

Improving Pre-K–12 Students' Executive Functions Using Digital Games: A Systematic Review

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Abstract: Executive functions (EFs) are critical cognitive skills that influence learning, decision-making, and problem-solving. This systematic review examines the impact of digital games on improving EF skills in Pre-K–12 settings by following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Contributions from diverse fields, including psychology, education, and technology, reflect the interdisciplinary interest in this area. Based on the analysis of game design integrations, this systematic review organizes game design elements into two categories: high-impact, where games are purposefully designed to improve EF skills, and low-impact, where games are not intentionally designed to target EFs. The findings reveal trends in game design elements, such as adaptive challenges and feedback systems, that contribute to EFs improvements. This study highlights digital games as promising tools for enhancing EFs. Findings underscore the need for more rigorous designs and future research on higher-order EFs.

Introduction

Executive functions (EFs) are a group of top-down mental processes that help with focus and attention (Diamond, 2013). These skills become necessary when relying on automatic or instinctual responses is inadequate or insufficient to address the demands of the task (Burgess & Simons, 2005; Diamond, 2013; Espy, 2004; Miller & Cohen, 2001). EFs involve thinking before acting, addressing unforeseen problems, resisting temptations, and maintaining concentration (Diamond, 2013). EF skills are essential for regulating higher-level cognitive processes such as sequencing, planning, decision-making, reasoning, and problem-solving (Cristofori et al., 2019; Miyake et al., 2000). EFs also promote academic success, physical and mental well-being, and overall cognitive, social, and psychological growth (Diamond, 2013). According to the World Economic Forum's report, analytical thinking, creative thinking, cognitive flexibility, and attention are among the top ten core skills desired by employers in 2023 (Zahidi, 2023).

According to Soussini et al. (2022), EFs have been defined in various ways, depending on the theoretical point of view and the age range or population studied. For example, the unitary perspective (Friedman & Miyake, 2004; Garon et al., 2008) stresses common processes among measures of EFs. All sub-facets of EFs are linked together and operate as a single, unified cognitive ability rather than as independent processes. For example, when a student solves a math problem by using working memory to hold numbers, inhibition to block distractions, and cognitive flexibility to switch strategies, thereby showing how these abilities function together. The modular or componential view (Diamond, 2013) emphasizes dissociable EF processes and distinct developmental patterns for each process. For example, a child uses their working memory to remember the steps needed to complete a puzzle but struggles to control anger when the puzzle is taken away with weak inhibition. Despite these different models conceptualizing EFs, there is a broad consensus among researchers that EFs comprise three facets (Miyake et al. 2000; Souissi et al., 2022): *inhibition*, or *attentional control* in other words at the level of *attention* (i.e., not attending to irrelevant features), *updating* or *working memory* (i.e., keeping track of multiple events), and *cognitive flexibility* or *task shifting* (i.e., switching from one task to another). These three facets are the foundation for developing more complex, higher-order EFs, such as reasoning, problem-solving, and planning (Diamond, 2013).

Several initiatives have demonstrated the potential of high-quality early education to support EF skills development, indicating that EFs can be trainable (David et al., 2017; Diamond & Ling, 2020) except in cases where a child has neurological impairments. Through cultivating EFs from a young age, individuals can be prepared for the multifaceted demands of society.

Digital games are efficient tools for fostering cognitive skills (Plass et al., 2015). Most individuals begin playing games at a young age. According to a report by the Entertainment Software Association's (2023), 26% of American video game players are under the age of 18. Research shows that well-designed digital games can enhance EFs, underscoring their potential as a tool for cognitive development (Homer et al., 2018; Parong et al., 2017; Plass et al., 2019). Well-designed games integrate interactive problem-solving, clear goals, adaptive challenges, player control, ongoing feedback, uncertainty, and sensory stimuli to enhance engagement and

learning (Shute & Ke, 2012). Therefore, the purpose of this study is to synthesize the literature's findings and explore how digital games impact Pre-K–12 children's EF skills.

