et al., 2019) and increase pup corticosterone release (Raineki et al., 2010). Scarcity–adversity rearing conditions persisted from PN8-12. This procedure has been used previously by our lab and others (Roth and Sullivan, 2005; Cui et al., 2006; Raineki et al., 2010, 2012, 2015; Perry and Sullivan, 2014; Rincón-Cortés and Sullivan, 2016; Doherty et al., 2017; Walker et al., 2017).

Peer Housing Intervention

After weaning at PN23, animals were pair-housed in polypropylene cages (34 × 29 × 17 cm) based on matched or mismatched early-life rearing conditions. In matched housing conditions, two age- and sex- matched control reared rats were housed together, or two age- and sex-matched scarcity–adversity reared rats were housed together. In mismatched housing conditions, one control reared rat and one scarcity–adversity reared rat (age and sex matched) were housed together. For all housing conditions, animals were supplied with *ad libitum* food (Purina LabDiet #5001) and water, as well as ample wood shavings materials and a plastic tube. Peer housing conditions were maintained for at least 2 weeks, spanning from weaning at PN23 until time of testing in peri-adolescence (PN37-47).

Spontaneous Alternation Task

Spatial working memory was assessed using a spontaneous alternation task, which is based on the natural proclivity of rodents to sequentially alternate between arms during exploration of a T- or Y-maze (Lalonde, 2002). Subjects were tested one time only in peri-adolescence (PN37-47) using a Y-maze apparatus (76.2 × 64.8 × 18.1 cm). The apparatus was constructed with a black Plexiglas floor and walls, and a clear Plexiglas lid. The maze did not contain any visual cues, but extra-maze cues were visible from all three arms to allow spatial orientation. The subject was placed in the center of the Y-maze and allowed to freely roam the apparatus for the duration of the 8-min task. All testing occurred during the light period (ZT3-ZT7, zeitgeber time, ZT0 represents light on/ZT12 represents light off). Behavior was recorded using a video camera positioned approximately 1.5 m above the apparatus. The number and sequence of arm entries were manually scored offline by an observer blinded to experimental conditions. Spontaneous alternation consists of sequential entry into each of the three arms. Therefore, percentage of spontaneous alternations was calculated by dividing the total number of alternations by the number of possible alternations: [number of alternations/(number of total arm entries − 2)]*100. Through continuous assessment of spontaneous alternation, this task provides the advantage of allowing the experimenter to avoid repetitive stressful handling of subjects, such as occurs in trial-based assessments of working memory. Furthermore, this spontaneous alternation task allows for the measure of locomotor activity, as indicated by the frequency of arm entries (Hughes, 2004).

Social Behavior Task

Social behavior was assessed using a two-chamber Plexiglas apparatus (45.5 × 30.5 × 45 cm). The chambers were divided by a Plexiglas division with a square opening (8 × 6 cm) that allowed animals to cross between chambers. Two metal cubes (6 × 6 × 6 cm) with 1-cm circular holes were placed in each chamber. The subject was acclimated to the apparatus for 5 min prior to the start of testing. Animals were excluded from testing if they did not habituate to both chambers (spent less than 20% of time in either chamber). This exclusion criterion led to the exclusion of one control reared rat (in matched post-weaning housing) when tested in peri-adolescence. Following the acclimation period, a younger (PN25-35), same-sex animal was placed inside of the metal cube in the social stimulus chamber, while the metal cube of the other chamber remained empty. The test subject was then placed in the chamber without the social stimulus and allowed to freely roam the apparatus for the duration of the 10-min task. All testing occurred during the light period (ZT3-ZT7, zeitgeber time, ZT0 represents light on/ZT12 represents light off). Testing was recorded using Ethovision software (Noldus, Leesburg, VA, United States). Social behavior was quantified as the total time spent in each chamber, with decreased time spent in the chamber containing the social stimulus relative to the non-social chamber defined as social avoidance (Toth and Neumann, 2013). Number of crossings between chambers was also measured as an index of general locomotor activity (Raineki et al., 2012; Rincón-Cortés and Sullivan, 2016). All behavior was manually scored from videos by an observer blinded to the experimental conditions. Subjects were tested one time only in a social behavior task at either pre-weaning (juvenile; PN20-22) or peri-adolescence (PN37-47), to assess social behavior at ages immediately preceding and following the peer socialization intervention which spanned from PN23 until time of testing in peri-adolescence (PN37-47).

Statistical Analysis

All experimental data were analyzed using Prism 7 (GraphPad Software, Inc., San Diego, CA) using two-tailed Student's *t*-tests for paired comparisons or two-way ANOVA, followed by *post hoc* Fisher's LSD tests between groups. Significance of results was accepted at $p < 0.05$. Tests were designed assuming normal distribution and variance for control versus scarcity–adversity groups. *A priori* power analyses using G*Power 3.1 software indicated that a minimum final group size of six to eight rats was required to have a probability of detecting significant group effects, depending on the experiment. Specifically, power calculation of *t*-tests comparing early-life experience indicated that a minimum sample size of six (**Figure 1B**) or eight (**Figure 3B**) rats per group was necessary to achieve power of 0.8 and an error probability of 0.05. Similar power analysis calculated the requirement of a minimum sample size of six rats per experimental group for two-way ANOVA to achieve power of 0.8 and an error probability of 0.05 (**Figures 2B**, **3C**). All data were checked for statistical outliers using Grubbs' outlier test. One significant outlier was removed from the control reared, mismatched housing condition for **Figure 3C**. Final sample sizes are as follows: **Figure 1B**—8 control, 7 scarcity–adversity; **Figure 2B**—8 control matched, 8 scarcity–adversity, 7 control mismatched, 7 scarcity–adversity mismatched; **Figure 3B**—8 control, 8 scarcity–adversity; **Figure 3C**—8 control matched, 8 scarcity–adversity matched, 8 control mismatched, 8 scarcity–adversity mismatched.

RESULTS

Our rodent model of early-life scarcity–adversity exposure significantly reduced peri-adolescent (PN37-47) subjects' spatial working memory as assessed via spontaneous alternations in a Y-maze (**Figure 1A**), relative to control reared subjects [**Figure 1B**; $t_{(13)} = 3.10$, $p = 0.01$, Cohen's $d = 1.602$, *t*-test]. Sensitivity analyses revealed that group differences in spontaneous alternations were not driven by differences in locomotor activity, as assessed via overall number of arm entries during the task [**Figure 1C**, $t_{(13)} = 1.02$, $p = 0.33$, *t*-test]. Additionally, *t*-tests indicated there were no group differences in percentage of entries into arm A [**Figure 1D**, $t_{(13)} = 0.15$, $p = 0.89$], arm B [**Figure 1D**, $t_{(13)} = 0.25$, $p = 0.81$], or arm C [**Figure 1D**, $t_{(13)} = 0.31$, $p = 0.76$] of the maze. Finally, one-sample *t*-tests comparing mean percent arm entries to chance performance (33% entry per arm) indicated that neither experimental group displayed a preference in entering arm A [**Figure 1D**, Control—$t_{(7)} = 0.41$, $p = 0.69$, Scarcity–adversity—$t_{(6)} = 0.42$, $p = 0.69$], arm B [**Figure 1D**, Control—$t_{(7)} = 0.72$, $p = 0.50$, Scarcity–adversity—$t_{(6)} = 1.25$, $p = 0.26$], or arm C [**Figure 1D**, Control—$t_{(7)} = 0.50$, $p = 0.63$, Scarcity–adversity—$t_{(6)} = 0.77$, $p = 0.47$].

However, if scarcity–adversity exposed subjects were housed with a control reared peer from weaning (PN23) until time of testing in peri-adolescence (PN37-47) (**Figure 2A**), the negative effect of early-life scarcity–adversity rearing on later-life working memory was attenuated. Specifically, results of a 2 × 2 ANOVA revealed a significant interaction of early-life experience (scarcity–adversity vs. control) and peer housing condition (matched vs. mismatched) on percentage of spontaneous alternations in a Y-maze [**Figure 2B**; $F_{(1,26)} = 4.67$, $p = 0.04$]. *Post hoc* tests indicated that scarcity–adversity subjects placed in mismatched peer housing conditions were significantly improved in percentage of spontaneous alternations relative to scarcity–adversity subjects in matched peer housing conditions ($p < 0.05$, Cohen's $d = 0.85$). Furthermore, scarcity–adversity subjects placed in mismatched peer housing did not significantly

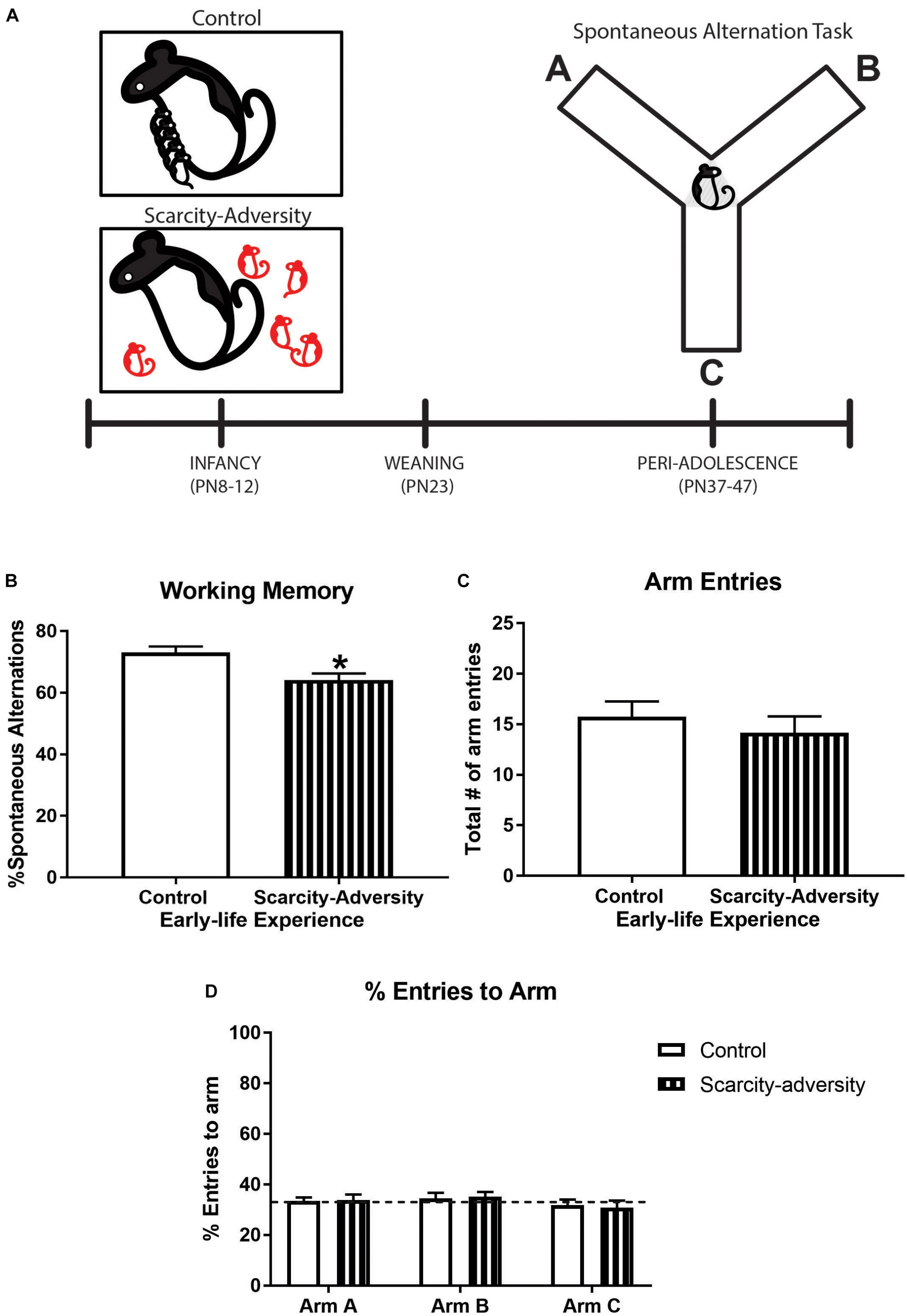

FIGURE 1 | Early-life scarcity–adversity rearing reduced spatial working memory in peri-adolescence. **(A)** Experimental timeline. **(B)** Mean (± SEM) levels of percent spontaneous alternation in the spontaneous alternation task (*significant difference between groups, $p < 0.05$, $n = 7$–8/group). **(C)** Mean (± SEM) levels of total number of maze arm entries during spontaneous alternation task ($n = 7$–8/group). **(D)** Mean (± SEM) percent levels of entries into each individual arm of the Y-maze during the spontaneous alternation task (dotted line represents level of entries at chance, i.e., 33%; $n = 7$–8/group).

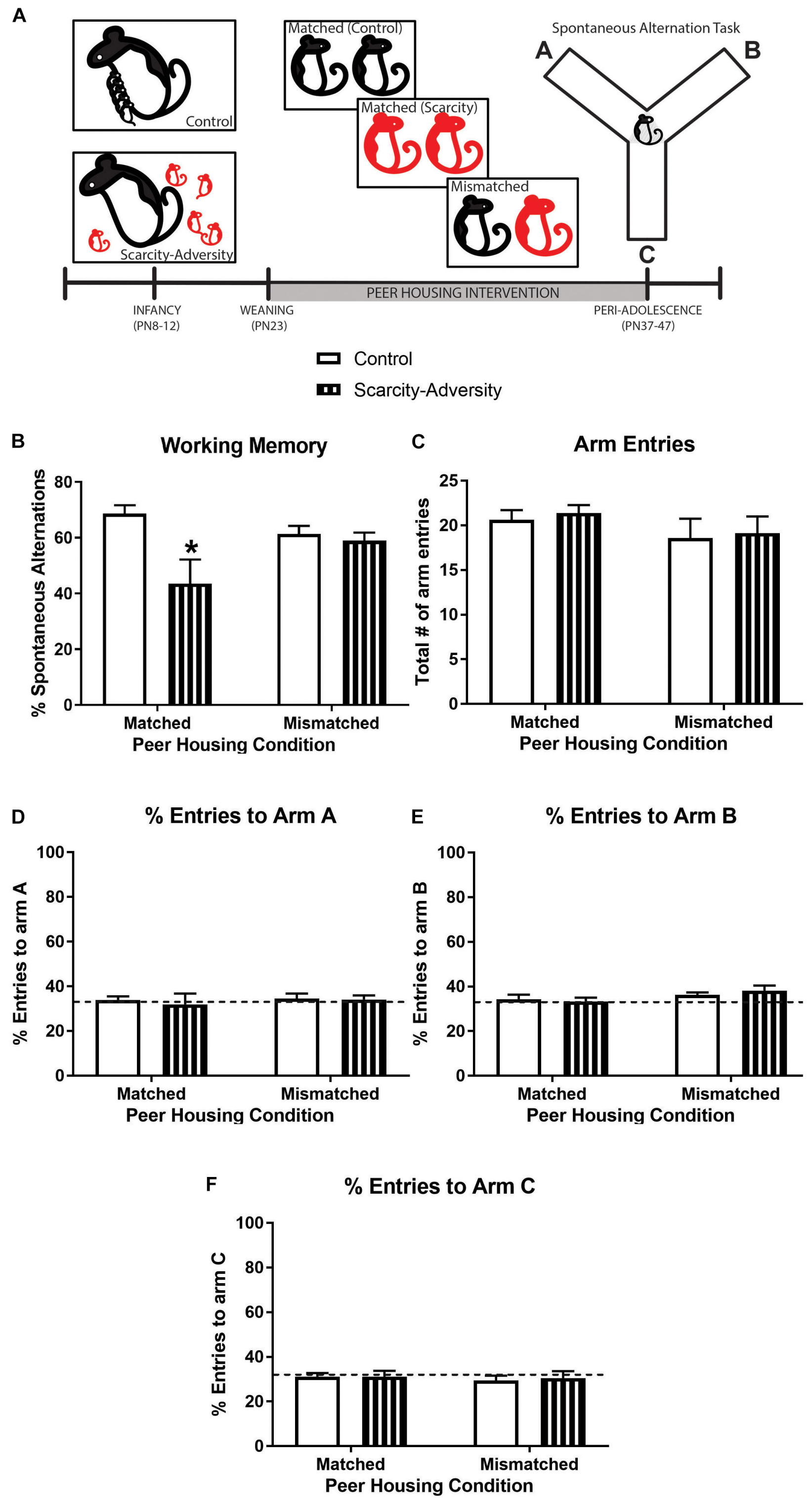

FIGURE 2 | A peer housing intervention rescued spatial working memory following early-life scarcity–adversity exposure. **(A)** Experimental timeline. **(B)** Mean (± SEM) levels of percent spontaneous alternation in the spontaneous alternation task (*significantly different from all groups, $p < 0.05$, $n = 7$–8/group). **(C)** Mean (± SEM) levels of total number of maze arm entries during spontaneous alternation task ($n = 7$–8/group). **(D)** Mean (± SEM) percent levels of entries into arm A of the Y-maze during the spontaneous alternation task (dotted line represents level of entries at 33%; $n = 7$–8/group). **(E)** Mean (± SEM) percent levels of entries into arm B of the Y-maze during the spontaneous alternation task (dotted line represents level of entries at 33%; $n = 7$–8/group). **(F)** Mean (± SEM) percent levels of entries into arm C of the Y-maze during the spontaneous alternation task (dotted line represents level of entries at chance, i.e., 33%; $n = 7$–8/group).

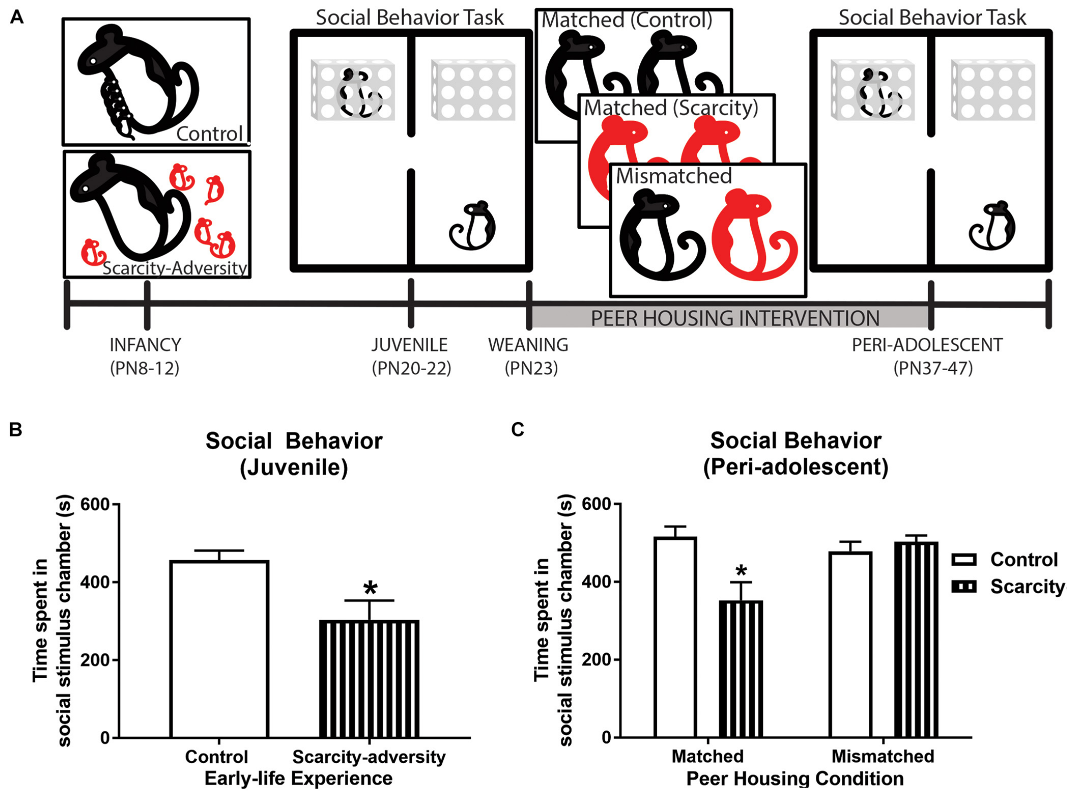

FIGURE 3 | Scarcity–adversity reared subjects had improved social behavior following the peer housing intervention. **(A)** Experimental timeline. **(B)** Mean (± SEM) time spent in the social stimulus chamber during the social behavior test (*significant difference between groups, $p < 0.05$, $n = 8$/group). **(C)** Mean (± SEM) time spent in the social stimulus chamber during the social behavior test (*significant difference between groups, $p < 0.05$, $n = 8$/group).

differ from control reared subjects in their levels of spontaneous alternation (*post hoc tests*, $p < 0.05$). Sensitivity analyses indicated that group differences in spontaneous alternations were not driven by differences in overall number of arm entries during the task [**Figure 2C**, interaction—$F_{(1,26)} = 0.01$, $p = 0.95$; main effect of peer housing—$F_{(1,26)} = 1.94$, $p = 0.18$, main effect of early-life experience—$F_{(1,26)} = 0.18$, $p = 0.67$, 2 × 2 ANOVA]. Furthermore, 2 × 2 ANOVAs revealed that there were no group differences in percentage of entries to arm A [**Figure 2D**, interaction—$F_{(1,26)} = 0.07$, $p = 0.79$; main effect of peer housing—$F_{(1,26)} = 0.20$, $p = 0.66$, main effect of early-life experience—$F_{(1,26)} = 0.15$, $p = 0.70$, 2 × 2 ANOVA], arm B [**Figure 2E**, interaction—$F_{(1,26)} = 0.63$, $p = 0.43$; main effect of peer housing—$F_{(1,26)} = 3.38$, $p = 0.08$, main effect of early-life experience—$F_{(1,26)} = 0.07$, $p = 0.79$, 2 × 2 ANOVA], or arm C [**Figure 2F**, interaction—$F_{(1,26)} = 0.05$, $p = 0.83$; main effect of peer housing—$F_{(1,26)} = 0.24$, $p = 0.63$, main effect of early-life experience—$F_{(1,26)} = 0.04$, $p = 0.84$, 2 × 2 ANOVA] of the maze. Lastly, one-sample t-tests comparing mean percent arm entries to chance performance (33% entry per arm) indicated that neither experimental group displayed a preference in entering arm A [**Figure 2D**, Control Matched—$t_{(7)} = 0.59$, $p = 0.57$, Scarcity-adversity Matched—$t_{(7)} = 0.21$, $p = 0.84$, Control Mismatched—$t_{(6)} = 0.66$, $p = 0.53$, Scarcity-adversity Mismatched—$t_{(6)} = 0.64$, $p = 0.55$], arm B [**Figure 2E**, Control Matched—$t_{(7)} = 0.67$, $p = 0.52$, Scarcity-adversity Matched—$t_{(7)} = 0.25$, $p = 0.81$, Control Mismatched—$t_{(6)} = 0.17$, $p = 0.87$, Scarcity-adversity Mismatched—$t_{(6)} = 0.1.45$, $p = 0.20$], or arm C [**Figure 2F**, Control Matched—$t_{(7)} = 1.12$, $p = 0.30$, Scarcity-adversity Matched—$t_{(7)} = 0.69$, $p = 0.51$, Control Mismatched—$t_{(6)} = 1.68$, $p = 0.15$, Scarcity-adversity Mismatched—$t_{(6)} = 0.79$, $p = 0.46$].

Lastly, we checked if our peer housing mismatched condition improved scarcity–adversity reared subjects' social behavior, as intended (**Figure 3A**). Pre-weaning juvenile (PN20-22) scarcity–adversity reared subjects displayed a significant reduction in time spent with a social stimulus rat during the social behavior task relative to control reared subjects [**Figure 3B**; $t_{(14)} = 2.78$, $p = 0.015$, Cohen's $d = 1.39$, t-test]. Furthermore, assessment of social behavior in peri-adolescence (following the peer housing intervention) revealed a significant interaction of early-life experience and post-weaning housing condition on time spent with a social stimulus [**Figure 3C**; $F_{(1,28)} = 9.49$, $p = 0.01$, 2 × 2 ANOVA]. Specifically, if scarcity–adversity reared subjects were housed in matched peer housing conditions, they displayed reduced time spent with a social stimulus rat relative to control reared subjects (*post hoc tests*, $p < 0.05$, Cohen's $d = 1.53$). However, if scarcity–adversity reared subjects were housed in mismatched peer housing conditions, they did not differ from control subjects in time spent with a social stimulus rat (*post hoc* tests, $p < 0.05$), and spent significantly more time with a social stimulus relative to scarcity–adversity subjects in matched peer housing conditions (*post hoc* tests, $p < 0.05$, Cohen's $d = 1.52$).

DISCUSSION

It has long been theorized that humans develop higher mental functions, such as EFs, within the context of interpersonal interactions and social relationships (Vygotsky, 1978; Carlson, 2009; Lewis and Carpendale, 2009; Moriguchi, 2014; van Lier and Deater-Deckard, 2016). In the present study, we began to test the causal relations between social and EF development by using a rodent model to experimentally examine the contributions of peer socialization (the mismatched housing condition) to the development of working memory. Given the lack of research examining social contributions to EF development beyond early childhood, we focused our assessment on the contributions of post-weaning peer socialization on subsequent working memory performance. Specifically, we demonstrated that early-life scarcity–adversity, as modeled by rearing infant rat pups and their mother with insufficient wood shavings materials for nest building, reduced spatial working memory in peri-adolescence, as evidenced by reduced spontaneous alternation between arms of Y-maze. Notably, early-life scarcity–adversity did not produce alterations in overall number of arm entries during the Y-maze task, nor did it lead to a preference for entering a specific arm of the maze. Thus, it appears that early-life scarcity–adversity uniquely impacted spontaneous alternation between the maze arms, which we interpret as decreased working memory ability. However, we also found causal evidence that housing a scarcity–adversity reared rat with a control reared rat normalized working memory performance of scarcity–adversity reared peri-adolescents. This mismatched co-housing condition appears to have operated, at least in part, by improving scarcity–adversity reared subjects' social behavior, which is consistent with a broad literature supporting that EFs (such as working memory) develop through social interactions and the attainment of appropriate social skills (Vygotsky, 1978; Carlson, 2009; Lewis and Carpendale, 2009; Moriguchi, 2014; van Lier and Deater-Deckard, 2016; Perry et al., 2018b).

Prior research from Sullivan and colleagues established that our early-life scarcity–adversity model induces social avoidance in juvenile, adolescent, and adult rats (Raineki et al., 2012, 2015; Rincón-Cortés and Sullivan, 2016). Here, we replicated and expanded upon these findings by providing novel evidence that this socially avoidant phenotype co-occurs with working memory problems in peri-adolescent rats. Thus, the present study's findings supported our hypothesis that scarcity–adversity rearing would produce cognitive development problems, as evidenced via spatial working memory performance in a Y-maze. Our findings that social behavior and cognitive problems co-occurred by peri-adolescence align with increasing evidence that social and cognitive aspects of development are functionally and reciprocally linked (Riggs et al., 2006; Carlson, 2009; Lewis and Carpendale, 2009; Moriguchi, 2014; van Lier and Deater-Deckard, 2016; Perry et al., 2018b). Furthermore, our findings of scarcity–adversity induced working memory problems are consistent with human literature suggesting that poverty-related adversity negatively impacts EF development (Raver et al., 2013; Ursache et al., 2015; Perry et al., 2018b). Thus, our rodent model of scarcity–adversity appears to be somewhat translationally valid and can be further leveraged to discern behavioral and neurobiological mechanisms by which scarcity–adversity exposure influences EF development.

The present study's findings also support our hypothesis that socializing a scarcity–adversity reared subject with a control reared rat (via co-housing) would improve the scarcity–adversity reared subject's social behavior and working memory. Specifically, we demonstrated that pair housing a scarcity–adversity reared rat with a control reared rat rescued their socially avoidant behavior, as well as spatial working memory in a Y-maze. It is important to note that in our mismatched housing condition, the scarcity–adversity rat was not detrimental to control subjects' social behavior or working memory post-intervention. Altogether, these findings are consistent with ours and others' prior human research findings that support a theory of change whereby EFs of at-risk children can be improved by peer-based socialization that promotes the attainment of appropriate social skills. In humans, peers are powerful mediators of learning and gain increasing influence across development (Harris, 1995; Steinberg and Monahan, 2007; Rubin et al., 2011; Cappella et al., 2013; Telzer et al., 2018). Thus, peer-based interventions, particularly in middle childhood and beyond when peers become more central in youth's lives, are of high potential merit for the improvement of child EF outcomes. In human research, individual peer-based socialization interventions have been successfully employed in school-based settings for the improvement of prosocial behavior (Zhang and Wheeler, 2011), externalizing or internalizing problems (Fantuzzo et al., 2005), and learning outcomes (Odom and Strain, 1984; Topping, 1996; Fuchs et al., 2008, 2009). Furthermore, peer-based interventions have leveraged natural opportunities for peer interactions in school settings to successfully overcome high student-to-staff ratios and teacher burden (Bouffard and Little, 2003; Fantuzzo et al., 2005). However, few studies have begun to assess the efficacy of peer-based interventions in improving EFs (Christ et al., 2017).

Limitations and Future Directions

A major strength of this study was the use of an experimental design that provides high internal validity, allowing for a clearer definition of cause–effect relationships between social experiences and working memory performance. However, the current findings should be interpreted with the following limitations in mind. First and foremost, the high internal validity of the present study's rodent experimental design comes with a trade-off to the study design's external validity. Rodent models cannot encompass the complexity of human conditions (such as social and cultural phenomena), and thus appropriate caution should be taken when interpreting the present study's results (Perry et al., 2019). Additionally, while the present study's rodent findings provide causal support for the notion that peer interactions can be leveraged for the improvement of working memory, we have assessed working memory via only one outcome measure. Expanding ways in which working memory (and other measures of EFs) is assessed in rodent experimental designs would strengthen the present study's findings and interpretations.

Indeed, future rodent research should replicate and expand upon the assessment of working memory by exploring if early adversity similarly impacts in other domains of EF development (e.g., cognitive flexibility, inhibitory control). While considered functionally distinct "core" domains of EF, working memory, cognitive flexibility, and inhibitory control are related and typically operate together (Miyake et al., 2000; Friedman and Miyake, 2017). For example, working memory and inhibitory control largely support one another such that one skill is rarely called upon without the other (Diamond, 2013). Furthermore, cognitive flexibility, which develops later, builds upon working memory and inhibitory control (Diamond, 2013). Thus, it is plausible that scarcity–adversity induced differences in working memory might co-occur with problems related to inhibitory control and cognitive flexibility. However, working memory, inhibitory control, and cognitive flexibility differ in their developmental trajectories, and are subserved by overlapping but unique neural networks (for review see Perry et al., 2018a) which could be differentially impacted by scarcity–adversity. Thus, it is also plausible that scarcity–adversity might uniquely impact the development of each core EF based on the developmental timing of adversity exposure and/or the mechanisms by which adversity influences the developing brain areas underlying EF development.

The high internal validity of our rodent model also warrants future rodent research to disentangle the mechanisms mediating the functional interplay between social processes and EF development. Indeed, future experiments should attempt to discern the specific mechanisms by which mismatched peer housing conditions improve working memory performance. For example, observations of naturalistic rodent behaviors in the mismatched housing conditions will provide evidence to if and how control reared subjects scaffold scarcity–adversity reared subjects' social behavior. It is also possible that benefits of mismatched housing conditions are imparted via less directly observable mechanisms. For example, prior research has identified that microbial reconstitution rescues social behavior deficits in a mouse model of autism spectrum disorder (Buffington et al., 2016). Specifically, Buffington et al. (2016) utilized a mismatched housing intervention whereby offspring of mothers on a high-fat diet (MHFD) were co-housed with offspring of mothers on a regular diet (MRD). These mismatched housing conditions rescued social behavior deficits of MHFD offspring via a mechanism dependent on gut microbiota transfer from MRD offspring to MHFD offspring. Given the impact of gut microbiota on the brain (Cryan and Dinan, 2012), microbial transfer could underlie recovery of both social behavior and working memory. Future experimentation will help discern if similar mechanisms underlie our mismatched housing intervention, and thus provide important insight into means by which to improve EF development. Our rodent model can also be leveraged to determine how benefits to EF outcomes vary as a function of the developmental timing of our mismatched peer intervention, which would provide important insight for peer-based intervention efforts.

CONCLUSION

In conclusion, the present study has provided novel, causal evidence that a peer-based intervention spanning from immediately post-weaning to peri-adolescence rescues early-life scarcity-adversity induced working memory problems in rodents. Furthermore, the positive effects of this peer-based intervention appear to be operating, at least in part, via the improvement of scarcity-adversity reared subjects' social behavior. These findings converge with our lab's previous human research, as well as prior literature supporting an overarching theory that humans develop higher mental functions such as EFs within the context of interpersonal interactions and social relationships.

To the best of our knowledge, the present findings are the first of its kind using a rodent model, which opens opportunities for studies to assess the specific behavioral and neurobiological mechanisms by which social interactions influence cognitive development. Animal models, when carefully designed and considered within the context of human research findings, provide powerful means for the efficient assessment of theory-based mechanisms of change. Furthermore, animal models have a high potential to contribute to the development of mechanism-based, biologically sensitive interventions. While EF training can be effective in many forms, interventions targeting the improvement of social skills and social interactions may prove to be particularly efficacious and generalizable across context and areas of functioning, and thus should be the focus of continued research.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The animal study was reviewed and approved by New York University and Nathan Kline Institute's Animal Care and Use Committee.

AUTHOR CONTRIBUTIONS

RP, RS, MO, CA, and CB contributed to the conception and design of the study. RP performed rodent experiments and statistical analyses, and wrote the first draft of the manuscript. SB, MR-C, and DC performed rodent experiments. DC created illustrations for the figures. AB-A helped write sections of the manuscript. All authors contributed to manuscript revision, and read and approved the submitted version.

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Coding in Primary Grades Boosts Children's Executive Functions

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Several programs have been developed worldwide to improve children's executive functions (EFs). Yet, the role played in EF development by learning activities embedded in the school curriculum has received scarce attention. With two studies, we recently tested the effects of *computational thinking* (CT) *and coding*—a new element of the primary school curriculum—on the development of children's EFs. CT stimulates the ability to define a clear and orderly sequence of simple and well-specified steps to solve a complex problem. We conjecture that CT skills are associated to such EF processes as response inhibition and planning. In a first between-group cluster-randomized controlled trial, we tested the effects of 1-month coding activities on 76 first graders' planning and response inhibition against those of 1-month standard STEM activities of a control group. In a second study, we tested the effects of 1-month coding activities of 17 second graders in two ways: within group (longitudinally), against 7 months of standard activities experienced by the same children (experimental group); and between groups, in comparison to the effects of standard STEM activities in a control group of 19 second graders. The results of the two studies show significant benefits of learning to code: children exposed to coding improved significantly more in planning and inhibition tasks than control children did. The longitudinal data showed that improvements in planning and inhibition skills after 1 month of coding activities (eight lessons) were equivalent to or greater than the improvement attained after 7 months of standard activities. These findings support the hypothesis that learning CT *via* coding can significantly boost children's spontaneous development of EFs.

Keywords: coding, computational thinking, programming, executive function, primary school children

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INTRODUCTION

Between the ages of 5 and 7, in the transition period from preschool to primary school, children undergo rapid changes in their cognitive functioning (Roebers et al., 2011; Traverso et al., 2015; Vandenbroucke et al., 2017). The product of these changes, i.e., their resulting executive functioning (EF), has long-lasting effects on their future academic achievements and self-regulation skills (Altemeier et al., 2006; Friedman et al., 2014; Blair, 2016; Schmitt et al., 2017; Escobar et al., 2018; Stad et al., 2018). Interventions to enhance executive functions (EFs) in this time window thus are extremely important. The scientific literature suggests that the training of EFs has wider benefits if implemented early (Diamond et al., 2007; Espinet et al., 2013; Traverso et al., 2015; Blair, 2017) and if embedded in children's everyday activities (Traverso et al., 2015; Diamond and Ling, 2016; Blair, 2017).

Several studies have been conducted in the last few years to test the contribution of early intervention on the development of EFs (Liu et al., 2015; Traverso et al., 2015; Howard et al., 2018; Zhang et al., 2019). Other studies have explored the efficacy of *ad hoc* EF training programs (Kronenberger et al., 2011; Espinet et al., 2013; Grunewaldt et al., 2013; Hardy et al., 2016; Aarnoudse-Moens et al., 2018; Boivin et al., 2019; Zhang et al., 2019). For a review of intervention programs, see Diamond and Ling (2019). To date, however, the role played by everyday curriculum-based, learning activities on children's EFs has received scarce attention.

This paper addresses this gap by examining the effects of a new curriculum-based activity (coding) on first and second graders' EFs. Coding (i.e., programming) is the instrumental skill of computational thinking (CT), broadly referred to as the set of problem-solving processes that underlie the solution of computational problems (i.e., those whose solution can be performed by a computing agent) (Wing, 2006; Roman-Gonzalez et al., 2017). Although related to an approach to problem-solving that is proper of computer science (Wing, 2006; Nardelli and Ventre, 2015; Florez et al., 2017), CT can be conceived as a general way of thinking of problems, and thus it can be generalized to various types of problems that do not directly involve programming tasks or computers (Wing, 2006). Coding is the prime means used to teach CT in primary schools (Lye and Koh, 2014; Nardelli and Ventre, 2015; Saez-Lopez et al., 2016; Roman-Gonzalez et al., 2017; Tuomi et al., 2018).

Testing the Effects of Coding on EF

Some studies have focused on the general effects of schooling on EFs (Brod et al., 2017; Zhang et al., 2019). Yet, very few studies have examined the association between specific curriculum-based activities at school (e.g., literacy activities) and EFs (Diamond et al., 2007; Burrage et al., 2008; Baker et al., 2015). Except for a few notable exceptions (e.g., Diamond et al., 2007; Blair and Raver, 2014), such studies did neither apply a randomized controlled trial design (Baker et al., 2015) nor compare children of the same level of instruction (Burrage et al., 2008). For example, Burrage et al. (2008) compared pre-kindergarten to kindergarten children of the same age, the former waiting to enter the kindergarten, the latter attending it. Thus, their study lacked a comparison condition in which the specific literacy activity (e.g., letter and word reading) had not been introduced yet in the curriculum at that grade level (kindergarten).

The problem in determining the benefits for EFs drawn from specific learning activities in school is that no control groups (i.e., children who lack the relevant experience) typically exist: All children learn to read and write, though with alternate success. However, the recent introduction of CT, and with it, of coding in the primary school curriculum in Europe and the United States, provides the opportunity to test the effects of a new curriculum-based learning activity on children's EFs.

Computational thinking involves a set of higher order cognitive abilities, such as (1) to analyze problems and decompose them in smaller parts; (2) to plan a sequence of steps or instructions for the solution of each sub-problem, intended for the execution by either a computer or a human agent; (3) to recognize errors in the solution, and fix them (i.e., debugging); (4) to generalize or apply the problem-solving strategies learnt to different contexts and other kinds of problem-solving tasks (Wing, 2006; Shute et al., 2017). Owing to its being a problem-solving process, CT makes significant demands on the individual's EFs, requiring a significant extent of working memory capacities (Shute et al., 2017), response inhibition (Di Lieto et al., 2017), and planning (Chao, 2016). Conceivably, therefore, guided experience of CT problems, through coding activities in school, might boost children's EFs significantly.

In several countries, including Italy, children enter school with no prior or very limited knowledge of coding. While spreading worldwide, coding instruction is not yet adopted in all schooling institutions and classroom laboratories. These circumstances allow researchers to explore the effects of this specific learning activity on children's cognitive skills and EFs.

The Teaching of Coding in Primary School

The state-of-the-art literature in this field suggests that several approaches and tools can be used to teach coding in primary schools (Florez et al., 2017), with block-based visual programming, like Scratch[1] (Resnick et al., 2009; Saez-Lopez et al., 2016) or Code.org[2] (Kalelioglu, 2015), seen as the most effective for preschoolers and children beginning primary school (Saez-Lopez et al., 2016). The two studies presented in this paper used resources from Code.org to train the coding skills (and EFs through them) of Italian children in first and second grades.

Code.org is an open-source programming platform launched by the Code.org non-profit to expand access to computer science in schools among young children (Kalelioglu, 2015; Nardelli and Ventre, 2015), and to increase participation to it by under-represented gender and social minorities. Coding exercises on Code.org employ intuitive drag-and-drop applications and block-based visual language, particularly appropriate for young learners (Kalelioglu, 2015; Saez-Lopez et al., 2016). The platform provides engaging scenarios for children of different age and gender, and personalized feedback, which allow tailoring the pedagogical experience to the individual child. The teaching of coding may involve plugged (computer based) and unplugged (e.g., paper and pencil) learning activities, whose common goal is to introduce children to problem-solving through programming. Children are introduced to a programming language (prevalently block-based and visual) and to the use of the logical operators involved in developing a program, such as sequencing (defining a sequence of steps to achieve a goal), or debugging (locating errors in the program and correcting them). A program is operatively defined to children as any sequence of instructions that guide an artificial agent (a computer) or a fellow human to achieve a stated goal. Thanks to the accessibility of resources like Code.org or Scratch, instructional coding activities are slowly spreading across schools. Yet, the schools in which coding has been regularly embedded in the STEM curriculum are still few, and most teachers lack familiarity with coding resources

[1] http://scratch.mit.edu

[2] https://code.org/

as well as with the instructional basics to introduce their classrooms to coding.

To the best of our knowledge, the only study that has investigated the cognitive effects of Code.org activities at primary school (Kalelioglu, 2015) exposed fourth graders to a 5-h course (1 h per week) through the Code.org platform. Kalelioglu (2015) assessed the effects of that learning activity on children's reflective thinking toward problem-solving. Such trial found no evidence of significant positive effects of coding on it. Yet, the ability assessed by Kalelioglu (2015) (reflective thinking, which is part of critical thinking) might arguably be too complex for fourth graders, and with insufficient sensitivity to the nuances in cognitive changes induced by the coding activities at that age.

In the two studies presented in this paper, we tested the effects of coding (problem-solving) activities selected from Code.org on 5- to 6-year-old children's planning and response inhibition skills. Those two EFs are especially interesting as their development undergoes substantial changes from preschool to the first years of primary school (Davidson et al., 2006; Diamond, 2006; Magi et al., 2016; Zelazo et al., 2016; Di Lieto et al., 2017). We also show how 1 month of *ad hoc* designed coding activities in second grade can produce a greater improvement in these EFs than that observed in the same children after 7 months of regular curriculum and learning activities.

The teaching of coding involves the ability to analyze problems and to conceive algorithmic procedures (i.e., plans) for their solution (Florez et al., 2017). Given the role played by planning in (computational) problem-solving (Chao, 2016; Chen et al., 2017), we believe that the cognitive ability to plan can be scaffolded and enhanced by appropriate CT activities in the class. For instance, putting individual program instructions into an ordered sequence, a key methodical skill of CT, does involve working memory and planning, that is, the ability to organize a sequence of actions in a manner apt to achieve a given goal (Bers et al., 2014). Moreover, as analyzing the problem space to devise a multi-step plan also requires cognitive control over immediate and impulsive responses (Luciana et al., 2009; Wang and Chiew, 2010; Magi et al., 2016), we conjecture that learning to code—to solve computational problems—may also foster the development of children's response inhibition skills. Some preliminary evidence (Di Lieto et al., 2017) suggests the association between coding and the development of inhibition skills in young children (aged 5–6 years). Di Lieto et al. (2017) demonstrated the positive effects of programming in a tangible environment (one in which children interact with physical objects, robots, in a physical space, e.g., a room), on the working memory and inhibition skills of a group of 12 5–6-year-old preschoolers. Being tangible, that is, concrete, the learning environment of educational robotics is deemed particularly appropriate to stimulate the cognitive skills of preschoolers and young primary school children (Wyeth and Wyeth, 2001; Bers et al., 2014; Shim et al., 2017). Our studies extend the findings of Di Lieto et al. (2017) by examining whether also *virtual* learning environments, such as those provided by the Code.org platform, can be effective in improving 5–6-year-old children's EFs, i.e., planning and inhibition skills.

As noted above, transition to school is a particularly sensitive period for the development of EFs (Roebers et al., 2011; Macdonald et al., 2014; Magi et al., 2016; Poutanen et al., 2016). Recently, Macdonald et al. (2014) observed that response inhibition skills develop rapidly in the early school years, from the age of 5 to 7. Also, planning skills seem to develop significantly in the first years of schooling (Magi et al., 2016; Poutanen et al., 2016) and their development relate significantly to that of reading and math skills (Crook and Evans, 2014; Magi et al., 2016). Thus, interventions designed to boost the development of response inhibition and planning can be particularly effective in this time window. Delivered at this age, they also may have positive impact on other school achievements.

STUDY 1

Study 1 addressed the following two research questions:

(1) Can a short training with coding (4 weeks) through Code.org enhance the planning and response inhibition skills of first graders? Based on prior research (Di Lieto et al., 2017), we anticipated that learning to code would affect positively both planning and response inhibition, increasing planning time and accuracy on standardized planning tasks, and contributing to decrease inhibition errors and inhibition time on standardized inhibition tasks.
(2) Are the positive effects of such training retained at 1 month from the end of the intervention? We predicted that positive training effects would be maintained.

We performed a cluster-randomized controlled trial (Campbell et al., 2012) to test the effects of exposure to Code.org activities. Four classrooms of first graders (80 children) were randomly assigned to an experimental condition (coding) or control condition (waiting list), based on a matched design procedure. Classrooms were matched in pairs on gender distribution, age, socio-economic status (SES), and for teachers (i.e., each classroom pair had the same team of teachers), and then randomly assigned to either coding training or the waiting-list condition. The coding abilities, planning skills, and response inhibition skills were tested before (pre-test, T1) and after (post-test, T2) the coding intervention, as well as at 1-month distance from the training (delayed post-test, T3). The waiting-list group received the coding intervention after the post-test (T2); hence, the assessment at T3 was the post-test for this group (see **Figure 1**).

Participants

Eighty 5–6-year-old children at the beginning of first grade participated in the study. The experimental group included 44 first graders (20 girls, 45%, 24 boys, 54%, mean age 6.07). The waiting-list group consisted of 36 first graders (21 girls, 58%, 15 boys, 42%, mean age 5.9). None of those children needed or received treatment for learning disabilities or developmental disorders. All were native Italian speakers. Parental written informed consent was collected before the study for all participants. The study was approved by the Ethical Committee

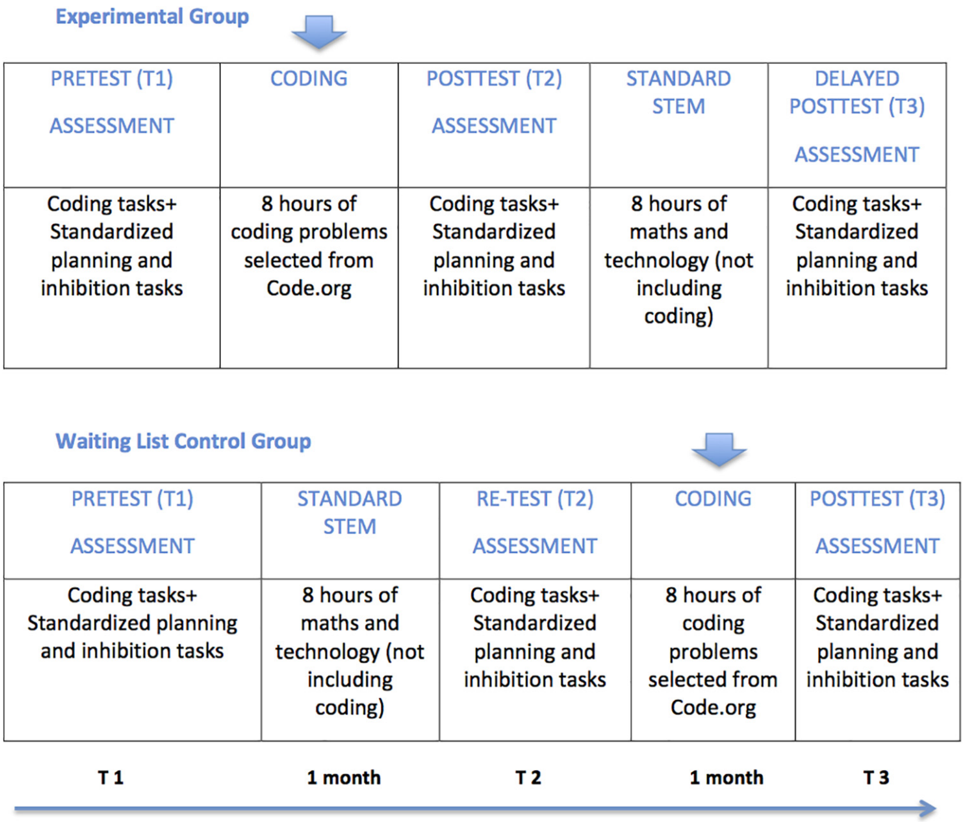

FIGURE 1 | Experimental design study 1.

of the Department of Developmental Psychology (University of Padova, Italy). Demographic data for the experimental and waiting control group are reported in **Table 1**.

Socio-Economic Status

As children's ability to benefit from coding can be mediated by low SES (Israel et al., 2015) and SES is associated with poorer EF skills and school achievement in STEM (Blair and Raver, 2016; Blums et al., 2017), the SES of the two groups was assessed to make sure they not differ on this variable. Socio-economic data were collected through a socio-demographic questionnaire that parents returned with the written informed consent to the study. Children's SES was estimated based on parents' education (from 0, less than elementary school, to 4, college) and occupation (from 1, unemployed, to 4, professional roles). A composite score was calculated as the sum of the highest education score and the highest occupation score obtained by either parent (Arfé et al., 2018), with a maximum score of 8.

TABLE 1 | Study 1: Demographic characteristics of the experimental and waiting group.

