Shih, JL. et al. (Eds.) (2023). Proceedings of the 31st International Conference on Computers in Education. Asia-Pacific Society for Computers in Education

Executive Functions Training-oriented Digital Games: Effectiveness and Experience

Chi-Fang HUANG[a*] , Hui-Ling HSU[a] & Zhi-Hong CHEN[a, b]
[a]*Graduate Institute of Information and Computer Education, National Taiwan Normal University, Taiwan*
[b]*Institute for Research Excellence in Learning Sciences, National Taiwan Normal University, Taiwan*
*81008001e@ntnu.edu.tw

Abstract: Executive function governs important cognitive abilities such as cognitive resource allocation, which is related to daily life and can affect learning performance. However, current executive function training mostly relies on self-administered tests, which leads to a dull process, and low interest, thereby influencing training effectiveness. To assist the affective domain during training, previous research attempted to gamify the training. However, prior studies indicated that the training intention might be influenced by the game-based design, and the game scenario also impacts the training process. Therefore, we developed a training-oriented digital game that closely simulates real-life situations to train executive function based on classic training, and discussed its effectiveness, and user experience. 38 college students were recruited to experience the training-oriented digital game and classic games and found that the training-oriented digital game effectively improved inhibition ability in executive function. Additionally, the game developed in this study showed significantly higher confidence and satisfaction than the classic game, while there was no significant difference in flow, positive affect, and behavioral intention. This indicates that the game developed in this study could be used to train executive function while maintaining support for the affective domain of gaming. We discuss further implications in the study.

Keywords: Executive functions, Digital games, Situational, Training-oriented game

1. Introduction

In the field of cognitive development, the development of executive function (EF) and related research have received increasing attention. EF refers to the cognitive ability to regulate and allocate cognitive resources, which significantly impacts reading, problem-solving, planning, decision-making, and other life-related skills (Miyake et al., 2000; Baggetta & Alexander, 2016). In comparison to Intelligence Quotient (IQ), which is commonly used in intelligence testing and future performance prediction, EF is a better predictor of life quality, mental and physical health, and future achievement (Ahmed et al., 2019; Follmer, 2018; Moffitt et al., 2011). This shows the importance and recent trend of studies related to EF. Miyake et al. (2000) identified three core cognitive abilities of EF: updating, inhibition, and shifting. Among these three, inhibition refers to the ability to resist interference from irrelevant information or impulses during cognitive processing, emphasizing the control of cognitive resources. As human attention is limited, inhibition has a certain degree of influence on other abilities and performances. This ability not only requires control over cognitive resources, but also affects other cognitive abilities or performances related to everyday situations, directly or indirectly affecting learning outcomes, work, and life. Therefore, it is particularly important and deserves special attention.

Studies have found that EF is not only an innate ability but can also be improved through training (Diamond, 2013; Kassai et al., 2019). And digitalized training has been particularly effective in enhancing EF (Jak et al., 2013). However, previous studies often use existing EF tests with minor adjustments and repeat them to achieve training effects, such as

n-back (Soveri et al., 2017; Lo et al., 2021), Go-NoGo (Tschuemperlin et al., 2019; Najberg et al., 2021). Therefore, these training systems are often composed of simple materials and continuous repeat of training. This leads to boredom and reduced intention for training (Prins et al., 2013). Moreover, the training effects may decrease over time without continued training, resulting in a need for longer training periods or repeated training sessions to maintain training effects (Anguera et al., 2021; Söderqvist et al., 2012). Therefore, to maintain and sustain the training effects of EF and to affect daily life positively, it is crucial to consider users' affective experiences and intention of training.

To improve user experience and training intention, digital games are often used in the training process. For example, McCord et al. (2020) asked elderly people to play Star Wars Battlefront and show significant enhancement on EF after three weeks. Both short-term and long-term training is effective in achieving training goals and positively impacting affective aspects, optimizing the gaming experience, and enhancing training intention (Anastasiadis et al., 2018; Stanmore et al., 2017; Bediou et al., 2018; Nagle et al., 2018). Martincevic and Vranic (2020) also used multiple games for EF training. However, no significant improvement was shown and this may be because the casual video games are not designed for EF training. Despite the effectiveness of enhancement on EF divided in prior studies, the positive effect of game-based design is still undeniable. Digital games provide adaptive information and training content based on users' needs, levels, and performance (Bennis & Amali, 2019). The level settings in games not only allow users to choose suitable levels for practice, but also challenge users to establish goals, enhance achievement, stimulate learning motivation, and even affect metacognition and performance (Sun-Lin & Chiou, 2017).