Current study

In this review, we examine studies in the literature that highlight various approaches through which digital games or tools enhance EFs across diverse populations. There are several systematic reviews and meta-analyses that have examined the effects of serious games, exergames, and video games on attention, EFs, and overall cognitive skills (Wiley et al., 2023; Abd-Alrazaq et al., 2022; Parthasarathy et al., 2023). These studies explore the impact of digital game genres, gamification, and game-based learning approaches on learning and cognitive performance. Additionally, these studies often focus on specific groups, such as youth or individuals with cognitive impairments (Eng et al., 2023; Li et al., 2022). Several studies also emphasized supervised methods, such as rubrics or functional Magnetic Resonance Imaging (MRI) techniques, to assess the cognitive benefits of gaming interventions (Huang & Cheng, 2022). The most relevant study to the current systematic review was conducted by Choi et al. (2020), in which they examined exergaming effects on EFs in children for pediatric purposes.

To our knowledge, there is no systematic review in the literature that focused on the effects of digital games in promoting EFs within Pre-K–12 educational settings. In this systematic review, we aim to address this question. Specifically, we focus on the design considerations of digital games and how they support the development of EFs in this study. The following research questions guide our systematic review:

- RQ 1) What are the trends (e.g., target audience, sub-skills being targeted, game genres) in using digital games to improve EFs?
- RQ 2) What are the effects of digital games on EFs?
- RQ 3) What are the common game design considerations in digital games to improve EFs?

By addressing these questions, this systematic review aims to expand the growing body of literature on effective educational game interventions and to inform the design of future digital games for promoting EFs. In the following section, we discuss the methodology we used to identify the relevant studies.

Method

This systematic review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009) to synthesize findings on the effects of digital games on EFs in Pre-K–12 educational settings.

Inclusion and exclusion criteria

First, through an iterative process, the authors developed inclusion and exclusion criteria (see Table 1) to ensure the selection of relevant studies that were aligned with the research objectives. The inclusion criteria for this systematic review focused on available full-text studies published in English. We did not restrict the date range for selected studies to ensure the selection of studies aligned with the research objectives.

Table 1
Inclusion and Exclusion Criteria

	Inclusion criteria	Exclusion criteria
Language	English	Others
Relevance	Digital games, Executive functions, cognitive skills studies that examine the effects of the particular game or several games on EFs	No mention of digital game, Non-digital games, Studies that looked at correlations between gameplay and EFs irrelevant skills without having participants play any digital games
Type of study	Book chapters, dissertations, peer review articles, conference proceedings	Reports, reviews, and meta-analyses
Educational level & target audience	Pre-K–12 or the age range of 6–17 (even if the sample is a mix of people from k-12 and beyond)	Higher education, adult learning, students with disabilities

Search and screening process

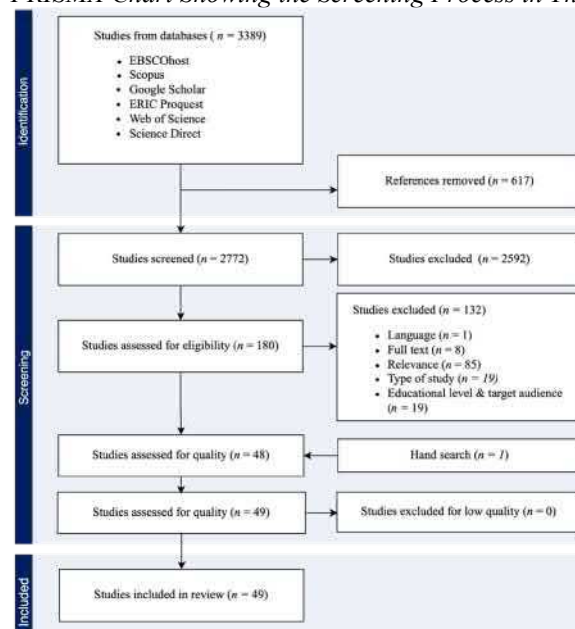
This systematic search was conducted across several academic databases, including EBSCOhost, ERIC, Web of Science, ScienceDirect, ProQuest, Google Scholar, and Scopus for comprehensive coverage of the studies in the literature. The search strings used were designed to capture a wide range of studies and included terms such as: (“executive function” OR “working memory” OR “task shifting” OR “inhibition” OR “task switching” OR “cognitive flexibility” OR “Cognitive ability” OR “Cognitive training” OR “cognitive processes” OR “cognitive control” OR “cognitive skills” OR “set shifting” OR “brain training”) AND (student OR “elementary education” OR “middle school” OR “high school” OR “junior high” OR “k-12” OR learner) AND (“digital game*” OR “video game*” OR game) NOT (ADHD OR “disease” OR “special education” OR impaired). The search terms are tailored for each database to align with its unique format. A combination of broad and narrow search terms was used to ensure comprehensive coverage of relevant literature.