	Experimental	Waiting	*p*-value
Gender			
Girls (*n*, %)	19, 45%	20, 59%	0.25
Boys (*n*, %)	23, 55%	14, 41%	
Age (*M*, *SD*)	6.05 (0.58)	5.97 (0.46)	0.53
SES (*M*, *SD*)	6.14 (1.42)	5.71 (1.73)	0.23

Procedure and Materials

We used a selection of Code.org coding problems for training (Arfé et al., under review). With Code.org, children move blocks of basic instructions (code) to generate sequences of commands that instruct a sprite (e.g., an angry bird) to perform actions, in the intent to achieve a given goal. The platform provides visual and written informative feedback upon execution. Task difficulty increases progressively as children improve in coding, so that children face coding trials of rising difficulty: e.g., sequences, loops, and conditional instructions. The overall lesson plan involved eight coding sessions (two lessons a week for 4 weeks) and was designed to cause children to switch computing functions or scenarios frequently, to maintain a problem-solving approach to the coding tasks. Course 1 of the Code.org platform "Programma il futuro"[3] was used, as our participants were beginning readers.

Children worked alone at their computer in a laboratory. A post-graduate student, trained by the first and second author of this study, conducted the coding lessons. Each coding lesson

[3]https://programmailfuturo.it/come/lezioni-tecnologiche/corso-1

TABLE 2 | Lesson plan.

Coding sessions	Course A	Trial number	Content
Session 1	Lesson 3	1, 6	Jigsaw: Drag and Drop
	Lesson 4	2, 5, 6, 7	Maze: Sequence
Session 2	Lesson 4	8, 10	Maze: Sequence
	Lesson 5	3, 4, 5, 6, 7	Maze: Debugging
Session 3	Lesson 5	8, 9,10	Maze: Debugging
	Lesson 8	4, 5, 6, 7, 8	Artist: Sequence
Session 4	Lesson 8	9, 10, 11	Artist: Sequence
	Lesson 10	4, 5, 6, 7, 8	Artist: Shapes
Session 5	Lesson 13	1, 2, 3, 4, 5, 6, 7	Maze: Loops
Session 6	Lesson 13	8, 9, 10, 11, 12	Maze: Loops
Session 7	Lesson 14	3, 5, 6, 7, 8, 9	Bee: Loops
Session 8	Lesson 18	2, 4, 5, 6, 7	Artist: Loops
Closing session	Classroom discussion	What have we learned?	Metacognitive reflection on the goals of computational thinking and the meaning of programming

lasted about 60 min, and involved the execution of five to eight coding problems (see **Table 2** for the full lesson plan).

Pre-test, Post-test, and Delayed Post-test Assessment

Coding skills

At the pre-test and post-test, and at the delayed post-test, children performed four coding problems from Code.org (Course 1, Italian platform) individually: trial 9 (lesson 4), trial 2 (lesson 5), trial 3 (lesson 8), and trial 4 (lesson 14). Both the experimental and the waiting group first familiarized with the Code.org platform and the drag-and-drop mechanics, performing the first trial of lessons 4, 5, 8, and 14 from Course 1, assisted by the experimenter. The pre-test started after this familiarization phase.

For each test trial, we recorded both accuracy and planning time:

(1) *Accuracy*: a score of 2 was given if the child successfully solved the item at first attempt, 1 on solving it at the second attempt, 0 otherwise;
(2) *Time spent planning*: the seconds elapsed from the moment the child received the task instructions to the moment s/he moved the first block was recorded.

Planning and response inhibition skills

We used standardized tests to assess children's response inhibition and planning at T1, T2, and T3: two tasks were used to assess inhibition and planning skills to verify whether potential benefits on EFs generalized across different tasks.

Planning skills

The *Elithorn maze test* (Spinnler and Tognoni, 1987) and the *Tower of London* (ToL; Luciana et al., 2009) were used to assess non-verbal planning skills.

The Elithorn maze test assesses non-verbal planning by requesting the child to trace a line on a maze to connect a number of black dots, arranged randomly on grids. Three rules are given: trace lines from the bottom up; do not cross over the grid; and do not backtrack. The overall test consists of eight mazes, each of which to be performed in no more than 2 min. Although originally standardized for Italian adolescents aged 12–18 years (BVN, Batteria per la Valutazione Neuropsicologica) (Gugliotta et al., 2009), recently the task has been used also with younger children, from the age of 6, demonstrating good sensitivity to their planning skills (Arfé et al., 2018). The children's individual performance was scored for:

(1) *Accuracy*: i.e., the total number of mazes successfully completed within 2 min. The scoring system was 2 for each trial successfully solved within 1 min; 1 if the task was solved within 2 min; 0.5 when the solution was incomplete (i.e., all the dots except for the final one) at the expiry of the 2 min; 0 otherwise.
(2) *Planning time*: the response latency, in seconds, from the time the child receives the instructions until when s/he starts tracing the path on the grid.

The ToL assesses problem-solving and planning skills in children and adolescents (Luciana et al., 2009). The version used in this study is standardized for a population aged 4–13 years (Fancello et al., 2013). The task requires reproducing a configuration of three colored balls (blue, red, and green) on three vertical sticks of different heights, according to a set of rules: moving one ball at a time; once picked up, not holding the ball or placing it on the table; not placing more than one ball on the lower stick; not placing more than two balls on the medium stick. The entire test consists of 12 trials of increasing difficulty. Only one attempt per trial was allowed, and all 12 trials were presented, with no interruption criteria. The children's performance was scored for:

(1) *Accuracy*: the attempt was scored 1 if the child performed the trial correctly within 1 min, without breaking any rule; 0 otherwise.
(2) *Planning time*: the seconds elapsed from when the trial is shown to the child until when s/he makes the first move.

Response inhibition skills

The *inhibition (squares/circles) subtest* of NEPSY-II (Korkman et al., 2007) and the *Numerical Stroop test* of the *Batteria Italiana ADHD* (BIA, Marzocchi et al., 2010) were used to assess children's ability to inhibit automatic responses.

The *NEPSY-II inhibition (squares/circles) subtest* is standardized for children aged 3–16 (Korkman et al., 2007). The child is presented with a sheet displaying a set of figures (squares and circles) in five rows (eight figures per row) and asked to name aloud the figures from left to right as quickly and accurately as possible. The *inhibition task* is then performed: the child is instructed to say "circle" when seeing a square, and say "square" when seeing a circle, thus inhibiting automatic name retrieval. The children's execution time is recorded.

The children's performance was scored for:

(1) *Accuracy*: number of errors and self-corrections made by the child in performing the task;
(2) *Inhibition time*: the seconds required to complete the task.

The *Numerical Stroop test* of the BIA (Marzocchi et al., 2010) is standardized for children aged 6–11. The test assesses response inhibition by asking the child to suppress automatic digits recognition to pronounce the number of digits (ranging from 1 to 5) displayed on a table. Each cell of the table shows a digit from 1 to 5 repeated *n* times (for example, the digit 5, repeated three times). The child is asked to say as quickly and accurately as possible how many times the given digit (in the example, "5") is shown in the cell (in the example, "three" times). The children's performance is scored for:

(1) *Accuracy*: number of errors and self-corrections;
(2) *Inhibition time*: the seconds required to complete the task.

Data Analyses

Scores distribution was checked by inspecting skewness and kurtosis. Four outliers were identified (two with absolute skewness >2 and two with absolute kurtosis >7) and deleted from subsequent analyses resulting in a final sample size of 76 (n = 42 for the training group and n = 34 for the waiting-list group). Levene tests showed that variance was homogeneous between groups. The first research question of this study was whether training coding skills through Code.org would enhance the planning and response inhibition skills of first graders. Our hypothesis was that learning to code would enhance not only children's coding skills but also their planning and response inhibition, increasing planning time and accuracy on standardized planning tasks, and contributing to decrease inhibition errors and inhibition time on standardized inhibition tasks. The second research question of the study was whether the positive effects of such training would be retained at 1 month from the end of the intervention. We predicted that positive training effects would be maintained.

As assignment to the different treatment conditions was at classroom level, a multilevel analysis was initially conducted to test the hypotheses of the study, while accounting also for the nested structure of the data. Intervention effects were tested by comparing the post-test performance of the two groups, with classroom as random contextual factor. Age, SES, and pre-test scores were included as covariates. The models showed non-significant and insufficient inter-cluster variance (across classrooms). Only intra-cluster variance (i.e., at participant level) was significant. As only the fixed-factor (group) and the covariates accounted for significant variance in children's performance scores, analyses of variance (ANOVAs) were subsequently used to test the effects of the intervention and their maintenance. According to our hypotheses, learning to code (i.e., improvements in coding skills) would transfer to planning and response inhibition skills. Thus, we first tested that the training was effective in developing coding skills, and then verified its effects on children's planning and response inhibition skills. Accordingly, planning time and accuracy on the coding tasks, planning time and accuracy on the Elithorn and ToL tasks, and inhibition time and accuracy on the NEPPSY-II and the numerical Stroop task were the dependent measures of the ANOVAs. A two (Group: experimental, waiting-list control) × two (Time: T2-post-test, T3-delayed post-test) mixed ANOVA tested the effects of the intervention. SES, age, and pre-test scores were covaried. Pre-test (T1) scores were covaried to control for variance in the dependent variables at the pre-test. This analytic strategy allowed testing in the same analysis both hypothesis 1 (the positive effects of the coding training) and hypothesis 2 (retention of the training effects at the delayed post-test). As the experimental group received the intervention between T1 and T2, while the wait list control group received it between T2 and T3 (see **Figure 1**), an interaction between Group and Time was expected, with better performance of the experimental group at the post-test (T2) and significant improvement of the performance of the wait list control group only between T2 and T3. Lack of significant differences between T2 (post-test) and T3 (delayed post-test) for the experimental group would indicate that the training effects were retained at 1 month from the end of the intervention. Significant interactions were explored by paired- and independent-samples t-tests. Effect sizes were computed using Cohen's d, and correlations between repeated measures were used to correct for dependence between means (Morris and DeShon, 2002).

Results

Between-group differences in age and SES and in the dependent (EF and coding) variables' pre-test scores were explored by t-tests. A chi-square analysis was conducted to test for differences in gender distribution. The analyses showed that the two groups were equivalent for age, $t(74) = -0.63$, $p = 0.53$, SES, $t(74) = -1.21$, $p = 0.23$, and gender, $\chi^2 = 1.39$, $p = 0.24$. Statistically significant differences between the groups at the pre-test were found for accuracy on the coding task, $t(74) = -3.47$, $p = 0.001$ and the ToL, $t(74) = -2.88$, $p = 0.005$. In both cases, the experimental group showed a better pre-test performance than the wait list control group (see **Tables 3**, **4**). The difference approached significance for inhibition time and errors on the NEPSY-II, $t(74) = 2.00$, $p = 0.05$ and $t(74) = 1.96$, $p = 0.05$ (see **Table 3**). In the following, we report the results of the mixed ANOVAs for each dependent measure (planning time and accuracy at coding tasks, and planning time and accuracy, response inhibition time, and errors at standardized tasks).

Effects of Learning to Code on Coding Skills: Planning Time

The covariates planning time at T1 and age were significant: $F(1,71) = 6.49$, $p = 0.01$, $\eta_p^2 = 0.08$, and $F(1,71) = 4.42$, $p = 0.05$, $\eta_p^2 = 0.06$. The main factor Group was also significant, with a large effect size: $F(1,71) = 36.04$, $p < 0.001$, $\eta_p^2 = 0.34$. Finally, also the interaction between Time and Group was significant (the effect size was very large): $F(1,71) = 46.56$, $p < 0.001$, $\eta_p^2 = 0.40$. At the post-test (T2), the experimental group spent significantly less time than the waiting-list (control) group on planning, $t(74) = 6.78$, $p < 0.001$, Cohen's $d = -1.56$ (the effect size was very large), but no significant differences between the two groups were observed at T3, after the wait list control group received the intervention, $t(74) = -0.16$, $p = 0.87$ (see also **Table 4**). Between T2 and T3, the waiting-list group's planning time decreased significantly, with a very large effect size, $t(33) = -6.53$, $p < 0.001$, Cohen's

TABLE 3 | Study 1—between-group comparison: planning and response inhibition at T1, T2, and T3.

		Wait list *M* (*SD*)	Experimental *M* (*SD*)	Independent samples *t*-test	Cohen's *d*
Planning time Elithorn	$T1^{pre\text{-}test}$	22.76 (15.97)	25.71 (13.92)	−0.859	0.19
	$T2^{post\text{-}test}$	20.61 (11.61)	25.50 (10.38)	−1.93	0.45
	$T3^{delayed\ post}$	23.88 (9.59)	23.18 (7.78)	0.35	−0.08
Accuracy Elithorn	$T1^{pre\text{-}test}$	5.47 (3.35)	6.75 (2.87)	−1.79	0.41
	$T2^{post\text{-}test}$	7.29 (3.53)	9.96 (3.04)	−3.54***	0.82
	$T3^{delayed\ post}$	11.06 (3.29)	11.51 (2.54)	−0.677	0.15
Planning time ToL	$T1^{pre\text{-}test}$	9.20 (4.42)	7.77 (3.33)	1.60	−0.37
	$T2^{post\text{-}test}$	8.21 (3.33)	7.22 (3.09)	1.35	−0.31
	$T3^{delayed\ post}$	9.04 (4.17)	7.93 (3.77)	1.21	−0.28
Accuracy ToL	$T1^{pre\text{-}test}$	6.03 (2.47)	7.52 (2.05)	−2.88**	0.66
	$T2^{post\text{-}test}$	7.85 (2.08)	9.71 (1.86)	−4.11***	0.95
	$T3^{delayed\ post}$	10.29 (2.29)	9.93 (1.99)	0.74	−0.17
Inhibition time NEPSY-II	$T1^{pre\text{-}test}$	56.21 (14.57)	50.97 (7.83)	2.00	−0.46
	$T2^{post\text{-}test}$	47.88 (11.46)	45.45 (7.92)	1.09	−0.25
	$T3^{delayed\ post}$	39.66 (9.21)	42.33 (8.24)	−1.33	0.31
Errors NEPSY-II	$T1^{pre\text{-}test}$	3.56 (2.58)	2.43 (2.43)	1.96	−0.45
	$T2^{post\text{-}test}$	2.85 (2.35)	1.56 (1.65)	2.84*	−0.65
	$T3^{delayed\ post}$	1.26 (1.78)	2.02 (2.36)	−1.55	0.36
Inhibition time Stroop	$T1^{pre\text{-}test}$	216.3 (65.93)	218.0 (56.13)	−0.12	0.03
	$T2^{post\text{-}test}$	186.1 (69.85)	178.1 (36.75)	0.64	−0.15
	$T3^{delayed\ post}$	152.3 (37.11)	157.2 (39.20)	−0.56	0.13
Errors Stroop	$T1^{pre\text{-}test}$	7.97 (6.14)	6.83 (6.47)	0.78	−0.18
	$T2^{post\text{-}test}$	5.47 (5.09)	2.02 (2.38)	3.89***	−0.90
	$T3^{delayed\ post}$	2.53 (2.38)	3.33 (3.91)	−1.05	0.24

****p* ≤ 0.001; ***p* < 0.005; **p* < 0.01. Adjusted p = 0.02 after Bonferroni corrections.*

TABLE 4 | Study 1—between-group comparison: performance at the coding tasks at T1, T2, and T3.

		Wait list *M* (*SD*)	Experimental *M* (*SD*)	Independent samples *t*-test	Cohen's *d*
Planning time coding	$T1^{pre\text{-}test}$	48.00 (23.29)	42.30 (22.45)	1.08	−0.25
	$T2^{post\text{-}test}$	38.95 (25.26)	11.56 (6.29)	6.78***	−1.56
	$T3^{delayed\ post}$	11.33 (6.89)	11.54 (4.43)	−0.16	0.04
Accuracy coding	$T1^{pre\text{-}test}$	3.09 (1.60)	4.31 (1.46)	−3.47***	0.80
	$T2^{post\text{-}test}$	3.68 (1.92)	6.12 (1.06)	−7.03***	1.62
	$T3^{delayed\ post}$	5.70 (0.94)	5.81 (1.09)	−0.44	0.11

****p* < 0.001. Adjusted p = 0.02 after Bonferroni corrections.*

$d = 3.21$, whereas no significant differences were observed for the experimental group, $t(41) = -0.022$, $p = 0.98$.

Effects of Learning to Code on Coding Skills: Accuracy

The covariates coding pre-test accuracy and age were significant, respectively: $F(1,71) = 31.72$, $p < 0.001$, $\eta_p^2 = 0.31$, and $F(1,71) = 11.96$, $p = 0.001$, $\eta_p^2 = 0.14$. Group was significant, $F(1,71) = 13.00$, $p = 0.001$, $\eta_p^2 = 0.15$. The effect size was large. Moreover, also the interaction Time × Group was significant, with a very large effect size: $F(1,71) = 32.93$, $p < 0.001$, $\eta_p^2 = 0.32$. **Table 4** shows that the experimental group, who received the coding intervention between T1 and T2, performed significantly better than the wait list control group at the post-test (T2): $t(74) = -7.03$, $p < 0.001$, Cohen's $d = 1.62$ (the effect size was very large). However, at T3, once the waiting-list group was exposed to the intervention, the difference between the two groups was no longer significant, $t(74) = -0.44$, $p = 0.66$. In fact, the performance of the waiting-list group improved significantly between T2 and T3, with the intervention, $t(33) = 6.63$, $p < 0.001$, Cohen's $d = -1.94$ (the effect size was very large), whereas that of the experimental group remained stable, $t(41) = -1.73$, $p = 0.09$.

Effects of Learning to Code on Planning Skills: Planning Time

Elithorn

The ANOVA did not reveal significant effects of Group or Time on Elithorn planning time. The covariates (age, SES, and pre-test Elithorn planning time) were non-significant.

ToL

The covariates, pre-test planning time, and age were significant: respectively, $F(1,71) = 17.16$, $p < 0.001$, $\eta_p^2 = 0.19$ and $F(1,71) = 8.94$, $p < 0.005$, $\eta_p^2 = 0.11$. The main factor Time was also significant, $F(1,71) = 4.44$, $p < 0.05$, $\eta_p^2 = 0.06$. The means reported in **Table 3** show that planning time slightly increased for both groups between T2 and T3. Group and the interaction Time × Group were non-significant.

Effects of Learning to Code on Planning Skills: Planning Accuracy

Elithorn

The covariate Elithorn pre-test accuracy was significant, $F(1,71) = 9.65$, $p < 0.005$, $\eta_p^2 = 0.12$. Group and the interaction Time × Group were also significant, both with a medium effect size: $F(1,71) = 4.62$, $p < 0.05$, $\eta_p^2 = 0.06$ (Group), and $F(1,71) = 5.28$, $p < 0.05$, $\eta_p^2 = 0.07$ (Time × Group). The *post hoc* *t*-tests, reported in **Table 3**, show that at the post-test (T2) the experimental group performed significantly better than the control group: $t(74) = -3.54$, $p < 0.001$, Cohen's $d = 0.80$. The effect size was large. However, at the delayed post-test (T3), the wait list control group caught up with the experimental group: $t(74) = -0.677$, $p = 0.500$. The paired-samples *t*-tests showed that the waiting-list group improved indeed significantly from T2 to T3 (the effect size was large): $t(33) = 5.68$, $p < 0.001$, Cohen's $d = -1.01$. Also, the experimental group improved, but less: $t(41) = 3.19$, $p < 0.005$, Cohen's $d = 0.55$ (see **Figure 2A**).

ToL

The covariates age and pre-test ToL accuracy were significant, respectively, $F(1,71) = 7.01$, $p = 0.01$, and $\eta_p^2 = 0.09$, and $F(1,71) = 18.10$, $p < 0.001$, and $\eta_p^2 = 0.20$. The interaction Time × Group was significant, $F(1,71) = 16.84$, $p < 0.001$, and $\eta_p^2 = 0.19$. The effect size of the interaction was large. The experimental group performed significantly better than the wait list control group at T2 (the post-test), $t(74) = -4.11$, $p < 0.001$, Cohen's $d = 0.95$. Between T2 and T3, with the intervention, the performance of the waiting-list group improved significantly: $t(33) = 6.30$, $p < 0.001$, $d = -1.03$ (the effect size was large), equaling that of the experimental group at T3, $t(74) = 0.744$, $p = 0.459$ (see **Table 3**). No significant differences were found between T2 and T3 for the experimental group, $t(41) = -0.795$, $p = 0.43$, indicating that the performance of this group remained stable (see **Figure 2B**).

Effects of Learning to Code on Response Inhibition Skills: Response Inhibition Time

NEPSY-II

The covariate, pre-test inhibition time, and the factor Group were significant, respectively: $F(1,71) = 72.07$, $p < 0.001$, $\eta_p^2 = 50$, and $F(1,71) = 4.36$, $p < 0.05$, $\eta_p^2 = 06$. The interaction Time × Group approached statistical significance, $F(1,71) = 3.92$, $p = 0.05$, $\eta_p^2 = 0.05$ (the effect size was medium). However, no significant differences emerged between the two groups at the post-test (T2): $t(74) = 1.09$, $p = 0.28$, or at the delayed post-test (T3), $t(74) = -1.33$, $p = 0.19$. Between the post-test (T2) and the delayed post-test (T3), inhibition time decreased significantly for both groups, with a large effect size for the waiting-list control group, $t(33) = -4.68$, $p < 0.001$, and, $d = 0.92$, and a small effect size for the experimental group, $t(41) = -2.47$, $p < 0.05$, and $d = 0.37$. Inspection of the means reported in **Table 3** shows that the decrease in inhibition time was steady from T1 to T3 for both groups.

Stroop

The analyses revealed only an effect of the covariate, pre-test Stroop time, $F(1,71) = 88.99$, $p < 0.001$, $\eta_p^2 = 0.56$. **Table 3** shows that the between-group difference was not significant at the post-test (T2), $t(74) = 0.64$, $p = 0.52$ or at the delayed post-test (T3), $t(74) = -56$, $p = 0.58$. For both groups, Stroop time decreased significantly between T2 and T3: The effect size was large for the wait list control group, $t(33) = -3.62$, $p = 0.001$, $d = 1.07$, and medium for the experimental group, $t(41) = -4.29$, $p < 0.001$, $d = 0.64$. Similar to the NEPSY-II inhibition task, a steady decrease in inhibition time from T1 to T3 was observed (see **Table 3**).

Effects of Learning to Code on Response Inhibition Skills: Response Inhibition Errors

NEPSY-II

The covariate, pre-test inhibition errors, was statistically significant, $F(1,71) = 5.71$, $p < 0.05$, $\eta_p^2 = 0.07$. The interaction Time × Group was also significant, $F(1,71) = 7.97$, $p < 0.01$, $\eta_p^2 = 0.10$ (the effect size was medium). The experimental group, who received the intervention between T1 and T2, made significantly fewer errors than the waiting-list group at T2, $t(74) = 2.84$, $p < 0.01$, Cohen's $d = -0.65$ (the effect size was medium), but at T3, the performance of the two groups was equivalent, $t(74) = -1.55$, $p = 0.12$. Indeed, between T2 and T3, the wait list control group showed a significant decrease in the number of inhibition errors, $t(33) = -3.76$, $p < 0.001$, Cohen's $d = 0.76$ (the effect size was medium). The performance of the experimental group remained instead stable in this time interval, $t(41) = 1.18$, $p = 0.246$ (**Figure 3A**).

Stroop

The covariate T1 Stroop errors was significant, $F(1,71) = 11.76$, $p = 0.001$, $\eta_p^2 = 0.14$. The interaction Time × Group was also significant, $F(1,71) = 21.00$, $p < 0.001$, $\eta_p^2 = 0.23$ and the effect size was very large. At T2, the experimental group made significantly fewer Stroop errors than the wait list control group, $t(74) = 3.89$, $p < 0.001$, Cohen's $d = -0.90$ (the effect size was large). At T3, the difference between the two groups was no more significant, $t(74) = -1.05$, $p = 0.30$ (see **Table 3**), due to the significant decrease in the number of inhibition errors of the waiting-list group between T2 and T3, $t(33) = -3.74$, $p = 0.001$, Cohen's $d = 1.16$ (see **Figure 3B**). The effect size was large. The number of Stroop errors slightly increased for the experimental group between T2 and T3, $t(41) = 2.58$, $p = 0.01$, Cohen's $d = -0.35$. The effect size was small.

Conclusions From Study 1

The results of study 1 confirmed that learning to code may benefit planning and response inhibition skills significantly

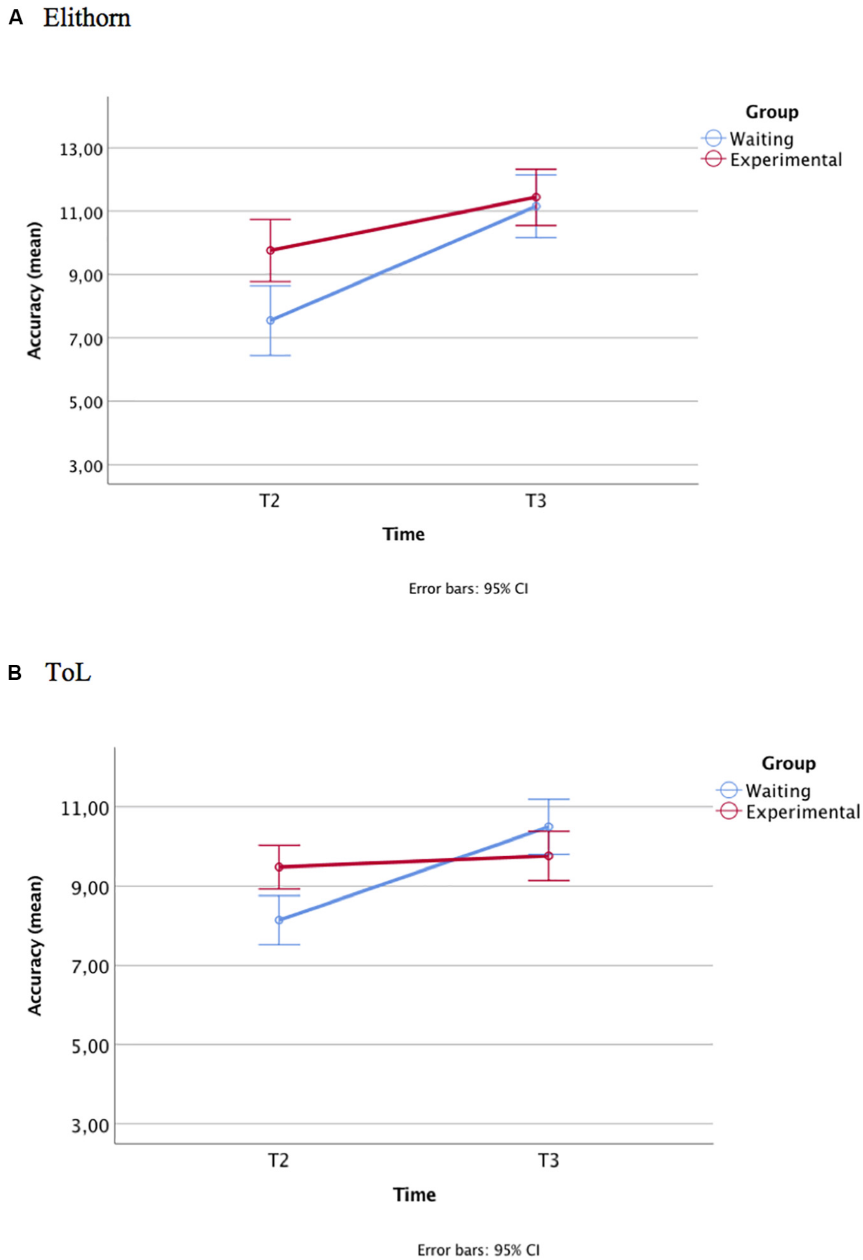

FIGURE 2 | Study 1: planning accuracy at T2 and T3 (age, SES, and accuracy at TI covariates) at the Elithorn **(A)** and ToL **(B)** tasks.

even after relatively short practice with coding. A stepped-wedge cluster randomized trial design (Campbell et al., 2019) was used to test the effects of the intervention, with the experimental and wait list control group receiving the intervention at different times (the former between T1 and T2; the latter between T2 and T3). After the coding training, at T2, the experimental group outperformed the wait list control group on the two standardized planning tasks (Elithorn and ToL) and the two standardized inhibition tasks (NEPPSY-II and Stroop). Between T2 and T3, with the coding training, also the waiting-list control group improved significantly in coding and, with it, in planning and response inhibition, showing at T3 levels of performance equivalent to those of the experimental group. The performance of the experimental group remained stable, indicating that the positive effects of the coding training were retained at the delayed post-test. The only exception is the Stroop task, for which the performance of experimental group worsened between T2 and T3.

The benefits of the coding activities were also more evident on accuracy than on planning or inhibition time. In fact, the findings did not confirm the predicted increase of

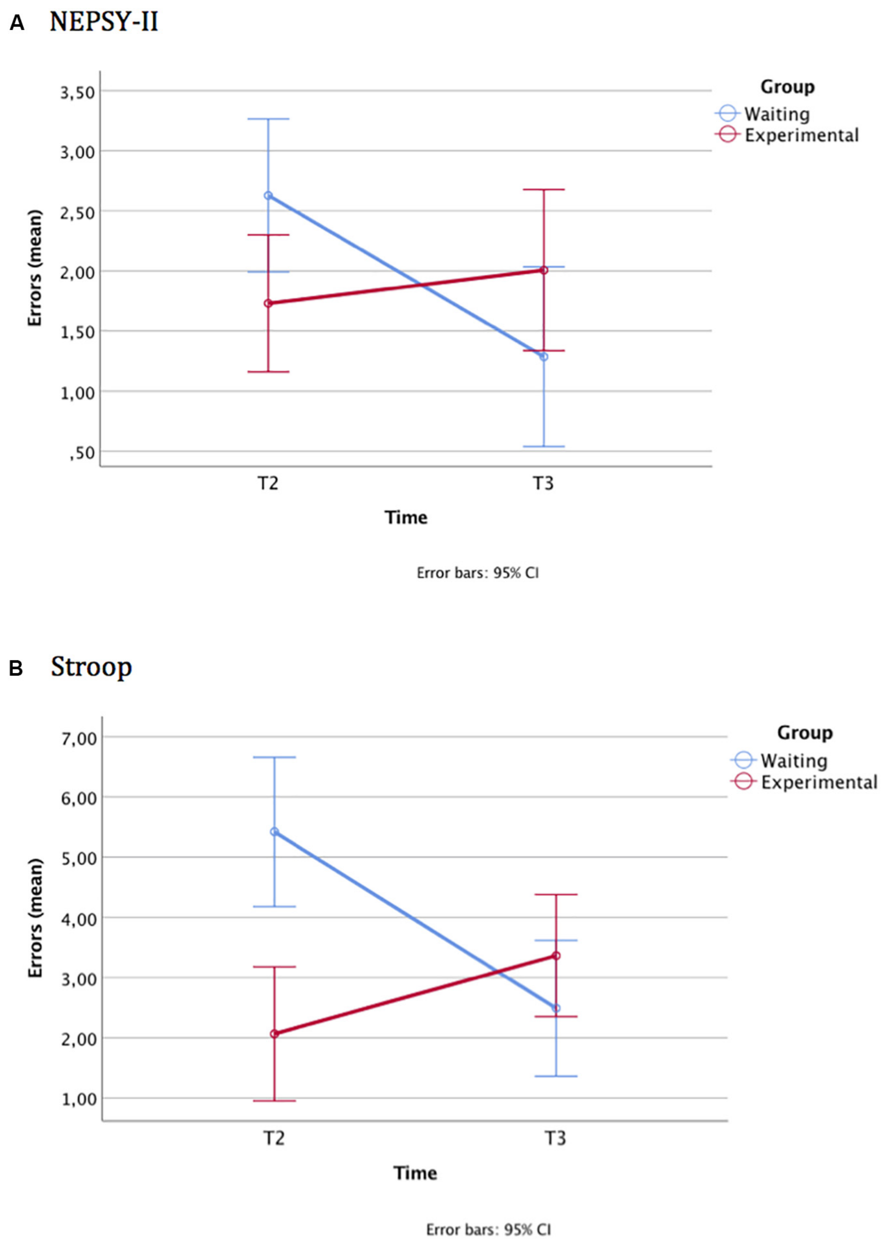

FIGURE 3 | Study 1: errors in response inhibition at T2 and T3 (errors at TI covariate): NEPSY-II **(A)** and Stroop **(B)** tasks.

time spent planning following the intervention. A possible explanation of this unexpected effect is that the latency time before initiating the task (our planning time measure) may reflect other processes than planning alone (for example, children's exploration of the problem space or familiarity with the task). Consistently with this interpretation, after the coding intervention, by becoming familiar with the Code.org platform and its tooling (e.g., the visual block commands), the children likely needed significantly less time to explore the visual interface and the trials. Consequently, their planning time (measured as response latency) decreased (rather than increase) and such decrease was associated with an increase in accuracy on the same tasks. (We return to this point below). Thus, this finding can be interpreted as an indication of the acquired efficiency of the children in solving the coding problems.

The analysis of performance on the coding and standardized tasks proves that the children exposed to coding not only learned to code, but also developed planning and response inhibition skills, showing significant transfer effects. To check whether the improvement observed in EF was associated to children's gains in coding, bivariate correlations were run between change scores (i.e., score difference between T2 and T1 and between T3 and T2) in coding and the corresponding change scores in planning accuracy and response inhibition at the EF assessment. These further analyses showed that a decrease in planning time on the coding tasks between T1 and T2 was significantly associated with coding accuracy, $r(76) = -0.61$, $p < 0.001$, and with improvements in accuracy on the Elithorn and ToL tasks between T1 and T2, respectively, $r(76) = -0.29$, $p = 0.01$ and $r(76) = -0.31$, $p < 0.01$. Change scores in coding accuracy between T1 and T2 were also positively associated with change scores in accuracy on the Elithorn, $r(76) = 0.26$, $p < 0.05$. A decrease in planning time on the coding tasks, between T2 and T3, was significantly associated with change scores (improvement) in coding accuracy in the same time period, $r(76) = -0.70$, $p < 0.001$, with the improvement in accuracy on the Elithorn and ToL tests: $r(76) = -0.38$, $p = 0.001$ and $r(76) = -0.47$, $p < 0.001$, and also with a decrease in inhibition errors on the NEPSY-II, $r(76) = 0.23$, $p < 0.05$, and Stroop tasks, $r(76) = 0.45$, $p < 0.001$. Finally, improvements in coding accuracy between T2 and T3 were positively associated with improvements in accuracy on the Elithorn, $r(76) = 0.33$, $p < 0.005$, and ToL task, $r(76) = 0.42$, $p < 0.001$, and were negatively associated with the decrease in inhibition errors on the Stroop test, $r(76) = -0.35$, $p < 0.005$.

Complementing other recent investigations (Di Lieto et al., 2017) showing that experience with coding in tangible (i.e., physical) environments can improve significantly children's working memory and inhibition skills, the findings of study 1 suggest that guided exposure to coding through a virtual learning environment can benefit considerably also more complex EFs such as planning, and these effects can be detected from an early age (5–6 years).

The question of whether learning to code can accelerate the development of 5–6-year-old children's EFs significantly was further explored in study 2, by integrating these results with longitudinal data.

STUDY 2

This second study explored further the effects of coding on children's EFs by combining a longitudinal and randomized controlled trial design. The aims of the study were:

(1) To replicate the findings of study 1 with a group of second graders, novice to coding;
(2) To examine the extent to which coding experience could boost the spontaneous development of children's planning and inhibition skills. We explored whether children's improvements in planning and response inhibition following 1-month coding intervention were greater than those occurring in the same children in 7 months of spontaneous development and standard curricular activities.

This experimental design was similar to that of study 1, except that one group of children (experimental group) was followed longitudinally, and tested at three time points (T0, test; T1, pre-test, after 7 months from T0, to assess the spontaneous development of EFs in a long time period; and at T2, post-test, after 1 month of exposure to coding). The other group (control group) was tested only twice (at T1 and T2) (see **Figure 4**).

Participants

Thirty-eight second graders participated in this trial. The experimental group included 19 children followed longitudinally for 1 year, from grade 1 to grade 2 (7 girls, 37%, 12 boys, 63.2%, mean age, 6.89), the control group consisted of other

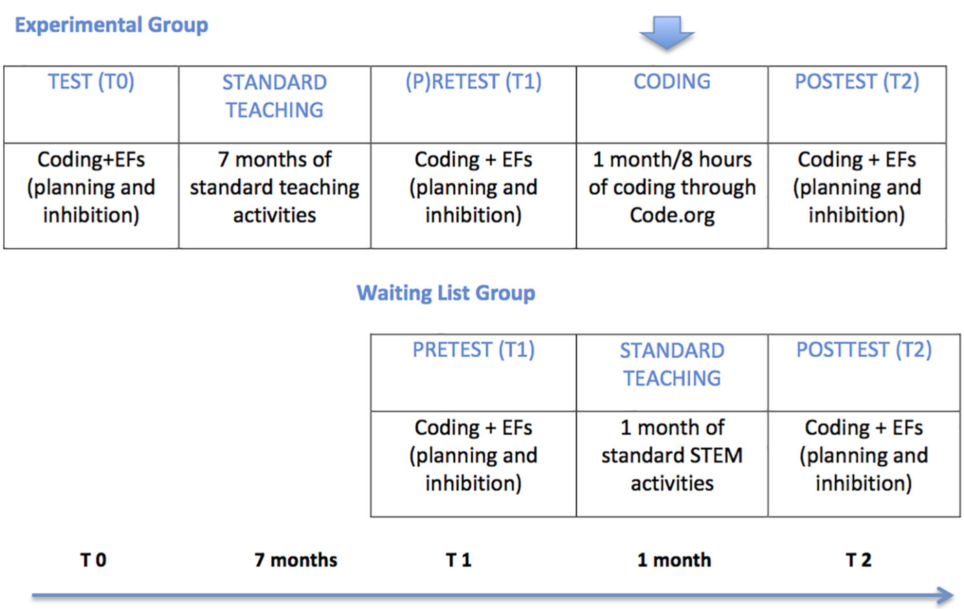

FIGURE 4 | Experimental design study 2.

TABLE 5 | Study 2—demographic characteristics of the experimental and control group.

	Experimental	Control	*p*-value
Gender			
Girls (*n*, %)	7, 36.8%	10, 52.6%	0.32
Boys (*n*, %)	12, 63.2%	9, 47.4%	
Age (*M*, *SD*)	6.89 (0.205)	6.89 (0.315)	1.00
SES (*M*, *SD*)	6.11 (1.56)	6.79 (1.18)	0.14

19 second graders matched on age, gender, and SES to the experimental group (10 girls, 53%, 9 boys, 47.4%, mean age 6.89), from a different school. All children were native speakers of Italian and not signaled for learning disabilities or other developmental disorders. Parental written informed consent was collected before the study for all participants. Demographic data are reported in **Table 5**.

Procedure and Materials

The procedure and materials were the same as for study 1.

Results are presented separately for the randomized controlled trial and longitudinal part of the study.

Results of the Randomized Controlled Trial

The two groups were equivalent in Age, $t < 1$, $p = 1.00$, SES, $t(36) = -1.52$, $p = 0.14$, and for gender distribution, $\chi^2 = 0.96$, $p = 0.32$. Between-group differences at the pre-test (T1) were explored by *t*-tests, which confirmed that the two groups did not differ significantly in any dependent measure except for T1 accuracy on the ToL, $t(36) = 2.22$, $p = 0.03$, where the control group outperformed the experimental group.

Skewness and kurtosis values were within critical thresholds, with the exception of Stroop time T1, for which kurtosis slightly exceeded the critical value of 3.00 (kurtosis = 3.54). Levene tests confirmed equal variance between the two groups. Between-group ANOVAs were thus used to address the first objective of the study (i.e., replicate the results of study 1 with second graders) and explore between-group differences in the dependent measures at T2 (post-test) with T1 (pre-test) performance, age, and SES as covariates. **Table 6** displays group means and independent samples *t*-tests for group comparison at the two time points (T1 and T2). Similar to study 1, the intervention effects on children's coding skills were tested first, followed by transfer effects on children's planning and response inhibition.

Effects of Learning to Code on Coding Skills: Planning Time

The covariate, pre-test planning time was significant, $F(1,33) = 19.60$, $p < 0.001$, $\eta_p^2 = 0.37$, and no significant effects of Group were observed. As shown in **Table 7**, the two groups spent equivalent time planning both at T1 and T2.

Effects of Learning to Code on Coding Skills: Accuracy

The analyses revealed a significant effect of the covariate T1 coding accuracy, $F(1,33) = 25.95$, $p < 0.001$, $\eta_p^2 = 0.44$, and of Group, $F(1,33) = 38.11$, $p < 0.001$, $\eta_p^2 = 0.54$. (The effect size was very large). **Table 7** shows that whereas at T1, the performance of the two groups was equivalent, at T2, the experimental group performed significantly better than the control group, and the effect size was very large: $t(36) = -5.87$, $p < 0.001$, Cohen's $d = 1.91$.

TABLE 6 | Study 2—between-group comparison: planning and response inhibition at T1 (pre-test) and T2 (post-test).

		Control *M* (*SD*)	Experimental *M* (*SD*)	Independent samples *t*-test	Cohen's *d*
Planning time Elithorn	$T1^{pre-test}$	24.34 (11.72)	20.27 (11.58)	1.09	−0.35
	$T2^{post-test}$	18.24 (8.41)	19.17 (8.26)	−0.34	0.11
Accuracy Elithorn	$T1^{pre-test}$	9.26 (4.19)	9.79 (4.91)	−0.36	0.12
	$T2^{post-test}$	9.00 (4.10)	12.68 (3.33)	−3.04**	0.96
Planning time ToL	$T1^{pre-test}$	5.48 (2.64)	5.34 (2.14)	0.19	−0.06
	$T2^{post-test}$	4.77 (2.14)	6.52 (3.15)	−2.00#	0.65
Accuracy ToL	$T1^{pre-test}$	8.58 (2.27)	7.00 (2.11)	2.22#	−0.72
	$T2^{post-test}$	8.11 (2.49)	10.16 (1.86)	−2.87*	0.93
Inhibition time NEPSY-II	$T1^{pre-test}$	36.88 (7.26)	35.75 (8.39)	0.44	−0.14
	$T2^{post-test}$	37.51 (7.22)	34.05 (9.77)	1.24	−0.40
Errors NEPSY-II	$T1^{pre-test}$	3.79 (2.68)	3.74 (3.31)	0.05	−0.02
	$T2^{post-test}$	2.89 (2.13)	1.05 (1.27)	3.24**	−1.05
Inhibition time Stroop	$T1^{pre-test}$	124.88 (14.72)	138.24 (26.62)	−1.91	0.62
	$T2^{post-test}$	127.77 (16.58)	132.27 (30.80)	−0.56	0.18
Errors Stroop	$T1^{pre-test}$	3.68 (2.89)	4.32 (4.29)	−0.53	0.17
	$T2^{post-test}$	2.74 (2.42)	2.11 (2.35)	0.82	−0.26

***p < 0.005; *p < 0.01, #p ≤ 0.05. Adjusted p = 0.02 after Bonferroni corrections.*

TABLE 7 | Study 2—between-group comparison: performance at coding tasks at T1 (pre-test) and T2 (post-test).

		Control *M* (*SD*)	Experimental *M* (*SD*)	Independent samples *t*-test	Cohen's *d*
Planning	T1$^{pre-test}$	9.77 (3.62)	7.42 (4.36)	1.81	−0.59
time Coding	T2$^{post-test}$	8.46 (2.47)	7.78 (3.80)	0.65	−0.21
Accuracy	T1$^{pre-test}$	5.58 (1.17)	6.05 (1.08)	−1.30	0.42
Coding	T2$^{post-test}$	5.21 (1.08)	7.16 (0.96)	−5.87***	1.91

****p < 0.001. Adjusted p = 0.02 after Bonferroni corrections.*

Effects of Learning to Code on Planning Skills: Planning Time

Elithorn

Only the covariates Age and planning time at T1 were significant: $F(1,33) = 4.78$, $p < 0.05$, $\eta_p^2 = 0.13$, and $F(1,33) = 4.77$, $p < 0.05$, $\eta_p^2 = 0.13$. Group was not significant. As shown in **Table 6**, the independent-samples *t*-tests did not reveal statistically significant differences between the two groups neither at T1 nor at T2.

ToL

The covariate T1 planning time was significant, $F(1,33) = 30.61$, $p < 0.001$, $\eta_p^2 = 0.48$. Group was statistically significant, $F(1,33) = 11.04$, $p < 0.005$, $\eta_p^2 = 0.25$, and the effect size was very large. At T1, the two groups spent equivalent time planning (see **Table 6**), whereas at the post-test (T2), the experimental group spent more time planning than the control, and the difference approached statistical significance once Bonferroni corrections were applied: $t(36) = -2.00$, $p = 0.05$, Cohen's $d = 0.65$. The effect size was medium.

Effects of Learning to Code on Planning Skills: Planning Accuracy

Elithorn

The covariate T1 accuracy was statistically significant, $F(1,33) = 35.06$, $p < 0.001$, $\eta_p^2 = 0.51$. Group was also statistically significant, $F(1,33) = 15.94$, $p < 0.001$, $\eta_p^2 = 0.32$. The effect size was very large. As shown also in **Table 6**, at T1, the performance of the two groups was equivalent, whereas at the post-test (T2), the experimental group performed significantly better than the control group, with a large effect size: $t(36) = -3.04$, $p < 0.005$, Cohen's $d = 0.96$.

ToL

Also for the ToL, the covariate T1 accuracy was significant, $F(1,33) = 23.10$, $p < 0.001$, $\eta_p^2 = 0.41$. The analysis showed a significant difference between the two groups at the post-test (T2): $F(1,33) = 29.32$, $p < 0.001$, $\eta_p^2 = 0.47$ (the partial eta-squared shows that the effect size was very large). Inspection of **Table 6** shows that while the control group outperformed the experimental group at the pre-test (T1), $t(36) = 2.22$, $p < 0.05$, Cohen's $d = -0.72$ (the effect size was medium), the situation reversed at the post-test (T2), where the experimental group performed significantly better, $t(36) = -2.87$, $p < 0.01$, Cohen's $d = 0.93$. The effect size was large.

Effects of Learning to Code on Response Inhibition Skills: Response Inhibition Time

NEPSY-II

The analysis did not reveal any significant between-group difference. Only the covariate T1 inhibition time was statistically significant, $F(1,33) = 69.43$, $p < 0.001$, $\eta_p^2 = 0.68$.

Stroop

Like for the NEPSY-II inhibition task, only the covariate T1 Stroop time was significant, $F(1,33) = 37.19$, $p < 0.001$, $\eta_p^2 = 0.53$. The independent-samples *t*-tests showed a difference in inhibition time between the two groups, approaching significance at T1, $t(36) = -1.91$, $p = 0.06$, Cohen's $d = 0.62$. The experimental group showed longer inhibition time than the control and the effect size was medium. Yet, the two groups did not differ significantly at the post-test (T2) (see **Table 6**).

Effects of Learning to Code on Response Inhibition Skills: Response Inhibition Errors

NEPSY-II

The covariate T1 inhibition errors were significant, $F(1,33) = 14.63$, $p < 0.001$, $\eta_p^2 = 0.31$. Group was also statistically significant, $F(1,33) = 10.75$, $p < 0.005$, $\eta_p^2 = 0.25$. The effect size was large. The independent-samples *t*-tests showed that the performance of the two groups did not differ significantly at the pre-test (T1) (see **Table 6**). However, at the post-test (T2), the experimental group made significantly fewer errors than the control group and the effect size was large: $t(36) = 3.24$, $p < 0.005$, Cohen's $d = -1.05$.

Stroop

On the Stroop task, only the pre-test errors resulted significant, $F(1,33) = 26.19$, $p < 0.001$, $\eta_p^2 = 0.44$ (see **Table 6**). The performance of the two groups did not differ significantly at T1 or at T2.

Overall, the results of study 2 largely replicated those of study 1: the experimental group improved more than the control group in the ability to code, while greater gains in EFs (planning and response inhibition) were observed than those made by the control group. After the coding training, the experimental group spent significantly more time planning on the ToL and was significantly more accurate than the control group on both standardized planning tasks (Elithorn and ToL). The experimental group also made significantly fewer errors than the control group on the NEPSY-II inhibition task. Pearson correlations confirmed that change scores (between T1 and T2) in planning and response inhibition were significantly associated with change scores in coding accuracy and time planning on coding tasks. Like in study 1, change scores in coding accuracy and coding planning time were significantly correlated: $r(38) = 0.46$, $p < 0.005$. Yet, unlike study 1 (in which a negative correlation occurred between time spent planning and accuracy), a positive correlation emerged between these two measures: the increased accuracy on coding tasks was associated with increased time spent planning in the coding tasks and with increased time planning on the ToL, $r(38) = 0.43$, $p < 0.01$. Moreover, increase in planning time on the coding and on the ToL tasks were significantly correlated: $r(38) = 0.35$, $p < 0.05$. Positive significant correlations were also found between children's gains in coding accuracy and gains in accuracy on the Elithorn, $r(38) = 0.38$, $p < 0.05$, and ToL, $r(38) = 0.35$, $p < 0.05$, tasks. Finally, increased accuracy on coding tasks was significantly associated with a decrease of errors in the NEPSY-II inhibition task.

The experimental group was followed longitudinally and tested also at T0, 7 months before the pre-test (T1) and the intervention. The longitudinal data refer to only 17 children, as two children of this group were not assessed at T0. To determine in which measure the coding intervention boosted the development of the children's EFs (the second objective of study 2), we compared the changes in the EFs of the experimental group between T0 and T1, i.e., a period of 7 months in which they were *not* exposed to coding, to those occurring between T1 and T2, after 1 month (4 weeks) of coding training. Change scores were used to compare children's improvement in EFs and coding between the T0–T1 and T1–T2 time intervals. Cohen's *d* effect size was calculated and correlations between repeated measures were used to correct for dependence between means (Morris and DeShon, 2002). Means and standard deviations are reported in **Table 8**.

TABLE 8 | Study 2–longitudinal data: performance of the experimental group at T0 (test), at T1 (pre-test), and at T2 (post-test).

