Video Game Playing Enhances Young Children's Inhibitory Control

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Abstract. Inhibitory control (IC), one of the main components of executive function, is a high-order cognitive process that enables individuals to suppress prepotent reactions and resist irrelevant interference. It develops rapidly in early childhood and provides a foundation for cognitive and psychosocial development in children. Although differing perspectives exist, there is some agreement that IC may be enhanced through video game practice and training, and that the level of cognitive engagement (CE) may affect the training outcomes. This study explored the effects of training video games on IC (measured by a Go/No-Go task) in 90 four- to six-year-old children. Participants were randomly assigned to one of three conditions: low CE (played *Whack-A-Mole*), high CE (played *Talking Tom Gold Run*), or a control group (received no training). Both training groups were asked to play the assigned video game for 5 min/day for 5 consecutive days. Results showed that the experienced gamers performed better at IC than did non-gamers. Video game training triggered significant improvements (preschoolers responded more accurately and quickly in the Go/No-Go task after a total of 25 min of training). Reaction times were negatively correlated with accuracy, i.e., children who responded faster also made fewer mistakes. However, the level of CE in video games had no differential impact on IC in the present group of young children. These results highlight the potential beneficial effects of video games on IC in preschoolers, and indicate that video game training may serve as a promising alternative to conventional IC interventions.

Keywords: Video games · Young children · Inhibitory control · Executive function · Go/No-Go task

1 Introduction

In this era of information and technology, video games have become almost ubiquitous in children's lives. A considerable literature has grown up on the potential effects of video games on cognitive ability [1, 2]. Recent evidence has suggested that video gaming might lead to enhanced *inhibitory control* (IC) [3, 4]. However, some other studies have found that IC is negatively affected by video game experience [5, 6]. In considering here whether playing video games improves IC, we begin by explaining the meaning of the term IC.

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1.1 Executive Function and Inhibitory Control

IC is a central component of *executive function* (EF). According to Najdowski et al., EF can be regarded as the chief executive officer of one's brain [7]. Although an established concept in psychology, EF is difficult to precisely define and there remain different beliefs about the structure of EF. Some researchers have conceptualized EF as a unitary system [8, 9] whereas others have considered EF to be a multidimensional construct [10]. To date, most researchers have reached the agreement that EF consists of three separable but interrelated higher-order cognitive processes (IC, cognitive flexibility, and working memory), which regulates goal-directed action and adaptive responses to the changing environment [11].

As a core function of EF, IC involves the ability to resist automatic but task-irrelevant responses. Classic examples of IC in early childhood include suppressing the impulse to eat a forbidden cake or to avoid touching an appealing but banned toy. Children who score highly on measures of IC are able to behave themselves in such situations, while those with lower scores seem to be more reckless. IC plays a crucial role in one's physical, cognitive, and psychosocial development [12]. It is a reliable predictor of young children's school readiness as well as achievement in mathematics and reading [13, 14]. Deficient IC has been detected in individuals with attention deficit hyperactivity disorder [15] and autism spectrum disorder [16].

The *Go/No-Go task* is the most important measure used in assessing IC [3]. This paradigm is an Information and Communication Technologies based task, aiming to evaluate a participant's capacity to inhibit inappropriate responses [17]. A Go/No-Go task requires the participants to perform an action (e.g., press a button) as quickly as possible when they see certain stimuli (i.e., Go trials), but withhold their responses when other stimuli are present (i.e., No-Go trials). IC is indexed by response accuracy and reaction times (RTs), with higher accuracy and shorter RTs indicating higher efficiency in IC [18, 19].

1.2 Inhibitory Control in Young Children

The rudiment of IC in young children is the effortful control of one's primitive reflexes and other pre-dominant behaviors, such as reaching an attractive toy [20]. The ability to refrain from a prepotent response begins to emerge in infancy, likely in the first year of life [21], and develops most rapidly in the preschool period [22]. The growth in IC during the early years can be explained in part by the maturation of attention and integration of different EF skills [23]. Another possible explanation is that functional changes in the prefrontal cortex during this period also contribute to the development of IC [24, 25].