The initial search retrieved 3389 studies across the databases. After removing duplicates, 2772 unique records were screened. The screening process involved two researchers who independently reviewed titles and abstracts, followed by a full-text review for studies meeting the inclusion criteria. We used Covidence (Veritas Health Innovation, 2023), a web-based tool designed to optimize systematic review workflows. Discrepancies in study selection were resolved through discussion and consensus. Following this process, 49 studies were selected for quality assessment.

Quality assessment

To ensure the included studies were of high quality, we used the Critical Appraisal Skills Programme (CASP) checklist (Singh, 2013) to evaluate the quality of the studies. CASP focuses on research goals, methods, and data collection as the main areas for quality in research articles. The quantitative studies ($n = 44$) and mixed-methods studies ($n = 5$) were assessed using a modified CASP checklist with additional criteria from Pluye et al. (2009), including sampling, measurement, confounding variables, and generalizability. Mixed-methods studies also included criteria assessing data integration and the reliability of findings. Studies were rated as high (greater than 70%), medium (40 – 70%), or low (lower than 40%) quality. A second reviewer validated the ratings and confirmed that all studies met the minimum quality threshold of 40%. As a result, all 49 studies were included.

Figure 1
PRISMA Chart Showing the Screening Process in This Systematic Review



Data extraction and synthesis

After identifying the studies, we extracted relevant data that could address our research questions. We used a standardized form that included information about the publication year, country, target population, study design, and findings related to EF outcomes. Next, we analyzed the extracted data to identify themes, methodological trends, and gaps in the literature regarding the promotion of EFs through digital games in Pre-K–12 settings. Table 2 presents a sample of the studies we reviewed.

Table 2
Selected Studies in this Systematic Review (N = 49)

First author (Year)	Field of study	Country	TA	SEF	SZ	Effects	Game name	Genre	Q (%)
Conesa, P. J. (2021)	ED	Spain	ES	I & WM	713	Mixed	Cognifit	BT	100
Le, M. (2020)	ED	France	ES	I & CF	205	Mixed	Brume	BT	75
Li, J. (2020)	ED	US	H	WM & I & CF	40	Positive	Reflex	BT	100
St.Clair- Thompson, H. (2010)	Psychology	UK	ES	WM	254	Positive	Memory Booster	Puzzle	75
Plass, J. L. (2019)	ED	US	MS & HS	CF	101	Positive	Alien Game	Puzzle	100
Núñez Castellar, E. (2015)	Psychology	Belgium	ES	WM	67	Positive	Monkey Tales	Puzzle	100
Pawar, S. (2020)	CS	US	MS & HS	WM & I & CF	317	Positive	Alien Game	Puzzle	100
Johann, V. E. (2019)	NP	Germany	ES	I & CF	153	Positive	Kingdom Asfallon	BT	100
Boendermaker, W. J. (2018)	Psychology	ND	HS	WM	84	Positive	City Builder	SB	100
Nin, V. (2023)	NP	Uruguay	PR	I & WM & P	137	No Effect	Mate Marote	BT	87.5
Homer, B. D. (2019)	NP	US	MS & HS	CF	233	Positive	Alien Game	SG	87.5
Rosas, R. (2019)	ED	Chile	PR	WM & I & CF	70	Positive	Custom	SG	70
Hsieh, C.Y (2019)	ED	Taiwan	ES	I	123	Positive	Pokemon Go	Action	95

