THE ROLE OF TECHNOLOGY IN THE COGNITIVE DEVELOPMENT OF CHILDREN

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This is to certify that I have examined this copy of a doctoral thesis by

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STATEMENT OF AUTHORSHIP

This dissertation contains no material that has been accepted for any awards or other degrees or diplomas in any university or other institution. It is affirmed by the candidate that, to the best of her knowledge, the dissertation contains no material previously published or written by another person, except where due reference is made in the text of the dissertation.

Meryem Şeyda Özcan

DISSERTATION ABSTRACT

Digital technologies have become an integral part of children's everyday lives, shaping how they interact with their environments and engage in technology-related activities. This dissertation examines how children's experiences with digital technology, both as consumers and producers, are associated with executive function (EF) skills, which are essential for goal-directed behavior, self-regulation, and learning. Guided by the Dynamic, Relational, Ecological Approach to Media Effects Research (DREAMER), this dissertation investigates the cognitive effects of technology use during early and middle childhood, with attention to factors such as media content, context, and relational processes.

The dissertation comprises four interrelated studies that together capture the role of technology from consumer to producer perspectives. **Chapter Two** presents a meta-analysis of 30 studies (N = 7,740) examining the relationship between media use and EF in children aged 0–6. Findings indicate that interactive media use, when limited in duration, is positively associated with EF, whereas extended exposure to receptive or uncategorized media is negatively associated. **Chapter Three** builds on these results through an empirical study of preschool-aged children, testing potential mediators (i.e., sustained attention, displacement of play) and moderators (i.e., educational content, parental mediation, child temperament) in the media–EF link. Results showed that media type mattered: playing digital games was positively associated with EF, whereas watching videos was not significantly related. Mediation analyses revealed no significant indirect effects via sustained attention or displacement of activities. Of the tested moderators, only negative affectivity emerged as significant, revealing nuanced patterns in how temperament may influence the media–EF association.

Chapter Four shifts focus to the producer role, synthesizing 18 studies on programming education. Results suggest that coding interventions are associated with improvements in higher-order EF skills such as planning and problem-solving, though methodological limitations were identified. **Chapter Five** addresses these limitations through a randomized controlled trial with 174 fourth-grade students. Findings indicated that children in the coding group showed significant improvements in computational thinking (near transfer), whereas far-transfer effects on broader cognitive skills were not observed compared to reading and mathematics intervention groups.

Together, these studies highlight the complex and context-dependent ways in which children's technology use relates to EF development. The findings support the value of a theoretical framework that considers media content, usage context, and relational processes. This dissertation contributes to a more nuanced understanding of how technology engagement is linked to children's cognitive development and offers considerations for future research, educational practices, and policy.

TEZ ÖZETİ

Dijital teknolojiler, çocukların günlük yaşamlarının ayrılmaz bir parçası hâline gelerek onların çevreleriyle etkileşim kurma biçimlerini ve teknolojiyle ilişkili etkinliklere katılımını şekillendirmektedir. Bu tez, çocukların dijital teknolojilerle hem tüketici hem de üretici olarak edindikleri deneyimlerin, amaçlı davranış, özdenetim ve öğrenme için kritik öneme sahip olan yürütücü işlev (Yİ) becerileri ile nasıl ilişkili olduğunu incelemektedir. Medya Etkileri Araştırmalarına Dinamik, İlişkisel, Ekolojik Yaklaşım (DREAMER) çerçevesinde yürütülen bu çalışma, erken ve orta çocukluk dönemlerinde teknoloji kullanımının bilişsel etkilerini; içerik, bağlam ve ilişkisel süreçler gibi önemli faktörleri dikkate alarak araştırmaktadır.

Tez, teknolojiyle etkileşimin tüketici ve üretici rollerini kapsayan dört birbiriyle ilişkili çalışmadan oluşmaktadır. **İkinci bölüm**, 0–6 yaş arası çocuklarda medya kullanımı ile Yİ arasındaki ilişkiyi inceleyen 30 çalışmanın (N = 7.740) meta-analizini sunmaktadır. Bulgular, sınırlı süreli etkileşimli medya kullanımının Yİ ile pozitif yönde ilişkili olduğunu, ancak uzun süreli alıcı türde veya türü belirlenmemiş medya kullanımının Yİ ile negatif yönde ilişkili olduğunu göstermektedir. **Üçüncü bölüm**, okul öncesi çocuklarla yürütülen ampirik bir çalışma ile bu sonuçları genişletmekte; aracı değişkenler (örn., sürdürülen dikkat, oyun etkinliklerinin yerini alma) ve düzenleyici değişkenleri (örn., eğitsel içerik, ebeveyn arabuluculuğu, çocuk mizacı) test etmektedir. Bulgular, medya türünün önemli olduğunu göstermiştir: dijital oyun oynamak Yİ ile pozitif yönde ilişkili bulunurken, video izleme ile Yİ arasında anlamlı bir ilişki saptanmamıştır. Aracılık analizleri, sürdürülen dikkat veya etkinliklerin yerini alma üzerinden anlamlı dolaylı etkiler ortaya koymamıştır. Test edilen düzenleyiciler arasında yalnızca olumsuz duygulanım anlamlı bulunmuş ve mizacın medya–Yİ ilişkisini nasıl şekillendirebileceğine dair nüanslı örüntüler ortaya çıkmıştır.

Dördüncü bölüm, üretici rolüne odaklanarak programlama eğitimi üzerine yürütülmüş 18 çalışmayı sentezlemektedir. Bulgular, kodlama müdahalelerinin planlama ve problem çözme gibi üst düzey Yİ becerilerinde gelişim ile ilişkili olduğunu, ancak yöntemsel sınırlılıklar bulunduğunu göstermektedir. **Beşinci bölüm**, bu sınırlılıkları 174 dördüncü sınıf öğrencisi ile yürütülen bir rastgele kontrollü deney ile ele almaktadır. Sonuçlar, kodlama grubundaki çocukların bilişimsel düşünme (yakın aktarım) becerilerinde anlamlı gelişim gösterdiğini, ancak okuma ve matematik gruplarına kıyasla daha geniş bilişsel becerilerde (uzak aktarım) anlamlı farklılıklar bulunmadığını ortaya koymuştur.

Genel olarak bu çalışmalar, çocukların teknoloji kullanımının yürütücü işlev gelişimi ile olan ilişkisinin karmaşık ve bağlama bağlı olduğunu vurgulamaktadır. Bulgular, medya içeriği, kullanım bağlamı ve ilişkisel süreçleri dikkate alan kuramsal yaklaşımların önemini desteklemektedir. Bu tez, teknoloji ile etkileşimin çocukların bilişsel gelişimi ile nasıl bağlantılı olduğuna dair daha incelikli bir anlayış sunmakta ve gelecekteki araştırmalar, eğitim uygulamaları ve politika için çeşitli öneriler getirmektedir.

DEDICATION

To my family: past, present, and future

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CHAPTER 1

The Role of Technology in the Cognitive Development of Children

Technology plays an increasingly prominent role in children's lives, with its presence continuing to grow yearly (Rideout & Robb, 2020). For example, children aged 0–8 spend approximately 2.5 hours per day on screens in the United States. The time spent using technology increases to over 4 hours for children aged 8–12 and nearly 7.5 hours for adolescents aged 12–18 (Rideout et al., 2022; Rideout & Robb, 2020). Children engage with technology through various activities, including watching television at home, playing video games with peers, exploring educational apps, and learning to program in school. Despite the diversity of these experiences, they all involve some form of interaction with digital media. Accordingly, digital technology has become a central feature of children's everyday environments. Given the well-established influence of environmental contexts on child development (Rosa & Tudge, 2013), it is both timely and necessary to examine the developmental implications of children's technology use.

To investigate the role of technology in child development more comprehensively, it is helpful to distinguish between two broad roles children assume when engaging with technology: consumer and producer. These roles differ significantly in the cognitive demands they place on children (Bers, 2010; Papert, 1980). The consumer role typically involves passive or reactive interactions, such as watching television or using mobile applications, which have been shown to relate to children's attention, memory, and regulatory skills (see Chapter 2). In contrast, the producer role involves active creation, problem-solving, and iterative thinking those processes that are closely linked to higher-order cognitive development. Understanding this distinction is critical for evaluating the developmental implications of technology use.

While traditional forms of consumer media use, such as television viewing, have been extensively studied (e.g., Anderson & Pempek, 2005), further research is needed to clarify when, how, and why media use relates to various developmental outcomes. As educational systems increasingly incorporate programming and maker-centered learning into early curricula, children are not only consuming technology but also creating with it. This shift from passive to active engagement raises important questions about how producing technology may contribute to cognitive development, particularly in areas such as planning, reasoning, and problem-solving. Despite its growing relevance, the producer role has received far less empirical attention than media consumption and requires further investigation.

Executive functions (EFs) are a set of higher-order cognitive processes essential for goal-directed behavior, including inhibitory control, working memory, and cognitive flexibility. These foundational abilities enable children to regulate their actions, maintain attention, and adapt to changing circumstances. EFs emerge in early childhood and serve as the foundation for more complex skills such as planning, reasoning, and problem-solving (Miyake et al., 2000; Diamond, 2013). They are also closely linked to important developmental outcomes across multiple domains, including academic achievement (Blair & Raver, 2015), social competence (Best & Miller, 2010), and mental health (Zelazo & Müller, 2012). EFs are particularly relevant in digital contexts because they support children's ability to filter distractions, manage cognitive load, and persist through goal-directed tasks. These demands are especially pronounced in digital environments, which often feature rapid pacing, multiple streams of information, and competing sources of stimulation. Understanding how technology use influences these core cognitive systems is essential for designing developmentally appropriate learning experiences and media environments.

Given the increasing role of digital technologies in early childhood and education, it is crucial to examine how technology use—both in consumer and producer roles—may support or hinder the development of executive functions (EFs). This need is particularly pressing because existing research has produced mixed findings. Some studies report negative associations between excessive screen time and EF-related outcomes such as attention and self-regulation (e.g., Gueron-Sela & Gordon-Hacker, 2020; Corkin et al., 2021), whereas others find benefits linked to specific media formats, including interactive games and educational content (e.g., Yang et al., 2017; Rosenqvist et al., 2016).

Similarly, although coding education—where children assume the producer role in technology use—is often promoted for its potential to enhance cognitive skills, empirical support remains limited. To address these complexities, this dissertation adopts a comprehensive approach to examine the role of digital media in EF development. It makes a novel contribution by applying the Dynamic, Relational, Ecological Approach to Media Effects Research (DREAMER) framework (Barr et al., 2024) not only to children's media consumption but also to their technology production, an area that remains underexplored. By analyzing both naturalistic and structured interactions with technology, this research bridges multiple domains and addresses a critical gap in our understanding of how diverse technological experiences shape developing cognitive functions.

Theoretical Framework

The DREAMER framework (Barr et al., 2024) provides the theoretical foundation for this dissertation. This model moves beyond a simple focus on the quantity of screen time and instead emphasizes what children engage with, how and with whom they engage, and how these experiences evolve over time. Unlike earlier approaches that primarily centered on aggregate screen exposure, DREAMER conceptualizes media effects through three interrelated dimensions: the content of the media, the context in which media is used, and the relational processes surrounding media engagement. Content may vary in purpose, such as educational versus entertainment-oriented, or in style, such as fast-paced versus narrative-driven. Context refers to the setting in which media use occurs, for example during meals, before bedtime, or within classroom activities. Relational processes capture the social aspects of media engagement, including whether it is experienced with a caregiver, alone, or with peers or siblings.

These dimensions interact dynamically with children's individual characteristics, such as age, temperament, and prior experiences within their broader developmental ecology. The framework aligns with contemporary developmental science, which emphasizes multilevel, transactional, and contextually embedded influences on learning and cognition. By adopting a systems perspective, DREAMER helps explain why certain media uses may be beneficial in one context but detrimental in another, and why effects often vary across individuals, families, and cultures. Although DREAMER has been applied primarily to media consumption, it also offers a valuable structure for examining children's experiences as technology producers. Extending the framework to the producer role underscores the importance of learning context and relational engagement in coding and creative technology environments (see Bers, 2010; Strawhacker & Bers, 2019).

Building on this framework, the following chapters examine the role of digital media in EF development using diverse methodological approaches. Each chapter maps onto key elements of DREAMER and applies them across both naturalistic and structured technology experiences, as well as consumer and producer roles. By combining meta-analytic, observational, review-based, and experimental methods, this work provides both breadth and depth in understanding media's developmental impact. This methodological diversity enhances the ability to detect broad patterns while also identifying nuanced contextual effects.

Chapter Two presents a meta-analysis of 30 studies involving 7,740 children aged 0 to 6, examining how media content, such as interactive versus receptive media types and exposure duration relate to EF skills, including inhibition, working memory, and cognitive flexibility. While the overall association between media use and EF was non-significant, moderator analyses revealed that low-duration interactive content was positively associated with EF, whereas high-duration receptive or uncategorized media use was negatively associated. These results highlight the importance, emphasized in the DREAMER framework, of considering both media types and intensity when examining developmental outcomes.

Chapter Three builds on the meta-analytic findings through an empirical study with 94 preschool-aged children and their parents, focusing on both contextual and relational factors in the media–EF association. The study tested two potential mediators which were sustained attention and displacement of activities, and three moderators which were educational content, parental mediation, and child temperament (negative affectivity, effortful control, surgency). Media use was measured separately for watching videos and playing digital games, and EF outcomes included inhibition, visuospatial and phonological working memory, and cognitive flexibility. The results indicated that media type mattered where playing digital games was positively associated with EF, whereas watching videos was not significantly related. Mediation analyses revealed no significant indirect effects via sustained attention or displacement of activities. Of the moderators examined, only negative affectivity was significant for both media types, with patterns indicating nuanced ways in which temperament may shape media–EF links.

Chapter Four shifts the focus to the producer role, presenting a systematic review of 18 studies conducted between 2010 and 2024 that evaluated the effects of programming education on higher-order EF skills such as planning, problem-solving, and reasoning. Most studies reported positive effects, particularly for problem-solving and planning, although methodological limitations were common. In particular, many studies were not randomized controlled trials, limiting the generalizability of the findings. Additionally, results indicated that instructional strategies mattered above and beyond the amount of instruction children received. This chapter demonstrates how DREAMER can be applied beyond media consumption, emphasizing how instructional strategies in coding education may influence cognitive development. This chapter demonstrates how DREAMER can be applied beyond media consumption, emphasizing how instructional strategies in coding education may influence cognitive development.

Chapter Five addresses some of the limitations identified in the review through a 10-week randomized controlled trial with 174 fourth-grade students. Participants were randomly assigned to coding, math, or reading instruction, with equivalent instructional time. The study assessed computational thinking (near-transfer), fluid intelligence, and spatial orientation (far-transfer). Results indicated that only the coding group showed significant gains in computational thinking, while no group showed improvements in spatial orientation. Fluid intelligence improved across all conditions. This chapter operationalizes DREAMER's dimensions in a structured setting, illustrating how intentional design in both content and context can shape domain-specific cognitive outcomes.

Chapter Six synthesizes the findings across all four studies, reinforcing the value of the DREAMER framework in capturing the complex, multifaceted, and context-dependent nature of technology's influence on EF. The synthesis emphasizes that media use is not inherently beneficial or harmful, and its effects depend on the type, duration, and context of use. It also highlights that coding education holds promise for improving problem-solving and computational skills, although evidence for broader transfer remains limited. Finally, it calls for future research to prioritize methodological rigor and contextual sensitivity, offering practical recommendations for educational design and policy to support the developmentally informed integration of both media consumption and technology production into children's learning environments.

References

Anderson, D. R., & Pempek, T. A. (2005). Television and very young children. *American Behavioral Scientist, 48*(5), 505–522. https://doi.org/10.1177/0002764204271506

Barr, R., Dore, R. A., Nichols, D., & Troseth, G. (2024). The DREAMER framework: A dynamic, relational, and ecological approach to media effects research. *Child Development Perspectives*. Advance online publication. https://doi.org/10.1111/cdep.12487

Bers, M. U. (2010). *Blocks to robots: Learning with technology in the early childhood classroom*. Teachers College Press.

Best, J. R., & Miller, P. H. (2010). A developmental perspective on executive function. *Child Development, 81*(6), 1641–1660. https://doi.org/10.1111/j.1467-8624.2010.01499.x

Blair, C., & Raver, C. C. (2015). School readiness and self-regulation: A developmental psychobiological approach. *Annual Review of Psychology, 66*, 711–731. https://doi.org/10.1146/annurev-psych-010814-015221

Carlson, S. M., Mandell, D. J., & Williams, L. (2004). Executive function and theory of mind: stability and prediction from ages 2 to 3. *Developmental psychology*, *40*, 1105-1122. https://doi.org/10.1037/0012-1649.40.6.1105

Corkin, M. T., Peterson, E. R., Henderson, A. M., Waldie, K. E., Reese, E., & Morton, S. M. (2021). Preschool screen media exposure, executive functions, and symptoms of inattention/hyperactivity. *Journal of Applied Developmental Psychology*, *73*, 101237. https://doi.org/10.1016/j.appdev.2020.101237

Diamond, A. (2013). Executive functions. *Annual Review of Psychology, 64*, 135–168. https://doi.org/10.1146/annurev-psych-113011-143750

Gueron-Sela, N., & Gordon-Hacker, A. (2020). Longitudinal Links Between Media Use and Focused Attention Through Toddlerhood: A Cumulative Risk Approach. *Frontiers in psychology*, *11*. 569222. https://doi.org/10.3389/fpsyg.2020.569222

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: A latent variable analysis. *Cognitive Psychology, 41*(1), 49–100. https://doi.org/10.1006/cogp.1999.0734

Moffitt, T. E., Arseneault, L., Belsky, D., Dickson, N., Hancox, R. J., Harrington, H., ... & Caspi, A. (2011). A gradient of childhood self-control predicts health, wealth, and public safety. *Proceedings of the national Academy of Sciences*, *108*, 2693-2698. https://doi.org/ 10.1073/pnas.1010076108

Moreno-León, J., & Robles, G. (2016). Code to learn with Scratch? A systematic literature review. In *2016 IEEE Global Engineering Education Conference (EDUCON)* (pp. 150-156). IEEE.

Nikkelen, S. W., Valkenburg, P. M., Huizinga, M., & Bushman, B. J. (2014). Media use and ADHD-related behaviors in children and adolescents: A meta-analysis. *Developmental psychology*, *50*, 2228-2241.

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. Basic Books.

Rideout, V., & Robb, M. B. (2020). *The Common Sense Census: Media use by tweens and teens, 2020*. Common Sense Media. https://www.commonsensemedia.org/research/the-common-sense-census-media-use-by-tweens-and-teens-2020

Rideout, V., Peebles, A., & Robb, M. B. (2022). *The Common Sense Census: Media use by kids age zero to eight, 2022*. Common Sense Media. https://www.commonsensemedia.org/research/the-common-sense-census-media-use-by-kids-age-zero-to-eight-2022

Rosa, E. M., & Tudge, J. (2013). Urie Bronfenbrenner's theory of human development: Its evolution from ecology to bioecology. *Journal of Family Theory & Review*, *5*, 243-258. https://doi.org/10.1111/jftr.12022

Rosenqvist, J., Lahti-Nuuttila, P., Holdnack, J., Kemp, S. L., & Laasonen, M. (2016). Relationship of TV watching, computer use, and reading to children's neurocognitive functions. *Journal of Applied Developmental Psychology*, *46*, 11-21. https://doi.org/10.1016/j.appdev.2016.04.006

Scherer, R., Siddiq, F., & Viveros, B. (2018). The Cognitive Benefits of Learning Computer Programming: A Meta-Analysis of Transfer Effects. *Journal of Educational Psychology*. Advance online publication. https://doi.org/10.1037/edu0000314

Strawhacker, A., & Bers, M. U. (2019). "I want my robot to look for food": Comparing children's programming comprehension using tangible, graphical, and hybrid user interfaces. *International Journal of Technology and Design Education, 29*, 581–602. https://doi.org/10.1007/s10798-018-9440-2

Wing, J. M. (2006). Computational thinking. *Communications of the ACM*, *49*, 33-35. https://doi.org/10.1145/1118178.1118215

Yang, X., Chen, Z., Wang, Z., & Zhu, L. (2017). The relations between television exposure and executive function in Chinese preschoolers: The moderated role of parental mediation behaviors. *Frontiers in psychology*, *8*, 1833. https://doi.org/10.3389/fpsyg.2017.01833/full

Zelazo, P. D., & Müller, U. (2012). Executive function in typical and atypical development. In U. Goswami (Eds.), The Wiley-Blackwell handbook of childhood cognitive development (2nd ed., pp. 574-603). Wiley-Blackwell.

CHAPTER 2

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Exposure to Interactive Media, but at Low Levels, Is Associated with Better Executive Functioning in Children: A Meta-Analysis

Numerous studies have emphasized the importance of executive functions (EFs) in multiple dimensions of children's lives, spanning from academic accomplishments (Blair & Razza, 2007) to social relations (Razza & Blair, 2009). Notably, early childhood assumes particular significance in the development of EFs, given the substantial changes observed during this stage (Carlson et al., 2004; Marcovitch & Zelazo, 2009). Environmental factors especially play a crucial role in developing executive functions, particularly during early childhood (Zelazo & Carlson, 2012). Screen media is a prevalent component of children's daily routines, with an average of 2 to 3 hours spent engaging with media (Common Sense Media, 2020), it has become essential to consider it as a potential environmental influence that impacts EF development (Jusienė et al., 2020). Previous research has yielded mixed results regarding the association between media exposure and executive functions (Barr et al., 2010; Nathanson et al., 2014). The complex nature of media-related activities likely contributes to these varying findings (McHarg et al., 2020; Yang et al., 2020). To investigate this matter comprehensively, the current study seeks to conduct a meta-analysis to explore the relation between media usage in young children and their executive functions. Through this research, valuable insights will be gained regarding how media interactivity type and the extent of exposure to executive functions can have an influence on this association.

Executive Functions

Executive functions are a collection of cognitive skills that are related but distinct from one another (Miyake et al., 2000). Traditionally, these functions are divided into two main categories: lower-order skills, which encompass inhibition, working memory (WM), and cognitive flexibility (Diamond, 2013), and higher-order skills, which involve planning, problem-solving, and reasoning (Diamond, 2013). It is worth noting that higher-order skills necessitate a combination of lower-order skills, making the latter the core components. Among these core components are cognitive inhibition, which involves suppressing dominant responses in the presence of competing information; working memory, entailing the capacity to retain and manipulate perceptually absent information; and cognitive flexibility, enabling the adaptation to new demands by shifting perspectives (Diamond, 2013).

According to a prominent view in the literature on executive functions, the fundamental components are interconnected but different from each other (Miyake et al., 2000). For example, inhibiting a dominant response requires holding relevant information in mind, and conversely, holding information in mind necessitates inhibiting irrelevant information. In addition to each having unique requirements, this dynamic relation has led to the proposal that the different components of EFs share a common factor (Miyake et al., 2000).

Previous research has indicated that executive functions may initially start as a unified factor but diverge as individuals age (Anderson, 2002; Brydges et al., 2014). Additionally, the core EF skills vary in complexity depending on the specific EF tasks (Anderson et al., 2001; Best & Miller, 2010). For instance, a cognitive flexibility task requires utilizing both inhibition and working memory for successful performance (Diamond, 2013).

Executive Functions and Media Usage

Research exploring the connection between media usage and executive functions has yielded inconsistent results. Media usage is a multifaceted concept, including diverse content and tools. Previous studies have categorized media content into two primary headings: educational media and pure entertainment media (Nikkelen et al., 2014). Within these categories, media use may involve various tools, such as television (TV), computers, or touchscreen devices, and comprises a range of activities, including watching programs on TV/ touchscreen devices or playing games on computers/ handheld devices (Jusienė et al., 2020).

When exploring the mechanism underlying the link between media and executive functions, one notion is that the content of the media plays a crucial role in determining its impact on EFs (Barr et al., 2010; Christakis, 2009). Educational media, particularly for young children, has been suggested to have either a positive or neutral relation with EFs (e.g., Barr et al., 2010; Blankson et al., 2015; Radesky & Christakis, 2016). Conversely, the effects of entertainment media tend to be neutral or negative. However, the findings on the association between EFs and entertainment media have been inconsistent. While some studies have found evidence supporting the detrimental effects of media exposure on EFs (e.g., Harmon, 2021; McHarg et al., 2020; Suggate & Martzog, 2021), others have reported no significant relation between media exposure and EFs (e.g., Jusienė et al., 2020).

One possibility is that this relation may vary across different types of media tools. For instance, a study found that computer use was positively linked to EFs, whereas TV viewing was negatively associated (Rosenqvist et al., 2016). To gain a comprehensive understanding, the literature requires a synthesis of media usage and EFs to elucidate the conditions and types of media that are linked with EFs.

The literature has put forth several hypotheses to explain the potential negative association between entertainment media usage and the executive functions of young children. The most prominent theory is the displacement theory, which suggests that media usage displaces other activities that could otherwise benefit executive function development (Himmelweit et al., 1958; Krcmar et al., 2007; Kostyrka-Allchorne et al., 2017; Naigles &

Mayeux, 2001; Neuman, 1988). In simpler terms, because children have limited time during the day, engaging in media activities may lead them to miss out on other crucial activities, such as play or social interaction (Hinkley et al., 2014; Veraksa et al., 2021). Relatedly, studies have found that children engage in less play during television viewing (Barr et al., 2010; Blankson et al., 2015), which is an essential component in executive function development (Carlson & White, 2013). Similarly, the presence of background television has been shown to impact the quality and quantity of parent-child interaction negatively (Krikorian et al., 2009).

The second hypothesis proposed that media usage may have an adverse impact on attention development (Corkin et al., 2021; Gueron-Sela & Gordon-Hacker, 2020). Media programs often have a rapid pace and use cuts/edits, potentially teaching children a problematic type of attention known as scan-and-shift attention, which captures attention in a bottom-up manner (Jensen et al., 1997; Yang et al., 2017). The fast-paced nature of media content captures attention and limits the practice of attention regulation (Lillard & Peterson, 2011), potentially causing children to become accustomed to processing information in brief and superficial segments (Nathanson et al., 2014). Being accustomed to this type of attention might be detrimental to voluntary control of sustained attention, a crucial aspect of executive function skills (Jensen et al., 1997). Furthermore, children often consume media while engaging in other activities, such as eating, in environments with numerous distractions (Barr et al., 2010). As a result, frequent distractions may disrupt voluntary attention skills (Barr et al., 2010), making it challenging for children to participate in activities requiring sustained attention or inhibit dominant needs, such as reading or other tasks that necessitate executive functions (Christakis, 2009).

In a similar vein, it has been proposed that media usage may restrict opportunities for practicing self-regulation. For example, parents might use media tools to manage children's distress by allowing them to watch cartoons when they refuse to eat (Gueron-Sela & Gordon-Hacker, 2020). Additionally, media exposure has been suggested to increase dopamine release, leading to feelings of reward and pleasure (Dresp-Langley, 2020). Consequently, this may cause children to prefer activities that provide instant dopamine release while disliking activities that do not offer the same immediate reward.

Potential Moderators

Media Interactivity

Previous literature has presented various explanations for the relation between media usage and executive functions, with most of the support stemming from studies conducted with television (Hinkley et al., 2014). Consequently, the prior proposed explanations are primarily relevant to television use. However, other media forms, such as computers, touchscreen devices, or video games, may impact EF differently due to their distinctive nature, which allows for potential interactivity (McNeil et al., 2021). As a result, the effects of these different media forms on executive functions may diverge from those observed with traditional television viewing.

The media literature typically categorizes media interactivity into interactive (e.g., playing games) or receptive (e.g., viewing a cartoon) types (Suggate & Martzog, 2021). Children's activity levels during media consumption can vary depending on the activity or the media tool used (Hu et al., 2020; Jusienė et al., 2020; Nathanson & Beyens, 2018). Anderson and Davidson (2019) provided explanations for these terms. "Receptive media" refers to media that can be understood and perceived without requiring explicit responses, such as watching TV. The term "passive" is not preferred because it implies that the viewer is not mentally engaged. On the other hand, interactive media like video games necessitate some form of response from the user for the content to progress. Receptive media follows a predetermined course as long as the viewer pays attention, while interactive media can be influenced by the user's actions. Due to these differences in the interactivity levels of various media interactions, it has been suggested that active and receptive media usage may have varying effects on developmental outcomes (Hu et al., 2020; Veraksa et al., 2021). Moreover, Anderson and Davidson (2019) proposed that different brain pathways can be active during receptive or interactive media exposure.

Interactive media usage such as playing video games, has the potential to enhance executive functions (Yang et al., 2021). For instance, certain studies have suggested that expert video game players perform better in all three core EF tasks (inhibition, working memory, and shifting) (e.g., Boot et al., 2008). Engaging with interactive media, including video games or apps, offers children opportunities to practice these core EFs (Nathanson & Beyens, 2018). Consequently, interactive media usage might not have adverse effects like those associated with receptive media usage. On the other hand, interactive and receptive media still share some similarities, such as displacing other activities or practicing problematic attention types. For example, video game playing can lead to increased dopamine release, potentially causing children to lose interest in other activities that do not provide immediate dopamine rewards. Additionally, parents may allow their young children to play games in settings where they might practice regulatory skills, limiting opportunities for self-regulation skill development.

Touchscreen devices, computers, or smartphones provide a unique situation where children can stream programs and play games with them. This versatility allows parents and children to interact while using these devices, as they can pause or replay the content based on the child's needs (Estraisch, 2018; Nathanson & Beyens, 2018). The relation between the use of devices and executive functions would be more similar to receptive media consumption. The reason is that previous findings have shown that young children spend the majority of their media usage time (approximately 70%) on receptive activities, such as watching TV or using other program viewing tools (Common Sense Media, 2020). Additionally, these devices are often given to children to provide entertainment during challenging situations, like car rides or dinner, which may limit opportunities for self-regulation (Nathanson & Beyens, 2018).

Duration of Media Use

The duration of media exposure also plays a significant role in the association (Nikkelen et al., 2014). For instance, previous longitudinal studies have demonstrated that the duration of time children spend exposed to media is linked to lower performance on executive function tasks (e.g., Blankson et al., 2015). The overall duration of media exposure measured in studies can vary due to differences in samples (e.g., Antrilli et al., 2018; Nathanson & Fries, 2014). According to the displacement theory, the quantity of media exposure could account for differences in the relations found across various studies. In other words, the more time children spend with media, the less time they will have for other activities.

Previous Reviews

Several systematic and literature reviews have been conducted on media use and cognitive development. One systematic review, for example, examined the relation between television viewing and various outcomes, including executive functions, attention, academic performance, language, and play (Kostyrka-Allchorne et al., 2017). After analyzing 76 studies, they found that the relation between television viewing and child outcomes is complex and may be influenced by individual characteristics, family contexts (such as co-viewing or family socioeconomic status), and the type of exposure. For instance, they suggested that watching educational content during preschool may have positive effects, but it might have a negative relation during infancy. Further, the review suggested that the link between television exposure and child outcomes depends on child characteristics, TV program content, and contextual factors. For instance, a negative relationship between television watching and executive functions (EFs) was found in high-risk families in one study (Linebarger et al., 2014), but this was not replicated in another study (Nathanson et al., 2014). This highlights the importance of contextual factors in the relationship between TV exposure and child outcomes. While the review provided valuable insights, it did not empirically test the relationship. Additionally, its focus on television viewing alone does not offer insights into the role of other media interactivity categories. Another systematic review, which included 11 studies, investigated the impact of touchscreen devices on the cognitive development of children under five years of age (Rocha & Nunes, 2020). They concluded that, in general, the use of touchscreen devices tends to have more adverse effects, and the content and context of media use might play a crucial role in determining the outcomes. This systematic review provided valuable insights into the use of touchscreen devices but did not test the impact of different media interactivity categories on child outcomes. Additionally, the limited number of articles included in the review covered broad subjects, making it challenging to draw specific conclusions about EFs. A more recent and comprehensive systematic review, including 39 articles, aimed to explore the relation between screen media use and self-regulatory skills (Uzundag et al., 2022). The review highlighted that the type of media use, content, and context of media usage could moderate the relation. For instance, watching fantastical content was suggested to be negatively associated with self-regulatory skills. The systematic review included a comprehensive list of articles and focused specifically on self-regulatory skills, such as self-regulation and executive functions (EFs), but it did not empirically test these relationships. Therefore, future meta-analyses are needed to provide empirical evidence on the suggested roles of media interactivity, content, and context. Conversely, a recent meta-analysis by Bustamente et al. (2023) investigated the relation between media use and exposure and executive functions in children under six. The study included 15 articles and 44 effect sizes, and their analysis did not reveal a statistically significant relation between media use and executive functions. Additionally, the meta-analysis did not find any significant relations for various moderators, such as duration of media use, media interactivity, or types of executive functions. However, it is worth considering that the null findings of this meta-analysis may have resulted from the inclusion of a limited number of studies in the analyses. One possible limitation is their search strategy, which appears to be constrained only within the titles of the studies, potentially limiting the scope of the literature reviewed. Furthermore, the previous meta-analysis used both parent-reported and task-based measures of executive functions as outcome variables. However, previous research has indicated that scale and task-based measures of executive functions are only moderately correlated (Pino Muñoz & Arán Filipetti, 2021). Similarly, while rating-based measures tend to capture typical functioning, task-based measures focus on optimal functioning (Toplak et al., 2013). Given these differences in measurement approaches, outcomes measured through parent-reported assessments may reflect parental perceptions of their ’children’s behavior rather than objective performance, potentially introducing bias into the meta-analysis.