	Time	Score M (SD)	Change score	Paired t-test	Cohen's d
Planning time	T0	16.32 (12.66)			
Elithorn	$T1^{pre\text{-}test}$	19.23 (11.69)	2.91^{T1-T0}		
	$T2^{post\text{-}test}$	17.47 (5.83)	-1.76^{T2-T1}	0.78	−0.19
Accuracy	T0	5.65 (3.30)			
Elithorn	$T1^{pre\text{-}test}$	8.91 (4.72)	3.26^{T1-T0}		
	$T2^{post\text{-}test}$	12.71 (3.50)	3.79^{T2-T1}	−0.27	0.08
Planning time	T0	5.39 (1.33)			
ToL	$T1^{pre\text{-}test}$	5.10 (2.14)	-0.29^{T1-T0}		
	$T2^{post\text{-}test}$	6.46 (3.30)	1.35^{T2-T1}	−1.82	0.44
Accuracy ToL	T0	6.00 (1.87)			
	$T1^{pre\text{-}test}$	7.12 (2.18)	1.12^{T1-T0}		
	$T2^{post\text{-}test}$	10.18 (1.98)	3.06^{T2-T1}	$-2.18^{\#}$	0.62
Inhibition time	T0	36.44 (4.77)			
NEPSY-II	$T1^{pre\text{-}test}$	34.13 (6.81)	-2.31^{T1-T0}		
	$T2^{post\text{-}test}$	31.89 (6.63)	-2.24^{T2-T1}	−0.02	0.01
Errors	T0	2.12 (2.20)			
NEPSY-II	$T1^{pre\text{-}test}$	3.76 (3.47)	1.64^{T1-T0}		
	$T2^{post\text{-}test}$	1.06 (1.30)	-2.70^{T2-T1}	2.82^{*}	−0.74
Inhibition time	T0	157.68 (22.05)			
Stroop	$T1^{pre\text{-}test}$	134.21 (21.29)	-23.47^{T1-T0}		
	$T2^{post\text{-}test}$	127.71 (25.16)	-6.49^{T2-T1}	−1.70	−38
Errors Stroop	T0	7.00 (8.82)			
	$T1^{pre\text{-}test}$	4.35 (4.50)	-2.65^{T1-T0}		
	$T2^{post\text{-}test}$	2.24 (2.44)	-2.12^{T2-T1}	−0.18	0.03
Planning time	T0	13.00 (5.24)			
Coding	$T1^{pre\text{-}test}$	6.70 (2.54)	-6.30^{T1-T0}		
	$T2^{post\text{-}test}$	7.15 (3.18)	0.45^{T2-T1}	-3.58^{**}	0.75
Accuracy	T0	4.29 (0.920)			
Coding	$T1^{pre\text{-}test}$	6.06 (1.14)	1.76^{T1-T0}		
	$T2^{post\text{-}test}$	7.24 (0.970)	1.18^{T2-T1}	1.11	−0.24

$^{**}p < 0.005$; $^{*}p < 0.01$; $^{\#}p \leq 0.05$. Adjusted p = 0.02 after Bonferroni corrections.

Longitudinal Data: Results

Effects of Learning to Code on Coding Skills: Planning Time

The difference between the two time intervals (T0–T1 and T1–T2) was significant $t(16) = -3.58$, $p < 0.005$, Cohen's $d = 0.75$. The (negative) change score between T0 and T1, indicating a decrease in the time spent planning, was larger than the (positive) change score (increase in planning time) between T1 and T2 (see **Table 8**).

Effects of Learning to Code on Coding Skills: Accuracy

Accuracy in the coding tasks increased from T0 to T1 and from T1 to T2. The dimension of the change was not significantly different between the two time intervals.

Effects of Learning to Code on Planning Skills: Planning Time

Elithorn

No statistically significant difference was found between the two time intervals.

ToL

Also for the ToL, no statistically significant difference was found. The means reported in **Table 8** show that the time spent planning on the ToL decreased between T0 and T1 and increased between T1 and T2, but the difference between the change scores was not significant.

Effects of Learning to Code on Planning Skills: Planning Accuracy

Elithorn

On the Elithorn, the difference in the accuracy change scores between T0–T1 and T1–T2 was not significant. The means in **Table 8** show an equivalent improvement in accuracy during the two time intervals.

ToL

Applying Bonferroni corrections, the difference in change scores approached statistical significance, $t(16) = -2.18$, $p = 0.04$, Cohen's $d = 0.62$. The effect size was medium. As shown by **Figure 5A**, the improvement in accuracy was significantly greater between T1 and T2 (1 month of exposure to coding) than between T0 and T1 (7 months of regular learning activities).

Effects of Learning to Code on Response Inhibition Skills: Response Inhibition Time

NEPSY-II

No significant differences emerged for inhibition time between T0–T1 and T1–T2. As shown by change scores in **Table 8**, children's inhibition time decreased progressively from T0 to T2.

Stroop

Like for the NEPSY-II task, no significant differences were found between the two time intervals (T0–T1 and T1–T2).

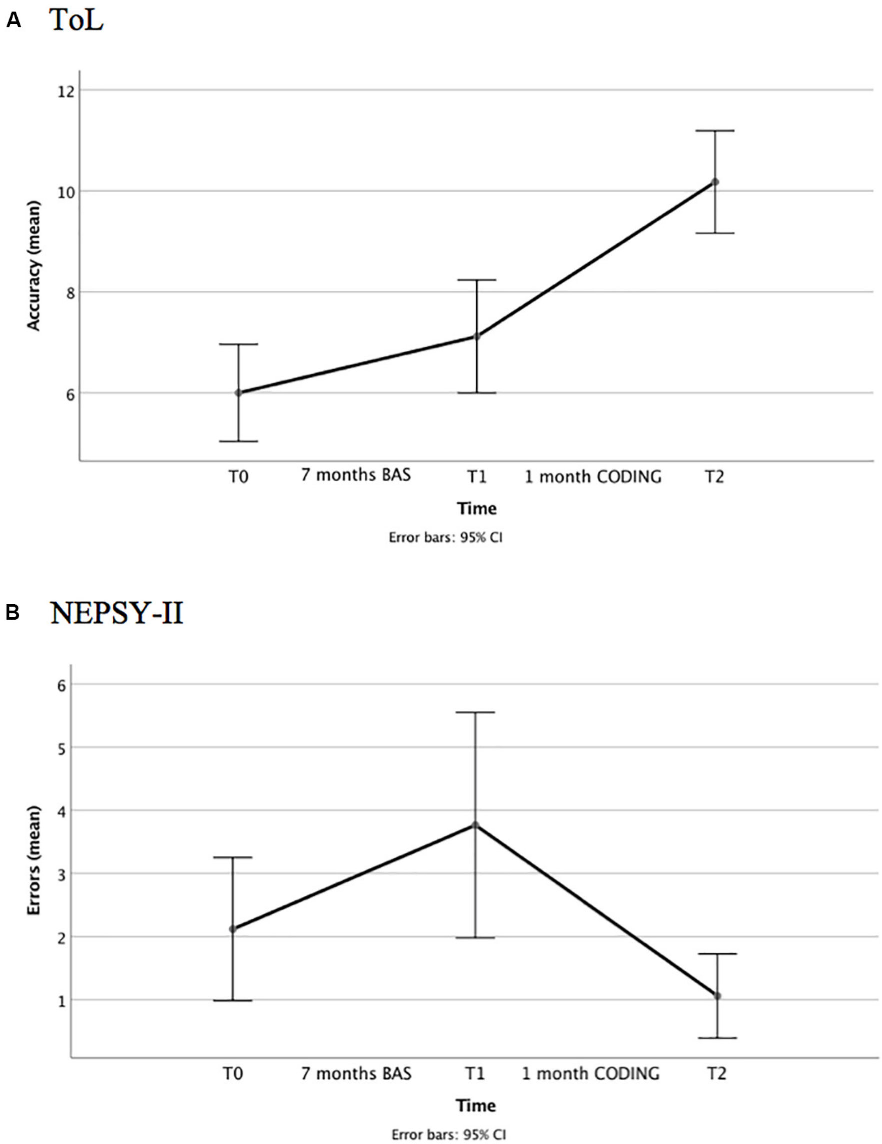

FIGURE 5 | Study 2: longitudinal data: **(A)** ToL accuracy and **(B)** NEPSY-II inhibition errors at TO (test), TI (pre-test), and T2 (post-test). BAS = business-as-usual.

Effects of Learning to Code on Response Inhibition Skills: Response Inhibition Errors

NEPSY-II

A statistically significant difference in change scores was found between the two time intervals, $t(16) = 2.82$, $p = 0.01$, Cohen's $d = -0.74$. The effect size was medium. As shown in **Figure 5B**, inhibition errors increased between T0 and T1, but decreased between T1 and T2 (see also change scores reported in **Table 8**). The dimension of the change was larger between T1 and T2.

Stroop

The negative change scores reported in **Table 8** indicate a decrease in inhibition errors from T0 to T1 and from T1 to T2. The difference between these two time intervals was not significant.

Conclusions From Study 2

Study 2 replicated the findings of study 1, but also furthered our comprehension of the effects of coding on children's EFs, showing that learning to code can boost the development of children's EFs. The evidence we collected shows that children with no prior experience of coding may benefit from a short (1-month) coding intervention in terms of planning and response inhibition. Notably, the longitudinal data showed that, on the Elithorn task, the gains in planning after 1 month of coding experience were equivalent to those obtained in the development of the same function with 7 months of exposure to standard curricular activities. On the ToL task, which involves a greater extent of problem-solving skills (Luciana et al., 2009), the observed gains, measured by change scores, were greater than those occurring after 7 months of standard learning activities.

Much like in study 1, we noted in study 2 too that the effects of the intervention were more apparent for accuracy than for planning and response inhibition time. Remarkably, inhibition errors decreased in the experimental group, followed longitudinally, only *after* the coding intervention and the change occurring during the time interval between T1 and T2 (1 month) was greater than that between T0 and T1. This finding suggests that focused and targeted instructional problem-solving activities, like those involved in coding, help boost inhibition skills in children in their first years of schooling.

It could be argued that the greater gains made by the experimental group in planning and response inhibition after the training were due to the shorter time lag (1 month versus 7 months) between the repeated standardized tasks, which could have emphasized task familiarity effects. However, the finding that similar improvements did not occur in the control group suggests that the effects observed do relate to the specific benefits of the training more than to task familiarity.

In terms of planning time, the effects of the intervention were evident only on the ToL task. The children of the experimental group spent more time planning than at the post-test, and they planned better (with more accuracy) than the control group. Moreover, the change in planning accuracy on the ToL was significantly greater than that obtained after 7 months of standard learning activities. The fact that the effects on planning time were limited to the ToL might reflect the nature of the task, which is more complex (and thus likely more sensitive) than the Elithorn, where the child can visually explore the tracks in the maze.

The relationship found between planning time and accuracy differs in the two studies. Whereas in study 1 their association is negative, indicating that an increase in planning accuracy corresponds to a decrease in planning time, the opposite appears in study 2: An increase in accuracy in the coding tasks correlates with an increase in the time spent planning. Several variables could explain these divergent findings, including children's characteristics, or the different emphasis teachers may put on planning skills in regular classroom activities. A difference between study 1 and 2 is, however, the older age of the participants in study 2. Older children could be more self-regulated and thus more prone to plan (Magi et al., 2016; Poutanen et al., 2016). A quick comparison between the average planning time of study 1 and study 2 (see **Tables 3**, **6**) suggests, though, that this is not the case: The children of study 1 devoted on average the same, or more, time planning than those of study 2. Yet, the participants of study 2 showed on average greater accuracy on the planning tasks (Elithorn and ToL). It may be that these older children were simply more efficient in using planning to perform the tasks.

GENERAL DISCUSSION

The two studies presented in this paper explored the effects of coding, a learning activity recently introduced in the primary school curriculum, on first and second graders' planning and response inhibition skills. Examining the role played by everyday curriculum-based learning activities on children's EFs is essential to taking informed educational decisions. Examples of such decisions include determining at what age specific learning activities should be introduced or what kind of activities can be more fruitful at a given age for children's cognitive development.

As discussed earlier in this paper, the studies that explore the effects of curricular activities on the development of children's EFs are often challenged by the fact that it is difficult to find a control group at equal educational level, not bound to receive the target intervention (e.g., reading, writing, or math) at the same time (Baker et al., 2015). The recent introduction of coding instruction in primary school offers a "natural experiment" to developmental and educational psychologists. Since its integration in national curricula worldwide is not yet completed, comparisons between children who receive coding intervention and children who do not indeed are possible.

The two studies reported in this paper suggest the opportunity to introduce children early—at the beginning of primary school—to CT by means of guided exposure to coding. Faced with the challenge of coding problems, children seem to develop not only response inhibition skills (that is, command of prepotent responses), but also more complex EFs such as planning abilities. The positive effect of coding on children's inhibition skills has been observed earlier (Di Lieto et al., 2017) and our findings provide further confirmatory evidence in this direction. Furthermore, the two studies reported in this paper also provide the first empirical evidence that learning coding early in school positively affects complex EFs, such as planning.

Response inhibition and planning support learning and humans' problems solving (Hongwanishkul et al., 2005; Altemeier et al., 2006; Roebers et al., 2011; Crook and Evans, 2014; Liu et al., 2015; Blair, 2017; Purpura et al., 2017). Thus, improvements in these skills may have in turn strong impact on children's academic success and everyday life (Crook and Evans, 2014; Blair and Raver, 2016; Blair, 2017).

In general, the coding intervention deployed in the two studies reported in this paper has been more effective for the development of children's planning than inhibition skills. The finding that planning skills are plastic in first and second graders and can be boosted effectively by curricular activities like coding is an important finding, especially so, considering that planning involves also more basic EF processes, such as inhibition and working memory (Luciana et al., 2009).

However, whereas the planning abilities developed through coding in studies 1 and 2 transferred to both standardized planning tasks (the Elithorn and the ToL), the effects on inhibition skills seemed less robust and generalized. In study 1, the accuracy gained in the Stroop task was not retained at 1 month from the intervention, and in study 2, the positive effects of the training did not generalize to the Stroop task. This observation could relate to general lesser plasticity of inhibition processes or to specific training effects, that is, to factors related to the nature of the training tasks or the duration of the training. As noted above, response inhibition is involved in planning (Luciana et al., 2009). However, promoting response inhibition indirectly through planning may lead to less strong or robust effects than direct interventions targeting inhibition skills. Another explanation is that longer training might be required to consolidate gains in response inhibition skills. Response inhibition may be more vulnerable indeed to situational and external factors (e.g., tiredness, mood) than planning. The latter, in fact, is a more complex cognitive process, which may involve greater strategic control. The hypothesis that the reduced effects on inhibition can originate from the short duration of the intervention matches findings that suggest that longer trainings lead to significant positive effects on children's response inhibition (Di Lieto et al., 2017) and other EFs (Kronenberger et al., 2011).

Limitations

The short duration of the coding intervention and the lack of a long-term follow-up are the two main limitations of the present studies. Di Lieto et al. (2017), who found positive effects of a coding training on 5-year-old children's response inhibition, employed a longer training than the one we had in studies 1 and 2: 13 sessions/6 weeks versus 8 sessions/4 weeks. Other EF trainings destined to children of similar age to those involved in these studies, although lasting 1 month, are typically more intensive (Traverso et al., 2015). Traverso et al. (2015), for example, asked children to take part in 12 training sessions over a period of 1 month. The well-known CogMed WM training involves 25 training sessions, from 10 up to 40 min each, administered 5 days a week for 5 weeks (Kronenberger et al., 2011; Grunewaldt et al., 2013, 2016; Hardy et al., 2016). Some of the findings of the two studies discussed in this paper (i.e., the reduced impact of the training on inhibition) might be explained by the short duration or moderate intensity of the training (see Diamond and Ling, 2016, for a discussion of the effects training duration and intensity). Future studies should test this hypothesis by comparing coding training of different duration and intensity. Interestingly, however, the short duration of our training was sufficient for children to earn significant benefits for simple and complex EFs, and to retain them after 1 month from the end of the intervention.

Our delayed post-test (follow-up) was at 4 weeks/1 month distance from the end of the training, which prevents us from drawing any conclusion about the long-term retention of the effects. Yet, a comparison with other studies that used similar follow-ups (Kronenberger et al., 2011) suggests that our training was effective. Kronenberger et al. (2011) tested the efficacy of CogMed, an intensive computerized working memory training of the duration of 5 weeks. In their study, the magnitude of children's gains at post-training was retained only for forward digit span scores (among four verbal and spatial WM measures) at a 1-month follow-up. Given the duration and intensity of our training, maintenance of the training effects at 1 month from the end of the intervention can be regarded as a truly good outcome in terms of efficacy.

A final limitation of the present studies is the lack of information on the participants' cognitive level or general intelligence (IQ). Although none of the participants in these studies were referred to intervention for intellectual disabilities, an assessment of the children's IQ performance through standardized tests could have provided a better picture of the sample involved in the coding training and helped interpret the effects of the intervention. The same coding activities could have, in fact, different effects based on the initial non-verbal and/or verbal cognitive resources of a child.

CONCLUSION

The studies reported in this paper show how practice with coding in school not only improves measurably children's ability to solve (computational) problems, but it may also show transfer effects on important EFs such as planning and response inhibition. In our two studies, these effects have been observed in the period of transition to school or the first years of schooling, which has been shown to be a particularly sensitive time window for the development of EFs (Roebers et al., 2011; Macdonald et al., 2014; Magi et al., 2016; Poutanen et al., 2016). Future studies should test whether the positive effects of coding extend also to older children and whether impairing factors such as low SES may mediate the efficacy of coding interventions in school. At present, coding is increasingly becoming part of the primary school curriculum worldwide. However, little is known as yet about the effects of this new learning activity on children's cognitive development. More research should study the learning conditions that may amplify the effects of coding on children's EFs and thus promote children's cognitive development. The work we are conducting aims at bridging this knowledge gap.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethical Committee of the Department of Developmental Psychology (University of Padova, Italy). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

BA contributed to study design, statistical analyses, and manuscript writing. TV contributed to study design and manuscript writing. CM and ML contributed to data collection.

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Improving Executive Functions at School in Children With Special Needs by Educational Robotics

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Children with Special Needs represent a highly heterogeneous group in terms of neurofunctional, behavioral, and socio-cognitive characteristics, but they have in common a frequent impairment of Executive Functions. Educational Robotics is generally dedicated to study the effects of constructing and programming robots based on children's learning and academic achievement. Recently, we found that being engaged in progressively more challenging robot planning and monitoring (ER-Lab) promotes visual–spatial working memory and response inhibition in early childhood during typical development, and that an ER-Lab can be a feasible rehabilitative tool for children with Special Needs. The present study aimed to verify the efficacy of the ER-Lab on Executive Functions in children with Special Needs for the first time by using an RCT within their school environment. To pursue these aims, this study reports the results obtained in 42 first-grade children with Special Needs engaged in school Educational Robotics Laboratories (ER-Lab) to promote Executive Functions by means of enjoyable, intensive, and incrementally more challenging activities requiring them to program a bee-shaped robot called Bee-bot® (Campus Store). Several adaptations were done to meet different motor, cognitive, and social needs. All children were evaluated by means of standardized tests performed by each child before and at the end of the ER-Lab activities. Children with Special Needs had significantly improved inhibition skills, and children with attentional impairment had more benefits in their inhibition of motor responses tasks with respect to children with a language deficit. Results of the study and future perspectives on how ER-Lab programs could become a powerful tool in classrooms with children with special needs are discussed.

Keywords: educational robotics, special needs, response inhibition, working memory, executive functions, children

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INTRODUCTION

Children with Special Needs (SN) require exceptional educational and teaching strategies because of social, physical, or mental problems. They represent a highly heterogeneous group in terms of neurofunctional, behavioral, and socio-cognitive features. Children with SN may have sensorial or motor disabilities, Autism Spectrum Disorders, Mild or Severe Intellectual Disabilities, and specific neurodevelopmental disorders, such as Attention Deficit Hyperactivity Disorder (ADHD), Specific Learning Disorders, Specific Language Disorders, or other unspecified difficulties (McFarland et al., 2018; MIUR – Ufficio Statistica e Studi, 2018). Despite this variability, it is nowadays well accepted that specific processes for cognitive control, such as Executive Functions (EFs), are frequently impaired across different developmental disorders and special needs (Pennington and Ozonoff, 1996). EFs have been found to be frequently altered in children with socio-economic disadvantages (Noble et al., 2007), Mood Disorders (Vilgis et al., 2015), Attention Deficit Hyperactivity Disorder (ADHD) (Castellanos et al., 2006), Autistic Spectrum Disorder (ASD) (Pellicano, 2012; Margari et al., 2016), Language and Learning Disabilities (Moll et al., 2014; Kapa and Plante, 2015; Peng and Fuchs, 2016), Down Syndrome (DS) (Lott and Dierssen, 2010; Lanfranchi et al., 2015), neuromuscular disorders (Astrea et al., 2016; Battini et al., 2018), and Cerebral Palsy (CP) (Pirila et al., 2011; Di Lieto et al., 2017a). The casual relationship between EF impairment and Special Needs is far from linear as three main scenarios may be suggested: in some circumstances, a clear EF deficit is a part of the "core cognitive difficulties" of a certain SN group; in other conditions, only subtle difficulties are found; finally, it may be that it is the clinical or social problem itself that induces the EF impairment (Astrea et al., 2016).

The complexity of the EFs–SN relationship may, in part, be due to the fact that EFs are a complex construct, described by different theoretical frameworks. Although multi-componential models define the main basic EF components differently (e.g., Miyake et al., 2000; Diamond, 2013; Friedman and Miyake, 2017; Morra et al., 2018), within a developmental prospective focused on early ages, there is agreement on their role as precioues "tools of learning" for academic skills at different grades (Diamond, 2013). The ability to manipulate information held in the memory is highly involved in language acquisition, decoding, text comprehension (Swanson et al., 2009; Christopher et al., 2012), and in mathematical achievement, such as counting and mental arithmetic (St Clair-Thompson and Gathercole, 2006; Mammarella et al., 2010; Caviola et al., 2012; Viterbori et al., 2015). The ability to inhibit prepotent responses, concerning the suppression of compelling thoughts or memories and behavior, and resist distractor interference, which is selectively attuned to what we choose, thereby removing attention to other interferent stimuli, allows us to focus on relevant information during reading comprehension (Borella et al., 2010) or solving arithmetic problems (D'Amico and Passolunghi, 2009; Gilmore et al., 2015). Finally, the ability to rapidly change task, operations, mental sets, or strategies seems to be connected to academic learning (Bull and Lee, 2014). According to Diamond's model (Diamond, 2013), these processes concern three main basic EFs components, namely working memory, inhibition, and cognitive flexibility. Inhibition, working memory, and, to a lesser extent, cognitive flexibility have frequently been found to be impaired in several types of Special Needs (Vicari and Di Vara, 2017).

Given the predictive role EFs have on academic achievement, early interventions on working memory and inhibition in children with SN may prevent cascade effects on quality of life, school attendance, and social functioning (Diamond and Lee, 2011).

Different approaches have been proposed to empower the main EF components in typical and atypical development. In the preschoolers, they have been focused mainly on self-regulation by paper and pencil school activities (Dias and Seabra, 2015; Traverso et al., 2015; Duncan et al., 2018; Howard et al., 2018; Diamond et al., 2019), while computerized training has been proposed mainly for school-aged children (Klingberg et al., 2005; Aksayli et al., 2019). Moreover, aerobics, martial arts, yoga, and mindfulness have recently been suggested as efficacious tools to empower EFs (Diamond and Lee, 2011). Results across the different studies are variable and not easily comparable because of theoretical and methodological differences. Among all, studies varied for the outcome measures used, for the generalization effects found, and for their conformity to different EF constructs (Morra et al., 2018; Aksayli et al., 2019). By reviewing the different approaches, Diamond and Lee (2011) suggested that, in order to empower the efficacy of the EF interventions and the power of generalization to several daily life activities, the presence of the following principles are needed: (i) constantly challenging activities (Diamond and Ling, 2016); (ii) adaptive and intensive schedules (Klingberg et al., 2005; Thorell et al., 2009); (iii) repeated practice (Diamond and Lee, 2011); (iv) the involvement of emotional, physical, and social aspects (Diamond and Lee, 2011); (v) variability of the tasks (Klingberg et al., 2005; Rueda et al., 2005; Wass et al., 2011); and (vi) the high-motivation mentoring skills of the trainers (Diamond and Ling, 2016).

In order to propose new EF training that embeds the above characteristics, the use of new technologies in day-to-day life and social contexts, such as school, may be promising.

Among the new technologies implemented for educational purposes, Educational Robotics (ER) has been used with typically developed children in educational settings to enhance problem solving, planning, and computational thinking (La Paglia et al., 2011; Benitti, 2012; Kazakoff and Bers, 2014), basic EFs components (Di Lieto et al., 2017b), and academical learning, especially in the area of Science, Technology, Engineering, and Mathematics (STEM area; Hussain et al., 2006; Barker and Ansorge, 2007; Nugent et al., 2008). ER refers to a learning approach based on the design, assembly, and programming of robots and takes its psycho-pedagogical background both from the constructivism and constructionism theories of learning and cognitive development (Piaget and Inhelder, 1966; Papert and Harel, 1991) and from social learning theories (Bandura, 1962; Bandura et al., 1966; Vygotsky, 1987).

Recently, an increasing number of studies have proposed ER to SN populations with the aim of offering new learning and socially inclusive opportunities. Examples of the application of robots, in both clinical and school settings, have been documented in different types of special needs (Cook et al., 2010; Cheng et al., 2018), including learning difficulties (Conchinha et al., 2016), motor disorders (Robins et al., 2012), intellectual disabilities (Businaro et al., 2014; Bargagna et al., 2018), autism (Robins et al., 2004; Robins et al., 2005), and ADHD (Fridin and Yaakobi, 2011).

Indeed, aside from elicit engagement and social behaviors (Diehl et al., 2011; Scassellati et al., 2012), STEM learning (Lindsay and Hounsell, 2017), play and exploration activities (Cook et al., 2000), educational robots have been used in the SN population to investigate specific cognitive functions, such as cognitive flexibility in children with ASD (Costescu et al., 2015) or the effect of robot-mediated learning (Krishnaswamy et al., 2014). The study by Krishnaswamy investigated the effects of a robotic training to improve visual motor skills in children with learning disabilities and visual motor delays, by comparing robot programming with traditional occupational therapy. The results showed that the children who participated in the ER activities improved visual–motor performances more than children following the traditional curriculum. Another study by Conchinha presented two single cases who, by participating in ER activities with Lego Mindstorm, improved learning, language, and inclusion (Conchinha et al., 2016). Finally, after finding that intense, challenging, and entertaining ER training (ER-Lab), organized according to incremental difficulty, improved visuo-spatial working memory and inhibition in typical preschoolers (Di Lieto et al., 2017b), we verified the feasibility of the ER-Lab in a group of children with Down Syndrome in a clinical setting (Bargagna et al., 2018).

The above evidence indicates that the ER-Lab is a flexible tool, adaptable to both clinical and educational environments for both SN and typically developing children, for cognitive improvement; indeed, it may be useful for personalizing interventions in neurodevelopmental disorders. The ER-Lab appears to simultaneously incorporate several characteristics to promote efficacy of the EFs trainings. ER-Lab activities may be intense, challenging, and adaptable to individual functioning, thus acting in the proximal development zone (Vygotsky, 1987); it can promote several EF components, either simultaneously or separately, because robot programming requires sequential reasoning before acting by inhibiting impulsive responses, holding and manipulating visuo-spatial and verbal information in memory, and shifting between different commands/rules (Di Lieto, submitted). ER activities can be performed in every school context, creating a group setting and an attractive learning environment, thus promoting students' interest and motivation (Alimisis, 2013), and this allows for interventions not only on cognitive empowerment but also on social and emotional inclusion. Finally, the ER-Lab ensures the presence of a mentor who can adapt the activity to the need of the single subject.

Given the prevalence of the executive and visuo-spatial domains in the ER-Lab, our previous results (Di Lieto et al., 2017b) and in line with the recent theories of EFs development, which hypothesize a two-factor model with inhibition as a distinct dimension from working memory in children aged 5–7 years old (Usai et al., 2014), significant improvements in inhibition and visuo-spatial working memory were expected in first-grade children. In the present study, the ER-Lab was used in SN children with multiple aims:

- to evaluate the feasibility of an intensive school ER-Lab for children with SN in the first class of the primary school,
- to adapt the ER-Lab training to different types of SN children,
- to measure by standard tests of inhibition and visuo-spatial working memory the training effect of the ER-Lab in SN children,
- to compare the efficacy of the ER-Lab across SN subgroups differing for type and degree of the neuropsychological impairment,
- to estimate the improvements in the Bee-bot programming skills during the ER-Lab in SN children.

MATERIALS AND METHODS

Participants

A total of 13 classes from nine schools participated in the study, from which 187 children with typical development and 42 children with SN from such classes (in Italy all children with SN attend regular classes) were selected (14 females; 28 males; age range 5–7 years, mean age 5.9; and standard deviation 0.7). To fulfill the goals of this study, only data collected from children with SN, identified on the basis of their medical certificates and on the basis of teachers' reports, were presented and discussed. The phase of enrollment of the participants' schools has been developed with the collaboration of the District of Pisa in order to reach as many schools as possible. This research project has been approved by the Pediatric Ethics Committee of Tuscany Region. All parents gave written consent for their children participating in the study and for the publication of the results.

ER-Lab Training

The ER-Lab was conducted twice a week for 10 weeks (20 ER training sessions of 60 min) and involved not only the children with SN but all the children of the class. The ER-Lab was conducted during school time. To choose the most proper robot for our research purposes, a survey was conducted, individuating two models: Bee-bot (Campus Store), a bee-shaped robot, and Pro-bot (Campus Store), a car-shaped robot. Bee-bot robot was selected because it is one of the most utilized robots for school-aged children (Janka, 2008) as it is considered one of the most suitable hardwares for lower primary school children in educational technology (Janka, 2008), and it was expected to be challenging for children with SN aged 5–7.

Bee-bot has a child-friendly design, with a black/yellow bee outline (see **Figure 1**). The Bee-bot can be programmed by some buttons positioned on its back that allow the motion or the rotation of the robot. By four orange buttons it is possible to move the robot either forward or backward (15 cm), and rotate it right or left (90° rotation); a central green button (GO button) makes the programmed sequence start; a blue button removes memory of the robot and starts a new sequence that does not include the program previously inserted (CLEAR or X); another blue button programs a short stop during robot motion (PAUSE or II). At the end of the programmed sequence, Bee-bot furnishes visual and acoustic feedback.

FIGURE 1 | The Bee-bot robot.

During ER-Lab activity, specific activities were proposed, such as asking the child to move the Bee-bot robot in the space, delimited by a carpet (see **Figure 2**) representing a city map or another narrative context, to reach a specific area.

The ER-Lab activities were carried out in a group setting, dividing the children into small groups of five or six children maximum. This choice was made in order to promote the involvement of all the children favoring the observational learning, collaboration, and involvement among peers. Two teachers and one experimenter directed the ER-Lab in each class. According to an adaptive paradigm, the cognitive and robot-programming goals were progressively increased in terms of difficulty. To think before taking action was encouraged, promoting not only a "learn by doing" but also a "learn by thinking" approach and utilizing a metacognitive method.

Every week, the ER-lab trained specific cognitive competencies, focusing mainly on visuo-spatial working memory, response inhibition, and interference control. Mental planning, the capacity to rapidly switch mental sets or strategies during tasks (such as set-shifting and task-switching), language comprehension, and sustained attention were required too. The first 2 weeks were focused on robot familiarization thought simple visuo-spatial robot planning; the third and fourth weeks concentrated on the training of spatial working memory through the programming of more complex robot visuo-spatial planning; the fifth and sixth weeks were focused on robot activities that stressed working memory and inhibition abilities; the seventh and eighth weeks were focused on inhibiting automatic answers in set-shifting or task-switching robot tasks; and the ninth and tenth weeks were dedicated to improving academic skills through the use of robotic programming. Moreover, additional and optional activities, directed to the consolidation of the objectives, were included. Details of cognitive and robot-programming goals for children with SN and examples of adapted activities provided for each ER-Lab week are reported in **Table 1**.

For SN children, *ad hoc* adaptations of both the robots and of the activities were proposed. General indications to perform the activities with SN children were followed. In particular:

- to work in a small group,
- to place the child near the teacher and in a place with few distractions,
- to favor the teamwork and collaboration between children,
- to favor attention and motivation toward customizable reinforcements.

Examples of adaptation of the activities are the following:

- For children with linguistic or cognitive problems, some cardkeys were created, representing the different buttons of Bee-bot. The cardkeys helped the children in the robot programming by being a visual prompt to be associated with the oral command in order to facilitate the learning and permitting a non-verbal response in case of linguistic problems.
- For children with attentional and behavioral problems, attention time was progressively increased, frequent breaks were proposed, and token economy strategies were used to introduce the respect of the group activity rules, such as the turn respect.
- For children with socio-relational problems, imitation learning, collaboration, and involvement among peers were favored throughout relational reinforcements.

In addition to this, Bee-bot has been adapted to children with motor or visual disabilities who could have had difficulties in using small commands to program Bee-bot. Thus, the programming interface was modified, and special larger sensors, switched on/off sensors of 65 mm diameter (Jelly Bean), were inserted in the place of the original ones (**Figure 3**). Modified Bee-bot was used for children with cognitive disability too as Jelly Bean sensors could be temporarily put off-line, thus limiting the choices of planning and making the activities simpler.

Study Design

According to the waitlist randomized trial design, the school classes were randomly split into two groups, and children with SN were thus divided in two Experimental Conditions (Experimental Condition A, $n = 22$ and Experimental Condition B, $n = 20$) for the sequential training rollout. Given this study design, children with a diverse degree and type of impairment were not evenly distributed in the groups under the two conditions. Both experimental conditions were assessed by neuropsychological tests (for details see section Outcome Measures) at time point T0 (in September 2016). After the evaluation, children in Experimental Condition A immediately started ER-Lab training, while those in Experimental Condition B continued their normal academic program. After 10 weeks, all children (Experimental Condition A and B) were re-tested at time point T1 (January 2017). After T1 assessment, Experimental Condition B started ER-Lab training, while Experimental Condition A continued normally academic program. After another 10 weeks, all children were retested at time point T2 (May 2017) (see **Figure 4** for the

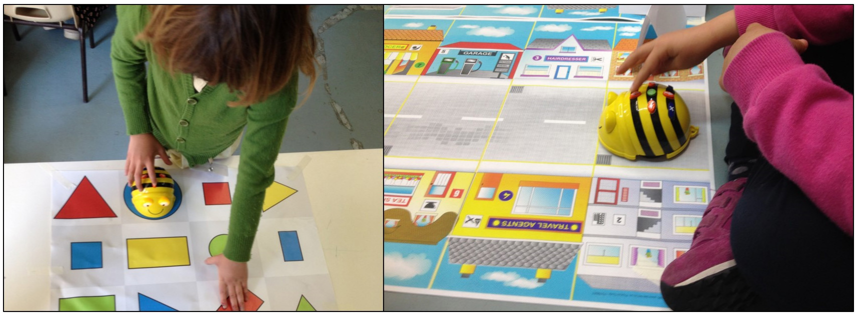


FIGURE 2 | The carpets utilized with the Bee-bot robot.

Study Flow Diagram). The evaluators, who tested children at the three time points, recorded the data, while separate examiners collected and entered data in a database. The evaluators and examiners were blind to the study design and external to the research team.

Outcome Measures

In order to accomplish the aims mentioned, several tests tapping into visuo-spatial working memory and inhibition were selected. Children were assessed by standardized neuropsychological tests and qualitative measures of robotic-programming skills. Several tests were used.

Visuo-Spatial Memory

- Forward Corsi Block Tapping subtest (BVS test). This test measured visuo-spatial memory through the evaluation of the span, representing the longest visuo-spatial information sequence that the child could remember. The visuo-spatial sequence was represented by a sequence of blocks, inserted in a plastic board, that the child had to touch in the same order that the examiner did. The longest sequence of blocks correctly repeated represented the span obtained, and this was computed as the final score of the test (range score 2–8) (Mammarella et al., 2008).

Executive Functions

Visuo-spatial working memory

- Backward Corsi Block Tapping subtest (BVN test). This test was similar to the Forward Corsi Block Tapping subtest, but it measured visuo-spatial working memory by asking the child not only to remember but also to manipulate visuo-spatial information by touching the blocks indicated by the examiner in the reverse order. The longest sequence of blocks correctly repeated in the reverse order represents the span backward obtained, and it was then computed as the final score of the test (range score 1–7) (Bisiacchi et al., 2005).
- Matrix Paths (BVS-Corsi). This test assessed verbal and visuo-spatial working memory by asking the child to identify the final destination on a matrix by listening to a sequence of spatial steps read by the examiner that got progressively longer. The final score was the sum of the correct responses (range score 0–30) (Mammarella et al., 2008).

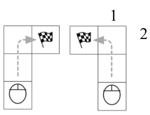
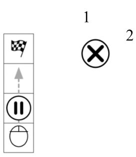
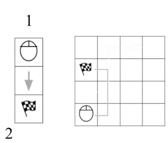
Prepotent response inhibition and interference control

- Inhibition subtest (NEPSY-II test). This test measured the ability to inhibit automatic verbal answers in favor of no-intuitive ones. The first condition was the baseline (Naming condition). The child had to denominate a sequence of alternating figures (square and circle). In the second condition, the Inhibition one, the child had to name "circle" when a square was present and to name "square" when a circle was present. In this test, the score was made by computing the number of errors (range score 0–40), self-correcting responses (range score 0–40), and time (range score 0"–240") of both conditions. All the scores were included in the statistical analysis (Korkman et al., 2007; Urgesi and Fabbro, 2011).
- Little frog's subtest (BIA). This test assesses sustained attention and the ability to inhibit automatic motor answers. The child had to listen to a sequence of acoustic commands: a "Go" command, which indicated that the child should make a graphic tick with a pencil, and a "No-Go" command, very similarly to the first one, which indicated that the child should stop the graphic sequence. The number of correct responses were counted (range score 0–20) (Marzocchi et al., 2010).
- Pippo-says test (a modified version of Simon-says). This test mainly assessed motor inhibition. In this test, two conditions were present: in the first one, the examiner read a sequence of commands to the child that he had to perform only if the command started with the words "Pippo dice." In the second condition, the one utilized in the present study, the instructions were identical, but the examiner performed all the command, and so the child had to inhibit the command not starting with "Pippo dice," and at the same time, control the interference due to examiner performances. Each condition as made by 10 commands. The number of correct commands were computed (0–10 range score) (Marshall and Drew, 2014).

ER-Lab Test

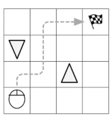
In our first pilot study (Di Lieto et al., 2017b), an ER-Lab test was created to estimate the improvements in the Bee-bot

TABLE 1 | Details of cognitive and robot programming goals and example of activities and adaptations for each ER-Lab week.

ER-Lab	Goals for children with SN	Examples of activity	Goal and methodological adaptations for children with SN
Week 1	**Cognitive**: Familiarization of Bee-bot use, simple visuo-spatial planning **Robot programming:** To reach a target placed two footsteps forward (1). 	*Bee visits the city* Bee arrives in the city! Let's make a tour of the city represented on the carpet reaching different targets (the bar or the school, or the restaurant. . .).	*Motor or visual disabilities:* to promote familiarization of adapted Bee-bot use *Language or cognitive problems:* to favorite verbal comprehension and robot programming of more complex paths, proposing visual supports, as cardkeys and gestural commands, for each robot programming steps. *Attentional or behavioral problems:* to progressively increase attention and behavioral control, proposing breaks if necessary, promoting turn's respect and providing small reward when child is able to respect behavioral and attentional targets. *Socio-relational problems:* to promote social participation and learning by imitation, stimulating collaboration within the group and mutual observations.
Week 2	**Cognitive**: More complex visuo-spatial planning **Robot programming:** To reach a target placed on the right (1) or on the left (2). 	*Happy birthday, Bee!* Bee has organized a birthday party and has to deliver the invitations to it friends moving around the city-carpet.	*Motor or visual disabilities:* to reach the predetermined target and deliver his birthday invitations, child uses the adapted Bee-bot *Language or cognitive problems:* the same adaptations of previous week are proposed. *Attentional or behavioral problems:* the same adaptations of previous week are proposed. *Socio-relational problems:* the same adaptations of previous week are proposed.
Week 3	**Cognitive**: Working memory and visuo-spatial planning **Robot programming:** To understand "pause" command (1); To understand "clear" command (2). 	*Bee is hungry!* Bee is hungry and decides to reach some flowers to pick up pollen. The flowers are represented by geometric shapes on the carpet with different colors, shapes, and sizes. The child has to follow instructions given by a teacher with an incremental challenging and make a "pause" on the target (for example a simple instruction is "the best pollen is in red flowers" while a hard command is "the best pollen is in yellow, big flowers, and in red little flowers"). The instructions are written on cards that the teacher catches.	*Motor and visual disabilities:* to consolidate easier cognitive and robot programming goals, before switching to more complex ones. *Language or cognitive problems*: to consolidate previous goals if necessary, using visual supports. *Attentional and behavioral problems:* to consolidate previous goals if necessary, involving the child in card distribution to sustain attention. *Socio-relational problems:* to consolidate previous goals, involving the child in card distribution to favorite social interaction.
Week 4	**Cognitive**: working memory and inductive logical reasoning **Robot programming:** To reach a target placed footsteps backwards (1), or at the end of a brief pathway concerning multiple rotations (2) 	*Bee's dance* Bee wants to learn a new dance. The teacher gives hidden commands to the Bee-bot and shows the final dance to the children. They have to guess the correct dance steps given.	*Motor and visual disabilities:* to continue adapted Bee-bot use, proposing cardkeys to support robot programming if necessary. *Language and cognitive problems:* the same adaptations of previous weeks are proposed. *Attentional and behavioral problems:* the same adaptations of previous weeks are proposed, proposing simple and progressively more complex sequences to maintain a high motivation *Socio-relational problems:* the same adaptations of previous weeks are proposed, requiring to children of the group to play bells or other noisily objects when the child who program Bee-bot guess the correct sequences.
Week 5	**Cognitive**: working memory and inhibition	*Finding Bee-Bot!* Bee wants to meet a friend, but doesn't remember the road to reach him, and often makes one wrong step. The teacher gives a wrong command to Bee; thus, the child has to consider it before to program Bee-bot to reach the friend because the child cannot press the "clear" command but he can only add more commands.	*Motor and visual disabilities:* to continue adapted Bee-bot use. If the child is not able to understand the required task, simplify the activity and do not provide the wrong command. *Language and cognitive problems:* to remind the child which wrong button was pressed, using the cardkey as memorandum and allowing more attempts. If the task is too complex, continue the activity but not provide the wrong command.

(Continued)

TABLE 1 | Continued

ER-Lab	Goals for children with SN	Examples of activity	Goal and methodological adaptations for children with SN
	Robot programming: To reach a target placed at the end of a complex pathway (characterizing by much steps forward or/and backward, on the right and/or left).		*Attentional and behavioral problems:* to sustain the child attention on wrong button, using the cardkey as memorandum and allowing more attempts. If the task is too complex, simplify it not providing the wrong command. Decrease the number of rewards per behavioral and attentional targets. *Socio-relational problems:* the same adaptations of previous weeks are proposed, involving the child when the wrong command is given.
Week 6	**Cognitive**: working memory and inhibition **Robot programming:** To reach one or two targets placed at the end of a complex pathway and to avoid some obstacles (8). 8 	*Be careful to buds!* Bee has to pick up as much pollen as possible, moving on the flowers represented as geometric shapes on the carpet. But be careful, some flowers must be avoided! The teacher gives the command about the flower to avoid.	*Motor and visual disabilities:* the same adaptations of previous weeks are proposed. *Language and cognitive problems:* the same adaptations of previous weeks are proposed, using a visual image associated to verbal command to sustain working memory and allowing more attempts. *Attentional and behavioral problems:* the same adaptations of previous weeks are proposed, using a visual image associated to verbal command to sustain attention and allowing more attempts. *Socio-relational problems:* the same adaptations of previous weeks are proposed, involving the child in the command distribution to favorite social interaction.
Week 7	**Cognitive**: Inhibition, set-shifting and task-switching **Robot programming:** To follow a high number of commands given	*Bee meets Pinocchio and Jiminy Cricket* Two new characters are presented: Pinocchio, who lies, and Jiminy Cricket, who tells the truth. When Pinocchio gives the command, the child has to perform the opposite command (e.g., if Pinocchio says 2 steps forward, the child has to perform 2 steps backwards), while if Jiminy Cricket gives the command, the child follows it because it is correct. In the second phase of the activity, the characters' roles are inverted.	*Motor and visual disabilities:* to continue adapted Bee-bot use and to consolidate the cognitive goals of the first phase of activity before switching to the second. *Language or cognitive problems*: the same adaptations of previous weeks are proposed, using a visual image associated to verbal command to sustain working memory and proposing easier reversed commands. *Attentional and behavioral problems:* further decrease the number of rewards per behavioral and attentional targets and utilize the cards as memorandum. If it is necessary to maintain attention, involve the child in the distribution of the commands. *Socio-relational problems:* the same adaptations of previous weeks are proposed.
Week 8	**Cognitive**: Inhibition, set-shifting and task-switching **Robot programming:** To follow a high number of commands given	*Bee play by Goose game!* A final target is posed on the carpet and children pick some notes with commands written. If the note is green, the child has to follow the command; if the note is red, child as to perform the opposite command of what written (reverse); if the note is black, the child misses a turn (stop). Help Bee-bot to reach the final target!	*Motor and visual disabilities:* to continue adapted Bee-bot use, proposing easier reversed commands. *Language and cognitive problems:* the same adaptations of previous week are proposed. *Attentional and behavioral problems:* the same adaptations of previous week are proposed. *Socio-relational problems:* the same adaptations of previous week are proposed, stimulating group collaboration and group thinking.
Week 9	**Cognitive**: Phonological working-memory, alpha-numeric ability **Robot programming:** To reach a target placed at the end of a complex pathway	*Bee learns to write!* Every child writes his/her own name with Bee-bot reaching the corresponding letters on the carpet and pressing the "pause" button when Bee-bot arrives on each of them.	*Motor and visual disabilities:* to continue adapted Bee-bot use, proposing the weekly activity if alphanumeric knowledge is acquired; otherwise, proposing previous activities using letters as target for a greater integration. *Language or cognitive problems*: the same adaptations of the previous week are proposed, proposing the weekly activity if alphanumeric knowledge is acquired, otherwise proposing previous activities using letters as target for a greater integration. *Attentional and behavioral problems:* the same adaptations of previous weeks are proposed, proposing easier but progressively more complex letter sequences to limit frustration. *Socio-relational problems:* the same adaptations of previous weeks are proposed.
Week 10	**Cognitive**: Phonological working-memory, alpha-numeric ability	*Bee learns to calculate!* Children have to perform some arithmetic calculation, first reaching the numbers of the calculation and then the result with Bee-bot on the carpet.	*Motor and visual disabilities:* the same adaptations of previous week are proposed with the carpet with numbers. *Language or cognitive problems*: the same adaptations of previous week are proposed with the carpet with numbers.

(Continued)

TABLE 1 | Continued

ER-Lab	Goals for children with SN	Examples of activity	Goal and methodological adaptations for children with SN
	Robot programming: To reach a target placed at the end of a complex pathway		*Attentional and behavioral problems:* the same adaptations of previous weeks are proposed, involving the child in the distribution of the commands, to maintain high motivation and attention. *Socio-relational problems:* the same adaptations of previous weeks are proposed, involving the child in the assignment of the commands and in the planning of social rewards.

programming skills during the ER-Labs. The test was composed of nine tasks, and they were divided into subscales on the basis of their complexity: (i) tasks one to five assessed Bee-bot simple utilization (Bee Programming); (ii) tasks six to eight assessed the ability to plan complex visuo-spatial pathways (Mental Anticipation); (iii) task nine assessed inhibition abilities during Bee-bot navigation (Inhibition) (**Figure 5**).

The ER-Lab test was administered at the beginning, at the middle, and at the end of ER-Lab training. Zero points were accredited if the goal was not reached, half a point was given if the goal was achieved with concrete support (such as anticipating correct navigation by using their own hand or the Bee-bot), and one point was given if the goal was reached without any concrete help.

ER-Lab Logbooks

At the end of each week, teachers filled a logbook in which different aspect of the ER-Lab were qualitatively evaluated. In particular, teachers were asked to report the principal weakness and strengths of children that were met during the ER-Lab training activities of the week.

Statistical Analysis

All statistical analyses were performed using R, the R Project for Statistical Computing software package, version 3.6.0, with a significance level of 5%.

Given the high heterogeneity of the sample, preliminary analysis of the pre-training assessment was conducted based on the degree (mild vs. severe) and the type (attention vs. language problem) of impairment by independent sample Student t tests in case normality assumptions were met. Mann–Whitney tests were used otherwise.

In order to test the effect of the training, separate linear mixed-effects models for each outcome measure were used, with (binary) variables representing ER-Lab training and Experimental Condition A/B as fixed factors and subject ID as random factor, in a repeated measure design. Family-wise estimations obtained by general linear hypotheses were used to test for the following two *post hoc* contrast variables of interest in determining neuropsychological differences during ER-Lab training in both Experimental Conditions (names assigned are indicative of interpretation of the contrasts):

- Training Effect. This was calculated by adding delta changes for time points T1 and T0 for Experimental Condition A and delta changes for time points T2 and T1 for Experimental Condition B.
- Within Baseline Effect. This was calculated by adding delta changes baseline in Experimental Condition B (T1–T0 for Experimental Condition B) and follow-up in Experimental Condition A (T2–T1 for Experimental Condition A).

The differences in the training effects according to the degree and type of impairments were evaluated, comparing pre-post delta changes in each neuropsychological outcome measure between subgroups.

Repeated measure ANOVAs, with *post hoc* Bonferroni corrections to *p*-values, were performed to test differences in ER-Lab tests at the beginning, middle, and end sessions of the training.

RESULTS

Sample Characteristics

Clinical and descriptive data of the sample are listed in **Table 2**.

Children showed different special needs: 14 had attentional problems, 8 had language difficulties, 10 had cognitive impairment, 5 had intellectual deficits, 2 had Autism Spectrum disorder, and 3 had neuro-motor disabilities. The degree of the impairment varied across children: 13 out of 42 children had more severe clinical problems and needed Learning Support Teachers in their classroom who provided them help to reach maximum proficiency in academic achievements for their possibilities, while 29 children showed minor clinical impairments and pursued the academic objectives of their classes using methodological adaptations based on their specific clinical impairments (see **Table 2**).

Comparing children according to the degree of the impairment, reported in **Table 2**, differences at pre-training assessment were only found in the Forward Corsi Block Tapping test [$t(38) = -2.07$, $p = 0.045$] as children with minor clinical problems showed better performances when compared to those with severe clinical impairment.