In recent years, there have been studies attempting to develop game-based training to especially aim at improving EF. Homer et al. (2019) focused on training inhibition ability in nearly a hundred adolescents, using digital games to improve EF. They found that not only the training significantly improved EF, but the design of game elements also impacted users' preferences and interests. In other studies, Ober et al. (2021) developed a digital EF training game called Gwakkamole, which required participants to click on regular avocados on the screen and avoid clicking on avocados wearing a helmet. The empirical results indicated that this game effectively improves EF. Another study found that the effectiveness of different sub-abilities of EF varies in the same training. Moreover, the design of challenging game elements in the game also has an impact on user experience (Wells et al., 2021). In addition, there is a series of studies that developed EF training games with aliens, including The Alien Game (Homer et al., 2018) and All You Can ET (Mayer et al., 2019). The empirical studies using these games to train EF, show significant training effectiveness of EF. Aside from the effectiveness, the impact of game design on learners is also discussed. In addition to establishing goals and achievements in challenging levels, which can help improve training effectiveness, real-time feedback in the game also has certain assist effectiveness for users (Parong et al., 2020).

Notably, most scenario designs are set in virtual worlds, far from real-life situations. However, Gray et al. (2019) have suggested that the effectiveness of EF training is influenced by the degree to which the training process mimics real-life experiences and actions, and whether the effects can be maintained. Therefore, this study aims to develop a training-oriented digital game that is closer to real-life situations to explore whether it can achieve the goal of improving EF and to further discuss the gaming experience when training. The research questions are as follows: 1. Does the training-oriented digital game enhance inhibition ability more effectively than classic games? 2. Does the training-oriented digital game produce a more positive gaming experience than classic games?

2. System design

This study aims to develop a series of 4 EF training games based on real-life scenarios, with inhibition as the training target, as shown in Figure 1. Based on the commonly used Simon task (Simon et al., 1967) and Stroop test (Stroop, 1935) for measuring inhibition ability, the game system includes two types of games: button selection and voice recognition. The button selection games are mainly adapted from the Simon task and are divided into three stages with increasing difficulty. In the first stage, users need to click on the left or right according to

the required rule after viewing an image. After getting familiar with the rules, the second stage of the game introduces interference from the left and right movements and flips to train users' ability to inhibit habitual responses. The third stage adds rule changes, requiring users to make choices opposite to their familiar operations in specific situations, in order to train rule switching, inhibition of previous habits, and increase game challenges. On the other hand, the voice recognition game is based on the Stroop test, and in multiple consecutive stages, users are required to speak out the content according to the rule requirements. During this period, rules are gradually stacked, and users need to inhibit interference from other types of icons and speak out corresponding content based on the rules.

Figure 1. Samples of screens of training-oriented game system

The system was developed using Construct 3 with the aim of training EF skills. To enhance the user gaming experience and encourage intention to keep on training, game elements are added, which include real-life scenarios, sound effects, animations, levels, time limits, and scores. Real-life scenarios are the main characteristics of the game design to make the training process more realistic, and we selected sports, food, and pet interaction as the theme of the game series. Different training scenarios, such as games, restaurants, and rooms, were presented in rich colors to enhance the sense of immersion. Aside from the scenarios, sound effects and animations were provided to offer users instant feedback during transitions, enabling them to know immediately whether their answer was correct or incorrect. This helped users to stay focused on the training objectives and remain immersed in the process. Then, the levels were designed to gradually increase in difficulty. This adds a challenging element to the game. Also, time limits were incorporated into the game to gain challenges. A countdown timer is displayed on the screen to remind users to respond quickly and accurately, with 10 seconds for each response, and faster responses result in higher scores. Last, the scoring system is also important. A scoring board or heart icons that closely matched the packaging scenarios, providing users with a quantifiable and intuitive sense of achievement.

3. Method

3.1 Research design

The research design focused on examining the effectiveness and experience of training-oriented digital games developed in this study. The game usage was set as the independent variable, with the participants' original EF ability as the control variable, and the training effectiveness and experience as the dependent variables. To address the research questions, a pretest was conducted before the experiment to assess the participants' initial EF ability. After each intervention using the game, a post-test was conducted to examine the training effectiveness, and a questionnaire was administered to understand the game experience, as shown in Figure 2.