In light of these considerations, we deliberately choose to exclusively include task-based measures in our meta-analysis. Task-based measures provide a more objective assessment of executive function (EF) performance, minimizing the influence of subjective parental perceptions and enhancing the validity and reliability of our findings. This approach ensures a more rigorous examination of the relationship between media use and cognitive outcomes.

Previous systematic reviews and meta-analyses have highlighted limitations, suggesting that literature could benefit from a more comprehensive search with stringent inclusion and exclusion criteria. This approach might yield results that align with prior suggestions that other factors such as media interactivity and different durations moderate the link (Uzundag et al., 2022).

Our meta-analysis contributes to literature in several keyways. Firstly, by examining various media interactivity categories, we test their distinct roles in cognitive development. Secondly, by focusing specifically on executive functions (EFs), our study provides a nuanced explanation of how different forms of media relate to EFs. Thirdly, by exclusively utilizing task-based measures, we ensure a more rigorous assessment of objective EF performance. Lastly, through a comprehensive literature search, our meta-analysis empirically examines how media interactivity, duration, and age influence the relationship between media use and cognitive outcomes, consistent with previous systematic reviews.

The Present Study

The present study is a meta-analytic review examining the relation between media exposure and executive functions (working memory, inhibition, and cognitive flexibility) in children between 0 and 6 years of age. Our primary objective is to synthesize findings from various studies to gain insights into how and when media usage may be related to executive functions in this specific age group. We chose to narrow our focus to under six years of age due to its crucial role in executive function development. During this period, there are significant changes in executive function skills, and environmental factors can have a substantial impact. Additionally, executive functions develop over time, and the complexity of tasks that children can perform changes with age (Anderson et al., 2001). As a result, it would not be reasonable to combine studies from a wide age range.

Our study explores various potential moderators that may influence the relation between media usage and executive functions in children between 0 and 6 years of age. One such moderator is the duration of media exposure. Although all the studies included in our analysis measured exposure to media, they reported different durations of time children spent on these activities. Thus, the quantity of exposure could potentially explain the divergent findings observed in the existing literature.

Additionally, previous research has suggested that interactive and receptive media may have distinct relations with executive functions. Understanding how different forms of media, such as interactive games or receptive viewing, may affect EFs differently is essential in comprehending the overall impact of media usage on young children's cognitive development.

Conceptualization of the main variables

Media Interactivity. In our study, we classified media exposure interactivity into three categories: interactive, uncategorized, and receptive media usage and exposure. Receptive media exposure refers to program viewing on television or any technological device where children are consumers of the content without the need for any explicit response. In other words, the viewer is not required to provide any input for the program to continue. The uncategorized media exposure and usage category includes computer, tablet, and smartphone usage, as these devices offer the potential for both receptive and interactive use, depending on the activity. Some studies only reported overall media usage, which could involve several media activities, and we classified such cases as uncategorized media exposure, as well. Therefore, we classified media usage and exposure as uncategorized when studies did not specify the activity these devices were used for, as this category accounts for cases where the type of engagement was not indicated. Interactive media usage and exposure include video games, handheld games, and tablet apps/games, as these activities require children's input during usage to continue. Notably, when we included video games under the interactive category, it means that the studies specified the activity as gaming, regardless of the device used (e.g., console, computer, or phone). This classification allows us to test the role of media interactivity in each activity that children engage in, as well as to examine the overall role of media usage and exposure. By categorizing media exposure interactivity in this manner, we aim to better understand how different media usage and exposure types may impact executive functions in children between zero and six years of age.

Executive Functions. Following the approach of previous meta-analyses on executive functions (e.g., Devine & Hughes, 2014), our study has adopted the conceptualization of executive functions as lower-order and higher-order EFs (Diamond, 2013). We aggregated different EF measures into composite scores (either lower or higher) or included reported composite EFs to analyze the data. It is essential to note that while most EF measures are designed to assess specific EF components, they often measure multiple EF components simultaneously, leading to what is known as the task impurity problem (Obradović & Willoughby, 2019). Additionally, the literature has suggested that EF might initially start as a unity factor and then diverge with age (e.g., Brydges et al., 2014). Thus, during early childhood, it is possible that different tasks designed to measure distinct EF skills may actually be tapping into the same underlying unity of EF. In line with this problem, when we look at how EF can be measured across different age groups, it seems that several tasks under the overarching category of EFs were assessed (Anderson, 2002). For instance, in infants and toddlers, simpler tasks targeting specific EF components like inhibition and working memory are commonly used (e.g., Choi et al., 2018; Lui et al., 2021). In contrast, assessments for preschoolers and kindergarteners often employ more complex EF batteries that capture multiple EF components (e.g., Gashaj et al., 2021; Ribner et al., 2017). As a result, composite scores may provide a more comprehensive view, accommodating the various age-appropriate tasks used across studies.

However, we also coded information from different EF components, similar to the approach used in the study conducted by Devine & Hughes (2014), because it has been suggested that different EF tasks have varying levels of complexity (Anderson et al., 2001). As a result, there could be differences in task performance depending on the complexity of the EF components being assessed. For instance, cognitive flexibility tasks like the Dimensional Change Card Sort (DCCS) require both inhibition and working memory. Consequently, media exposure may influence performance on more complex tasks differently, depending on the interplay of different EF components.

Duration. In our meta-analysis, we encountered variations in how media usage was measured across different studies. Some of the studies measured media usage in categories, and some of them were measured as continuous. As a result, we decided to categorize media exposure duration into two groups: low media exposure and high media exposure. Following the guidelines from the American Academy of Pediatrics (Hill et al., 2016), we used a 10-minute cut-off for children under 18 months, which aligns with the previous literature (Portugal et al., 2023). We used a 30-minute cut-off for children aged between 18 to 24 months. In line with the AAP recommendation, we used a 1-hour cut-off for children aged 2 to 4. Finally, we used a 2-hour cut-off for five and 6-year-olds. Conversely, we labeled media usage exceeding the cut-off as high duration and usage below the cut-off as low duration. This categorization allows us to examine potential differences in executive functions based on the level of media exposure experienced by children between zero and six years of age.

Research Questions

In this study, we have formulated the following research questions to explore the association between media exposure and executive function skills in children between zero and six years of age:

Research Question 1: Is there an association between overall media exposure and EF skills of children between zero and six years of age?

Research Question 2: Does the relation between media exposure and EF skills differ according to the interactivity levels of children during media exposure?

Research Question 3: Does the relation between media exposure and EF skills differ by the duration of exposure?

Research Question 4: Does the relation between media exposure and EF skills differ by different EF skills?

Research Question 5: Does the relation between media exposure and EF skills differ by age?

By addressing these research questions, we aim to comprehensively understand how media exposure may be related to executive functions in children between zero and six years of age and identify potential factors that may moderate this relation. This meta-analysis, by examining media interactivity (receptive and interactive) and duration levels, emphasizes the importance of conceptualizing media in a nuanced manner to fully comprehend its relation not only with Executive Functions (EFs), which are fundamental for the development of various skills but also with numerous other outcomes linked to media usage. Insights into how different interactions with media, such as varying types or durations, might relate to cognitive functions can guide educational policies. This can include designing and selecting age-appropriate media content and developing interventions that support cognitive development across various groups.

Methods

Inclusion and Exclusion Criteria

For inclusion in the present meta-analysis, studies needed to meet specific criteria. These criteria were as follows:

a) The age range of the children should be between 0 and 6 years old. This age range was selected because early childhood is a critical period for the development of executive functions (EF), with significant growth occurring during these years (Zelazo & Müller, 2012). By focusing on this age range, we aim to capture the association between media use and EFs during this crucial developmental stage.

b) The children should not have any developmental disorder (e.g., ADHD, autism) or special conditions (e.g., bilingualism, preterm birth). This exclusion criterion is selected to avoid confounding variables that could impact the development of EF independently of media usage. Previous studies have shown that these conditions can significantly influence EF (Diamond, 2013), making it crucial to control these factors.

c) The studies should include at least one measure of executive functions such as inhibition, working memory, cognitive flexibility, problem-solving, planning, reasoning, or composite EF. Following the EF conceptualization of Diamond (2013), both lower-order and higher-order EFs are included.

d) The studies should also include at least one measure of media usage and exposure (e.g., TV, touchscreen devices, computers, smartphones, video games, handheld games, touchscreen apps, or unspecified overall media use). The inclusion of diverse media interactivity categories ensures the possibility of testing moderation across media interactivity.

e) Executive functions should be assessed using behavioral or neurocognitive tasks. This decision was informed by existing literature indicating that parent-reported measures and task-based measures of executive functions (EFs) are only moderately correlated (Pino Muñoz & Arán Filipetti, 2021). This suggests that including both types of measures within the same analysis may introduce confounding, as they may not necessarily capture the same underlying constructs.

f) Media usage should be reported by parents. Media usage reported by parents is included to ensure consistency of the data as that is the common source of information available on the literature.

g) The correlation coefficient between media usage and EF should be either presented in the paper or calculated using available information (e.g., means, standard deviations, sample size) from the study manuscript.

Search Strategy

Table 1 presents the study's search details, including the keywords utilized in the search process. The search was confined to articles published in English up to May 2024. Additionally, the bibliographies of existing meta-analyses (Bustamente et al., 2023) and reviews (Kostyrka-Allchorne et al., 2017) were scrutinized to identify relevant papers. The study selection process involved two steps. In the first step, the titles and abstracts of the identified studies were reviewed to determine which ones met the inclusion criteria. Subsequently, in the second step, the first author read the full texts of the studies selected from the first step and finalized the list of studies to be included in the review.

To ensure the reliability of the included studies, a second reviewer, blinded to the decisions of the first reviewer, independently reviewed 10% of the initial search results and carried out the selection process. Following the selection phase, both reviewers compared the studies included in the final list, resulting in full agreement between them.

Table 1
Search criteria

Category	Keywords
Study	Studies that have at least one measure of EF (e.g., inhibition, WM, cognitive flexibility, or composite EF) and at least one measure of media usage (e.g., TV, touchscreen devices, computers, smartphones).

Population	Aged between 0 to 6 who do not have any developmental disorder (e.g., ADHD, autism) or special conditions (e.g., bilingualism, preterm birth)
Measurement	Executive functions should be measured with task-based behavioral tasks. Media usage should be parent-reported.
Method	Cross-sectional or longitudinal studies
	Correlation coefficient between media usage and EF should be either presented in the paper or calculated using available information
Source	Search term within the titles and abstracts of the papers
Web of Science ERIC ACM Digital Library PubMed EBSCOHOST ProQuest	((“tablet” OR “iPad” OR “touchscreen” OR “television” OR “TV” OR “video game” OR “app” OR “online games” OR “computer games” OR “cartoon” or “screen media” or “media”) AND (“executive function*” or “EF” or “EFs” or “executive function skills” or “EF skills” or “working memory” or “inhibition” or “shifting” or “flexibility” or “cognitive flexibility” or “problem solving” or “problem-solving” or “planning” or “sequencing” or “fluid intelligence” or “matrix reasoning” or “cognitive reasoning” or “attention” or “higher-order thinking” or “higher-order skills” or “higher order skills” or “higher order thinking skills”) AND (“children” OR “kindergarten” OR “preschool” OR “toddler” OR “early childhood” OR “childhood”) NOT (“tool” OR “training”))

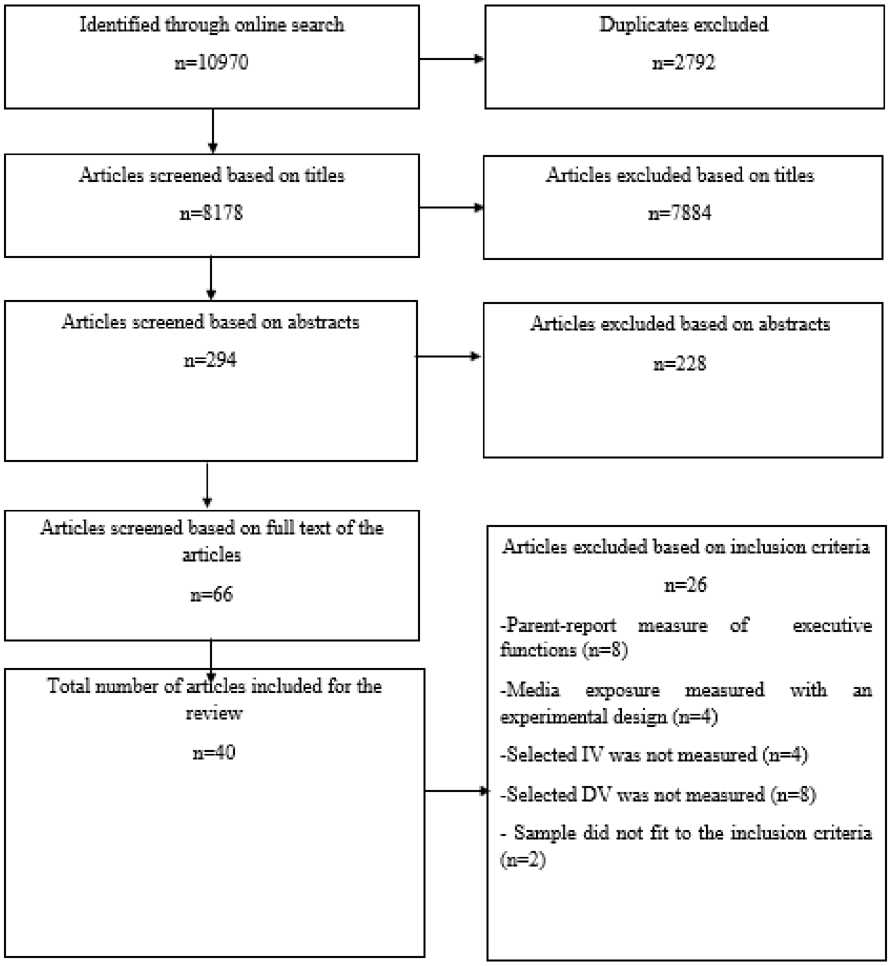
Study Selection

After conducting the search in six databases and examining previous reviews, a total of 10,970 articles were identified (Web of Science: 4,859, ERIC: 869, ACM Digital Library: 233, PubMed: 2,188, EBSCOhost: 1,830, ProQuest: 991, Bibliographies: 11). Following the removal of duplicates, 8,178 studies remained for the initial review. The titles of these studies were reviewed, leading to the selection of 294 papers for the second stage of the review process. In the second stage, the abstracts of these 294 papers were assessed, and studies that did not meet the inclusion criteria were excluded. After thoroughly reading the remaining 66 studies, 40 were ultimately included in the current meta-analysis (refer to Figure 1 for the

Flow Diagram illustrating the study selection process). Twenty-six studies were excluded in total for various reasons: eight papers were excluded due to their use of parent-reported measures of executive functions, four studies were excluded because they measured media exposure using an experimental design, twelve studies were excluded because either the selected independent variable (IV) or dependent variable (DV) was not measured, and two studies were excluded due to its sample not fitting the inclusion criteria. Out of the 40 selected papers, two studies (Nathanson & Fries, 2014; Nathanson et al., 2014) utilized the same sample and reported identical correlations. As a result, we retained only one of them for inclusion in our meta-analysis. One paper used secondary data and did not apply the correct weighting in correlation calculations (Beatty & Egan, 2020). Consequently, we opted not to include it in our study. One paper did not have subscale item scores for every participant in their sample (Zhao et al., 2022). Two papers did not have separate data for media use as they measured overall sedentary behaviors (Bezerra et al., 2023; Luo et al., 2023). Additionally, four papers lacked sufficient information to calculate correlation coefficients, and despite attempts to contact the authors via email for the required data, they did not respond (Antrilli & Wang, 2018; Horowitz-Kraus et al., 2023; McNeil et al., 2019; Rhodes et al., 2020). Therefore, the final sample for our meta-analysis comprised 30 papers.

Figure 1

Flow diagram of the study selection process



Statistical Analysis

This meta-analysis utilized the correlation coefficient Pearson's *r* as the effect size measure. In cases where the correlation coefficient was reported using a different coefficient, such as Spearman's rho, we communicated with the article authors to acquire Pearson's r correlation coefficients. To facilitate the combination and comparison of effect sizes and address the skewed distribution of r (Hedges & Olkin, 1985), Fisher's transformation (Fisher, 1946) was employed, resulting in Zr. The effect sizes were then weighted based on the inverse variance method to assign greater weight to studies with larger sample sizes, as larger sample size studies tend to have smaller standard errors (Card, 2015; Lipsey & Wilson, 2001). While presenting the results, we reverted the Zr values back to r for easier interpretation.

To address the issue of obtaining multiple effect sizes from the same study due to various subcategories of media use and exposure and different types of executive functions, we took into consideration the dependent structure of effect sizes within studies. This dependency could lead to inflated Type I errors if not accounted for properly in the analyses (Becker, 2000). To handle this, we applied robust variance estimation (RVE) with the small-sample correction technique (Hedges et al., 2010; Tipton, 2015). Our study adopted an expanded working model known as the Correlated and Hierarchical Effects (CHE) working model, which effectively captures the interrelated and hierarchical nature of effect size estimates (Pustejovsky & Tipton, 2022). Unlike the multilevel meta-analysis (Van den Noortgate et al., 2013), the CHE model considers the Level 1 sampling errors as correlated, accurately reflecting the structure of the meta-analytic data under investigation. Additionally, the CHE model allows for estimating variance components at various levels of analysis, providing valuable insights into the presence and explanation of heterogeneity by moderators, unlike robust variance estimation (Fernández-Castilla et al., 2020).

In this meta-analysis, some studies provided multiple correlations from the same participants, such as between TV watching and inhibition skills, as well as computer game playing and working memory skills. This created a dependency among the correlations nested within individuals and studies. To appropriately handle this data structure, we applied the Correlated and Hierarchical Effects (CHE) working model, recognized by Pustejovsky and Tipton (2022) as a versatile model applicable to social science meta-analyses. In using the CHE model, we assumed a consistent correlation value of 0.6 for the effect sizes within studies. We also tested the model with constant correlation values of 0.4 and 0.8, but the results remained essentially unchanged.

Two main models can be employed to compute the average effect size across studies (Card, 2015). The first approach is the fixed effects model, which assumes that the variation across effect sizes is solely due to sampling error. The second approach is the random-effects model, which posits that the variation in effect sizes comprises two sources: sampling error and systematic variability. For the current study, we opted to use the random-effects model for the overall analysis because it is reasonable to assume that there will be variation in the effect sizes due to factors beyond sampling error (Borenstein et al., 2010). Furthermore, if there are no variations in effect sizes other than sampling error, then both the fixed and random effects models would yield identical results.

To estimate the average correlation between media use and exposure variables and EF skills and to examine whether this correlation was influenced by media interactivity, EF category, duration of exposure, age, and gender distribution, we employed the random-effects meta-regression model utilizing the CHE working model. For all analyses, we used the R packages metafor (Viechtbauer, 2010), robumeta (Fisher et al., 2017), and clubSandwich (Pustejovsky, 2021).

Publication Bias

To assess publication bias, we employed several techniques. Firstly, we used a modified version of Egger's test known as Egger's sandwich (Rodgers & Pustejovsky, 2020), which is suitable when there is an effect size dependency present. Additionally, we visually inspected the contour-enhanced funnel plot of individual effect sizes and the funnel plot of aggregated effect sizes for the studies. The contour-enhanced funnel plot provides insights into the statistical significance of the effect sizes. In the presence of publication bias, the funnel plot would appear skewed to one side at the bottom, resulting in missing points in the lower-left part of the funnel (Sterne et al., 2005). Lastly, we tested the moderator effect of publication status.

Results

Descriptives

The meta-analysis encompassed 121 effect sizes derived from 30 studies involving a total of 7,740 children aged 0 to 6 years, including various media interactivity types and executive function (EF) categories. A comprehensive summary of the included studies is provided in Supplementary Materials, Table 1. Notably, 24 out of the 30 studies reported multiple effect sizes, ranging from 2 to 20 effect sizes coming from the same study. Table 2 displays the distribution of studies based on media interactivity type, duration, and EF categories.

Most effect sizes (27 studies) were obtained from published journal articles, while three studies were derived from gray literature (Esteraich, 2018; Harmon, 2021; Sümer, 2018). The studies were conducted in diverse countries, with nine from the United States, four from the United Kingdom, five from China, two from Turkey, two from Russia, and one from Germany, Canada, Brazil, Australia, Switzerland, Taiwan, Lithuania, and New Zealand. Additionally, most of the studies (23 studies) utilized a cross-sectional design.

Overall Correlation

To estimate the pooled correlations between media exposure and EFs with 121 effect sizes, we fit an intercept-only meta-regression with the Correlated and Hierarchical Effects (CHE) working model. The pooled effect size in the correlation coefficient metric was -.026 (95% CI [-.071, .019]), and it was not statistically significantly different from zero (β = -.026, SE = .021, t (19.682) = -1.206, p=.24). The estimated between-study heterogeneity ($\tau 2$) was .002. The estimated within-study heterogeneity ($\omega 2$) was .012. Figure 2 indicates the effect sizes included in the current meta-analysis. The forest plot was adapted to represent aggregated effect sizes from the same sample for ease of representation.

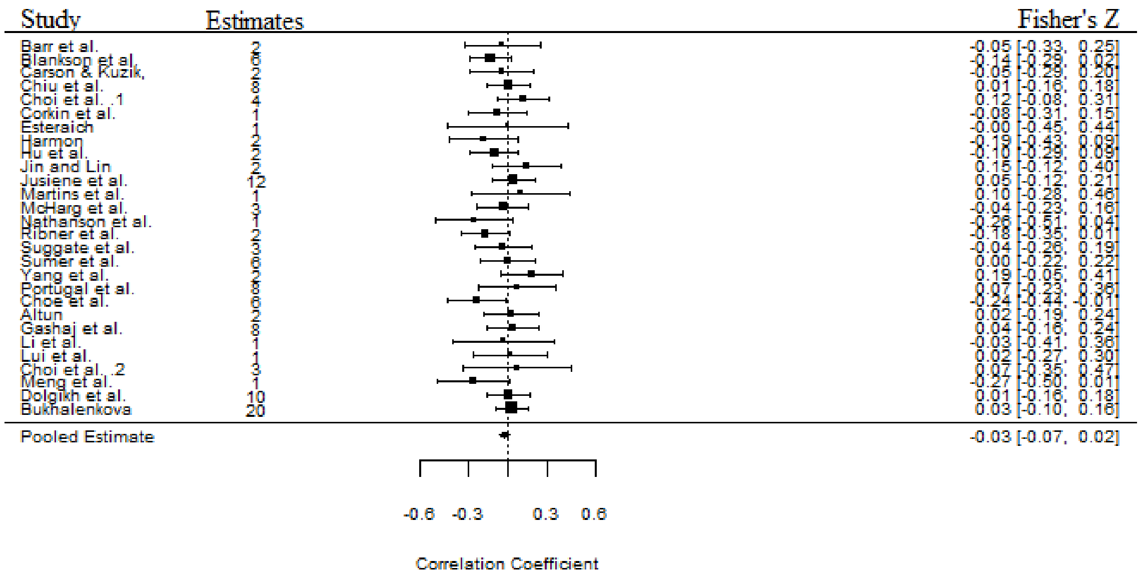
Table 2
The distribution of effect sizes based on media interactivity type, duration, and EF categories

Number of effect sizes

	High duration			**High duration Total**	**Low duration**			**Low duration Total**	**Total**
	Higher order	Lower order	Mixed		Higher order	Lower order	Mixed		
Interactive					1	26	2	19	29
Receptive	1	30	3	34	1	12		13	47
Uncategorized		17		17	2	26		28	45
Total	1	57	3	61	4	54	2	60	121

Figure 2

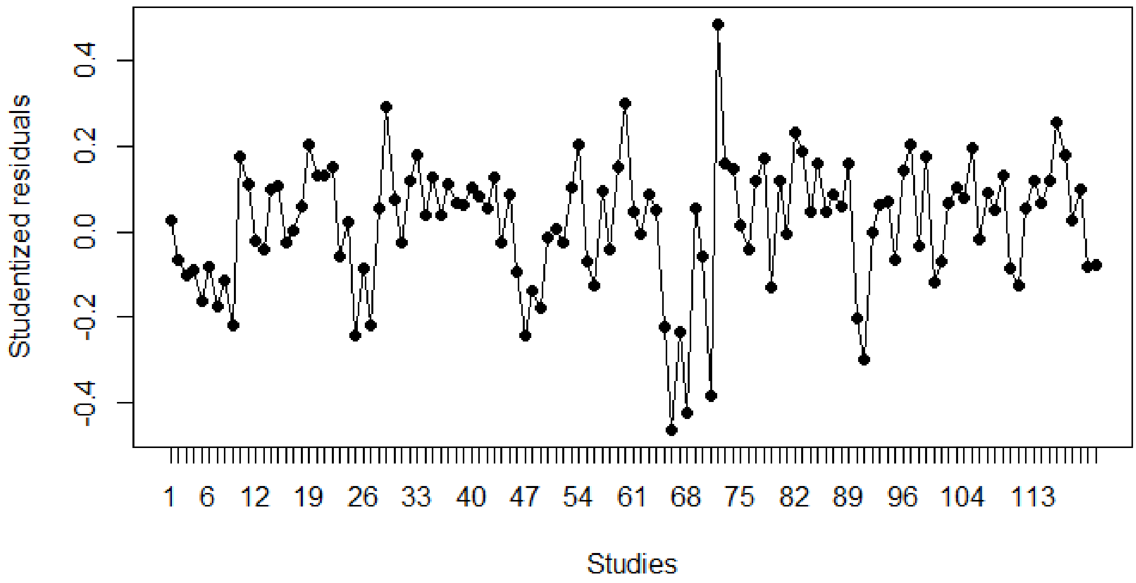
Forest plot of the pooled effect sizes of the included studies with their respective 95% confidence interval.



As shown in Figure 3, sensitivity analysis suggested that none of the effect sizes play an outlier effect, indicated by the standardized residuals within the established cut-offs (-1.96-1.96).

Figure 3.

The studentized residuals for each effect size.



Note. The diamond shape at the bottom of the figure indicates the average correlation of the pooled data set. Larger positive or negative effect sizes indicate a closer relationship between media use and EFs.

Moderator Analyses

Test for heterogeneity suggested that heterogeneity exists across studies indicating potential moderator effects, *Q* (119) = 678.95, *p*< .0001. To explain the heterogeneity, we conducted moderation analyses using a meta-regression approach. Table 3 reports the results of all moderators. The percentage of girls, age in months, study design, publication status, and publication year did not moderate the relation between media exposure and executive functions. Media interactivity significantly moderated this relation. Receptive media exposure was negatively related to EFs, (*r* = -.11, SE = 0.05, 95% CI [−.26, .04], p =.0006). Similarly, uncategorized media exposure was negatively related to EFs (*r*=-.09, SE=.04, 95% CI [-.18, .00], *p*=02). On the other hand, interactive media usage was positively related to EFs (*r*=.06, SE=.03, 95% CI [-.03, .15], *p*=.06). The duration of exposure also moderated the relation between media exposure and EFs. While high-duration media exposure was negatively linked to EFs (*r*=-.09, SE=.03, 95% CI [-.16, -.02], *p*=0006), low-duration was positively related (*r*=.12, SE=.05, 95% CI [.02, .22], *p*=0003).

Furthermore, we tested whether there is an interaction between the moderators (see Table 4). Findings indicated that in the case of low-duration exposure, interactive media usage was significantly and positively related to better EF skills (*r*=.11, SE=.04, 95% CI [.02, .20], *p*=003). In addition, uncategorized media was significantly and negatively related to EF skills (*r*=-.09, SE=.03, 95% CI [-.18, .00], *p*=02). In the case of high-duration exposure, receptive media usage was significantly and negatively related to EF skills (*r*=-.15, SE=.05, 95% CI [-.24, -.06], *p*<0001).

Table 3

Results of Categorical and Continuous Moderators

Moderator	k_{ES}	*r* [95% CI]	*SE*	*p*
Percentage of Girls	116	.00[-.02, .01]	.00	.41
Age (in months)	121	.00[-.00, .00]	.00	.613
Media Interactivity	121			.002**
Interactive	29	.06 [-.03, .15]	.03	.065*
Receptive	47	-.11 [-.26, .04]	.05	.0006***
Uncategorized	45	-.09 [-.18, -.00]	.04	.02*
Duration of Exposure	121			.0003**
Low Duration	80	.12 [.02,.22]	.05	.0003**
High Duration	41	-.09[-.16, -.02]	.03	.0006**
EF	121			.45
Inhibition	45	.02[-.04, .19]	.05	.72
WM	37	.01[-.11, .13]	.05	.90
Flexibility	19	.07[-.010, .14]	.05	.21
Reasoning	5	-.01[-.36, .34]	.08	.86
Composite	12	-.04[-.17, .08]	.05	.35
EF Category	116			.233
Lower order	111	.03 [-.69, .74]	.06	.626
Higher order	5	-.06 [-.72,.60]	.07	.297
Study Design	121			.93
Longitudinal	33	.00 [-.11-.10]	.04	.93
Cross sectional	88	-.03 [-.07-.02]	.02	.28
Publication Status	121			.628
Published	112	-.02[-07, .02]	.02	.30
Unpublished	9	-.04[-.21, .13]	.09	.63
Publication Year	121	.01 [.00-.03]	.01	.071

Notes: A significant *p*-value indicates a statistical difference between the levels of the moderator. k_{ES}=number of effect sizes; *r*= correlation coefficient; CI=confidence interval; SE=standard error. *p<.05, **p<.01, ***p<.001.

Table 4

Results of Moderators within the Subcategory of Another Moderator

Moderator	k_{ES}	*r* [95% CI]	*SE*	*p*
Low Duration				
Media Interactivity	80			
Receptive	23	-.05 [-.10, .01]	.01	.077
Interactive	29	.11 [.02, 20]	.03	.003**
Uncategorized	28	-.09 [-.18, .00]	.03	.022
High Duration				
Media Interactivity	41			.090
Receptive	24	-.15 [-.24, -.06]	.0	<.0001***
Interactive	-			
Uncategorized	17	.10 [-.01, .21]	.05	.064

Notes: A significant *p*-value indicates a statistical difference between the levels of the moderator. kES=number of effect sizes; *r*= correlation coefficient; CI=confidence interval; SE=standard error.

**p*<.05, ***p*<.01, ****p*<.001.

Publication bias

Two different techniques were employed to investigate the potential presence of publication bias. Firstly, we used a modified version of Egger's test to examine funnel plot asymmetry, suitable for cases where effect size dependency is present (Egger et al., 1997; Rodgers & Pustejovsky, 2020). The results of the Egger's sandwich test indicated no potential publication bias ($p = 0.186$). Additionally, we visually inspected the contour-enhanced funnel plot for individual effect sizes and aggregated study effect sizes, as presented in Figure 4 and Figure 5, respectively. The funnel plots did not suggest the existence of publication bias. Furthermore, we tested whether the publication status acted as a moderator, and the results indicated that it did not significantly moderate the relation. The comparison between published and unpublished studies revealed highly similar results, as shown in Table 3. Given the non-significant overall effect, there was no evidence to suspect publication bias or selective reporting in the meta-analysis.