Note. ED = Ed CS = Computer Science, NP = Neuropsychology, ND = Netherlands, TA = Target Audience, ES = Elementary School, MS = Middle School, HS = High School, PR = Primary School, P = Pre-K–12, SEF = Sub-facet of EF, I = Inhibition, WM = Working Memory, CF = Cognitive Flexibility, P = Planning, SM = Simulation, SG = Serious Game, SB = Sandbox, BT = Brain Training Q = Quality

Results

RQ 1: What are the trends in using digital games to improve EFs?

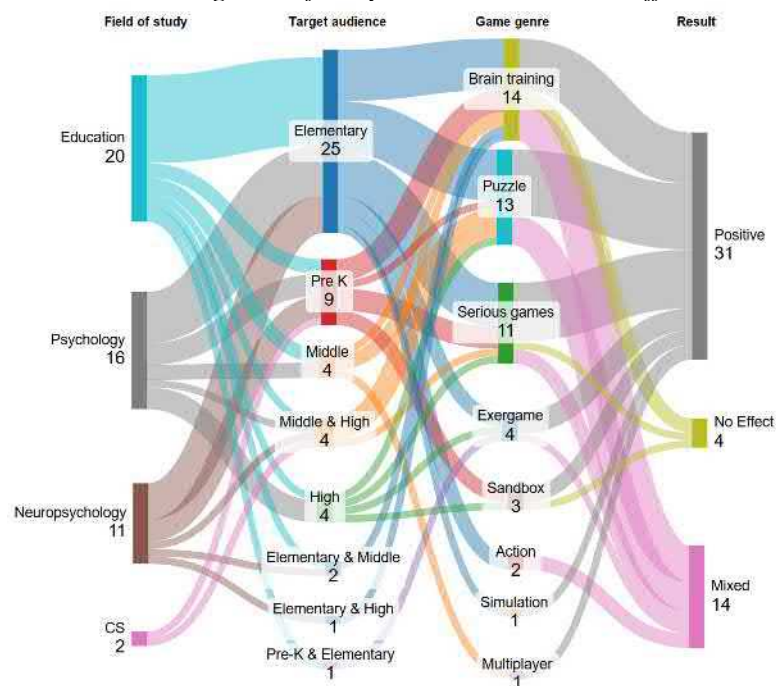
The included studies comprised journal articles ($n = 39$), conference proceedings ($n = 5$), and dissertations ($n = 5$). Most studies were conducted in the United States ($n = 13$), followed by Brazil ($n = 4$), Argentina ($n = 3$), Spain ($n = 2$), Canada ($n = 2$), and Australia ($n = 2$). One study each came from Germany, China, and the United Kingdom. This distribution demonstrates global interest and highlights the international scope of research on digital games for EFs.

Reviewed studies investigate the sub-facets of EFs working memory ($n = 19$), followed by inhibition ($n = 14$), and cognitive flexibility ($n = 4$). Visuospatial working memory (VSWM) was addressed in only one study ($n = 1$). However, most studies investigated multiple sub-facets of EFs that reflect interconnected and hierarchical nature of executive function components. A notable number of studies combined working memory, inhibition, and cognitive flexibility ($n = 10$), while others focused on inhibition and cognitive flexibility ($n = 7$) or inhibition and working memory ($n = 7$). Higher-order EFs, such as problem-solving and planning, were explicitly addressed in a smaller subset of studies ($n = 7$). This pattern shows a balanced research focus on foundational EFs and their integration with higher-order cognitive processes in targeted interventions.