To date, evidence for whether IC can be improved by training has been mixed. Some studies have failed to show any beneficial effect or transfer of IC training to other tasks [26, 27]. In contrast, other cognitive intervention studies have demonstrated that IC, just like other EF components, may improve with training [28, 29]. A number of researchers have identified that consistent exercise through cognitive stimulation or aerobic activities is able to strengthen brain connections and enhance IC [29, 30]. Furthermore, IC training yields stronger effects for young children than for adults [31].

1.3 Video Game Training

Studies on the benefits of gaming have documented that video game experiences may have the potential to facilitate IC in children [3, 4]. Certain types of video game, especially those requiring a high level of *cognitive engagement* (CE), have been found to be capable of enhancing EF [32]. CE refers to a mental state in which people devote their cognitive energies and allocate their attentional resources to master acquisition of challenging knowledge and skills. Complexity, novelty, and diversity have been identified as the key factors of highly cognitive engaging training programs [33].

Computerized cognitive training may take 2 to 14 weeks to benefit EF, and a longer training duration has been found to produce better EF outcomes [29]. However, recent evidence suggests that young children's behavior may be easily affected by even brief exposure to video games, due to the vital function of play during early childhood [36]. Further studies regarding whether IC can be stimulated by video game training over a short period of time would be worthwhile.

1.4 The Present Study

Although the effects of IC training remain controversial, given the brain plasticity of young children and the importance of IC [35], future research is needed to better understand the impacts of video game training in this context. Considering that the level of CE and the length of intervention time may influence the outcomes of IC training, this study aimed to elucidate whether a short duration (25 min in total) of low or high CE video game training could improve the IC of young children IC as measured by a Go/No-Go task.

Based on previous findings, we hypothesized that (1) experienced video gamers would outperform non-gamers in IC at pre-test; (2) video game training would promote young children's IC in less than 2 weeks; and (3) high CE video game training would produce greater improvements than low CE video game training at post-test.

2 Method

2.1 Participants

Ninety children (47 boys and 43 girls) aged 4.46 to 6.03 ($M_{\text{age}} = 5.04$, $SD_{\text{age}} = 0.31$) participated in this study. They were recruited from a kindergarten in China, and written informed consent was obtained all parents/guardians for children to participate. Prior to commencing the intervention, parents reported their child's gender, date of birth, and previous video game experience, including (1) whether their child had played video games before, (2) how many times their child played video games on a weekly basis (in general), and (3) how many minutes their child spent gaming per week on average.

2.2 Procedure

Figure 1 illustrates the structure of the study. The pre-test assessment took place two days before the start of the training, and the post-test took place two days after the end of the training. In the training session, participants were randomly assigned to one of three groups. One group played a low CE video game (*Whack-A-Mole*), another group played a high CE video game (*Talking Tom Gold Run*), and the third group which served as a control group continued with their routine activities. Training was completed for 5 consecutive days (5 min per day). Children completed all the tasks and training sessions individually in a quiet and familiar room inside their kindergarten.

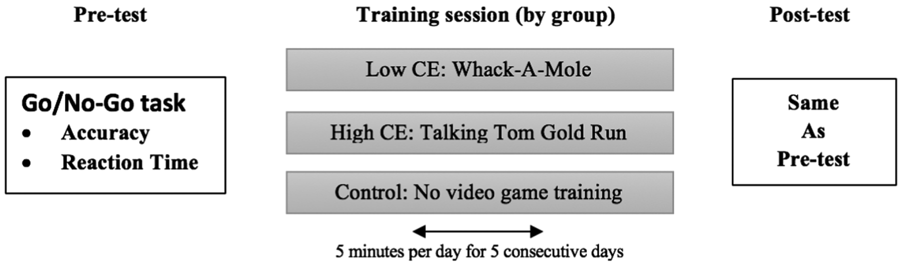

Fig. 1. Procedure across groups (n = 30 for each group).