Figure 4

The contour-enhanced funnel plot for individual effect sizes.

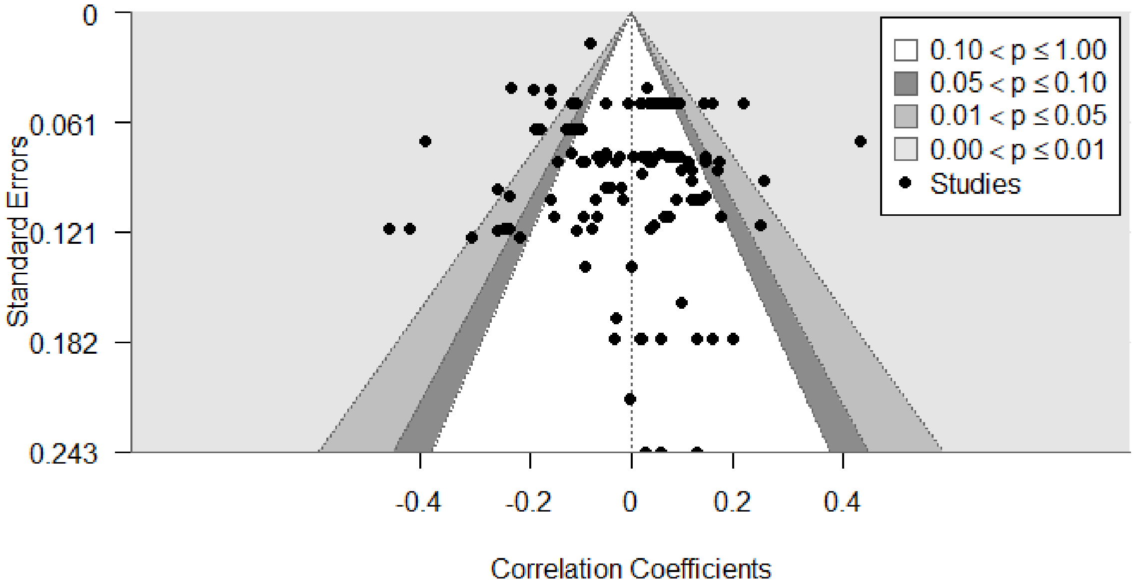
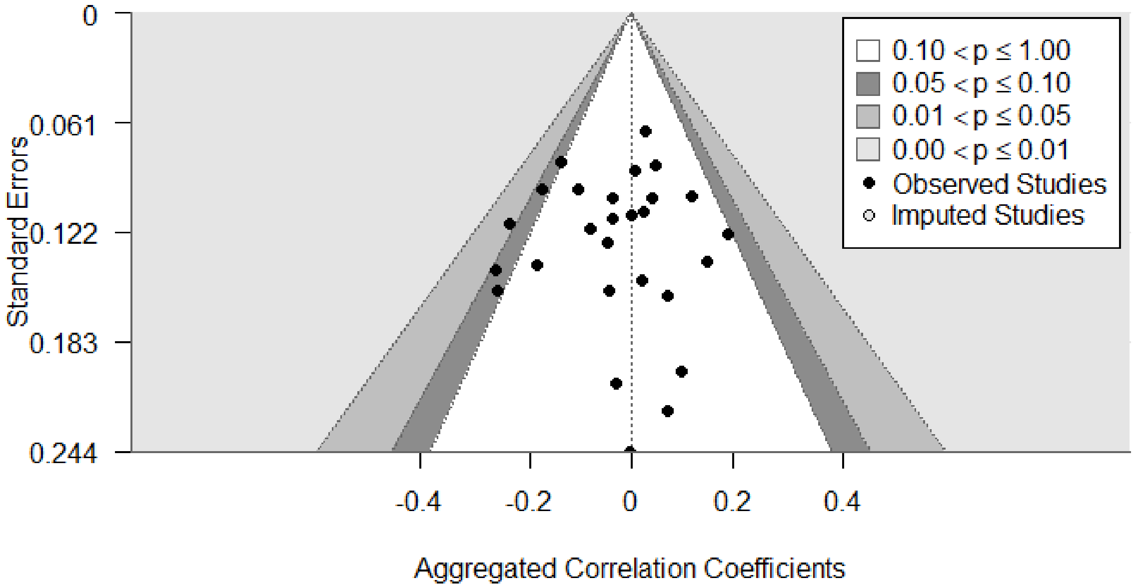


Figure 5.

The contour-enhanced funnel plot for aggregated effect sizes.



Discussion

The present study included a comprehensive meta-analysis, combining data from 30 studies and analyzing 121 effect sizes, to explore the association between media usage and executive function skills of children between zero and six years of age. Overall, the aggregated results indicated a non-significant relation between media usage and EF skills.

This finding aligns with a recent meta-analysis that also reported mixed results in the literature on this topic (Bustamente et al., 2023). It appears that when considering the link between media use and EFs in a general sense, without considering specific media interactivity types or the duration of exposure, the results tend to be non-significant. However, the current study emphasized the importance of investigating potential moderators to better understand this relation. By examining factors such as media interactivity types and the duration of exposure, we can better understand the nuanced nature of this relation. These moderators may help identify specific conditions or contexts in which media use could significantly impact EFs. Consequently, the overall correlation result underscores the need for a more nuanced and context-specific approach when examining the influence of media use on EFs. From the moderators, our analysis revealed that age did not exert a significant moderating effect. This result might seem contradictory to the earlier findings of Kostyrka-Allchorne et al. (2017), suggesting that media exposure can benefit preschoolers but not infants. Their conclusion was based on watching high-quality television content on broader outcomes. Therefore, age moderation can be specific to learning from educational media and might not be generalizable to other forms of media use. In addition, the result indicating no moderation effect of age on the relation between media use and executive functions is consistent with the findings of a previous meta-analysis by Bustamente et al. (2023). This outcome was not surprising, given that most of the studies included in our analysis focused on preschool-aged children.

Executive functions undergo substantial development throughout childhood, and the complexity of EF tasks can vary considerably across different age groups. Therefore, including a broader age range in the analysis may not be feasible, as it could lead to a wide variation in the types of EF tasks used across different age groups. By focusing on children between zero and six years of age, our study was able to provide a more focused investigation of the relation between media use and EFs during this critical developmental stage. As such, our findings contribute to existing literature by providing insights into the relation between media use and EFs, specifically within early childhood.

The gender distribution within the study samples did not moderate the relation between media use and EFs. Notably, a majority of the studies included in our analysis had nearly equal proportions of male and female participants. As a result, the absence of a significant relation can be attributed to the limited variance observed among the studies in terms of gender distribution. The literature on this topic is characterized by inconsistency and small effect sizes (Shinohara & Moriguchi, 2021). While some studies have suggested the existence of sex differences in EFs, the evidence supporting such differences remains inconclusive. Therefore, the lack of moderation based on gender distribution aligns with the current understanding of the limited and inconsistent nature of sex differences in EF performance. Our findings are consistent with a recent meta-analysis that reported no evidence for gender distribution moderation in the relation between media use and EFs (Bustamente et al., 2023). Overall, our results suggest that gender distribution may not significantly influence the relation between media use and EFs. This supports the idea that any potential sex differences might be subtle and warrant further investigation.

The analysis of EFs revealed no significant differences among the subcategories of lower-order EFs, which include inhibition, working memory, and flexibility. This finding aligns with the notion that EF development initially begins as a unified factor and gradually diverges as children mature (Miyake et al., 2000). We did not observe any statistically significant differences between lower-order and higher-order EFs regarding their association with media usage. This suggests that higher-order EF skills may also be part of the unity factor previously proposed in the literature, indicating that they develop in conjunction with lower-order EFs. Alternatively, it is worth considering that the available literature may have predominantly focused on lower-order EF skills. As a result, there may not have been sufficient statistical power to detect any existing distinctions in EF performance between lower-order and higher-order skills. Therefore, further research with a more balanced emphasis on both lower-order and higher-order EF skills could provide more comprehensive insights into the potential impact of media use on different aspects of executive functioning.

The type of media interactivity significantly moderated the relation between media use and executive functions. Specifically, receptive and uncategorized media exposures were found to be negatively associated with EFs, while low-duration interactive media showed a positive relation. This important moderation effect was not captured in a recent meta-analysis, likely due to the limited number of studies and a lack of statistical power (Bustamente et al., 2023). However, our findings are consistent with previous experimental studies. For example, a study with two and three-year-old children demonstrated that interactive app use had a positive effect on EFs compared to educational or entertainment receptive media exposure (Huber et al., 2018). The results suggest that the relation between media interactivity and EFs is a complex process that goes beyond simply displacing other activities. Interactive media, with its unique characteristics, may offer young children valuable opportunities to actively practice and develop core EF skills such as inhibition or working memory (Altun, 2022; Nathanson & Beyens, 2018). By engaging in interactive media experiences, children might enhance their cognitive abilities by exercising these fundamental executive function skills. These findings underscore the importance of taking a nuanced approach when evaluating the impact of media use, considering the specific features of media interactivity. Recognizing the potential cognitive benefits associated with interactive media use can inform the development of guidelines and interventions that harness the positive aspects of media interactions to support the development of EFs in young children. Encouraging the use of interactive media in a balanced and purposeful manner may contribute to children's cognitive development and EF skills.

The duration of media exposure was found to moderate the relation between media use and executive functions. Specifically, a higher duration of media exposure was significantly associated with lower EF scores, while a lower duration of media exposure was related to higher EF scores. This suggests that media exposure may not harm child development when used in limited durations. Promoting a balanced approach to media use is essential, encouraging low durations of media exposure and emphasizing the importance of engaging in other cognitively stimulating activities. This approach may help mitigate the potential adverse effects of excessive media use on executive functions (EFs) and support children's overall cognitive development. These findings partially support the displacement hypothesis, which suggests that extensive media use can displace beneficial activities for EFs development, such as play (e.g., Himmelweit et al., 1958; Krcmar et al., 2007). However, the role of media on EFs extends beyond displacement. As our findings show, examining media duration and interactivity together reveals a more nuanced picture of their distinct effects on cognitive development, which we will discuss in the next paragraph.

In addition, because of the significant moderation effect of media interactivity and duration, we also explored the moderation of media interactivity type within different levels of exposure. Interestingly, we found that low-duration interactive media use showed a significant positive relation with EFs, suggesting a potentially beneficial impact on cognitive abilities. This finding implies that limited engagement with interactive media could potentially enhance EFs and improve executive functions in young children. These results are consistent with previous findings related to EF interventions. The existing literature suggests that EF interventions that are meaningful, motivating, and consistently challenging tend to be more effective in enhancing executive functions (Diamond & Ling, 2019). In this context, interactive media may serve as a form of EF training that includes the suggested components. Children are often motivated to spend time with interactive media, which may offer engaging and enjoyable experiences that involve practicing and developing core EF skills such as inhibition, working memory, and cognitive flexibility. By recognizing the potential benefits of interactive media use for EF development, we can design interventions and educational programs that strategically incorporate interactive media experiences to support enhancing executive functions in young children.

On the contrary, our findings revealed a negative correlation between high exposure to receptive media and EFs but not a significant relation between low exposure to receptive media. This suggests that excessive consumption of receptive media content may harm cognitive functioning, particularly in the realm of executive functions. These results emphasize the significance of considering both the duration of exposure and the type of media interactivity when studying the impact of media use on EFs. By acknowledging the distinctions and complexities of various media forms, we understand the intricate relation between media consumption and executive functions.

Contributions

Overall, our meta-analysis reveals that interactive and receptive media have different associations with executive functions (EFs) in children. Low-duration interactive media is positively associated with EFs, suggesting potential cognitive benefits from certain types of media use. This finding highlights the importance of a comprehensive and nuanced approach to examining media 'use's associations with EFs. Considering the duration of exposure and the interactive nature of media content is crucial when assessing its potential influence on cognitive development.

The complex nature of media, as highlighted by our findings, has significant implications for broader theories of media psychology. This insight challenges simplistic negative views on media exposure and invites a more nuanced understanding of how media can be positively leveraged in educational and developmental contexts.

Our findings can guide the selection of media interactions that support cognitive development through active participation. This approach can assist educators, parents, and policymakers in making informed decisions about media usage guidelines and interventions to support children's cognitive development and overall well-being.

Limitations

Our meta-analysis offers valuable insights into the connection between media use and executive functions. However, it is important to acknowledge several limitations. Our analysis is limited to studies published in English, potentially excluding relevant research conducted in other languages. This language restriction might have resulted in the omission of valuable studies. Additionally, our findings are specific to children without diagnosed developmental conditions or disorders, limiting our results' generalizability to this specific population. The impact of media use on EFs in individuals with developmental conditions or disorders may differ from what is observed in typically developing children, necessitating separate investigation and consideration.

A limited number of studies are available for each subcategory of the moderators. Specifically, insufficient data for high-duration interactive media use prevented us from fully exploring its association with EFs. Similarly, we recognize the limitation of categorizing media duration rather than using a continuous measure, which may have implications for the precision of our findings. While we believe that if it were feasible, including duration as a continuous variable would be better to capture its role, many of the studies used categories or Likert scales to measure media use. Therefore, in order to include all the studies in the meta-analysis, we decided to use cut-off points to conceptualize the duration of exposure.

Additionally, most studies within our age range focused on preschoolers, limiting our ability to investigate the role of age as a moderator across broader developmental periods such as infants or toddlers. Similarly, we could not test the role of high-duration interactive media due to the absence of studies meeting this criterion. Therefore, it is possible that high-duration interactive media use might also be negatively associated with executive functions (EFs). Additionally, older children may use interactive media for longer durations. Consequently, investigating this link with school-aged children might reveal a potentially different story.

In addition, the current meta-analysis lacked enough studies to test the effects of significant moderators, such as media interactivity and duration within the levels of EF categories, particularly due to the low number of studies conducted with higher-order EFs. When sufficient data on higher-order EFs is accumulated, the role of these moderators should be further investigated.

Despite the literature's emphasis on content, most studies in our meta-analysis did not measure the content of media use. Consequently, we could not empirically test the role of content in the association between media use and EFs. Future studies should measure content when investigating media use to examine its role empirically.

It is essential to recognize that our study's correlational nature prevents us from establishing a causal relation. Potential confounding variables, such as socioeconomic status, which have been linked to both the development of executive function skills and media use patterns, might explain the associations that we established in the current study. While conducting experimental research might not be feasible considering the focus on naturalistic media usage, future research should aim to address these confounders more comprehensively to provide a clearer understanding of the relation between media use and executive functions.

Furthermore, it is important to note that most studies included in our meta-analysis used a cross-sectional design. While cross-sectional studies provide valuable insights, they do not establish causal relations or capture the dynamic developmental trajectories of EFs and the impact of media use over time. To better understand the potential role of media use in shaping EF development, future research should incorporate longitudinal designs to capture the temporal dynamics of the relation.

Conclusion

In conclusion, this comprehensive meta-analysis examined the relation between media use and executive functions while considering various moderators, including media interactivity types, duration of exposure, EF categories, age, gender distribution, and study characteristics. The overall analysis did not find a significant relation between media use and EFs, which aligns with recent meta-analyses and reflects the mixed findings in the literature. This suggests that considering specific factors is essential to detect meaningful associations between media use and EFs.

Moderator analyses revealed that media interactivity type and duration of exposure significantly influenced the relation, with low-duration interactive media showing a positive association and high-duration receptive and uncategorized media having a negative association with EFs.

The findings from this meta-analysis contribute to the understanding of the conditions under which media exposure may enhance or impair cognitive functions and recognize the importance of specifying the type and context of media use in research. Future research can more effectively study how media influences cognitive development, social behavior, and learning. This approach encourages a holistic view of media psychology, emphasizing that media effects are not uniform but contingent on a complex interplay of content, context, and individual differences.

References

Ahmed, S. F., Tang, S., Waters, N. E., & Davis-Kean, P. (2019). Executive function and academic achievement: Longitudinal relations from early childhood to adolescence. *Journal of Educational Psychology*, *111*, 446-458.https://doi.org/ 10.1037/edu0000296

*Altun, D. (2022). Family ecology as a context for children's executive function development: the home literacy environment, play, and screen time. *Child Indicators Research*, *15*, 1465-1488. https://doi.org/ 10.1007/s12187-022-09920-w

Anderson, P. (2002). Assessment and development of executive function (EF) during childhood. *Child Neuropsychology*, *8*, 71-82. https://doi.org/ 10.1076/chin.8.2.71.8724

Anderson, V. A., Anderson, P., Northam, E., Jacobs, R., & Catroppa, C. (2001). Development of executive functions through late childhood and adolescence in an Australian sample. *Developmental neuropsychology*, *20*(1), 385-406. https://doi.org/ 10.1207/S15326942DN2001_5

Anderson, D. R., & Subrahmanyam, K. (2017). Digital screen media and cognitive development. *Pediatrics*, *140*, 57-61. https://doi.org/ 10.1542/peds.2016-1758C

Antrilli, N. K., & Wang, S. H. (2018). Toddlers on touchscreens: immediate effects of gaming and physical activity on cognitive flexibility of 2.5-year-olds in the US. *Journal of Children and Media*, *12*, 496-513. https://doi.org/ 10.1080/17482798.2018.1486332

*Barr, R., Lauricella, A., Zack, E., & Calvert, S. L. (2010). Infant and early childhood exposure to adult-directed and child-directed television programming: Relations with cognitive skills at age four. *Merrill-Palmer Quarterly 56*, 21-48.

Becker, B. J. (2000). Multivariate meta-analysis. *Handbook of applied multivariate statistics and mathematical modeling*, 499-525. https://doi.org/ 10.1016/B978-012691360-6/50018-5

Best, J. R., & Miller, P. H. (2010). A developmental perspective on executive function. *Child Development*, *81*, 1641-1660.https://doi.org/ 10.1111/j.1467-8624.2010.01499.x

Bezerra, T., Esteban-Cornejo, I., Goulart, N., Mota, J., Souza Filho, A., Clark, C. C., ... & de Lucena Martins, C. M. (2024). Are there associations between sedentary time inside and outside preschools with preschoolers' executive function?. *Child Neuropsychology*, 1-12. https://doi.org/ 10.1080/09297049.2024.2310101

Blair, C., & Razza, R. P. (2007). Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. *Child development*, *78*, 647-663.https://doi.org/ 10.1111/j.1467-8624.2007.01019.x

*Blankson, A. N., O'Brien, M., Leerkes, E. M., Calkins, S. D., & Marcovitch, S. (2015). Do hours spent viewing television at ages 3 and 4 predict vocabulary and executive functioning at age 5?. *Merrill-palmer quarterly*, *61*, 264-289.https://doi.org/ 10.13110/merrpalmquar1982.61.2.0264

Borenstein, M., Hedges, L. V., Higgins, J. P., & Rothstein, H. R. (2010). A basic introduction to fixed-effect and random-effects models for meta-analysis. *Research synthesis methods*, *1*, 97-111.https://doi.org/ 10.1002/jrsm.12

Brydges, C. R., Fox, A. M., Reid, C. L., & Anderson, M. (2014). The differentiation of executive functions in middle and late childhood: A longitudinal latent-variable analysis. *Intelligence*, *47*, 34-43.https://doi.org/ 10.1016/j.intell.2014.08.010

*Bukhalenkova, D. A., Chichinina, E. A., & Almazova, O. V. (2023). How Does Joint Media Engagement Affect the Development of Executive Functions in 5to-7 year-old Children?. *Psychology in Russia: State of the art*, *16*, 109-127. https://doi.org/

Bustamante, J. C., Fernández-Castilla, B., & Alcaraz-Iborra, M. (2023). Relation between executive functions and screen time exposure in under 6 year-olds: A meta-analysis. *Computers in Human Behavior*, 107739. https://doi.org/ 10.1016/j.chb.2023.107739

Card, N. A. (2015). *Applied meta-analysis for social science research*. Guilford Publications.

Carlson, S. M., Mandell, D. J., & Williams, L. (2004). Executive function and theory of mind: stability and prediction from ages 2 to 3. *Developmental psychology*, *40*, 1105-1122.https://doi.org/ 10.1037/0012-1649.40.6.1105

Carlson, S. M., & White, R. E. (2013). Executive function, pretend play, and imagination. In M. *Taylor (Ed.), *The Oxford handbook of the development of imagination* (pp. 161–174). Oxford University Press.

*Carson, V., & Kuzik, N. (2021). The association between parent–child technology interference and cognitive and social–emotional development in preschool-aged children. *Child: Care, Health and Development*, *47*, 477-483. https://doi.org/ 10.1111/cch.12859

*Chiu, K., Lewis, F. C., Ashton, R., Cornish, K. M., & Johnson, K. A. (2022). Higher tablet use is associated with better sustained attention performance but poorer sleep quality in school-aged children. *Frontiers in Psychology*, *12*, 742468. https://doi.org/ 10.3389/fpsyg.2021.742468

*Choe, D. E., Lawrence, A. C., & Cingel, D. P. (2022). The role of different screen media devices, child dysregulation, and parent screen media use in children's self-regulation. *Psychology of Popular Media*, Advance online publication. https://doi.org/ 10.1037/ppm0000412

*Choi, K., Kirkorian, H. L., & Pempek, T. A. (2018). Understanding the transfer deficit: Contextual mismatch, proactive interference, and working memory affect toddlers' video-based transfer. *Child Development*, *89*, 1378-1393.https://doi.org/ 10.1111/cdev.12810

*Choi, K., Kirkorian, H. L., & Pempek, T. A. (2021). Touchscreens for Whom? Working Memory and Age Moderate the Impact of Contingency on Toddlers' Transfer From Video. Frontiers in Psychology, 12, 621372. https://doi.org/ 10.3389/fpsyg.2021.621372

Christakis, D. (2009). The effects of infant media usage:What do we know and what should we learn? *Acta Paediatrica. 98*, 8–16. https://doi.org/ 10.1111/j.1651-2227.2008.01027.x

Collier, K. M., Coyne, S. M., Rasmussen, E. E., Hawkins, A. J., Padilla-Walker, L. M., Erickson, S. E., & Memmott-Elison, M. K. (2016). Does parental mediation of media influence child outcomes? A meta-analysis on media time, aggression, substance use, and sexual behavior. *Developmental psychology*, *52*, 798-812. https://doi.org/ 10.1037/dev0000108

Common Sense Media (2020). The common sense census: media use by kids age zero to eight.NewYork, NY.

Cooper, H. (1998). Synthesizing research: A guide for literature reviews (3rd ed.). Thousand Oaks, CA: Sage.

*Corkin, M. T., Peterson, E. R., Henderson, A. M., Waldie, K. E., Reese, E., & Morton, S. M. (2021). Preschool screen media exposure, executive functions, and symptoms of inattention/hyperactivity. *Journal of Applied Developmental Psychology*, *73*, 101237. https://doi.org/ 10.1016/j.appdev.2020.101237

Davis-Kean, P. E., Tang, S., & Waters, N. E. (2019). Parent education attainment and parenting. In M. H. Bornstein (Ed.), *Handbook of parenting: Biology and ecology of parenting* (pp. 400–420). Routledge/Taylor & Francis Group. https://doi.org/ 10.4324/9780429401459-12

Diamond, A. (2013). Executive functions. *Annual review of psychology*, *64*, 135-168.https://doi.org/ 10.1146/annurev-psych-113011-143750

Diamond, A., & Ling, D. (2019). Review of the evidence on fundamental questions surrounding and efforts to improve executive functions (including working memory). In J. Novick, M. Bunting, M. Dougherty, & R. W. Engle (Eds.), *Cognitive and working memory training: Perspectives from psychology, neuroscience, and human development*. New York, NY: Oxford University Press.

Dolgikh, A., Bayanova, L., & Chichinina, E. (2023). Potential impact of extra education on the development of executive functions within a year in preschool children: an exploratory research. *Frontiers in Psychology*, *14*, 1193472. https://doi.org/ 10.3389/fpsyg.2023.1193472

Dresp-Langley, B. (2020). Children's health in the digital age. *International journal of environmental research and public health*, *17*, 3240. https://doi.org/ 10.3390/ijerph17093240

Duval, S., & Tweedie, R. (2000). A nonparametric "trim and fill" method of accounting for publication bias in meta-analysis. *Journal of the American statistical association*, *95*, 89-98. https://doi.org/ 10.1080/01621459.2000.10473905

*Esteraich, J. M. (2018). *Young Children's Use and Parent-child Co-use of Tablets: Investigating Mobile Media's Effects on Children's Executive Function*. The University of Nebraska-Lincoln.

Fernández-Castilla, B., Jamshidi, L., Declercq, L., Beretvas, S. N., Onghena, P., & Van den Noortgate, W. (2020). The application of meta-analytic (multilevel) models with multiple random effects: A systematic review. *Behavior research methods*, *52*, 2031-2052. https://doi.org/ 10.3758/s13428-020-01373-9

Fisher, R. A. (1946). *Statistical methods for research workers*. Edinburgh, UK: Oliver & Boyd.

Fisher, Z., Tipton, E., & Hou, Z. (2017). robumeta: Robust variance metaregression (R package Version 2.0) [Computer software]. https://CRAN .R-project.org/package=robumeta

*Gashaj, V., Dapp, L. C., Trninic, D., & Roebers, C. M. (2021). The effect of video games, exergames and board games on executive functions in kindergarten and 2nd grade: An explorative longitudinal study. *Trends in Neuroscience and Education*, *25*, 100162. https://doi.org/ 10.1016/j.tine.2021.100162

Gueron-Sela, N., & Gordon-Hacker, A. (2020). Longitudinal Links Between Media Use and Focused Attention Through Toddlerhood: A Cumulative Risk Approach. *Frontiers in psychology*, *11*. 569222. https://doi.org/ 10.3389/fpsyg.2020.569222

Hackman, D. A., Gallop, R., Evans, G. W., & Farah, M. J. (2015). Socioeconomic status and executive function: Developmental trajectories and mediation. *Developmental science*, *18*, 686-702.https://doi.org/ 10.1111/desc.12246

*Harmon, T. M. (2021). Mobile Technology Use and School Readiness in Low-Income Preschoolers.

Hedges, L.V., & Olkin, I. (1985). *Statistical methods for meta-analysis*. Orlando, FL: Academic Press.

Hedges, L. V., Tipton, E., & Johnson, M. C. (2010). Robust variance estimation in meta-regression with dependent effect size estimates. *Research synthesis methods*, *1*, 39-65. https://doi.org/ 10.1002/jrsm.5

Hill, D., Ameenuddin, N., Reid Chassiakos, Y. L., Cross, C., Hutchinson, J., Levine, A., ... & Swanson, W. S. (2016). Media and young minds. *Pediatrics*, *138*. https://doi.org/ 10.1542/peds.2016-2591

Himmelweit, H. T., Oppenheim, A. N., & Vince, P. (1958). *Television and the child: An empirical study of the effect of television on the young*. London: Oxford University Press

Hinkley, T., Verbestel, V., Ahrens, W., Lissner, L., Molnár, D., Moreno, L. A., ... & Idefics Consortium. (2014). Early childhood electronic media use as a predictor of poorer well-being: a prospective cohort study. *JAMA pediatrics*, *168*, 485-492. https://doi.org/ 10.1001/jamapediatrics.2014.94

*Hu, B. Y., Johnson, G. K., Teo, T., & Wu, Z. (2020). Relation between screen time and Chinese children's cognitive and social development. *Journal of Research in Childhood Education*, *34*, 183-207. https://doi.org/ 10.1080/02568543.2019.1702600

Huber, B., Yeates, M., Meyer, D., Fleckhammer, L., & Kaufman, J. (2018). The effects of screen media content on young children's executive functioning. *Journal of* *experimental child psychology*, *170*, 72-85. https://doi.org/ 10.1016/j.jecp.2018.01.006

Huedo-Medina, T. B., Sánchez-Meca, J., Marín-Martínez, F., & Botella, J. (2006). Assessing heterogeneity in meta-analysis: Q statistic or I² index? *Psychological Methods, 11*, 193–206. https://doi.org/10.1037/1082-989X.11.2.193

Jensen, P. S., Mrazek, D., Knapp, P. K., Steinberg, L., Pfeffer, C., Schowalter, J., et al. (1997). Evolution and revolution in child psychiatry: ADHD as a disorder of adaptation. *Journal of the American Academy of Child & Adolescent Psychiatry, 36,* 1672–1681. https://doi.org/ 10.1097/00004583-199712000 00015

*Jin, Y. R., & Lin, L. Y. (2022). Relation between touchscreen tablet usage time and attention performance in young children. *Journal of Research on Technology in Education*, *54*, 317-326. https://doi.org/ 10.1080/15391523.2021.1891995

*Jusienė, R., Rakickienė, L., Breidokienė, R., & Laurinaitytė, I. (2020). Executive function and screen-based media use in preschool children. *Infant and Child Development*, *29*, e2173. https://doi.org/ 10.1002/icd.2173

Konok, V., & Szőke, R. (2022). Longitudinal Associations of Children's Hyperactivity/Inattention, Peer Relation Problems and Mobile Device Use. *Sustainability*, *14*, 1-18. https://doi.org/ 10.3390/su14148845

Kostyrka-Allchorne, K., Cooper, N. R., & Simpson, A. (2017a). The relation between television exposure and children's cognition and behaviour: A systematic review. Developmental Review, 44, 19–58. https://doi.org/ 10.1016/j.dr.2016. 12.002

Krcmar, M., Grela, B., & Lin, K. (2007). Can toddlers learn language from television? An experimental approach. *Media Psychology*, *10*, 41–63. https://doi.org/10.108/15213260701300931

Krikorian, H. L., Pempek, T. A., Murphy, L. A., Schmidt, M. E., & Anderson, D. R. (2009). The impact of background television on parent–child interaction. *Child Development*, *80*, 1350–1359. https://doi.org/10.1111/j.1467-8624.2009.01337.x

*Li, H., Wu, D., Yang, J., Luo, J., Xie, S., & Chang, C. (2021). Tablet use affects preschoolers' executive function: fNIRS evidence from the dimensional change card sort task. *Brain sciences*, *11*, 567. https://doi.org/ 10.3390/brainsci11050567

*Liebherr, M., Kohler, M., Brailovskaia, J., Brand, M., & Antons, S. (2022). Screen Time and Attention Subdomains in Children Aged 6 to 10 Years. *Children*, *9*, 1393. https://doi.org/ 10.3390/children9091393

Lillard, A. S., & Peterson, J. (2011). The immediate impact of different types of television on young children's executive function. *Pediatrics*, *128*, 644-649. https://doi.org/ 10.1542/peds.2010-1919

Lipsey, M.W., & Wilson, D.B. (2001). *Practical meta-analysis*. Thousand Oaks, CA: Sage Publications.

Luo, X., Herold, F., Ludyga, S., Gerber, M., Kamijo, K., Pontifex, M. B., ... & Zou, L. (2023). Association of physical activity and fitness with executive function among preschoolers. *International Journal of Clinical and Health Psychology*, *23*, 100400. https://doi.org/ 10.1016/j.ijchp.2023.100400

Marcovitch, S., & Zelazo, P. D. (2009). A hierarchical competing systems model of the environemergence and early development of executive function. *Developmental science*, *12*, 1-18. https://doi.org/ 10.1111/j.1467-7687.2008.00754.x

*Martins, C. M. D. L., Bandeira, P. F. R., Lemos, N. B. A. G., Bezerra, T. A., Clark, C. C. T., Mota, J., & Duncan, M. J. (2020). A network perspective on the relation between screen time, executive function, and fundamental motor skills among preschoolers. *International Journal of Environmental Research and Public Health*, *17*(23), 8861. https://doi.org/ 10.3390/ijerph17238861

*Meng, X., Liang, X., Liu, C., Cheng, N., Lu, S., Zhang, K., ... & Wang, Z. (2024). Associations between screen media use and young children's inhibitory control: Evidence from behavioral and fNIRS study. *Computers in Human Behavior*, *152*, 108041. https://doi.org/ 10.1016/j.chb.2023.108041

McHarg, G., Ribner, A. D., Devine, R. T., & Hughes, C. (2020). Screen time and executive function in toddlerhood: A longitudinal study. *Frontiers in Psychology*, *11*. https://doi.org/ 10.3389/fpsyg.2020.570392

McNeill, J., Howard, S. J., Vella, S. A., & Cliff, D. P. (2019). Longitudinal associations of electronic application use and media program viewing with cognitive and psychosocial development in preschoolers. *Academic pediatrics*, *19*, 520-528. https://doi.org/ 10.1016/j.acap.2019.02.010

McNeill, J., Howard, S. J., Vella, S. A., & Cliff, D. P. (2021). Cross-Sectional Associations of Application Use and Media Program Viewing with Cognitive and Psychosocial Development in Preschoolers. *International Journal of Environmental Research and Public Health*, *18*, 1608. https://doi.org/ 10.3390/ijerph18041608

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive psychology*, *41*, 49-100. https://doi.org/ 10.1006/cogp.1999.0734

Naigles, L., & Mayeux, L. (2001). Television as incidental language teacher. In D. G. Singer & J. L. Singer (Eds.), *Handbook of children and the media* (pp. 135–153). Thousand Oaks, CA: Sage.

