# TRACK CHANGES

The transfer effect of programming building block play on preschool children's executive functions

**Abstract**

**While some prior research demonstrated that sensory-motor training can facilitate executive abilities in young children,** it is widely unknown whether programming building block play training may enhance executive functions in preschool children. A total of 117 children were randomly allocated to experimental or control groups. The experimental group underwent 60 minutes of programming building block play weekly for eight weeks, while the control group performed daily classroom activities. The results showed that children in the programming building block games group improved significantly in inhibitory control and cognitive flexibility. The working memory, however, did not show a significant improvement. These findings suggested that programming building block play can promote the development of executive functions in preschool children.

**Key words:** Executive functions; Programming building block play; children; development; Lego

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Dear Tiantian,

Thank you once again for choosing our services. It was a pleasure to proofread and review the manuscript titled 'The transfer effect of programming building-block play on preschool children's executive functions'. This paper was handled by Dr. Milosh who performed Scientific Editing, and by Ms. Andrijana who performed professional proofreading and copyediting. Below you can see track changes of the text we processed. On the right side, there are our comments addressed to you in particular. You should consider these comments very carefully, in order to confirm changes we made to your text or to make some changes by yourself (e.g., to update the reference list).

**Note.** Feel free to contact us with any questions you may have and we will give our best to reply as fast as possible (within 24 hours).

Best wishes and,
good luck,
Milosh

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1. Introduction

Nowadays, programming building block games demonstrate powerful effects on education by stimulating children's cognitive abilities in early development. have become a major concern for education and society. The programming building block game places more emphasis on children's early programming education compared to the classic building block game. Early programming instruction has been shown to improve children's cognitive development, including computational thinking, logical reasoning, cognitive control, working memory, and problem-solving abilities (Pérez-Marín et al., 2020; Unal & Topu, 2021; Wing, 2006; Scherer, 2019). Childhood is the golden period of enlightenment and thinking cultivation in the process of human thinking development (Sun et al., 2022), which potentially provides a plausible environment for programming building block use for additional cognitive development.

However, previous research (Koupritzioti & Xinogalos, 2020) has demonstrated that game-based teaching creates a gamified environment for children, allowing them to participate in engaging and dynamic programming activities (Koupritzioti & Xinogalos, 2020). Bers (2002) also suggested that early childhood programming education should make abstract programming concepts concrete, tangible, and playable. A traditional building block activity is ideal for all preschoolers and provides robust fun, simple operation, and visualization. As a result, this study used traditional building blocks as the teaching carrier combined with early programming education to illuminate children's early programming skills.

Previous studies have found that early programming education and building blocks can help children develop cognitive abilities, such as mathematical (Hawes et al., 2017) problem-solving (Verdine et al., 2017; Flannery & Bers, 2013), planning (Yelland, 2011), and self-regulation (Weipeng Yang et al.,2022) ability. Moreover, these abilities are closely related to Executive Functions (EF) (Diamond, 2013). EF are functional structures in the psychological process of problem solving critical for the individual cognitive, social, and psychological development (Brown & Landgraf, 2010; Morrison et al., 2010). EF are incredibly plastic and can be improved over time (Diamond & Ling, 2016); however, the plasticity of EF tends to show a gradual

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downward trend with aging (Fernández-Ballesteros et al., 2003). Therefore, in the early stage of children's development, targeted EF training can promote reaching a higher level of the development of cognitive functions and physical and mental health. For example, Diamond and Lee (2011) summarized the training methods of EF, including computerized training, computerized and non-computerized mixed training, physical exercise training (aerobic exercise, yoga, martial arts), mindfulness training, and school curriculum training. A recent study (Cao et al., 2020) using computerized training reported on a moderate effect of improving children's EF. However, computerized training demonstrated some downsides for young children: it is relatively dull and requires children 'sitting position in addition to increased focus for prolonged periods of time. Furthermore, it is difficult for young children to experience games involving planning and problem solving (Martinovic et al., 2015); hence, video game training in early childhood is not feasible. Physical activity and mindfulness training are also difficult in early childhood due to their low attractiveness.

Although previous research has investigated the relationship between programming and children's cognition, there has been less focus on how to teach programming to young children. The programming curriculum demands students to learn proper computer programming language logic and grammar, as well as to create algorithms to solve problems (Bosch & D'Mello, 2017; Kalelioğlu, 2015). Lack of programming experience in early childhood may lead to negative feelings (Salleh et al., 2018; Tsai, 2019) and computer programming anxiety, which impede the development of programming skills in young children (Owolabi et al., 2014).