Figure 2 illustrates the connections between the four key variables examined in this systematic review: field of study, target audience, game genre, and result. The first layer categorizes the field of study, which contains

Education ($n = 20$), Psychology ($n = 16$), Neuropsychology ($n = 11$), and Computer Science ($n = 2$). The second layer presents target audiences. These studies highlighted the variety of platforms used to share research on EFs. Participants in reviewed studies ranged from Pre-Kindergarten (Pre-K) to high school. Participants in the reviewed studies ranged from Pre-K-12 to high school, with the largest group comprising elementary school students ($n = 25$), followed by Pre-K students ($n = 9$), and smaller representations from middle school ($n = 4$) and high school students ($n = 4$). Additionally, there were mixed-age group studies ($n = 7$). The third layer highlights the game genres that have been used in studies that we reviewed. Plass et al. (2015) mentioned different genres in digital games. In the current study, Brain Training Games (i.e., commercially available games designed to enhance cognitive abilities, e.g., *Lumosity*) were the most frequent genre ($n = 14$), followed closely by Puzzle Games (i.e., games that challenge players' reasoning and problem-solving skills, e.g., *Tetris*) ($n = 13$) and Serious Games (i.e., games designed primarily for educational or training purposes, e.g., *DuoLingo*) ($n = 11$). Exergames (i.e., games that combine physical activity with gameplay, e.g., *Wii Fit*) were included in a smaller number of studies ($n = 4$), while Sandbox games (i.e., games that encourage creativity and exploration, e.g., *Minecraft*) appeared in even fewer cases ($n = 3$). Action games (i.e., fast-paced games focused on physical challenges, e.g., *Call of Duty*) ($n = 2$), Multiplayer games (i.e., games emphasizing cooperative or competitive play among multiple players, e.g., *Among Us*) ($n = 1$), and Simulation games (i.e., games that replicate real-world activities for learning or entertainment, e.g., *The Sims*) ($n = 1$) were the least frequently represented genres. The final layer shows study outcomes. Most studies reported positive effects ($n = 31$), while a few found no significant impact ($n = 4$), and some reported mixed results ($n = 14$).

Figure 2
The Relation Among Field of Study, Game Genre, and the Effect



Note. CS = Computer Science, High = High School.

RQ 2) What are the effects of digital games on EFs?

As mentioned above, the majority of the included studies investigating the effects of digital games on EFs reported positive outcomes ($n = 31$), with some mixed results ($n = 14$) and a few showing no effects ($n = 4$). Although further speculation on these results is beyond the scope of this systematic review, meta-analyses may offer further insights. We now turn to these studies and present our analysis of the effects we reported. Games designed with adaptive mechanics, and targeted cognitive tasks often demonstrated improvements in EFs components such as working memory, task-shifting, and selective attention. For example, studies using puzzle and strategy games (Plass, 2019; St. Clair-Thompson, 2010) revealed that incorporating dynamic and engaging elements could enhance cognitive flexibility and adaptability. Similarly, brain training games strengthen working memory, inhibition, and problem-solving through repetitive cognitive challenges tailored to participants' abilities (Ramsay,

2015). Games tailored to individual differences in cognitive abilities, such as the *Reflex*TM platform, were found to have promising results by addressing visuospatial working memory and anxiety (e.g., Li, 2020). However, not all EF domains were equally impacted in these studies; while some games effectively improve task-switching or memory (Le, 2023; Plass, 2019), others fail to address skills such as inhibition (Le, 2023). This finding underscores the importance of alignment between game design and targeted EFs outcomes. The diversity in game genre and methodologies contributes to variations in observed effects. Brain training games, such as *City Builder*, which integrated working memory training with game mechanics, often succeeded in improving motivation and engagement but showed comparable cognitive gains to non-gamified versions (Boendermaker, 2018). Moreover, while some studies demonstrated significant improvements in emotional intelligence and sociability alongside EFs enhancements, as seen with *Pokémon GO* (Hsieh, 2019), others highlighted limited effects in specific areas such as cognitive flexibility (St Clair-Thompson, 2010). These findings suggest that while digital games hold promise for supporting EFs, their effectiveness depends on the EFs sub-facets they target, game design preferences, and the context in which they are implemented.