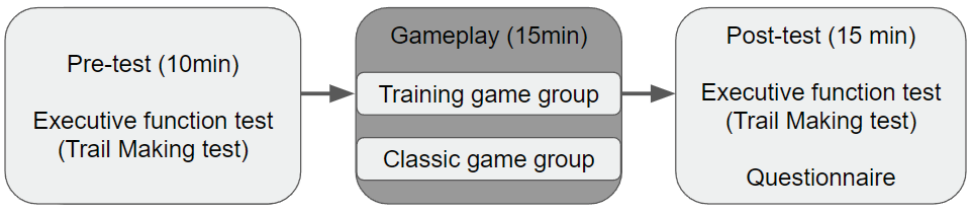

Figure 2. Research process and instruments

For the game intervention, the participants were divided into an experimental group and a control group, which used the training-oriented digital game and classic game, respectively. The study design referenced previous research designs (Homer et al., 2019; Plass et al., 2019), and the participants were instructed to operate the digital game for 15 minutes within an effective training period that did not induce fatigue.

3.2 Participants

This study recruited 38 college students without any cognitive-related disorders as participants, aged between 20 to 24 years old, including 10 males and 28 females. To avoid the influence of gaming experience on the training process and experience, the weekly gaming duration of the participants was investigated. 18 participants played digital games for more than half of the days in a week, while 20 participants played games for less than half of the time. This shows an evenly distributed pattern and is expected not to affect the research results.

3.3 Research instrument

The research instruments used in this study include not only the training-oriented digital games mentioned above but also classic games used in the control group as a comparison. To assess the effectiveness of the intervention, both EF assessment and questionnaires were used to examine both cognitive and affective aspects, which are described in detail below.

To parallel the training-oriented digital games, 4 classic games were selected. The selected classic games were common ones, including Pong, FreeCell, Pinball, and Minesweeper. These games were chosen to familiarize participants with the game rules. And to examine the effectiveness of the training, Trail making test was used in the pretest and post-test to assess participants' original inhibition ability and training outcomes. The test is frequently used in previous studies related to EF training (Sousa et al., 2020; Sosa & Lagana, 2019), Comprises a series of circle-linking tasks, and participants have to inhibit the effects of different types of circles, while others require participants to link circles in a specific order. After the intervention, a five-point Likert scale questionnaire was used to understand participants' gaming experience. The gaming experience questionnaire includes three dimensions, namely flow, positive affect, and behavioral intention (Law et al., 2018; Hwang et al., 2013). The flow and positive affect dimensions consist of 4 questions each, while behavioral intention has 5 questions.

3.4 Data analysis

To answer the research question, this study utilized IBM SPSS for data analysis. Specifically, an Analysis of Covariance (ANCOVA) was conducted using the differences in games as the between-group variable, pretest scores as the covariate, and post-test scores as the dependent variable to examine whether there were significant differences in performance between groups after intervention. In addition, an Analysis of Variance (ANOVA) was employed to investigate the user experience, with game intervention differences as the independent variable and participants' experiences as the dependent variable. The questionnaire on experience was used for comparative analysis.

4. Result and discussion

4.1 Training effectiveness

According to the research results, there is a significant difference between pre-test and post-tests of inhibition ability, as shown in Table 1. Through ANCOVA, it shows no significant difference in pre-test scores between the two groups. Moreover, after using the training games, the inhibition ability of the training game group was significantly improved compared to the classical game group, with an average increase from 0.37 to 0.51, and an F-value of 5.34. It can be concluded that participants were able to enhance their inhibition ability more effectively after using training-oriented digital games than classical games.

Table 1. The result of training effectiveness on inhibition

	Group	Pre-test		Post-test		F	eta^2
		Mean	SD	Mean	SD		
Inhibition	Training game (n=19)	0.37	.29	0.51	.24	5.34*	.132
	Classic game (n=19)	0.69	.29	0.39	.22		

*p < .05；**p < .01

The results of the present study are consistent with previous research, which showed that EF training-oriented games can effectively achieve the goal of enhancing EF abilities. Homer et al. (2019) conducted inhibition ability training on adolescents using a digital game and found significant improvement in training effectiveness. Similarly, Wells et al. (2021) developed a digital EF training game, Gwakkamole, and not only indicates that this game could effectively train EF but also mentions that the design of challenging game elements in the game would also have an impact on the training process. Another series of studies of EF training games take aliens as the game theme, including The Alien Game (Homer et al., 2018) and All You Can ET (Mayer et al., 2019). Empirical research similarly found significant improvements in inhibition ability and noted the impact of game design on learners. Establishing goals and achievements through the challenges of the game can help improve training effectiveness, and real-time feedback in the game can also assist users (Parong et al., 2020). These findings are consistent with the present study, as the design of challenging elements, such as levels and scores, as well as real-time feedback, such as sound effects and animations, has become an essential part of the game process to assist learners in achieving better training results.