Concerning clinical subgroups, which were divided according to the type of neuropsychological impairment, for two of them (Autism Spectrum Disorder and Intellectual Disability), no outcome measures were administrable due to the strict rules of standardized measures to obtain reliable data. Moreover, because of the small sample size and the high internal variability of other neuropsychological subgroups, it was not possible to directly compare all the different subgroups. For a visual inspection of data see **Table 3**.

FIGURE 3 | (a) Switched on/off sensors of 65 mm diameter, Jelly Bean; **(b)** The adapted Bee-bot.

For this reason, statistical analyses were run to compare children with attentional (n = 14) and language (n = 8) problems in order to verify whether difficulties in sustaining attention or in instruction comprehension could affect the ER-Lab efficacy. At pre-training assessment, children with language problems showed significant worse performances in the Matrices Path tests [$t(20)$ = 2.28, p = 0.033] compared to the other subgroup, and no other difference between these two subgroups was found at pre-training assessment.

Outputs of Feasibility Study

The Small Group Context

From the qualitative analysis of the ER-Lab logbooks, all children performed the ER-Lab within a small group setting, showing motivation and interest in proposed activities and in social interactions with other children. Only one child (S36) had not followed activities in a group context due to the severe cognitive, motor, and visual problems, which required a one-to-one relationship with the teacher. However, this child performed the ER-Lab sessions within the classroom, and could thus observe the performances of other children and obtain encouragement and incentive from the others.

Methodological and Goals Adaptations

Children with attentional impairments carried out frequent breaks to maintain high levels of motivation and better focus on behavioral control and on activities. The token economy strategy had been performed only with children with hyperactivity disorders in addition to attentional problems. Cardkeys had been used with children, both with those with verbal comprehension deficits and those with intellectual disabilities, to facilitate and

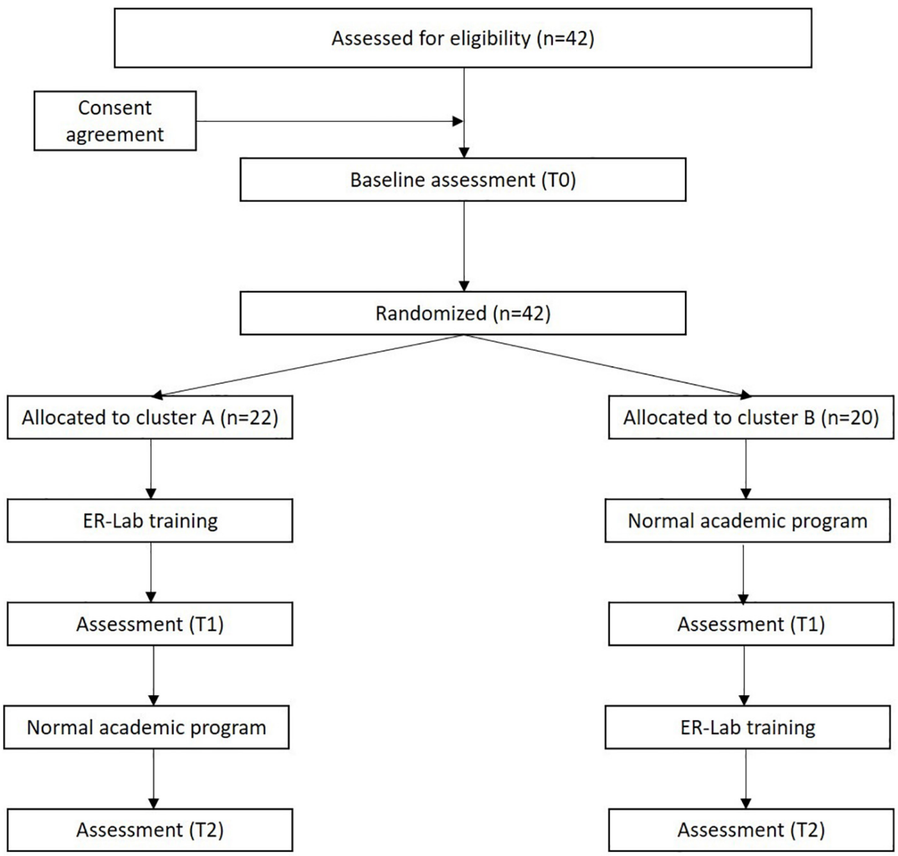


FIGURE 4 | The study flow diagram.

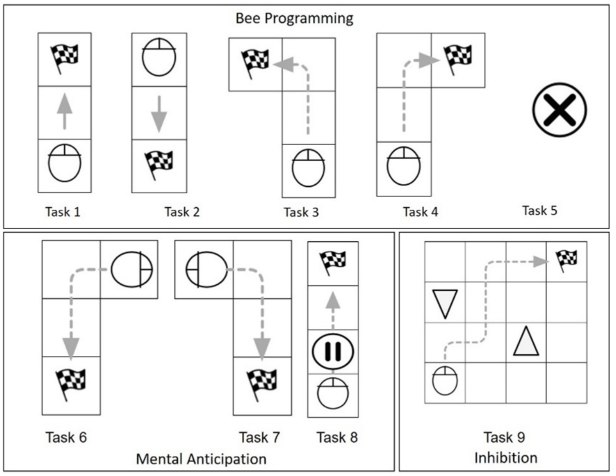


FIGURE 5 | The ER-Lab test.

decompose the different robot steps needed for the more complex sequences of planning. For children with autism, the ER-Lab activities were planned in smaller groups of children, beginning with a one-to-one activity, mediated by an adult, and progressively inserting the child with autism into bigger groups of children in order to promote imitation learning, collaboration, and social involvement, adaptations particularly crucial for children with autism.

The modified Bee-bots had been proposed to children with motor disorders, intellectual disability (S36, S30), and with autism. The children with motor disorders did not show an interest or perceived benefit from this adaptation because the motor problems concerned inferior limbs or one side of the body. Only one of these children (S36) had continually used the modified Bee-bot, showing motivation and pleasure. The other child with a severe intellectual disability and a child with autism, instead, preferred to use modified Bee-bot as an alternative to the standard Bee-bot in order to feel more integrated in the activities.

The adaptations of the robot programming request and of the cognitive goals were used with all children with intellectual disabilities who needed to repeat the same activities several times, also in subsequent sessions, to reach minimum goals.

Neuropsychological Assessments

Three children with more severe problems (S19, S29, and S24) did not complete all tests at all time points. Only one child (S36) did not perform any test because of the severity of the difficulties, thus he was excluded from statistical analysis. Not relevant difficulties were found in the neuropsychological assessments of the other children.

Effect of the ER-Lab Training

Comparing Experimental Conditions, no difference in chronological age [$t(40) = -1.7$, ns], gender [$\chi^2(1) = 0.05$, ns], or any neuropsychological tests at T0 time points ($p > 0.05$) were found.

As shown in **Table 4**, at the end of the training, improvement performances were found in 54% of children in the Matrices Path test, in 77 and 66% of children in the Naming and Inhibition speed, and in 55% of children in the Inhibition self-correcting responses.

The statistical analysis of ER-Lab effects on neuropsychological outcomes in both Experimental Conditions are reported in **Table 5**. Significant improvements after ER-Lab training were found in Naming and Inhibition speed ($p = 0.001$; $p = 0.008$, respectively) and in Naming Self-correcting responses ($p = 0.01$). No other significant differences emerged in any other delta changes pre- and post-ER-Lab training, neither in visuo-spatial memory and working memory domains, nor in the inhibition of automatic motor responses. No delta change was found during normally academic programs in any neuropsychological measures ($p > 0.05$).

No difference in the pre-post ER-Lab Delta changes emerged between mild and severe impairment subgroups in any neuropsychological test ($p > 0.05$), while children with attentional problems showed higher pre-post changes in the Simon Says test compared to the subgroup with language problems [$t(13.56) = 2.39$, $p = 0.032$]; no other significant difference emerged in any other neuropsychological outcomes.

In the ER-Lab test, as shown in **Figure 6**, the children displayed a positive learning trend on the Bee Programming subscale [$F(1, 36) = 89.5$, $p < 0.001$], with performances significantly higher at the end of ER-Lab training with respect to both the beginning [$t(36) = -9.5$; $p < 0.001$] and middle [$t(36) = -6.3$, $p < 0.001$] sessions. Positive trends were also found on the Mental Anticipation subscale [$F(1, 35) = 125.8$, $p < 0.001$], with significant benefits of training displayed at the end with respect to the beginning [$t(35) = -11.4$, $p < 0.001$] and middle [$t(36) = -7.7$, $p < 0.001$] sessions. As with previous subscales, also on the Inhibition subscale performances were significantly improved during ER-Lab training [$F(1, 33) = 21.4$, $p < 0.001$], being higher at the end in comparison to the beginning [$t(35) = -5.1$, $p < 0.001$] and middle [$t(34) = -3.9$, $p < 0.001$] sessions.

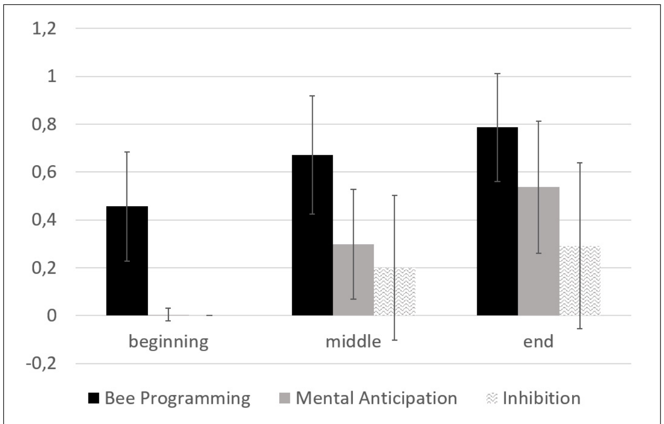


FIGURE 6 | Visual inspection of changing in ER-Lab test at the beginning, middle, and end sessions.

TABLE 2 | Clinical and descriptive data of the study group of children with SN.

	Age range (y,m)	Schools	Classes	Type of cognitive or neuropsychological impairment	Degree of impairment
Experimental condition A					
S1	6,51–7,00	School 1	Class 1	Language	Mild
S2	6.51–7,00	School 1	Class 1	Attention	Mild
S3	5,51–6,00	School 1	Class 1	Cognitive impairment	Mild
S4	6,01–6,50	School 1	Class 1	Attention	Mild
S5	5,01–5,50	School 1	Class 1	Attention	Mild
S6	5,51–6,00	School 2	Class 2	Cognitive impairment	Mild
S7	5,51–6,00	School 2	Class 2	Attention	Mild
S8	5,51–6,00	School 2	Class 2	Language	Mild
S9	7,51–8,00	School 2	Class 2	Attention	Mild
S10	8,01–8,50	School 2	Class 2	Language	Mild
S11	5,51–6,00	School 3	Class 3	Intellectual deficit	Severe
S12	5,51–6,00	School 3	Class 4	Autism	Severe
S13	5,01–5,50	School 3	Class 3	Cognitive impairment	Mild
S14	5,01–5,50	School 3	Class 3	Attention	Mild
S15	5,01–5,50	School 3	Class 3	Attention	Mild
S16	5,01–5,50	School 3	Class 4	Cognitive impairment	Mild
S17	5,01–5,50	School 4	Class 5	Language	Mild
S18	6,01–6,50	School 4	Class 5	Cognitive impairment	Mild
S19	7,51–8,00	School 5	Class 6	Intellectual deficit	Severe
S20	5,51–6,00	School 5	Class 6	Attention	Mild
Mean (*SD*)	6,90 (0,9)				
Range	5,01–8,00				
Experimental condition B					
S21	6,01–6,50	School 6	Class 7	Cognitive impairment	Severe
S22	7,01–7,50	School 6	Class 7	Motor disorder	Severe
S23	7,01–7,50	School 6	Class 7	Attention	Severe
S24	6,01–6,50	School 6	Class 7	Autism	Severe
S25	6,01–6,50	School 6	Class 7	Language	Mild
S26	6,01–6,50	School 6	Class 7	Language	Mild
S27	5,51–6,00	School 6	Class 7	Attention	Mild
S28	6,51–7,00	School 6	Class 7	Cognitive impairment	Mild
S29	7,51–8,00	School 7	Class 8	Intellectual deficit	Severe
S30	6,51–7,00	School 7	Class 8	Intellectual deficit	Severe
S31	6,51–7,00	School 7	Class 9	Motor disorder	Severe
S32	6,01–6,50	School 7	Class 9	Attention	Mild
S33	5,51–6,00	School 8	Class 10	Cognitive impairment	Mild
S34	6,01–6,50	School 8	Class 10	Attention	Mild
S35	6,01–6,50	School 9	Class 11	Motor disorder	Severe
S36	7,01–7,50	School 9	Class 12	Intellectual deficit	Severe
S37	6,01–6,50	School 9	Class 13	Cognitive impairment	Severe
S38	5,51–6,00	School 9	Class 11	Cognitive impairment	Mild
S39	5,01–5,50	School 9	Class 11	Attention	Mild
S40	5,01–5,50	School 9	Class 13	Attention	Mild
S41	5,51–6,00	School 9	Class 13	Language	Mild
S42	6,01–6,50	School 9	Class 13	Language	Mild
Mean (*SD*)	6,4 (0,6)				
Range	5,01–8,00				

DISCUSSION

The present study found that ER-Lab training had a significant effect on inhibition skills in a group of children with SN, supporting that it is possible to empower one of the main EFs components in children with SN within an ecological context, incorporating social, emotional, and cognitive significances.

TABLE 3 | Mean and Standard Deviation on pre- and post-training performances for each outcome in each neuropsychological subgroup.

Subgroups according the type of neuropsychological impairment	Pre- or post-training	Forward Corsi Block Tapping test	Backward Corsi Block Tapping test	Matrices Paths test	Time in naming condition	Errors in naming condition	Self-correcting responses in naming condition	Time in inhibition condition	Errors in inhibition condition	Self-correcting responses in inhibition condition	Little frogs test	Pippo says test
Attentional problems	Pre-	3.14 ± 1.03	2.00 ± 0.78	6.07 ± 4.14	94.43 ± 29.74	2.79 ± 6.22	2.50 ± 2.98	110.36 ± 33.46	5.64 ± 8.97	6.00 ± 5.38	9.14 ± 2.93	6.21 ± 1.97
	Post-	3.36 ± 0.74	2.21 ± 1.05	8.14 ± 3.68	68.93 ± 13.63	1.36 ± 1.78	1.43 ± 1.02	99.78 ± 27.13	4.71 ± 6.30	4.43 ± 3.06	11.36 ± 5.24	7.71 ± 1.90
Language difficulties	Pre-	2.88 ± 0.83	2.00 ± 1.07	2.43 ± 2.70	107.43 ± 54.04	1.86 ± 2.11	2.14 ± 1.34	149.14 ± 72.68	6.86 ± 7.69	3.71 ± 2.81	7.00 ± 3.51	7.14 ± 2.79
	Post-	3.50 ± 0.53	2.25 ± 1.03	6.14 ± 4.22	90.57 ± 41.67	1.14 ± 1.46	1.57 ± 1.27	127.43 ± 57.66	6.43 ± 7.85	4.00 ± 3.27	7.57 ± 5.91	6.14 ± 1.46
Cognitive impairment	Pre-	2.70 ± 0.67	1.70 ± 0.48	2.70 ± 1.89	104.40 ± 41.16	2.40 ± 3.24	3.70 ± 3.71	132.30 ± 45.45	12.30 ± 14.88	5.10 ± 3.41	6.70 ± 7.10	5.60 ± 2.84
	Post-	2.80 ± 0.42	2.20 ± 0.92	4.80 ± 2.97	88.20 ± 32.79	3.00 ± 4.03	1.50 ± 1.65	123.20 ± 48.49	8.10 ± 8.77	4.80 ± 3.29	8.10 ± 5.72	7.00 ± 2.62
Neuromotor disabilities	Pre-	2.67 ± 0.58	2.00 ± 1.00	6.00 ± 3.46	132.67 ± 32.02	3.00 ± 2.65	8.00 ± 8.66	159.67 ± 6.66	7.67 ± 6.43	7.00 ± 6.08	5.67 ± 4.16	8.33 ± 2.89
	Post-	2.33 ± 0.57	2.33 ± 0.58	7.67 ± 0.57	84.67 ± 16.50	1.33 ± 0.58	1.67 ± 0.58	123.33 ± 20.50	4.33 ± 1.53	4.67 ± 6.43	3.33 ± 1.52	6.67 ± 3.05

NS, not available.

To reach this purpose, the ER-Lab for EFs within schools appeared to be a suitable tool thanks to its technical characteristics, the adaptability and flexibility of interfaces, and its increasing pedagogical implementation (Di Lieto et al., 2017b, 2019). This study was the first attempt to adopt a rigorous and scientific approach, both in terms of study design and of intervention methodology, to improve EFs by ER in a sufficiently large sample of children with SN.

The ER-Lab logbook observations suggested that, first of all, despite the wide variability of clinical problems in the sample, all children showed a high level of interest and motivation during ER activities, and all, except one, performed ER-Lab within small groups of children. According to teachers' qualitative observations, this setting has been important to favorize social inclusion and more efficient learning. Mutual concrete and verbal feedback among children helped to sustain the gradual development of self-control capacities and careful reflection regarding the pre-set goals to evaluate the need of change or modifications. Moreover, the different methodological and goal adaptations were organized according to the type of neuropsychological or cognitive deficits in order to favorize gradual and efficient learning, following the specific strengths and weaknesses of children with SN. By qualitative observations, methodological and goal adaptations were positively accepted by children, both when they were oriented to the behavior (e.g., breaks or token economy strategies) or to cognitive strategies (e.g., cardkeys or the simplification of robot-programming goals). Not all children with severe motor or intellectual disabilities or with autism accepted the modified Bee-bots, however, because the different shape of Bee-bot may favor self-perception of diversity in comparison with their peers. Nevertheless, children with more severe clinical problems and, thus, with significant difficulties in Bee-bot programming, accepted the modified Bee-bots and used them exclusively or alternatively to the standard Bee-bots.

Concerning the neuropsychological assessment, conducted according to the waitlist randomized trial design, a majority of the children completed all of the tests without relevant difficulties, which is suggestive of the feasibility of a quantitative approach to measure ER-Lab effects in children with SN.

An increasing number of researchers on EF interventions in children with SN employ high-cost technologies, which is not easily accessible or achievable for families or schools (Shinaver et al., 2014). The present study provides a first attempt at implementing an EF intervention in school classes; it is flexible in terms of methodological and goals adaptations for children with SN, taking advantage of the positive characteristics of the new technologies, such as its appeal, the possibility it displays to decompose complex programming into simpler tasks, and the possibility of using ecological, flexible, and low-cost tools.

The main finding of the present study was the significant effect the ER-Lab training had on inhibition skills in terms of speed of processing (Time in Inhibition condition test) and rapid automatization naming in terms of speed of processing

TABLE 4 | Descriptive data on pre- and post-training performances for each outcome in children with SN.

Neuropsychological outcomes	Pre-training* Mean ± SD	Post-training° Mean ± SD	% of children with improve performances+
Forward Corsi Block Tapping test	2.80 ± 0.85	2.95 ± 0.80	32%
Backward Corsi Block Tapping test	1.85 ± 0.77	2.13 ± 0.96	33%
Matrices Paths test	3.83 ± 3.56	5.90 ± 4.00	54%
Time in naming condition	104.97 ± 38.26	87.20 ± 36.08	77%
Errors in naming condition	2.45 ± 4.18	2.02 ± 2.93	44%
Self-correcting responses in naming condition	3.13 ± 3.67	1.69 ± 1.42	49%
Time in inhibition condition	129.82 ± 47.34	116.26 ± 41.37	66%
Errors in inhibition condition	8.55 ± 10.27	7.24 ± 8.93	50%
Self-correcting responses in inhibition condition	5.00 ± 4.33	4.24 ± 3.29	55%
Little frogs test	7.43 ± 4.66	8.68 ± 5.70	50%
Pippo says test	6.33 ± 2.37	6.85 ± 2.15	35%

**Pre-training, performances at time point T0 for Experimental Condition A and T1 for Experimental Condition B;°Post-training, performances at time point T1 for Experimental Condition A and T2 for Experimental Condition B; +% of children with improve performances, percentage of children with a post-training score at least of 1 point higher than the pre-training.*

TABLE 5 | Results of mixed effects model and *post hoc* comparisons on delta changes in all children with SN.

Neuropsychological outcomes	Within baseline effect+	*Post hoc* comparison	Training effect§	*Post hoc* comparison
	Estimated Mean (CI)	*p*	Estimated Mean (CI)	*p*
Forward Corsi Block Tapping test	0.14 (−2.05, 2.33)	0.982	−1.66 (−4.75, 1.43)	0.347
Backward Corsi Block Tapping test	0.53 (−2.35, 3.42)	0.848	−0.60 (−4.63, 3.43)	0.898
Matrices Paths test	4.06 (−5.69, 13.82)	0.499	1.60 (−12.08, 15.29)	0.936
Time in naming condition	−44.08 (−137.86, 49.70)	0.427	−210.08 (−345.21, −74.95)	0.001*
Errors in naming condition	1.48 (−10.53, 13.49)	0.926	−11.31 (−28.49, 5.86)	0.225
Self-correcting responses in naming condition	6.31 (−2.42, 15.03)	0.175	−15.75 (−28.21, −3.29)	0.011*
Time in inhibition condition	−67.39 (−149.39, 14.61)	0.117	−153.50 (−270.62, −36.39)	0.008*
Errors in inhibition condition	2.32 (−22.34, 26.98)	0.959	−33.38 (−68.30, 1.53)	0.063
Self−correcting responses in inhibition condition	−0.28 (−11.24, 10.68)	0.998	−1.90 (−17.42, 13.62)	0.930
Little frogs test	−0.93 (−14.89, 13.03)	0.981	8.43 (−11.58, 28.44)	0.493
Pippo says test	−2.59 (−8.52, 3.33)	0.469	1.76 (−6.61, 10.13)	0.812

*Estimated Mean (CI), the mean and the Confidence of Interval estimated on the basis of the statistical model for each outcome measure. +Within Baseline Effect, differences during normally academic program in both Experimental Conditions, calculated adding delta changes baseline in Experimental Condition B (T1–T0 for Experimental Condition B) and follow-up in Experimental Condition A (T2–T1 for Experimental Condition A); §Training Effect, differences during ER-Lab training in both Experimental Conditions, calculated by adding delta changes for time points T1 and T0 for Experimental Condition A and delta changes for time points T2 and T1 for Experimental Condition B. *Significant result.*

and accuracy (Time and Self-correcting responses in Naming condition test). Thus, after the training, children with SN showed a significant increase, in comparison to the pre-training assessment, in the speed of their cognitive control of inappropriate responses and in the number of self-monitoring responses they displayed; this was for the improvement of performances of the Self-correcting responses parameter in the Naming condition test. This result was expected because the ER-Lab activities were implied to inhibit automatic responses through programming activities that trained the capacity to think before acting or to give the opposite response with respect to a certain command (see **Table 1** for a more detailed description of activities and cognitive goals). No pre-post differences were found, and this was in contrast to what we expected in relation to our previous study (Di Lieto et al., 2017b), in working memory and in other inhibition tests. It may be hypothesized that, because of the functional heterogeneity of SN, the ER-Lab training may affect mainly inhibition, that is, according to recent literature, the main basic EFs, emerging as single undifferentiated factor in early ages (Wiebe et al., 2008; Fuhs and Day, 2011; Wiebe et al., 2011; Willoughby et al., 2012; Gandolfi et al., 2014). Moreover, although not directly explored in the present study, heterogeneity in the EFs profile in SN, as documented by several studies (Castellanos et al., 2006; Lanfranchi et al., 2010; Kapa and Plante, 2015; Vilgis et al., 2015; Astrea et al., 2016; Margari et al., 2016; Di Lieto et al., 2017a), can also partially explain the smaller ER-Lab training effect in SN than in typical children. In addition, we hypothesized that, as ER-Lab training stressed different abilities, the direct effect on specific EF components, such as inhibition and working memory, may be mild within a heterogeneous population.

Due to the missing data for two clinical subgroups, the small sample size, and the high internal variability of other clinical subgroups, it was not possible to directly compare all the different subgroups; thus, apart from subgroup visual inspections, explorative analyses were conducted on subgroups of children, divided according to the degree of impairment and the neuropsychological problems. The comparisons showed differences in ER-Lab training effects. No difference was found between the two subgroups based on the degree of the impairment in any of the neuropsychological tests, suggesting that the ER-Lab training may have a positive effect in children, both for those with mild difficulties and with a more severe impairment. For that which concerns specific neuropsychological criteria, children with attentional impairment had more benefits in the inhibition of motor responses task when compared to children with language deficit. This specific positive effect of the ER training, therefore, concerns an EF component representing, more than in developmental language disorders, a core deficit in children with attentional problems because it is also associated with a specific neuro-functional pattern (for a meta-analysis see Lei et al., 2015).

The present study has some limitations. First of all, we conducted statistical analyses only in some clinical subgroups based on the type of cognitive or neuropsychological impairments (attention vs. language problems), excluding comparisons with other type of clinical population (cognitive impairment, intellectual deficit, Autism Spectrum disorder, and neuro-motor disabilities) due to missing data for Autism Spectrum Disorder and Intellectual Disability subgroups and due to small sample sizes and heterogeneity of the samples for cognitive impairment and neuro-motor disabilities subgroups. In light of this, the feasibility and efficacy results of this study need to be confirmed in larger samples, differentiated according to neuro-developmental disorders with the addition of other neuropsychological outcome measures to assess children with more severe intellectual and social communication deficits. Despite these limitations, the results of this study seem to be particularly important because they contribute to the implementation of new evidence-based interventions, which may be used in synergy to clinical and home-based trainings in children with SN. Another relevant limitation involves the training transfer effects on school achievements or on school adjustment, that were not investigated and that can be addressed in future studies. Moreover, different tests (for example, to study spatial working memory or other cognitive abilities involved in the training, such as the attention domain) can be utilized in future studies to better understand the ER-Lab effect. Finally, future studies are needed to compare ER training to other training oriented to improve EFs in order to confirm the key points individuated in the literature to define a EFs training as being effective in a clinical sample.

CONCLUSION

In conclusion, this study may suggest new and interesting elements about the educational role of robotics in the scholastic system also in children with neurodevelopmental disorders. These activities may favorize both the cognitive learning, exploiting the adaptability of the robots, and the social inclusion thanks to the context of the group setting of the ER activities.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Pediatric Ethics Committee of Tuscany Region. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

MD, EC, CP, GS, and EI conceptualized and designed the work, data collection, data analysis, and data interpretation and participated in the writing and critical revision of the manuscript. FC, PD, and GC conceptualized and designed the work and performed the critical revision of the article. All authors approved the final version.

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SYSTEMATIC REVIEW
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Is Cognitive Training Effective for Improving Executive Functions in Preschoolers? A Systematic Review and Meta-Analysis

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In the present meta-analysis, we examined the effect of cognitive training on the Executive Functions (EFs) of preschool children (age range: 3–6 years). We selected a final set of 32 studies from 27 papers with a total sample of 123 effect sizes. We found an overall effect of cognitive training for improving EF ($g = 0.352$; $k = 123$; $p < 0.001$), without significant difference between near and far transfer effects on executive domains. No significant additional outcome effects were found for behavioral- and learning-related outcomes. Cognitive training programs for preschoolers are significantly more effective for developmentally at-risk children (ADHD or low socio-economic status) than for children with typical development and without risks. Other significant moderators were: individual vs. group sessions and length of training. The number of sessions and computerized vs. non-computerized training were not significant moderators. This is the first demonstration of cognitive training for transfer effects among different executive processes. We discuss this result in relationship to the lower level of modularization of EFs in younger children.

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INTRODUCTION

Executive Functions (EFs) are a set of top-down cognitive processes that underpin goal-directed behaviors (Shallice and Burgess, 1996; Diamond, 2013).

EFs have been distinguished in three major core executive processes: Working Memory (WM), Inhibitory Control (IC), and Cognitive Flexibility (CF) (Miyake et al., 2000). WM refers to holding in mind and mentally manipulating information. IC refers to the ability to resist impulses, distractions, and habits, and to actively suppress interfering representations for producing an adequate response. CF refers to the ability to *think outside the box* and adjust to change (Diamond, 2013). These skills allow us to monitor and flexibly adapt our behavior to changes in context, and to learn new actions and strategies to solve new and complex problems.

Over the past decades, an increasing body of empirical results has demonstrated that the development of EFs during early childhood plays an important role in supporting school readiness and social-emotional development, and in predicting which cognitive abilities will be required for succeeding in school (Best et al., 2011). Furthermore, EFs are also critical cognitive domains for understanding the heterogeneous nature of neurodevelopmental disorder phenotypes, since EFs impairments have already been observed at this age in neurodevelopmental disorders, such as Attention Deficit Hyperactivity Disorder (ADHD), Autism Spectrum Disorder (ASD), and Specific Language Impairment (SLI) (Craig et al., 2016; Slot and Von Suchodoletz, 2018).

Preschool age marks the passage from infancy to childhood and represents the most critical period for child development (Diamond, 2006; Garon et al., 2008; Best and Miller, 2010). In this period of life, we experience major performance improvements in many EF tasks, in parallel with structural and functional changes of the prefrontal cortex, like the wide pruning of synaptic connections (Huttenlocher, 1979) and the maturation of subcortical prefrontal myelination (Kinney et al., 1988). The rapid changes occurring in preschoolers make it difficult to define the organization of EFs clearly. Contrary to adulthood, in which there is a general consensus about the EFs multi-domain structure, the question of the development and the structure of EFs in early childhood is still open. Studies have provided empirical evidence in support of both a global unitary nature and a multifaceted nature of the EFs structure over the preschool years, although both the number and the nature of these functions have differed across studies.

Given the rapid and heterogeneous nature of EFs development over the preschool period (Howard et al., 2015), the practice of investigating the issue by collapsing participants into overly large age bands might have obscured qualitative age-related differences in their organization. Furthermore, Howard et al. (2015) reported that EFs followed dynamic developmental trajectories every 6 months across the preschool period, and did not become linearly more differentiate, as was largely theorized by factorial studies. Moreover, Nelson et al. (2016) found that the degree of unity of EFs during these years did not decrease linearly over time.

Studies targeting the EFs structure in 3 year old children found that a unitary model describes the EFs organization better than a two- or three-factor structure (Hughes et al., 2010; Wiebe et al., 2011), while those focusing exclusively on children of 4, 5, and 6 years have found both a two-factor (Usai et al., 2014; Stålnacke et al., 2019) and a latent single-factor model (Wiebe et al., 2008; Fuhs and Day, 2011). Garon et al. (2008) proposed a hierarchical integrative model, in which each executive component is built on earlier developing functions in the first years of life, whose precursor is attention. Working memory is the component that develops first, followed by inhibitory control and, finally, cognitive flexibility is built on both of them. Diamond (2013) considers EFs as a unitary construct with three separable components, which develop supporting each other and all together carry out higher order executive processes (i.e., problem solving and planning, also referred as fluid intelligence).

Recent research comparing unitary vs. fractionated EFs models-fit in the entire preschool age band (Miller et al., 2012; Lerner and Lonigan, 2014; Howard et al., 2015; Monette et al., 2015), has highlighted methodological issues related to task selection in the studies supporting a single-domain organization of EF. This new evidence suggests that a two-factor structure comprising WM and IC as *diverse but united* components may summarize and better explain EFs during the preschool period.

Due to the important role of EFs for many aspects of human life (Best et al., 2011), many recent empirical studies have focused on cognitive training aimed at improving EFs and their precursors (e.g., attention) in preschoolers. The idea that EF impairments may place constraints on other higher cognitive functions suggests that, if training can enhance EFs, this should produce transfer effects to diverse tasks that place demands on the untrained executive processes and have important benefits for aspects of everyday functioning that are widely considered to depend on EFs.

These effects are commonly differentiated in near- and far-transfer effects. *Near-transfer effects* refer to the effects of cognitive interventions on various tasks tapping onto the same trained cognitive mechanisms (Melby-Lervåg and Hulme, 2013; Sala and Gobet, 2016, 2017; Kassai et al., 2019). *Far-transfer effects* refer to the effects of training on various aspects of behavior and learning, functionally related (but distinct) to Executive Functioning (Melby-Lervåg and Hulme, 2013; Sala and Gobet, 2016, 2017). However, some authors refer to far transfer effects also with reference to tasks tapping onto other executive processes, not directly trained by the intervention activities (Kassai et al., 2019), because it is questionable whether, in the case of children, training one EF has an effect on other, untrained, executive skills.

For instance, the near transfer effects of visuo-spatial working memory training in preschoolers would be measured on tasks such as Corsi backward or matrix span tasks, while far transfer effects of the same training in preschoolers would be measured on numeracy/literacy skills (learning) or Stroop-like tasks (inhibitory control, not directly trained).

Some studies demonstrated that children at risk (i.e., children from low-income families, with psychopathology traits, born preterm) may benefit particularly from EF programs, since improvement in EFs may lead to better academic performance (Diamond and Lee, 2011) and generally to better adaptation, leveling the playing field and reducing the achievement gap (St. John et al., 2019). Given the relevance of EFs in human life, it could be useful to also sustain and enhance the development of these skills in typically developing preschoolers. Empirical evidence showed that cognitive training may improve near-trained EFs across childhood, particularly for working memory (Wass et al., 2012), but to date there are no meta-analytic studies on their effectiveness focused in the 3–6 age range, which represents a critical period for EFs development.

Referring to cognitive interventions, Diamond and Lee (2011) found that training inhibitory control significantly improved these skills, but its effects do not generalize to delay of gratification performance in school-age children. As concerns working memory treatments, in a meta-analysis of 23 published training studies, Melby-Lervåg and Hulme (2013) concluded that these interventions led to reliable improvements in working memory skills, but the improvement did not transfer to other skills, such as reasoning, inhibitory processes, word decoding, and arithmetic skills. Still, Sala and Gobet (2017) reported only a small far-transfer effect of working memory training on mathematics and literacy in school-aged typically developing children, but no transfer to fluid intelligence.

Recently, Kassai et al. (2019) and Takacs and Kassai (2019) reviewed the effectiveness of multi-domains and single-domain EFs training in 2–12 year old children, finding no convincing evidence of far-transfer among EFs themselves, or in multi-domain EFs cognitive training. Thus, although meta-analytic studies so far have shown that training EFs is possible, the transfer seems to be narrow and limited to tasks tapping the trained abilities.

However, the current meta-analysis specifically focuses on studies targeting only the preschool population. Since the EF components are still developing and less differentiated between the ages of 3–6 years than in middle childhood, cognitive training aimed at improving one or more of executive skills might also show significant effects on untrained EF tasks in this younger population. Furthermore, far-transfer effects may occur when children, during the training activities, learn and automatize a new cognitive routine, which is not yet established in their mind architecture (Gathercole et al., 2019). For instance, cognitive training tasks that load heavily on working memory skills might improve math performance; controlling, regulating, and actively maintaining relevant numerical information are fundamental processes to accomplish mental and written calculation, as well as number dictation and problem solving. As, plausibly, new cognitive routines are more easily established in preschoolers than in older children, we should therefore expect that far transfer effects to learning and behaviors are more likely in preschoolers. Many researches showed that targeting younger individuals have reported more widespread transfer of training effects and young children have generally shown significantly larger benefits from training than older children (Wass et al., 2012; Melby-Lervåg and Hulme, 2013).

Accordingly, our study aims to examine the evidence regarding the near- and far-transfer effects of cognitive training in preschoolers aged between 3 and 6 years old. To investigate these effects, we refer to Diamond's hierarchical model (Diamond, 2013), thus considering both core and high-level EF: working memory, inhibitory control, cognitive flexibility, planning, and problem solving (also referred to as fluid intelligence). Based on the literature, we also took into consideration that far transfer effects both behaviors and cognitive skills predicted or related to EFs development.

We included data of both typically developing and developmentally at-risk children, with the aim to contribute to the existing knowledge on the clinical question on the effectiveness of cognitive training for improvements in EFs and children's everyday functioning.

Based on the literature, the following hypothesis and research questions were investigated:

1. we expected significant near-transfer effects and possible significant far transfer effects of cognitive training both on the untrained executive components and on additional outcomes related to EFs, such as learning related processes (i.e., numeracy and literacy), adaptive and problem behaviors (e.g., inattention, hyperactivity, and impulsivity);
2. we also wanted to investigate if such transfer effects would vary across:

- targeted population: (a) age of participants, (b) developmentally at-risk children vs. not-at-risk children.
- type of control group: (c) active vs. passive
- characteristics of the training: (d) computerized vs. not computerized; (e) individual vs. group; (f) number of sessions; (g) length in minutes.

METHODS

Operational Definitions

We categorized the cognitive interventions based on the characteristics of the training and on the EF it targeted. Specifically, we categorized the training as *computerized* when activities were carried out with the help of a computer, tablet, robot, or virtual reality and *not computerized* when they were conducted in a classical manner, that included paper and pencil tasks and/or activities involving the children's bodies. All interventions utilized game-like activities aimed at improving one or more EF skills by practicing tasks involving a precursor of EFs, such as attention, or one or more executive processes.

As reported by Takacs and Kassai (2019), the main feature of EFs training is that children are not given new strategies, but they have to apply their own existing set of strategies. We categorized training as *group* interventions when it was based on the presence of small groups of peers during the activities, and *individual* interventions, when based only on trainer-child interactions. To differentiate near- and far-transfer effects we categorized each outcome measure according to which major executive process it assessed, based on the preschool EFs assessment literature (Garon et al., 2008; McCormack and Atance, 2011; Anderson and Reidy, 2012; Diamond, 2013). For instance, tasks requiring active manipulation of information kept in mind, such as backward digit, word, or spatial span tasks, were coded respectively as verbal and visuospatial working memory measures, as well as those that involved mostly memory updating processes (e.g., keep track, Mr. X or Odd-One-Out). Forward span-like tests were considered to measure short-term memory since they did not require working memory processes (Alloway et al., 2006) therefore, we did not include them in the meta-analysis. If a study collapsed forward and backward trials in a single measure, we included it as a general measure of working memory process. We considered those tests that required children to inhibit either a distractor (Commissions of the Continuous Performance Test), a prepotent (Stroop like task and Go/NoGo paradigm), or automatized response (Head Toes Knees Shoulders), as well as tasks requiring them to wait for gratification, as measures of inhibitory control. We categorized tests requiring a *shift* among different response sets and flexibly adjusting the response according to new rules (e.g., last phase of Shape School, Trail Making Test, and Dimensional Change Card Sort) as measures of cognitive flexibility. We classified tests that required the children to order events mentally in advance (McCormack and Hanley, 2011), such as Tower-like tasks, as measures of planning abilities; we considered tasks that challenged thinking, demanding to abstract, reason and recognize visuo-spatial pattern, such as

Raven Matrices and Cube Drawing, as measures of problem solving skills.

It should be pointed out that we considered each of these outcome domains as separate to differentiate near- from far-transfer effects on untrained EFs processes. For example, we considered the effect of IC training on an IC task as near-transfer, while we categorized the effect of IC training on working memory, cognitive flexibility, planning, or problem solving tasks as far-transfer. Since to date there is no consensus among scientists over the factorial organization of EFs in early childhood, it is necessary to previously establish if far transfer from separate executive functions is possible, before addressing questions about generalization to other far-aspects, such as learning and behavior. We considered these far-aspects as additional outcomes, that is, measures of the effects on fields related to (but different from) EFs. This definition of far-transfer is consistent with Thorndike and Woodworth's (1901) common element theory. We collected three type of non-EF far-transfer measures, based on previous literature. Specifically, we considered effects on EFs related problem behaviors, including inattention, hyperactivity, and conduct issues, measured by a parent and teacher rating scale; on learning related outcomes, measured by early numeracy and literacy tasks or mean grades (at kindergarten); and EFs related behaviors including emotional self-regulation abilities, and social and adaptive abilities connected to EFs.

Search Strategy

In accordance with the PRISMA statement (Moher et al., 2009), we used a systematic search strategy to find the pertinent studies. Using different combinations of the terms "executive functions," "training," and "preschoolers" and their synonyms (see **Appendix A** for a sample of the detailed search string), we searched on PubMed, PsycInfo, Web of Science, Dialnet, ERIC, Redalyc, ProQuest Dissertations & Theses Global, Base de Datos de Tesis Doctorales (TESEO), e-thesis online service (EThOS), DART-Europe E-theses Portal, and the Biblioteca Nazionale Italiana Doctoral Thesis Repository to identify all potential journal articles and unpublished studies, as doctoral dissertations, that reported on the effects of cognitive training programs aimed at improving EFs in children aged 3–6 years old. We also published posts on Researchgate, Facebook, Linkedin, and Twitter, sent e-mails to Italian Psychological Associations and researchers in the field, to invite researchers to send us their unpublished works and inaccessible data on the topic. Despite our extensive research of the gray literature, we found only a small amount of unpublished studies. Preliminary analyses ruled out the presence of publication bias; the size of the EF training effects was bigger in the unpublished studies. Adopting a conservative approach, we excluded the gray literature from the principal analyses to avoid a possible source of bias, due to their low numerosity and atypically high EF effects. However, a parallel analysis conducted including these studies, reported in **Supplementary Material**, showed that the differences in results were negligible.

After excluding duplicates, 6,573 records remained. The first and second authors independently screened all of them, based on title and abstract and according to inclusion and exclusion criteria. The agreement rate in this phase was 98%. As a secondary search, the references of the selected studies ($n = 141$), in addition to relevant systematic reviews, were checked to find other eligible studies. Full texts of the identified papers were reviewed by the first and second author and we solved disagreements through discussion with the fourth author. Also in this phase, the agreement rate between the two raters was high (95%). Finally, as shown in the flow chart, we identified 27 articles (32 studies) with 123 contrasts that were eligible for the present meta-analytic review. Details concerning the method of literature search and criteria for inclusion and exclusion of studies are shown in **Figure 1**.

Inclusion Criteria

The included studies had to meet the following criteria:

- at least one EF outcome measure;
- pre-post treatment designs and randomized control trials with at least a (either active or passive) control group;
- at least one of the EF measures was an objective neurocognitive measure;
- at least 8 participants per condition;
- at least 10 sessions;
- paper written in English, Italian or Spanish.

Exclusion Criteria

Firstly, we excluded all the studies where participants were not 3–6 years old. In doing so, we strictly considered the age criterion (3–6 years old children), disregarding grade attendance since preschool attendance years vary across countries and we could have potential review papers from about 63 different countries (calculate based on Lewis's *Ethnologue Language of the World* data; Lewis, 2009). This decision was also substantiated by evidence over the 5–6 years period, which revealed there are no relevant differences among EFs organization between older preschoolers and first graders (Usai et al., 2014).

Then, we excluded all studies utilizing training strictly based on physical exercise, drama, and art activity, as well as preschool curricula created to enhance EFs, mindfulness-based, and neurofeedback training, because the current meta-analysis aims to establish the effect of cognitive training to EFs. We also excluded works that combined cognitive training with parent training or, more generally, were part of a multimodal system intervention, because we are interested in disentangling the effects of cognitive training from other types of intervention in combination.

With regards to outcome measures, we included performance-based measures collected by EFs tasks and EFs-related cognitive abilities, like literacy, numeracy, and academic achievement. All outcomes were based on continuous data. To avoid near-transfer overestimation, we excluded from the analysis outcome measures that were merely based on the same tasks practiced during the intervention. Furthermore, we run additional analyses on far transfer combining verbal and visuo-spatial working memory (WM) into a single outcome

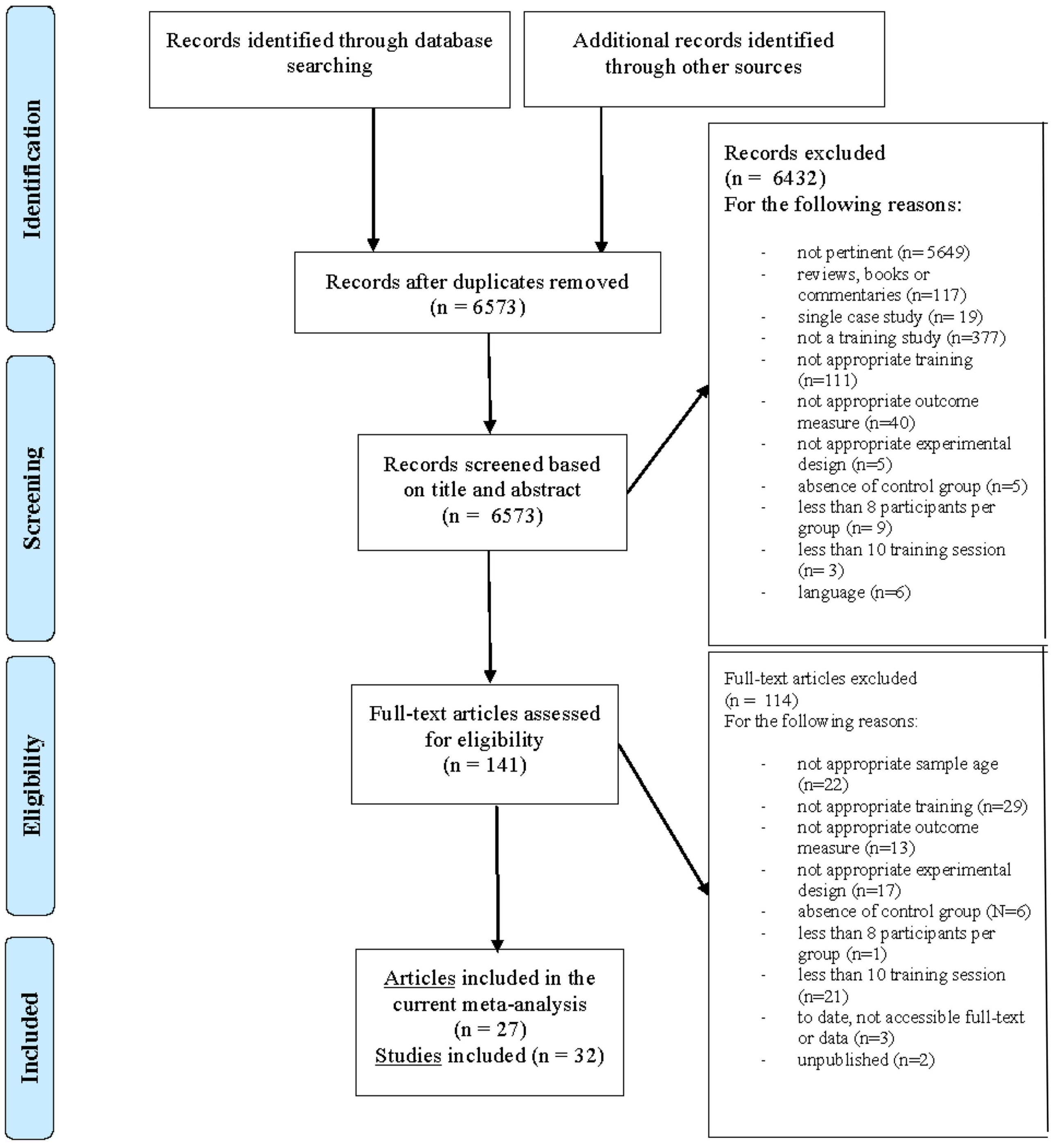

FIGURE 1 | Prisma flow diagram.

(see **Supplementary Material**) to avoid executive far-transfer overestimation, since the two dimensions of WM could be more related to each other than other analyzed processes. Where available, instead of reaction time, we reported accuracy or error rates, due to their higher reliability across childhood (Diamond et al., 2007). We included only studies having at least 8 children per group, as smaller sample sizes would increase the risk of publication bias. We included only studies having at least 10 training sessions, as from a clinical point of view, this number can be considered the minimum amount of sessions required to observe improvement in the EFs development.

Finally, we accepted measures of problem behaviors and social-emotional aspects collected through teacher and parent reports, but only if studies also reported at least one neurocognitive EFs measure.

Coding

During the coding phase, the first and second author coded each record according to a predefined coding schema, collecting information about bibliographic information [i.e., title, author(s), and year of publication], sample characteristics (i.e., sample size, mean age, and standard deviation of each group, clinical risk status of the sample), characteristics of the cognitive training (i.e., individual vs. group and computerized vs. non-computerized), its duration in term of number of sessions and total duration in minutes, type of control group involved (i.e., active or passive), the kind of outcome measure (i.e., verbal and visuo-spatial working memory, inhibitory control, cognitive flexibility, planning, and problem solving), and additional outcome measures (i.e., learning, behaviors, and problem behaviors related constructs), the near and far transfer measures.

For the studies reporting more than one intervention or control condition that met our inclusion criteria, we included more contrasts. If there were two or more eligible cognitive training programs, these were both included as compared with the control group (Thorell et al., 2009; Bergman Nutley et al., 2011; Howard et al., 2017; Romero López, 2018; Zhang et al., 2018). We did the same when there were multiple control conditions like an active and a passive control in the same study (i.e., Thorell et al., 2009; Peng et al., 2017; Pozuelos et al., 2019). Furthermore, if there were two or more experimental conditions, we selected those that met the inclusion criteria as experimental conditions, while considering those that did not as active control conditions. For instance, Passolunghi and Costa (2016) tested the effects of working memory and early numeracy training alone by comparing them to a passive control condition. In this case, only working memory training met our inclusion criteria; thus we considered the early training condition an active control condition and compared both it and passive control group to WM training group (see also Kassai et al., 2019).

Meta-Analytic Procedures

We used R version 3.5.1 (R Core Team, 2018), RStudio version 1.1.453 (R Studio Team, 2016), and the Metafor package (Viechtbauer, 2015; see Assink and Wibbelink, 2016) to conduct the analyses. R code and data are openly available as **Supplementary Material**.

We computed the size of the EFs effect as the standardized mean of the difference in the pre-post outcome change between the experimental and control group. We chose Hedges' *g* over Cohen's *d* because it corrects for small sample sizes (Borenstein et al., 2009). A positive *g*-value reflected the advantage of the intervention condition, while a negative effect indicated that the control group outperformed the intervention group. We computed Hedge's *g* based on Morris (2008). The summary statistics required for each outcome were the number of participants in intervention and control groups, the mean value of the outcomes in each group pre and post-treatment (or, as an alternative, the mean change from baseline), and the pooled pre-intervention standard deviation. For one study (Traverso et al., 2015), the available data did not allow to compute the effect size following Morris (2008). However, the authors reported the Cohen's *d*, and we computed *g* based on this value.