Moreover, the transferability of EFs into real-world settings remains a key area of interest in reviewed studies. Results in this area are varying across studies. For example, Goldin et al. (2014) demonstrated a far transfer of EFs to academic domains. Elementary school students showed significant improvements in language and math performance, which highlights the potential for EFs-focused digital game interventions to impact real-world educational outcomes. Some studies found promising results regarding the far transfer of working memory capacity. Ramani et al. (2020) reported sustained improvements in working memory several weeks after training. Results show the potential for digital game interventions to foster lasting cognitive skills. Similarly, Johann and Karbach (2019) found long-term transfer effects of game-based EFs training. Game-based inhibition training led to lasting improvements in reading speed, and cognitive flexibility training resulted in sustained gains in reading comprehension. On the other hand, some studies find contradicting results. Flynn and Richert (2017) cannot confirm whether the observed short-term change in EFs can transfer to other contexts over time. Even though studies found limited evidence of far transfer effects for some sub-facets of EFs, researchers suggested that the results might be task-specific and should be addressed in future research (Dörrenbächer et al., 2014).

RQ 3) What are the common game design considerations in digital games that can improve EFs?

Reviewed studies analyzed game design integration into the improvement EFs at two levels: *high* and *low*. Most studies demonstrated high integration ($n = 27$), where games were explicitly designed or significantly modified to enhance EFs. For example, Berg et al. (2021) aimed to develop and test *eFun* designed to measure and improve EFs in primary school children. *eFun* used engaging game elements such as interactive stories, fun characters, and adaptive difficulty levels. The results showed that these game elements improved task engagement and supported the development of EFs. Similarly, Ober et al. (2021) investigated patterns of engagement and impact on inhibition in a custom-made digital game named *Gwakkamole*. *Gwakkamole* has game elements such as Go/No-go tasks, adaptive difficulty, and delayed response mechanics. Results showed students improved inhibition skills based on reaction time and accuracy when playing *Gwakkamole*. High-level game design integration studies also used targeted mechanics such as adaptive difficulty or incentive systems. For instance, Li (2020) aimed to examine how adaptive difficulty in the *Reflex*TM game-based platform influenced elementary students' math fact mastery and EFs. *Reflex*TM adjusted the difficulty of math problems based on each student's performance. The results showed that adaptive difficulty improved students' math skills and executive functions, especially for students with strong visuospatial working memory. However, Pawar (2020) found contrasting results. The researchers used a custom-designed game called *All You Can E.T.* to explore task-shifting skills in three different adaptive conditions. Researchers adjusted the difficulty level of the game in adaptive conditions. However, there is no significant difference found in EFs between the treatment and control groups. Moreover, incentive systems are a commonly used game design element in high-level integration games (Castellar et al., 2015; Alzubi et al., 2018; Weijer-Bergsma et al., 2016; Ramos et al., 2019). Various forms of incentives, such as rewards (Berg et al., 2020), bonus points (Rosas et al., 2019), and stars (Tam, 2023), are frequently employed across studies. Incentive systems are shown to be effective in working memory (Berg et al., 2020). Additionally, narration is another game design element used and shown to be effective in high-integration games like *BrainWare Safari* (Sittiprapaporn, 2019) and *Memory Booster* (St. Clair-Thompson et al., 2010).

Several studies fell under the low integration category ($n = 21$). The studies in this category included games that were pre-existing (not specifically designed to target EFs) or focused primarily on other skills, with EFs improvement as a secondary or indirect outcome. For example, Lorant and Lieury (2014) investigated the effects of different types of digital games on the development of cognitive skills and academic achievement in elementary school students. The recreational games used in this study, such as *Kawashima's Brain Training*, *Big*

Brain Academy and *New Super Mario Bros*, lacked specialized design elements targeting EFs development. Results showed no statistically significant improvements in EFs or academic achievement in these games. In another study, Monteiro et al. (2021) introduced an Attentional Skills Training (AST) program for elementary school students that focused on enhancing attentional and EFs. The study included games named *Attention Bird Alert*, *Climb It*, and *Twins*, which targeted visual processing, working memory, decision-making, and inhibitory control. The results showed a 40–50% improvement in attentional skills on standardized visual decision-making tasks. However, there were no significant changes in mindfulness self-reports or parent-reported EFs.