2.3 Assessment (Go/No-Go Task)

The IC task was a Go/No-Go task for children. It was created and implemented using E-Prime™ software (Psychology Software Tools, Inc). The Go/No-Go task contained two types of trials: Go trials and No-Go trials. Participants were instructed to press the space bar when they saw a “Go” stimulus (an animal other than crocodile) and refrain from responding when a “No-Go” stimulus (a crocodile) appeared. The practice session composed of 16 trials including 4 No-Go trials, and the test session comprised 40 trials of which 25% were No-Go trials. Figure 2 shows the sequence of events during each trial. First, a fixation point was presented in the center of the screen for 500 ms. It was followed by a randomized distributed Go or No-Go stimulus, which appeared and remained on the screen until the participant made a response, for a maximum of 800 ms. Feedback was given during the practice trials but omitted during the testing trials. The number of correct responses and RTs were recorded. Higher accuracy scores and shorter RTs reflected higher levels of IC.

2.4 Video Game Training

The training device was an iPad (Apple Inc.). Both training games were free commercial games that could be downloaded via the iTunes App store (Fig. 3). Both games required the ability to inhibit prepotent responses to environmental stimuli. In the training groups, each child was instructed to play the assigned game for 5 min per day for 5 consecutive days (total training = 25 min).

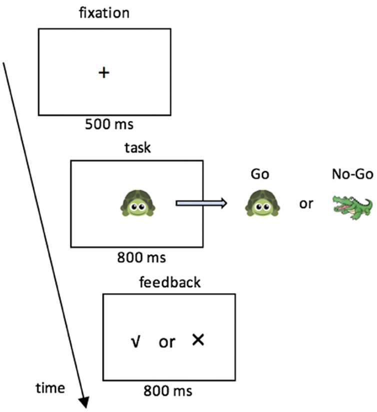

Fig. 2. Illustration of the sequence of events on a trial. Feedback was only provided in the practice trials.

Fig. 3. Screenshots of the two video games: Whack-A-Mole (*left*), and Talking Tom Gold Run (*right*).

Low CE video game. Whack-A-Mole (CLCM Inc). The goal of the game is to force the popped-up moles back into the holes by whacking them with a mallet, and to avoid hitting other objects, such as bombs. The moles and other objects were presented randomly. Children were instructed to respond as quickly and accurately as possible.

High CE video game. Talking Tom Gold Run (Outfit7 Limited). This is a runner game in which players are enabled to run indefinitely. During the running sequence, children were required to move their characters (such as Talking Tom) to avoid obstacles and collect items (e.g., gold bars). The game became more difficult as the child proceeded and children were asked to run as far as they could.

In order to examine the degree of CE, children were asked to evaluate the complexity, novelty, and diversity of the video games on a 5-point Likert scale after their first exposure to the games. The 5-point scale was illustrated using five circles of different sizes, with the smallest circle representing the least degree and the largest circle representing the highest degree. Higher mean scores on this scale indicated that the video game involved more CE.

3 Results

3.1 Manipulation Checks

The high CE video game was scored more highly by participants for complexity, novelty, and diversity than the low CE video game (see Table 1 for details). These results indicated that CE between the two games was successfully manipulated.

Table 1. Manipulation check, demographic, and video game experience variables by group

	Low CE (n = 30)		High CE (n = 30)		Control (n = 30)		Statistic	Effect Size
Variable	M/n	SD/%	M/n	SD/%	M/n	SD/%	$t/F/\chi^2$	$d/\eta^2/\Phi$
Manipulation Check:								
Complexity	3.50	1.17	4.03	1.00			$-1.90^{\dagger}$	0.49
Novelty	3.37	1.13	3.93	1.26			$-1.84^{\dagger}$	0.47
Diversity	3.37	1.30	4.00	1.08			-2.05^{*}	0.53
Demographic:								
Age	5.07	0.30	5.07	0.31	4.99	0.31	0.62	0.01
Gender	14 F	46% F	11 F	37% F	18 F	60% F	3.30	0.11
Game Experience:								
Frequency	2.67	1.95	2.27	1.67	1.77	1.76	1.90	0.04
Time	19.83	10.04	19.67	8.50	15.33	11.67	1.90	0.04

* $p < 0.05$, † $p < 0.10$.