Practical EF training should be enjoyable to motivate children to stay focused on their current activity. In addition, activities also need to constantly challenge the child's executive functioning and work on multiple executive functioning competencies, focusing on the child's emotional, social, and character development (Diamond, 2011, 2012). The programming building block play curriculum is not only easy to operate and enjoyable but also constantly challenges young children's thinking and collaborative problem-solving skills during the training process. Therefore, it may be an effective form of training for the development of executive functions in young

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Previous studies have found that early programming education and building blocks can help children develop cognitive abilities, such as mathematical ability (Hawes et al., 2017) and problem-solving ability (Verdine et al., 2017; Flannery & Bers, 2013), planning ability (Yelland, 2011), self-regulation ability (Weipeng Yang et al.,2022). However, these abilities are closely related to Executive function (EF) (Diamond, 2013). EFxecutive function is a functional structure that must be used in the psychological process of problem-solving and is critical to individual cognitive, social, and psychological development (Brown & Landgraf, 2010; Morrison et al., 2010). EF is incredibly plastic and can be improved over time (Diamond & Ling, 2016). However, the plasticity of EF tends to show a gradual downward trend with aging (Fernández-Ballesteros et al., 2003). Therefore, in the early stage of children's development, targeted EF training can promote the development of cognitive function as well as physical and mental health to a higher level. Diamond and Lee(2011)summarized the training methods of EF, including computerized training, computerized and non-computerized mixed training, physical exercise training (aerobic exercise, yoga, martial arts), mindfulness training, and school curriculum training. Computerized training is one of them, and it has a moderate effect on improving children's executive function (Cao et al.,2020). However, computerized training is not the best training method for young children because it is relatively dull, and requires children to sit and concentrate for extended periods of time. Furthermore, it is difficult for young children to experience games involving planning and problem solving (Martinovic et al., 2015), so video game training in early childhood is not feasible. Physical activity and mindfulness training are also difficult in early childhood due to their low attractiveness.

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children. However, according to our knowledge, no studies have directly examined whether programming building block training can facilitate EF in young children.

Taken together, we combined early programming ability and computational thinking with the traditional building block games. The present study re-examined whether the training with programming building block games in preschool children would facilitate EF of inhibitory control, cognitive flexibility, and working memory.

## 2. Method

### 2.1. Participants

A total of 135 preschool children (Mage = 4.6±0.29) were selected from four regular kindergarten classes in Jilin Province; however, due to sample dispersal caused by leaving or school-transferring, a total of 117 participants were included in the statistical analysis. A power analysis of the sample size was conducted a priori by G*Power 3.1 (Faul et al., 2007), based on Cohen f = 0.20, an alpha level of (α) = 0.05, power (1-β) = 0.95, r = 0.50, and 2 × 2 repeated-measures statistical test. The estimated sample size was 84, however, we increased it for more than approximately 35% to ensure statistical effects.

Two regular classes (n = 55) were randomized as the programming building- block group (29 males, (*M*age = 4.51±0.25; 26 females, *M*age = 4.44±0.34), and the other two regular classes (n = 62) as the control group (33 males, *M*age = 4.48±0.26; 29 females, *Mage* = 4.44±0.33). There was no significant difference between the experimental and the control group in age ($t$ = 0.19, $p$ = 0.85), gender ($t$ = 1.01, $p$ = 0.52), father's occupation ($t$ = -0.02, $p$ = 0.99), father's education ($t$ = 0.51, $p$ = 0.61), mother's occupation ($t$ = -0.42, $p$ = 0.67), mother's education ($t$ = 1.11, $p$ = 0.70), and previous Lego game experience ($t$ = 0.55, $p$ = 0.59). All participants were right-handed and with no reported intellectual, hearing, or visual disabilities as documented by the school administration. Each child received a reward for study participation. The conducted procedures

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in the present study were in accordance with the World Medical Association (Declaration of Helsinki) whereas informed consent was obtained from the school administration and children's parents.

2.2. Training Curricula

The "Coding Express" Lego set was used as a training material for children aged 3-6. It included *four building blocks* and *four software programming courses* (see Table 1 for an example of a training scheme). In building blocks, teachers guided children to build trains and tracks based on card models and to solve the course tasks using various sensing block functions followed by software programming use in order to guide children towards problem-solving. During the training teachers allowed the children to build by hand but they did not participate in the construction process. When the children encountered difficulties that could not be solved or if they became disengaged from the activity, the teacher used scaffolding to provide support.