As discussed before, many studies in the dataset reported several potentially correlated relevant outcomes, and some studies comprised multiple control groups or multiple intervention groups, which caused the same group to be present in more than one contrast. Both of these aspects created dependencies in the data. So far, several solutions have been introduced to avoid dependency (Borenstein et al., 2009; Assink and Wibbelink, 2016): analyzing the outcomes as if they were independent (i.e., ignoring the dependency), averaging the dependent outcomes into a single effect size, selecting only one outcome for each study, and multilevel meta-analysis. Ignoring the dependency might bias the results; averaging or eliminating effect sizes, on the other hand, would decrease the power of the analysis and limit the research questions that we could ask, as we would not be able to compare near and far transfer effects. We, therefore, conducted a three-level meta-analytic analysis, following Assink and Wibbelink (2016). The meta-analytic model considered three different sources of variance: the participants at level 1, the outcomes at level 2, and the studies at level 3.

We used the rma.mv function of the Metafor package and set the tdist parameter as TRUE. Therefore, we based the test statistics and confidence intervals on the t distribution, applied the Knapp and Hartung (2003) adjustment, and used the Restricted Maximum Likelihood estimation method (REML) for estimating the parameters.

RESULTS

Included Studies

Thirty-two studies were eligible for inclusion, for a total of 123 different outcomes, with 977 participants in the training, 341 participants in the active control, and 719 in the passive control conditions.

Tables 1, **2** summarized the characteristics of the studies: in particular, in **Table 1**, EF measures and near-far transfer effects are reported; in **Table 2**, we described additional outcome measures.

Inspection for Publication Bias

To investigate for potential publication bias, we explored the funnel plot and checked for differences in effect sizes between published and unpublished studies. The funnel plot is presented in **Figure 2**, left panel. No evidence of publication bias emerged, Kendall's tau $= -0.052$, $p = 0.389$. A visual inspection shows that only a few studies fall outside of the triangular region of the pseudo-confidence interval.

Next, we compared the effect sizes of published and unpublished studies, as higher effects for published studies might be an important indication of publication bias. We were able to locate only two unpublished studies, with a total of five different outcomes. No evidence of publication bias emerged.

TABLE 1 | Summary of the studies included into the meta-analysis: EF outcome measures and Near vs. Far Transfer effects.

References	Mean age (in months)	Clinical risk status of sample	Training condition	Number of session	Control condition	Executive outcome measure	Type of transfer	Hedge's g, [95% CI]
Bergman Nutley et al., 2011	51,2	Typically developing	Visuospatial WM training (Individual, Computerized)	25	Passive control (*n* = 25)	Fluid intelligence		
Contrast 1			(*n* = 24)			- Raven matrix - Block design	Far transfer	−0.164, [−0.320, −0.008]
						- Leiter's problem Solving task	Far transfer	−0.118, [−0.273, 0.037]
						Visuospatial WM		
						- Odd one out	Near transfer	0.889, [0.718, 1.060]
						Verbal WM		
						- Word span	Far transfer	0.216, [0.060, 0.372]
Bergman Nutley et al., 2011	51,2	Typically developing	Non-verbal reasoning training (Individual, Computerized)	25	Passive control (*n* = 25)	Fluid intelligence		
Contrast 2			(*n* = 24)			- Raven matrix - Block design	Near transfer	0.302, [0.146, 0.459]
						Visuospatial WM		
						- Verbal dual task	Far transfer	0.295, [0.138, 0.452]
						- Odd one out	Far transfer	0.553, [0.392, 0.714]
						Verbal WM		
						- Word span	Far transfer	−0.068 [−0.223, 0.087]
Bergman Nutley et al., 2011	51,2	Typically developing	Combined visuospatial WM and Non-verbal reasoning training (Individual Computerized)	25	Passive control (*n* = 25)	Fluid intelligence		
Contrast 3			(*n* = 27)			- Raven matrix - Block design	Near transfer	0.350, [0.202, 0.499]
						Visuospatial WM		
						- Odd one out	Near transfer	0.775, [0.617, 0.933]
						Verbal WM		
						- Word span	Far transfer	−0.019, [−0.165, 0.128]
Brock et al., 2018	72,84	Typically developing	Executive functions training (Group)	73	Active control (*n* = 43)	Inhibitory control and cognitive flexility		
			(*n* = 44)			- Nepsy (three subtests)	Near transfer	0.721, [0.627, 0.815]
Capodieci et al., 2018	65,88	ADHD symptoms	Working Memory training Sviluppare la concentrazione e l'autoregolazione. Giochi e attività sul controllo della memoria di lavoro (both Individual and Group)	16	Passive control (*n* = 16)	Verbal WM		
			(*n* = 18)			- Backward digit span	Near Transfer	1.171, [0.911, 1.431]
						Visuospatial WM		
						- Selective working memory	Near Transfer	0.719, [0.483, 0.954]
						Inhibitory control		
						- Matching familiar figures	Far transfer	0.464, [0.237, 0.691]
						- Walk nowalk	Far transfer	0.717, [0.481, 0.952]
Foy and Mann, 2014	62,15	Low SES	Visuo-spatial WM training Cogmed JM (Individual, Computerized)	25	Passive control (*n* = 28)	Visuospatial WM		
			(*n* = 23)			- Corsi backward	Near transfer	0.465, [0.310, 0.619]
						Verbal WM		
						- Digit backward	Far transfer	0.344, [0.191, 0.496]
						Inhibitory control		
						- HTKS	Far transfer	0.288, [0.136, 0.441]

(Continued)

TABLE 1 | Continued

References	Mean age (in months)	Clinical risk status of sample	Training condition	Number of session	Control condition	Executive outcome measure	Type of transfer	Hedge's g, [95% CI]
Gade et al., 2017	62,39	Typically developing	Visuo-spatial WM training (Individual)	11	Active control (*n* = 10)	Verbal WM		
Study 1			(*n* = 10)			- Word span	Far transfer	0.230, [−0.132, 0.592]
						Visuospatial WM		
						- Matrix span	Near transfer	0.225, [−0.137, 0.587]
						- Object span task	Near transfer	0.361, [−0.005, 0.727]
Gade et al., 2017	67,19	Typically developing	Visuo-spatial WM training (Individual)	12,5	Active control (*n* = 16)	Verbal WM		
Study 2			(*n* = 15)			- Word span	Far transfer	0.643, [0.390, 0.896]
						Visuospatial WM		
						- Matrix span	Near transfer	0.108, [−0.133, 0.348]
						- Color span backward	Near transfer	−0.364, [−0.609, −0.120]
Gade et al., 2017	72	Typically developing	Visuo-spatial WM training (Individual)	13,5	Active control (*n* = 10)	Verbal WM		
Study 3			(*n* = 10)			- Word span	Far transfer	0.257, [−0.106, 0.619]
						Visuospatial WM		
						- Matrix span	Near transfer	−0.319, [−0.683, 0.046]
						- Color span backward	Near transfer	0.368, [0.002, 0.735]
Gade et al., 2017	61,3	Typically developing	Visuo-spatial WM training (Individual)	12	Active control (*n* = 10)	Verbal WM		
Study 4			(*n* = 10)			- Word span	Far transfer	−0.463, [−0.833, −0.093]
						Visuospatial WM		
						- Matrix span	Near transfer	−0.875, [−1.273, −0.478]
						- Color span backward	Near transfer	−0.574, [−0.950, −0.198]
Garcia Fernandez et al., 2018	74,39	Typically developing	Motor and executive functions training motor area Activity with executive functions program (Group)	45	Passive Control (*n* = 31)	Cognitive flexibility		
			(*n* = 35)			- Design fluency test	Near transfer	0.844, [0.717, 0.971]
						Inhibitory control		
						Inhibitory executive function test	Near transfer	0.255, [0.137, 0.372]
Howard et al. (2017)	52,79	Typically developing	Executive functions training using quincey Quokka's quest (Group)	10	Passive control (*n* = 18)	Visuospatial WM		
Contrast 1			(*n* = 22)			- MrAnt	Near transfer	0.205, [0.014, 0.397]
						Inhibitory control		
						- Go/No-Go	Near transfer	−0.046, [−0.237, 0.144]
						Flexibility		
						- Card sorting	Near transfer	0.415, [0.221, 0.609]
Howard et al., 2017	52,79	Typically developing	Executive functions training using Quincey Quokka's quest (Group)	10	Passive control (*n* = 18)	Visuospatial WM		
Contrast 2			(*n* = 25)			- MrAnt	Near transfer	−0.038, [−0.219, 0.142]
						Inhibitory control		
						- Go/No-Go	Near transfer	−0,185, [−0.367, −0.004]
						Flexibility		
						- Card sorting	Near transfer	0.851, [0.654, 1.048]
Joekar et al., 2017	68,8	ADHD symptoms	Visual attention training pay attention program (Individual)	11	Passive control (*n* = 15)	Inhibitory control		

(Continued)

TABLE 1 | Continued

References	Mean age (in months)	Clinical risk status of sample	Training condition	Number of session	Control condition	Executive outcome measure	Type of transfer	Hedge's g, [95% CI]
			(*n* = 15)			- Toulouse pieron test (commission errors)	Far transfer	1.054, [0.771, 1.338]
Liu et al., 2015	58,61	Typically developing	Inhibitory control training (Individual, Computerized)	12	Active control (*n* = 20)	Inhibitory control		
			(*n* = 16)			- Stroop	Near transfer	0.129, [−0.083, 0.340]
						Verbal WM		
						- Backward digit span	Far transfer	0.060, [−0.151, 0.271]
						Fluid intelligence		
						- Raven matrix	Far transfer	0.632, [0.410, 0.854]
Romero López (2018)	67,19	Typically developing	Executive functions training EFE - 5 (Group)	21	Active control (*n* = 50)	Inhibitory control		
(Dissertation) Contrast 1			(*n* = 66)			- Luria's test	Near transfer	1.652, [1.561, 1.743]
Romero López (2018)	67,19	Typically developing	Executive functions training EFE - 5 Cog (Group)	21	Active control (*n* = 50)	Inhibitory control		
(Dissertation) Contrast 2			(*n* = 69)			- Luria's test	Near transfer	1.659, [1.569, 1.748]
Mulvey et al. (2018)	61,67	Low SES	Executive functions and motor training SKIP (Group)	12	Passive control (*n* = 57)	Inhibitory control		
			(*n* = 50)			- Head toes knee skip	Near transfer	0.477, [0.403, 0.552]
Passolunghi and Costa (2016)	65,1	Typically developing	WM training (Group)	10	Passive control (*n* = 18)	Verbal WM		
Contrast 1			(*n* = 15)			- Verbal dual task	Near transfer	0.968, [0.712, 1.224]
						Visuospatial WM		
						- Visuospatial dual task	Near transfer	0.990, [0.733, 1.247]
Passolunghi and Costa (2016)	65,235	Typically developing	WM training (Group)	10	Active control (*n* = 15)	Verbal WM		
Contrast 2			(*n* = 15)			- Verbal dual task	Near transfer	0.896, [0.622, 1.170]
						Visuospatial WM		
						- Visuospatial dual task	Near transfer	0.466, [0.212, 0.721]
Pellizzoni et al. (2019)	65,1	Typically developing	Executive functions training (Group)	20	Passive control (*n* = 51)	Inhibitory control		
			(*n* = 55)			- Delay (Time)	Near transfer	0.557, [0.481, 0.633]
						- Gift wrap (time)	Near transfer	0.327, [0.253, 0.401]
						- Gift wrap (violations)	Near transfer	0.203, [0.129, 0.276]
						- Circle drawing (Time)	Near transfer	0.496, [0.421, 0.572]
						- Day/Night	Near transfer	0.449, [0.374, 0.524]
						Verbal WM		
						- Backward word span	Near transfer	0, [−0.073, 0.073]
Peng et al. (2017)	58,67	Typically developing	WM training (Individual, Computerized)	14	Active control (*n* = 25)	Fluid intelligence		
Contrast 1			(*n* = 23)			- Raven matrix	Far transfer	1.144, [0.959, 1.330]
Peng et al. (2017)	58,91	Typically developing	WM training (Individual, Computerized)	14	Passive Control (*n* = 26)	Fluid intelligence		
Contrast 2			(*n* = 23)			- Raven matrix	Far transfer	0.743, [0.577, 0.910]
Pozuelos et al. (2019)	63,55	Typically developing	Executive attention training with metacognitive scaffolding (Individual Computerized)	10	Active control (*n* = 33)	Inhibitory control		

(Continued)

TABLE 1 | Continued

References	Mean age (in months)	Clinical risk status of sample	Training condition	Number of session	Control condition	Executive outcome measure	Type of transfer	Hedge's g, [95% CI]
Contrast 1			(*n* = 33)			- Simon says	Near transfer	0.173, [0.056, 0.289]
						Verbal WM		
						- Backward digit span WISC	Far transfer	0.164, [0.047, 0.280]
						Fluid intelligence		
						- k-BIT matrix	Far transfer	0.610, [0.489, 0.732]
Pozuelos et al., 2019	63,6	Typically developing	Executive attention training (Individual, Computerized)	10	Active control (*n* = 33)	Inhibitory control		
Contrast 2			(*n* = 31)			- Simon says	Near transfer	0.318, [0.196, 0.439]
						Verbal WM		
						- Backward digit span WISC	Far transfer	1,73E-16, [−0.120, 0.120]
						Fluid intelligence		
						- k-BIT matrix	Far transfer	0.469, [0.346, 0.592]
Re et al., 2015	63,225	ADHD symptoms	Executive functions training Sviluppare la concentrazione e l'autoregolazione (Group)	17	Passive control (*n* = 13)	Inhibitory control		
Study 1			(*n* = 13)			- Walk no walk	Near transfer	0.263, [−0.023, 0.548]
Re et al., 2015	65,38	Typically developing	Executive functions training Sviluppare la concentrazione e l'autoregolazione (Group)	17	Passive control (*n* = 13)	Inhibitory control		
Study 2			(*n* = 13)			- Walk no walk	Near transfer	0.804, [0.497, 1.111]
Ríos et al., 2014	63,71	Typically developing	Planning training Prototipo online de entrenamiento Cognitivo (Individual, Computerized)	12	Passive control (*n* = 8)	Planning		
			(*n* = 8)			- Tower of Mexico	Near transfer	0.061, [−0.377, 0.499]
Rojas-Barahona et al., 2015	52,3	Low SES	WM training (Individual, Computerized)	16	Active control (*n* = 124)	Verbal and visuospatial WM		
			(*n* = 144)			- Visuospatial and phonological WM	Near transfer	0.551, [0.521, 0.581]
Röthlisberger et al., 2012	60,45	Typically developing	Executive functions training (Group)	30	Passive control (*n* = 38)	Inhibitory control		
Study 1			(*n* = 33)			- Simple flanker	Near transfer	0.060, [−0.048, 0.169]
						Flexibility		
						- Mixed flanker	Near transfer	0.513, [0.401, 0.626]
						Visuospatial WM		
						- Complex SPAN TASK	Near transfer	0.747, [0.631, 0.863]
Röthlisberger et al., 2012	72,9	Typically developing	Executive functions training (Group)	30	Passive control (*n* = 34)	Inhibitory control		
Study 2			(*n* = 30)			- Simple flanker	Near transfer	0.227, [0.107, 0.348]
						Flexibility		
						- Mixed flanker	Near transfer	0.335, [0.214, 0.457]
						Visuospatial WM		
						- Complex span task	Near transfer	0.291, [0.170, 0.412]
Rueda et al., 2012	64,7	Typically developing	Executive attention training (Individual, Computerized)	10	Passive control (*n* = 18)	Inhibitory control		
			(*n* = 19)			- ANT (commissions)	Near transfer	−0.153, [−0.357, 0.050]
						- ANT (executive task)	Near transfer	0.004, [−0.199, 0.207]
						- Delay of self gratification	Near transfer	0.459, [0.251, 0.668]
						Fluid intelligence		

(Continued)

TABLE 1 | Continued

References	Mean age (in months)	Clinical risk status of sample	Training condition	Number of session	Control condition	Executive outcome measure	Type of transfer	Hedge's g, [95% CI]
						- k-BIT matrix	Far transfer	0.097, [−0.106, 0.300]
						Self regulation		
						- Gambling task	Far transfer	0.278, [0.073, 0.483]
Salvaguardia et al., 2009	71	ADHD symptoms	WM training Sviluppare la concentrazione e l'autoregolazione: Giochi e attività sul controllo della memoria di lavoro (Group)	21	Passive control (*n* = 14)	Visuospatial WM		
			(*n* = 18)			- Dual request selective task	Near transfer	0.613, [0.365, 0.861]
Schmitt et al., 2018	55,2	Typically developing	Executive functions training using block play (Individual)	14	Passive control (*n* = 35)	Inhibitory Control		
			(*n* = 24)			- Stroop	Near transfer	0.291, [0.155, 0.426]
						- Head Toes Knee Skip	Near transfer	0.153, [0.019, 0.288]
						Flexibility		
						- Card sorting	Near transfer	−0.019, [−0.153, 0.115]
Schmitt et al., 2015	51,645	Low SES	Executive functions training (Group)	16	Passive control (*n* = 150)	Inhibitory control		
			(*n* = 126)			- Head toes knee skip	Near Transfer	0.426, [0.397, 0.455]
						Flexibility		
						- Card sorting	Near Transfer	0.159, [0.130, 0.187]
Sivó Romero, 2016	58,5	Typically developing	WM training (both Individual and Group)	117	Passive control (*n* = 48)	Verbal WM		
(Dissertation)			(*n* = 49)			- Backward digit span	Near transfer	1.134, [1.042, 1.228]
						Inhibitory control		
						- Shape school (II)	Far transfer	−0.224, [−0.305, −0.144]
						Flexibility		
						- Schape school (III)	Far transfer	0.149, [0.069, 0.229]
Thorell et al., 2009	56	Typically developing	Visuospatial WM training Cogmed (Individual, Computerized)	25	Active Control (*n* = 14)	Visuospatial WM		
Contrast 1			(*n* = 17)			- Span board	Near transfer	0.442, [0.194, 0.691]
						Verbal WM		
						- Word spans	Far transfer	1.104, [0.823, 1.385]
						Inhibitory control		
						- Stroop	Far transfer	0.244, [0.0002, 0.488]
						- Go/No-Go	Far transfer	0.036, [−0.206, 0.278]
						Problem solving		
						- Block design	Far transfer	−0.026, [−0.268, 0.216]
Thorell et al., 2009	57	Typically developing	Visuospatial WM training Cogmed (Individual, Computerized)	25	Passive control (*n* = 16)	Visuospatial WM		
Contrast 2			(*n* = 17)			- Span board	Near transfer	0.699, [0.459, 0.940]
						Verbal WM		
						- Word spans	Far transfer	1.070, [0.809, 1.330]
						Inhibitory control		
						- Stroop	Far transfer	0.342, [0.112, 0.571]
						- Go/No-Go	Far transfer	−0.022, [−0.248, 0.204]
						Problem solving		

(Continued)

TABLE 1 | Continued

References	Mean age (in months)	Clinical risk status of sample	Training condition	Number of session	Control condition	Executive outcome measure	Type of transfer	Hedge's g, [95% CI]
						- Block design	Far transfer	0.332, [0.102, 0.561]
Thorell et al., 2009	56	Typically developing	Inhibition training Cogmed (Individual, Computerized)	25	Active control (*n* = 14)	Visuospatial WM		
Contrast 3			(*n* = 18)			- Span board	Far transfer	−0.671, [−0.922, −0.421]
						Verbal WM		
						- Word spans	Far transfer	0.178, [−0.060, 0.415]
						Inhibitory control		
						- Stroop	Near transfer	0.208, [−0.029, 0.446]
						- Go/No-Go	Near transfer	−0.195, [−0.432, 0.043]
						Problem solving		
						- Block design	Far transfer	−0.060, [−0.297, 0.176]
Thorell et al., 2009	57	Typically developing	Inhibition training Cogmed (Individual, Computerized)	25	Passive control (*n* = 16)	Visuospatial WM		
Contrast 4			(*n* = 18)			- Span board	Far transfer	−0.414, [−0.639, −0.188]
						Verbal WM		
						- Word spans	Far transfer	0.178, [−0.044, 0.399]
						Inhibitory control		
						- Stroop	Near transfer	0.268, [0.045, 0.491]
						- Go/No-Go	Near transfer	−0.267, [−0.490, −0.045]
						Problem solving		
						- Block design	Far transfer	0.382, [0.158, 0.607]
Tominey and McClelland, 2011	54,5	Typically developing	Executive functions training red light purple light (Group)	16	Passive Control (*n* = 37)	Inhibitory control		
			(*n* = 28)			- Head toes knee skip	Near transfer	0.153, [0.033, 0.273]
Traverso et al., 2015	68,65	Typically developing	Executive functions training (Group)	12	Passive control (*n* = 32)	Inhibitory control		
			(*n* = 43)			- Delay time	Near transfer	0.693, [0.582, 0.804]
						- Gift wrap	Near transfer	0.435, [0.328, 0.543]
						- Circle drawing	Near transfer	0.346, [0.240, 0.453]
						- Matching familiar figures	Near transfer	0.445, [0.338, 0.553]
						- Arrow flanker	Near transfer	0.277, [0.171, 0.383]
						- Go/No-Go	Near transfer	−0.020, [−0.124, 0.085]
						- Dots	Near transfer	0.524, [0.416, 0.633]
						Verbal WM		
						- Backward digit span	Far transfer	0.426, [0.319, 0.533]
						Visuospatial WM		
						- Mr. Cucumber	Near transfer	0.267, [0.162, 0.373]
						- Keep track	Near transfer	0.643, [0.533, 0.753]
Volckaert and Noël, 2015	60,32	Typically developing	Inhibition training (Group)	16	Active control (*n* = 23)	Inhibitory control		
			(*n* = 24)			- Traffic Lights, Cat/Dog, Head Toes Knee Skip, Stroop	Near transfer	0.463, [0.297, 0.629]
						WM		
						- Catego span, Word span, Block tapping	Far transfer	0.733, [0.560, 0.905]
						Flexibility		
						- Traffick light, Cat/Dog, Monster (mixed condition)	Far transfer	0.362, [0.198, 0.526]

(Continued)

TABLE 1 | Continued

References	Mean age (in months)	Clinical risk status of sample	Training condition	Number of session	Control condition	Executive outcome measure	Type of transfer	Hedge's g, [95% CI]
Zhang et al., 2018	73,5	Typically developing	Visuospatial WM training (Individual, Computerized)	20	Passive control (n = 22)	Verbal WM		
Contrast 1			(n = 20)			- Backward digit span	Far transfer	−0.215, [−0.396, −0.034]
						Inhibitory control		
						- AX CPT	Far transfer	−0.127, [−0.307, 0.054]
						Fluid intelligence		
						- Raven Matrix	Far transfer	0.192, [0.011, 0.373]
Zhang et al., 2018	73,5	Typically developing	Inhibitory control training (Individual, Computerized)	20	Passive control (n = 22)	Verbal WM		
Contrast 2			(n = 21)			- Backward digit span	Far transfer	0.198, [0.022, 0.375]
						Inhibitory control		
						- AX CPT	Near Transfer	−0.456, [−0.636, −0.275]
						Fluid intelligence		
						- Raven matrix	Far transfer	−0.057, [−0.232, 0.119]

On the contrary, the size of the effect was almost three times bigger for the two unpublished studies than for the published studies: for the unpublished studies the effect was g = 0.949, SE = 0.220, 95% CI = (0.514, 1.383) and for the published studies the effect was g = 0.345, SE = 0.059, 95% CI = (0.227, 0.462). We, therefore, excluded the two unpublished studies from the analyses reported in the manuscript as a conservative strategy to avoid the risk of inflated estimations of the effects. We conducted parallel analyses, including data from the two unpublished studies. These analyses revealed very similar patterns of results and are presented in **Supplementary Material**. The funnel plot for the dataset of the published studies, on which we conducted the analysis, is presented in **Figure 2**, right panel. Also in this case, the funnel plot presented no evidence of publication bias, Kendall's tau = −0.0513, p = 0.402. A subsequent analysis indicated that the size of the effect was not related to the year of publication of the study (**Table 3**). Moreover, a sample size moderator analysis was performed, which did not find significant effects (p = 0.430), suggesting that differences in sample size are not an important source of the heterogeneity of the results.

Main Analyses

Overall Effect of EFs Training

A significant overall effect of training of low-to-medium size emerged, g = 0.342, SE = 0.056, $t_{(122)} = 7.408$, $p < 0.001$, 95% CI = (0.252, 0.451). The test for heterogeneity revealed significant variation between effect sizes, $Q_{(122)} = 172.340$, $p <$ 0.001. The log-likelihood tests indicated that the within-study variance and the between-study variance were both significant. The estimated variance between the outcomes within studies was 0.005 and, based on Cheung (2015)'s formulas (see Assink and Wibbelink, 2016), we estimated that it accounted for 12.360% of the variance. The estimated between studies variance was 0.035, and we estimated that it accounted for 47.981% of the variance. The remaining 39.658% of the variance could be attributed to within study sampling variance. In sum, effect sizes varied substantially between studies, but also a modest within study variance emerged. The likelihood ratio indicated that only the between studies variance was significant (LRT = 0.291, p = 0.295, and LRT = 7.506, p = 0.003, respectively for outcome and for study, both one-sided). Moreover, the 75% rule (Hunter and Schmidt, 1990) suggests that we should inspect heterogeneity if <75% of the total amount of variance can be attributed to within study sampling variance. Therefore, we proceeded to investigate potential moderators, following the research questions outlined above.

Investigation of the Potential Moderators

Table 3 reports the results of the tests of the moderators. For categorical moderators, we report the coefficients and tests for the moderation (which indicates the difference between the two categories), and for the intercepts based on each level of the variable (dummy coded, indicating the effect size for each category of the moderator separately). For continuous moderators (meta-regression), the unstandardized regression coefficient and significance for the slope is reported, which

TABLE 2 | Summary of the studies included into the Meta-analysis: *Addition*al Outcome Measures.

References	Age (in months)	Clinical status of the sample	Training condition	Control condition	Additional outcomes	Hedge's g, [95% CI]
Brock et al., 2018	72,84	Typically developing	Executive functions training (Group) (*n* = 44)	Active control (*n* = 43)	Problem behaviors: Social Skills Improvement System + Child Behavior Rating Scale	−0.303, [−0.392, −0.213]
					Learning-related behaviors: Social Skills Improvement System + Child Behavior Rating Scale	−0.031, [−0.120, 0.057]
Capodieci et al., 2018	65,88	ADHD symptoms	Working Memory training *Sviluppare la concentrazione e l'autoregolazione. Giochi e attività sul controllo della memoria di lavoro* (both Individual and Group) (*n* = 18)	Passive control (*n* = 16)	Inattention: PDDAI (Identificazione Precoce del Disturbo da Deficit di Attenzione/iperattività per Insegnanti) (Teacher)	0.022, [−0.199, 0.243]
					Hyperactivity: IPDDAI (Teacher)	0.029, [−0.192, 0.249]
					WM items of IPDDAI (Teacher)	0.230, [0.008, 0.452]
					Inattention: IPDDAG (Identificazione Precoce del Disturbo da Deficit di Attenzione/iperattività per Genitori) (Parent)	−0.237, [−0.459, −0.015]
					Hyperactivity: IPDDAG (Parent)	0.177, [-0.044, 0.399]
Foy and Mann, 2014	62, 15	Low SES	Visuo-spatial WM training *Cogmed JM* (Individual, Computerized) (*n* = 23)	Passive control (*n* = 28)	Letter Knowledge: Letter Naming Fluency (LNF) subtest of the Dynamic Indicators of Basic Early Literacy Skills (DIBELSNext) assessment tool	1.191, [1.013, 1.368]
Garcia Fernandez et al., 2018	74,39	Typically developing	Motor and executive functions training *Motor area Activity with Executive Functions Program* (Group) (*n* = 35)	Passive control (*n* = 31)	Phoneme Awareness: First Sounds Fluency (FSF) subtest of the DIBELSNext test	−0.836, [−0.999, −0.672]
					Literacy: CUMANIN (Infant neuropsychological maturity questionnaire)—reading subscale	0.163, [0.046, 0.280]
					Literacy: CUMANIN (Infant neuropsychological maturity questionnaire)—writing subscale	0.482, [0.362, 0.601]
					Math: TEMA-–3 (Test of early mathematics ability-3)	0.212, [0.095, 0.329]
Joekar et al., 2017	68,8	ADHD symptoms	Visual Attention Training *Pay Attention Program* (Individual) (*n* = 15)	Passive control (*n* = 15)	Inattention: CSI-4 (Child symptom inventory-4) (Parent)	−0.083, [−0.330, 0.165]
					Inattention: CSI-4 (Teacher)	−0.209, [−0.457, 0.040]
					Hyperactivity: CSI-4 (Parent)	0.461, [0.207, 0.716]
					Hyperactivity: CSI-4 (Teacher)	0.441, [0.187, 0.695]
Romero López (2018) (Dissertation) Contrast 1	67,19	Typically developing	Executive functions training *EFE – 5* (Group) (*n* = 66)	Active control (*n* = 50)	EF: BRIEF-P (Behavior rating inventory of executive function–Preschool version)	1.434, [1.349, 1.520]
Romero López (2018) (Dissertation) Contrast 2	67,19	Typically developing	Executive functions training *EFE – 5* (Group) (*n* = 69)		EF: BRIEF-P	1.206, [1.127, 1.285]
Passolunghi and Costa, 2016 Contrast 1	65,1	Typically developing	WM training (Group) (*n* = 15)	Passive control (*n* = 18)	Early numeracy: ENT (Early numeracy test)	0.390, [0.157, 0.622]

(Continued)

TABLE 2 | Continued

References	Age (in months)	Clinical status of the sample	Training condition	Control condition	Additional outcomes	Hedge's g, [95% CI]
Passolunghi and Costa (2016) Contrast 2	65,235	Typically developing		Active control (*n* = 15)	Early numeracy: ENT	−0.496, [−0.751, −0.240]
Re et al., 2015 study 1	63,225	ADHD symptoms	Executive Functions training *Sviluppare la concentrazione e l'autoregolazione* (Group) (*n* = 13)	Passive control (*n* = 13)	Inattention: PDDAI (Identificazione Precoce del Disturbo da Deficit di Attenzione/iperattività per Insegnanti) (Teacher)	−0.118, [−0.401, 0.165]
					Hyperactivity: IPDDAI (Teacher)	−0.029, [−0.312, 0.254]
Re et al., 2015 study 2	65,38	Typically developing	Executive Functions training *Sviluppare la concentrazione e l'autoregolazione* (Group) (*n* = 13)	Passive control (*n* = 13)	Inattention: PDDAI (Teacher)	−0.626, [−0.923, −0.328]
					Hyperactivity: IPDDAI (Teacher)	−0.036, [−0.319, 0.247]
Rojas-Barahona et al., 2015	52,3	Low SES	WM training (Individual, Computerized) (*n* = 144)	Active control (*n* = 124)	Literacy: ELS (Tejas LEE test)—overall	0.680, [0.649, 0.711]
Salvaguardia et al., 2009	71	ADHD symptoms	WM training *Sviluppare la concentrazione e l'autoregolazione: Giochi e attività sul controllo della memoria di lavoro* (Group) (*n* = 18)	Passive control (*n* = 14)	Inattention: SDAI (Scala di disattenzione e iperattività) (Teacher)	−0.386, [−0.628, −0.145]
					Hyperactivity: SDAI (Teacher)	−0.307, [−0.546, −0.067]
Schmitt et al., 2018 study 1	55,2	Typically developing	Executive functions training using block play (Individual) (*n* = 24)	Passive control (*n* = 35)	Early numeracy: PENS-B (Preschool Early Numeracy Skills Screener -Brief Version)	0.125, [−0.009, 0.259]
Schmitt et al., 2015 study 2	51,645	Low SES	Executive functions training (Group) (*n* = 126)	Passive control (*n* = 150)	Problem behaviors: CBRS (Child behavior rating scale)	−0.047, [−0.076, −0.019]
					Maths: Applied problems	−0.001, [−0.029, 0.027]
					Literacy: Letter/Word identification	0.137, [0.109, 0.166]
Tominey and McClelland, 2011	54,5	Typically developing	Executive functions training *Red Light Purple Light* (Group) (*n* = 28)	Passive control (*n* = 37)	Literacy: Letter/Word identification	0.424, [0.301, 0.547]
					Maths: Applied problems (counting, additions, reading numbers)	0.022, [−0.098, 0.142]
Volckaert and Noël, 2015	60,32	Typically developing	Inhibition training (Group) (*n* = 24)	Active control (*n* = 23)	Problem behaviors: CPRS (Conners parent rating scale)—conduct problems	0.205, [0.043, 0.368]
					Problem behaviors: CPRS—hyperactivity	0.402, [0.237, 0.567]
					Problem behaviors: CPRS—impulsivity	0.351, [0.187, 0.515]
					Problem behaviors: CTRS (Conners teacher rating scale)—conduct problems	−0.164, [−0.326, −0.002]
					Problem behaviors: CTRS—inattention	0.505, [0.339, 0.672]
					Problem behaviors: CTRS—hyperactivity	−0.053, [−0.215, 0.108]

Italic text indicates the commercial name of that training programs.

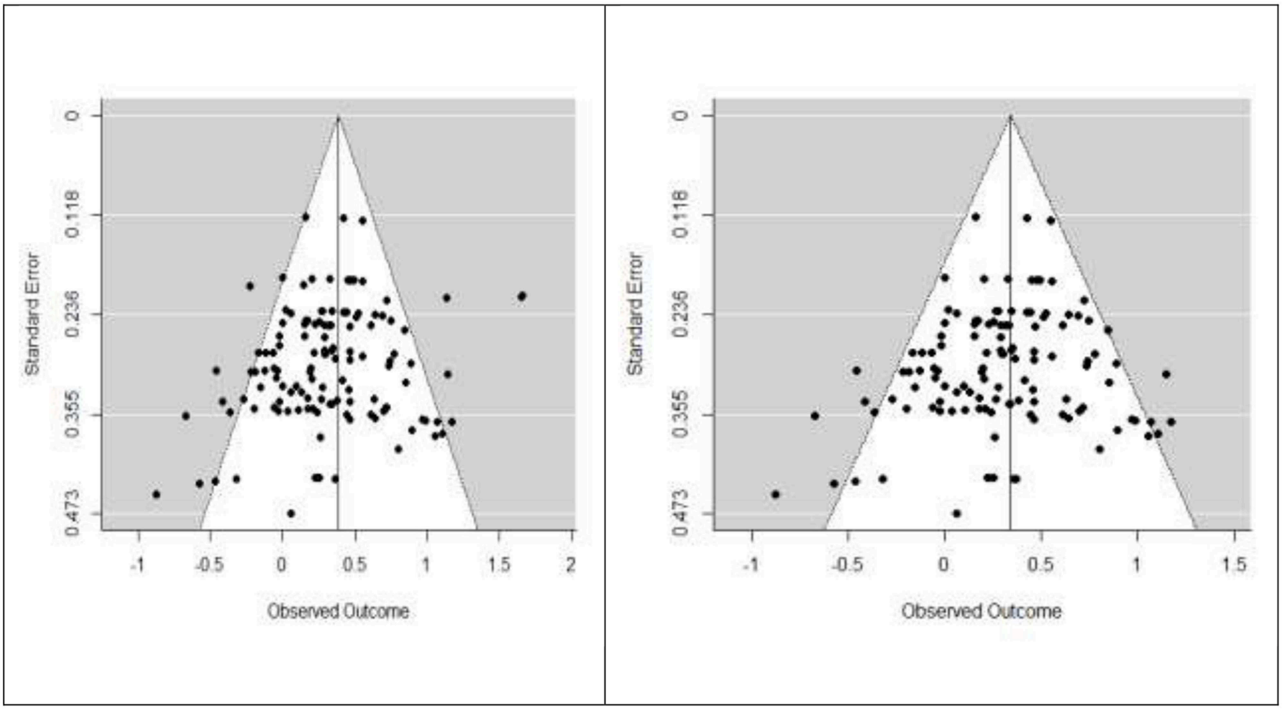

FIGURE 2 | Funnel plot of the meta-analysis of main outcomes of all studies **(left)** and of published studies **(right)**. Each plotted point represents the standard error and standardized mean difference (Hedge's g) between control and Intervention group for a single outcome. The white triangle represents the region where 95% of the data points are expected to lie in the absence of publication bias. The vertical line represents the estimated effect size, based on the meta-analysis.

indicates the impact of each unitary change in the moderator on the effect size.

Subsequently, we investigated the impact of two moderators related to the children: the mean age of the sample and developmental risk status. The mean age ranged between 51.2 and 74.4 months and did not significantly influence the EFs training effect. We categorized the presence of a developmental risk into three groups: children without developmental risks, children with symptoms of ADHD, and children characterized by low SES. The analysis indicated that the presence of a developmental risk significantly increased the effect of training ($p = 0.033$). The number of studies involving at-risk populations of children, however, was relatively small: we found only four studies, with a total of eight different effects and 112 participants characterized by ADHD, and four studies, with a total of seven effects and 651 participants characterized by low socio-economic status. Subsequent analyses indicated that the effect of EFs training was significant both for children with and without developmental risk. Two comparisons were performed to specifically test for the presence of differences in the effect of EFs training between children with typical development on the one hand, and children from low SES families and children with ADHD symptoms on the other hand. It emerged that the effect of EFs training did not differ significantly between children from low SES and other children without developmental risks ($p = 0.339$). However, a significant difference emerged for the comparison between children with ADHD symptoms and other children in average SES families ($p = 0.007$).

We, next, compared studies with active and passive control groups. The difference in the EFs training effect was non-significant and negligible in terms of effect size. Two characteristics of the training, on the other hand, proved significant: in particular, effects of non-computerized training were twice as big as those of computerized training, and effects of group training were twice as big as those of individual training. However, also in the computerized training and individual training conditions, the effects of training were significant, albeit much smaller in size. On the other hand, the number of sessions effect was not significant, but the overall length of the training significantly influenced its efficacy.

Finally, the comparison between near and far transfer effects showed that both near and far training effects were significant. While the far transfer effect was slightly smaller than the near transfer effect, this difference was not significant.

Effect of EF Training on Additional Non-EF Outcomes

Finally, we investigated the transfer of EF training on non-EF outcomes, based on a total of 39 outcomes from 15 studies. The overall effect of training on these effects was not significant and low in size, $g = 0.169$, $SE = 0.106$, $t_{(38)} = 1.583$, $p = 0.122$, 95% $CI = (-0.047, 0.383)$.

Three forest plots showing all effect sizes concerning Near Transfer, Far Transfer, and Additional Outcome Measures are presented in **Supplementary Material** describing.

TABLE 3 | Moderation effects for the primary outcomes of the meta-analysis.

Effect	No. outcomes	No. studies	Estimated g	SE	95% CI		*p*-value
Year of publication	13	32	0.015	0.017	−0.018	0.049	0.368
Variables of the children							
Children's age (months)	120	30	0.007	0.006	−0.006	0.020	0.278
Development at risk	123	32	0.234	0.108	0.019	0.448	0.033
No-risk	*108*	*31*	*0.291*	*0.050*	*0.192*	*0.390*	*<0.001*
Low SES	*7*	*6*	*0.430*	*0.107*	*0.219*	*0.641*	*<0.001*
ADHD	*8*	*8*	*0.785*	*0.169*	*0.451*	*1.120*	*<0.001*
Variables of the study							
Control group	123	32	0.054	0.086	−0.116	0.224	0.529
Passive	*84*	*23*	*0.360*	*0.055*	*0.251*	*0.468*	*<0.001*
Active	*39*	*12*	*0.306*	*0.076*	*0.156*	*0.455*	*<0.001*
Training: computerized	121	32	0.092	0.098	−0.102	0.286	0.102
Computeriz.	*59*	*13*	*0.281*	*0.079*	*0.124*	*0.137*	*<0.001*
Non Comp.	*62*	*19*	*0.373*	*0.058*	*0.258*	*0.488*	*<0.001*
Training: group	121	32	0.271	0.109	0.055	0.486	0.014
Individual	*46*	*17*	*0.211*	*0.056*	*0.055*	*0.343*	*<0.001*
Group	*75*	*16*	*0.443*	*0.075*	*0.330*	*0.556*	*<0.001*
Number of sessions	121	32	0.005	0.004	−0.003	0.012	0.225
Length (minutes)	121	32	0.00023	0.00008	0.0006	0.0040	0.008
Variables of the outcome							
Near vs. Far training	123	32	0.034	0.068	−0.101	0.169	0.619
Near	*76*	*30*	*0.352*	*0.050*	*0.252*	*0.451*	*<0.001*
Far	*47*	*16*	*0.318*	*0.068*	*0.186*	*0.449*	*<0.001*

Italic text indicates the levels of the categorical variables.

DISCUSSION

The aim of the present meta-analysis was to assess the efficacy of cognitive EFs training programs in preschool children aged from 3 to 6 years old. The final dataset consisted of 32 studies published between 2009 and 2019, 21 of which had been published between 2015 and 2019, showing a trend of an increasing number of studies.

We were interested in assessing whether cognitive training could improve EFs in preschool children, comparing near and far transfer effects and analyzing various potential moderators, such as age, presence of developmental risk, and type of cognitive training.

First of all, we found evidence that cognitive training programs are beneficial for EFs in children aged between 3 and 6: the overall effect is medium ($g = 0.342$), but the most interesting results are that near and far transfer effects on EFs were statistically significant and that their sizes were not significantly different.

Near transfer refers to the effect of the cognitive training on the EF measures specifically trained (Working Memory, Inhibitory Control, Cognitive Flexibility, Planning, and Fluid Reasoning, as defined by Diamond, 2013). Far transfer refers to the effect of the training on EFs variables not directly trained. We expected to find a near transfer effect, as many other authors proposed (Diamond and Lee, 2011; Diamond and Ling, 2016) and confirmed in a recent meta-analysis (Kassai et al., 2019). Previous studies did not find far transfer effects on EFs (Melby-Lervåg and Hulme, 2013; Sala and Gobet, 2017; Kassai et al., 2019). The present meta-analysis showed that cognitive EFs training for preschoolers produced both near and far transfer effects, with similar effect sizes ($g = 0.352$ and $g = 0.318$, respectively). Compared to Kassai et al. (2019) we found similar results in terms of near transfer (their g was 0.44), but different considering the far transfer effects (their g was 0.11). However, our meta-analysis has important differences compared to the previous ones. First, we included 32 studies specifically focused on preschoolers; secondly, we selected only cognitive training programs, excluding motor-based activities, curriculum based programs, or mindfulness interventions; third, the present meta-analysis was based on a different set of studies (only five papers in our database were present also in the datasets of the previous meta-analyses).

The younger ages of the children of the samples in the present dataset, as compared to the previous meta-analytical studies, is probably the key aspect to explaining the difference of the present results: A far transfer effect is observable in preschoolers probably because their EFs structure is not so well-defined and separate as it becomes at older ages. Accordingly, we assume that cognitive training for improving a specific EF could affect other, not directly trained, EFs because of the intercorrelation and overlap between EFs at this developmental stage. For instance, some authors proposed one single EF factor (Hughes et al., 2010; Wiebe et al., 2011) or two factors (Usai et al., 2014; Scionti and Marzocchi, submitted) and it is, therefore, plausible that a modularization of the EFs is not still completed in preschoolers.

A second important aspect is participants' age: We included the age effect in the analysis to check whether cognitive EFs training was more effective in younger vs. older preschoolers. Age, considered as a continuous variable, was found to be not significant, therefore we conclude that in this age range, a cognitive EF training is similarly effective for younger and older preschool children. Therefore, it is possible that an absence of complete modularization of EF is present also in older preschoolers. The absence of an age effect confirmed the results obtained by other meta-analyses that included older participants (Kassai et al., 2019; Takacs and Kassai, 2019).

In the current research, we found that EFs cognitive training programs in preschoolers are more effective for developmentally-at-risk children than for children without risks. In particular, children with symptoms of ADHD did benefit from EFs training, and the effect size was particularly interesting ($g = 0.785$). Previous studies reported that children with ADHD showed a significant EF improvement after cognitive training, in particular concerning Working Memory (Klingberg et al., 2005; Holmes et al., 2010; Rapport et al., 2013). Cortese et al. (2015) found a small but significant effect of cognitive training in children with ADHD ($d = 0.37$), in particular on inattention symptoms ($d = 0.47$), but not on hyperactivity, concluding that inattention is more malleable to training than hyperactivity. Rapport et al. (2013) focused their meta-analysis on Working Memory training for children with ADHD and found a higher effect ($d = 0.63$) than Cortese et al. (2015). Therefore, we supposed that specific training interventions for Working Memory could be more effective for children with ADHD than a general EF training, since Working Memory difficulties is a key endophenotypes of ADHD (Castellanos and Tannock, 2002). In our study, the effect size of the EF training in children with symptoms of ADHD was even higher ($g = 0.785$) than in Rapport et al. (2013): We suppose that training EFs in preschoolers via a cognitive program could be a useful strategy to improve their neuropsychological skills, in particular in younger children (between 3 and 6 years old) and if they present a disadvantaged condition. Actually, in the current meta-analysis, only 4 studies including ADHD children were present, therefore more research is needed to draw stronger conclusions.

In our study, the effect of cognitive training on EFs development was also significant in children of families with low SES ($g = 0.430$). Other studies demonstrated a similar effect (Blair and Raver, 2014), confirming the hypothesis that an educational program, even in a school setting, for children with socially disadvantaged conditions is important to reduce subsequent psychological risk factors. Although our results confirm the higher effect of the EFs training for children with ADHD or low SES, we found a significant positive effect also in children without developmental risk. This result is encouraging because we hypothesize that cognitive EFs training is useful mostly in an educational context (kindergartner) in order to strengthen the cognitive development and prevent future developmental risk. On this vein, Melby-Lervåg et al. (2016) and Takacs and Kassai (2019) found a significant and positive effect of EFs training on cognitive processes, in particular on working memory in follow-up studies. Future researches could help us to understand whether cognitive EFs training, probably repeated more than once, could help children to reduce possible developmental risks and increase their school and social achievement when they become older.

A controversial issue regarding the EFs cognitive training effect is the comparison between trained and control groups; it is possible that a child would benefit from an EFs training just because s/he receives a cognitive stimulation. If this is the case, it is impossible to disentangle the effect of EFs training from the general and unspecific benefit of being part of a trained group. For this reason, different researches proposed a comparison between a trained and active control group whose participants are involved in other cognitive activities unrelated to EFs. In the current study, a comparison between trained vs. active control group and trained vs. non-active control groups was carried out, assuming that the difference between trained vs. non-active control groups would be higher than the comparison trained vs. active group. Contrary to our expectation, we did not find any difference between the two comparisons. Therefore, we conclude that cognitive EFs training is specifically effective in enhancing cognitive processes and these benefits are not just related to an undifferentiated cognitive stimulation, because the Intervention group demonstrated higher benefit than both the active and passive control groups. A previous meta-analysis on children aged between 2 and 12 years old (Kassai et al., 2019) found similar results, without differentiation between passive and active control groups.

According to the literature, a promising way to improve EFs in children is related to the use of computerized programs, probably because computerized training, for children, could be as motivating as playing a videogame. As Martinovic et al. (2016) demonstrated, videogames are engaging if they are simple and rewarding, but they are not motivating if they ask the children to improve their attention and problem-solving skills. Moreover, in their meta-analysis concerning computerized EF training programs, Webb et al. (2018) found a small effect on the three EF factors (Inhibition, Updating, and Shifting): Hedges' g effect size ranged from 0.005 (Updating) to 0.16–0.17 (Shifting and Inhibition). It is important to note, however, that Webb et al. (2018) analyzed a large sample of participants, mostly older adults, probably not very familiar to work with a computer: For this reason, they are, most probably, not the best target for a computerized training. In our study, we did not find a significant difference between computerized and non-computerized training. Although the average effect of the computerized training was higher than in the work of Webb et al. (2018) (current study = 0.281; Webb = 0.17), we found a non-significant ($p = 0.10$) higher benefit for non-computerized training ($g = 0.373$). Therefore, as underlined by Diamond and Ling (2016), computerized training probably could be effective only for the Inhibition component of EFs. In other words, playing with cards, doing body exercises, and paper and pencil activities could be more effective for improving EFs than using a tablet or a computer, but the available empirical evidence does not allow to draw a firm conclusion on this point.

A further comparison was made to investigate whether EF training could be more effective if presented in a group or individually. Both conditions have pros and cons: For preschoolers a group could be more motivating and fun, but less specific and, in some cases, more confusing. According to our results, cognitive training is more effective if administered in groups than individually, contrary to what Moreau and Conway (2014) proposed about individualized training tailored to one's particular needs and expectations. Both conditions can produce positive effects on EFs development, but in the group, the profit of cognitive training is more than double than in individually administered training. Actually, Moreau and Conway (2014) underlined the importance of individualized training for the general population, while our study was focused on preschoolers, that probably gain more in group and in individualized training. Many training programs for preschoolers are presented in a group format in kindergartners, and the positive effect of this condition has been already demonstrated (e.g., Röthlisberger et al., 2012; Kassai et al., 2019). In terms of cost/benefits ratio, it is encouraging to know that group-administered cognitive training is even more effective, because it could be proposed both at school and in clinical settings, saving up economic resources without reducing its efficacy.

According to previous studies (Ericsson, 2009), training length was supposed to be related to higher improvement of EFs. Our results partly support this hypothesis; if we consider the number of sessions the positive effect is not significant, but if we consider the total amount of training time there is a positive and significant association. This result is consistent with other results reported in a previous meta-analysis (Takacs and Kassai, 2019) and it underlines the importance of the minimum amount of time before observing significant improvement in the EFs development, and that benefits need exercise.

A final comment concerns the effect of the cognitive training on the additional outcomes (see forest plot in **Supplementary Material**): the effect size was not significant ($g = 0.10$) confirming the difficulty to generalize from a cognitive EF training to other psychological domains, such as learning prerequisites and behavioral aspects.