*Nathanson, A. I., Aladé, F., Sharp, M. L., Rasmussen, E. E., & Christy, K. (2014). The relation between television exposure and executive function among preschoolers. *Developmental psychology*, *50*, 1497-1506. https://doi.org/ 10.1037/a0035714

*Nathanson, A. I., & Fries, P. T. (2014). Television exposure, sleep time, and neuropsychological function among preschoolers. *Media Psychology*, *17*(3), 237-261. https://doi.org/ 10.1080/15213269.2014.915197

Neuman, S. B. (1988). The displacement effect: Assessing the relation between television viewing and reading performance. *Reading Research Quarterly*, *23*, 414–440. https://doi.org/10.2307/747641

Nikkelen, S. W., Valkenburg, P. M., Huizinga, M., & Bushman, B. J. (2014). Media use and ADHD-related behaviors in children and adolescents: A meta-analysis. *Developmental psychology*, *50*, 2228-2241.

Obradović, J., & Willoughby, M. T. (2019). Studying executive function skills in young children in low-and middle-income countries: Progress and directions. *Child Development Perspectives*, *13*, 227-234. https://doi.org/ 10.1111/cdep.12349

Pino Muñoz, M., & Arán Filippetti, V. (2021). Confirmatory factor analysis of the BRIEF-2 parent and teacher form: Relation to performance-based measures of executive functions and academic achievement. *Applied Neuropsychology: Child*, *10*, 219-233. https://doi.org/ 10.1080/21622965.2019.1660984

*Portugal, A. M., Bedford, R., Cheung, C. H., Mason, L., & Smith, T. J. (2021). Longitudinal touchscreen use across early development is associated with faster exogenous and reduced endogenous attention control. *Scientific Reports*, *11*, 2205. https://doi.org/ 10.1038/s41598-021-81775-7

*Portugal, A. M., Hendry, A., Smith, T. J., & Bedford, R. (2023). Do preschoolers with high touchscreen use show executive function differences?. *Computers in human behavior*, *139*, 107553. https://doi.org/ 10.1016/j.chb.2022.107553

Pustejovsky, J. (2021). clubSandwich: Cluster-robust (sandwich) variance estimators with small-sample corrections. (R package Version 0.5.3) [Computer software]. https://CRAN.R-project.org/package=clubSand wich

Pustejovsky, J. E., & Tipton, E. (2022). Meta-analysis with robust variance estimation: Expanding the range of working models. *Prevention Science*, *23*, 425-438. https://doi.org/ 10.1007/s11121-021-01246-3

Radesky, J. S., & Christakis, D. A. (2016). Increased screen time: implications for early childhood development and behavior. *Pediatric Clinics*, *63*, 827-839. https://doi.org/ 10.1016/j.pcl.2016.06.006

Razza, R. A., & Blair, C. (2009). Associations among false-belief understanding, executive function, and social competence: A longitudinal analysis. *Journal of Applied Developmental Psychology*, *30*, 332-343. https://doi.org/ 10.1016/j.appdev.2008.12.020

*Ribner, A., Fitzpatrick, C., & Blair, C. (2017). Family socioeconomic status moderates associations between television viewing and school readiness skills. *Journal of Developmental & Behavioral Pediatrics*, *38*, 233-239. https://doi.org/ 10.1097/DBP.0000000000000425

Rodgers, M. A., & Pustejovsky, J. E. (2021). Evaluating meta-analytic methods to detect selective reporting in the presence of dependent effect sizes. *Psychological methods*, *26*(2), 141-160. https://doi.org/10.1037/met0000300

Rosenqvist, J., Lahti-Nuuttila, P., Holdnack, J., Kemp, S. L., & Laasonen, M. (2016). Relation of TV watching, computer use, and reading to children's neurocognitive functions. *Journal of Applied Developmental Psychology*, *46*, 11-21. https://doi.org/ 10.1016/j.appdev.2016.04.006

Rocha, B., & Nunes, C. (2020). Benefits and damages of the use of touchscreen devices for the development and behavior of children under 5 years old—a systematic review. *Psicologia: Reflexão e Crítica*, *33*.https://doi.org/ 10.1186/s41155-020-00163-8

Rosenthal, R. (1979). The file drawer problem and tolerance for null results. *Psychological bulletin*, *86*, 638-641. https://doi.org/ 10.1037/0033-2909.86.3.638

Scionti, N., Cavallero, M., Zogmaister, C., & Marzocchi, G. M. (2020). Is cognitive training effective for improving executive functions in preschoolers? A systematic review and meta-analysis. *Frontiers in psychology*, *10*, 2812. https://doi.org/ 10.3389/fpsyg.2019.02812

Shinohara, I., & Moriguchi, Y. (2021). Are there sex differences in the development of prefrontal function during early childhood?. *Developmental Psychobiology*, *63*, 641-649. https://doi.org/ 10.1002/dev.22039

Strouse, G. A., & Troseth, G. L. (2014). Supporting toddlers' transfer of word learning from video. *Cognitive Development*, *30*, 47-64.https://doi.org/ 10.1016/j.cogdev.2014.01.002

*Suggate, S. P., & Martzog, P. (2021). Screen-time influences children's mental imagery performance. *Developmental science*, *23*, e12978. https://doi.org/ 10.1111/desc.12978

*Sümer, C. (2018). *Relations Between Preschoolers' Screen-Based Media Use and Self-Regulation Abilities* (Master Thesis, Bilkent Universitesi (Turkey)).

Tipton, E. (2015). Small sample adjustments for robust variance estimation with meta-regression. *Psychological methods*, *20*, 375-393. https://doi.org/ 10.1037/met0000011

Uzundağ, B. A., Altundal, M. N., & Keşşafoğlu, D. (2022). Screen Media Exposure in Early Childhood and Its Relation to Children's Self-Regulation. *Human Behavior and Emerging Technologies*, *2022*. https://doi.org/ 10.1155/2022/4490166

Zhao, C., Zhao, C., Zhao, M., Wang, L., Guo, J., Zhang, L., ... & Zhu, W. (2022). Effect of exergame training on working memory and executive function in older adults. *Sustainability*, *14*, 10631. https://doi.org/ 10.3390/su141710631

Valcan, D. S., Davis, H., & Pino-Pasternak, D. (2018). Parental behaviours predicting early childhood executive functions: A meta-analysis. Educational Psychology Review, *30,* 607-649. https://doi.org/ 10.1007/s10648-017-9411-9

Van den Noortgate, W., López-López, J. A., Marín-Martínez, F., & Sánchez-Meca, J. (2013). Three-level meta-analysis of dependent effect sizes. *Behavior research methods*, *45*, 576-594. https://doi.org/ 10.3758/s13428-012-0261-6

Veraksa, N., Veraksa, A., Gavrilova, M., Bukhalenkova, D., Oshchepkova, E., & Chursina, A. (2021, April). Short-and Long-Term Effects of Passive and Active Screen Time on Young Children's Phonological Memory. *Frontiers in Education, 6,* 600687. https://doi.org/ 10.3389/feduc.2021.600687

Viechtbauer, W. (2010). Conducting meta-analyses in R with the metafor package. *Journal of statistical software*, *36*, 1-48. https://doi.org/ 10.18637/jss.v036.i03

*Yang, X., Chen, Z., Wang, Z., & Zhu, L. (2017). The relations between television exposure and executive function in Chinese preschoolers: The moderated role of parental mediation behaviors. *Frontiers in psychology*, *8*, 1833. https://doi.org/ 10.3389/fpsyg.2017.01833/full

*Yang, X., Wang, Z., Qiu, X., & Zhu, L. (2020). The relation between electronic game play and executive function among preschoolers. *Journal of Child and Family Studies*, *29*, 2868-2878. https://doi.org/ 10.1007/s10826-020-01754-w

Zelazo, P. D., & Carlson, S. M. (2012). Hot and cool executive function in childhood and adolescence: Development and plasticity. *Child development perspectives*, *6*, 354-360. https://doi.org/ 10.1111/j.1750-8606.2012.00246.x

CHAPTER 3

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Understanding The Role of Digital Media on Young Children's Executive Functions: Testing Potential Moderating and Mediating Effects

The widespread use of digital media in early childhood (Common Sense Media, 2020) has raised growing interest in understanding how media exposure may influence the development of foundational cognitive skills. During early childhood, due to rapid brain development and high neural plasticity, the environment plays a critical role in the development of executive function (EF) skills (Zelazo & Carlson, 2012). Executive functions, including inhibitory control, working memory, and cognitive flexibility, are crucial for goal-directed behavior and school readiness and show substantial development during preschool (Diamond, 2013). Since technology is a big part of children's ecologies, it is not surprising that it has been suggested as one of the crucial predictors of these cognitive skills (Barr et al., 2024).

Although a growing number of studies have examined the association between media exposure and EF skills, the findings remain mixed. Some studies report negative associations, particularly with high levels of non-interactive (i.e., watching videos) media exposure (e.g., McHarg et al., 2020; Nathanson et al., 2014), while others have found positive or null effects depending on content and interactivity (Portugal et al., 2021; Yang et al., 2020). As indicated in a recent meta-analysis, these inconsistencies likely reflect the heterogeneous nature of media experiences, which vary by content and format, as well as by how much, when, and with whom children engage with media (Ozcan & Kisbu, 2025). Despite theoretical interest in potential mechanisms linking media use to EF, such as displacing developmentally supportive activities or teaching ineffective attention styles (Nikkelen et al., 2014; Yang et al., 2017), empirical research that directly tests these mechanisms remains limited. Understanding not just whether, but how and under what conditions media use relates to EF development is critical for informing both theory and practice.

The present study investigates the associations between media exposure and executive function in preschool-aged children by examining potential mediating variables, including displacement of activities and sustained attention, and moderating variables such as media interactivity, educational content, and parental involvement. By modeling both direct and indirect pathways, this study aims to clarify the mechanisms that may account for the divergent effects of media on EF development in early childhood.

Executive Functions

Executive functions (EFs) refer to a set of interrelated cognitive processes that support goal-directed behavior, particularly in situations requiring planning, regulation, and flexibility (Miyake et al., 2000). Core EF components include inhibitory control, the ability to suppress automatic or dominant responses in favor of more appropriate ones; working memory is the capacity to hold and manipulate information over short periods; and cognitive flexibility, which is the skill of shifting attention or adapting to changing rules or perspectives (Diamond, 2013). Although these components are conceptually distinct, research in early childhood suggests that they are best represented as a unitary construct during this developmental stage due to the high intercorrelation among EF tasks (Miyake et al., 2000). This supports the use of a composite EF score in early childhood research.

EFs are consistently linked to a wide range of developmental outcomes. For example, early EF skills have been associated with the development of the Theory of Mind (Carlson et al., 2004), long-term health and financial outcomes (Moffitt et al., 2011), and academic success (Blair & Razza, 2007; Bull et al., 2008; Denham, 2015). The preschool years, typically between ages 3 and 5, represent a period of rapid growth in EF abilities, supported by structural and functional maturation of the prefrontal cortex (Zelazo & Müller, 2012). As such, understanding the environmental factors that influence EF development during this period, such as children's engagement with media, is of particular importance.

Media and Executive Functions

Research examining the relationship between media use and executive function (EF) skills has grown substantially over the past two decades. Initial studies, particularly those focused on television exposure, raised concerns about adverse effects on children's attention and self-regulation (Nikkelen et al., 2014). Since then, the scope of research has expanded to include a broader range of media formats, such as computers, tablets, and smartphones, as well as more diverse forms of engagement, including passive viewing, educational games, and interactive apps (Jusienė et al., 2020). These differences in format and activity type complicate efforts to draw consistent conclusions about how media use relates to EFs.

Indeed, findings across the literature remain mixed. Some studies report negative associations between media exposure and EF (e.g., McHarg et al., 2020), while others have found positive or null effects depending on factors such as content and interactivity (e.g., Portugal et al., 2021). These inconsistencies may be partly explained by the heterogeneous nature of media experiences and the varying ways in which children engage with them.

Several reviews and meta-analyses have sought to synthesize these patterns. An early meta-analysis by Nikkelen and colleagues (2014), which included 45 studies examining the link between media use and ADHD-related behaviors, found a small but significant association with attention problems. However, this analysis did not find consistent effects of media type or content, limiting its ability to explain variation across studies. A later systematic review of 39 articles (Uzundag et al., 2022) highlighted the importance of considering how children use media (e.g., background exposure) and what they are exposed to (e.g., fantastical vs. realistic content). Although this review emphasized the potential moderating roles of content and context, it did not empirically test these factors.

More recently, Bustamante et al. (2023) conducted a meta-analysis of 15 studies and found no significant overall association between screen exposure and EF skills, and no moderation effects based on media interactivity, age, or frequency of use. In contrast, a more extensive meta-analysis including 30 studies (Ozcan & Kisbu, 2025) found that media format does matter: while receptive media use (e.g., watching TV) was negatively associated with EF, interactive media use (e.g., engaging with touch-based apps) showed a positive association. These findings underscore the importance of disaggregating media types and considering content and interactivity when evaluating how digital experiences relate to children's cognitive development.

Media Interactivity

One critical distinction in understanding the cognitive effects of media use is the level of interactivity. Researchers generally differentiate between two broad categories: receptive media, which include activities such as watching television or streaming videos, and interactive media, which involve user-driven engagement, such as playing digital games or using touchscreen apps (Suggate & Martzog, 2021; Yang et al., 2020). In receptive media, content progresses regardless of user input, whereas interactive media requires ongoing responses from the user to advance the experience.

Although these terms help clarify engagement patterns, they are not without nuance. Anderson and Davidson (2019) note that the term "passive" is often used to describe receptive media but may be misleading, as it implies an absence of cognitive processing. Children may still be mentally engaged while watching television, but the experience does not typically require real-time decision-making or behavioral responses. In contrast, interactive media often demands sustained attention, inhibition, and flexible problem-solving, which are highly related to the core components of executive function (Nathanson & Beyens, 2018; Hu et al., 2020).

Recent findings suggest that these different media types may have differential associations with cognitive development. For example, receptive media use has often been negatively associated with EF outcomes, particularly when media displaces developmentally enriching activities such as play, conversation, or sleep (Barr et al., 2010; Veraksa et al., 2021). However, some studies suggest that this association weakens when contextual factors, such as parental involvement, are considered (Blankson et al., 2015). This highlights the importance of examining not just media type but also the broader social context in which media is used.

In contrast, some studies have associated interactive media with more favorable EF outcomes. Research on video games and digital apps indicates that children may have opportunities to practice inhibition, working memory, and cognitive flexibility through gameplay (Yang et al., 2021; Nathanson & Beyens, 2018). For instance, expert video game players have been found to outperform non-players on EF tasks involving shifting and inhibition (Boot et al., 2008). However, it is important to note that not all interactive media experiences are equally beneficial. In some cases, highly stimulating games may reduce children's interest in slower-paced, cognitively demanding activities. Additionally, when interactive media is used primarily to occupy children in emotionally charged or unstructured contexts, it may limit opportunities for developing independent self-regulation skills.

Overall, these findings emphasize the need to distinguish between different forms of media use and consider both the media content's demands and the context in which children engage with it. The present study examines media interactivity as a potential moderator of the relationship between media use and EF development in early childhood.

Potential Mechanisms Explaining Media and Executive Functions Association

Several theoretical explanations have been proposed to account for the link between media use and EF development in early childhood. These mechanisms are generally conceptualized as complementary rather than competing and include reduced language exposure, displacement of developmentally enriching activities, and teaching of attentional styles that may hinder sustained attention (Nikkelen et al., 2014; Uzundag et al., 2022; Yang et al., 2017). While some empirical work has examined the role of language exposure (e.g., Fries, 2018), findings have not consistently supported its mediating role. The present study focuses on two alternative pathways, displacement of activities and teaching ineffective attention styles, both of which remain relatively underexplored in empirical research.

Displacement of Activities. The displacement hypothesis suggests that time spent engaging with media may come at the expense of developmentally enriching experiences, such as pretend play, shared reading, or caregiver-child interaction (Christakis, 2009; Zimmerman & Christakis, 2007). Initially proposed in early television research (Himmelweit et al., 1958), this theory posits that media may displace activities that serve a similar cognitive or emotional function (Hall et al., 2019; Lee & Kuo, 2002). To better understand the association between media exposure and EFs, we should consider other leisure activities that could potentially promote EF development. The literature offers numerous examples of such activities, including play, reading, and parent-child interactions (Uzundag et al., 2022; Vandewater et al., 2007). Previous research has demonstrated the positive impact of these activities on EFs (Hammond et al., 2012; Howard et al., 2017; Thibodeau-Nielsen et al., 2020). If media use reduces the frequency or quality of such experiences, it may negatively impact EF development. Although the displacement hypothesis has been widely discussed in theoretical and review literature (Kostyrka-Allchorne et al., 2017; Vandewater et al., 2007), it has rarely been tested using formal mediation models. The present study aims to empirically assess whether displacement of activities serves as a pathway linking media use to EF outcomes in early childhood.

Teaching Ineffective Attention Styles. A second potential mechanism is the teaching ineffective attention styles hypothesis. This perspective suggests that fast-paced, visually stimulating media, characterized by rapid scene changes and high sensory input (e.g., vivid colors), may promote an attentional style based on scanning and shifting rather than sustained attention (Lang et al., 2000; Singer, 2009). Such attentional patterns may be maladaptive in contexts requiring prolonged concentration, such as academic learning or problem-solving (Jensen et al., 1997). Longitudinal findings support this concern: for example, Gueron-Sela and Gordon-Hacker (2020) found that early media exposure was negatively associated with focused attention one year later in toddlers. Additionally, the compelling nature of screen media may reduce children's motivation to engage in slower-paced, cognitively demanding tasks, potentially undermining the development of regulatory capacities (Singer, 2009).

Together, these two mechanisms, displacement of activities and ineffective attention teaching, offer plausible explanations for how media use may influence EF development. The present study tests both as potential mediators in the relationship between media exposure and EF skills in preschool-aged children. In addition to examining whether each mechanism accounts for the association, the study also explores whether one pathway may be more salient than the other under specific conditions, such as differences in media interactivity or content.

Potential Moderators

A guiding theoretical approach for understanding how children engage with media is the Dynamic, Relational, Ecological Approach to Media Effects Research (DREAMER; Barr et al., 2024). This framework highlights the importance of examining three key dimensions: media content (e.g., educational vs. entertainment, pacing), media context (e.g., where and when media is used), and relational processes (e.g., co-use with caregivers, mediation styles). These dimensions interact dynamically with children's characteristics, such as temperament, within their broader developmental ecology. This conceptualization emphasizes that children's media experiences are influenced by individual child characteristics, the nature of the media content, and the social and environmental context in which media use occurs. Child-level factors relate to individual differences such as temperament, interests, or regulatory capacities. Content-related factors concern the quality, pace, or educational nature of the media. Contextual factors refer to the social environment during media use, including parental behaviors and routines.

Child Temperament. One important child-level factor is temperament. In early childhood, individual differences in reactivity and self-regulation, core elements of temperament, are strongly associated with EF development (Conway & Stifter, 2012). Temperament and EF share overlapping developmental trajectories and are positively correlated in multiple domains (Rothbart & Bates, 2006). Prior studies suggest that temperament moderates associations between environmental influences and EF outcomes. For example, children's temperament has been shown to moderate the effects of maternal depressive symptoms (Comas et al., 2014) and maternal attention-maintaining behaviors (Conway & Stifter, 2012) on EF.

Temperament also plays a role in shaping media use and media-related behaviors. Children with higher negative affectivity, greater surgency, or lower effortful control are more likely to engage with media for emotion regulation purposes, often leading to greater screen time and problematic media use (Coyne et al., 2021). Furthermore, parents' decisions regarding the duration and purpose of media exposure often reflect their perceptions of their child's temperament (Nabi & Krcmar, 2016). While several studies have explored links between temperament and media use, as well as temperament and EF, more research is needed to examine how these constructs interact to moderate media-EF associations.

Media Content. Media content is a multidimensional construct including message characteristics, pacing, and the degree to which the content is educational. Early studies primarily focused on violent content, consistently finding that exposure to violent media is negatively associated with attention and EF outcomes (Nikkelen et al., 2014). For example, frequent exposure to violent content before age three has been linked to attention problems in later childhood (Zimmerman & Christakis, 2007).

Another content-related factor is pacing. Fast-paced content has been shown to impair children's attentional and EF performance, likely due to overstimulation or mismatches with developmental capacities (Lillard & Peterson, 2011). In one experiment, children exposed to fast-paced television performed worse on EF tasks compared to those in slower-paced or non-screen conditions. Additional work has shown that fantastical content may impair EF performance regardless of pacing (Lillard et al., 2015). These findings underscore the importance of disentangling specific content features when assessing media's cognitive effects.

A broader framework for understanding content effects involves distinguishing between educational and entertainment media. Educational media is typically defined by its alignment with developmental goals: promoting engagement, supporting meaningful learning, and fostering social interaction (Hirsh-Pasek et al., 2015; Kolak et al., 2020). Studies have found that developmentally appropriate educational media is associated with positive or neutral EF outcomes, particularly among children from lower-SES backgrounds where such content may provide important cognitive stimulation (Barr et al., 2010; Blankson et al., 2015; Linebarger et al., 2014). In contrast, entertainment media, which often lacks features that support learning, tends to be neutral or negatively associated with EF (Kirkorian & Anderson, 2008; Harmon, 2021; Jusienė et al., 2020; McHarg et al., 2020; Suggate & Martzog, 2021). Therefore, clarity around content type is essential when interpreting media-EF associations.

Family context. Parental behaviors and broader family dynamics also moderate how children engage with and are affected by media. The most commonly studied form of parental involvement is parental mediation, which can take three main forms: restrictive mediation (setting limits on content or time), active mediation (discussing or explaining media content), and co-viewing (watching media together) (Valkenburg et al., 1999). These practices influence children's understanding and processing of media and are associated with improved comprehension and reduced adverse effects (Barr et al., 2020).

Empirical research has shown that active and restrictive mediation strategies are linked to reduced problematic media use (Collier et al., 2016; Fam et al., 2023). Moreover, parental mediation has been found to moderate the relationship between television exposure and EF outcomes (Yang et al., 2017). However, more research is needed to clarify how these effects operate across different media types.

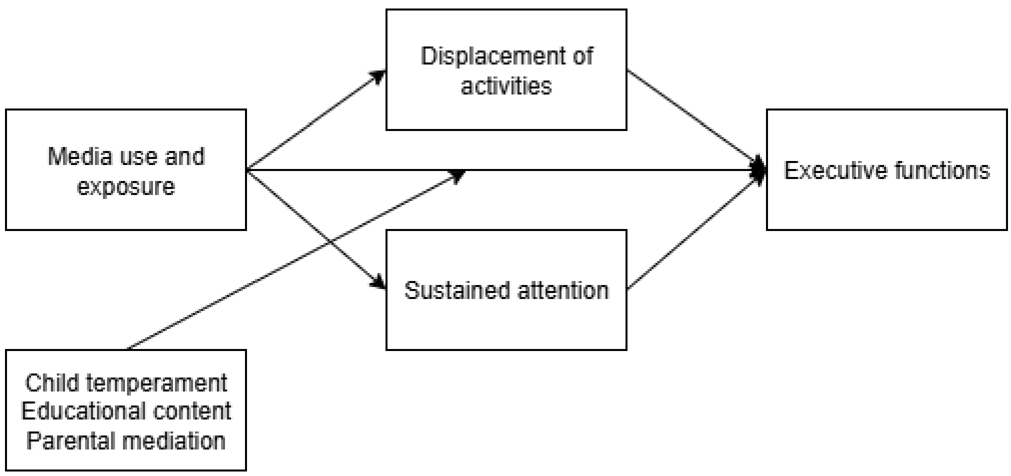
Taken together, these moderating factors, child temperament, media content, and family context, highlight the complex interplay between individual, media-based, and environmental influences. The present study incorporates these variables to examine when and for whom media exposure is most likely to support or hinder EF development.

The Present Study

The present study offers a comprehensive investigation of the associations between media use and executive function (EF) skills in preschool-aged children. Drawing on recent empirical findings and the DREAMER framework (Barr et al., 2024), we distinguish between receptive and interactive media use, recognizing that these forms of engagement may differentially relate to EF development. As such, we model these media types separately in our analyses. To better understand the underlying mechanisms of the media–EF association, we examine two theoretically grounded mediators: the displacement of developmentally supportive activities and teaching ineffective attention styles. These pathways have been proposed in the literature but have received limited empirical testing in early childhood samples. In addition, we explore potential moderating variables aligned with the DREAMER framework, including media content (e.g., educational), child temperament, and relational/contextual factors such as parental mediation. These moderators are expected to clarify the conditions under which media use is more or less likely to support EF development. Taken together, this study aims to advance the literature by identifying not only whether media use is associated with EF outcomes, but also how these associations are shaped by underlying mechanisms and contextual influences. A conceptual model of the proposed associations is presented in Figure 1.

Figure 1

The proposed model for media use, exposure and EFs.



The following hypotheses were formed from the model based on the previous literature:

H1: Receptive media exposure will be negatively associated with EFs, while interactive media use and exposure will be positively associated.

H2: Educational content, child temperament, and parental mediation will moderate the association between both receptive and interactive media and EFs. Specifically, receptive and interactive media will exhibit a negative association with EFs when there are low levels of educational content and parental mediation. Media use will be more negatively associated with EF when children's temperament is characterized by greater emotional reactivity, lower regulatory control, or higher activity and impulsivity.

H3: The association between receptive media use and interactive media use and EFs will be significantly explained through the mechanisms of displacement of other activities and ineffective attention.

Methods

Participants

Ninety-four children aged 3 to 5 years (*M*age = 4.35, *SD* = .85; 49% girls) and their parents (*M*age = 36.96, *SD* = 5.16; 81% women) participated in the study. Data were collected in and around the New River Valley region of Virginia, United States. Most parents (89%) had a bachelor's degree or higher. Over half (57%) were employed full-time, while about 18% were employed part-time, and another 18% were not employed. Household income was relatively high, with 59% of families reporting annual incomes over $100,000. Most parents identified as White (81%), followed by Asian (9%), Black (5%), and smaller proportions identifying as mixed race or other backgrounds.

Procedure

All study procedures were approved by the Virginia Tech Institutional Review Board. Written consent and permission forms were obtained from the parents. After that, parents were asked to complete an online questionnaire related to media use and exposure through the Qualtrics platform. The child data were only collected if parents completed the questionnaire. Before starting the child session for the behavioral measures, child assent was taken. Behavioral measures were either collected by visiting the preschools, inviting children and their parents to the lab, or by visiting their homes. The baseline analyses were conducted to make sure these three groups do not significantly differ from each other at the baseline. Child data were collected on different days. On Day 1, sustained attention and control variables were collected. On Day 2, executive function variables were collected. Sessions were ideally spaced one week apart, although there were some variations depending on family schedules. To quantify this variation, we calculated the number of days between Day 1 and Day 2 for each participant. Across the sample, the mean interval was 9.18 days (*SD* = 6.05), with a median of 7 days and a range from 1 to 41 days.

Materials and Measures

Media use and exposure-related variables

A questionnaire developed by the Comprehensive Assessment of Family Media Exposure (CAFÉ) Consortium was used to measure media use and exposure-related variables (Barr et al., 2020).

Recessive and interactive media use and exposure. Receptive and interactive media use and exposure were assessed using an online questionnaire. Parents were first asked whether their child had engaged in the following activities—watching videos and playing digital games, at least once in the past month. For each activity, they then reported how frequently their child engaged in these using a 7-point Likert scale ranging from has never done this to several times a day.

Education and entertainment media use and exposure. Educational and non-educational media use and exposure were assessed using an online questionnaire. To determine the educational content of the activities, we asked parents to report the three common shows/games their children watch/play. Then, parents were asked to indicate how educational they think these shows are with a four-point Likert scale from very educational to not at all educational.

Parental mediation during media use and exposure. As part of the CAFÉ questionnaire, parental mediation during media use was measured using the Parent Mediation Scale (Valkenburg et al., 1999). The scale includes five questions related to restrictive mediation and five questions related to active mediation behaviors. Parents rated the mediation behaviors on a Likert scale from never to very often (1–5). An example item for restrictive mediation behaviors is, "Restrict the amount of time your child can watch videos?" An example item for active mediation behaviors is, "Try to help your child understand what they see in videos?"

Mediating variables

Displacement of activities. Displacement of activities was assessed in a similar way to media use measures using an online questionnaire. Reading and playing without the usage of technological devices were considered potential activities that could be displaced by media use and be essential for developmental outcomes. For each activity, parents were asked how frequently their child engaged in these activities using a 7-point Likert scale ranging from has never done this to several times a day. The higher scores on the scale indicated lower levels of displacement of activities.

Sustained attention. Sustained attention ability was measured with the LAB-TAB (Bead Sorting for sustained attention) sustained attention task (Gagne et al., 2011; Goldsmith et al., 1993). In this measurement, researchers placed mixed beads of three different colors in front of children and asked them to separate the beads according to their colors. Then, the researcher left the children alone for three minutes and recorded the children's behaviors as they organized the beads. The aim of the task was to see whether the child would continue to be engaged in a task presented as a "chore" task rather than a fun task. The amount of time children spent sorting beads was coded as a proxy of sustained attention.

Outcome variable

The outcome variable was assessed using four tasks from the Early Years Toolbox: inhibition (Go/No-Go), visuospatial working memory (Mr. Ant), phonological working memory (Not This), and cognitive flexibility (Card Sorting). A composite working memory score was first created, which was then combined with the inhibition and cognitive flexibility scores to generate an overall EF composite. The following sections provide detailed information on the tasks used to measure each EF skill.

Inhibition. Inhibition was measured using an iPad-based Early Years Toolbox-Go/No-Go task. The basic principle of this task is to tap on the go trials (catch the fish) and not tap on the no-go trials (avoid the shark). During the task, 80% of the trials are go-trials, which makes the tapping behavior as the prepotent response. The task starts with the practice trials. First, instructions related to the go-trials are given, followed by five go-trials. The same procedure is conducted for the no-go trials. Then, go/no-go instructions are given, followed by ten mixed trials (80% go-trials). Auditory feedback is given during all practice trials. The test phase includes 75 trials presented in 3 blocks. The test blocks never start with no-go trials, and no more than two successive trials are no-go stimuli. The score is calculated by the proportion of go and no-go trial accuracy.

Working Memory. Visuospatial working memory was measured using an iPad-based Early Years Toolbox-Mr. Ant task (Howard & Melhuish, 2017). Children are asked to remember the location of stickers placed on a cartoon ant figure. The difficulty of the task increases as the number of stickers increases from one to eight. First, Mr. Ant is presented with an n-number of stickers related to the difficulty of the task for 5 seconds. Then, a blank screen is shown for 4 seconds. After that, children are asked to indicate the location of the stickers presented earlier. Each difficulty level has three trials. The task ends if children fail to respond correctly to all three trials. Accuracy and response time scores are computed for this task. Starting at Level 1, children receive one point for every consecutive level, where at least two out of the three trials were completed accurately. Additionally, children receive 1/3 of a point for every correct trial beyond that.

Phonological working memory was measured using an iPad-based Early Years Toolbox-Not-This task. Children are asked to point to the stimulus that is not the same color, shape, or size. Each level (Levels 1 to 8) has five trials. The difficulty of the task increases as the number of stimuli that need to be considered increases. While level 1 may ask children to find an object that is not blue, level 3 may ask children to find an object that is not blue, big, and a triangle. Starting at Level 1, children will receive one point for each consecutive level where at least three out of the five trials were performed accurately. Furthermore, they will receive 1/5 of a point for every correct trial beyond that point.