3.2 Demographic and Video Game Experience

After random assignment, no gender or age differences were found among the experimental groups (Table 1). The groups did not differ in previous gaming frequency or time spent per week on gaming.

Preliminary analyses revealed that the experienced gamers performed better at pre-test than non-gamers. Compared to those who had never played video games ($M = 33.07$, $SD = 3.71$, $n = 15$), gamers ($M = 36.23$, $SD = 3.02$, $n = 75$) responded with greater accuracy on the Go/No-Go task, $t(89) = -3.56$, $p < 0.001$, $d = 1.01$. The RTs of gamers ($M = 594.55$, $SD = 52.80$) were faster than those of non-gamers ($M = 631.77$, $SD = 58.21$), $t(89) = -2.45$, $p < 0.05$, $d = 0.65$. The more time spent video gaming each week, the more accurate ($r = 0.35$, $p < 0.001$) and faster ($r = -0.27$, $p < 0.01$) gamers responded at pre-test (Fig. 4). In addition, as gaming frequency increased, gamers' IC pre-test accuracy increased ($r = 0.33$, $p < 0.01$) and RTs reduced ($r = -0.282$, $p < 0.01$). Additionally, gaming time was positively correlated with gaming frequency, $r = 0.58$, $p < 0.001$.

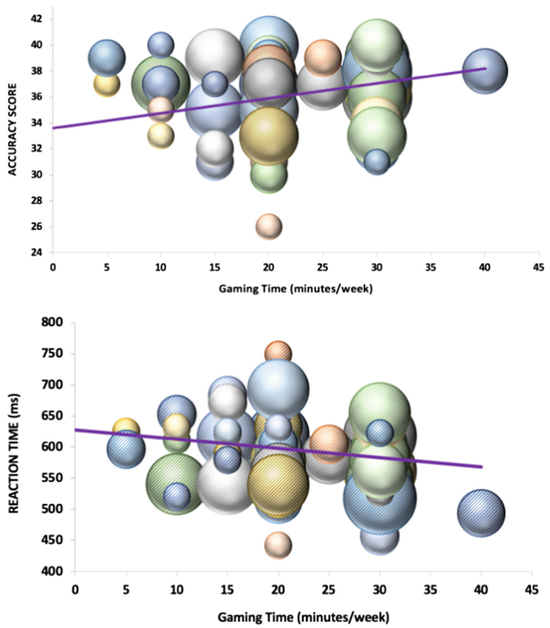

Fig. 4. Correlations among gaming time, frequency, and accuracy (*top*)/ reaction times (*down*). Gaming frequency is represented through the size of the bubbles.

3.3 Training-Induced Inhibition Changes

Accuracy. To determine the influence of training on IC accuracy, a repeated measures analysis of variance (ANOVA) was performed, with Time (pre-test, post-test) as the within subject factor and Group (low CE, high CE, control) as the between subject factor. Descriptive statistics for the pre- and post-test scores are shown in Table 2. Analysis revealed a significant effect of Time [$F(1,87) = 5.36$, $p = 0.023$, $\eta^2 = 0.06$], as well as main effect of Group [$F(2,87) = 5.62$, $p = 0.005$, $\eta^2 = 0.11$]. At post-test, participants showed improved accuracy (pre-test: $M = 35.81$, $SD = 3.32$; post-test: $M = 36.56$, $SD = 2.69$). Children in the low and high CE groups were more accurate

Table 2. Means and standard deviations for accuracy and reaction time scores, *t* test statistics, *p* values and effect sizes (*d*) for comparisons conducted between pre-test and post-test