Discussion

EFs have been recognized as critical for cognitive and academic development (Miyake et al., 2000; Diamond, 2013). This review identified 49 studies in the literature that used digital games to improve EFs, including working memory, inhibition, and cognitive flexibility. The first key point of discussion is the diversity of research fields, EF sub-facets, and target audiences represented in the reviewed studies. Researchers from fields such as psychology, neuropsychology, education, and computer science contributed to this body of work, spanning various global contexts. These studies often targeted specific EF subdomains, with participants ranging from Pre-K to high school. Elementary school students comprised the largest group, reflecting the emphasis on early cognitive development.

Additionally, the interconnected and hierarchical nature of EFs resulted in some inconsistency in outcomes and focus areas. For example, some studies specifically targeted working memory or inhibition, while others focused on different sub-facets such as the cognitive flexibility of EFs. This variability highlights the complexity of EFs as a construct and the challenges in designing interventions that comprehensively address its multiple dimensions.

Despite these challenges, the findings reveal both opportunities and limitations in using digital games to foster transferable EFs. While some studies demonstrate promising far transfer effects, others highlight variability and task-specific outcomes. This inconsistency suggests that the design and context of interventions play a crucial role in determining their effectiveness. Notably, games with high levels of integration EFs consistently demonstrated positive outcomes, particularly in enhancing cognitive flexibility, working memory, and inhibition simultaneously. These games used complex, adaptive challenges that required players to engage in sustained mental effort and strategic thinking. Plass et al. (2019) found that digital games designed with adaptive difficulty adjustments effectively improved task-shifting skills across various age groups. Similarly, Homer et al. (2019) reported that emotionally engaging game designs activated adolescents' EFs and led to significant improvements in cognitive flexibility. Well-crafted interventions can lead to significant promise for improving EFs. However, studies reporting mixed or no effects suggest the need for further investigation into factors such as game design, duration of interventions, and contextual variables that may influence outcomes (Diamond & Ling, 2020).

The findings highlight the critical role of intentional and targeted design in digital games aimed at enhancing EFs. High-integration games, which incorporate features such as adaptive difficulty, incentive systems, and engaging narratives, demonstrate significant potential for improving specific EF skills. However, the variability in outcomes across studies underscores the complexity of designing universally effective interventions. Mixed results suggest that contextual factors, such as the implementation of game mechanics, the duration of gameplay, and individual differences among participants, significantly influence the efficacy of these interventions. In contrast, low-integration games often lack the specialized mechanics needed to directly target EFs, resulting in limited or secondary improvements. These findings suggest that while general-purpose games may support some cognitive skills, their impact on EFs is inconsistent and less pronounced. Moving forward, it is essential to explore how game mechanics can be optimized to address the nuanced demands of EFs, ensuring that interventions are both engaging and effective. Additionally, further research should investigate how contextual variables, such as classroom integration and player motivation, interact with game design to influence EF development. Future research will explore how specific game design elements impact EFs to provide clearer insights into their effectiveness. This focus will guide researchers in developing more targeted and effective games for enhancing EFs across various contexts.

Conclusion

EFs are critical for cognitive skills that influence planning, problem-solving, and decision-making in our daily lives. This study reviewed the existing literature to assess the potential of digital games to enhance EFs. Digital games have shown promise as tools for strengthening EFs and have demonstrated evidence of transfer to real-world outcomes. However, this review highlights a gap in comprehensive studies specifically designed to improve the long-term impact of game-based interventions on EFs. Addressing this gap could open new pathways for

researchers to design targeted, evidence-based digital games that support the development of these essential cognitive skills.

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