Cognitive Flexibility. Cognitive flexibility will be measured using an iPad based on the Early Years Toolbox- Card Sorting Task. The target stimuli consist of a red rabbit, a blue boat, a blue rabbit, and a red boat. Participants are asked to select the target stimulus that matches the relevant dimension of the test stimulus, either based on shape or color. This task consists of four blocks: practice, pre-switch, post-switch, and mixed. In the practice block, participants are given a demonstration and two practice trials, where they are instructed to match test stimuli presented centrally on a touch screen with one of two target stimuli that are presented based on shape or color.

The testing phase begins with a pre-switch block consisting of six trials where children are instructed to sort based on either color or shape. The structure and timing of each stimulus trial are the same as in the practice block. No feedback is provided during the testing trials. To proceed to the mixed block, where children are asked to sort based on either color or shape, depending on the higher-order rule (whether the picture has a black outline or not), children should correctly sort at least five out of six pre-switch and post-switch trials. The mixed block consists of six trials presented in random order, including three color and three shape trials. The scores are computed by the accurate sorting number after the pre-switch block.

Vocabulary Skills. The vocabulary skills will be measured using an iPad-based NIH-Toolbox Picture Vocabulary Test. Children are instructed that they will hear a word and see four pictures on the screen, and asked to click on the picture that best matches the meaning of the word. Testing begins with a practice phase; children see the correct response for two practice items. The first item that is going to be presented after the practice items depends on the chronological age of the child. Children are given 20-30 items depending on their performance.

Results

Preliminary Analyses

Before testing the hypothesized model, preliminary analyses were conducted. A one-way between-groups ANOVA examined whether children's executive function (EF) scores differed by assessment setting (lab, home, or school). Results indicated no significant differences across settings, $F(2, 82) = 1.04$, $p = .358$. In addition, we tested whether the number of days between the first session and the second session was not associated with EF after controlling for age. The regression analysis indicated that the number of days between sessions was not a significant predictor of EF ($\beta = -.116$, $p = .232$). Correlational analyses showed that among potential control variables, age and children's picture vocabulary scores were significantly associated with several outcome variables, including sustained attention and EFs (Table 1). Accordingly, age and picture vocabulary scores were included as covariates in the main analyses. Playing digital games was positively correlated with *EF*, whereas watching videos was not. None of the temperament subdimensions were significantly correlated with EFs. As expected, sustained attention was positively correlated with EF

Table 1

Correlation among study variables and descriptives

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Age	-														
2. Child sex	.00	-													
3. PVT	.28**	.29**	-												
4. Watching videos	-.13	-.004	-.08	-											
5. Playing digital games	.22**	.002	.07	.28*	-										
6. Surgency	-.01	-.23*	-.05	.13	.07	-									
7. Negative affectivity	.23**	.03	-.005	.21*	.21*	-.03	-								
8. Effortful control	-.04	.27**	-.04	-.10	-.13	-.22	.10	-							
9. Active mediation (video)	-.09	.25*	.03	.05	-.06	-.16	.002	.19	-						
10. Active mediation (digital games)	.15	.17	-.02	.05	.21	.00	.05	-05	.54**	-					
11. Educational content (video)	-.24*	.10	-.16	.04	-.14	-.02	.00	.18	.07	.04	-				
12. Educational content (digital games)	-.11	.20	.008	.16	-.07	-.14	-.14	.06	.08	.14	.46**	-			
13. Sustained attention	.46**	.09	.28*	-.17	.17	-.16	.16	.12	-.04	-.04	-.23	-.04	-		
14. Displacement	-.170	.25*	.25*	.22	-.07	-.07	-.01	.21*	.23*	.11	.20	.21	.00	-	
15. EF	.50**	.06	.26*	-.12	.25*	.05	.14	-.07	.01	.09	-.09	-.007	.36**	.14	-
M	4.35	1.49	96.18	5.85	3.17	4.02	3.75	5.20	2.63	2.11	1.56	1.51	126.40	6.48	1.96
SD	.85	.50	15.83	.90	2.42	.82	.81	.63	.70	1.18	.70	.91	52.49	.68	1.30
Range	3.10-6.09	1-2	54-146	3-7	0-7	1.42-5.83	1.50-5.50	3.83-6.42	1-4	0-4	0-3	0-3	2-180	4.75-7	.09-4.48
N	94	94	90	94	94	92	92	92	94	63	93	59	90	94	85

Note. Child sex was coded as 1 = boy and 2 = girl; PVT = NIH Toolbox Picture Vocabulary Task (age-corrected scores); EF = aggregated executive function score from Early Years Toolbox tasks assessing visuospatial and verbal working memory, inhibition, and cognitive flexibility. p < .05, p < .01.

Main Analyses

Before proceeding with the main analyses, we conducted a Missing at Random (MAR) test to evaluate whether the missing data were systematically related to observed variables. The test was not significant, supporting the assumption that data were missing at random. Therefore, all available data were retained using Full Information Maximum Likelihood (FIML) estimation, which provides unbiased parameter estimates under the MAR assumption (Enders, 2010).

Given the sample size, the hypothesized model was tested separately for mediation and moderation effects. Specifically, mediation paths from media use to executive functions (EFs) through displacement and sustained attention were tested independently for watching videos and playing digital games. Likewise, moderation analyses were conducted separately for each moderator—temperament, educational content, and active mediation—and for each media type. This approach helped reduce model complexity and improve estimation stability, as recommended when sample sizes are modest and models include multiple interaction or indirect pathways (Kline, 2015; Hayes, 2018).

For the mediation models, we employed bootstrapping procedures with 5,000 resamples to generate bias-corrected 95% confidence intervals for indirect effects, which is considered a robust method for testing mediation, especially in smaller samples (Preacher & Hayes, 2008). Model fit was evaluated using multiple indices based on widely accepted thresholds: the root mean square error of approximation (RMSEA $\leq .06$), the standardized root mean square residual (SRMR $\leq .08$), the comparative fit index (CFI $\geq .95$), and the Tucker–Lewis index (TLI $\geq .95$) (Hu & Bentler, 1999).

Executive Functions

Executive functions (EFs) were assessed using four subdimensions: visuospatial working memory, verbal working memory, inhibition, and cognitive flexibility, in accordance with prior EF conceptualization and measurement models (Miyake et al., 2000). First, an average working memory (WM) score was computed by combining visuospatial and phonological WM. Subsequently, a confirmatory factor analysis (CFA) was conducted to create a latent EF factor comprising WM, inhibition, and cognitive flexibility. Given that the model was just identified (df = 0), global fit indices could not be interpreted. Factor loadings were satisfactory, with standardized estimates of .77 for WM, .67 for inhibition, and .55 for cognitive flexibility. Therefore, the latent EF factor was used as the primary measure of EFs in subsequent analyses.

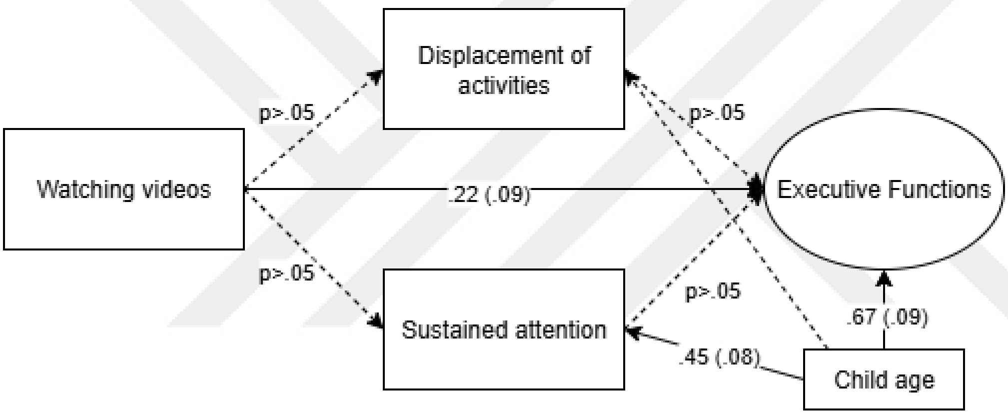
Watching videos

Mediation Analyses. A mediation analysis was conducted to examine the associations between watching videos and a latent executive function (EF) factor mediated through sustained attention and displacement of activities, controlling for child age in months (Figure 2). Child picture vocabulary scores were removed from the model as they did not predict EF to reduce the number of variables included. The model fit indices indicated a very good fit to the data, χ^2 (9) = 9.19, $p = .420$, RMSEA = .02 (90% CI = [0.000, 0.118]), CFI = .998, TLI = .996, SRMR = .04.

For the direct effects, watching videos was not significantly associated with latent EF ($\beta = .00$, $p = .996$), whereas age was positively associated with EF ($\beta = .71$, p < .001). Watching videos was not significantly related to sustained attention ($\beta = –.10$, $p = .290$), though age was positively associated with sustained attention ($\beta = .45$, $p < .001$). Watching videos was marginally positively associated with displacement of activities ($\beta = .20$, $p = .085$), while age was not significantly associated with displacement (β = –.15, p = .206). Neither sustained attention (β = .12, p = .273) nor displacement (β = .04, p = .694) significantly predicted EF. Indirect effects via sustained attention and displacement were not significant. The indirect effect through sustained attention was β = –.01, [95% CI: –.05, .02] and through displacement was β = .01, [95% CI: –.01, .04].

Figure 2

Mediation model testing the association between watching videos *and executive functions through displacement of activities and sustained attention, controlling for child age.*

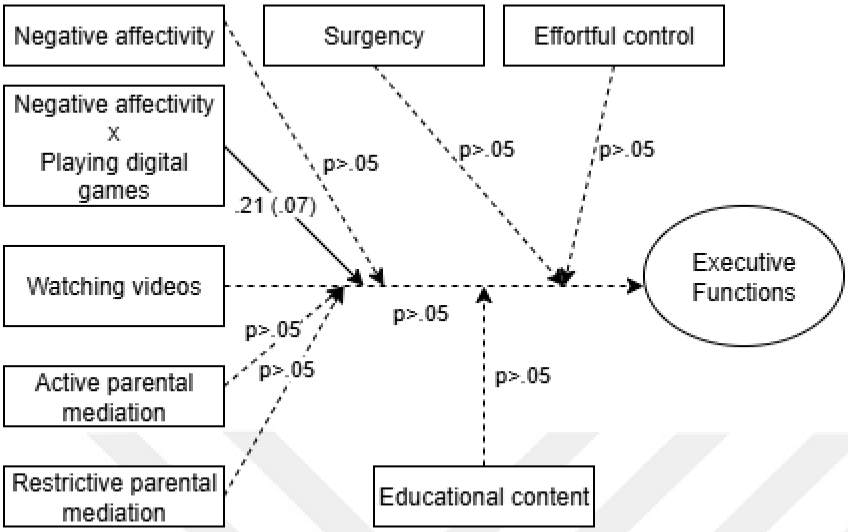


Note. EF is specified as a latent factor comprising working memory, inhibition, and cognitive flexibility. Values represent standardized estimates, with standard errors in parentheses. Solid lines indicate significant paths (p < .05); dashed lines indicate non-significant paths.

Moderation Analyses. We tested the moderator roles of educational content of the videos, children's temperament, and parental mediation during program viewing on the link between watching videos and EFs. Models were tested separately for each moderator given the sample size to avoid over-fitting (Figure 3).

Figure 3

Moderation model for the association between watching videos *and EFs.*



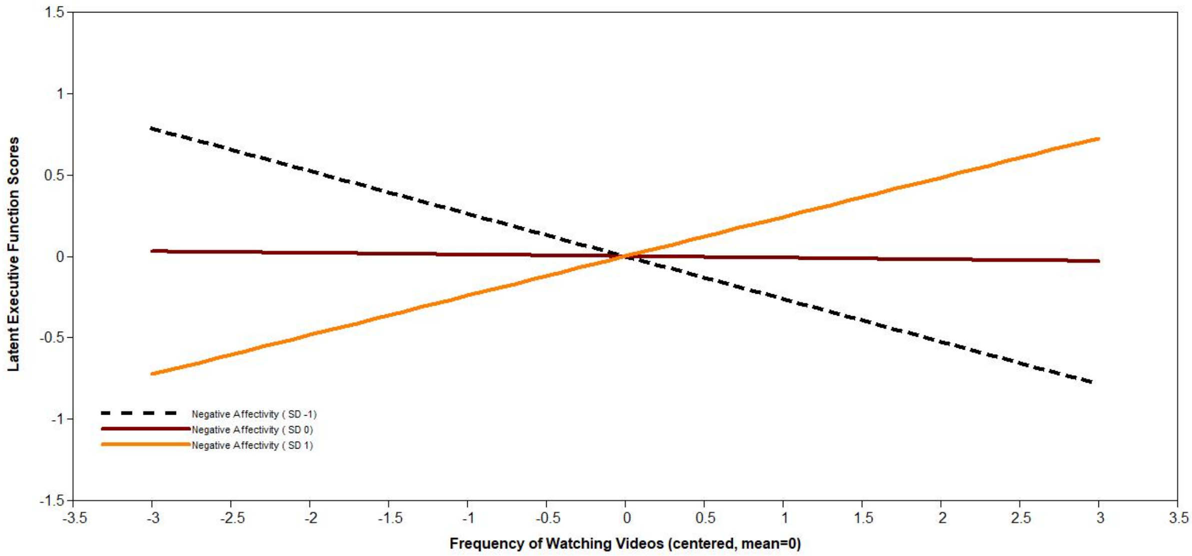
Note. EF is specified as a latent factor comprising working memory, inhibition, and cognitive flexibility, and controlling for child age. Values represent standardized estimates, with standard errors in parentheses. Solid lines indicate significant paths ($p < .05$); dashed lines indicate non-significant paths. Each moderator—temperament subdimensions (surgency, effortful control, negative affectivity), parental mediation (active, restrictive), and educational content—was tested in a separate model to reduce complexity and avoid overidentification. Interaction terms for the other moderators were not included in the displayed model because they were non-significant. Age was a significant positive predictor of executive functions in all models.

We tested whether the association between watching videos and latent EF was moderated by the level of active parental mediation during viewing, controlling for child age in months. The model fit the data very well, χ^2 (8) = 4.93, p = .765, RMSEA = .000 (90% CI = [.000, .084]), CFI = 1.00, TLI = 1.00, SRMR = .03. The interaction term between watching videos and active parental mediation was not statistically significant (β = .003, p = .974), indicating that the relation between video viewing and EF did not vary by parental active mediation behaviors. Neither the main effect of watching videos (β = –.007, p = .932) nor the main effect of active parental mediation (β = .023, p = .786) was significant. Age remained a strong positive predictor of EF (β = .754, p < .001). We examined whether the association between watching videos and latent EF was moderated by the level of restrictive parental mediation during viewing, controlling for child age in months. The model showed a good fit to the data, χ^2 (8) = 9.52, *p* = .300, RMSEA = .045 (90% CI = [.000, .134]), CFI = .984, TLI = .970, SRMR = .048. The interaction between watching videos and restrictive parental mediation was not statistically significant (β = .079, *p* = .409), suggesting that the relationship between video viewing and EF did not vary as a function of restrictive mediation. Neither the main effect of watching videos (β = .018, *p* = .849) nor the main effect of restrictive mediation (β = .074, *p* = .437) was significant. Age was a strong positive predictor of EF (β = .758, $p < .001$).

Then, moderation analysis was conducted to examine whether children's temperament subdimensions—surgency, negative affectivity, and effortful control—moderated the association between watching videos and EFs, controlling for child age. The model showed a good fit to the data, χ^2 (12) = 10.85, *p* = .54, RMSEA = .00 (90% CI = [.00, .10]), CFI = 1.00, TLI = 1.00, SRMR = .039. The main effect of watching videos was not significant (β = –.01, *p* = .910). Main effects of surgency (β = .07, p = .437), negative affectivity (β = .17, *p* = .059), and effortful control (β = .10, *p* = .189) were also not statistically significant. The interaction term between watching videos and negative affectivity was statistically significant, β = .252, *p* = .002. Simple slope analyses indicated that for children with higher negative affectivity (+1 SD), greater watching videos was associated with higher EF scores, whereas for children with lower negative affectivity (–1 SD), the association was negative (Figure 4).

Figure 4

Line graph depicting the interaction between negative affectivity and watching videos at –1 SD, 0 SD, and +1 SD levels of negative affectivity.



Finally, a moderation analysis was conducted to examine whether the frequency of educational content in videos moderated the association between watching videos and latent EF, controlling for child age. The model showed a good fit to the data, χ^2 (8) = 11.92, *p* = .154, RMSEA = .072 (90% CI = [.00, .15]), CFI = .961, TLI = .927, SRMR = .049. The main effect of watching videos was not significant (β = .001, *p* = .994). The main effect of educational video content was also not significant (β = .098, *p* = .252). The interaction term between watching videos and educational video content was not statistically significant (β = –.139, *p* = .105).

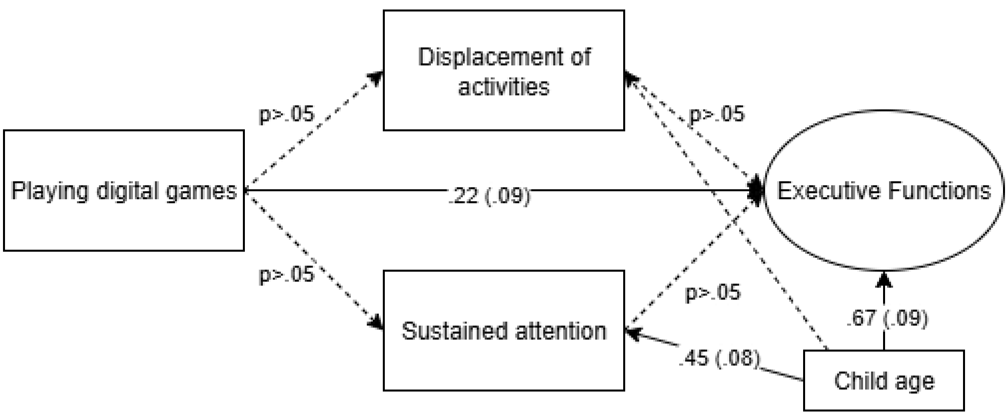
Playing digital games

Mediation Analyses. Mediation analyses were conducted to examine the associations between playing digital games and a latent executive function (EF) factor mediated through sustained attention and displacement of activities, controlling for child age in months (Figure 5). Child picture vocabulary scores were removed from the model as they did not predict EF to reduce the number of variables included. The model fit indices indicated a good fit to the data. The Chi-Square test of model fit was non-significant, χ^2 (9) = 8.78, *p* = .45, suggesting that the model adequately represented the data. Additional fit indices supported this conclusion, RMSEA = .00 (90% CI = [.00, .12]), CFI = 1.00, TLI = 1.00, SRMR = .04.

When considering the direct effects, playing digital games significantly predicted the latent EF (β = .22, p = .011). Additionally, age was a significant predictor of latent EF (β = .67, p < .001). On the other hand, playing digital games was not significantly associated with displacement of activities (β = –.04, p = .753), and age did not significantly predict displacement of activities (β = –.16, p = .167). Playing digital games also did not predict sustained attention (β = .07, p = .515), while age significantly predicted sustained attention (β = .45, p < .001). Indirect effects were calculated to explore potential mediation through sustained attention and displacement of activities. The indirect effect of playing digital games on EFs through sustained attention was not significant (β = .006, 95% CI [–.02, .04]), as was the indirect effect through displacement of activities (β = -.001, 95% CI [–.04, .02]).

Figure 5

Mediation model testing the association between playing digital games *and executive functions through displacement of activities and sustained attention, controlling for child age.*

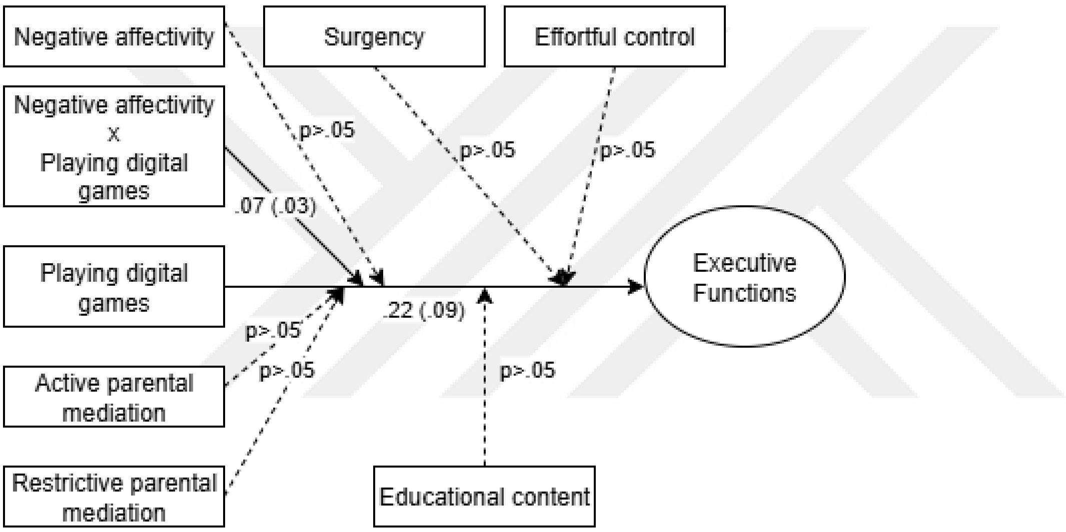


Note. EF is specified as a latent factor comprising working memory, inhibition, and cognitive flexibility. Values represent standardized estimates, with standard errors in parentheses. Solid lines indicate significant paths (p < .05); dashed lines indicate non-significant paths.

Moderation Analyses. We tested the moderator roles of educational content of the digital games, children's temperament, and parental mediation during playing digital games on the link between playing digital games and latent EF. Models were tested separately for each moderator, given the sample size to avoid over-fitting (Figure 6).

Figure 6

Moderation model for the association between playing digital games and executive functions (EFs).



Note. EF is specified as a latent factor comprising working memory, inhibition, and cognitive flexibility, and controlling for child age. The figure depicts the significant interaction between negative affectivity and playing digital games. Values represent standardized estimates, with standard errors in parentheses. Solid lines indicate significant paths ($p < .05$); dashed lines indicate non-significant paths. Each moderator—temperament subdimensions (surgency, effortful control, negative affectivity), parental mediation (active, restrictive), and educational content—was tested in a separate model to reduce complexity and avoid overidentification. Interaction terms for the other moderators were not included in the displayed model because they were non-significant. Age was a significant positive predictor of executive functions in all models.

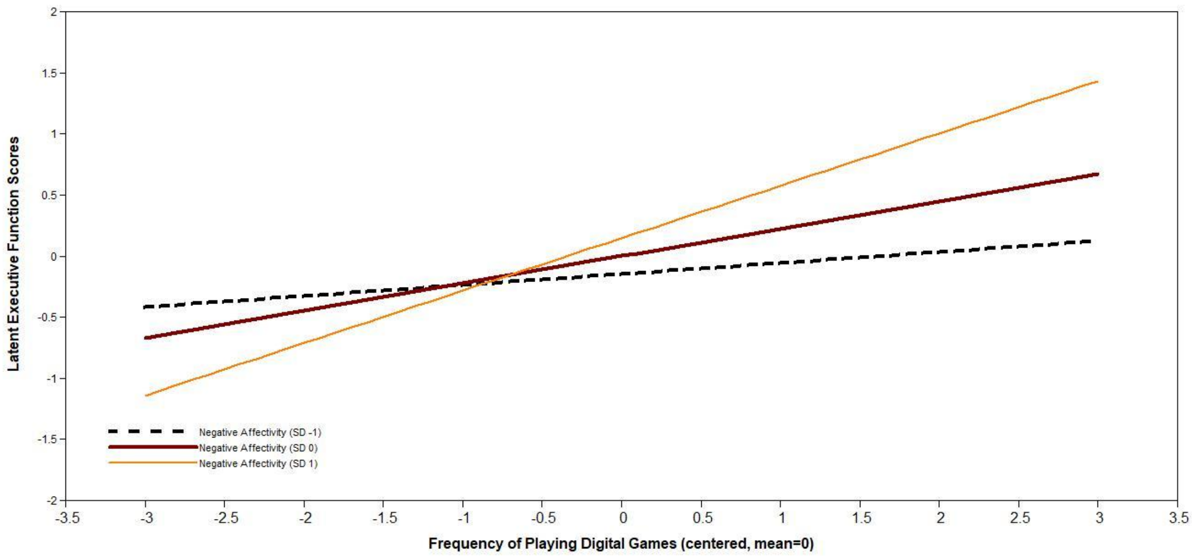
We conducted a moderation to examine whether active parental mediation moderated the association between playing digital games and latent EF, controlling for child age.The model showed a good fit to the data, χ^2 (8) = 4.75, p = .784, RMSEA = .00 (90% CI = [.00,

.08]), CFI = 1.00, TLI = 1.00, SRMR = .032. The main effect of playing digital games was statistically significant (β = .205, p = .043). The main effect of active parental mediation (β = –.134, p = .366) was not statistically significant. The interaction between playing digital games and active mediation was also not statistically significant (β = .203, p = .210). Then, we conducted another moderation analysis to examine whether restrictive parental mediation moderated the association between playing digital games and latent EF, controlling for child age. Model fit was adequate, $\chi^2(8) = 9.891$, p = .273, RMSEA = .050, (90% CI [.000, .137]), CFI = .982, TLI = .966, and SRMR = .064. Age (β = .699, $p < .001$) and playing digital games (β = .223, p = .021) were positively associated with latent EF. Restrictive parental mediation was not directly associated with EF (β = −.043, p = .744), and the interaction between restrictive parental mediation and playing digital games was not significant (β = .143, p = .283).

Then, moderation analysis was conducted to examine whether children's temperament subdimensions—surgency, negative affectivity, and effortful control—moderated the association between playing digital games and latent EF, controlling for child age. The model showed a good fit to the data, χ^2 (12) = 10.92, p = .54, RMSEA = .00 (90% CI = [.00, .10]), CFI = 1.00, TLI = 1.00, SRMR = .042. The main effect of playing digital games was significant (β = .22, p = .005). Main effects of surgency (β = .07, p = .38), negative affectivity (β = .15, p = .099), and effortful control (β = .15, p = .054) were also not statistically significant. The interaction term between playing digital games and negative affectivity was statistically significant, β = .205, p = .013. Simple slope analyses indicated that for children with higher negative affectivity (+1 SD), greater playing digital games was associated with higher EF scores, whereas for children with lower negative affectivity (–1 SD), the association was negative but not statistically significant (Figure 7).

Figure 7

Line graph depicting the interaction between negative affectivity and playing digital games at –1 SD, 0 SD, and +1 SD levels of negative affectivity.



Finally, a moderation analysis was conducted to examine whether the frequency of educational content in digital games moderated the association between playing digital games and latent EF, controlling for child age. The model showed a good fit to the data, χ^2 (8) = 4.69, p = .79, RMSEA = .00 (90% CI = [.00, .08]), CFI = 1.00, TLI = 1.00, SRMR = .036. The main effect of playing digital games was significant (β = .23, p = .009). The main effect of educational video content was not significant (β = -.07, p = .55). The interaction term between video playing digital games and educational video content was not statistically significant (β = .111, p = .259).

Discussion

The current study had two primary aims. The first was to test potential mechanisms that could explain the association between media use and executive functions (EFs) by examining two pathways proposed in the literature: displacement of developmentally supportive activities (e.g., shared reading, play) and sustained attention (Nikkelen et al., 2014;

Yang et al., 2017). Consistent with prior work, we distinguished between watching videos (receptive media use) and playing digital games (interactive media use), as these media types may have differential effects on EFs (Ozcan & Kisbu, 2025; Suggate & Martzog, 2021). Mediation models for each media type were tested separately. The second aim was to examine moderators derived from the DREAMER framework (Barr et al., 2024) that could influence the media–EF association. Drawing on existing research, we focused on three key dimensions: child characteristics (temperament), media content (educational value), and context (parental mediation).

In line with these aims, the first hypothesis was that media type woud play an important role in the media–EF association, with different patterns expected for watching videos and playing digital games. We further hypothesized that receptive media exposure would be negatively associated with EF. Consistent with the hypothesis that media type matters (Ozcan & Kisbu, 2025; Suggate & Martzog, 2021), the present study found a positive association between playing digital games and EF, whereas watching videos was not significantly related to EF. The positive link for interactive media aligns with research suggesting that cognitively demanding games may provide opportunities to practice EF-related skills such as inhibition, working memory, and cognitive flexibility (Boot et al., 2008; Nathanson & Beyens, 2018; Yang et al., 2021). By contrast, the null association for watching videos differs from our expectations and from prior studies reporting negative associations for high-duration receptive media exposure in preschool-aged children (McHarg et al., 2020; Nathanson et al., 2014). One possible explanation is that the current sample was highly educated, and parents may have greater access to higher-quality, developmentally appropriate video content (Barr et al., 2010), potentially offsetting negative effects. Additionally, the use of parent-reported media usage and exposure rather than actual usage and exposure may have limit the findings.

The second hypothesis predicted that the association between media use and EF would be moderated by child temperament, educational content, and parental mediation. Specifically, we anticipated that lower educational content, lower parental mediation, and certain temperament profiles (e.g., higher negative affectivity, lower effortful control, higher surgency) would exacerbate negative associations between media use and EF. Results provided partial support for this hypothesis. Of the tested moderators, only negative affectivity emerged as a significant moderator, and this effect was evident for both watching videos and playing digital games.

Interestingly, the direction of this moderation effect diverged from our initial predictions. Contrary to expectations and some prior findings suggesting that higher emotional reactivity may intensify negative media effects (Nabi & Krcmar, 2016), our results indicated that greater negative affectivity was linked to stronger positive relationships between playing digital games and EF. Importantly, the positive association between playing digital games and EF was observed across different temperament levels; however, it was most pronounced among children high in negative affectivity. One possible explanation is that emotionally reactive children may benefit from the structured, goal-oriented, and engaging nature of certain digital games, which may provide repeated opportunities to practice EF-related skills such as self-regulation, working memory, and cognitive flexibility (Coyne et al., 2021; Conway & Stifter, 2012). Additionally, prior suggestions regarding the risks of high emotional reactivity in the media context may have been based primarily on more traditional, receptive media formats such as television viewing, where associations with cognitive and regulatory outcomes have tended to be negative (Nabi & Krcmar, 2016). In contrast, interactive media such as digital games may engage emotionally reactive children in a way that promotes rather than hinders EF development.

For watching videos, the moderation pattern was more nuanced. Among children high in negative affectivity, greater video viewing was associated with higher EF scores. This finding may reflect exposure to developmentally appropriate, calming, or emotionally engaging video content that helps these children regulate their emotions and sustain attention. In contrast, among children low in negative affectivity, greater video viewing was associated with lower EF, consistent with displacement or passivity hypotheses in which receptive media use may reduce opportunities for active, cognitively demanding activities. For children with average levels of negative affectivity, video viewing was not significantly related to EF, suggesting that for this group, video exposure may be largely neutral in its effects.

The other tested moderators, educational content and parental mediation, did not play significant roles in the associations between either watching videos or playing digital games and EF. The absence of a significant moderation effect for educational content is unlikely to be explained by a restricted range in scores, as the data showed substantial variability across the full 0–3 scale. In the present study, educational content was measured separately for videos ($M = 1.56$, $SD = .70$) and for games ($M = 1.51$, $SD = .91$), with higher scores indicating greater educational value. On average, exposure fell around the midpoint of the scale, suggesting a moderate level of educational value, but the variability indicates that some children consumed media rated as very educational while others engaged with content rated as not educational at all. One possible explanation for the absence of moderation is that, within this relatively high-SES sample, even the lower-rated content may have been of generally acceptable quality, reducing the contrast between lower and higher scores. Moreover, the measure captured parental perceptions of educational value, which may not perfectly align with objective assessments of content quality, thereby introducing additional measurement error. Together, these factors may have reduced the likelihood of detecting moderation effects, even if educational content plays a role in more heterogeneous or lower-resource populations.