2.3. Measures

2.3.1. Inhibitory control

Inhibitory control was measured by the day-night Strop task and the HTSK task. **The day-night Stroop task** (Gerstadt et al. 1994). This inhibitory control task predicts ambiguous figure switching by involving the principles of Go and No-Go participants' responses. The task consisted of three stages. In the first stage, participants were asked to answer "day" when a picture of the sun was displayed and "night" when a picture of the moon was displayed. In the second stage, participants were asked to answer "night" when the image of the sun was presented or "day" when the image of the moon was presented. Both stages included four practice trials and eight formal trials. The third stage included four practice trials and sixteen formal trials. Participants answered "night" upon seeing pictures of a goat and the sun and "day" upon seeing pictures of a goat and the moon. However, when a wolf appeared, participants did not respond.

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Stimulus pictures were presented using the DMDX computer program. First, the visual stimulus reminder was exposed (e.g., +) for 1000ms, followed by a picture presentation for 3000ms. The intertrial interval covered by the blank screen lasted for 500 ms. We recorded the number of times the participant provided the correct "day" or "night" response.

**The HTSK task** (Ponitz et al., 2008). This task measures behavioral regulation through two procedural sections: first, participants were told to perform a motor activity opposite of the experimenter's verbal instruction; for example, after a verbal order 'touch your head 'participants would touch their feet, and vice versa. Second, participants were told to touch their knees when the experimenter instructed them to 'touch their shoulders, and vice versa. The task was performed 20 times, including the associations of head-foot, foot-head, shoulder-knee, and knee-shoulder. The participants 'correct, self-corrected, and incorrect responses were registered by 2, 1, and 0, respectively.

2.3.2. Cognitive flexibility

**The Dimensional Change Card Sort** (DCCS; Zelazo 2006). This task is a standard procedure for estimating cognitive flexibility in early development. Participants are required to sort a series of bivalent test cards in accordance with color and shape visual dimension. In the shape classification game, participants had to decide whether the image depicted a rabbit or a boat. In the color classification game, participants had to judge the color of the picture. The formal experiment consisted of 36 trials, which were presented in the following order: shape, color, shape, color, shape, color. The participants 'correct responses were registered by 1, whereas absent and incorrect responses were registered by 0.

2.3.3. Working memory

**The six boxes task** (Diamond et al., 1997). In this task, used for measuring working memory, the experimenter put a sticker into each of the six boxes of the same shape and different colors, closed the lid, and asked participants to select a box to find a sticker. Each time, the experimenter put the

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box in which the sticker had been found back among the other five boxes and shuffled them, then asked the participants to find the next sticker until they found all the stickers — a maximum of 15 tests were performed. The participants 'working memory score (0-9) was calculated using the formula 15-X (X is the number of times to find all the stickers).

2.4. Procedure

The procedure for the experimental group involved training that lasted for 8 weeks and included 60 minutes of building block programming once per week while the control group was only required to participate in regular classroom activities. Each participant in the experimental group was administered individually for 15-20 minutes in a quiet testing room. All children completed four tasks of cognitive abilities prior to and after the training to assess executive functions.

To maintain participant homogeneity, socioeconomic status including the parents' occupation and education was evidenced by questionnaires.

2.5. Statistical Analysis

All analyses were computed using IBM SPSS Statistics 25. The scores of the four tasks were used as dependent variables in this experiment, whereas the Time Points (pre-test vs. post-test) and Groups (experimental vs. control group) were used as independent variables. The experimental design included a two-way repeated-measures ANOVA with the Time Points used as the intra-group variables and the Groups as the inter-group variables. All data with a standard deviation greater than three was removed or replaced with a serial average.

**3. Results**

The scores of children's executive function tasks prior to and after the programming building block play training are shown in Table 2. The results of the 2 (Time Points: T1 vs. T2) × 2 (Groups: the experimental vs. the control group) two-way repeated-measures ANOVAs are as follows.

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Table 2 The executive function task data of the experimental group and the control group.

| | Experimental group | | | Control group | |
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| | T1 | T2 | | T1 | T2 |
| Day/night Stroop | 13.24(1.90) | 14.49(1.05) | | 13.29(2.85) | 13.66(2.08) |
| DCCS | 28.65(2.95) | 32.71(2.90) | | 28.79(4.98) | 28.87(6.27) |
| Six boxes | 7.13(1.55) | 7.82(0.86) | | 6.13(1.85) | 6.35(1.66) |
| HTSK | 28.04(5.47) | 32.38(2.29) | | 28.65(7.01) | 30.02(5.69) |

*3.1. The effect of the programming building block play on children's inhibitory control*

In the day-night Stroop task, there was a significant main effect of Time, $F(1, 115) = 15.25$, $p < .001$, $\eta_p^2 = 0.12$, and a non-significant main effect of Group, F(1,115) = 1.39, p = .24, ηp2 = 0.01, while it turned out that the interaction between Time and Group, $F(1,115) = 4.51$, $p < 0.05$, $\eta_p^2 = 0.04$ was significant. Compared with the control group, training significantly improved the performance of the intervention group on the day-night Stroop task.