In summary, the current meta-analysis on cognitive training for enhancing EFs in preschool children showed positive and significant results in terms of benefits for psychological development. This is the first meta-analysis on EF cognitive training for preschoolers: As hypothesized, we found a positive and significant effect concerning near and far transfer effects on Executive Functioning. Positive effects of EF training programs were significant for children with or without developmental risks. Moreover, cognitive EFs training programs are more effective if administered in group.

LIMITATIONS

The current meta-analysis has some limitations: firstly, the far transfer effect could also be due to task impurity, because tests for preschoolers usually activate multiple cognitive processes, and we cannot exclude that some tasks aimed to assess far EFs effect, actually assess partly near EFs. Secondly, there was considerable variability in the size of the samples included in the studies. Despite the exclusion of studies with less than eight participants per group, some of the studies included in the analysis still have small sample sizes, which might potentially overestimate treatment effects. We found no evidence of a relationship between sample size and EFs effect, but we nevertheless urge the reader to be cautious before drawing strong conclusions about the effects of the cognitive EFs training in preschoolers. Thirdly, we tried to include unpublished studies, but their atypical results (extremely large size of the effects) could bias the results, therefore, we decided to exclude these two analysis. Finally, we found few studies on preschool children with developmental risks and only one type of neurodevelopmental disorder, namely ADHD. We did not find studies on EFs training for preschoolers with other neurodevelopmental disorders (autism, language impairment, motor coordination disorder), although an EFs impairment has been demonstrated in these groups. Future research is necessary to assess whether cognitive EFs training could be useful with children presenting other neurodevelopmental disorders.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/**Supplementary Material**.

AUTHOR CONTRIBUTIONS

NS and MC contributed to conceptualization, design and methodology of the study and data collection, discussed interpretation of results, and wrote part of the manuscript. CZ contributed to conceptualization, design and methodology of the study, was responsible for outcome assessments and data collection, carried out data analyses and interpretation of data, and wrote part of the manuscript. GM contributed to conceptualization of the study, supervised data collection, was responsible for interpretation of data, and wrote part of the manuscript. All authors gave final approval of the version to be published and agreed to be accountable for all aspects of the work.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.02812/full#supplementary-material

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APPENDIX A

"preschoolers" OR "preschool" OR "early childhood" OR "3-6 years"
AND
"training" OR "therapy" OR "intervention*" OR "program" OR "treatment"
AND
"executive function*" OR "attention*" OR "working memory*" OR "updating" OR "inhibitory control" OR "self-regulation" OR "self-regulation" OR "cognitive flexibility" OR "mental flexibility" OR "shifting" OR "set shifting" OR "effortful control" OR "cognitive control" OR "problem solving" OR "planning" OR "executive control" OR "metacognition" OR "behavioral control" OR "self-control" OR "response inhibition" OR "interference control" OR "executive attention" OR "focused attention" OR "selective attention"

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Everyday Practices and Activities to Improve Pre-school Self-Regulation: Cluster RCT Evaluation of the PRSIST Program

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The Preschool Situational Self-Regulation Toolkit (PRSIST) Program was developed as a low-cost and embedded approach for educators to foster pre-schoolers' self-regulation and related abilities (e.g., executive function, school readiness). This study reports on a cluster RCT study with 50 Australian pre-school services to evaluate the effectiveness of the PRSIST Program for improving children's self-regulation, executive function and school readiness, compared to current routine practice. Pre-school centers were recruited to reflect the breadth of geography, pedagogical quality, and socio-economic catchment areas across the early childhood education and care sector. All children identified as in their final year of pre-school education at these centers were invited to participate, resulting in a sample of 473 3-5-year-old children at baseline. Centers were randomly assigned to groups after baseline data collection, and data collectors were blinded to group assignment throughout the study. It was hypothesized that engagement in the PRSIST Program would improve children's self-regulation, executive function and school readiness, over and above normal age-related rates of development. Results indicated small but significant improvements in executive functioning for the intervention group, after adjusting for cluster, baseline results and key covariates. All other outcomes were descriptively in favor of the intervention group but failed to reach significance. Levels of use of the program remained high by most educators throughout the intervention period, suggesting its acceptability and sustainability within these contexts. Together, results show promise for this approach to self-regulation development. Opportunities that might further strengthen this approach are discussed. This study was registered with the Australia and New Zealand Clinical Trials Registry (ACTRN12617001568303) and study protocols published in advance of commencement. Funding for this study was provided by the Australian Research Council's Discovery Early Career Researcher Award research grant scheme.

Keywords: self-regulation, executive function, school readiness, preschool, intervention, RCT

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INTRODUCTION

For many parents, early childhood educators and professionals, the term self-regulation evokes episodes of exactly the opposite – a child's dysregulation, which requires their attention and intervention to restore calm to the child and situation (Nixon, 2002; Papadopoulou et al., 2014). Efforts to address these situations are essential, as dysregulations – such as conflict, impulsive behaviors, over-reactions to the situation, and tantrums – are indicative of a child in need, whether temporary or persistent. Unaddressed, these episodes can undermine a child's relationships with their peers, effective communication with adults and productive engagement in positive developmental experiences (Miller et al., 2010; Williford et al., 2013). Where persistent or severe, dysregulation in childhood increases the risk of developing ongoing behavioral and mental health problems (Althoff et al., 2010; Hyde et al., 2012).

Strategies to foster self-regulation, however, should not begin and end with instances of child dysregulation. For one, efforts to return a dysregulated child to stasis will do little to aid the self-regulation of children not overtly dysregulated and those who "fly under the radar." For instance, research highlights pervasive gender differences in the manifestation of behavior problems, with girls inordinately channeling this into internalizing problems (e.g., dissociation, surrender, emotional disturbances), while boys more often engage in externalizing behaviors (e.g., hyper-arousal, aggression, acting out; Hodas, 2006). As the latter is likely to be more disruptive and distressing to adults, it is also more often noticed and addressed by educators (Beaman et al., 2007). This may be a contributing factor in the higher rates of specialist referral for boys (Vardill and Calvert, 2000), despite evidence that the prevalence and degree of behavior problems are comparable in girls (McGee et al., 1987; Keenan and Shaw, 1997). Second, reactive and short-lived attempts to address episodes of dysregulation through co-regulation often fail to foster children's capacity to preemptively – and increasingly independently – control their attention and thinking, behavior, emotional reactions and social interactions in future.

To support and promote genuine *self*-regulation abilities, these capacities should also be fostered in times of good regulation; with children at lower (but often not enough to draw attention), average and higher self-regulation ability. Indeed, any-cause improvements in child self-regulation have been found to be associated with improvements in later-life outcomes even for children initially at average or high levels of self-regulation (Moffitt et al., 2011). This implies that all children could benefit from self-regulation-promoting experiences in the early years. There are few readily accessible programs for educators (or parents), however, to support early self-regulation development beyond instances of dysregulation. Those that do exist often have barriers to access, in terms of cost (requires purchase or expert induction/delivery) or time (supplementing, rather than complementing, the existing daily routines and requirements). The *Preschool Situational Self-Regulation Toolkit (PRSIST) Program* was developed in response – in consultation and collaboration with early years educators and service providers – as a freely and widely available collection of professional learning, supportive adult practices, and child activities that can be embedded within existing pre-school routines. This manuscript reports on a cluster randomized controlled trial (RCT) evaluating the efficacy of the PRSIST Program for the first time.

The Nature of Early Self-Regulation: Importance and Development

Although there are numerous definitions of self-regulation (Burman et al., 2015), one conceptualization that has come to the fore is self-regulation as the ability to control our attention and thinking, behaviors, emotional reactions, and social interactions, despite any impulses or distractions to the contrary (also termed self-control). In the pre-school years, this includes sustaining attention and resisting distraction, taking turns, persisting with challenging tasks, and initiating or ceasing behaviors that conflict with immediate preference or impulses (e.g., listening to other children in a group activity). The evidence in relation to this formulation of self-regulation is clear: childhood self-regulation abilities robustly predict health, wealth and criminality into adolescence and adulthood (Moffitt et al., 2011). Children with low self-regulation in the pre-school years are more likely to have poorer school readiness and success (McClelland and Cameron, 2011), and poorer health habits and outcomes, socioeconomic position, and mental health in adulthood (Althoff et al., 2010; Moffitt et al., 2011). Research also shows the malleability of early self-regulation, with those children who become more self-controlled achieving better outcomes in later-life (Moffitt et al., 2011). Self-regulation has thus become particularly interesting for researchers, educators and parents, as a means to not only support children's immediate and pressing needs, but also their long-term outcomes.

There is compelling research supporting the value of 'earlier' interventions in forecasting lasting, stable and cost-effective change (Heckman, 2006; Wass et al., 2012). Considered alongside evidence that self-regulation improvements yield benefits not only for children with low self-regulation, but also children at or above age norms (Moffitt et al., 2011), positions scalable early self-regulation interventions as a promising opportunity to improve population trajectories across the lifespan. Despite these compelling findings and possibilities, however, this knowledge has not yet yielded a framework for understanding self-regulatory change, nor has it generated particularly consistent or widespread approaches for enacting this change.

The Nurture of Early Self-Regulation: Interventions and Programs

Paralleling the diversity in characterizations of self-regulation, there are similarly diverse approaches for attempting to foster children's self-regulation. One prominent approach to self-regulation intervention derives from a seminal study that reported 4-year-old's performance on a delay of gratification task – in which the child would receive an enhanced reward if they were able to resist eating a marshmallow for a few minutes – which robustly and longitudinally predicted self-regulation outcomes (Mischel et al., 1989). On the basis of these findings, Mischel et al. (1989) speculated that cognitive and attentional control processes may be essential for successful self-regulation. Decades of investigation that followed has focused on executive functions (EFs) as a core component of self-regulation – via their direction and control of attention, and inhibition of impulses and distractions (Diamond, 2016) – and a means by which to improve diverse outcomes that are associated with good self-regulation. Interventions deriving from this research most prominently features a proliferation of technology-based "brain training" programs, which engage users in activities of increasing cognitive challenge to promote more effective executive functioning. While this approach is now pervasive, programs that adopt this approach can be time- and cost-intensive, and usually necessitate removal of a child for individual sessions that oftentimes require professional administration. The non-routine nature of these programs may constrain their suitability for fostering children's self-regulation development in their social context. This is evidenced by a typical pattern of findings when adopting this approach: modest gains in EFs and limited transfer of these benefits to untrained tasks, domains and real-world outcomes (Karch et al., 2013; Melby-Lervag and Hulme, 2013).

In contrast to this approach, and expanding on Carver and Scheier's (1981) feedback loop model of self-regulation, Baumeister and Heatherton (1996) proposed three essential aspects of successful self-regulation: goal selection; sustained motivation to achieve this goal, through reducing discrepancies between current and goal states; and a sufficient capacity to overcome distractions/barriers to achieving this goal. Following from this model, research from education and social psychology has tended to focus on the behavioral, emotional, and social dimensions of self-regulation, such as persistence in challenging tasks, frequency of temper tantrums, and self-directedness (Baumeister and Heatherton, 1996; Hofmann et al., 2012). This has included approaches that foster educators' self-regulation knowledge and educational supports (Raver et al., 2011), explicit teaching of self-regulation strategies (Flook et al., 2015), embedding activities with self-regulation challenge in children's daily routines (Tominey and McClelland, 2011) and integrated curricula (Diamond et al., 2007).

These intervention approaches, which target educator practices and classroom curricula, have arguably shown greater promise for improving children's self-regulation and outcomes (Diamond and Lee, 2011). Indeed, meta-analyses of curriculum-based intervention effects found improved self-regulation after 16 of the 21 curricular programs evaluated and, where available, positive effects on some distal outcomes (Pandey et al., 2018). As one example from this approach, Tools of the Mind (Bodrova and Leong, 2007) is a comprehensive curriculum that embeds EF and self-regulatory challenge within content areas such as literacy and numeracy (Diamond et al., 2007; Barnett et al., 2008). Through its comprehensive programing and schedule, Tools of the Mind directs and supports educators to scaffold children's higher-order thinking in planning, social learning and play – particularly make-believe play – and, following principles outlined by Vygotsky (1978), gradually withdraw this support with increasing child proficiency. Evaluations of this program have yielded mixed findings (for a review, Baron et al., 2017), although a reconciliation of these results appears to suggest that committed engagement in the Tools of the Mind curriculum can yield positive effects on EF (Diamond et al., 2007) and teacher-reported problem behaviors (Barnett et al., 2008).

Another curriculum-based approach for supporting and enhancing self-regulation is the preschool adaptation of the Promoting Alternative Thinking Strategies (PATHS: Kusche and Greenberg, 1994) program. Rather than a particular and explicit focus on EF skills, as in Tools of the Mind, PATHS focuses on fostering social and emotional knowledge and competencies. Educators engaging with the program are provided with lessons, materials and guidance that focus on topics such as understanding feelings and interpreting social cues. Weekly "circle time" is used to deliver lessons, which are sequenced into thematic units over the year (e.g., compliments, simple versus complex feelings, self-control strategies; Domitrovich et al., 2007). In their evaluation of this program, Domitrovich et al. (2007) found that 3-4-year-old children who were involved in the PATHS program for 9 months had greater emotional literacy, social competency and less social withdrawal than did children in a wait-list control condition. Integration of the PATHS curriculum in the Head Start Research-Based Developmentally Informed (REDI) program in 25 Head Start preschools showed longitudinal benefit: improved academic outcomes for the intervention group in third grade, and improved EF scores for children on low-EF-development trajectories (Sasser et al., 2017).

The Chicago School Readiness Project (CSRP; Raver et al., 2008) takes yet another approach, although is similarly embedded within a comprehensive and structured curriculum. CSRP was designed to enhance school readiness amongst preschool-aged children from low-income backgrounds. To achieve this, CSRP builds early childhood educators' knowledge of behavior management strategies through extensive professional development and expert coaching from a mental health consultant (Raver et al., 2011). Mental health consultants also provide specialist supports for children with particularly severe self-regulation issues (Raver et al., 2009). While this is a resource-intensive approach to intervention, evaluations of CSRP have reported improved EF, pre-academic skills and teacher-reported behavior problems after less than 12 months of program participation (Raver et al., 2009, 2011).

Curricular approaches seem particularly promising, not only in their ability to generate immediate self-regulation improvements, but also sustained and flow-on impacts after program completion. However, approaches in this tradition are often plagued by time, inflexibility and cost constraints that are prohibitive for many pre-school services and educators (e.g., requires adopting a comprehensive curriculum or intensive program focused on self-regulation). This may be a source of their mixed results, as comprehensive and prescriptive programs may not suit all contexts and educators (thereby impacting program adherence), and effects would not be expected where adherence to program requirements is low (Diamond and Lee, 2011; Wilson and Farran, 2012).

Theoretical Model of Self-Regulation Change

Another possible explanation for the modest effects of some approaches is their focus on only some elements of self-regulation, which is exacerbated by resource-related barriers to effective, consistent and sustained program implementation (e.g., time, cost, ability to induct new staff). Curricular approaches, for instance, often neglect the role of cognitive control processes for successful self-regulation (although see Tools of the Mind for a curricular approach with this as an explicit focus). Hofmann et al. (2012) propose EFs as the capacity component of self-regulation, providing the cognitive control to direct and sustain attention, remain goal-directed, and override competing interests and distractions. EF "brain training" approaches address this component explicitly, but rarely include components that promote goal setting, motivation and problem solving, which are essential for successful self-regulation according to Baumeister and Heatherton's (1996) model.

Although this model of self-regulation has yet to be empirically evaluated, it may explain why many existing interventions yield limited transfer to children's real-world outcomes. That is, while each approach creates conditions necessary for improvement in those abilities (e.g., continual challenge, diversity of intervention activities that are ecologically valid, sustained participation; Diamond and Lee, 2011), they are incomplete in their self-regulatory targets. Given that self-regulatory failure can derive from any one of these aspects (i.e., not selecting a particular self-regulated goal, abandoning progress toward the goal due to weakening motivation or inability to resolve challenges, or insufficient capacity to override contrary impulses and distractions that arise), interventions that support and foster each of these elements may be more likely to succeed. Further, interventions (and their theories of change) must recognize developmental sequences in these abilities, such that capacity and goal-setting components are relatively more constrained in early childhood (and thus require experiences and opportunities that present appropriate but achievable challenge to facilitate development), whereas motivation is often quite high (creating opportunity to leverage this intrinsic interest and motivation toward activities that can promote goal-setting and capacity for control).

From this proposition emerges an approach that acknowledges both the cognitive and socially mediated mechanisms of self-regulatory change. In aiming to foster children's self-regulation in its social context, this approach should identify those environments, routines and practices that engage and extend (or provide an opportunity to engage and extend) children's *capacity* to self-regulate. This includes adult practices to promote the conditions for successful self-regulation (e.g., ensure children feel safe and supported, included, and valued), as well as fostering strategies and opportunities for children to *select goals* and experience success in self-regulation (e.g., leading, making choices, planning, experiencing success through effort). To leverage children's interests and motivation, experiences should be fun and playful. Further, to enhance the likelihood that these experiences yield real-world and everyday improvements, they should be embedded in children's social contexts. Minimizing the burdens of program induction and implementation – while maximizing program flexibility, educators' choice and agency, and alignment with current practices and routines – would support implementation and maintenance of the program with minimal additional burdens or resource requirements. Lastly, scalability requires a program that is free, accessible without barriers and can be implemented by those who spend the majority of the time with the children (e.g., parents, educators).

Programs exist that combine at least some of these elements. For instance, the Red Light, Purple Light Circle Time Games Program (Tominey and McClelland, 2011) organizes children into small-to-large playgroups for 20 min, twice per week, during which children play one of five group games that invoke self-regulatory challenge (e.g., doing the opposite of a natural response, such as dancing slow to a fast song). Evaluations have shown feasibility and benefit, such as increases in self-regulation for children initially low in self-regulation (Tominey and McClelland, 2011), and improvement in literacy (Tominey and McClelland, 2011; Schmitt et al., 2015) and math (McClelland et al., 2019). Other programs, such as Kids in Transition to School (KITS), have shown similar success when integrating self-regulation activities (as well as early literacy and prosocial skills) into group activities for children with developmental disabilities (Pears et al., 2015).

Yet the absence of some of the aforementioned criteria may constrain consistency or size of program effects, and/or possibility for widespread program uptake. For instance, given their different theories of self-regulatory change, some theorized components of self-regulation (i.e., goal setting, motivation) are not explicitly targeted through educator practice or child activities. The constrained number and context of self-regulation-promoting situations further limits the everyday situations (e.g., in dyads, in full-group activities, in physically active play) in which children are given an opportunity to practice and extend these abilities. In terms of accessibility, this approach often requires delivery or face-to-face training by a master interventionist, and/or ongoing coaching, which present barriers to access and implementation. Given the successes of this approach and opportunity to empower those who have amongst the greatest opportunity to influence children's early trajectories, the PRSIST Program was designed to adopt a similar approach but also address these additional criteria.

Current Study

To address limitations in current pre-school self-regulation intervention approaches, the PRSIST Program was designed with this theory of change in mind. Specifically, the PRSIST Program provides educators with: online professional development, to foster practices that set conditions for optimal self-regulation (i.e., reducing factors that have been shown to undermine children's self-regulation, such as stress and loneliness; Diamond, 2013), and support children's goal-setting through choice and success (fostering the goal-setting and motivation elements of self-regulation); and playful small- and large-group activities with embedded self-regulation challenge, to extend children's capacity to control their attention, behaviors, emotions and interactions (to develop the capacity component of self-regulation). The PRSIST Program was designed in consultation with early childhood educators to ensure its acceptability (to children and educators), flexibility and compatibility with current routines, to maximize the likelihood of sustained program implementation. The PRSIST Program was thus developed as a comprehensive – but flexible, embedded, and readily scalable – approach to support early self-regulation in pre-school contexts. In this initial evaluation study, the PRSIST program was implemented and evaluated with 50 pre-school services, using a cluster RCT design, to determine its effectiveness for improving children's self-regulation, EF and school readiness outcomes. We hypothesized that children in the intervention group would show greater improvements in self-regulation, executive function and school readiness compared with children in the control (typical pre-school practice) group. To maximize the quality of evidence generated, conduct and reporting of this study follows the CONSORT statement for cluster RCTs.

MATERIALS AND METHODS

Design and Participants

This study was a 6-month, 2-arm cluster randomized controlled trial comparing a pre-school self-regulation program (*PRSIST Program*) with typical practice (control group). Fifty pre-school centers in metropolitan and regional areas of Australia were recruited to be broadly representative of population proportions for geography (84% metropolitan), socio-economic decile for their catchment area (M = 5.91, SD = 2.24, range = 1–10), and statutory quality assessment rating (i.e., 44% Exceeding, 48% Meeting, 4% Working Toward, 4% unrated against the National Quality Standard). Australia's early childhood education and care (ECEC) sector includes a range of pre-school provision (e.g., preschool for 4–5-year old children in the year before formal schooling, long-day care services from infant to age 5, family day care) that is delivered by not-for-profit, for-profit or state providers. While there is no state or national curriculum for the Australian ECEC sector, all pre-school services are required to follow the Australian *Early Years Learning Framework*, which outlines expected outcomes of children from birth to age 5. For this study, participating pre-schools: were structurally equivalent in terms of being long-day care services providing care to children aged 2–5 years, up to 5 days/week; were run by community or not-for-profit providers; and had at least one Bachelor-qualified educator (or government waiver).

The focus of the study was the final year prior to formal schooling, which yielded a total of 52 classrooms (most centers had one pre-K room, except for two services that had two). One-hundred and sixty-one educators participated in the study. Characteristics of these educators were broadly consistent with those in the sector: a majority were female (98.8%) and full-time (59.0%); had an average of 10.48 years of experience in the industry (range = 0–36 years) and 4.29 years at their center (range = 0–20 years); and were diverse in qualifications (58 degree, 55 diploma, 41 certificate and 4 no formal qualification).

All children in their final prior-to-school year in these centers, who attended at least one of the 1–2 assessment days, were invited to participate in this study. There were no further exclusion criteria. Parental consent to participate was provided for 547 3-5-year old children, all of whom were identified as likely to be attending school in the subsequent year. The flow of participants throughout the study is depicted in **Figure 1**. At baseline, 473 of these children were assessed (86.5%), with non-participation largely due to absence on the day of assessment. The mean age of this sample was 4.44 years (SD = 0.38, range = 3.20–5.33), with a relative balance of boys and girls (48.2% girls). Children who were identified as of Aboriginal or Torres Strait Islander descent comprised 7.2% of the sample, which is in line with population estimates for this age group (Australian Institute of Health and Welfare (AIHW), 2012). Family income was diverse: 11.9% of families qualified for full childcare benefit subsidies (low income); 65.5% of families qualified for some childcare benefit (low-middle to middle-high income); and 22.7% of families did not qualify for any childcare benefit subsidy (high income). Maternal education levels were also diverse: 9.5% did not complete high school; 9.3% completed only high school; 30.6% had completed a diploma, trade, certificate; 34.6% completed a tertiary degree; and 16.0% a post-graduate qualification. At follow-up, 426 children were assessed, which corresponded to a 90.1% retention rate. Non-participation at follow-up was due to the child having left the center or absence on the day of assessment.

Centers were randomized after baseline data collection, using a computerized random number generator. As such, those involved in recruitment of centers and assessment of children at baseline were unaware, at time of recruitment, to which group centers would be allocated. The trial was registered with ACTRN (ACTRN12617001568303) and protocols were published prior to the trial's commencement (Howard et al., 2018). The study was approved by the university's Human Research Ethics Committee, and participants were those whose parents provided informed written consent and themselves provided verbal assent to participate.

Intervention (*PRSIST Program*)

The *Preschool Situational Self-Regulation Toolkit (PRSIST) Program* aims to engage, challenge and extend young children's self-regulation in ways that are playful, low-cost, routine, and target each of the aspects required for successful self-regulation (i.e., goal setting, motivation, problem solving, self-regulatory capacity). The PRSIST Program is a collection of professional learning, adult practices, play-based child activities, and home-based resources to support the development of children's self-regulation. The PRSIST program was designed to be compatible across a range of early learning contexts, but in this study was implemented by pre-school educators. Educators were inducted into the program through hard copy program materials, a program website[1], and monthly 1-h teleconference calls to

[1] www.prsist.com.au

FIGURE 1 | Example story page and linked child activity pertaining to cognitive self-regulation. The picture books were developed so that educators could read the rhyming story to children, and after the story facilitate an activity linked to primary plot points – as a soft entry into doing the activities with children. This example is from a book with a cognitive self-regulation storyline – the main character must remember a shopping list despite distraction and competing interests. The rhyming story and associated image take up the majority of the page, while an activity that can be completed after the story – which is linked to the plot of the current page – is provided in the panel on the right. This image is reproduced with permission of the publisher, Ceratopia Books Ltd.

highlight different aspects of the program and discuss educators' experiences and challenges. All program materials are freely available on the program website for inspection, replication, revision or adoption of program elements.

In previous phases of this research, all program elements were piloted, evaluated and revised on the basis of feedback from early years educators (e.g., child and educator enjoyment, program compatibility with pre-school contexts, routines and practices, perceived benefit). In line with this feedback, the program was developed so that it can be flexibly implemented for varying durations, intensities, and using different combinations and sequences of elements.

For the current trial, however, educators were asked to implement the program over the course of 6 months, implementing each of the program's four core elements described below. While all program elements were made available on completion of baseline assessments, the program elements were explicitly introduced and emphasized in a staged manner, to ensure sufficient foundations for implementation. Specifically, the first month focused on completion of online professional development, the second month on child activities, third month focused on formative assessment and fourth month focused on increasing challenge in child activities. Minimum expectations of engagement in the program were communicated to educators, which are outlined in relation to each program element below.

Professional Development (Adult Practices)

Educators were asked to engage with the program's nine accredited online professional development videos within the first 2 months of the program. These videos, which were drawn from the self-regulation components of the evidence-based Fostering Effective Early Learning (FEEL) professional development (Siraj et al., 2018), introduce the nature and development of early self-regulation, and supportive adult practices. These videos were complemented by a practice manual that describes 11 principles, and associated practices, to support children's self-regulation development and minimize factors that undermine self-regulation (e.g., stress, sadness). In the manual the principles are described (e.g., foster intrinsic motivation through encouragement), contextualized in a real-life scenario to illustrate its importance (e.g., a child shows an educator a construction they have worked hard on), and specific practices are provided related to the principle (e.g., open-ended questioning).

Child Activities

In addition to the adult practices, a collection of 28 play-based activities were provided to extend children's self-regulatory capacity. These activities were developed from: practices already occurring in high quality pre-school services; minimal modification of existing practices (i.e., modified to maximize self-regulatory benefit) in high-quality centers, which were identified as high quality in the FEEL study (Neilsen-Hewett et al., 2019); or newly created activities that were piloted and revised based on the feedback of educators across a range of pre-school services. In addition to being made available online and in hard copy manuals, activities were compiled into a series of children's books as an easy entry for educators to read about and conduct the activities. The storyline for each book relates to a domain of self-regulation (i.e., behavioral, cognitive, social-emotional), with self-regulation activities linked to central plot points and a full compendium of activities in an appendix at the end of the book (see example at **Figure 2**).

All activities included instructions for implementation, how to increase the challenge of the activity as children became more proficient, how the abilities required for the activity relate

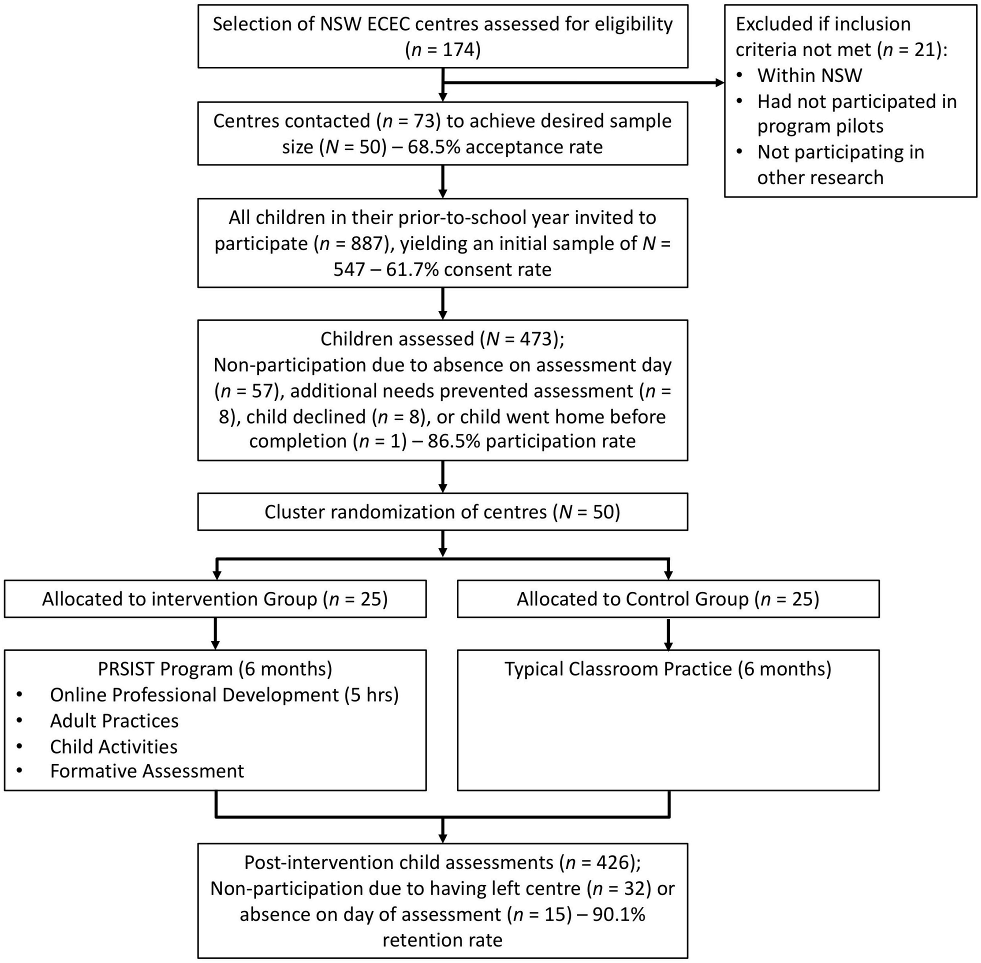

FIGURE 2 | CONSORT flowchart of stages and participants in the study.

to children's everyday self-regulation, and links to Australia's national Early Years Learning Framework. *Disciplined Dance* is one such activity done routinely in early childhood contexts, in which children dance whenever the music plays and stop when the music stops. A common tendency in this game, however, is to either eliminate a child who does not "freeze" (thereby giving the least amount of practice to children who perhaps could benefit most) or ignore that the child continued dancing. In our variation of this activity, all children continue to play the game throughout, but children who do not freeze are aided by removing some of the body parts from consideration. For instance, if a child does not freeze at the first stoppage of music, they kneel for the next round (removing their legs from consideration). If they are unable to freeze again, they sit. Upon successful freezing, the child returns to an earlier position. To make this activity even more challenging, educators reverse the sequence – children must be still when the music is playing, and dance when the music is turned off.

The program was designed so that the timing, intensity, selection, and sequence of child activities is flexible; however, within the current trial educators were asked to complete a minimum of three activities of their choosing per week. While educators were free to select the activities that they and the children enjoyed best, they were encouraged to complete activities of various types and categories each week. Fidelity of this intensity requirement was evaluated through monthly wall-calendar sticker charts, returned to the research team, that showed the date and frequency of each activity.

Formative Self-Regulation Assessment

To appropriately plan for and support children's self-regulation development, information about their current developmental progress in this area is essential. To support this understanding, participating educators were given access to online training for the PRSIST formative assessment tool. This tool involves observation of children as they perform everyday activities, but structures this observation to: (1) focus on key areas of self-regulation; and (2) provide actionable data based on a child's current developmental progress. Use of this tool was optional, but if used it was recommended that each child be assessed at least twice during the intervention period to support tailoring the complexity of the child activities to children's current developmental needs.

Parent Newsletters

While the trial did not explicitly focus on parental involvement, intervention centers were provided with monthly parent newsletters designed to support the sharing of information and practices with the home. Each of the six newsletters, which were one double-sided page in length, presented information relating to what self-regulation is, its importance in the early years, observing their child's self-regulation and ideas for supporting self-regulation development in the home.

Teleconferences

Directors and educators from intervention centers were invited to join 1-h teleconferences run monthly, at the end of the first, second, third, and fourth months of the program. Participants were invited to participate in any one of three repeat sessions in a given week. Educators who were unable to attend these sessions were offered a one-to-one debrief with a member of the research team. The aim of each teleconference was on: highlighting a particular program element to commence or focus on over the following month; facilitating discussion of educators' current experiences, challenges and needs in relation to the program; and creating an opportunity for educators to share with each other ideas and opportunities that arose from their engagement with the program. This was also an optional component of the program but had a high level of participation (88% attended at least two teleconference calls).

Control Group (Typical Practice)

The control group continued with their existing program, which included structured and free play time. Given the prevalence of self-regulatory concern amongst ECEC educators, it is likely that some of these activities targeted self-regulation. Further, it is expected that at least some of the educators would have attended professional development during the trial, and some of this might have concerned self-regulation. However, all of this can be considered current routine practice and represents an appropriately active control condition.

Measures

Outcomes were measured at the child level and pertained to self-regulation and related abilities (i.e., executive function, school readiness). Given the child activities resembled those routinely enacted in early childhood contexts (e.g., *Disciplined Dance*), and were not designed to approximate the outcome measures, results can be interpreted as near transfer to untrained contexts. The one exception to this was the PRSIST Assessment, which was made available to the educators as part of the program. However, for the purposes of program evaluation this was administered and scored by a trained researcher (rather than educator), and performance indices were not concerned with proficiency in the game *per se* (thereby limiting practice effects).

Self-Regulation

The primary outcome was a task that requires complex combination of EFs. *Head-Toes-Knees-Shoulders* (HTKS; McClelland et al., 2014) asks children to remember a correspondence between body parts (e.g., head and knees), and then perform the opposite action to what was indicated (e.g., touch their knees when the facilitator says 'touch your head'). In doing so it requires children to hold a correspondence in mind (working memory), inhibit the impulse to carry out the action as directed (inhibition), and flexibly switch between correspondences across task levels (cognitive flexibility). The task consists of six practice and 10 test trials at each of three levels: (1) correspondence between head and toes; (2) correspondence between knees-shoulders and head-toes; and (3) flexibly switching between the correspondences of head-knees and shoulders-toes. The task continues until completion or failing to achieve at least four points within a level (such that 2 points are awarded for a correct response and 1 point for a self-corrected correct response). Performance was indexed by the sum of points awarded for all practice and test trials attempted, yielding a score with a possible range from 0 to 94. HTKS has been shown to have good convergent validity with other task- and adult-report measures of self-regulation, predictive validity of academic learning (Ponitz et al., 2009), and psychometric reliability (e.g., α ranging from 0.92 to 0.94; McClelland et al., 2014). Reliability in the current study was similarly strong (Time 1 $\alpha = 0.97$, Time 2 $\alpha = 0.97$). Fieldworkers completed the online training module prior to in-field data collection to ensure accuracy of scoring and inter-rater reliability. All other outcomes were considered to be secondary.

Preschool Situational Self-Regulation Toolkit (PRSIST) Assessment (Howard et al., 2019) is an observational measure of early self-regulation that engages children in self-regulatory activities, and rates the child's behavior in relation to cognitive and behavioral self-regulation. The first PRSIST Assessment activity is a memory card game. In this activity children, in a group of four, take turns trying to find a matching pair of cards (e.g., 8 pairs for 4-year-olds, 14 pairs for 5-year-olds), taking around 10 min to complete. The second activity is an individual curiosity boxes activity, in which children are presented with a series of three boxes of increasing size and asked to guess their contents. The sequence of guessing occurs as follows: first, guess based only on the size of the box (no touching); second, guess after gently lifting the box to feel its weight (no shaking); third, guess after shaking the box (no opening); and lastly, guess after closing your eyes and feeling the object inside (no peeking). This activity takes approximately 5 min to complete. Each child's self-regulation was rated at the end of each activity. Items were scored along a 7-point Likert scale, with the ratings representing a judgment of the frequency and/or severity of behaviors pertaining to cognitive self-regulation (e.g., Did the child sustain attention, and resist distraction, during the instructions and activity?) and behavioral self-regulation (e.g., Did the child control their behaviors and stay within the rules of the activity?). This yielded two sets of ratings per child, which were averaged for the two activities before aggregating into cognitive (six items) and behavioral self-regulation indices (three items) with a possible range from 1 to 7. A full description of this measure and administration protocols are described elsewhere (Howard et al., 2019). To ensure inter-rater reliability, observers completed the online training module – at the end of which an observer rating ensures sufficient inter-rater reliability – and five joint observations of video data alongside a member of the research team prior to in-field data collection. This measure has shown good construct validity, reliability (α ranging from 0.86 to 0.95), and concurrent validity with task-based self-regulation (*r*s ranging from 0.50 to 0.63) and school readiness measures (*r*s between 0.66 and 0.75) (Howard et al., 2019). Reliability in the current study was similarly strong (Time 1 α = 0.92, Time 2 α = 0.90).

Educator-reports of children's self-regulation on the *Child Self-Regulation & Behaviour Questionnaire* (CSBQ; Howard and Melhuish, 2017) were also collected. This scale consists of 34 items pertaining to the typicality of children's everyday behaviors (e.g., "Persists with difficult tasks"). Each item was rated by the child's educator along a 5-point Likert scale from "Not true" to "Certainly true" about the child. Ratings on individual items were averaged to generate subscales of cognitive (five items), behavioral (six items), and emotional self-regulation (six items), as well as subscales concerning prosociality, sociability, internalizing problems, and externalizing problems. The subscales have shown good reliability (α ranging from 0.74 to 0.89) and convergent validity with other adult-report measures of children's behaviors (Howard and Melhuish, 2017). Reliability in the current study was similarly strong (Time 1: cognitive α = 0.87, behavioral α = 0.88, emotional α = 0.79; Time 2: cognitive α = 0.89, behavioral α = 0.87, emotional α = 0.85). To reduce the number of analyses performed, a single self-regulation index was generated by averaging the three self-regulation subscales.

Executive Functions

Individual EFs were indexed by measures of working memory, inhibition, and cognitive flexibility selected from the iPad-based *Early Years Toolbox (EYT*; Howard and Melhuish, 2017). Specifically, working memory was indexed by the *Mr. Ant* task, which asks children to remember the spatial locations of "stickers" placed on a cartoon ant, and identify these locations after a brief retention interval. Test trials increase in complexity as the task progresses (progressing from one to eight stickers), with three trials at each level, until the earlier of completion or failure on three trials at the same level of difficulty. Working memory was indexed by a point score that estimates working memory capacity, calculated as: one point for each level, from the first, in which at least two of three trials are performed correctly; and then one-third of a point for each correct trial thereafter (yielding a possible range from 0 to 8; Howard and Melhuish, 2017). Inhibition was assessed by the *go/no-go* task, which requires participants to respond to "go" trials ("catch fish") and withhold responding on the "no-go" trials ("avoid sharks"). The majority of stimuli are "go" trials (80% fish), thereby generating a pre-potent tendency to respond that children must inhibit on "no-go" trials (20% sharks). After instruction and practice, 75 test stimuli were presented across three 1-min blocks (separated by a short break and reiteration of instructions). Each trial involved presentation of an animated stimulus (i.e., fish or shark) for 1500 ms, each separated by a 1000 ms inter-stimulus interval. In line with protocols of Howard and Melhuish (2017), inhibition was indexed by an impulse control score, which is the product of proportional "go" (to account for the strength of the pre-potent response generated) and "no-go" accuracy (to index a participant's ability to overcome this pre-potent response), to yield a proportional accuracy score that ranged from 0.00 to 1.00. Finally, cognitive flexibility was assessed by the *Card Sort* task, which asks children to sort cards (i.e., red rabbits, blue boats) first by one sorting dimension (e.g., color), then switch to the other sorting dimension (e.g., shape). The task begins with a demonstration and two practice trials, after which children begin sorting by one dimension for six trials. In the subsequent post-switch phase, children are asked to switch to the other sorting dimension. For all test items, each trial begins by reiterating the relevant sorting rule and then presenting a stimulus for sorting. If the participant correctly sorts at least five of the six pre- and post-switch stimuli, they then proceed to a border phase of the task. In this phase, children are required to sort by color if the card has a black border or sort by shape if the card has no black border. Cognitive flexibility was indexed by the number of correct sorts after the pre-switch phase (yielding a score that ranged from 0 to 12; Howard and Melhuish, 2017). To more purely index EF (given findings of a single EF factor in the pre-school years, which is impurely indexed by any single task), and constrain the number of planned analyses, an exploratory factor analysis (EFA)-derived factor score was computed for these three EF tasks. Each of these tasks has shown good convergent validity with other task-based measures of EF (*r*s ranging from 0.40 to 0.46) and reliability with children of this age (Howard and Melhuish, 2017). Inter-task correlations in the current sample (*r*s from 0.16 to 0.30) were similar to those previously reported (Howard and Melhuish, 2017), as were correlations with the school readiness measure (*r*s from 0.27 to 0.42).

Academic Learning

The academic knowledge of participating children was assessed using the *Bracken School Readiness Assessment (BSRA,* 3rd edition; Bracken, 2007). BSRA is a standardized assessment of areas deemed important for school readiness. It includes subscales of colors (10 items), letters (15 items), numbers/counting (18 items), sizes/comparisons (22 items), and shapes (20 items). For each domain, the assessment continues until completion or three consecutive incorrect responses. BSRA has been shown to be predictive of kindergarten teacher ratings of children's school readiness and academic results (Bracken, 2007; Panter and Bracken, 2009). Children's academic learning was indexed by a total raw accuracy score, with a possible range of 0–85.

Demographic Covariates

Parents reported on demographic information used as covariates for analyses. These were: child's age (the date of assessment minus date of birth); child's sex (1 = male, 2 = female); identification as Aboriginal or Torres Strait Islander; home language (1 = English, 0 = Other than English); a quality of home learning environment (HLE) index from the EPPE Study (Melhuish et al., 2008), which asks about the frequency of eight in- and out-of-home enrichment activities (e.g., reading, sport, extra-curricular activities) to generate a 41-point HLE index; and a postcode-level index of socioeconomic decile created by the Australian Bureau of Statistics (Australian Bureau of Statistics (ABS), 2012), combining census data on factors such as education, household income, and unemployment. This area-level index was used over the family income variable given its increased sensitivity (reported in deciles) over the three wide income bands utilized to capture eligibility for childcare benefit.

Procedure

All tasks were administered to children in a quiet area of their pre-school center in five sessions across the same day, to maximize children's attention and minimize fatigue. Measures were administered in the same order to all children, as follows: (1) BSRA; (2) PRSIST curiosity boxes and HTKS; (3) Mr Ant and Go/No-Go; (4) PRSIST memory; and (5) Card Sort. Each session took 10–20 min to complete and were done near the start of children's final pre-school year (March–April 2018). These assessments were again conducted near the end of the year (October–November 2018), also in a quiet area of the child's pre-school. All fieldworkers involved in follow-up data collection were kept blind to cluster assignments.

Data Analysis

To evaluate the effect of the PRSIST Program intervention, data were analyzed using a linear mixed model with a random effect for clustering by center. Unadjusted models and models with sex, age, SES category (low, medium or high SEIFA), HLE index, identification as Aboriginal or Torres Strait Islander (Aboriginal or non-Aboriginal) and language (English or language other than English) are presented. Baseline by group interactions, and interactions between group and sex and group and age were considered for all variables. Data were analyzed using the mixed models procedure in IBM SPSS Statistics (Version 25, IBM Corp., Armonk, NY, United States).

RESULTS

Fidelity Checks

Adherence to intervention participation thresholds was evaluated in terms of educators' completion of the online professional development modules and having engaged children in a minimum of three child activities per week. Engagement with optional program components (i.e., use of formative assessment tool, participation in monthly teleconference calls) was also captured. Educators' engagement in the online professional development was captured via log in and tracking functionality of the professional development modules. Of the 25 intervention centers, 20 services (80%) had at least one educator complete the professional development within the first 3 months of the intervention period (20% of the services had more than one educator complete the professional development during this time). Type and frequency of child activities each month was captured through a custom-designed activity sticker calendar, which was returned monthly to the research team. On average, six of the program's self-regulation activities were facilitated with children each week across the intervention period, ranging from none per week to 22 per week. Further, the charts indicated the suggested diversity of activities was met by most centers in most weeks, and certainly over the duration of the program (by centers who engaged with the child activities).

Use of the formative assessment tool was not required, but educators at 16 of the centers completed the online formative assessment training module and successfully completed inter-rater reliability checks. Seven of these centers reported using the tool, while nine reported they had not yet used the tool. Five centers attempted the online training module but did not achieve the required level of inter-rater reliability and had not yet re-attempted the training. Four centers did not attempt the formative assessment training. Attendance at teleconference calls also was not mandatory, yet all except three centers joined at least one of the monthly teleconference calls (eight centers attended two calls, seven centers attended three calls, four centers attended all calls).

Based on these patterns of participation, 20 services (80%) were deemed to have met or exceeded the minimum threshold of participation (i.e., completed the professional development modules and met the minimum of three child activities per week). Those that did not participate in the program were a result of: preparations for government assessment and rating ($n = 1$); substantial illness, maternity leave or turnover of key staff that precluded participation ($n = 2$); or low- or non-participation for undisclosed reasons ($n = 2$). Two of these five centers did not participate in any program elements. The other three centers did not engage with professional development modules or induction teleconference call yet completed child activities. Overall, there were good levels of adherence to the program, especially amongst those centers without significant sector-imposed impediments to participation.

Intervention Efficacy

The Intra-Class Correlations (ICC) for all outcome measures were small – HTKS ICC = 0.02; PRSIST ICC = 0.08; CSBQ ICC = 0.08; EF ICC = 0.01; Bracken ICC = 0.05 – yet still advocated adjusting for nested data (Hox et al., 2010). Unadjusted and adjusted mean differences between the control and intervention group are shown in **Table 1**. For both the unadjusted analysis (accounting for clustering and baseline results only) and the adjusted analysis (additionally adjusting for sex, age, SES, HLE, ethnicity, and home language) there was a significant effect of the intervention on executive functioning. This result indicated significantly improved executive function in the treatment group, beyond typical age-related change (indexed by the control group), with an unadjusted mean difference of −0.16; a small yet significant effect, that indicated a negative change in the control group that was significantly greater than the positive effect in the treatment group (**Table 1**). Baseline by group interactions were conducted to evaluate whether effects differed by baseline levels of self-regulation but were not significant for any of the models (*p*s ranging from 0.101 to 0.834). Interactions between group and gender to determine whether effects differed by child gender (*p*s ranging from 0.121 to 0.937), and group by

TABLE 1 | Unadjusted and adjusted mean differences (95% CI) between control and treatment groups.

	Control baseline *M (SD)*	Control follow-up *M (SD)*	Treatment baseline *M (SD)*	Treatment follow-up *M (SD)*	Unadjusted mean difference (95%CI)	*P* value	Adjusted mean difference (95% CI)	*P* value	Effect size partial eta squared	*P* Value Group × Sex	*P* Value Group × Age
HTKS	23.06 (24.09)	41.83 (27.45)	21.48 (24.07)	42.87 (26.82)	−2.22 (− 8.16, 3.72)	0.455	−2.10 (− 8.85, 4.65)	0.533	0.003	0.710 (Int) 0.469 (Group)	0.135 (Int) 0.118 (Group)
PRSIST	7.60 (2.26)	8.46 (2.15)	7.66 (2.01)	8.87 (1.97)	−0.39 (− 0.93, 0.15)	0.154	−0.46 (− 1.05, 0.13)	0.138	0.012	0.691 (Int) 0.124 (Group)	0.510 (Int) 0.668 (Group)
SchRd	47.88 (15.55)	58.67 (14.15)	48.08 (16.05)	59.24 (13.57)	−0.39 (− 2.25, 1.47)	0.676	−0.85 (− 2.91, 1.21)	0.412	0.006	0.521 (Int) 0.297 (Group)	0.770 (Int) 0.707 (Group)
CSBQ	0.01 (1.04)	−0.09 (1.00)	0.03 (0.87)	0.07 (1.00)	−0.18 (− 0.42, 0.06)	0.139	−0.17 (− 0.42, 0.08)	0.172	0.005	0.121 (Int) 0.053 (Group)	0.123 (Int) 0.185 (Group)
EF	0.09 (0.791)	−0.06 (0.765)	0.03 (0.72)	0.07 (0.70)	−0.16 (− 0.30, −0.03)	0.017	−0.16 (− 0.31, −0.02)	0.029	0.016	0.937 (Int) 0.113 (Group)	0.581 (Int) 0.732 (Group)

Means and SD at baseline and follow-up represent mean values not accounting for clustering. The unadjusted mean difference accounts for clustering only, without covariates. Adjusted mean difference accounts for clustering and covariates: sex, age, SES category (low, medium or high SEIFA), HLE index, identification as Aboriginal or Torres Strait Islander (Aboriginal or non-Aboriginal), language (English or language other than English) and baseline values. Partial eta-squared is based on an ANCOVA with all covariates. HTKS, Head-Toes-Knees-Shoulders; PRSIST, Preschool Situational Self-Regulation Toolkit Assessment; SchRd, Bracken school readiness assessment; CSBQ, Child Self-Regulation & Behaviour Questionnaire; EF, latent factor scores for combination of Mr Ant, Go/No-Go, and Card Sort assessments. Analyses included n = 217 children in the intervention group and n = 209 children in the control group (except CSBQ, for which an additional six questionnaires for children who were absent for direct assessment, and EF, for which five intervention children and four control children did not complete one EF measure).

age to determine whether effects were conditioned by the child's age (*p*s ranging from 0.123 to 0.770), were not significant for any of the models (**Table 1**). All outcomes were directionally in favor of the intervention group (indicated by a negative unadjusted and adjusted mean difference) but did not reach significance. A table of correlations between all outcome measures is provided at **Table 2**.