Similarly, parental active mediation did not emerge as a significant moderator, despite prior research indicating that co-viewing and discussing media content can scaffold children's comprehension and self-regulation skills (Nathanson, 2001; Valkenburg et al., 1999). In the current study, parental mediation was measured separately for different media activities (e.g., video viewing and gameplay), allowing for a more precise assessment of context-specific mediation. Nonetheless, it is possible that the measure still reflected general patterns of mediation rather than capturing variations in how parents respond in specific moments of media engagement. Alternatively, if parents in this relatively high education level sample already engage in consistently high levels of active mediation across both media types, this homogeneity could mask potential moderation effects.

Overall, the lack of significant moderation for educational content and parental mediation suggests that in relatively advantaged, higher-SES samples, differences in these factors may be insufficient to influence the media–EF link. Future research, including more socioeconomically and culturally diverse samples, as well as finer-grained measures of mediation and content quality, is needed to clarify their potential moderating roles.

The third hypothesis proposed that the relationship between media use and EF would be explained, in part, by two mechanisms identified in the literature: displacement of cognitively enriching activities and sustained attention. These mechanisms were tested separately for watching videos (receptive media) and playing digital games (interactive media), consistent with prior work suggesting that different media types may engage distinct cognitive and behavioral pathways (Barr, 2013; Lillard et al., 2015).

For watching videos, neither displacement of activities nor sustained attention significantly mediated the association with EF. This finding is notable given that much of the prior mediation literature on video viewing has focused on negative pathways, in which greater viewing displaces enriching activities (McHarg et al., 2020) or teaches ineffective attention (Nathanson et al., 2014), leading to poorer EF outcomes. The absence of mediation here may reflect that video content in this sample was relatively high in developmental quality, potentially reducing the likelihood of such negative pathways. It is also possible that the use of parent-reported frequency limits the precision of displacement measurement.

In contrast, playing digital games was positively associated with EF. This difference in the direction of the direct effect means that, if mediation were present, the hypothesized pathways might operate differently from those for video viewing. Rather than explaining detrimental effects, mechanisms such as sustained attention or reduced displacement might be expected to contribute to beneficial outcomes. Indeed, interactive digital games can place demands on inhibition, working memory, and cognitive flexibility (Boot et al., 2008; Nathanson & Beyens, 2018; Yang et al., 2021), which may in turn strengthen EF. However, neither displacement of activities nor sustained attention significantly mediated the positive association, suggesting that these benefits are not explained by the two pathways tested here. It is possible that the absence of significant mediation reflects the relatively short temporal gap between measuring media use (i.e., video viewing and digital game play), the mediators, and EF outcomes in the current study. Longitudinal mediation models are needed to clarify directional mechanisms (e.g., Fung & Chung, 2023).

Theoretical Implications

The present findings contribute to the growing literature on the complex interplay between media use and young children's executive functions (EFs), offering several theoretical insights. First, the observation that playing digital games was positively associated with EF, whereas watching videos showed no significant association, reinforces the need for media theories to distinguish between interactive and receptive media modalities (Barr, 2013;

Lillard et al., 2015). Frameworks such as the DREAMER model (Barr et al., 2024) highlight that the type of media interaction, whether it actively engages children in cognitively demanding tasks or passively delivers content, can fundamentally shape cognitive outcomes. Our results suggest that these differences are not merely quantitative (i.e., amount of use) but qualitative, tied to the underlying cognitive processes that different media types require.

Second, the moderation findings, particularly for negative affectivity, extend existing theory by showing that child-level characteristics can shift the nature of media–EF associations. Previous work often conceptualized emotional reactivity as a vulnerability factor that exacerbates negative media effects (e.g., Nabi & Krcmar, 2016), but our results suggest that certain media contexts may instead provide structured opportunities for self-regulation practice that benefit emotionally reactive children. This aligns with the notion in the DREAMER framework that child characteristics interact with media content and context in complex, sometimes counterintuitive ways.

Finally, the relatively high parental education and reported educational value of content in this sample highlight the role of sociocultural and resource contexts in shaping both media experiences and their developmental consequences. The DREAMER framework explicitly incorporates these contextual layers, and our findings suggest that in higher-resource settings, the hypothesized risks of receptive media may be attenuated, while the potential benefits of interactive media may be amplified.

Together, these implications suggest that theory should move beyond broad generalizations about “screen time” toward more nuanced, contextually grounded models that account for media type, child characteristics, content quality, and sociocultural context as interacting determinants of EF outcomes.

Limitations

Several limitations should be acknowledged when interpreting the present findings. First, the study employed a cross-sectional design, which limits the ability to draw strong causal inferences about the directionality of media–EF associations. Although EF was assessed on a different day from the media and mediator measures (*M* = 9.18 days later, range = 1–41 days), which reduces potential same-occasion measurement bias (Cain et al., 2018), the design remains cross-sectional. The separation of measurements improves temporal ordering but does not establish temporal precedence in the causal sense, as no repeated measures of change over time were collected (Maxwell & Cole, 2007). Without longitudinal or experimental data, alternative explanations, including reverse causality or unmeasured third variables, remain plausible. Future research should address these limitations by employing longitudinal designs with multiple measurement points to test temporal ordering and reciprocal effects, or experimental interventions that manipulate media exposure to directly assess causal pathways.

Second, the sample consisted primarily of children from relatively high-SES, predominantly White U.S. families. This demographic homogeneity may limit the generalizability of our findings, as socioeconomic resources and cultural practices can influence both the type of media children access and the developmental implications of that media (Linebarger et al., 2014). Future studies should replicate and extend these findings in samples with broader socioeconomic, racial/ethnic, and cultural diversity to determine whether the observed patterns hold in different contexts and to identify potential cultural moderators.

Third, media exposure and content quality were assessed via parent report. While parent reports provide valuable insight into household media practices, they are subject to recall biases, social desirability effects, and inaccuracies, particularly when estimating time spent on specific media activities or judging educational value (Barr et al., 2020). Future work should incorporate more objective and fine-grained measurement approaches, such as passive digital tracking, application usage logs, time-use diaries, or in situ observation, to improve accuracy and capture the contextual nuances (e.g., co-viewing, multitasking) that may shape media's impact.

Fourth, our relatively modest sample size limited the statistical power to test more complex models. For instance, we tested moderators separately to avoid overparameterization, but a larger sample would allow for simultaneous inclusion of multiple moderators and for testing moderated mediation models. Future research should recruit larger, adequately powered samples to permit such multivariate modeling and to detect potentially small but meaningful interaction effects.

Conclusion

The present study examined both potential mechanisms and moderators underlying the relationship between media use and executive functions (EFs) in preschool-aged children. By differentiating between media types, watching videos (receptive media) and playing digital games (interactive media), and testing two theorized mechanisms from the literature, displacement of activities and sustained attention, this research contributes to a more nuanced understanding of how early media experiences relate to cognitive development.

Results indicated a positive direct association between playing digital games and EF, whereas watching videos was not significantly related to EF. This pattern emphasizes the importance of distinguishing between interactive and receptive media experiences, as they may engage in cognitive processes in qualitatively different ways. Mediation analyses did not support the proposed mechanisms, with limited evidence that displacement of activities or sustained attention explained the observed associations. Moderation analyses further revealed that child temperament, in particular, negative affectivity, plays a role in shaping the media–EF link, with patterns differing between media types. However, educational content and parental active mediation did not emerge as significant moderators, potentially reflecting high overall content quality and consistently high mediation in this relatively advantaged sample.

Taken together, these findings align with and extend the DREAMER framework, highlighting the interplay between media type, child characteristics, and environmental context in shaping developmental outcomes. While the cross-sectional design precludes causal inference, the separation of EF measurement from other study variables strengthens the temporal ordering of variables and reduces shared-occasion bias. Future research using longitudinal and experimental designs, more fine-grained media measures, and diverse samples will be critical to clarify causal pathways and to identify conditions under which media use supports or hinders EF development. Ultimately, this study provides evidence that not all media are equal in their associations with young children's cognitive outcomes and emphasizes the need for developmentally informed guidance for parents, educators, and policymakers in the digital age.

References

Anderson, D. R., & Davidson, M. C. (2019). Receptive versus interactive video screens: A role for the brain's default mode network in learning from media. *Computers in Human Behavior, 99,* 168–180. https://doi.org/10.1016/j.chb.2019.05.018

Barr, R., & Linebarger, D. N. (2017). *Media exposure during infancy and early childhood.* Springer Nature.

Barr, R., Kirkorian, H., Radesky, J., Coyne, S., Nichols, D., Blanchfield, O., Fitzpatrick, C., et al. (2020). Beyond screen time: A synergistic approach to a more comprehensive assessment of family media exposure during early childhood. *Frontiers in Psychology, 11,* 1283. https://doi.org/10.3389/fpsyg.2020.01283

Blair, C., Granger, D. A., Willoughby, M., Mills-Koonce, R., Cox, M., Greenberg, M. T., & FLP Investigators. (2011). Salivary cortisol mediates effects of poverty and parenting on executive functions in early childhood. *Child Development, 82,* 1970–1984. https://doi.org/10.1111/j.1467-8624.2011.01643.x

Bull, R., Espy, K. A., & Wiebe, S. A. (2008). Short-term memory, working memory, and executive functioning in preschoolers: Longitudinal predictors of mathematical achievement at age 7 years. *Developmental Neuropsychology, 33,* 205–228. https://doi.org/10.1080/87565640801982312

Bustamante, J. C., Fernández-Castilla, B., & Alcaraz-Iborra, M. (2023). Relation between executive functions and screen time exposure in under 6 year-olds: A meta-analysis. *Computers in Human Behavior,* 107739. https://doi.org/10.1016/j.chb.2023.107739

Cain, M. K., Zhang, Z., & Bergeman, C. S. (2018). Time and other considerations in mediation design. *Educational and Psychological Measurement, 78,* 952–972. https://doi.org/10.1177/0013164417743003

Carlson, S. M., & Wang, T. S. (2007). Inhibitory control and emotion regulation in preschool children. *Cognitive Development, 22,* 489–510. https://doi.org/10.1016/j.cogdev.2007.08.002

Carlson, S. M., Mandell, D. J., & Williams, L. (2004). Executive function and theory of mind: Stability and prediction from ages 2 to 3. *Developmental Psychology, 40,* 1105–1122. https://doi.org/10.1037/0012-1649.40.6.1105

Collier, K. M., Coyne, S. M., Rasmussen, E. E., Hawkins, A. J., Padilla-Walker, L. M., Erickson, S. E., & Memmott-Elison, M. K. (2016). Does parental mediation of media influence child outcomes? A meta-analysis on media time, aggression, substance use, and sexual behavior. *Developmental Psychology, 52,* 798–812. https://doi.org/10.1037/dev0000108

Comas, M., Valentino, K., & Borkowski, J. G. (2014). Maternal depressive symptoms and child temperament: Longitudinal associations with executive functioning. *Journal of Applied Developmental Psychology, 35,* 156–167. https://doi.org/10.1016/j.appdev.2014.03.005

Common Sense Media. (2020). *The common sense census: Media use by kids age zero to eight.* Common Sense Media.

Conway, A., & Stifter, C. A. (2012). Longitudinal antecedents of executive function in preschoolers. *Child Development, 83,* 1022–1036. https://doi.org/10.1111/j.1467-8624.2012.01756.x

Coyne, S. M., Shawcroft, J., Gale, M., Gentile, D. A., Etherington, J. T., Holmgren, H., & Stockdale, L. (2021). Tantrums, toddlers and technology: Temperament, media emotion regulation, and problematic media use in early childhood. *Computers in Human Behavior, 120,* 106762. https://doi.org/10.1016/j.chb.2021.106762

Domoff, S. E., Harrison, K., Gearhardt, A. N., Gentile, D. A., Lumeng, J. C., & Miller, A. L. (2019). Development and validation of the Problematic Media Use Measure: A parent report measure of screen media "addiction" in children. *Psychology of Popular Media Culture, 8,* 2–11. https://doi.org/10.1037/ppm0000163

Domoff, S. E., Radesky, J. S., Harrison, K., Riley, H., Lumeng, J. C., & Miller, A. L. (2020). A naturalistic study of child and family screen media and mobile device use. *Journal of Child and Family Studies, 29,* 2164–2174. https://doi.org/10.1007/s10826-020-01716-6

Dufford, A. J., Kim, P., & Evans, G. W. (2020). The impact of childhood poverty on brain health: Emerging evidence from neuroimaging across the lifespan. *Cognitive, Affective, & Behavioral Neuroscience, 20,* 680–693. https://doi.org/10.3758/s13415-020-00798-6

Duncan, R. J., Schmitt, S. A., Burke, M., & McClelland, M. M. (2018). Combining a kindergarten readiness summer program with a self-regulation intervention improves school readiness. *Early Childhood Research Quarterly, 42,* 291–300. https://doi.org/10.1016/j.ecresq.2017.10.002

Eisenberg, N., Spinrad, T. L., & Eggum, N. D. (2010). Emotion-related self-regulation and its relation to children's maladjustment. *Annual Review of Clinical Psychology, 6,* 495–525. https://doi.org/10.1146/annurev.clinpsy.121208.131208

Fisher, P. A., & Nelson, E. M. (2021). Early adversity, self-regulation, and developmental outcomes: Contributions of neurobiology and intervention research. *Annual Review of Developmental Psychology, 3,* 17–44. https://doi.org/10.1146/annurev-devpsych-121318-085005

Foster, M. A., Lambert, R., Abbott-Shim, M., McCarty, F., & Franze, S. (2005). A model of home learning environment and social risk factors in relation to children's emergent literacy and social outcomes. *Early Childhood Research Quarterly, 20,* 13–36. https://doi.org/10.1016/j.ecresq.2005.01.006

Garon, N., Bryson, S. E., & Smith, I. M. (2008). Executive function in preschoolers: A review using an integrative framework. *Psychological Bulletin, 134,* 31–60. https://doi.org/10.1037/0033-2909.134.1.31

Gentile, D. A., Coyne, S., & Bricolo, F. (2013). Pathological technology addictions: What is scientifically known and what remains to be learned. In K. E. Dill (Ed.), *The Oxford handbook of media psychology* (pp. 382–402). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780195398809.013.0019

Gioia, G. A., Espy, K. A., & Isquith, P. K. (2003). *Behavior rating inventory of executive function–preschool version (BRIEF-P).* Psychological Assessment Resources.

Huber, B., Yeates, M., Meyer, D., Fleckhammer, L., & Kaufman, J. (2018). The effects of screen media content on young children's executive functioning. *Journal of Experimental Child Psychology, 170,* 72–85. https://doi.org/10.1016/j.jecp.2018.01.006

Huber, B., Highfield, K., & Kaufman, J. (2020). Detailing the learning in toddler apps: A content analysis. *Journal of Children and Media, 14,* 198–217. https://doi.org/10.1080/17482798.2019.1684332

Jenkins, R., & Astington, J. W. (2000). Theory of mind and social behavior: Causal models tested in a longitudinal study. *Merrill-Palmer Quarterly, 46,* 203–220.

Kirkorian, H. L., Choi, K., & Pempek, T. A. (2016). Toddlers' word learning from contingent and noncontingent video on touch screens. *Child Development, 87*(2), 405–413. https://doi.org/10.1111/cdev.12508

Kirkorian, H. L., Pempek, T. A., Murphy, L. A., Schmidt, M. E., & Anderson, D. R. (2009). The impact of background television on parent–child interaction. *Child Development, 80*(5), 1350–1359. https://doi.org/10.1111/j.1467-8624.2009.01337.x

Kostyrka-Allchorne, K., Cooper, N. R., & Simpson, A. (2017b). Touchscreen generation: Children's current media use, parental supervision methods, and attitudes toward contemporary media. *Acta Paediatrica, 106*(4), 654–662. https://doi.org/10.1111/apa.13707

Lemish, D. (2015). *Children and media: A global perspective.* Wiley Blackwell.

Linebarger, D. L., & Vaala, S. E. (2010). Screen media and language development in infants and toddlers: An ecological perspective. *Developmental Review, 30*(2), 176–202. https://doi.org/10.1016/j.dr.2010.03.006

Linebarger, D. L., & Walker, D. (2005). Infants' and toddlers' television viewing and language outcomes. *American Behavioral Scientist, 48*(5), 624–645. https://doi.org/10.1177/0002764204271505

Linebarger, D. L., Barr, R., Lapierre, M. A., & Piotrowski, J. T. (2014). Associations between parenting, media use, cumulative risk, and children's executive functioning. *Journal of Developmental & Behavioral Pediatrics, 35*(6), 367–377. https://doi.org/10.1097/DBP.0000000000000070

Madigan, S., Browne, D., Racine, N., Mori, C., & Tough, S. (2019). Association between screen time and children's performance on a developmental screening test. *JAMA Pediatrics, 173*(3), 244–250. https://doi.org/10.1001/jamapediatrics.2018.5056

Madigan, S., McArthur, B. A., Anhorn, C., Eirich, R., & Christakis, D. A. (2020). Associations between screen use and child language skills: A systematic review and meta-analysis. *JAMA Pediatrics, 174*(7), 665–675. https://doi.org/10.1001/jamapediatrics.2020.0327

McNeill, J., Howard, S. J., Vella, S. A., & Cliff, D. P. (2019). Longitudinal associations of physical activity and sedentary behavior with cognitive and psychosocial development in preschool children. *Journal of Science and Medicine in Sport, 22*(4), 444–449. https://doi.org/10.1016/j.jsams.2018.09.230

Meltzoff, A. N., Kuhl, P. K., Movellan, J., & Sejnowski, T. J. (2009). Foundations for a new science of learning. *Science, 325*(5938), 284–288. https://doi.org/10.1126/science.1175626

Miller, A. L., Gearhardt, A. N., Fredericks, E. M., Katz, B., Shapiro, L. F., Holden, K., & Lumeng, J. C. (2018). Inhibitory control and eating in the absence of hunger among low-income toddlers. *Appetite, 127,* 19–25. https://doi.org/10.1016/j.appet.2018.04.011

Nathanson, A. I., Sharp, M. L., Aladé, F., Rasmussen, E. E., & Christy, K. (2013). The relation between television exposure and executive function among preschoolers. *Developmental Psychology, 49*(8), 1497–1506. https://doi.org/10.1037/a0035714

Nikkelen, S. W., Valkenburg, P. M., Huizinga, M., & Bushman, B. J. (2014). Media use and ADHD-related behaviors in children and adolescents: A meta-analysis. *Developmental Psychology, 50*(9), 2228–2241. https://doi.org/10.1037/a0037318

Portugal, A. M., Bedford, R., Cheung, C. H., Mason, L., & Smith, T. J. (2021). Longitudinal touchscreen use across early development is associated with faster exogenous and reduced endogenous attention control. *Scientific Reports, 11,* 2205. https://doi.org/10.1038/s41598-021-81775-7

Radesky, J. S., Kaciroti, N., Weeks, H. M., Schaller, A., & Miller, A. L. (2023). Longitudinal associations between use of mobile devices for calming and emotional reactivity and executive functioning in children aged 3 to 5 years. *JAMA Pediatrics, 177*(1), 62–70. https://doi.org/10.1001/jamapediatrics.2022.4052

Rothbart, M. K., & Bates, J. E. (2006). Temperament. In N. Eisenberg, W. Damon, & R. M. Lerner (Eds.), *Handbook of child psychology: Vol. 3. Social, emotional, and personality development* (6th ed., pp. 99–166). John Wiley & Sons.

Singer, J. L. (2014). The power and limitations of television: A cognitive-affective analysis. In *The entertainment functions of television* (pp. 31–65). Psychology Press.

Thibodeau-Nielsen, R. B., Gilpin, A. T., Palermo, F., Nancarrow, A. F., Farrell, C. B., Turley, D., ... & Boxmeyer, C. L. (2020). Pretend play as a protective factor for developing executive functions among children living in poverty. *Cognitive Development, 56,* 100964. https://doi.org/10.1016/j.cogdev.2020.100964

Uzundağ, B. A., Altundal, M. N., & Keşşafoğlu, D. (2022). Screen media exposure in early childhood and its relation to children's self-regulation. *Human Behavior and Emerging Technologies, 2022,* 1–13. https://doi.org/10.1155/2022/4490166

Valkenburg, P. M., Krcmar, M., Peeters, A. L., & Marseille, N. M. (1999). Developing a scale to assess three styles of television mediation: Instructive mediation, restrictive mediation, and social coviewing. *Journal of Broadcasting & Electronic Media, 43*(1), 52–66. https://doi.org/10.1080/08838159909364474

Vandewater, E. A., Rideout, V. J., Wartella, E. A., Huang, X., Lee, J. H., & Shim, M. S. (2007). Digital childhood: Electronic media and technology use among infants, toddlers, and preschoolers. *Pediatrics, 119*(5), e1006–e1015. https://doi.org/10.1542/peds.2006-1804

Yang, X., Chen, Z., Wang, Z., & Zhu, L. (2017). The relations between television exposure and executive function in Chinese preschoolers: The moderated role of parental mediation behaviors. *Frontiers in Psychology, 8,* 1833. https://doi.org/10.3389/fpsyg.2017.01833

Yang, X., Wang, Z., Qiu, X., & Zhu, L. (2020). The relation between electronic game play and executive function among preschoolers. *Journal of Child and Family Studies, 29,* 2868–2878. https://doi.org/10.1007/s10826-020-01754-w

Zelazo, P. D., & Carlson, S. M. (2012). Hot and cool executive function in childhood and adolescence: Development and plasticity. *Child Development Perspectives, 6*(4), 354–360. https://doi.org/10.1111/j.1750-8606.2012.00246.x

Zimmerman, F. J., & Christakis, D. A. (2007). Associations between content types of early media exposure and subsequent attentional problems. *Pediatrics, 120*(5), 986–992. https://doi.org/10.1542/peds.2006-3322

CHAPTER 4

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The Impact of Learning to Code on Higher-Order Executive-Functions: A Systematic Review of The Literature

Executive functions (EF) are a set of top-down cognitive skills that facilitate goal-directed behavior (Müller & Kerns, 2015). These cognitive processes are used when automatic responses are inadequate or impractical (Diamond, 2013). They can be classified into two main groups: lower-order executive functions, encompassing inhibitory control, working memory, and cognitive flexibility, and higher-order executive functions, involving reasoning, planning, and problem-solving. Significantly, higher-order skills often rely on multiple lower-level executive functions (Diamond, 2013). For instance, in problem-solving, children must employ all three lower-order EFs to resolve the problem successfully.

A substantial body of evidence highlights the significance of EFs in various aspects of child development, ranging from other cognitive skills and academic achievement (e.g., Blair & Razza, 2007) to mental well-being (e.g., Minzenberg et al., 2009). Improving EFs has been a central objective in developmental research, leading to numerous intervention programs to enhance these skills (e.g., Diamond & Ling, 2019).

Previous research on EFs interventions has suggested that the most effective programs involve specific characteristics of engaging children in continuously challenging and motivating activities that target multiple EFs components rather than focusing on training individual EFs (Blair, 2017; Diamond & Ling, 2019). Herein lies the potential of coding education to meet these requirements. Firstly, coding education is already integral to many children's daily lives (Duncan & Bell, 2015). Secondly, it can be made engaging and motivating, primarily when age-appropriate programming tools are employed (Duncan et al., 2014).

Zelazo et al. (1997) introduced a problem-solving framework to explain executive functions and their involvement in problem-solving tasks. They argue that individuals must first plan a solution, execute it, and adapt it as needed to effectively address a problem (Zelazo et al., 1997; Zelazo & Müller, 2012). This framework aligns with the cognitive processes involved in coding. During coding, children are required to represent the problem, plan potential solutions, execute the plan, and evaluate its effectiveness (Siegle, 2017; Chevalier et al., 2020). Consequently, coding has been suggested as a means for children to practice multiple executive functions simultaneously (Arfé et al., 2017; Chevalier et al., 2020). That is why focusing on higher-order EFs could be more suitable in the domain of coding education since coding would touch upon multiple EFs simultaneously rather than focusing on single EFs components.

Furthermore, prior evidence has shown that learning to code can lead to improvements in various cognitive skills, including problem-solving, computational thinking, collaboration, and creativity, all of which are closely linked to EFs (Barr et al., 2011; Moreno-León & Robles, 2016; Popat & Starkey, 2019; Scherer et al., 2018; Wing, 2006). Through coding, children actively engage in practices such as problem analysis, planning potential solutions, testing proposed approaches, and making necessary revisions based on outcomes (Blume & Schonen, 1988; Buitrago-Florez et al., 2017; Chevalier et al., 2020; Siegle, 2017;). These skills are integral toEFs, as well (Zelazo & Müller, 2012).

Understanding the developmental trajectory of executive functions is essential in determining which age group may benefit most from coding to enhance EFs. EFs are suggested to undergo protracted development throughout lifespan (Zelazo & Müller, 2012) and are amenable to improvement at any age (Diamond, 2013). The complexity of these skills influences their development, with lower-order and higher-order executive functions differing in rate of development (Diamond, 2013). Lower-order EFs often experience rapid growth during kindergarten (Zelazo & Jacques, 1997), whereas higher-order skills exhibit a more prolonged developmental pattern (Zelazo & Müller, 2012). For instance, planning and problem-solving start forming around preschool age and show developmental spurts during the school years, continuing to develop approximately until the age of 29, which is associated with the maturation of prefrontal regions (De Luca et al., 2003; Luciana et al., 2002; McGuckian et al., 2023).

As a result, some EFs may be more amenable to improvement in specific age groups than others. Comparing the early childhood period to other childhood stages may not be practical since different sets of EFs undergo growth spurts during those periods. In this study, we focus on school-aged children because the cognitive processes involved in coding are similar to higher-order EFs, and coding education is typically introduced in curriculums, often starting at the elementary school level. Additionally, higher-order EFs continue to develop throughout the school-aged period. This focus allows us to gain insights into the potential benefits of coding education provided by many countries for school-aged children at a crucial stage in their EF development.

Prior reviews were examined on the subject of programming education and cognitive skills to guide the current review and understand what is missing in the literature. We first looked at the results coming from prior meta-analyses to see the empirical evidence on the topic. While there are some prior meta-analyses suggesting potential benefits of programming education on cognitive skills (Liao & Bright, 1991; Liao, 2000), these studies were conducted on a broad set of cognitive skills across a wide age range, rather than focusing specifically on EFs. While these results were promising, significant time has passed since their execution, and children's environments have evolved substantially. They now live in a more technologically immersed world with greater computer access (Donley, 2018; Rideout, 2017). Consequently, the circumstances under which these studies were conducted may no longer accurately represent the effects of coding education in the current environment. A more recent meta-analysis by Scherer and colleagues (2018) involving 105 studies examined the effects of computer programming on both near and far transfers of learning to code. Their findings indicated a strong effect for near transfer and a moderate effect for far transfer. However, their study did not specifically focus on synthesizing the effects of recent coding education environment , nor did it specifically address executive functions. Similarly, a very recent meta-analysis with 11 studies published between 2006 and 2022 suggested a promising effect of learning to code on EFs (Montuori et al., 2023). However, the meta-analysis included studies that used both scale and task-measured EFs and did not include any studies on reasoning. In addition, they included early childhood together with school-aged children, which would limit the conclusions drawn based on specific age groups since early childhood and school-age children would widely differ on EF skills.

We then reviewed the systematic reviews on the topic of programming education and cognitive skills to gain insights from the previous studies. A systematic review explored the effects of learning to code on child outcomes, incorporating ten studies published between 1988 and 2017 (Popat & Starkey, 2019). This review covered a broad range of skills, such as social and problem-solving skills, suggesting that learning to code can positively impact various domains. Last, a systematic review focused on coding education in children between three and eight years, considering studies conducted between 2014 and the present (Macrides et al., 2022). The review indicated that when programming is taught developmentally appropriately, it can benefit collaboration, creativity, communication, and content creation. However, these studies did not specifically assess executive functions; the age group examined was young children, which may not be applicable to see higher-order EFs improvement.

In sum, previous systematic reviews and meta-analyses have indicated promising effects of learning to code on cognitive skills. While these studies provided valuable information on the role of learning to code on EFs, certain areas need to be addressed with more detail. These are: 1) higher-order EFs should be explicitly studied since they share underlying skills with coding 2) higher-order EFs should be examined with behavioral objective tasks since previous literature indicated that scales and tasks have low correlations (Ten Eycke & Dewey, 2016) 3) studies conducted in the last decade should be studied to understand the role of the current environment. Therefore, the systematic review aims to investigate the role of current programming education on higher-order EFs. This is a critical question, particularly considering many countries integrating coding into their curriculums (Duncan & Bell, 2015). Higher-order executive functions play a vital role in various essential skills and outcomes (e.g., Blair & Razza, 2007; Minzenberg et al., 2009), making it necessary to understand their potential impact on these skills.

The Present Study

In this systematic review, we examine the impact of programming and robotics education on higher-order EFs (problem-solving, planning, and reasoning) in school-aged children.The following research questions are formed based on the relevant literature.

Research Questions:

1) Do programming and robotics education have an effect on higher-order executive functioning?
2) Does the effect of programming and robotics education change between different higher-order EF skills (planning, problem-solving, and reasoning)?

3) Does the effect of programming and robotics education on different higher-order executive function skills change between different grade levels?

Method

Conceptualization of the Outcome Variables

In the current study, consistent with previous conceptualizations of higher-order executive functions (EFs) (Diamond, 2013), we included problem-solving, planning, and reasoning skills within the framework of higher-order EFs.

Problem-solving

The first component we wish to define among higher-order EFs is problem-solving. Problem-solving is a fundamental cognitive process to achieve a goal when no readily apparent solution exists (Mayer, 1992). This concept encompasses various challenges, from mathematical problems to everyday dilemmas (Jonassen, 2000). Previously, general problem-solving skills were suggested to underlie different types of problems, such as the ability to sequence the steps involved in problem-solving (Holyoak, 1990). Therefore, diverse problem-solving tasks may require the use of higher-order executive function skills, particularly general problem-solving skills.

Many theories use computer programming analogies to conceptualize problem-solving (Newell & Simon, 1972). For instance, production-system models describe problem-solving using if-then mechanisms (Holyoak, 1990). This use of analogies may be rooted in the shared underlying mechanisms between problem-solving and computer programming, such as sequencing (Blume & Schonen, 1988; Buitrago-Florez et al., 2017; Siegle, 2017). Consequently, we anticipate that coding education will enhance problem-solving skills, irrespective of the problem being addressed.

In the context of the 21st Century, problem-solving has emerged as a crucial skill (Rahman, 2019). Learning how to code has been proposed as a potential means to enhance problem-solving abilities (e.g., Akcaoglu & Koehler, 2014). This concept has been tested through various coding interventions (e.g., Pardamean & Suparyanto, 2015; Rodríguez-Martínez et al., 2020). The present study aims to consolidate the findings from these individual studies and provide more comprehensive insights into the relationship between learning to code and problem-solving skills.

Planning

The second higher-order EF component is planning. It involves mentally conceptualizing subsequent actions to solve problems before execution (Zelazo & Müller, 2012). It plays a pivotal role in executing solutions, actions, or behaviors and has even been likened to a blueprint of thinking (Friedman et al., 1987). This cognitive process enables individuals to anticipate potential dead ends and pitfalls in problems without executing them, thereby avoiding unnecessary failures (Holyoak, 1990).

Learning how to code has been suggested as a means to enhance planning skills through practice during coding activities (Arfé et al., 2020). Both planning and coding involve similar mechanisms, such as debugging (Friedman et al., 1987). In both activities, individuals are required to debug their solutions and devise alternative approaches based on feedback obtained from the execution of the initial plan. Consequently, several studies have explored the impact of learning to code on planning skills (e.g., Arfé et al., 2020; La Paglia et al., 2018). The present study synthesizes the findings from these studies to provide a comprehensive perspective on the effects of coding on planning skills.

Reasoning

The third component we want to introduce among higher-order EFs is the reasoning skill. Reasoning, often referred to as fluid intelligence, is the capacity to identify patterns and relationships to solve new and unfamiliar problems (Carpenter et al., 1990; Cattell, 1987). Evidence suggests that reasoning ability significantly predicts learning (Deary et al., 2007) and academic achievement (Lynn et al., 2007). Children may employ reasoning skills when solving problems in computer programming (Psycharis & Kallia, 2017). Consequently, learning to code has the potential to enhance reasoning skills by providing children with opportunities to practice these abilities. Several studies have explored this concept, demonstrating improvements in reasoning skills through learning to code (e.g., Atasay & Özden, 2020; Psycharis & Kallia, 2017). This systematic review aims to synthesize the findings from these studies and provide insights into the impact of coding interventions on reasoning skills.