However, the above research scenarios differ from real-life situations. The present study takes activities that are closer to real-life situations as the game scenario, based on the gap identified in previous research (Gray et al., 2019). The results of the study also showed that designs that are closer to real-life situations can effectively improve inhibition ability.

4.2 Game experience

In addition to exploring the training effectiveness for training-oriented games, this study further investigates the game experience. Firstly, the reliability of the questionnaire was confirmed with a Cronbach's alpha value of 0.95 for the training games group and 0.93 for the classic games group, demonstrating the trustworthiness of the questionnaire results. Subsequently, an ANOVA was conducted to compare participants' perceptions of training games and classic games, including three dimensions: flow, positive affect, and behavioral intention. The results showed no significant differences in these dimensions between the two groups, indicating that games designed for training purposes and classic games can both achieve a positive user experience. The results are presented in Table 2.

Table 2. Comparison of game experience between groups

	Training games (n=19)		Classic games (n=19)		F	eta^2
	Mean	SD	Mean	SD		
Flow	**3.64**	1.10	3.16	1.04	1.96	2.25
Positive affect	**3.72**	1.07	3.49	0.77	0.61	0.53
Behavioral intention	**3.22**	1.00	3.32	0.81	0.10	0.09

Homer et al., (2019) conducted an empirical study on digital training games and found that the game design has an impact on user preference and long-term usage intentions. In other empirical studies, Wells et al. (2021) compared the performance of EF training games with a control group and found that EF training-oriented designs have lower user affect and long-term usage intentions. The study also further emphasizes the impact of game elements, including challenges, on user experience. As the prior study has pointed out, enhancing EF requires continuous training, and users' affective experience and long-term usage intentions should be given more attention. Therefore, this study aims to design EF training-oriented games that not only focus on training effectiveness but also emphasize the affective domain. The training process incorporates gaming elements such as level design, time limits, and scores, to gain challenges. Also, we use other game elements such as scenarios and real-time feedback in sound and animation to achieve a positive user experience in training-oriented games. This study aims to bridge the research gap and guide users toward continuing their training to achieve long-term goals in improving EF.

5. Conclusion

The executive function (EF) controls important cognitive abilities and can impact learning performance and daily life. Although prior studies developed digital training and training games to enhance EF, the affective domain is yet to be improved (Wells et al., 2021). Moreover, game scenarios of most EF training games are often far from real-life, which also influences the training process (Gray et al., 2019). Therefore, this study developed a training-oriented digital game with real-life scenarios to address this research gap. Through empirical research, this study answers the following research questions: (1) Does the training-oriented digital game enhance inhibition ability more effectively than classic games? ANCOVA results show that inhibition ability significantly improved through training with the training-oriented digital game compared to the classic game, demonstrating the effectiveness of this training-oriented digital game design. (2) Does the training-oriented digital game produce a more positive gaming experience than classic games? The result of analysis through questionnaires shows no significant differences in the flow, positive affect, and behavioral intention dimensions between the training-oriented game and the classic game. This indicates that both types of games can achieve the goal of a positive gaming experience and the training-oriented game can guide users to continue training to enhance EF. This provides insights into the design of EF training games, the game elements and situation should be emphasized.

The present study has some limitations and suggestions for future research. Due to the constraints of time, the sample size of this study was limited. Therefore, future studies should focus on larger sample sizes to improve the appropriateness of research inference. In addition, the training time was only 15 minutes. Although the design was based on previous research and was found to be effective, it is recommended to increase the training duration or frequency. Also, as the effectiveness of enhancing inhibition has been proven, the training aim of other EF sub-skills should be considered in future game development and studies. Finally, the training game was designed with scenarios close to real life, and the study mainly discussed its effectiveness and gaming experience. Research further comparing real-life and virtual situations is expected to establish the importance of situation setting.

References

Homer, B. D., Ober, T. M., Rose, M. C., MacNamara, A., Mayer, R. E., & Plass, J. L. (2019). Speed versus accuracy: Implications of adolescents' neurocognitive developments in a digital game to train executive functions. *Mind, Brain, and Education, 13*(1), 41-52. https://doi.org/10.1111/mbe.12189

Ober, T. M., Brenner, C. J., Olsen, A., Homer, B. D., & Plass, J. L. (2021). Detecting patterns of engagement in a digital cognitive skills training game. *Computers & Education, 165*, 104144. https://doi.org/10.1016/j.compedu.2021.104144

Wells, A., Parong, J., & Mayer, R. E. (2021). Limits on training inhibitory control with a focused video game. *Journal of Cognitive Enhancement, 5*(1), 83-98. https://doi.org/10.1007/s41465-020-00184-2