		Pre-test		Post-test			
Measure	Group	M	SD	M	SD	t	d
Accuracy	Low CE	35.77	3.07	37.07	2.69	-2.43^{*}	0.45
	High CE	36.23	3.36	37.97	1.77	-3.30^{**}	0.65
	Control	35.43	3.56	34.63	2.39	1.32	0.26
Reaction Time	Low CE	607.23	54.54	582.75	61.52	$1.88^{\dagger}$	0.42
	High CE	596.03	57.66	583.75	45.79	$2.00^{\dagger}$	0.24
	Control	599.00	54.57	598.38	49.23	0.07	0.01

* $p < 0.05$, ** $p < 0.01$, † $p < 0.10$.

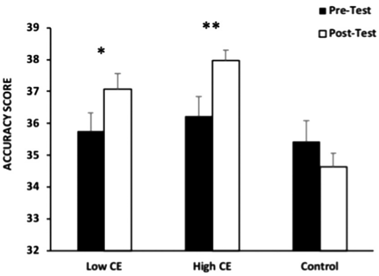

Fig. 5. Pre-test and post-test accuracy across groups. Error bars represent standard errors. $^{*}\,p < 0.05$; $^{**}\,p < 0.01$.

than control group children (low CE: $M = 36.42$, $SD = 2.49$; high CE: $M = 37.10$, $SD = 2.27$; control: $M = 35.03$, $SD = 2.53$). Importantly, there was a significant Time × Group interaction, $F(2,87) = 5.92$, $p = 0.004$, $\eta^2 = 0.12$. Post-hoc analyses showed significant improvements at post-test in both the low and high CE conditions with medium effect sizes, but no improvement was found in the control group (see Table 2 and Fig. 5 for details).

Reaction Times. A 2 (Time: pre-test, post-test) × 3 (Group: low CE, high CE, control) repeated measures ANOVA on RTs was carried out, and revealed a significant effect of Time, $F(1,87) = 4.75$, $p = 0.032$, $\eta^2 = 0.05$. Participants reacted more quickly at post-test than at pre-test (pre-test: $M = 600.75$, $SD = 55.19$; post-test: $M = 588.29$, $SD = 52.51$). No significant Group effect [$F(2,87) = 0.27$, $p = 0.77$, $\eta^2 = 0.006$] was observed. Time did not significantly interact with Group [$F(2, 87) = 1.45$, $p = 0.24$, $\eta^2 = 0.03$], although a downward trend was found in the low and high CE conditions, with small effect sizes (see Table 2 and Fig. 6 for details).

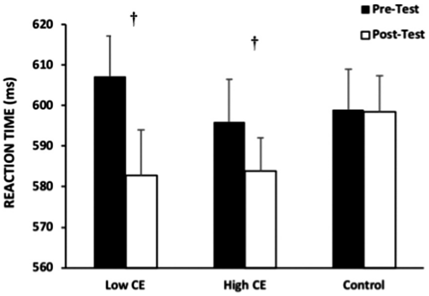

Fig. 6. Pre-test and post-test reaction times across groups. Error bars represent standard errors. $^{\dagger}\,p < 0.10$.

Correlations Between Accuracy and Reaction Times. As shown in Table 3, RTs were negatively correlated with accuracy scores, indicating that participants with shorter RTs also tended to be more accurate. Meanwhile, positive correlations were found between pre- and post-test accuracy, and between pre- and post-test RTs.

Table 3. Correlations between accuracy and reaction times (RTs)

	Pre-test accuracy	Pre-test RTs	Post-test accuracy
Pre-test RTs	-0.34^{***}		
Post-test accuracy	0.44^{***}	-0.29^{**}	
Post-test RTs	-0.36^{***}	0.49^{**}	-0.46^{***}

* $p < 0.05$, ** $p < 0.01$, † $p < 0.10$.