Systematic Review Procedure

Our systematic review follows the following definition: "a systematic review attempts to collate all empirical evidence that fits pre-specified eligibility criteria in order to answer a specific research question. It uses explicit, systematic methods that are selected with a view to minimizing bias, thus providing more reliable findings from which conclusions can be drawn and decisions made" (Higgings et al., 2019, p.6). In the literature, there are many guidelines on how to conduct systematic reviews across different areas (e.g.,Shaffril et al., 2021; Xiao & Watson, 2019). The current systematic review was conducted following the PRISMA Protocol developed by the Cochrane Collaboration because the PRISMA protocol is explicitly developed for systematic reviews of intervention studies (Higgins et al., 2019). The PRISMA protocol outlines the steps of conducting a systematic review as follows: 1) defining the review question and developing criteria for including studies, 2) searching for studies, 3) selecting studies and collecting data, 4) assessing risk of bias in included studies, 5) analyzing data, and 6) interpreting results and drawing conclusions. We followed this outline to conduct the current systematic review.

Inclusion Criteria

The inclusion criteria, as shown in Table 1, were as follows: (a) study designs were confined to randomized control trials (RCTs) or quasi-experimental designs with pre-test and post-test measurements to ensure relying on comparison data for effectiveness, (b) interventions provided coding education through educational robotics or virtual programming curriculums, (c) participants comprised school-aged children, spanning from elementary school to high school to make sure higher-order EFs could develop around this age group, (d) higher-order executive functions were assessed using task-based assessments to get an objective measure of EFs as possible, (e) comparison conditions encompassed “no intervention” (e.g., waitlist), “treatment-as-usual” (e.g., regular school activities), or “an alternative intervention” (e.g., math education intervention), and (f) published or unpublished studies conducted between 2010 and 2024. We decided to include studies after 2010 for two reasons. First, the first-ever iPad was introduced in 2010, and the technology use environment of children changed because of the introduction of tablet computers. Second, the inclusion of coding education in curriculums resurged around the mid-2010s, and the UK was the first country to include coding in the national curriculum in 2014.

Information Sources and Study Selection

First, to identify both published and unpublished studies on the topic, the following electronic databases were searched: Web of Science, PsycINFO, and ERIC, including the period from 2010 to April 2024. The keyword search employed specific filters for outcome variables (e.g., higher-order executive functions), interventions (e.g., coding training), sample characteristics (e.g., middle school), and study design (e.g., randomized trial), as outlined in

Table 1. Additionally, the bibliographies of an existing meta-analysis by Scherer et al. (2018) and two reviews by Moreno-León and Robles (2016) and Popat and Starkey (2019) were scrutinized to identify remaining papers.

The study selection process comprised of two primary steps. In the initial step, the titles and abstracts of the studies identified through database searches were reviewed to evaluate whether they met the inclusion criteria. In the subsequent step, the first author examined the full text of the studies selected from the first step and decided which studies would be included in the review.

Table 1

Included study selection

Study selection category	Description
Outcomes of the intervention	Executive function; reasoning; fluid-intelligence; planning; problem-solving; sequencing
Content of the intervention	Coding; computer programming; robotics
Population	Preschool; primary school; elementary school; middle school; high school; secondary education
Measurement	Variables measured with objective behavioral measures
Type of study	Training; intervention; effectiveness; trial; control; pre-test; post-test; randomized
Publication year	After 2010
Source	Web of Science, PsycInfo, ERIC, previous reviews, NSF CS4ALL CISE Directorate
Search terms	((“executive function*” OR “reasoning” OR “fluid intelligence” OR “fluid-intelligence” OR “planning” OR “problem-solving” OR “problem solving” OR “sequencing”) AND (“coding” OR “programming” OR “robot*” OR “computer programming” OR “robotics”) AND (primary school OR

	elementary school OR middle school OR high school OR secondary education) AND (training OR intervention OR effectiveness OR trial OR control OR pre-test OR randomized OR post-test OR pre-test OR post-test))

Risk of Bias

We conducted a risk of bias assessment to identify potential systematic bias influencing study outcomes. Systematic bias refers to deviations from truth that can result in underestimating or overestimating intervention effects (Higgins et al., 2019). Studies were categorized into different levels of bias, ranging from low to high risk, based on the magnitude of each criterion (Higgins et al., 2019). Evaluating bias risk is crucial for interpreting intervention effects while accounting for potential variations (Higgins et al., 2019).

Given the limited number of randomized controlled trials, the systematic review included both randomized and non-randomized studies, following the RoB 2 criteria for randomized studies (Sterne et al., 2019) and ROBINS-I for non-randomized studies (Sterne et al., 2016) (see Table 2). Studies were assessed as having low, some concerns or high risk of bias for each criterion (Higgins et al., 2019). The overall risk of bias for each study was determined by considering all criteria collectively. Studies with a low risk of bias exhibited low bias in every criterion. Those with some concerns had minor issues in one criterion but did not have a high risk of bias in any criterion. Studies with a high risk of bias had either high bias in one criterion or some concerns in multiple criteria. Notably, the review did not consider the lack of blinding of teachers and children as having a high risk of bias, considering their roles in delivering and receiving the training.

Table 2

Criteria of risk of bias

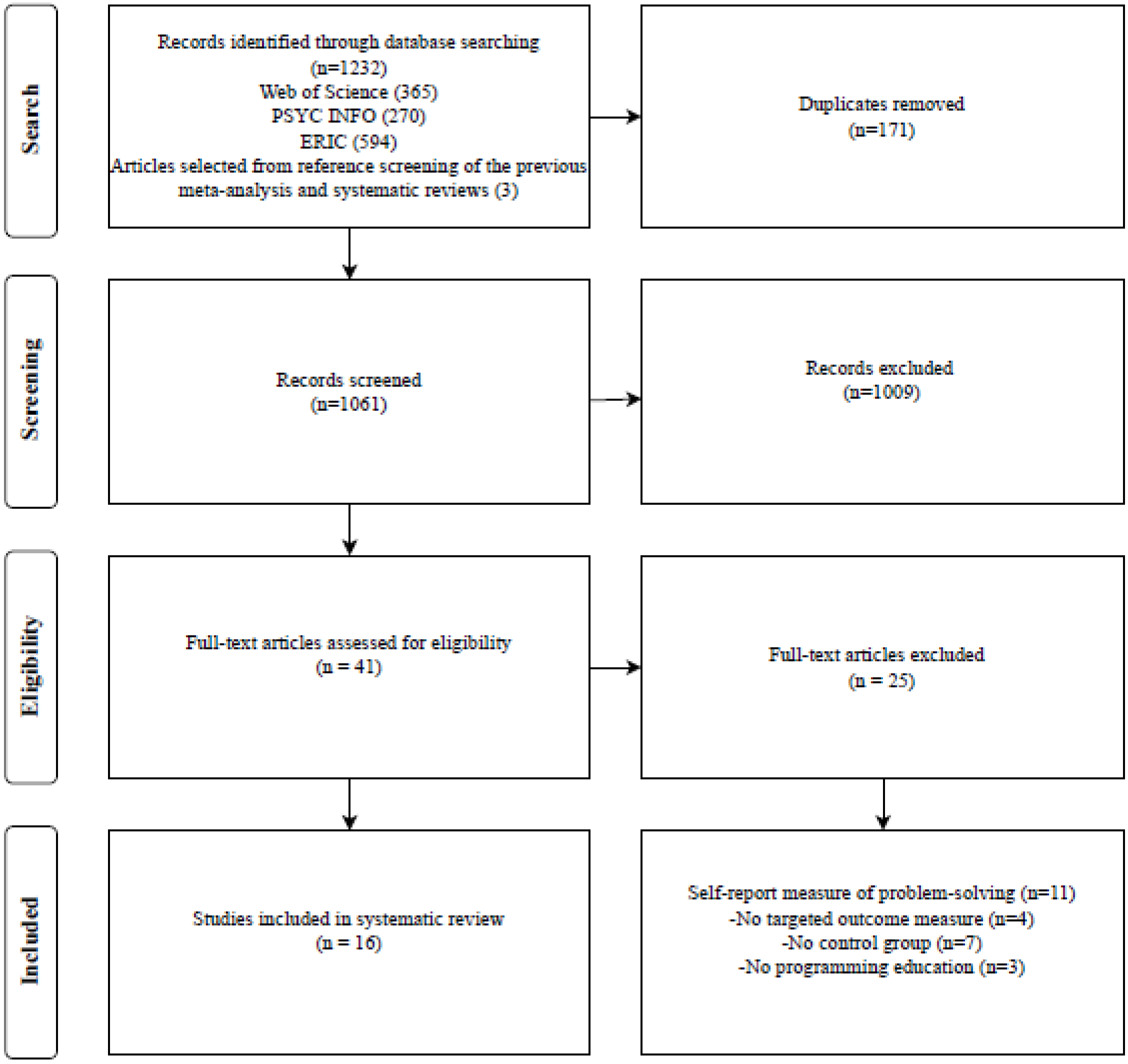
	Criterion	Assessment
Common criteria for both RoB2 and ROBIN	Deviations from interventions	The systematic error between the experimental and comparison groups due to the conditions that could affect the results.
	Missing data	Bias in the results arising from missing data of participants.
	Measures of outcomes	Systematic error in the outcome measurements between intervention groups due to the conditions of the participants.
	Selection of reported results	Bias arising from the selective reporting of some of the results could change the findings.
Criteria specific to RoB2 (randomized studies)	Randomization	The systematic error between the groups due to an error in the randomization processes due to the process of not being completely random. Bias in the baseline scores of groups could affect the outcome scores.
Criteria specific to ROBIN (non-randomized studies)	Confounding	Bias arises from other variables affecting the results besides the group assignments.
	Selection bias	The systematic error between groups due to including certain participants or having follow-up tests for a subgroup of participants could change the outcome results.
	Classification of interventions	Bias arises from the misclassification of intervention groups.

Results

Our comprehensive search across Web of Science, PsycINFO, and ERIC databases yielded a total of 1215 articles. Following the initial review of titles and abstracts, 38 papers were chosen for further evaluation. Three additional papers were identified from the bibliographies of previous meta-analyses and systematic reviews.

In the subsequent in-depth review step, 41 papers underwent careful evaluation. During this phase, 25 studies were excluded. Eleven studies were excluded due to the use of self-report scales to measure problem-solving (Atun & Usta, 2019; Breed et al., 2014; Durak et al., 2019; Erol & Çırak, 2022; Erümit, 2020; Feng & Chen, 2014; Kalelioğlu, 2015; Karaahmetoğlu & Korkmaz, 2019; Kim & Kim, 2018; La Paglia et al., 2011; Pellas & Vosinakis, 2018). An example of a self-report scale item was: “Instead of running away from my problems, I try to solve them.” Seven studies were excluded due to a lack of a control group (Çalışkan, 2020; Çetinkaya & Baykan, 2020; Karsenti & Bugmann, 2017; Kožuh et al., 2017; Merkouris & Chorianopoulos, 2018; Sun et al., 2022; Vico et al., 2019). Additionally, three studies were excluded because the training program did not include programming education (Andrzejewska & Stolinska, 2018; Fard et al., 2014; Resing et al., 2020). Lastly, four studies were excluded as they did not measure the targeted outcomes (Çınar & Tüzün, 2021; Hu et al., 2023; Kostousov & Simonova, 2019; Su et al., 2022). Ultimately, 16 individual papers, comprising 18 studies, were identified for inclusion in the systematic review (see Figure 1).

Figure 1 *Flow diagram of literature search.*



Study Characteristics

Sample Characteristics and Design

Geographical Distribution of Studies. The studies incorporated into the review spanned various countries: five in Italy, three in the USA, two in Turkey, two in Greece, one in Korea, one in Indonesia, one in Taiwan, one in Spain, one in Ireland, one in Colombia, and one in the North Cyprus Turkish Republic.

Grade Level Distribution. Regarding the distribution of studies across different grade levels, the majority of studies involved children from elementary school (eight studies) and middle school (seven studies) (see Table 3). One study included both elementary and middle school children. Finally, two studies focused on high school children.

Inclusion of Programming Education. Variability was observed regarding the inclusion of programming education in school curriculums. Eight studies were extracurricular and conducted either during or outside school hours. Nine studies integrated programming education into the regular school curriculum for children. Additionally, one study did not provide information on this aspect (Nam et al., 2010).

Intervention Characteristics

Among the eighteen studies, nine were randomized control trials. Seven of them (Arfé et al. (Study 2); Atasoy & Özden, 2020; Hayes & Stewart, 2016; La Paglia et al., 2017; La Paglia et al., 2018; Özcan et al., 2021; Robledo et al., 2023) had an individual-level randomized trial, while two studies (Arfé et al., 2019 (Study 1); Arfé et al., 2020) utilized clustered randomized trials.

Control groups predominantly consisted of education as usual or waitlist groups. One study considered programming training as the control group (Hayes & Stewart, 2016), however, for the purposes of this systematic review, we categorized the programming training delivered in that study as the experimental group.

Interventions also varied in content. For instance, one program (Akcaoglu & Koehler, 2014) included game-design components, while another (Nam, Kim, & Lee, 2010) incorporated scaffolding components. Sixteen studies were centered on programming training for children, and two papers (La Paglia et al., 2017; La Paglia et al., 2018) included robotics training and programming education.

There was also variability in the durations and frequencies of the studies (M=24.92, SD=26.55) (refer to Table 3). Some studies provided more extended interventions with longer durations, such as 90 hours (Psycharis & Kallia, 2017) or 29 hours (Hayes & Stewart, 2016). In contrast, others had shorter interventions with shorter durations, such as three hours (Brown et al., 2013) or eight hours (Arfé et al., 2020).

Effect Size Calculations

In our study, we employed the dppc2 effect size metric based on Morris's recommendation from 2008. This method entails standardizing the difference between pre-means and post-means for both the experimental and control groups using their pre-test standard deviations. The dppc2 measure was found to be the most suitable for our specific research design. Despite its label as 'Cohen's d,' it's calculated by default using Hedges' correction for small sample sizes, as Morris (2008) outlined. In cases where complete pre-test and post-test scores were not available for both intervention and control groups, Cohen's d was calculated based on the post-test scores of both groups. Additionally, various effect size metrics, such as eta-square, were transformed into Cohen's d to facilitate interpretation.

Narrative Overview

Due to the limited number of eligible studies with substantial variations in outcomes, age groups, and countries, conducting a meta-analysis was not feasible for this study. Instead, we opted for a narrative overview of the included studies. To provide a comprehensive narrative overview of the literature, we categorized studies on the impact of programming education on EFs according to the EFs assessed, grade levels studied, and duration of training programs. Additionally, we discussed the findings based on the specific methods used to measure each EF construct and how programming environments were integrated into the training methodologies.

Table 3
Study characteristics and findings across executive functions

Study	Sample size	Education level	Duration of the program (hours)	Measure	Findings	Effect size
Problem-solving						
Donley (2018)	24 (12 exp[1]., 12 cont.[2]) Exp. (7 girls) Cont. (4 girls)	Middle school	25	Woodcock-Johnson Test of Cognitive Abilities, Fourth Edition (concept formation subtest)	There was no significant difference between the experimental and control groups in the post-test compared to the pre-test.	d_{ppc2}=.364[c] (small) d_{cohen}=0[c] (no) (exp vs. cont at post-test)
Akcaoglu & Koehler (2014)	44 (20 exp., 24 cont.) Exp. (4 girls) Cont. (12 girls)	Middle school	15	PISA questions	There was a significant interaction effect of time and group on problem-solving, *p*<.001. The experimental group significantly improved problem-solving from the pre-test to the post-test compared to the control group.	$\eta 2$= .495[a] d_{cohen}=1.980[b] (large) d_{ppc2}=1.06[c] (large)
Nam, Kim, & Lee (2010)	60 (30 exp., 30 cont.)	Middle school	8	PISA questions	Students in both the experimental (*p*<.001) and control group	d_{ppc2}=.712[c] (medium) d_{cohen}=.581[c] (medium) (exp-cont at post-test)

	N/A				(p=.001) showed significant improvement in problem-solving from pre-test to post-test.	
Pardamean &Suparyanto, (2015)	128 (43 1st exp., 42 2nd exp, 43 cont.) 1st Exp. (24 girls) 2nd Exp. (22 girls) Cont. (24 girls)	Elementary school	11	Figural Problem Solving Test	There was a significant difference in problem-solving scores among groups at post-test 1, p=.035. The first experimental group was significantly different from the control group, p=.039. However, there is no difference among groups at post-test 2.	d_{ppc2}=.054 [c] (no) d_{cohen}=.259 [c] (small) (exp-cont at post-test)
Brown et al., (2013)	113 (73 exp., 40 cont.) N/A	Elementary and middle school	3	Math problems	There was a significant difference in problem-solving scores among groups at post-test 1, p<.05. While experimental groups showed a 9% increase from the pre-test to the post-test, the control group	d_{cohen} =.983 [c] (large) (using F statistics)

					showed a 26% decrease.	
Rodríguez-Martínez et al. (2020)	47 (24 exp., 23 cont.) Exp. 14 girls Cont. 14 girls	Middle school	3	Math problems	The experimental group showed significant improvement in the number of problems solved. However, there were not any group differences.	d_{ppc2}=.116 [c] (no)
La Paglia et al. (2017)	60 (30 exp. 30 cont.) Exp. 15 girls Cont. 15 girls	Middle school	30	Math problems	There was a significant group-by-time interaction.	d_{ppc2}=.333 [c] (small)
Psycharis & Kallia (2017) (Problem-solving)	66 (33 exp., 33 cont.) Exp. 13 girls Cont. 16 girls	High school	90	Math problems	The experimental group significantly improved problem-solving from the pre-test to the post-test, p=.020. There was a significant difference between the experimental and control groups at the post-test, p=.0357.	d_{cohen}=.228[b](small) (exp-cont at post-test) (using r statistics)
Reasoning						

Psycharis & Kallia (2017) (Reasoning)	66 (33 exp., 33 cont.) Exp. 13 girls Cont. 16 girls	High school	90	Cornell Reasoning Test	The experimental group significantly improved reasoning from the pre-test to the post-test, p<.000. There was a significant difference between the experimental and control groups at the post-test, p=.048.	d_{cohen} =1.109 [b] (large) (exp-cont at post-test) (using r statistics) d_{cohen} =.501[b] (medium) (exp-cont at post-test) (using r statistics)
Lai & Yang (2011)	130 (96 exp., 34 cont.) Exp. 45 girls Cont. 16 girls	Middle school	N/A	Raven's Matrices	There was no significant difference between the experimental and control groups in post-test control for pre-test scores.	d_{cohen} =.348[c] (small) (using F statistics)
Özcan et al. (2021)	174 (58 exp., 52 comp.[3], 64 cont.) Exp. 27 girls Comp. 23 girls Cont. 31 girls	Elementar y school	20	Matrix Reasoning	There was no significant interaction effect of time and group on reasoning skills.	ηp^2=.006[a] (no) d_{ppc2}=.17[c] (no) $d_{cohen=}$ -.119[c] (no) (exp-cont at post-test)
Hayes & Stewart (2016)	28	Elementar y school	29	Matrix Reasoning	There was no significant interaction	d_{ppc2}=-.232 [c] (small) d_{cohen}=-272 [c] (small)

	(14 exp., 14 cont.) Exp. 6 girls Cont. 7 girls				effect of time and group on reasoning skills.	(exp-cont at post-test)
Atasoy & Özden (2020)	60 (30 exp., 30 cont.) -	Middle school	8	Visuospatial Reasoning Task	There was a significant interaction effect of time and group on reasoning skills.	$\eta 2=.67^{a}$ (large) $d_{cohen}=-2.849^{b}$(large) $d_{ppc2}=. .776^{c}$ (medium)
Planning						
La Paglia et al., (2018)	30 (15 exp., 15 cont.) Exp. 6 girls Cont. 6 girls	Elementary school	20	Tower of London	There were significant interaction effects of time and group on TOL and reduction of attempts to TOL, p<.01 for both.	**TOL** $\eta p^{2}= .256^{a}$ (large) $d_{ppc2}=.422^{c}$ (small) $d_{cohen}=.859^{c}$ (large) (exp-cont at post-test) **Attempts to TOL** $\eta p^{2}= .649^{a}$ (large) $d_{ppc2}=-.1.024^{c}$ (large) $d_{cohen}=-1.337^{c}$ (large) (exp-cont at post-test)
Arfé, Vardanega, & Ronconi, (2020)	179 (88 exp., 91 cont.) Exp. 38 girls Cont.54 girls	Elementary school	8	The Elithorn maze test and Tower of London	There were significant interaction effects of time and group on the accuracy of TOL and Elithorn tasks, p=.001 p=.002, respectively. Students in both experimental and	**TOL** $d_{cohen}=1.27^{a}$ (large) (pre-test to post-test for exp.) $d_{cohen}=.79^{a}$ (medium to large) (pretest to post-test for cont.)

control groups significantly improved TOL and Elithorn scores from pre-test to post-test.	**Elithorn** d_{cohen} =1.10[a] (large) (pre-test to post-test for exp.)
There were significant interaction effects of time and group on the planning time of TOL and Elithorn tasks, *p*=.025 and p=.035, respectively. The planning time of TOL did not significantly change for the experimental group. However, for the control group, planning time significantly decreased, *p*=.014. The planning time of Elithorn significantly increased for the experimental group, *p*=.039. However, it was not significant for the control group.	d_{cohen} =.63[a] (medium) (pretest to post-test for cont.) **Planning time TOL** d_{cohen} =.08 [a] (large) (pre-test to post-test for exp.) d_{cohen} =-.26 [a] (small) (pretest to post-test for cont.) **Planning time Elithorn** d_{cohen} =.22 [a] (small) (pre-test to post-test for exp.) d_{cohen} =-.10 [a] (no) (pretest to post-test for cont.) **Calculated with the change scores** **Elithorn** d_{cohen}=3.04[c] (large)

						TOL d_{cohen} =4.68[c] (large) **Elithorn planning time** d_{cohen} =3.00[c] (large) TOL planning time d_{cohen} =3.167[c] (large)
Arfé et al. (2019) (Study 1)	80 (44 exp., 36 cont.) Exp. 20 girls Cont. 21 girls	Elementary school	8	The Elithorn maze test and Tower of London	Significant interaction effects were on the accuracy of TOL and Elithorn tasks, p<.001 *and* p<.005, respectively. The experimental group significantly improved TOL and Elithorn scores at the post-test compared to the control group, p<.001 for both. There were no significant interaction effects on TOL and Elithorn task planning time.	**TOL** ηp^2= .19[a] (large) d_{cohen} =.95[a] (large) (exp-cont at post-test) **Elithorn** ηp^2= .07[a] (medium) d_{cohen} =.80[a] (large) (exp-cont at post-test) **Planning time TOL** d_{cohen}=-.309[c] (small) (exp-cont at post-test) **Planning time Elithorn** d_{cohen}=.447 [c] (small) (exp-cont at post-test) **Planning time Elithorn** d_{ppc2}=.13 [c] (no) **Accuracy Elithorn** d_{ppc2}=.445 [c] (small) **Planning time TOL** d_{ppc2}=.113 [c] (no) **Accuracy TOL** d_{ppc2}=.163 [c] (no)

Arfé et al. (2019) (Study 2)	38 (19 exp., 19 cont.) Exp. 7 girls Cont. 10 girls	Elementary school	8	The Elithorn maze test and Tower of London	There was a significant effect of group for TOL, $p<.001$. The experimental group performed significantly better post-test than the control group, $p<.01$. There was a significant effect of group for Elithorn, $p<.001$. The experimental group performed significantly better on the post-test than the control group, $p<.005$. There was no interaction effect of group and time for planning time for the Elithorn task. There was a significant effect of the group for planning time of TOL, $p<.005$. The experimental group spent more time planning the post-test	**TOL** ηp^2= .47[a] d_{cohen} =.93[a] (exp-cont at post-test) **Elithorn** ηp^2= .32[a] (large) d_{cohen} =.96[a] (large) (exp-cont at post-test) **Planning time TOL** ηp^2= .25[a] (large) d_{cohen} =.65[a] (medium) (exp-cont at post-test) **Planning time Elithorn** d_{cohen}= .112[c] (no) (exp-cont at post-test) **Planning time Elithorn** d_{ppc2}=.42[c] (small) **Accuracy Elithorn** d_{ppc2}=.815[c] (medium) **Planning time TOL** d_{ppc2}=.77[c] (medium) **Accuracy TOL** d_{ppc2}=1.622[c] (large)

					than the control group, *p*=.05.	
Robledo-Castro et al. (2023)	30 (17 exp., 13 cont.)	Elementary school	32	Tower of Hanoi Porteurs Maze	There were significant interaction effects of time and group on TOH and Porteurs Maze.	**Number of moves TOH** d_{ppc2}=-1.207[c] (large) **Time spent TOH** d_{ppc2}=-.714[c] (medium) **Number of errors Porteurs Maze** d_{ppc2}=-.319[c] (small) **Time spent Porteurs Maze** d_{ppc2}=-.3[c] (small)

Notes. d_{ppc2} refers to the effect size calculated for the pre-test and post-test control group design (see Morris, 2008).

[a] Effect sizes reported by papers, [b] Given effect sizes were converted to Cohen's *d*, [c] Effect sizes were calculated with the information provided.

Analysis of Risk of Bias

Overall Risk of Bias

Considering all criteria, the comprehensive risk of bias analysis revealed that the majority of studies (12 studies, 67%) were assessed as having a high risk of bias (refer to Table 4 and Figure 2). Five studies (28%) received an overall judgment of "some concerns," while only one demonstrated a low risk of bias.

Notably, all non-randomized studies showed a high risk of bias. Therefore, when interpreting the findings, it is essential to consider that the results may be influenced by factors other than the intervention groups.

Risk of Bias According to Different Criteria

All studies in this review were evaluated as having a low risk of bias in the "deviation from interventions" and "measures of outcomes" criteria, primarily due to experimental designs and objective measurement tasks. The majority of studies (12 studies, 67%) also demonstrated a low risk of bias in the "missing data" criterion. However, it is worth noting that information on missing data was often lacking in the studies. We compared the total number of participants with those included in the analyses to interpret missing data. Some studies raised concerns (five studies, 28%) or were considered to have a high risk of bias (one study, 5%) in this criterion. For instance, some studies had fewer participants in the analyses but did not explicitly mention the missing data.

Regarding the criterion of "selecting reported results," almost all studies (17 studies, 95%) had some concerns regarding bias. The studies did not report an analysis or pre-registration plan, making it difficult to determine if the reported results included all relevant data. In contrast, all randomized studies had a low risk of bias in the "randomization" criterion. However, most non-randomized studies (five, 56%) raised concerns about potential confounders. Three studies did not mention confounders, which we considered to have a high risk of bias. Additionally, one study noted confounders but did not control their effects, leading us to judge it as having a high risk of bias (Donley, 2018).

Furthermore, in many of the non-randomized studies (56%), a low risk of bias was observed in the criterion of “selection bias.” However, one paper showed a high risk of bias (Psycharis & Kallia, 2017). In this study, students self-selected their groups based on the high school branch they wished to pursue, leading to selection bias.

Regarding the “classification of interventions” criterion, all studies demonstrated a low risk of bias. The eligible studies included in this review had distinct intervention conditions for the experimental and control groups. In most cases, students participated in different intervention programs based on their assigned conditions, minimizing the likelihood of misclassification between the intervention groups.

Table 4

Analysis of risk of bias

Study	Randomization	Confounding	Selection bias	Classification of Interventions	Deviations from Interventions	Missing Data	Measures of Outcomes	Selection of Reported Results*	Overall Risk of bias
Non-randomized studies									
Donley (2018)	N/A	High	Low	Low	Low	High	Low	Some concerns	High
Akcaoglu & Koehler (2014)	N/A	Some concerns	Low	Low	Low	Low	Low	Some concerns	High
Pardamean &Suparyanto, (2015)	N/A	Some concerns	Low	Low	Low	Low	Low	Some concerns	High
Brown et al. (2013)	N/A	Some concerns	Low	Low	Low	Some concerns	Low	Some concerns	High
Rodríguez-Martínez et al. (2020)	N/A	Some concerns	Low	Low	Low	Low	Low	Some concerns	High
Nam, Kim, & Lee (2010)	N/A	High	Low	Low	Low	Low	Low	Some concerns	High

Psycharis & Kallia (2017) (Problem-solving)	N/A	High	High	Low	Low	Low	Low	Some concerns	High
Psycharis & Kallia (2017) (Reasoning)	N/A	High	High	Low	Low	Low	Low	Some concerns	High
Lai & Yang (2011)	N/A	Some concerns	Low	Low	Low	Some concerns	Low	Some concerns	High
Randomized Studies									
La Paglia et al. (2017)	Low	N/A	N/A	N/A	Low	Low	Low	Some concerns	Some concerns
Özcan et al. (2021)	Low	N/A	N/A	N/A	Low	Low	Low	Low	Low
Hayes & Stewart (2016)	Low	N/A	N/A	N/A	Low	Some concerns	Low	Some concerns	High
Atasoy & Özden (2020)	Low	N/A	N/A	N/A	Low	Low	Low	Some concerns	Some concerns
La Paglia et al., (2018)	Low	N/A	N/A	N/A	Low	Low	Low	Some concerns	Some concerns
Arfé, Vardanega, & Ronconi, (2020)	Low	N/A	N/A	N/A	Low	Some concerns	Low	Some concerns	High

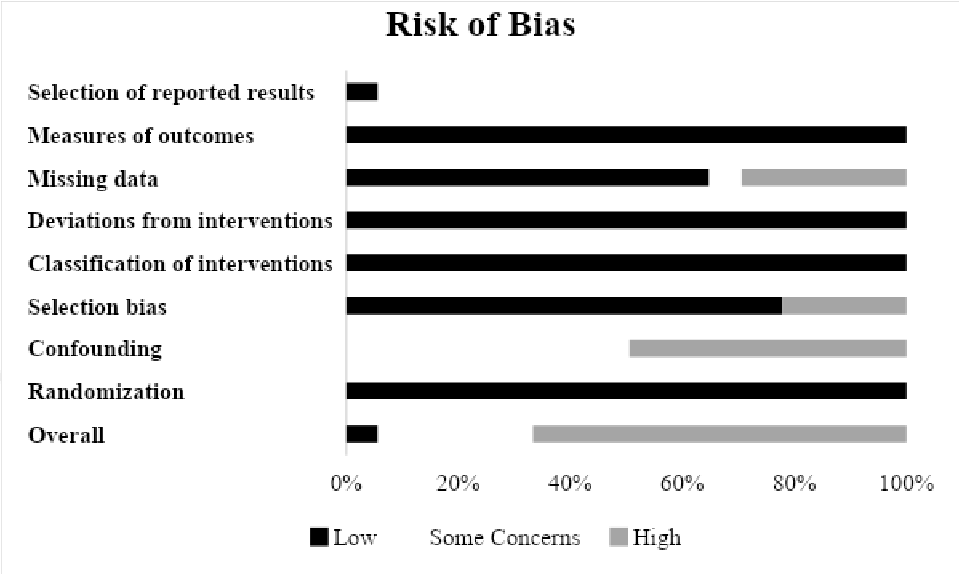
Arfé et al. (2019) (Study 1)	Low	N/A	N/A	N/A	Low	Low	Low	Some concerns	Some concerns
Arfé et al. (2019) (Study 2)	Low	N/A	N/A	N/A	Low	Some concerns	Low	Some concerns	High
Robledo-Castro et al. (2023)	Low	N/A	N/A	N/A	Low	Low	Low	Some concerns	Some concerns

Note. The randomization criterion does not apply to non-randomized studies. Confounding, selection bias, and the classification of interventions criteria do not apply to randomized studies.

* Due to the absence of preregistered reports for the studies raised some concerns regarding the criteria used in selecting the reported results. However, it remains unclear whether they reported the complete results or not.

Figure 2

Summary of risk of bias analysis



Note. The percentages are based on the specific criterion for randomized studies (randomization) conducted with ten studies. The percentages are based on specific criteria for non-randomized studies (confounding, selection bias, and classification of interventions) conducted with eight studies. For the other criteria, percentages were calculated with 18 studies.

Synthesis of Findings and Discussions

RQ1) Do programming and robotics education have an effect on higher-order executive functioning?