In the HTSK task, there was a significant main effect of Time, $F(1,115) = 25.61$, $p < .01$, $\eta_p^2 = 0.18$, and a non-significant main effect of Group, F(1,115) = 1.09,p = 2.99, ηp2 = 0.01, while the interaction between Time and Group, $F(1,115) = 6.93$, $p < .05$, $\eta_p^2 = 0.06$ was significant. Compared with the control group, training significantly improved the performance of the

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intervention group on the HTKS task. The control group did not change significantly. This demonstrated that programming block building game training may significantly improve children's inhibitory control ability.

*3.2. The effect of the programming building block play on children's cognitive flexibility*

In the Dimensional Change Card Sort task, there was a significant main effect of Time, $F(1, 115) = 23.27$, $p < .001$, $\eta_p^2 = 0.17$, and a significant main effect of Group, $F(1, 115) = 6.38$, $p < .05$, $\eta_p^2 = 0.05$, including their interaction, F(1,115) = 21.49, p < .001, ηp2 = 0.16 . Participants demonstrated higher cognitive flexibility in the experimental group compared to the control group. In addition, the T2 ratio was increased in comparison with T1. The findings indicated that programming block building game training may significantly enhance children's cognitive flexibility.

*3.3. The effect of the programming building block play on children's working memory*

In the Six boxes task, there was a significant main effect of Time, $F(1, 115) = 8.37$, $p < .01$, $\eta_p^2 = 0.07$, and Group, $F(1, 115) = 26.78$, $p < .01$, $\eta_p^2 = 0.19$, while their interaction, F(1,115) = 2.15, p = 1.14, ηp2 = 0.02 was non-significant. Experimental group participants demonstrated higher working memory abilities in comparison to the control group, including higher working memory scores in T1 than in T2 time point. The result meant that programming block building game training could not significantly improve children's working memory.

Figure 1 Trend graph of the change in performance of each task prior to and after the training

**4. Discussion**

The present study aimed to investigate the effects of programming building block game training on the development of executive functions in young children using an experimental and a control

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group Our study revealed that training with programming building block games could produce a training effect on the inhibitory control and cognitive flexibility of the children in the experimental group after an 8-week, once-a-week, 60-minute program. By contrast, no evidence was found of the programming building block game effect on working memory.

*4.1. The transfer effect of programming building block game training on inhibitory control*

The results showed that after eight weeks of training, the inhibitory control performance of the training group had significantly improved. Although previous studies have not directly explored the impact of programming building block games on the development of children's executive function, a study discovered that after six weeks of programming training or building block games intervention, the scores of two groups of children in the HTKS tasks significantly improved. However, no significant difference existed between the groups (Yang et al., 2022). Our findings suggest that regular performance of programming training and building block games in young children would influence executive functions by facilitating inhibitory control.

Programming training requires children to follow programming rules, programming procedures, and social rules during problem-solving with peers, so young children must regulate their behavior to conform to various rules to accomplish the ultimate programming goal (Caplovitz Barrett, 2005). Similarly, early childhood building block games can provide a learning environment for children to plan-build, structure, and solve problems through negotiation (Yelland, 2011). These are all crucial self-regulation factors (Miyake et al., 2000). Throughout the construction process, children practice self-regulation skills to help them better control their behavior and improve their inhibitory control.

However, our findings contradict those of Schmitt (2018), which may be related to the inhibitory control measurement task. Schmitt's study used a "timed task" (the child must respond correctly within 45 seconds) of the Sun/Moon task (Archibald & Kerns, 1999) and examined response speed and accuracy. Moreover, the building block game curriculum lacks reaction speed training (e.g., children are not instructed to build a tower as quickly as possible), whereas the training and

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inhibitory control tests are inconsistent. Furthermore, Montgomery and Koeltzow (2010) found that accuracy is usually used as an indicator to measure inhibitory control in the day-night Stroop tasks because when children in the tasks cannot take into account both accuracy and response time, these two tend to be inversely proportional. A higher accuracy rate is usually associated with a longer response time indicating possible speed-accuracy-trade-off. Some children's inhibitory control tasks are relatively simple and suitable for young children. In the standard version of the day-night Stroop task, children aged 4-5 years can achieve more than 70% accuracy (Montgomery & Koeltzow, 2010). Therefore, to avoid the ceiling effect in the tasks, our study used a more complex day-night task with nested rules and used the accuracy rate to assess inhibition and control ability.