4 Discussion

In this study, we found that brief exposure to video games requiring the ability to inhibit prepotent responses to environmental stimuli was beneficial in improving IC in children. The improvements in accuracy were larger than for RTs. Furthermore, previous video game experience was linked to higher IC performance at pre-test. These results, which are consistent with previous findings, support the prediction that video game playing can enhance IC in young children.

There are several possible explanations for the video game training-induced improvements in the IC of young children observed here. One possible explanation may relate to neuroplasticity in early childhood. More specifically, frequent video game exercise may help consolidate brain connections and brain structures, which in turn help enhance IC. Some neuroimaging studies have shown that video game interventions are able to cause increases in the frontal lobe gray matter (associated with EF) of non-gamers [36, 37]. Another possible explanation may be related to the training-related enhancement of attentional capacity. For instance, a recent study conducted by Qiu et al. [38] demonstrated that just 1 h of video game play was capable of improving the ability of participants to focus on relevant information while disregarding distractions, namely, visual selective attention. Such capacity is thought to be a fundamental resource underlying IC [23].

Another compelling finding of this study is that young children showed improved IC after only a short period of intervention, i.e., 25 min in total. This is a new finding in the literature. Existing evidence has consistently documented that IC training typically takes more than 2 weeks to take effect in older participants. This discrepancy may be due to the power of play during early childhood. Just as the old saying goes "play is a child's work", a considerable amount of research has confirmed that play is the most valuable way in which a child learns [39]. No other activity could supersede play as the most effective learning approach for preschoolers. The reasons why previous IC training studies have failed to elicit changes in a shorter time may be related to the sample used (e.g., older participants) or utilized less interesting intervention methods (e.g., a modified Stop Signal Test or aerobic exercises) [26, 40, 41].

The results of this study indicate that appropriate video games may serve as potential training tools to promote the development of IC in young children. Dale and Green [42] describe three unique properties of video games that make video game training an alternative and effective intervention. First, video games are more interesting, engaging, and rewarding than other training programs. Activities with these features are often associated with better learning. Second, dynamic game difficulty leads video game play to become a distributed practice (that is, practice that can be divided into many short study sessions over a long time), which is beneficial to individuals' learning. Third, gaming may prompt people to engage in a "learning to learn" mode, which means that video game training could help learners develop a cluster of abilities which assist their future learning.

Contrary to expectations, the levels of CE did not show any significant impact on children's IC performance. A possible explanation might be that both training games shared a common cognitive mechanism and activated similar brain networks [43]. This may be one of the reasons why some researchers have chosen to use a sedentary activity (such as watching a video) as a low CE manipulation [44]. Therefore, further research is needed to determine the effectiveness of cognitive engaging/disengaging IC training programs. In addition, this unexpected result may be explained by the fact that high CE programs are successful in promoting working memory [38] but it remains unknown whether they also function in the same way for IC.

This study is subject to a number of potential weaknesses. First, the findings that IC accuracy and speed are correlated with previous video game time and frequency should be interpreted with caution, because it is possible that these results have been confounded by computer experience. That is, people who play computer games may simply be learning to interact with the computer – regardless of the specific task. Second, gaming time and frequency as measured here were only a rough estimate provided by parents, so the validity of the correlations between video game experience and IC might be impaired. Third, this study only explored the immediate outcomes of video game training. Due to the fact that training benefits may diminish after practice ends, it is worth investigating the longer-term training effect in future studies.

5 Conclusion

Overall, this study strengthens the evidence that video game playing has the potential to improve IC in young children. The following findings are notable: (1) The experienced gamers were better in IC at pre-test than non-gamers. (2) Compared to the control group, children who received a short period of low/high CE video game training (5 min/day for 5 days) performed more efficiently in IC at post-test – more specifically, they responded more quickly and accurately in the Go/No-Go task. These findings contribute to a better understanding of the positive impact of video games on young children's development. In conclusion, this study suggests that video game training may serve as an alternative educational intervention for facilitating the development of IC in young children.

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