DISCUSSION

This program of research sought to design, implement and evaluate a program to support young children's self-regulation development, the product of which was the PRSIST Program. The PRSIST program was developed by reconciling insights from interviews and observations of educators with research-based understandings about the nature, development and change in self-regulation. After pilot and revision of intervention components with educators, the current cluster RCT evaluation of the program over a 6-month intervention period indicated small but significant improvement in EF for the intervention group. All other outcomes (self-regulation, school readiness) also showed descriptively greater improvement for the intervention group, although these changes did not reach significance. In the context of the short intervention period, during which the program was incrementally introduced, implemented and mastered, this pattern of results suggests promise and future enhancements for the PRSIST approach to fostering children's self-regulation in the pre-school context. Fidelity data further demonstrated that educators were willing and able to implement each of the program's components over a sustained period of time.

The small but significant positive effect of this intervention on children's EF – over and above the already rapid development of these abilities in the pre-school years (Anderson and Reidy, 2012) – is consistent with evidence of the ability to support and enhance children's EFs more broadly (Diamond and Lee, 2011), and preliminary evidence in favor of an embedded practice approach more specifically (e.g., Tominey and McClelland, 2011; Howard et al., 2017). The PRSIST Program contrasts more prevalent EF training approaches, which are often constrained to particular ages (typically older children, adolescents, and adults), contexts (individual, commonly requiring professional administration) and resource availabilities (e.g., time, cost). The current approach represents a low-cost and embedded alternative to these approaches that can be applied as a 'menu' of practices, activities and resources to flexibly suit different contexts. That the program's child activities involve real-world application of cognitive, behavioral and social-emotional control, rather than the targeted training of individual EFs specifically (e.g., through practicing computerized EF tasks; Blakey and Carroll, 2015), minimizes the possibility that improvements are an artifact of task-based learning (Shipstead et al., 2012).

While the primary outcome for the evaluation was child self-regulation, and there was a descriptively greater improvement in self-regulation in the intervention group for all indices, results for this outcome were non-significant. This contrasts

TABLE 2 | Correlations between outcome measures at baseline.

		1	2	3	4	5	6	7	8	9
1	HTKS	–	0.41*	0.31*	0.32*	0.17*	0.35*	0.31*	0.42*	0.52*
2	PRSIST Assessment		–	0.35*	0.41*	0.31*	0.43*	0.37*	0.29*	0.39*
3	CSBQ – Cog. SR			–	0.63*	0.46*	0.30*	0.34*	0.25*	0.40*
4	CSBQ – Behav. SR				–	0.66*	0.28*	0.39*	0.16*	0.28*
5	CSBQ – Emo. SR					–	0.12*	0.20*	0.07	0.12*
6	EYT Mr Ant (WM)						–	0.30*	0.28*	0.38*
7	EYT Go/No-Go (Inhibition)							–	0.16*	0.27*
8	EYT Card Sort (Shifting)								–	0.42*
9	Bracken School Readiness									–

HTKS, Head-Toes-Knees-Shoulders task; CSBQ, Child Self-Regulation & Behaviour Questionnaire; SR, self-regulation; EYT, Early Years Toolbox; WM, working memory.
$^*p < 0.05$.

other curricular approaches, which have successfully achieved improvements in indices of self-regulation after similar or longer intervention periods (Pandey et al., 2018). There was also a lack of significant improvement in academic knowledge, as an indicator of school readiness. While some studies have shown significant improvement in self-regulation and academic outcomes after intervention (Schmitt et al., 2015; Pandey et al., 2018), others found these outcomes difficult to shift over and above the rapid age-related change already occurring during the pre-school years (e.g., Tominey and McClelland, 2011).

In relation to the PRSIST Program, there are a number of possible explanations for this result. First, given self-regulation develops rapidly in the pre-school years (Montroy et al., 2016), the program may have been insufficient in intensity (e.g., minimum of only three child activities per week, lack of checks that child activities were modified to increase challenge as children improved in competency) and/or breadth (e.g., focus on fostering self-regulation during times of good regulation, with less emphasis on episodes of dysregulation) to outpace this typical developmental trajectory. Indeed, curricular approaches tend to involve more comprehensive and structured programs (e.g., Tools of the Mind), and/or provide more intensive supports (e.g., CSRP), in contrast to the PRSIST approach of providing practices and activities to complement current programing and curricula. While it is possible that the lack of consistent effects was related to insufficient program intensity or breadth, this does not articulate well with significant improvement in EF – cognitive capacities underpinning self-regulation – which also develops rapidly over the course of the pre-school years (Anderson and Reidy, 2012).

Second, it is possible that insufficient quality of implementation generated an estimate of program effectiveness (i.e., when implemented at scale), rather than efficacy (i.e., under the most rigorous and controlled conditions). This was an explicit decision from the outset of this study, given the goal of identifying low-cost, accessible and sustainable approaches that can be employed by pre-school educators. While it might be the case that effects would be more pronounced if the program were implemented with fidelity by members of the research team visiting centers, this would render the approach expensive and difficult to scale. A compromise between these options, however, could involve mentoring and coaching, which may expedite and strengthen educators' self-efficacy and fidelity in implementation. Indeed, there is ample evidence for the effectiveness of mentoring and coaching when attempting to influence the practices of the current educator workforce (Lambert et al., 2015), and this form of induction is a common feature of other curricular approaches (Barnett et al., 2008; McClelland et al., 2019). However, further research is needed to evaluate whether similar benefits would confer if applied to the PRSIST Program.

Third, it may be the case that children require greater duration and intensity of exposure to the program's components to detect a self-regulation effect (Diamond and Lee, 2011). In the current study, children in participating centers attended their service an average of 3 days/week (consistent with national enrollment patterns), limiting their opportunities for participation in the program. This was exacerbated by high levels of staff turnover that characterize this sector. Further, the program was incrementally introduced over the 6-month intervention period: i.e., the first month focused on completion of online professional development; the second month on child activities; the third month on formative assessment; and the fourth month on increasing challenge in the child activities. As such, educators' implementation and mastery of program components was likely incomplete until at least halfway through the 6-month intervention. It may thus be that children who receive longer and more frequent exposure to the program could achieve greater and clinically significant improvements in self-regulation. In the current instantiation, effects were limited to EF and are best characterized as small. Further research is required to evaluate a dose-response effect. There is also potential for latent effects in measured and unmeasured variables, which take time to manifest (c.f., Duncan et al., 2018). Examples may include adjustment and peer relationships upon school entry, and later academic learning following time to exert newly acquired proficiencies and capacities (e.g., EF). Longitudinal follow-up is planned to explore this possibility.

Inability to conclusively and exclusively provide evidence for one of these possibilities, however, highlights limitations within the current study. That is, although the evaluation was rigorously designed and executed according to CONSORT guidelines, funding considerations limited the roll-out and intervention period to only 6 months. It is possible that a full year of program implementation would yield stronger program effects (see, for example, Schachter, 2015). It is also possible that program effects would be strengthened with stricter adherence to high-quality program implementation. While fidelity data indicate good compliance in the frequency and timing of program elements, data are insufficient to evaluate the integrity with which program elements were implemented. While in-person or video fidelity checks were not possible in the current study, this would help monitor adherence. As a researcher-implemented model of delivery would violate our aspiration for a low-cost and barrier-free resource for educators, a plausible middle ground might be a coaching model that supports educators in implementation and adaptation of the program in their context. Lastly, the program was designed with the intention to foster self-regulation in all children, and thus did not focus on instances of dysregulation. However, it is clear that child dysregulation remains a significant concern for educators (Neilsen-Hewett et al., 2019), and future iterations of the program would do well to more explicitly provide support for these children. In guiding such an expansion of the program, there is evidence that children with frequent and severe dysregulation require a different approach to fostering self-regulation, as demonstrated successfully in trauma-informed practice approaches (Holmes et al., 2015). Future studies would also do well to consider implications of differing educator qualifications and experience, whereby different types and levels of support may be needed at varying levels of behavior challenges and educators' skills to address these.

This study provides preliminary support for some acute benefits of the PRSIST Program, in terms of improving children's EF, as well as identifies opportunities for further development of the program (e.g., further and differing approaches/supports for children experiencing high frequency or severity of dysregulation; evaluating additional benefits of educator coaching). The specific promise of this approach is further highlighted by its compatibility with pre-school contexts and routines. The flexibility of the program permitted educators to engage with online professional learning at their convenience, implement adult practices aligned to their specific needs, and select and scale child activities that were best enjoyed by children in their center. Acceptability of the program was evidenced by high levels of educator adherence to minimum program requirements – often exceeding these requirements – and, in cases where centers did not engage with the program, this was due to known sector-related issues (statutory rating, staff absence/turnover). The PRSIST Program is not intended to be a complete collection of practices and activities that could support children's self-regulation, but rather serves as a stimulus from which educators can expand these options. The accessibility and acceptability of the current approach creates a unique opportunity for embedded practices that yield benefits for young children, including those in less-advantaged contexts that are often most in need of support (Diamond and Lee, 2011; Diamond, 2013).

DATA AVAILABILITY STATEMENT

The dataset for this manuscript is not publicly available because ethics approval was not sought or granted for such use. Requests to access the dataset should be directed to SH at stevenh@uow.edu.au.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the University of Wollongong, Human Research Ethics Committee – Social Sciences. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

SH conceptualized the study, secured funding for the study, designed the child activity aspects of the intervention, oversaw data collection, was involved in data analysis, and led writing of the manuscript. EV aided in conceptualizing the study and design of the intervention, managed data collection and entry, and contributed to drafting of the manuscript. MB contributed to evaluation design and planning, led data analysis, and contributed to drafting the manuscript. CN-H led the pedagogical aspects of intervention design and delivery and contributed to drafting of the manuscript.

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Empowering Executive Functions in 5- and 6-Year-Old Typically Developing Children Through Educational Robotics: An RCT Study

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Educational Robotics (ER) is a new learning approach that is known mainly for its effects on scientific academic subjects such as science, technology, engineering, and mathematics. Recent studies indicate that ER can also affect cognitive development by improving critical reasoning and planning skills. This study aimed to quantify the ability of ER to empower Executive Functions (EF), including the ability to control, update, and program information, in 5- and 6-year-old children attending first grade, a crucial evolutionary window for the development of such abilities. A total of 187 typically developing children were enrolled and randomly allocated into two experimental conditions: A, for immediate ER training, and B, for waitlist. ER-Laboratories (ER-Lab) for small groups were organized at schools, using a child-friendly, bee-shaped robot called Bee-Bot® (Campus Store). Activities were intensive, enjoyable, and progressively more challenging over the 20 twice-weekly sessions. Outcome measures, based on standardized tests, were used to quantify the effects of ER on EF. Compared to the control group, the ER-Lab group showed significantly better ability to actively manipulate information in short-term memory and suppress automatic responses in favor of goal-appropriate actions. This RCT study provides the first quantitative evidence of the positive effects of ER activities for improving working memory and inhibition in the early school years.

Keywords: educational robotics, executive functions, response inhibition, working memory, children

INTRODUCTION

Educational Robotics (ER) refers to a learning approach requiring students to design, assemble, and program robots through play and hands-on activities. ER was developed in the 60 s through the integration of psycho-pedagogical cognitive development theories (Piaget and Inhelder, 1966; Papert, 1980) and social learning theories (Vygotsky, 1978; Bandura, 1986). ER creates a learning environment where students can simultaneously interact with peers and robots. Most ER studies conducted in schools have focused on examining the impact of ER activities on the "STEM" areas (Science, Technology, Engineering, and Mathematics), with particular focus on robot design and assembly (Hussain et al., 2006; Barker and Ansorge, 2007; Nugent et al., 2008, 2010). Other studies have examined using ER as an assistive device for improving motor and social-communication problems (Krebs et al., 2012; Vanderborght et al., 2012; Srinivasan et al., 2016). Recent studies have assessed the effects of robot programming on cognitive and learning processes, such as auto-monitoring, attention, decision-making, problem-solving, and computational thinking (Highfield, 2010; La Paglia et al., 2011; Kazakoff and Bers, 2014). Nevertheless, most of the studies lacked experimental designs or quantitative outcome measures; thus, it is still unclear which cognitive functions may be significantly improved through ER during childhood (Benitti, 2012; Alimisis, 2013).

Recently, we conducted a pilot study to measure how ER can improve cognitive and learning abilities in preschool children (Di Lieto et al., 2017). An intensive laboratory [ER-Laboratories (ER-Lab)] was conducted for 6 weeks using a bee-shaped robot, called Bee-Bot®, incrementally introducing more difficult robot programming activities. The children were assessed with standardized tests, and the results showed that ER-Lab activities promoted some superior cognitive functions, such as Executive Functions (EFs). Robot programming requires children to mentally plan a complex sequence of actions before the motor act: first the child had to set the target or targets to reach, then to plan the sequential steps needed to arrive at the target, and finally, at the end of the programming, to act and verify his or her behavior. Several complex superior cognitive functions are involved in this type of task, such as abstraction and logical reasoning, decision-making, sequential thinking, maintaining and updating information in memory, and problem-solving, all functions that concern the EFs cognitive domain. There is agreement in the literature that EFs represent a group of top-down processes that are important for adaptive and goal-directed behavior (Miyake et al., 2000; Lehto et al., 2003). However, several controversies exist regarding defining and differentiating separable EF components during the course of development because we now recognize the internal complexity of each factor and the unity and diversity of the different EF components (Miyake et al., 2000; Howard et al., 2014; Friedman and Miyake, 2017; Karr et al., 2018; Morra et al., 2018). Within a developmental perspective, the model proposed by Diamond (2013) is largely used. This model consists of three main EF factors: inhibition, working memory, and cognitive flexibility, which are strongly related to more complex EFs, such as reasoning, planning, and problem-solving. Following Diamond's definitions, inhibition represents a complex construct theorized as a set of functions rather than as a unitary construct, distinguishing response inhibition at the behavior level from interference control at the memory, thoughts, and attention levels; working memory involves holding visual or verbal information in mind and mentally working with it; and cognitive flexibility is the ability to efficiently change spatial and interpersonal perspectives.

Executive Functions develops over time and are completed during late adolescence (Garon et al., 2008). Pre-school and primary school are critical times for EFs maturation and are linked to attaining academic milestones (Diamond, 2013). EF development consists of both quantitative and qualitative changes. Some studies suggest that, in toddlers, there is an undifferentiated executive control factor, while a two-factor model consisting of inhibition and working memory emerges between 3 and 5 years (Miller et al., 2012). Another two-factor model where inhibition is distinguished from working memory and shifting (which partially resembles the cognitive flexibility component of Diamond's model) has been identified in 5- and 6-year-old children, followed by the emergence of a separate three-factor structure later in development (Usai et al., 2014). However, these trajectories are not universally supported, and results from a recent systematic review (Karr et al., 2018) show that no model consistently converges across samples but that there is evidence for greater EFs unidimensionality among child/adolescent samples. Disentangling the various hypotheses on the developmental EFs structure is beyond the purpose of the present study, but the types of tasks and tests used in the different studies may have contributed to the high variability of the results (Miller et al., 2012). Both the EF models and the measures used could affect the methodological choices and results obtained in intervention studies on enhancing EF development (Diamond and Lee, 2011).

Most previous studies that are focused on improving EFs during development differ from those focused on clarifying EFs structure and ways of measuring the different EF components; nevertheless, some general principles useful for intervention studies have been developed. In particular, recent studies suggest that EFs can be trained, and, to obtain significant changes, the training needs to: (1) create incrementally more challenging activities based on adaptive and intensive paradigms, as demonstrated by studies on home-based software (Thorell et al., 2009), (2) be administered over long training phases, especially for very young participants, (3) continuously monitor participation levels (Wass, 2015; Diamond and Ling, 2016), (4) constantly challenge EFs to produce improvements (Diamond and Ling, 2016), (5) provide different and heterogeneous training tasks serving the same purpose (Rueda et al., 2005; Wass et al., 2011) or targeting similar cognitive mechanisms (Klingberg et al., 2005), and (6) plan enjoyable and social activities because benefits will be greater if emotional, social, and physical needs are also addressed (Diamond and Ling, 2016).

According to the principles listed above, this study, which is part of a wider research project called "e-Rob," aimed to enhance EFs in first-grade children through in-school ER-Lab by means of enjoyable, intensive, and incrementally more challenging activities requiring students to program a bee-shaped robot called Bee-Bot® (Campus Store). Based on a previous pilot study on a small sample of preschoolers, the present research aimed to bring further evidence to the hypothesis that ER-Lab may induce positive effects in visuospatial working memory and inhibition during a critical period of development.

MATERIALS AND METHODS

Participants

A total of 187 typically developing first-graders (90 females, 97 males; age range from 5 years and 6 months to 6 years and 8 months) were selected to participate in ER-Lab. Enrollment was conducted in collaboration with the District of Pisa to contact as many schools as possible. Thirteen classes from nine schools were enrolled, from which 187 children with typical development and 42 children with special needs were selected. To comply with the aims of this study, only data collected from typically developing children are reported and discussed (see **Table 1** for details on the number of children and teachers involved in each class).

This research project was approved by the Pediatric Ethics Committee of the Tuscany Region. All parents gave written consent for their child's participation and for publication of the results.

ER-Lab Training

ER-Lab was conducted twice a week for 10 weeks (20 ER training sessions of 60 min) using the Bee-Bot robot (Bee-Bot®, Campus Store). The design of Bee-Bot is child-friendly, with a black/yellow bee shape, sounds, and lights that make it very attractive for children (**Figure 1A**). The Bee-Bot can be programmed with up to 40 instructions in a single program using buttons on its back to program motion or rotation. Four orange buttons move the robot either forward or backward (15 cm) and rotate it right or left (90° rotation); a central green button (GO button) starts the programmed sequence; a blue button clears the memory (CLEAR or X); and another blue button programs a short pause during robot motion (PAUSE or II). The user cannot modify the length of steps or degree of angular rotation. At the end of the programmed sequence, Bee-Bot provides visual and acoustic feedback. To guide robot programming and sustain motivation, different colorful carpets, characterized by a 15 × 15 cm matrix, were provided (**Figure 1B**).

TABLE 1 | Number of children and teachers involved in each school and class.

School	Class	Number of enrolled teachers	Number of enrolled typically developing children
School 1	Class 1	2	12
	Class 2	2	11
School 2	Class 3	2	23
School 3	Class 4	4	15
School 4	Class 5	2	15
	Class 6	2	11
	Class 7	2	11
School 5	Class 8	2	16
School 6	Class 9	2	17
	Class 10	2	18
School 7	Class 11	2	7
School 8	Class 12	2	20
School 9	Class 13	2	11
TOTAL		28	187

Small groups of five or six children were formed for each ER-Lab; each group had two Bee-Bots and a carpet. Two teachers and one experimenter in each class guided and participated in the ER-Lab. Different narrative contexts were presented in each activity to maintain high motivation and stimulate attention, teamwork, and collaboration among peers.

Following an adaptive paradigm, progressively more difficult activities were planned by experimenters and proposed to the classes to promote more complex competences in terms of cognitive and robot programming goals. Each week, specific cognitive and robot programming goals were proposed for the two ER-Lab sessions with Bee-Bot. Moreover, additional and optional activities with Bee-Bot were provided weekly, developed to reach the specific goals. The first 2 weeks focused on becoming familiar with the robot and improving simple visuospatial planning, the third and fourth weeks addressed complex visuospatial planning to increase working memory load through robot use, the fifth and sixth weeks focused on improving working memory abilities in response to inhibition tasks through robot use, the seventh and eighth weeks were directed at inhibiting automatic responses in set-shifting or task-switching conditions through robot use, and the ninth and tenth weeks were dedicated to using robotic programming to enhance academic skills. Details of cognitive and robot programming goals and examples of activities provided for each ER-Lab week are reported in the **Supplementary Materials**. Concurrently, a metacognitive approach was encouraged during ER-Lab activities, which included mentally planning complex sequences of actions before a motor act in a group context, sequential reasoning, and the ability to formulate feedback among peers. This approach promotes a problem-solving strategy based on "think before acting." The ER-lab activities were incrementally more challenging and directed mainly toward visuospatial planning, response inhibition, working memory, and cognitive flexibility.

Study Design

According to the waitlist randomized trial design, children were randomly split into two groups (experimental condition A, $n = 96$, and experimental condition B, $n = 91$) for the sequential training rollout. Both experimental conditions were assessed by neuropsychological tests (for details, see section "Outcome Measures") at time point T0 (September 2016). After evaluation, only children in experimental condition A started ER-Lab training immediately while those in experimental condition B continued their normal academic program. After 10 weeks, all children (experimental condition A and B) were re-tested at time point T1 (January 2017). After the T1 assessment, experimental condition B started ER-Lab training, while experimental condition A continued the normal academic program. After another 10 weeks, all children were retested at time point T2 (May 2017) (see **Figure 2** for the Study Flow Diagram). The evaluators tested children at the three time points and recorded the data, and separate examiners collected and entered data in a database. The evaluators and

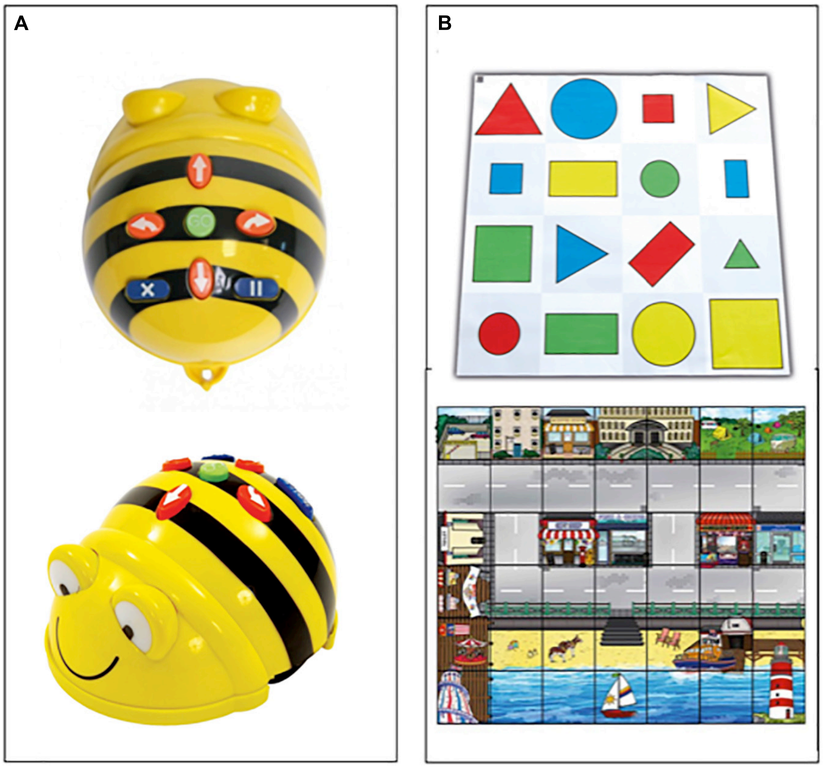

FIGURE 1 | (A) The Bee-Bot and **(B)** some examples of colorful carpets.

examiners were blind to the study design and external to the research team.

Outcome Measures

At each time point, children were assessed by standardized neuropsychological tests and qualitative measures of robotic programming skills. More than one test for each EF component of interest was selected to limit "task-impurity" that may have larger effects when only one measure is used. For visuospatial working memory, we chose Corsi Block Tapping and Matrix Path tests that require maintaining and updating information organized in a visual matrix and thus, are similar to planning robot navigation on carpets organized in a 15 × 15 matrix. While Corsi Block Tapping measures the maintenance of a global pattern in visual working memory, Matrix Path forces step-by-step information updating, thus loading working memory processes more than Corsi. Both Corsi Block Tapping and the Matrix Path test have been extensively reported in the literature and satisfy psychometric proprieties, including construct validity (Mammarella et al., 2008). Within the inhibition domain, we chose three tests, Inhibition, Little Frogs, and Pippo Says, that focus on response inhibition, rather than interference control, because the ER-Lab activities require children to inhibit automatic responses across different verbal domains (measured mainly by the Inhibition test), visual-motor domains (Little Frogs test), and motor domains (Pippo Says test). Raw scores were collected for each quantitative or qualitative measure of the administered subtests.

Visuospatial Memory

(1) Forward Corsi Block Tapping subtest (BVS test). This test assesses the child's visuospatial memory amplitude (called "span") by evaluating the longest visuospatial sequence the child can remember. The visuospatial sequence is represented by a sequence of blocks positioned on a plastic board that the examiner touches and the child has to touch in the same order. The longest sequence of blocks correctly repeated represents the obtained span and serves as the final test score. The subtest's validity and reliability ($r = 0.60$) are reported in the BVS-Corsi manual (Mammarella et al., 2008).

Executive Functions

Visuospatial working memory

(1) Backward Corsi Block Tapping subtest (BVS test). This test is similar to the preceding test but assesses visuospatial working memory abilities by asking the child to both maintain and elaborate the visuospatial information. The child has to touch the blocks in the reverse order of the examiner's touches, starting with the last block and ending with the first. The longest sequence of blocks correctly repeated in the reverse order represents the obtained backward span and represents the final score. The subtest's

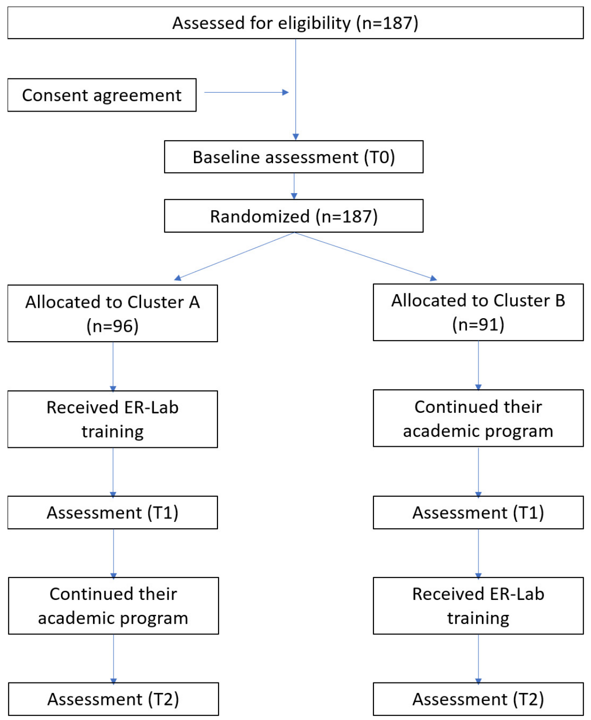

FIGURE 2 | Flow diagram of the study.

validity and reliability (r = 0.74) are reported in the BVS manual (Mammarella et al., 2008).

(2) Matrix Path (BVS-Corsi). This test assesses the ability to update visuospatial information based on verbal commands held in short-term memory. The child is asked to indicate in a matrix the final destination reached following a sequence of progressively longer steps read by the examiner. The final score is the sum of correct responses. The subtest's validity and reliability (Cronbach's α = 0.85) are reported in the BVS-Corsi manual (Mammarella et al., 2008).

Prepotent response inhibition and interference control

(1) The Inhibition subtest (NEPSY-II test) has two conditions: the control (naming) condition in which the child denominates a sequence of two alternating figures and the inhibition condition, where the child denominates the two figures exchanging the label (for example, he has to say "circle" when he sees a square and vice versa). By evaluating the number of errors, self-correcting responses, and time for each condition, this test measures the ability to inhibit automatic verbal responses. The subtest's validity and reliability (Pearson r coefficients ranged from 0.21 to 0.91 across all aged groups) are reported in the NEPSY-II clinical and interpretive manual (Korkman et al., 2007; Urgesi and Fabbro, 2011).

(2) In the Little Frogs subtest (BIA), the child marks steps on a small staircase drawn on a paper every time he or she hears the word "go" but must stop as soon as he or she hears the word "no-go." The score is the number of correct responses. This test primarily evaluates visual-motor response inhibition in the context of selective and sustained attention. The subtest's validity and reliability (percentage agreement 78%) are referred to the "Walk, don't walk" test included in the Test of Everyday Attention for Children, as mentioned in the BIA manual (Marzocchi et al., 2010).

(3) The Pippo-Says test (a modified version of Simon-Says) is composed of two conditions: in the first, the child is instructed to do a body action only when Pippo gives the command, and thus the phrase starts with "Pippo says"; in the second condition the examiner performs all the commands in front of the child regardless of whether "Pippo says," resulting in increased interference. The score is the number of correct responses. This test measures motor inhibition and interference control and the ability to switch between two task conditions (cognitive flexibility). The statistical characteristics and reliability (kappas > 0.90) of the test are reported by Marshall and Drew (2014).

ER-Lab Test

To assess improvements in Bee-Bot programming skills, we used a test created in our previous pilot study (Di Lieto et al., 2017). The test comprises nine tasks divided into three clusters: (1) Bee programming (tasks one to five) assesses Bee-Bot use knowledge, (2) mental anticipation (tasks six to eight) assesses the ability to plan complex visuospatial pathways using Bee-Bot, and (3) inhibition (task nine) assesses the inhibition abilities elicited by Bee-Bot use (**Figure 3**).

Children were asked to perform the nine tasks at the beginning, after 5 weeks, and at the end of ER-Lab training. For each task, zero points were awarded if the child failed to reach the final goal, a half-point was awarded if concrete help (such as anticipating correct navigation by using their own hand or the Bee-Bot) was used to reach the goal, and one point was awarded if no concrete help was necessary.

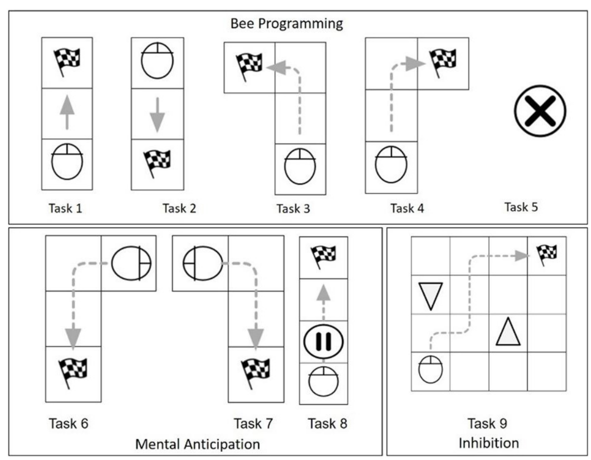

FIGURE 3 | ER-Lab test.

Statistical Analysis

Statistical analyses were performed using R, the R Project for Statistical Computing software package, version 3.6.0, with a significance level of 5%.

The effect of the training was tested by separate linear mixed-effects models for each outcome measure, with ER-Lab training and experimental condition (A or B) as fixed factors and subject ID as a random factor, in a repeated measures design. Simultaneous tests for general linear hypotheses were used to test the following two *post hoc* contrast variables for determining neuropsychological differences during ER-Lab training under both experimental conditions:

- Training effect, calculated by adding delta changes for time points T1 and T0 for experimental condition A and delta changes for time points T2 and T1 for experimental condition B
- Within-baseline effect, calculated by adding baseline delta changes in experimental condition B (T1-T0 for experimental condition B) and follow-up in experimental condition A (T2-T1 for experimental condition A).

Effect size (Cohen's *d*) was calculated compared pre- and post-training performances in each outcome measure in both experimental conditions.

Repeated measure ANOVAs, with *post hoc* Bonferroni corrections, were performed to test differences in ER-Lab tests at the beginning, middle, and end training sessions.

A *post hoc* correlation analysis was performed between the training effect (delta changes for T1–T0 for experimental condition A and for T2–T1 for experimental condition B) in the outcome measures that showed significant improvement after the training; the delta changes in each ER-Lab test cluster (first three sessions/last three sessions) were checked by Spearman rho non-parametric tests for bivariate correlations.

RESULTS

Descriptive statistics for time points T0, T1, and T2 for each neuropsychological outcome are reported in **Table 2**.

Differences Between Experimental Conditions at Baseline

Experimental conditions A and B did not differ on chronological age ($t(185) = 1.37$, ns) or gender ($\chi^2(1) = 0.12$, ns). No significant differences in any neuropsychological outcome measures were found between the two experimental conditions at T0.

Effect of ER-Lab Training on EF

As shown in **Table 3**, improved performance at the end of training was found in the Matrix Path test, in time, errors, and self-correcting responses in the naming and inhibition conditions, and in the Little Frogs test. As showed in **Table 4**, a moderate effect size was found in Matrix Path, Self-correcting responses in naming condition, Time in Inhibition condition and Little Frogs tests. A large effect was found in Time in naming condition test. No statistical differences emerged in the Forward and Backward Corsi Block Tapping and Pippo Says tests.

For the ER-Lab tests (**Figure 4**), experimental condition A showed a positive learning trend in the Bee programming cluster ($F(2,172) = 118.6$, $p < 0.001$), with performances significantly higher at the end of ER-Lab training with respect to both the beginning ($t(88) = -13.5$; $p < 0.001$) and middle ($t(87) = -6.6$, $p < 0.001$) sessions. Positive trends were also found in the mental anticipation cluster ($F(2,174) = 437.4$, $p < 0.001$), with significant benefits of training evident at the end with respect to the beginning ($t(89) = -28.3$, $p < 0.001$) and middle ($t(88) = -9.7$, $p < 0.001$) sessions. As in previous clusters, inhibition cluster performances significantly improved during ER-Lab training ($F(2,168) = 89.0$, $p < 0.001$), with higher scores at the end compared to the beginning ($t(89) = -12.4$, $p < 0.001$) and middle ($t(84) = -2.2$, $p = 0.03$) sessions. Similar results were found in ER-Lab test performances in experimental condition B. A positive learning trend emerged in the Bee programming ($F(2,168) = 139.09$, $p < 0.001$), mental anticipation ($F(2,168) = 452.34$, $p < 0.001$) and inhibition ($F(2,174) = 306.39$, $p < 0.001$) clusters, with performances significantly higher at the end of ER-Lab training compared to both the beginning ($p < 0.001$) and middle ($p < 0.001$) sessions in all clusters.

Post hoc correlation analysis showed a negative correlation between the mental anticipation cluster and the training effect for the delta changes in self-correcting responses in the naming condition (rho = 0.15, $p = 0.02$). No other significant correlations were found.

DISCUSSION

The main findings of this study suggest that intensive, enjoyable, and challenging ER activities presented with incremental difficulty of cognitive and robot programming goals can improve visuospatial working memory and inhibition processes in young typically developing children.

Our results were consistent with previous qualitative studies (Benitti, 2012; Alimisis, 2013); however, this is the first study to demonstrate quantitative positive effects of ER activities using a rigorous and scientific approach. Post ER-Lab, performance in assessed ability to actively manipulate relevant information in visuospatial working memory and suppress an automatic response in favor of a goal-appropriate action improved significantly compared to the control condition.

The assessments showing significant improvement included the Matrix Path test, which measures enhanced visuospatial working memory abilities, the number of correct responses in the Little Frogs test, and improved time, errors, and self-correcting responses in the inhibition test. However, not all measures showed significant ER-Lab effects: no significant changes were found in Corsi Block Tapping or the Pippo Says test.

These differences are not easily interpretable, because they might result from several factors, such as EFs task impurity, the EFs structure model, suitability for first-grade children, and the construct validity of each measure. Nevertheless, some hypotheses may be advanced: within

TABLE 2 | Mean and standard deviation on T0, T1, and T2 time points for each neuropsychological outcome in experimental conditions A and B.

Neuropsychological outcome	Experimental condition	T0 Mean ± SD	T1 Mean ± SD	T2 Mean ± SD
Forward Corsi Block Tapping test	A	3.03 ± 0.75	3.60 ± 0.84	3.77 ± 0.73
	B	3.08 ± 0.79	3.63 ± 0.68	3.76 ± 0.70
Backward Corsi Block Tapping test	A	2.09 ± 0.80	2.78 ± 0.88	2.96 ± 0.88
	B	2.24 ± 0.90	2.49 ± 0.79	2.95 ± 0.95
Matrix Path test	A	4.89 ± 4.20	8.42 ± 5.21	10.53 ± 5.60
	B	4.12 ± 3.60	6.57 ± 4.24	8.85 ± 4.53
Time in naming condition	A	94.01 ± 23.07	70.74 ± 13.66	63.25 ± 11.17
	B	92.98 ± 20.42	72.44 ± 15.12	64.81 ± 11.45
Errors in naming condition	A	2.00 ± 2.30	1.11 ± 2.34	0.98 ± 1.31
	B	1.44 ± 1.94	1.08 ± 1.54	0.86 ± 1.29
Self-correcting responses in naming condition	A	2.69 ± 2.12	1.20 ± 1.37	1.03 ± 1.24
	B	2.35 ± 1.95	1.49 ± 1.43	1.34 ± 1.47
Time in inhibition condition	A	126.29 ± 29.11	98.69 ± 22.22	88.49 ± 17.35
	B	130.71 ± 28.68	102.74 ± 22.15	91.54 ± 17.21
Errors in inhibition condition	A	6.75 ± 6.41	3.46 ± 4.12	2.68 ± 3.33
	B	4.70 ± 4.53	2.79 ± 3.58	1.88 ± 2.16
Self-correcting responses in inhibition condition	A	4.70 ± 2.83	3.32 ± 2.73	3.40 ± 3.10
	B	4.52 ± 2.53	3.25 ± 2.69	3.42 ± 2.47
Little Frogs test	A	9.72 ± 5.51	13.96 ± 4.53	14.38 ± 3.84
	B	9.64 ± 4.92	12.04 ± 4.95	14.65 ± 4.23
Pippo Says test	A	7.22 ± 2.06	8.39 ± 1.69	8.64 ± 1.45
	B	7.19 ± 2.10	8.27 ± 1.66	8.89 ± 1.56

Legend: T0 represents pre-training assessment in experimental condition A and baseline assessment in experimental condition B; T1 represents post-training assessment in experimental condition A and pre-training assessment in experimental condition B; T2 represents follow-up assessment in experimental condition A and post-training assessment in experimental condition B.

TABLE 3 | Results of mixed-effects model and *post hoc* comparisons on delta changes in all children.

Neuropsychological outcome	Within-baseline effect⁺	*Post hoc* comparison	Training Effect®	*Post hoc* comparison
	Estimated mean (CI)	*p*	Estimated mean (CI)	*p*
Forward Corsi Block Tapping test	0.05 (– 1.03, 1.13)	0.992	−1.03 (– 2.55, 0.49)	0.211
Backward Corsi Block Tapping test	−1.29 (– 2.54, −0.03)	0.044*	1.61 (– 0.15, 3.37)	0.075
Matrix Path test	0.36 (– 6.55, 5.83)	0.985	10.29 (– 1.60, 18.99)	0.017*
Time in naming condition	1.51 (– 16.78, 19.81)	0.971	−180.08 (– 205.86, −154.30)	0.001*
Errors in naming condition	2.00 (– 1.02, 5.03)	0.221	−6.94 (– 11.18, −2.71)	0.001*
Self-correcting responses in naming condition	2.07 (– 0.32, 4.46)	0.096	−9.58 (– 12.94, −6.22)	0.001*
Time in inhibition condition	−16.26 (– 41.66, 9.14)	0.245	−212.83 (– 248.63, −177.036)	0.001*
Errors in inhibition condition	5.42 (– 0.76, 11.60)	0.091	−23.63 (– 32.29, −14.96)	0.001*
Self-correcting responses in inhibition condition	−0.57 (– 3.59, 4.73)	0.912	−9.23 (– 15.06, −3.40)	0.001*
Little Frogs test	−4.91 (– 10.99, 1.18)	0.125	8.78 (0.23, 17.33)	0.043*
Pippo Says test	0.07 (– 2.32, 2.47)	0.997	−3.31 (– 6.68, 0.06)	0.055

*Legend: ⁺Within-baseline effect, differences during normal academic program in both experimental conditions, calculated by adding delta changes at baseline in experimental condition B (T1–T0 for experimental condition B) and in follow-up in experimental condition A (T2–T1 for experimental condition A); ® Training Effect, differences during e-Rob training in both experimental conditions, calculated by adding delta changes for time points T1 and T0 for experimental condition A and delta changes for time points T2 and T1 for experimental condition B; * statistical significant differences ($p < 0.05$).*

the working memory domain, robot programming requires active manipulation of sequential overt and covert verbal instructions and integrating them with visuospatial updates based on the robot's position. Therefore, it is plausible that this type of exercise may result in better performance in a test such as Matrix Path that requires online integration and updating of verbal-visual information. Although the Corsi Block tests may also be solved by global visual perception strategies that mentally link the target blocks, Matrix Path seems to require step-by-step processing and may therefore be more affected by training that involves updating of the working memory. Thus, ER-Lab seems to affect the ability to

TABLE 4 | Effect size values (Cohen's *d*) in each outcome measure in both experimental conditions.

Neuropsychological outcomes	Cohen's *d*
Forward Corsi Block Tapping test	0.46
Backward Corsi Block Tapping test	0.65
Matrix Path test	0.63
Time in naming condition	0.80
Errors in naming condition	0.28
Self-correcting responses in naming condition	0.50
Time in inhibition condition	0.77
Errors in inhibition condition	0.43
Self-correcting responses in inhibition condition	0.23
Little Frogs test	0.69
Pippo Says test	0.49

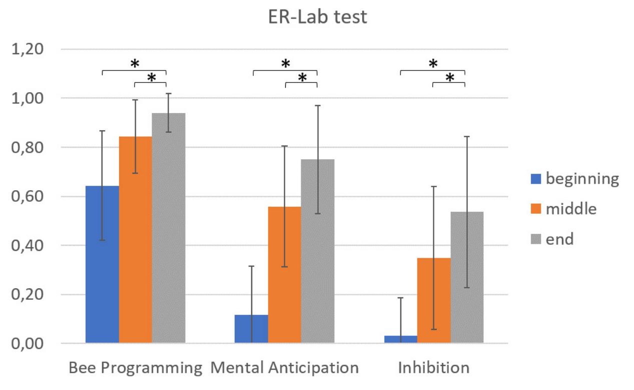

FIGURE 4 | Visual representation and significant differences (*$p < 0.05$) across ER-Lab test perfomances in the beginning, middle and end sessions.

construct a mental visuospatial model from verbal input and then operate on it.

Moreover, during ER-Lab activities, children had to reach a predetermined goal by planning and providing the correct commands to Bee-Bot while simultaneously respecting the rules and waiting for their turn. Therefore, ER-Lab tasks may have favored the ability to inhibit motor responses, as measured by the Little Frogs test, and control cognition and attention interference, as measured by the Inhibition test, which showed that a decreased number of self-correcting responses in a naming task was significantly related to increased ability to plan complex visuospatial pathways with Bee-Bot. It may be that the Little Frogs and Inhibition tests differ from the Pippo Says test, which showed no training effect, in that they require more child autonomy in selective and sustained attention. Consistent with this hypothesis, a ceiling effect was found in the easier condition of the Pippo Says task at the pre-training assessment.

These findings, in part, confirm the results of our previous study (Di Lieto et al., 2017, 2019), which showed improved performance in visuospatial working memory and inhibition, and are also consistent with recent literature on EF interventions in childhood showing that increasingly challenging working memory and inhibition exercises are crucial for cognitive development (Diamond and Lee, 2011; Wass et al., 2012; Wass, 2015; Spencer-Smith and Klingberg, 2016). Moreover, these two EF components are often impaired in neurodevelopmental disorders such as attention deficit with hyperactivity disorder (De La Fuente et al., 2013), specific learning disabilities (Kudo et al., 2015), autism spectrum disorders (Chen et al., 2016), and cerebral palsy (Bottcher et al., 2009). They are called "tools for learning" because they may represent early developing cross-modal basic processes that affect subsequent development of superior cognitive functions (Wass et al., 2012) and academic skill acquisition (Bull and Scerif, 2001; Blair and Razza, 2007; Van de Weijer-Bergsma et al., 2015).

This study has some limitations: first, EF tests were chosen according to the type of training used rather than specific cognitive theory; thus, the findings do not reference or link to a single theoretical framework. Moreover, the complexity of the EFs construct introduces task impurity effects that increase the difficulty of measuring separate EF components (Miyake et al., 2000). In addition, the study did not assess the distant effects of ER-Lab, such as eventual improvements in other cognitive or academic domains beyond EFs.

Given these limitations, future research is needed to confirm the results, compare ER training to other types of EF trainings, and better define and clarify its efficacy with respect to specific EF structure models.

CONCLUSION

This study provides the first quantitative evidence for the positive effects of ER-Lab activities on EFs, especially working memory and inhibition, and supports using ER-Lab as an evidence-based methodology (Klingberg et al., 2005; Rueda et al., 2005; Thorell et al., 2009; Wass et al., 2011; Wass, 2015; Diamond and Ling, 2016) to improve Efs in the early school years. ER-Lab, methodologically speaking, may be halfway between telerehabilitation (Klingberg et al., 2005; Thorell et al., 2009; Grunewaldt et al., 2013) and play-based approaches (Traverso et al., 2015) as a valid tool for improving Efs during childhood. Moreover, our results suggest the importance of early intervention and the potential of carrying out this type of training in a classroom environment to directly improve school performance and assist children with EF weaknesses in an ecological, inclusive and social context.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Pediatric Ethics Committee of the Tuscany Region. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

MD, CP, EC, EI, and GS designed the RCT, collected the data, conducted the statistical analyses, and interpreted the results. MD and CP wrote the first draft of the manuscript. EC, EI, and GS critically revised the manuscript. FC, PD, and GC participated in designing the RCT and critical revision of the manuscript. All authors approved the final version of the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.03084/full#supplementary-material

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Enhancing Executive Control: Attention to Balance, Breath, and the Speed *Versus* Accuracy Tradeoff

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Malleability of executive control and its enhancement through yoga training is unclear. In Study 1, participants (yoga group; $n = 27$, mean = 23.27 years) were tested on executive control tasks pre- and post-8 weeks of yoga training. The training focused on attention to postural control during yoga asanas and respiratory control during pranayama-breathing (30 min each of postural and breath control training, biweekly). Yoga training was assessed *via* performance ratings as to how well a posture was executed and by examining errors that reflected inattention/failures in postural and breath control. We also explored whether attentional demands on motor and respiratory control were associated with three components of executive control (working memory, cognitive flexibility, and inhibition) during nine executive control tasks. Partial correlation results revealed that the three components of executive control might be differentially impacted by postural and breath control and selectively associated with either speed or accuracy (except for cognitive flexibility). Attentional demands influenced the link between postural, breath, and cognitive control. In Study 2, comparisons between a yoga group and a gender-matched control group (control group; $n = 27$, mean = 23.33 years) pointed toward higher working memory accuracy and a better speed–accuracy tradeoff in inhibitory control in the yoga group. A ceiling-practice effect was addressed by examining yoga practice learning (i.e., practice-induced change in postural and breath control reflected in ratings and errors) on executive control performance across two sets of tasks: repeatedly tested (pre- and post-8 weeks) and non-repeatedly tested (post-8 weeks). Attention to motor and respiratory control during yoga might be considered as a potential mechanism through which specific components of executive control in young adults might be enhanced potentially *via* altering of speed–accuracy tradeoff.

Keywords: attention, executive control, yoga, posture, breath control, speed–accuracy

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INTRODUCTION

Malleability within different components of executive control in early adulthood is not well understood (e.g., Diamond and Lee, 2011; Diamond and Ling, 2016; Friedman et al., 2016). Even though attention and executive control processes could be influenced by yoga and other mindfulness practices (Jha et al., 2007; Teper and Inzlicht, 2013), the mechanism through which such practices enhance attention and executive control remains unknown. Scholars have pointed out several limitations of studies examining the cognitive enhancement of yoga and mindfulness practices, namely, a lack of specificity in defining the construct underlying the practice, lack of precision with measuring the construct, and failure to establish a link between the construct and the cognitive function presumably enhanced (Davidson and Dahl, 2018; Van Dam et al., 2018). The practice of yoga comprises postures (asanas) and breathing (pranayama) (Woodyard, 2011; Sengupta, 2012). Furthermore, attention training enhances different components of executive control by regulating the speed-accuracy tradeoff. The three components of executive control of greatest interest to the present study are working memory (i.e., storing information in the mind long enough to use it), cognitive flexibility (i.e., changing perspectives by shifting attention), and inhibition (i.e., selectively attending to one stimulus while ignoring another) (Miyake et al., 2000; Diamond, 2013).

Performing yoga postures involves planned movements and attaining specific body poses while maintaining balance. Attention to breathing involves monitoring, anticipating, and controlling the rate of respiration (e.g., slow *vs.* fast). In other words, both practices involve attention to two autonomic processes: motor and respiratory control. Studies on attention and motor control indicate that when attention is focused away from the body, natural control of body movement is enhanced (McNevin et al., 2003). Conversely, cognitive tasks that deplete attention interfere with postural balance (Balasubramaniam and Wing, 2002). Similarly, pranayama requires attending to the autonomic process of breathing (focusing on the breath) and though attention depletion due to cognitive load alters breathing (Grassmann et al., 2016), such depletion likely resets the autonomic nervous system (Jerath et al., 2006). It is possible that the attentional demands required for bringing these ordinary autonomic processes under volitional control transform these into controlled and goal-directed activity by using cognitive resources such as working memory, planning-flexibility, and inhibition. Therefore this could be one mechanism through which yoga practice enhances executive control.

There could be a differential role of attention during posture and breath control practice, and these two components of yoga training likely have separable influences on executive control. Though asanas and pranayama both aim at controlling autonomic processes, others have recommended that the effects of breath control be examined separately from those of postures (Jerath et al., 2006; Trakroo et al., 2013). During posture training, the eyes are open in order to regulate movements by imitating an external referent (e.g., yoga instructor, a picture, or a video), whereas breath control exercises are performed with the eyes closed, cultivating internal awareness by curtailing external referents. Attentional demands during monitoring and retaining an external referent will be different from the demands of maintaining self-focus while inhibiting external referents. Furthermore, the two types of yoga training differentially involve working memory and distinctly regulate speed of processing (e.g., executing a yoga posture involves motor planning and requires working memory; Anguera et al., 2011; Seidler et al., 2012). For instance, executing a posture relies on convenient access to a mental image of a body arrangement in the form of a specific posture (e.g., visuospatial image of a posture). Conversely, breathing exercises have no such memory demand, as no external reference or visual image is necessary to focus, monitor, or regulate breathing. Additionally, the distinction between postural control and breath control practice will involve the two components of working memory (visuospatial and verbal) differently. Verbal working memory, known as the "phonological loop," stores verbal or articulatory information, whereas a "visuospatial sketchpad" serves as the storage for non-verbal spatial information (Baddeley and Hitch, 1974). Postural control disrupts visuospatial rather than verbal working memory (Gunduz Can et al., 2017); whereas breath control is known to selectively affect visuospatial working memory (Jella and Shannahoff-Khalsa, 1991; Telles et al., 2012). This is mainly because the respiratory system plays a critical role in speech and articulation (Ackermann and Riecker, 2010). Next, attention toward slowing paced movements improves postural control (Wu, 2002), and slow-paced breathing has the most evident cognitive benefits (Pal and Madanmohan, 2004; Jerath et al., 2006). However, some have found that both slow- and fast-paced breathing enhances cognitive control (Sharma et al., 2014). Slow movements during standing yoga postures require maintaining postural control against gravity; postural control failures pose a risk of losing body balance and falling. However, regulating the speed of breathing (fast or slow-paced) typically occurs in a sitting position, posing minimal or no risk of loss of balance and subsequent falls. Furthermore, respiration contributes to the rhythm or speed of brain functions (Heck et al., 2017); therefore, attentional demands during speed-regulation of breath control will differ from those of posture control, revealing differential associations with speed of processing during executive control.