*4.2. The transfer effect of programming building block game training on cognitive flexibility*

We found that eight weeks of programming building block game training improved the cognitive flexibility of young children. Our findings are consistent with the findings of Schmitt et al. (2018) and mutually supportive of Bers and Sullivan (2019) findings on programming education for young children. Previous studies (Diamond et al., 2005; Dreher & Berman, 2002) demonstrated that for children to complete dimensional change card sort tasks, they must mobilize inhibitory control ability and effectively suppress the stimulus-response tendency unrelated to the current task. In this study, programming block-building game training could effectively improve children's inhibitory control ability, which may provide a foundation for complete task switching. Furthermore, Diamond and Ling (2016) proposed that practical executive function training should train various executive function abilities during the activity. Children in different courses face different rules and task requirements. During the construction phase, for example, children need to memorize and learn to use the initial functions of the five sensory blocks in sequence (such as making the train stop and whistle.). However, the functions of the sensor blocks change when they are connected to the sensors in the software programming stage (such as making caterpillars perform different facial expressions and miniature trains make different animal calls), which

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requires children to understand and change flexibly. Therefore, as the core rules of training tasks are constantly changing, children must flexibly switch between different dimensions to quickly adapt to the new regulations to complete the target behavior.

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Moreover, the curriculum also contains rich problem scenarios that help children develop problem-solving skills. Problem-solving abilities are high-level and integrated indicators of executive functioning, and repeated training promotes the development of core components of executive functioning (Diamond, 2013; Schmitt et al., 2018). As a result, the whole exercise and challenge of children's cognitive flexibility and other abilities in the curriculum content are potential reasons for improving their cognitive flexibility.

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*4.3. The transfer effect of programming building block game training on working memory*

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Our research found that programming building block games did not improve children's working memory. On the one hand, the three components of executive function develop at different rates, with children aged 3-6 years developing cognitive flexibility and inhibitory control faster than working memory (Willoughby et al., 2010). Around four years old, in particular, is a transitional and critical period for developing cognitive flexibility (Carlson et al., 2002; HalaHala et al., 2003; Zelazo et al., 2003) and inhibitory control (Carlson, 2005; Diamond, 2002). In contrast, working memory develops rapidly around the age of five (Carlson et al., 2010). In this study, the participants were 4.46 years old. The development of cognitive flexibility and inhibitory control was faster than that of the working memory at this age. Therefore, the effect of programming building block games on children of this age group's working memory may be limited to some extent.

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On the other hand, it may be related to the experimental task due to the periodicity and frequency of training. Our study selected the "six boxes" task as a working memory measurement, which included much of the cognitive updating. Children were required to encode, monitor, and store the new information related to the task while also deleting the old information in time. However, as children around the age of four do not have enough working memory capacity to meet the task

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requirements, it usually leads to update failure and low accuracy. In addition, due to the relatively short training period and low frequency of the training in this study, the programming building block game has no significant enhancement effect on children's working memory. Alternatively, working memory may require different types of training than block-building such as a memory related task. Diamond and Lee (2011) hypothesized that longer training durations and more frequent training would result in more significant changes in executive function. Therefore, future research could increase the training cycle and frequency while also monitoring the process to investigate the improvement effect and trajectory from a dynamic standpoint.

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**5. Future directions and limitations**

From the application perspective, integrating early programming enlightenment based on traditional building blocks can effectively promote the development of children's executive functions, which in turn can promote the development of children's cognition. Moreover, using physical building blocks as a carrier and games as a teaching form may be one of the most effective ways to begin early programming for children.

There are two main limitations of this study. First, considering the objective conditions such as the imperfection of the kindergarten curriculum itself and the energy limitations of teachers and young children, this study conducted training once a week for eight weeks. However, Diamond and Lee (2011) hypothesized that longer training periods and higher training frequencies could lead to more significant changes in executive functioning. Therefore, training periods and training frequencies should be increased in future studies. Second, our study did not include a traditional building block group. We cannot conclude that programming building block play can more effectively promote children's executive function development. Therefore, multiple groups could be established in future research to compare whether programming building block game training can better promote children's cognitive development.

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**6. Conclusion**

The present study found that programming building block game training promoted the development of inhibitory control and cognitive flexibility. However, it did not significantly promote the development of children's working memory.

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