The role of attention in linking motor, respiratory, and cognitive control can be delineated by demonstrating that variations in attentional demands during posture and breathing exercises are interlinked with executive control. Some postures, breathing exercises, and executive control components are less demanding than others; thus, attention is the key link between the three control systems. In this regard, the goal of Study 1 was to examine how the two components of yoga training (posture and breath control) are associated with three distinct components of cognitive control. In Study 2, we compared a yoga training group with an age–gender–education matched control group to examine changes in cognitive control as a function of yoga training.

STUDY 1

This study investigated whether two control systems (motor and respiratory control) involved with yoga postures (asanas) and breathing (pranayama) are differentially linked with speed and accuracy when performing three types of executive control tasks. Furthermore, the present study examined whether attentional demands alter the relationship between motor, respiratory, and executive control. This also involved testing the association between changes in motor and respiratory control through yoga training and executive control. We hypothesized that the three executive control components (speed and accuracy) would respond differently to the two types of yoga practice and that attention would accentuate the link between motor, respiratory, and cognitive control. In short, attention would be the mechanism through which the two yoga practice components would enhance executive control.

Materials and Methods

Measures

Nine tasks from the psychological experiment builder language (PEBL) were used to assess working memory, cognitive flexibility, and inhibition (Piper et al., 2016). Performance under high attentional demands was assessed by analyzing task complexity within each of the nine tasks (i.e., performance on task trials that were difficult/harder had higher demands as compared to performance on task trials that were simpler/easier).

Working memory

Digit span task (forward). This task assessed reaction time (RT) and accuracy of verbal/phonological working memory, with the participant recalling digits (1–9) presented in an increasing order.

Corsi block test (forward). This task assessed RT and accuracy of visuospatial working memory, which required participants recalling a sequence of blocks presented in increasing order.

Mental rotation task. This task assessed RT and accuracy of visuospatial working memory (Berteau-Pavy et al., 2011) and involved deciding whether two-dimensional shapes presented side-by-side on the screen were the same or different when rotated clockwise or counterclockwise at 50, 100, and 200°.

During the Corsi block test and digit span task, working memory demands increased sequentially: blocks and digits of a longer length placed more attentional demand on the participant.

Planning and cognitive flexibility

Toward of Hanoi. This task assesses planning, problem solving, and flexibility while revising plans, as it comprises rule-based transferring of three disks from one peg to another goal peg.

Tower of London. This task assesses planning and flexibility as participants are required to move three colored disks of the same size with a goal of preparing a specified stack/disk arrangement.

Berg's card sorting task. This task, modeled after the Wisconsin Card Sorting Task, measures rule learning and set shifting wherein a participant learns to sort stimuli based on three rule-changes (e.g., color, size, and form).

Although both the Tower of Hanoi and Tower of London are disk-transfer tasks used to assess planning and problem solving, the Tower of London is less demanding on working memory (Humes et al., 1997); however, for both tasks, attention and working memory load increases as the number of requisite steps increases (Spitz et al., 1984). Preservative errors are of greatest import during Berg's card sorting task, as these errors are the result of failures to shift attention from an old rule to a new rule (Barcelo, 1999).

Inhibition

Simon task. This task has a stimulus (a colored circle) presented on the right or left side of the screen, and the goal of the task is to respond to the color of the circle by pressing a button (red = left shift and blue = right shift). During incongruent trials, a red circle appears on the right side and vice versa, influencing RTs and accuracy, referred to as the Simon effect. Inhibition is required to suppress a target location-based response.

Stroop task. The names of the four colors (e.g., "blue," "green," "red," or "yellow") appear one-by-one on a screen, and a keypad response is mapped to each color. The color of the word either matches the name of the color (congruent) or is a mismatch (incongruent). RTs are slower when the color of the ink mismatches the name of the color. The task assesses the inhibition of word reading during color naming.

Iowa Gambling Task (IGT)

This task assesses decision-making where the participant has to choose between short-term risky *vs.* long-term safe rewards. A deficit reflects impulsivity and failure to inhibit the choice of an immediate, but risky, reward option.

In both the Simon and Stroop task, incongruent trials are more demanding than congruent trials. In the IGT, attentional and working memory demands during initial trials (blocks two and three) are higher (Bagneux et al., 2013).

Mood measure

The Positive and Negative Affect Schedule (PANAS) was used to assess mood. The mood measure was used for assessing the postsession mood (i.e., mood immediately after completing a session) and its alteration over the period of training (i.e., changes in postsession mood from the start to the end of the 8-week training period). We considered the difference between the first two sessions and the last two sessions to reflect alteration in postyoga mood analyzed over the period of yoga training (8 weeks). Due to multiple PANAS measures for each participant and unequal number of mood measures between the participants, Cronbach Alpha was not calculated.

Body Mass Index

BMI was calculated using the National Institute of Health protocol by dividing a participant's weight in kilograms by the square of his/her height in meters.

Participants

Twenty-seven healthy young adults (mean age: 23.37, *SD*: 3.89; 17 men) volunteered for the study. Inclusion criteria were as follows: >18 years and willing to undergo yoga training (postural and breath control). Participants were recruited by a female research assistant (RA) by sending emails to the hostel and institute email groups, requesting for participation (call for participation). Fifty two participants responded to the call, of which, total twenty five participants were excluded; reasons for exclusion were as follows: participants gave baseline but did not come for yoga stating due to lack of time (12), attended less than half of yoga sessions (seven), and participants did not give retest (six: four had left the campus, two were unresponsive). The participants were assessed for known psychiatric illnesses by using the Mini International Neuropsychiatric Interview (MINI). All participants were undergraduate (59%) or postgraduate students (∼40%) and yoga-naïve (self-declared first-time receivers of any form of yoga training). The ethics committee of the institute approved this study. All participants provided signed informed consent prior to participating. The participants also received a cash reimbursement (INR 500).

Procedure

After obtaining informed consent and demographic information from the participants, four cognitive tasks were administered prior to the start of the yoga training (task order: digit span task, Tower of Hanoi, Simon task, and IGT). Postural and breath control training (i.e., asanas and pranayama sessions) was imparted as per a preset schedule (see **Table 1**). Researchers have expressed concern over the absence of a detailed protocol for replicability with mindfulness-related practice studies (Van Dam et al., 2018). Thus, a detailed protocol is presented (**Table 2**). At the end of every yoga session, participants completed the PANAS questionnaire. After the last training session, participants were contacted and were asked to come back after 5 days for a retest. Participants were retested on the four executive control tasks, and after a 10-min break, participants were administered five new cognitive tasks (task order: Corsi block test, mental rotation task, Stroop task, Tower of London, and Berg's card sorting task). Data from the observation sheets of two research assistants, task output files, and PANAS sheets were entered into excel files and imported into a Statistical Software for Social Sciences (SPSS), version 18, database.

TABLE 1 | Yoga posture and pranayama breathing protocol performed by the yoga group ($n = 27$).

Postures	Duration
Warm-up (on spot jogging)	5 min
Padahastasana	2 min
Virabhadrasana*	2 min
Trikonasana*	2 min
Katichakrasana	2min
Tadasana	2 min
Ardha Chakrasana	2 min
Pranamasana*	2 min
Vrikasana*	2 min
Break	5 min
Breathing	Duration
Abdominal breathing	5 min
Thoracic breathing	5 min
Brahma mudra	5 min
Alternate nostril breathing	5 min
Observing breath	5 min
Mood measure (PANAS)	5 min

**Bilaterally done postures (1 min per side).*

TABLE 2 | Training session details as suggested by Van Dam et al. (2018) for yoga group ($n = 27$).

Teacher information	Number/types of retreats attended	5
	Experience in contemplative instruction	10 years
	Formal contemplative training	10 years
	Formal clinical qualification	None
	Blinded to experimental hypotheses	Yes
Practice information	Setting(s)	Student activity Centre
	Physical	Open space/Large hall (as per the weather)
	Social	19–22 students
	Overall duration	8 weeks
	Frequency of meetings	Twice a week
	Average length of meetings	70 min
	Types of formal practice	Yoga and breath control
	Approximate total percentage of each type of practice	50% yoga posture and 50% breathing (see **Table 1**)
	Types of informal practice	None
	Logs, practice review, guided	Logs maintained for each guided session
	Types of instructional materials used	Verbal instructions and demonstration from the trainer
General information	Instructor adherence assessed	Yes
	Control group used	No
	Randomization/allocation method	No
	Adverse events monitored	Yes
Participant information	Inclusion criteria	Yoga-naïve, age: 18–30 years
	Exclusion criteria	Exclusion: Psychiatric illness (MINI)
	Prior meditation experience	None
Conflict	Formal: Funding agency	Faculty Interdisciplinary Research Project
	Informal: Financial benefit	None

Yoga Training Session

A certified and experienced (>10 years) yoga instructor (female, age: 42 years) performed yoga postures (30 min) and five breathing exercises (30 min). Two research assistants (one male and one female) recorded and rated participants' performance during the posture and breathing sessions by using an observation sheet (see **Appendix 1**). To observe participants' performance, the two research assistants were seated in a designated position that provided a clear view of the participants. The participants were equally divided between the two research assistants for observation (average session attendance = 12 participants). The participants and research assistants switched sides every session to ensure that both research assistants contributed equally to participants' posture and breathing training ratings. The observation sheet was used to rate postures on a scale from 0 to 4 (0 denoting poor performance as compared to the instructor and 4 denoting precise performance and an exact replica of the instructor).

Failure to maintain posture or balance and movements that were not a part of designated posture-related movements were counted as motor control failures or errors. Similarly, breathing sessions were rated on a scale from 0 to 4 (0 denoting poor performance and 4 denoting precise performance). All postures were performed in a vertical, standing position. The breathing exercises were performed in a sitting position. Errors were counted as a disruption in the specified breathing activity (e.g., opening eyes midsession, moving when asked to hold still, or failure to follow any other breathing instructions). Ratings reflected participants' execution of the postural and breath control exercise compared to that demonstrated by the yoga instructor. To identify attention demands in posture and breath control, we classified postures and breathing exercises on the basis of the difficulty involved in execution. Classification of postures and breath control exercise on the basis of difficulty in execution (i.e., high *vs.* low demanding posture and breath control) rather than that of the participants on the basis of their ability to execute the posture or breath control (high/good *vs.* low/poor executers of postures and breath control exercises) enabled us to maximize the number of observations.

Variables and Data Analyses

Postural and breath control ratings as well as postural and breath control errors were treated as continuous variables (see observation sheet in **Appendix 1**). Accuracy and RTs were calculated to measure executive control performance on each task. Ratings and errors were negatively correlated for postures ($r = -0.76$, $p > 0.01$) and breathing ($r = -0.71$, $p > 0.01$); high motor and breath control were associated with fewer errors. Postures with a rating that is higher than the mean would be less demanding whereas postures with a low rating would be considered more demanding (i.e., difficult). Similarly, cognitive task trials with greater challenge were considered highly demanding trials. Partial correlations were analyzed to control for age, sex, and BMI. A first set of correlations tested the link between postural control (ratings and errors), breath control (ratings and errors), and cognitive task performance (accuracy/performance and RT) for (a) working memory (digit span task, Corsi block test, and mental rotation task), (b) planning and cognitive flexibility (Tower of Hanoi, Tower of London, and Berg's card sorting task), and (c) inhibition (Simon task, Stroop task, and the IGT). A second set of correlations then tested the link between postural, breath control, and executive control by accounting for various attentional demands. The third set of correlation analyses addressed ceiling-practice effects (i.e., cognitive task improvement in accuracy and RTs due to practice and repeated task exposure). The link between motor, respiratory, and cognitive control learning was tested for repeated (pre and posttraining assessment) and non-repeated tasks (posttraining assessment). The average of pre and posttraining performance was used for the repeated tasks.

Results and Discussion

Participant characteristics are listed in **Table 3**. Means and standard deviations for speed and accuracy observed across the nine executive control tasks are shown in **Table 4**.

TABLE 3 | Sample characteristics ($N = 27$).

Characteristic	Mean (*SD*), percentage
Age	23.37 (3.89)
Body mass index	22.54 (2.57)
Sex	Male: 63%; Female: 37%
Handedness	RH: 100%; LH: 0%
Vision	Corrected: 63%
Education	UG: 59%; PG: 41%

Working Memory

The association between postural and breath control and working memory was assessed using the digit span task (forward), Corsi block task (forward), and mental rotation task. Performance ratings and errors across the posture and breathing exercises were analyzed in comparison to speed and accuracy within the three working memory tasks (**Table 5**). Errors during breath control were associated with high accuracy on the digit span task ($r = 0.42$; $p = 0.04$). After factoring in attentional demands (**Table 6**), errors during the less demanding breath control exercises were associated with higher accuracy on the more demanding digit span trials (longer span; $r = 0.45$; $p = 0.03$). Postural control ratings during the less demanding postures were associated with faster RTs on the more challenging Corsi block trials (trials with longer block spans; $r = -0.42$; $p = 0.04$). Inattention during the less demanding breath control exercises was associated with slower RTs on the more demanding mental rotation task trials (mirror image; $r = 0.40$; $p = 0.05$). Overall, these results suggest a possible link between the demands on motor and respiratory control and the attentional demands on working memory.

We speculate that posture and breath control might have had a selective effect on visuospatial *vs.* verbal working memory. Responsiveness in regard to spatial or object rotation (mental rotation task) in reference to breath control is aligned with findings that breathing-related training improves spatial memory accuracy among women when compared with men (Jella and Shannahoff-Khalsa, 1993). Postural control seemed unrelated to verbal working memory as assessed by the digit span task. Others have also found that non-posture-related training, as compared to karate training (motor control training), has no effect on verbal working memory (Jansen et al., 2017). Non-posture-related training combined with goal training for substance abuse also reveals no improvement to verbal working memory among a trained group (Alfonso et al., 2011), or there is a weak link between posture control and verbal working memory (Telles et al., 2007, 2008). However, studies using a combined analysis of postures and breathing make it difficult to delineate training-induced improvement in verbal working memory (e.g., Purohit and Pradhan, 2017). Results might be suggestive of a selective link between pranayama breathing and verbal working memory possibly because verbal working memory (digit span task) implicates the phonological loop (Wang and Bollugi, 1994; Christie et al., 2013) and is associated with the respiratory process of breath control (Lau et al., 2015). Therefore, the

TABLE 4 | Descriptive table of speed and accuracy in general and highly demanding trials of the tasks representing the three components of executive control in the yoga group ($n = 27$).

EF component	EF tasks	Task speed (RT)	Task accuracy (score)	Highly demanding trial speed (RT)	Highly demanding trial accuracy (score)
Working memory	DS	73.3	101.34	18.85	−2.75
		(18.14)	(33.44)	(10.76)	(1.21)
	Corsi	69.22	71.19	18.41	−3.86
		(25.71)	(31.00)	(15.38)	(1.44)
	MRT	425.33	94.63	59.87	−6.71
		(192.2)	(25.83)	(64.41)	(23.12)
Cognitive flexibility	ToH	180.84	17.54	61.2	7.54
		(67.58)	(12.92)	(67.38)	(10.02)
	ToL	682.02	16.89	−94.89	−6.45
		(170.05)	(6.23)	(92.65)	(3.36)
	BSCT	218.89	27.04	30.96	62.52
		(52.13)	(13.04)	(22.96)	(19.19)
Inhibition	Simon	60.4	125.36	1.53	−1.43
		(17.22)	(29.88)	(1.96)	(1.38)
	Stroop	118.91	134.41	2.51	−0.82
		(20.48)	(13.4)	(2.56)	(2.06)
	IGT	127.83	13.67	3.74	−3.04
		(58.77)	(21.83)	(18.02)	(12.72)

TABLE 5 | Postural, breath control, mood, and cognitive control tasks (accuracy and RT) in the yoga group ($n = 27$).

Task Performance (cognitive-control)	Posture-control (motor control)		Breathe-control (respiratory control)		Mood (PANAS)	
	Posture rating	Posture error	Breathing rating	Breathing error	Positive	Negative
Working Memory						
DS score	−0.02	0.10	−0.27	0.42*	−0.11	0.03
DS RT	0.18	−0.31	0.06	−0.23	−0.02	0.30
Corsi score	−0.26	0.11	0.10	0.08	0.06	0.10
Corsi RT	−0.38	0.10	−0.18	0.24	−0.12	0.32
MRT score	−0.21	0.06	0.14	−0.00	−0.06	−0.20
MRT RT	−0.12	0.10	−0.06	0.17	−0.00	−0.26
Planning—cognitive flexibility						
ToH score-*R*	0.19	−0.11	0.05	−0.04	0.05	0.04
ToH RT-*R*	0.37	−0.09	0.43*	−0.48*	0.27	−0.01
ToL score	−0.26	0.14	0.19	0.20	−0.02	0.01
ToL RT	−0.46*	0.40*	−0.12	0.38	−0.04	0.15
BCST score	0.36	−0.19	−0.03	0.11	−0.04	−0.02
BCST RT	0.24	−0.22	−0.40*	0.40*	−0.06	−0.03
Inhibition						
Simon score-*R*	0.13	−0.32	−0.36	0.12	−0.19	−0.02
Simon RT-*R*	0.29	−0.39	−0.13	−0.00	−0.07	0.22
Stroop score	0.11	−0.17	0.13	0.12	−0.02	0.28
Stroop RT	0.07	0.09	−0.15	−0.07	0.26	−0.07
IGT score-*R*	0.06	−0.08	0.28	0.02	0.07	0.23
IGT RT-*R*	−0.17	0.24	0.09	−0.06	0.06	0.05

**Correlation significant at 0.05 level (two-tailed). DS score = block span × correct score; DS RT = RT for items; Corsi score = block span × correct score; Corsi RT = RT for items. MRT = Mental Rotation Task correct score/correct responses; MRT RT (Mental Rotation Task RT) = Task RT; ToH score = Tower of Hanoi Task score is steps minus shortest; ToH RT = Task RT; ToL score = Tower of London correct score/correct responses; ToL RT (Tower of London RT) = Task RT; BCST score = Berg's Card Sorting Task total error is total errors (preservation + non-preservation); BCST RT (Berg's Card Sorting Task RT) = Task RT. Simon score = correct responses; Simon RT = Task RT; Stroop score = Interference correct score; Stroop RT = Task RT; IGT score = Iowa Gambling Task net score [(C + D) − (A + B)]; IGT RT = Task RT.*

TABLE 6 | Postural, breath control, mood, and high demanding trials of cognitive control tasks (accuracy and RT) in the yoga group (n = 27).

Task performance (High cognitive-control)	Posture-control demand				Breath control demand				Mood (PANAS)	
	Low-R	High-R	Low-E	High-E	Low-R	High-R	Low-E	High-E	PA	NA
Working memory										
H-DS score	−0.14	−0.07	0.32	0.13	−0.33	−0.26	0.45*	0.36	−0.12	−0.06
H-DS RT	−0.05	0.00	−0.11	−0.19	−0.15	−0.30	0.13	0.07	−0.08	−0.22
H-Corsi score	−0.05	0.24	−0.06	−0.24	0.15	0.02	0.08	0.10	−0.29	−0.01
H-Corsi RT	−0.42*	−0.01	0.07	−0.04	−0.24	−0.14	0.29	0.25	−0.19	0.31
H-MRT score	0.01	−0.25	0.20	0.03	0.19	−0.31	−0.03	0.33	−0.20	−0.13
H-MRT RT	−0.11	−0.00	0.10	−0.13	−0.14	0.13	0.40*	0.14	−0.28	0.03
Planning—cognitive flexibility										
H-ToH score	−0.12	−0.25	0.01	0.29	−0.02	−0.16	0.07	0.21	0.03	0.03
H-ToH RT	0.08	0.15	−0.14	0.02	−0.06	0.06	0.07	0.01	0.13	0.22
H-ToL score	0.22	0.21	−0.40*	−0.17	0.10	−0.10	−0.12	0.13	0.02	0.15
H-ToL RT	0.10	0.03	0.01	0.21	0.04	−0.25	−0.00	0.09	0.08	0.22
H-BCST score	−0.34	−0.58**	0.44*	0.59**	−0.10	−0.25	0.01	0.37	0.15	0.02
H-BCST RT	0.30	0.56**	−0.38	−0.48*	0.05	0.06	0.08	−0.09	−0.09	0.03
Inhibition										
H-Simon score	0.10	−0.01	0.06	0.22	0.01	0.22	−0.04	−0.14	0.24	−0.26
H-Simon RT	0.25	0.05	−0.10	−0.03	0.31	0.46*	−0.17	−0.36	0.08	−0.00
H-Stroop score	0.13	−0.05	−0.16	0.00	0.11	−0.25	0.08	0.38	0.08	0.24
H-Stoop RT	0.00	0.10	−0.08	−0.09	−0.22	−0.09	−0.09	−0.20	0.02	−0.03
H-IGT score	−0.05	−0.08	0.17	0.17	0.09	0.30	−0.09	−0.27	0.08	−0.02
H-IGT RT	0.01	−0.13	−0.04	0.12	0.14	−0.18	−0.27	0.02	0.24	0.12

***Correlation is significant at 0.01 level (two-tailed); *Correlation is significant at 0.05 level (two-tailed). H-DS Score = block 2 (difficult) correct score - block 1 correct score (easy), and H-DS RT = RT of block 2 - RT of block 1; H-Corsi Score = scores of difficult block (block2) – scores of easy block (block1); H Corsi RT = RT of block 2 – RT of block 1; H MRT Score: accuracy of reverse object or Cond1 (difficult) - accuracy of original object image or Cond0 (easy); H MRT RT = RT for reversed object image – RT of original object image; H-ToH Score = correct score of trials with higher no. of steps (difficult) - correct score of trials with lower no. of steps (easy); H-ToH RT = RT of difficult – RT of easy trials; H-ToL Score = scores of difficult blocks (block 3&4; length 6&7) - scores of easy block (block 1&2; length 4&5); H ToL RT = RT of difficult block - RT of easy block; H BCST Score: percentage of preservation errors; H BCST RT: RT of total errors - RT of preservation errors; H-Simon Score = Interference suppression accuracy is incongruent trial's correct score (difficult) - congruent trial's correct score (easy); H-Simon RT = RT of incongruent - RT of congruent trials; H-Stroop Score = Incongruent trial's correct score (difficult) - congruent trial's correct score (easy); H-Stroop RT = RT of incongruent - RT of congruent trials; H-IGT score = net score of blocks 2&3 (difficult) - net score of blocks 4&5 (easy); H-IGT RT = RT of difficult blocks - RT of easy blocks.*

two components of working memory might have responded differently to the two yoga training components.

Planning and Cognitive Flexibility

Three tasks were used to assess the association between postural and breath control and planning and cognitive flexibility: Tower of Hanoi, Tower of London, and Berg's card sorting task. Breath control was correlated with RTs: better breath control was associated with slower RTs ($r = 0.43$; $p = 0.03$), while lower breath control was associated with faster RTs on the Tower of Hanoi task ($r = -0.48$; $p = 0.02$). Given that breath awareness is a measure of present moment awareness (Levinson et al., 2014), attention to the present moment facilitates insight during planning (Ostafin and Kassman, 2012). Mindfulness-related training improves planning and RTs among 10–13-year-old girls (Manjunath and Telles, 2001), adolescent girls with ADHD (Kiani et al., 2016), and patients with frontal lobe damage show better planning after breathing-focused mindfulness (Levine et al., 2011). Better postural control was also associated with faster RTs ($r = -0.46$; $p = 0.03$), whereas worse postural control was linked with slower RTs on the Tower of London task ($r = 0.40$; $p = 0.05$). Less demanding postures were related to lower accuracy on the demanding Tower of London trials ($r = -0.40$; $p = 0.05$).

Cognitive flexibility is reflected in preservative errors on the Berg's card sorting task, as these errors occur due to a failure to shift attention to a new sorting rule (Barcelo, 1999). Results suggested that better breath control was associated with faster RTs ($r = -0.40$; $p = 0.05$), while worse breath control was linked with slower RTs ($r = 0.40$; $p = 0.05$). Breath control seems to be associated with the regulation of speed/reaction time when shifting attention. When factoring in attentional demands, the less demanding postures were associated with more preservative errors ($r = 0.44$; $p = 0.03$). Conversely, better performance on the high-demanding yoga postures was related to fewer preservative errors ($r = -0.58$; $p = 0.003$) but slower RTs ($r = 0.56$; $p = 0.004$). Errors during the challenging postures were linked with faster RTs ($r = -0.48$; $p = 0.02$). Performing high demanding yoga postures with precise motor control indicates greater cognitive flexibility (fewer preservative errors); however, independent of demand, unplanned movements during yoga postures (i.e., posture errors) were associated with attention shifting failures. Attention to a goal-directed movement needed for performing a yoga posture seemed to be associated with attention shifting when learning a new rule, whereas breath control might be linked with the speed of planning and flexibility. Breath-focused mindfulness

(MBSR) did not affect cognitive flexibility among fifth-grade children (Wimmer et al., 2016) or patients with multiple sclerosis (Amiri et al., 2016), suggestive of the importance of postural control training. However, more focused efforts are needed to delineate the responsiveness of this cognitive domain to motor and respiratory components of the training and to test whether the interaction of motor and breath control impacts the speed–accuracy tradeoff.

Inhibition

Associations between inhibition and postural and breath control training were assessed with the Simon task, Stroop task (Color), and IGT. Postural and breath control were not associated with Stroop task performance. Other researchers have also found no effects of breath-focused training on Stroop task performance (Semple, 2010; Lee and Orsillo, 2014), citing ceiling effects (Anderson et al., 2007; Moore et al., 2012). Breath control was associated with Simon task performance but only when attention demands were considered: errors during high demand breath control exercises were associated with slower RTs (r = 0.46; p = 0.02). No other correlations were significant. Incongruence between the stimulus and response location produces slower RTs, reflecting the Simon Effect (Scerrati et al., 2017). Compared to the Stroop task, the Simon task is less verbal (Stroop task requires suppressing the conflict between naming a color *vs.* a word; Scerrati et al., 2017) and possibly relies more on spatial processing. A speculation that needs rigorous examination in future might be the role of working memory (i.e., spatial *vs.* verbal) in yoga-based enhancement of inhibitory control.

Counterintuitively, inhibiting impulsive choices in the IGT was not linked with postural and breath control. The IGT performance depends on somatic information that conveys body-states to the brain (Brinkmann, 2006), and inhibitory control is dependent on working memory and executive functions (Gansler et al., 2011; Bagneux et al., 2013). However, tertiary education and explicit knowledge interferes with somatic-guided decision-making (Evans et al., 2004). Others have observed that somatic awareness or attention to somato-sensory processes did not improve inhibition during longer-term decision-making (Cui et al., 2015); however, it is possible that the effects of somatic awareness and attention training are evident in a longer term and remain relatively implicit. Results are suggestive of inhibition being one of the most challenging domains for assessing cognitive-enhancement in younger adults.

Mood, Posture, and Breath Control

Mood assessments were taken immediately after the training session to reflect the most immediate training-altered affect. Posttraining mood showed no associations with any of the tasks. However, changes in posttraining mood (difference in mood ratings between the initial and last sessions), specifically negative mood was associated with diminished inhibitory control (Simon task) and faster RTs (IGT) (r = −0.43; p = 0.04). Posture, breathing, and relaxation training has been shown to increase positive mood and decrease negative mood (Narasimhan et al., 2011), whereas others observed that breath-focused mindfulness training tends to have less of an effect on mood (Eisenbeck et al., 2018). Posttraining mood might have contributed to the cognitive benefits of yoga training, possibly a negative posttraining mood being associated with fewer cognitive benefits. More efforts are needed to identify the effect of immediate mood or mood alterations on cognitive enhancement accrued from yoga training.

Yoga-Learning and Ceiling-Practice Effects

Executive control task performance tends to improve when tested twice, as is the case with a pre and postintervention design. This indicates a practice effect whereby a ceiling effect suggests that such improvement among healthy participants has a threshold or ceiling (Moore et al., 2012). To address a possible ceiling effect in the present pre and postyoga training comparison, we analyzed whether the difference in posture and breath control over the period of yoga training and accompanying mood changes (difference between the first and last two sessions) were correlated with two blocks of executive control tasks: (a) repeated tasks, wherein differences in pre and postintervention task performance was analyzed (i.e., four tasks that were repeated after the yoga training) and (b) non-repeated tasks, wherein task performance was assessed only once after the yoga training (five non-repeated tasks) (**Table 7**). This enabled a comparison as to differences in executive control performance as a function of a practiced *vs.* non-practiced task. It was expected that a celling effect would be more likely on the repeated/practiced tasks.

For the repeated tasks, verbal working memory (digit span) improved with changes in breath control (r = 0.49; p = 0.02). Inhibitory control in IGT accuracy diminished with improved posture control (r = −0.44; p = 0.03); however, factoring in attentional demands suggested that learning the highly challenging postures was associated with better performance on the high demanding inhibitory control (Simon task and IGT score) and planning (ToH) tasks as well as faster RTs on the IGT (all p < 0.05). Inattention/errors made during the high demanding postures were positively associated with improvements in inhibitory control (Simon task and IGT). Changes in regard to the less demanding breath control exercises were related to improved but slower inhibitory control (Simon accuracy and RTs).

As for the non-repeated tasks, breath control (errors) was associated with RTs for the planning tasks (ToL) (r = 0.43; p = 0.04). Attention attenuated the link between the control systems: errors with the low demand postures were associated with diminished and slower cognitive flexibility (Berg's card sorting task accuracy and RTs). Learning the high demanding postures was associated with poorer spatial working memory (MRT) but faster RTs (Corsi RT); learning the less demanding postures was associated with worse performance on the spatial working memory task (MRT). As expected, results from both the repeated and non-repeated tasks are suggestive of attention demands altering the link between improvement in the asanas and pranayama practice and the executive control tasks. The repeated/retested tasks revealed more significant correlations as compared to the non-repeated tasks, suggesting that practice effects should be considered while studying cognitive enhancement in yoga and breath control training.

TABLE 7 | Correlation of learning-induced changes in postural, breath control with mood, and ceiling-practice effect (retested and non-retested) in cognitive control task (accuracy and RT) with attention demands (yoga group: $n = 27$).

Task performance (cognitive-control)	Posture-control (motor control)		Breathe-control (respiratory control)		Mood (PANAS)	
	Posture rating	Posture error	Breathing rating	Breathing error	PA	NA
Retested cognitive control tasks						
DS score	0.23	−0.14	0.49*	0.41*	−0.07	0.26
DS RT	−0.00	0.06	0.01	−0.07	0.21	0.06
Simon score	−0.19	−0.16	−0.01	−0.15	0.27	−0.13
Simon RT	0.35	0.04	0.09	0.01	−0.07	−0.01
ToH score	−0.10	−0.13	0.15	0.08	0.18	0.08
ToH RT	0.02	0.10	−0.18	−0.06	−0.13	−0.17
IGT score	−0.44*	−0.28	0.02	0.05	0.26	−0.01
IGT RT	−0.15	−0.07	−0.17	−0.15	0.11	−0.43*
Non-retested cognitive control tasks						
BCST score	−0.30	0.09	−0.14	−0.26	−0.38	−0.04
BCST RT	0.14	0.13	−0.10	−0.19	−0.03	−0.14
Corsi score	−0.20	−0.20	−0.23	−0.09	0.15	−0.15
Corsi RT	−0.08	−0.35	−0.16	−0.00	−0.02	0.20
MRT score	0.03	0.06	−0.19	−0.13	0.38	−0.31
MRT RT	0.20	0.09	0.08	−0.08	−0.20	0.08
Stroop score	0.04	0.17	0.18	0.26	−0.00	0.28
Stroop RT	0.23	0.01	−0.02	−0.10	0.15	−0.22
ToL score	−0.03	0.10	−0.20	−0.15	0.20	−0.29
ToL RT	0.18	−0.22	0.23	0.43*	0.04	0.14

High cognitive-control	Posture-control demand				Breath control demand				Mood (PANAS)	
	Low-R	High-R	Low-E	High-E	Low-R	High-R	Low-E	High-E	PA	NA
Retested tasks and high attention demand trials										
H-DS Score	0.11	0.29	0.10	−0.21	0.25	0.23	0.08	0.20	−0.25	0.17
H-DS RT	0.08	0.25	0.16	0.01	0.29	−0.05	0.18	−0.05	0.13	−0.25
H-Simon Score	0.09	0.40*	0.28	0.41*	0.41*	−0.28	0.12	−0.17	0.19	−0.51**
H-Simon RT	0.18	0.21	0.17	−0.05	0.41*	0.05	0.05	0.16	0.13	−0.18
H-ToH Score	0.04	0.44*	−0.14	0.15	0.25	0.13	0.30	0.16	−0.06	−0.03
H-ToH RT	0.13	−0.18	0.36	−0.14	−0.01	0.11	−0.05	0.12	0.31	0.11
H-IGT Score	0.21	0.46*	0.36	0.53**	0.01	0.11	−0.12	−0.05	0.01	−0.27
H-IGT RT	−0.38	−0.48*	−0.02	−0.07	−0.15	−0.25	−0.14	−0.28	−0.35	0.35
Non-retested tasks and high attention demand trials										
H-BCST Score	−0.31	−0.18	−0.53**	−0.37	−0.15	−0.02	0.01	0.08	−0.02	0.15
H-BCST RT	0.13	0.24	0.49*	0.27	0.11	−0.04	0.01	−0.19	−0.00	−0.20
H-Corsi Score	−0.28	−0.17	−0.19	−0.08	0.00	−0.11	0.19	−0.02	0.08	0.00
H-Corsi RT	−0.10	−0.40*	−0.33	−0.32	−0.36	0.05	−0.23	0.18	−0.07	0.33
H-MRT Score	−0.47*	−0.43*	−0.21	0.13	0.06	−0.32	0.30	−0.29	0.14	−0.12
H-MRT RT	−0.04	−0.02	0.10	−0.03	−0.05	−0.31	−0.36	−0.30	−0.42*	0.04
H-Stroop Score	0.04	−0.28	0.29	0.09	0.09	0.02	0.20	0.02	0.07	0.23
H-Stoop RT	−0.02	0.17	−0.07	−0.25	−0.11	0.20	−0.10	0.10	0.28	0.03
H-ToL Score	−0.12	0.11	0.26	0.25	−0.03	0.23	−0.00	0.02	−0.34	−0.01
H-ToL RT	0.19	−0.09	−0.06	−0.20	0.17	0.19	0.33	0.37	0.17	0.27

***Correlation significant at the.01 level (two-tailed); *Correlation significant at the.05 level (two-tailed).*

STUDY 2

Cognitive functions seemed to be differentially responsive to learning the postural and breath control components, and practice effects may have confounded yoga practice-induced cognitive enhancement in Study 1 because repeated rather than ones that were novel showed more links to the training components. Attentional demands altered the association between postures, breathing, and cognitive control because yoga learning was associated with more of the cognitive tasks when attentional demands were factored in (e.g., inhibitory control), suggesting a critical role of attention in cognitive benefits. Even though the use of repeated and non-repeated tasks enabled the identification of practice effects, a non-yoga control group enables us to understand how yoga practice might facilitate executive control enhancement.

Therefore, in Study 2, we examined three components of executive control between individuals receiving 8 weeks of motor and respiratory training and a control group who did not receive yoga training. We employed the same cognitive control tasks (repeated and non-repeated), comparing performance as a function of attentional demands, maintaining the same 8-week time interval between testing.

Materials and Methods

Measures

The same tasks and measures were used from Study 1: working memory tasks, planning and cognitive flexibility tasks, inhibition tasks, mood measure, and Body Mass Index (BMI) measure.

Participants

Twenty-seven age, gender, and education matched healthy young adults (mean age: 23.33, *SD*: 3.11; 18 men) were recruited for the study to compare against the yoga group from Study 1 ($N = 54$; control = 27). A female RA (same as in Study 1) requested participation in the control group (requesting those who have not learned yoga and are not committed to learning yoga/mindfulness practice during the period of the study), and thirty-eight participants responded to this request. Eleven participants were excluded from the control group, of which, eight participants gave baseline test but did not come for biweekly mood measures, and three participants did not come for retest. Inclusion criteria were as follows: >18 years and 8-week long non-involvement with any yoga training. The MINI was used to screen for psychiatric illnesses. All participants were non-yoga learners (non-trained and non-practicing; see **Table 8** for sample descriptions). The ethics committee of the institute approved testing this control group. All participants provided signed informed consent and received a cash reimbursement (INR 500).

Procedure

After obtaining informed consent and demographic information, the same procedure as Study 1 was repeated except for the yoga training. Four cognitive tasks were administered at the start of the study (task order: digit span task, Tower of Hanoi, Simon task, and IGT). Mood measures were collected twice a week. After 8 weeks, participants were retested on the previous four tasks (repeated tasks). After a 10-min break, participants were administered the five non-repeated tasks (task order: Corsi block test, mental rotation task, Stroop task, Tower of London, and Berg's card sorting task).

TABLE 8 | Sample characteristics of the control group ($n = 27$).

Characteristic	Mean (*SD*), percentage
Age	23.33 (3.11)
Body Mass Index	20.86 (1.86)
Sex	Male: 66.67%; Female: 33.34%
Handedness	RH: 100%; LH: 0%
Vision	Corrected: 62%
Education	UG: 48.15%; PG: 51.86%

Variables and Analyses

To compare task performance between the two groups (yoga and control), we employed two analyses: (a) for the repeated four tasks, a mixed model analysis of variance (ANOVA) on accuracy and RTs (general and high attention demand trials) was conducted separately. Performance at baseline and at retest was the within-subjects variable, and group (yoga *vs.* control) was the between-subjects variable; age and gender were covariates. For the mood measures, positive and negative affect scores were within-subjects variables, and group was the between-subjects variable. (b) For the non-repeated five tasks, separate ANOVAs were conducted on accuracy and RTs as the dependent variable, group as the between-subjects variable and age and gender as the covariates.

Results and Discussion

Means and standard deviations for the speed and accuracy scores across the nine tasks are shown in **Table 9**.

Repeated Tasks

Performance on two of the four tasks differed significantly between the yoga and control group. There was no main effect of accuracy on the DS task, but there was a DS score × group interaction, $F(1,50) = 5.\ 20$, $p = 0.03$, $\eta_p^2 = 0.09$, experimental group showed increased accuracy from baseline ($M = 89.20$) to retest ($M = 113.99$; control group showed stable accuracy from baseline ($M = 84.59$) to retest ($M = 84.79$). There was no main effect of accuracy on the Simon task, but there was an accuracy × group interaction, $F(1,50) = 4.58$, $p = 0.04$, $\eta_p^2 = 0.08$ (experimental group baseline mean = 118. 23 and retest mean = 132.17; control group baseline mean = 134.14 and retest mean = 133.46). The Simon accuracy × age interaction was also significant $F(1,50) = 5.62$, $p = 0.02$, $\eta_p^2 = 0.10$. Though the RTs did not differ significantly between the two groups for any of the tasks, and the two groups did not vary as a function of attention demands, working memory and inhibition showed performance enhancement in the yoga group.

Non-repeated Tasks

Results revealed significant group differences for the Stroop task. Here, accuracy was significantly higher for the experimental group, $F(1,50) = 4.10$, $p = 0.05$, $\eta_p^2 = 0.08$ (experimental group mean accuracy = 133.94 *vs.* control group = 115.36) with RTs being significantly faster for the experimental group, $F(1,50) = 5.48$, $p = 0.02$, $\eta_p^2 = 0.10$ (experimental group = 119.53 *vs.* control group = 147.44).

Independent of group, gender had an effect on RTs for the spatial working memory task (MRT), $F(1,50) = 5.78$, $p = 0.02$, $\eta_p^2 = 0.10$ such that women had slower RTs compared to men. Gender also had an effect on cognitive flexibility (Berg's card sorting task) such that the percentage of preservative errors

TABLE 9 | Descriptive table of speed and accuracy in general and highly demanding trials of the tasks representing the three components of executive control of control group (n = 27).

EF component	EF tasks	Task speed (RT)	Task accuracy (score)	Highly demanding trial speed (RT)	Highly demanding trial accuracy (score)
Working memory	DS	72.38	84.95	18.47	−8.97
		(22.59)	(30.92)	(40.83)	(3.42)
	Corsi	70.37	74	16.11	−3.86
		(27)	(31.88)	(14.73)	(1.41)
	MRT	364.78	94.67	42.9	−10.15
		(194.84)	(25.24)	(41.43)	(30.02)
Cognitive flexibility	ToH	212.47	24.25	107.34	13.88
		(81.51)	(17.01)	(76.34)	(16.3)
	ToL	703.88	15.93	−132.84	−5.19
		(254.83)	(5.89)	(109.18)	(2.87)
	BCST	247.71	30	46.57	60.52
		(126.14)	(17.96)	(54.21)	(17.44)
Inhibition	Simon	103.25	181.19	2.88	−1.91
		(21.45)	(13.19)	(5.87)	(2.02)
	Stroop	148.08	114.89	2.95	−3.26
		(58.5)	(46.35)	(3.11)	(9.19)
	IGT	129.51	11.6	3.55	−3.52
		(63.65)	(12.29)	(14.31)	(8.22)

was greater among women compared with men, $F(1,50) = 6.06$, $p = 0.02$, $\eta_p^2 = 0.12$. The effect of age was significant for working memory such that younger compared to older participants (median 22 years) had better accuracy. For example younger participants showed higher general accuracy in Corsi block $F(1,50) = 7.54$, $p = 0.01$, $\eta_p^2 = 0.13$, and higher accuracy was observed on the demanding trials in MRT task, $F(1,50) = 5.66$, $p = 0.02$, $\eta_p^2 = 0.10$.

The two groups did not differ in terms of mood during the 8-week period. Those in the yoga group had better working memory (DS) compared to those in the control group; however, these benefits were observed for the repeated working memory task. The yoga group showed greater improvements in inhibition on the repeated (Simon task) and the non-repeated task (Stroop task) suggesting cognitive benefits might not be due to practice or task familiarity. Even though Study 1 results showed a weak link between inhibition and yoga training performance, the inhibition component of executive control might stand to benefit the most from yoga training as compared to working memory and cognitive flexibility.

GENERAL DISCUSSION

The present study first explored how two specific components of yoga practice, namely attention to postural control (motor control) and breath control (respiratory control), might be associated with two attributes (i.e., speed and accuracy) of executive control (working memory, planning and cognitive flexibility, and inhibition). Furthermore, the present study explored whether the relationship between motor, respiratory, and executive control alters as a function of attentional demands placed on the three control systems. We observed that attention to postural control during yoga asanas—and attention to breath control during pranayama—might be a potential mechanism through which yoga enhances specific components of executive control. Here, we report that attention to yoga postures and pranayama breathing might have revealed selective associations on the speed–accuracy tradeoff (except for cognitive flexibility assessed with the Berg's card sorting task). This tentative assertion is in line with the unity–diversity model of executive control (Friedman and Miyake, 2017), responsiveness within specific components of executive control to specific components of yoga training might highlight the diversified nature of executive control. Further, regulation of the speed–accuracy tradeoff within the three components of executive control might be the unifying mechanism through which yoga training is influential. Studies examining the effect of mindfulness-related practice on cognitive task performance report either speed (RT) or accuracy, but not both, as in the case with working memory tasks (e.g., Jella and Shannahoff-Khalsa, 1993; Jyothsna and Rao, 2014; Sharma et al., 2014; Johnson et al., 2015; Jansen et al., 2017; Purohit and Pradhan, 2017; Crivelli et al., 2018), planning and cognitive flexibility (e.g., Levine et al., 2011; Kiani et al., 2016), and inhibitory control (e.g., Lakey et al., 2007; Semple, 2010; Alfonso et al., 2011; Moore et al., 2012; Kiani et al., 2016; Wimmer et al., 2016). Results suggest that analyzing speed–accuracy tradeoff might be useful in exploring the unifying mechanism by which yoga and other mindfulness practices might enhance executive control. We also probed and found preliminary support for yoga postures and breath-regulation exercises along with the cognitive tasks employed being linked by attentional demands placed on motor (yoga postures), respiratory (pranayama breathing), and executive resources. Further, by comparing executive control performance on repeated and non-repeated tasks, as well as performance between a yoga and control group, we attempted to address practice and ceiling effects on postintervention executive control enhancement—results revealed that task exposure (repetition) might play a critical role in pre–post comparison of cognitive enhancement, especially for working memory. Results also are indicative of inhibition component of executive control being a challenging domain in terms of being directly linked to yoga training; at the same time, it could also possibly be a domain that is most benefited by yoga training.

LIMITATIONS AND FUTURE DIRECTIONS

The nature of this investigation was exploratory; it aimed at exploring attention as a mechanism through which postural and breath control might exert domain-specific effects on cognitive control. The findings should be interpreted within the limitations of our approach. For instance, cognitive enhancement due to physical exercise has been analyzed using sample sizes smaller than those utilized in the present study (e.g., McMorris and Graydon, 1997; Kruk et al., 2001; Draper et al., 2010); nevertheless, sample size in Study 1 is a limitation. To understand the extent of these limitations, we carried out retrospective power analysis (using G*power) and observed that the correlation values obtained in Study 1 were within the critical range, but the beta errors exceeded the acceptable limit (Banerjee et al., 2009). Some researchers observe that the retrospective power analysis violates the key assumptions of a random sample (Zhang et al., 2019); however, the results of Study 1 should be interpreted within the limitation of small sample size and its impact on the power to detect significant correlations. Similarly, the non-random assignment of participants to the two groups also limits generalization; however, the yoga group represents a population that self-selects and seeks yoga training for cognitive benefits. Others have also noted that the choice of a control group in mindfulness-based research poses a great challenge (Kinser and Robins, 2013). To verify the extent of this limitation, we carried out a retrospective power analysis for Study 2 (using G*Power), and the results suggested that the obtained F values were well within the critical range, and the beta error were also within the acceptable limit. The lack of an intelligence test was also a limitation; however, participants were students from an educational institute and were admitted through a highly competitive national level entrance test. Yoga asanas were followed by pranayama; counter-balancing the order of yoga postures and pranayama breathing was not possible. Thus, order effects regarding the training must be considered. While we ensured that only yoga-naïve participants participated and practiced only in the presence of the instructor (no home-based practice), we did not control for other activities that might have influenced physical and respiratory fitness during the 8-week study intervals. Finally, testing of the yoga and control group took place at two different points (due to budget/resource constraints, specifically participant payment).

CONCLUSION

Specific components of the speed–accuracy tradeoff in regard to cognitive control performance might have been differentially responsive to specific aspects of yoga training within this young adult sample. Yoga training is commonly imparted as a combination of postures and breath exercises and occasionally is combined with other activities such as listening to music, chanting, deity worship, experience-sharing, and motivational speeches (e.g., Manjunath and Telles, 2001; Levine et al., 2011; Kiani et al., 2016). Each of these activities could differentially influence executive control. Conversely, there could be a possibility that different components of executive control could respond uniquely to yoga training. Precise effects of multiple components that form a yoga practice, and the differential effects of each component on specific domains of executive control, will help address issues regarding the lack of a definition, mechanism, and established causality on the enhancement of executive control through yoga training. The present findings, though exploratory, provide preliminary support to this endeavor.

DATA AVAILABILITY STATEMENT

The raw data reported in this article are available from the corresponding author upon request.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Institute Ethics Committee (IEC No. P003), Indian Institute of Technology, Delhi. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

VS: conceptualization, funding acquisition, investigation, methodology, analyses, and original draft preparation. VM: data entry and coding, research assistance, and project administration.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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APPENDIX 1

Observation Sheet

Rater's name: ____________________

Session no. __________ Date: ______________Time: ________________

Participants:

TABLE A1 | Observation sheet for posture ratings and posture errors.

Posture	Duration	Attributes	P1	P2	P3	P4	P5
Padahastasana		Rating					
		Error Freq.					
Virabhadrasana*		Rating					
		Error Freq.					
Trikonasana*		Rating					
		Error Freq.					
Katichakrasana		Rating					
		Error Freq.					
Tadasana		Rating					
		Error Freq.					
Ardha Chakrasana		Rating					
		Error Freq.					
Pranamasana*		Rating					
		Error Freq.					
Vrikasana*		Rating					
		Error Freq.					

**Bilaterally done postures (1 min per side).*

Section I: Postures

Please follow these rating instructions

(A) Rate each posture, posture-attaining process using the following scale to indicate how well the posture was performed. The Instructor's posture will be used as an ideal comparison for the ratings.

0	1	2	3	4
Great difficulty	Difficulty	Moderate difficulty/Ease	Ease	Great Ease

(B) Put a tally mark to indicate loss of balance/fall/tripping/deviation from planned posture movement during the posture attaining duration (error frequency).

Section II: Breathing

(A) Rate each breathing exercise and breathe-exercise process using the following scale to indicate how well the breathing exercises were performed. The Instructor's breathing session will be used as an ideal comparison for the ratings.

0	1	2	3	4
Very Restless	Rest-less	Slightly Still	Still	Calm-Composed

(B) Put a tally mark to indicate loss of attention/moving/fidgeting/deviation from planned breathing activity (e.g., opening their eyes too soon when expected to remain with closed eyes, looking, turning around) during the breath exercise duration (error frequency).

TABLE A2 | Observation table for breathing exercise, and breathing exercise errors.

Breathing	Duration	Attributes	P1	P2	P3	P4	P5
Abdominal breathing	5 min	Rating					
		Error Freq.					
Thoracic breathing		Rating					
		Error Freq.					
Brahma mudra		Rating					
		Error Freq.					
Alternate nostril breathing		Rating					
		Error Freq.					
Observing breath		Rating					
		Error Freq.					

Special note/Observations:

Rater's signature and date:

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