The findings from the current systematic review suggest that programming education can be beneficial to EFs. Most of the studies included in the review indicated positive significant effects of programming education. However, the review warrants that this result should be interpreted with caution due to the high risk of bias, which indicates that the findings reported in the studies might stem from factors other than the targeted interventions.

RQ2) Does the effect of programming and robotics education change between different higher-order EF skills (planning, problem-solving, and reasoning)?Higher-Order EFs

To answer the second research question, the studies were investigated separately based on different EFs measured. Half of the studies included in the review were conducted on problem-solving. This can be expected as it was suggested that problem-solving and computational thinking share underlying skills (Chevalier et al., 2020). While the existing studies did not directly compare different EFs for us to answer the second research question, we can infer that some EF skills such as planning can benefit more from programming education compared to reasoning or problem-solving skills. Each higher-order EF category was examined in more detail below.

Problem-solving

Ten studies were scrutinized to explore the correlation between programming education and problem-solving skills (Akcaoglu & Koehler, 2014; Brown et al., 2013; Donley, 2018; La Paglia et al., 2017; Nam et al., 2010; Pardamean & Suparyanto, 2015; Psycharis & Kallia, 2018; Rodríguez-Martínez et al., 2020). The reported effect sizes in these studies varied, ranging from no to a large effect (see Table 3 for effect sizes of individual studies). Notably, two studies (Donley, 2018; Rodríguez-Martínez et al., 2020) indicated no statistically significant positive effect of programming education on problem-solving.

Upon further analysis, we computed the effect sizes using the provided information in both studies. In Donley (2018), the programming training showed a small effect (d_{ppc2} = 0.364) compared to the control group from the pre-test to the post-test. This study's absence of a significant positive effect may be attributed to the relatively small sample size (n = 24).

Problem type. Studies employed various different tasks to assess problem-solving skills among school-aged children. Donley (2018) utilized the concept formation subtest of the Woodcock-Johnson Test of Cognitive Abilities, Fourth Edition, a standardized battery for measuring cognitive skills through tasks such as identifying similarities, categorization, and understanding abstract relationships. Additionally, two studies (Akcaoglu & Koehler, 2014; Nam et al., 2010) utilized the PISA (Program for International Student Assessment) problem-solving questionnaire, designed to evaluate students' abilities in applying knowledge and skills in real-world contexts, fostering critical thinking, and demonstrating proficiency across diverse domains. Moreover, some studies used math problems to test the improvement of problem-solving skills related to programming education programs (e.g., Brown et al., 2013; La Paglia et al., 2017). Considering the diverse problem-solving assessments employed in the studies, it became evident that evaluations varied, including math problems (e.g., Brown et al., 2013) and PISA questions (e.g., Akcaoglu & Koehler, 2014), which involve system analysis, troubleshooting, and decision-making in different general scenarios. The positive effects observed across different problem types support the notion of shared underlying problem-solving skills (Holyoak, 1990), suggesting that learning to code may offer opportunities for children to practice general problem-solving skills (Blume & Schonen, 1988; Buitrago-Florez et al., 2017; Siegle, 2017).

Programming education environment. Studies investigating problem-solving skills have employed various programming education environments. Akcaoglu and Koehler (2014) evaluated the impact of a game-design and learning program utilizing Microsoft Kodu, engaging middle school students in game design activities to foster problem-solving and critical reasoning skills. Pardamean and Suparyanto (2015) utilized the LOGO programming language to teach programming concepts. Additionally, several studies utilized the Scratch programming language with different educational designs aimed at enhancing problem-solving abilities. For instance, Donley (2018) incorporated Scratch as the programming language, integrating both computerized and non-computerized activities such as debugging tasks into the program. Nam et al. (2010) also employed Scratch, incorporating scaffolding techniques to facilitate children's learning. Similarly, Brown et al. (2013) utilized the Scratch programming language alongside solving math problems using computer science techniques. The diverse usage of programming languages emphasizes the potential for employing varied techniques to enhance problem-solving skills. The prevalent use of the Scratch programming language aligns with previous assertions that Scratch offers a developmentally appropriate platform for teaching programming concepts, given its tinkerable, meaningful, and social features (Resnick et al., 2009).

However, it is crucial to note that all studies examining problem-solving had a high risk of bias (Table 4), with only one study (La Paglia, 2017) utilizing a randomized control design. Consequently, other factors may influence the results, leading to systematic errors. Therefore, conducting more studies with improved methods is essential to thoroughly investigate the role of programming education in enhancing problem-solving skills.

Planning

Five studies (Arfé et al., 2019 (Study 1); Arfé et al., 2019 (Study 2); Arfé, Vardanega, & Ronconi, 2020; La Paglia et al., 2018; Robledo-Castro et al., 2023) investigated the influence of programming education on planning skills. All these studies reported significant positive effects of programming education on planning, with effect sizes ranging from small (dppc2 = 0.300) to large (dppc2 = 1.622). Among these, three studies (Arfé et al., 2019 (Study 2); La Paglia et al., 2018; Robledo-Castro et al., 2023) employed random assignment of participants to groups, while the other two studies (Arfé et al., 2019 (Study 1); Arfé, Vardanega, & Ronconi, 2020) used clustered random assignment by randomly assigning classrooms to the conditions.

Planning type. The planning measurements in all five studies were based on well-established objective tower tasks, including the Tower of Hanoi and the Tower of London, which share common principles. Four studies utilized the Tower of London task as a measure of planning skills, while one study (Robledo-Castro et al., 2023) employed the Tower of Hanoi. Due to the fact that these tasks are not directly related to programming concepts, the observed improvement in performance suggests a potential far-transfer effect of programming education on planning skills (Scherer et al., 2019). However, given the similarity between the tasks of the Tower of Hanoi and the tasks of the Tower of London, further research utilizing different planning tasks is necessary to assess the potential benefits of programming education on planning skills fully.

Programming education environment. Studies investigating the effect of programming education on planning skills have employed diverse programming environments. La Paglia et al. (2018) utilized robot programming with LEGO Mindstorm as the programming language, allowing children to code the behaviors of robots and observe their actions to enhance planning skills. Several studies employed Code.org, an online programming education initiative, enabling children to solve various programming-related problems (Arfé et al., 2019 (Study 1); Arfé et al., 2019 (Study 2); Arfé et al., 2020). Additionally, Robledo-Castro et al. (2023) employed a combination of unplugged and plugged activities supported by MakeCode to facilitate planning skills in young children. These activities involved practicing programming concepts without electronic devices and coding micro:bit devices to observe their behaviors. The utilization of diverse programming education environments suggests that improvements in planning skills may be linked to programming concepts in general rather than specific programming environments.Overall, although some concerns about the risk of bias were identified in these studies, the overall risk was lower compared to non-randomized studies (Table 4). Therefore, the evidence suggests that learning to code has a promising effect on improving planning skills, supported by robust methodologies and consistently significant results across all studies.

Reasoning

Five studies investigated the effects of programming education on the reasoning skills of children.Among these studies, three exhibited a high risk of bias, one showed some concerns regarding bias, and one demonstrated a low risk of bias, highlighting potential biases in the findings. Of the three studies indicating significant positive effects of programming training (Atasoy & Özden, 2020; Lai & Yang, 2011; Psycharis & Kallia, 2018), effect sizes were dppc2 = 0.776, dcohen = 0.348, and dcohen = 1.109, respectively.

Conversely, two studies (Hayes & Stewart, 2016; Özcan et al., 2021) did not report significant positive effects of programming education (dppc2 = 0.17 and dppc2 = -0.232, respectively). Notably, these studies measured reasoning using a matrix reasoning task and employed randomized control trials.

In one study with null findings (Hayes & Stewart, 2016), programming education served as the control group, with another intervention being the targeted intervention to improve reasoning skills. To examine whether programming education enhanced reasoning skills, we estimated the effect size for the coding intervention from pre- to post-test (dcohen = 0.256). This analysis revealed a slight improvement in reasoning skills from the pre-test to the post-test in the coding condition.

The other study (Özcan et al., 2021) that did not find a significant effect showed improvements in reasoning for both the control and experimental groups. The task might have a practice effect, especially for children from disadvantaged neighborhoods who may not be familiar with the face-to-face task format. Therefore, the null findings in both studies might be attributed to other design-related factors rather than an actual lack of effects.

Reasoning type. Studies examining reasoning skills have employed various established tasks from the literature. For instance, Psycharis & Kallia (2017) utilized the Cornell Reasoning Test, assessing logical thinking and deductions based on provided information through sentence completion tasks. Atasoy & Ozden (2020) employed a visuospatial reasoning task involving mental rotation, depth perception, and mental completion with visual patterns to measure reasoning abilities. Additionally, three studies (Hayes & Stewart, 2016; Lai & Yang, 2011; Ozcan et al., 2021) utilized non-verbal tests like Raven's Matrices or Matrix Reasoning, where individuals identify missing elements within matrices based on underlying patterns. The use of diverse reasoning tasks suggests that programming education may potentially enhance reasoning skills, possibly indicating a far-transfer effect (Scherer et al., 2019).

Programming education environment. Upon examining the programming education environments utilized in studies on reasoning, it seems that almost all programs employed the Scratch programming language to teach programming concepts. For instance, Lai and Yang (2010) integrated Scratch into their curriculum, incorporating problem-solving activities supported by scaffolding. Similarly, Ozcan et al. (2021) utilized Scratch for teaching programming concepts through various activities on the platform. Hayes and Stewart (2016) also evaluated the impact of Scratch, focusing on game creation as a means to teach programming concepts. Another study (Atasoy & Ozden, 2020) emphasized spatial concepts alongside programming knowledge using Scratch. Only one study conducted on reasoning with high-school children did not use Scratch, they evaluated the impact of a programming course that was included in the curriculum (Psycharis & Kallia, 2017). While the prevalence of Scratch programming language usage suggests potential benefits, particularly for older children, compared to elementary school children, there is a need to explore other programming education environments to fully understand the role of different programming components in enhancing reasoning skills

In conclusion, the results regarding the effect of coding on reasoning skills are mixed, and further studies with better designs are needed to provide a clearer understanding of this relationship.

RQ3) Does the effect of programming and robotics education on different higher-order executive function skills change between different grade levels?

The current study examined research conducted with school-aged children to investigate the role of programming education, which is part of the K-12 education curriculum in many countries, on higher-order executive functions (EFs) which continue to develop into adolescence and young adulthood. To answer the third research question, we examined the findings separately according to grade levels. Below, each grade level was discussed in more detail. Overall, the majority of the studies were conducted with elementary school children and the results were promising for especially planning and problem-solving skills.

Grade

Elementary school. The majority of studies (50%) included in the review focused on elementary school children, with most reporting positive effects of programming education on higher-order executive functions. Specifically, all studies examining planning were conducted with elementary school children, showcasing promising effects of programming education on this cognitive domain (Arfé et al., 2019 (Study 1); Arfé et al., 2019 (Study 2); Arfé, Vardanega, & Ronconi, 2020; La Paglia et al., 2018; Robledo-Castro et al., 2023). However, the potential benefits of programming education on planning warrant exploration across diverse age groups, as highlighted in the previous section. In contrast, studies on reasoning skills in elementary school children did not find significant effects of programming education

(Hayes & Stewart, 2016; Özcan et al., 2021), suggesting a potential limitation in enhancing reasoning skills in this age group. Conversely, studies focusing on problem-solving skills reported significant positive effects of programming education (Brown et al., 2013; Pardamean & Suparyanto, 2015). Overall, the findings suggest that programming education may positively impact higher-order executive functions, particularly planning and problem-solving, in elementary school children. However, we need to acknowledge the variations in methodologies and the risk of bias among studies, emphasizing the need for additional research to establish more conclusive insights.

Middle school. Among the studies conducted with middle school children (44%), the majority reported significant positive effects of programming education on higher-order executive functions (EFs). Six studies specifically focused on problem-solving skills (Akcaoglu & Koehler, 2014; Brown et al., 2013; Donley, 2018; La Paglia et al., 2017; Nam et al., 2010; Rodríguez-Martínez et al., 2020), while two studies investigated the effects on reasoning skills (Atasoy & Özden, 2020; Lai & Yang, 2011). However, one study (Donley, 2018) examining problem-solving did not find a significant positive effect of programming education. In conclusion, the evidence suggests that coding education can benefit middle school children by enhancing higher-order executive function skills, particularly problem-solving. Nonetheless, additional studies investigating the effects of coding education on planning and reasoning skills in this age group are needed to strengthen these conclusions further.

High school. Two studies involving high school children (Psycharis & Kallia, 2017) demonstrated positive results for both reasoning and problem-solving outcomes. However, both studies exhibited a high risk of bias and lacked randomization, limiting the existing evidence on the impact of programming education on executive functions in high school children. Consequently, more studies with robust methodologies are essential to establish definitive conclusions.

Overall, studies across different grade levels underscore the potential of programming training to enhance higher-order executive functions in various educational settings. However, there is a notable clustering of studies around specific grade levels and skills. While studies conducted on reasoning skills with older children showed a significant positive impact, studies conducted with elementary school-aged children did not find significant results. Even though empirical studies are needed to provide evidence on the topic, it is possible that reasoning skills, as they require solving problems without relying on prior knowledge, may need abstract thinking, which develops later in life (Carpenter et al., 1990; Cattell, 1987). Therefore, coding education might benefit older children's reasoning skills.

Another example of clustering around grade levels is that all investigations into planning skills were conducted with elementary school children, while most studies involving middle school children focused on problem-solving skills. Therefore, it still remains an open question that whether planning or problem-solving skills could be improvable with programming education in different age categories. To achieve a more comprehensive understanding, further studies encompassing diverse age groups and exploring various executive function skills are imperative. Additionally, more randomized control trials will help determine which grade levels might benefit more significantly from programming education for specific executive function skills.

Duration of the Training

The duration of programming training across the included studies varied widely, ranging from 3 to 90 hours (see Table 3). To delve into the potential influence of training duration, we scrutinized studies where significant effects of programming education were not observed (Donley, 2018; Hayes & Stewart, 2016; Özcan et al., 2021; Rodríguez-Martínez et al., 2020), with training durations of 29, 25, 20, and 3 hours, respectively. Among these, two studies investigated reasoning skills (Hayes & Stewart, 2016; Özcan et al., 2021), and two were centered on problem-solving (Donley, 2018; Rodríguez-Martínez et al., 2020).

Surprisingly, the current evidence suggests that the duration and frequency of training may not significantly influence the intervention effects on executive function skills. While positive effects were observed in some studies with shorter durations, others with longer durations did not yield significant results. Further exploration into the role of duration revealed methodological issues in studies with longer durations, such as participant self-selection or comparisons of programming with other interventions targeting reasoning skills. These methodological challenges might contribute to the unexpected findings related to duration.

The existing studies did not directly compare different duration levels within the same training paradigm. Consequently, the specific factors influencing why certain short-duration studies demonstrated significant effects while others with longer durations did not remain unknown. Future research should undertake randomized trials to systematically investigate the impact of exposure levels, shedding light on the necessary exposure duration to observe positive effects. An in-depth understanding of the educational theory underpinning interventions may contribute to a more nuanced comprehension of the relationship between training duration and improvement in executive function skills.

Practical Implications

Educational guidance

Numerous studies have explored potential mechanisms by which learning to code enhances children's cognitive skills. Some propose that problem-solving practice during programming education contributes to skill improvement (e.g., Pardamean & Suparyanto, 2015), while others suggest that the inclusion of a game design component in programming training might be beneficial for cognitive development (e.g., Akcaoglu & Koehler, 2014).

However, detailed information about educational guidance during training or fidelity checks to ensure proper intervention implementation was not consistently provided across studies. Only a handful offered explicit descriptions of the guidance provided. For example, Nam et al. (2010) compared the effects of the same training with either scaffolding or demonstration, revealing that the group with scaffolding scored significantly higher than the demonstration group.

In comparing effect sizes between studies with and without detailed educational guidance or fidelity checks, an interesting trend emerged – studies with clear guidance tended to exhibit larger effect sizes (see Table 5). This pattern persisted even in studies with shorter training durations, as seen in Arfé et al.'s (2020) study. Even though empirical studies are needed to test this idea, these findings suggest that implementing programming training and clear educational guidance plays a crucial role in the intervention's effectiveness in improving cognitive skills. In this systematic review, we considered educational guidance as a broad concept spanning from game design to scaffolding. This implies that for coding education to be more successful, designers may need to consider the educational components and how children learn in addition to the coding content. Future studies should meticulously attend to the implementation process and provide comprehensive information about the educational guidance imparted during training to maximize the impact of programming education on executive functions.

Table 5

Educational guidance provided during the interventions

Study	dpp2	dcohen	Duration (hour)	Explanation	Instructional Design Explanation
Donley (2018)	0.364	0	25	Game-based, collaboration, problem-solving	No information
Akcaoglu & Koehler (2014)	1.06	1.98	15	Game design, problem-solving	Yes
Nam et al. (2010)	0.712	0.581	8	Scaffolding	Yes
Pardamean &Suparyanto, (2015)	0.054	0.259	11	Problem-solving	No information
Brown et al., (2013)	-	0.983	3	Problem-solving	No information
Psycharis & Kallia (2017) (Problem-solving)	0.116	-	3	Problem-solving	No information
Psycharis & Kallia (2017)(Reasoning)	0.333	0.121	30	Meta-cognition	No information
Rodríguez-Martínez et al.(2020)	-	0.228	90	Problem-solving, Reasoning, Self-efficacy	No information
La Paglia et al.(2017)	-	1.109	90	Problem-solving, Reasoning, Self-efficacy	No information

Lai & Yang (2011)	-	0.348		Problem-solving, scaffolding	Yes
Özcan et al. (2021)	0.17	0.119	20	Problem-solving, reasoning, computational thinking	No information /weekly plan
Hayes & Stewart (2016)	-0.232	-0.272	29	Problem-solving, reasoning	No
Atasoy & Özden (2020)	0.776	2.849	8	Reasoning	No information/weekly plan
La Paglia et al., (2018)	0.422	0.859	20	Reasoning	No information
Arfé et al. (2020)	-	3.04 and 4.68 3.86	8	Computational thinking	Yes/fidelity check
Arfé et al., (2019) (Study 1)	.445 and .163 .304	.95 and .80 .875	8	Computational thinking	No information/code.org provides feedback
Arfé et al. (2019) (Study 2)	1.622 and .815 1.218	.93 and .96 .945	8	Computational thinking	No information/code.org provides feedback
Robledo-Castro et al. (2023)	-1.207 -.714 -.319 and -.3	-1.019 -1.119 -.476 and -1.249	32	Computational thinking	No information. General outline.

Discussions

The practical implications of the findings from this systematic review hold significant relevance for educators and policymakers alike. Programming education has recently been incorporated into K-12 curricula worldwide without synthesizing the findings from empirical research (e.g., Akcaoglu & Koehler, 2014; Robledo-Castro et al., 2023) to understand for whom or which skills programming education can be beneficial (Hubwieser et al., 2015)..The findings of this systematic review support the inclusion of programming education in curricula by demonstrating its potential and positive effects on higher-order executive functions in school-aged children. Integrating coding into the curriculum can thus be considered a valuable educational tool. EFs have consistently been associated with various academic outcomes and skills in prior research (Emslander & Scherer, 2022; Spiegel et al., 2021). Therefore, educators and policymakers should explore the integration of coding into national education strategies, acknowledging its potential to enhance not only computational skills but also broader cognitive abilities. Educators may consider incorporating coding activities to support skills such as planning and problem-solving, even for children who may not pursue programming careers but face challenges in executive function (EF) skills. This recommendation is supported by prior evidence indicating that children with low EF skills benefit the most from EF interventions (Diamond & Ling, 2019), providing educators with an opportunity to engage young learners in activities aimed at improving their higher-order executive functions. These activities can have a cascading effect, positively impacting various skills closely associated with EFs (Ahmed et al., 2021).

The findings related to educational guidance in programming education underscore the critical role of educators in program design. Studies incorporating educational guidance (e.g., Akcaoglu & Koehler, 2014, Nam et al., 2010), even in brief durations, have shown significantly positive outcomes compared to those lacking such components. This finding aligns with prior research highlighting the significance of instructional design and learning (Rittle-Johnson et al., 2017; Rowland & DiVasto, 2008).

However, educators and policymakers must be mindful of the methodological considerations and potential biases highlighted in the review. While existing studies offer promising insights into the potential beneficial role of programming education in improving EFs(e.g., Arfé et al., 2019
; La Paglia et al., 2017), the presence of high risk of bias in the study results and the limited number of randomized controlled trials emphasize the critical need for rigorous research in this area. Moreover, the review suggests that programming education programs may achieve better outcomes when supplemented with educational guidance. Thus, it is essential to collaborate with educators to ensure that programming education programs incorporate age-appropriate educational guidance components, effectively supporting child learning. As such, the implementation of coding education should be approached judiciously, with attention to study design, duration, and clear educational guidance, to maximize the benefits for students' cognitive development.

Interpreting the current findings requires caution due to several limitations. First, most studies in this review lacked randomized control trials, which are considered the gold standard for establishing causality in evidence-based research (Hariton & Locascio, 2018). The risk of bias analysis underscored that most studies carried a high risk of bias (12 studies, 67%), implying that factors beyond the intervention itself may influence observed effects. While the existing studies suggest that coding education can enhance executive function skills, conducting more rigorous methodological designs, specifically randomized control trials with a low risk of bias, is crucial for more robust evidence.

Another limitation pertains to the control groups used in the studies, with most opting for waitlists or regular activities as the comparison condition (e.g., Akcaolu & Koehler, 2014;

Arfé et al., 2019). While these control groups are instrumental in assessing whether an intervention is considered successful compared to a no intervention condition, they fall short in providing insights into whether coding education is more effective than other educational activities or curricular options. Future studies should aim for a comprehensive assessment by comparing coding education with various control conditions, including other educational interventions or curricular activities.

Furthermore, the current studies have not adequately delved into the components of coding education that are most effective in developing cognitive skills. A deeper investigation is needed to understand which aspects of coding education have a more pronounced impact on executive function development. Future studies should focus on comparing different elements of coding education to identify critical components leading to improvements in cognitive skills. By addressing these limitations and conducting more rigorous and targeted research, a better understanding of the true impact of coding education on higher-order executive functions can be achieved.

Additional research is needed to determine the most effective age group for coding education in improving specific executive function skills. Currently, all four studies examining planning skills focused on young elementary school children (Arfé et al., 2019; Arfé et al., 2020; La Paglia et al., 2018; Robledo-Castro et al., 2023), leaving uncertainty about whether coding education can similarly enhance planning in older children. As many countries integrate coding education into middle school curricula, future studies should encompass a more comprehensive age range to determine the most opportune time for incorporating coding education.Therefore, , there is a need for comparative studies across different age groups to determine the specific benefits of programming education for various skills and age groups. While current research indicates potential improvements in executive functions (EFs) for certain age groups, future randomized control trials should investigate which EF skills are enhanced by coding education within each age group.

Moreover, the existing literature lacks a comprehensive understanding of the mechanisms through which coding education fosters improvements in executive function skills. Future studies should employ multiple measurement points to analyze skills and their predictors. Rather than solely measuring the success rate of problem-solving tasks (Brown et al., 2013; Donley,2018; Nam et al., 2010), researchers can explore the strategies used by learners at different stages. Analyzing the development of problem-solving strategies over time can provide valuable insights into the cognitive processes underpinning skill enhancement.

Addressing these research gaps will contribute to a better understanding of how coding education affects executive function skills across various age groups and unravel the underlying mechanisms driving these improvements. Such insights will aid in designing more effective and targeted coding education programs tailored to learners' unique needs and developmental stages.

Contributions

The study makes several - contributions to the existing reviews in literature. First, most of the previous reviews included studies that were not conducted in recent years (e.g., Scherer et al., 2018). However, a review that examines the role of current programming education was needed. This current systematic review explicitly centers on the current state of coding education, recognizing the prevalence of programming languages in today's technologically advanced environment. This context is essential for understanding the contemporary effects of coding on executive functions. Similarly, prior reviews included several diverse outcomes when synthesizing the findings of programing education (e.g., Popat

& Starkey, 2019). This makes it harder to draw conclusions regarding the role of programming education on EFs. The current systematic review examines the effects of coding education on higher-order EFs in school-aged children, recognizing the significant importance of enhancing these skills for academic achievement and various cognitive abilities. Last, the current study critically evaluates this issue while considering factors such as age, education level, and program duration. This comprehensive approach provides a nuanced understanding of how variables may influence the relationship between coding education and higher-order executive functions. By addressing these aspects, this systematic review contributes to advancing knowledge in the field. It sheds light on the potential benefits of coding education for higher-order cognitive skills in school-aged children.

Conclusion

This systematic review explored programming training's impact on higher-order executive functions (problem-solving, planning, and reasoning), revealing predominantly positive outcomes. While most studies showed favorable effects, a subset of four studies reported no significant improvements in problem-solving (Donley, 2018; Rodríguez-Martínez et al., 2020) and reasoning skills (Hayes & Stewart, 2016; Özcan et al., 2021).

Despite positive support in problem-solving, a higher bias risk calls for better-designed studies to strengthen evidence. Planning consistently showed positive outcomes with lower bias risk. However, in elementary school children, learning code didn't exhibit expected impacts on reasoning skills. Further research into age-specific benefits and diverse variables in programming education is crucial to clarify this relationship. Considering such factors will enhance our understanding, paving the way for more effective educational strategies.

References

Ahmed, S. F., Kuhfeld, M., Watts, T. W., Davis-Kean, P. E., & Vandell, D. L. (2021). Preschool executive function and adult outcomes: A developmental cascade model. *Developmental Psychology, 57*, 2234-2249.https://doi.org/https://doi.org/10.1037/dev0001270

Akcaoglu, M., & Koehler, M. J. (2014). Cognitive outcomes from the Game-Design and Learning (GDL) after-school program. *Computers & Education, 75*, 72-81.https://doi.org/ 10.1016/j.compedu.2014.02.003

Anderson, P. (2002). Assessment and development of executive function (EF) during childhood. *Child Neuropsychology*, *8*, 71-82.https://doi.org/ 10.1076/chin.8.2.71.8724

Andrzejewska, M., & Stolińska, A. (2018). The eye tracking technique in the analysis of mechanisms for solving algorithmic problems. *E-mentor*, *2*, 10-18.

Arfé, B., Vardanega, T., & Ronconi, L. (2020). The effects of coding on children's planning and inhibition skills. *Computers & Education, 148,* 1-16. https://doi.org/ 10.1016/j.compedu.2020.103807

Arfé, B., Vardanega, T., Montuori, C., & Lavanga, M. (2019). Coding in primary grades boosts children's executive functions. Frontiers in Psychology, 10, 2713.

Atasoy, R., & Özden, C. (2020). The Effect of Coding on Students' Visual-spatial Reasoning Skills. *Croatian Journal of Education: Hrvatski časopis za odgoj i obrazovanje*, *22*, 865-912.https://doi.org/ 10.15516/cje.v22i3.3522

Atun, H., & Usta, E., (2019). The effects of programming education planned with TPACK framework on learning outcomes. *Participatory Educational Research*, *6*, 26-36.https://doi.org/ 10.17275/per.19.10.6.2

Barr, D., Harrison, J., & Conery, L. (2011). Computational thinking: A digital age skill for everyone. *Learning & Leading with Technology, 38,* 20-23.

Blair, C. (2017). Educating executive function. *Wiley Interdisciplinary Reviews: Cognitive Science*, *8*, 1-6.https://doi.org/ 10.1002/wcs.1403

Blair, C., & Razza, R. P. (2007). Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. *Child development*, *78*, 647-663.https://doi.org/ 10.1111/j.1467-8624.2007.01019.x

Blume, G. W., & Schoen, H. L. (1988). Mathematical problem-solving performance of eighth-grade programmers and nonprogrammers. *Journal for Research in Mathematics Education*, *19,* 142-156.https://doi.org/ 10.2307/749408

Breed, B., Mentz, E., & Van der Westhuizen, G. (2014). A metacognitive approach to pair programming: Influence on metacognitive awareness.

Brown, Q., Mongan, W., Kusic, D., Garbarine, E., Fromm, E., & Fontecchio, A. (2013). Computer aided instruction as a vehicle for problem solving: Scratch programming environment in the middle years classroom. *Retrieved September*, *22*, 1-14.

Buitrago Flórez, F., Casallas, R., Hernández, M., Reyes, A., Restrepo, S., & Danies, G. (2017). Changing a generation's way of thinking: Teaching computational thinking through programming. *Review of Educational Research*, *87*, 834-860.https://doi.org/ 10.3102/0034654317710096

Çalışkan, E. (2020). The effects of robotics programming on secondary school students' problem-solving skills. *World Journal on Educational Technology: Current Issues*, *12*, 217-230.

Carpenter, P. A., Just, M. A., & Shell, P. (1990). What one intelligence test measures: A theoretical account of the processing in the raven progressive matrices test. *Psychological Review*, *97*, 404-431.https://doi.org/ 10.1037/0033-295X.97.3.404

Cattell, R. B. (1987). *Intelligence: Its Structure, Growth and Action.* Amsterdam, North-Holland.

Çetinkaya, A., & Baykan, Ö. K. (2020). Prediction of middle school students' programming talent using artificial neural networks. *Engineering Science and Technology, an International Journal*, *23*, 1301-1307.https://doi.org/ 10.1016/j.jestch.2020.07.005

Chang, Y. K., Tsai, C. L., Hung, T. M., So, E. C., Chen, F. T., & Etnier, J. L. (2011). Effects of acute exercise on executive function: a study with a Tower of London Task. *Journal of Sport and Exercise Psychology*, *33*, 847-865.https://doi.org/ 10.1123/jsep.33.6.847

Chevalier, M., Giang, C., Piatti, A., & Mondada, F. (2020). Fostering computational thinking through educational robotics: a model for creative computational problem solving. *International Journal of STEM Education*, *7*, 1-18.https://doi.org/ 10.1186/s40594-020-00238-z

Çınar, M., & Tüzün, H. (2021). Comparison of object-oriented and robot programming activities: The effects of programming modality on student achievement, abstraction, problem solving, and motivation. *Journal of Computer Assisted Learning*, *37*, 370-386.https://doi.org/ 10.1111/jcal.12495

Coding - the 21st century skill. (2018). Retrieved from https://ec.europa.eu/digital-single-market/en/coding-21st-century-skill

De Luca, C. R., Wood, S. J., Anderson, V., Buchanan, J. A., Proffitt, T. M., Mahony, K., & Pantelis, C. (2003). Normative data from the CANTAB. I: development of executive function over the lifespan. *Journal of clinical and experimental neuropsychology*, *25*, 242-254.https://doi.org/ 10.1076/jcen.25.2.242.13639

Deary, I. J., Strand, S., Smith, P., & Fernandes, C. (2007). Intelligence and educational achievement. *Intelligence*, *35*, 13-21.https://doi.org/ 10.1016/j.intell.2006.02.001

Diamond, A. (2013). Executive functions. *Annual review of psychology*, *64*, 135-168.https://doi.org/ 10.1146/annurev-psych-113011-143750

Diamond, A., & Ling, D. (2019). Review of the evidence on fundamental questions surrounding and efforts to improve executive functions (including working memory). In J. Novick, M. Bunting, M. Dougherty, & R. W. Engle (Eds.), *Cognitive and working memory training: Perspectives from psychology, neuroscience, and human development*. New York, NY: Oxford University Press.

Donley, K. S. (2018). *Coding in the Curriculum: Learning Computational Practices and Concepts, Creative Problem Solving Skills, and Academic Content in Ten to Fourteen-Year-Old Children*. Temple University.

Duncan, C., Bell, T., & Tanimoto, S. (2014). Should your 8-year-old learn coding? In Proceedings of the 9th workshop in primary and secondary computing education, pp. 60–69. https://doi.org/10.1145/2670757.2670774

Duncan, C.,&Bell, T. (2015). A pilot computer science and programming course for primary school students. In Proceedings of the workshop in primary and secondary computing education, pp. 39–48. https://doi.org/10.1145/2818314.2818328

Durak, H. Y., Yilmaz, F. G. K., & Yilmaz, R. (2019). Computational Thinking, Programming Self-Efficacy, Problem Solving and Experiences in the Programming Process Conducted with Robotic Activities. *Contemporary Educational Technology*, *10*, 173-197.https://doi.org/ 10.30935/cet.554493

Emslander, V., & Scherer, R. (2022). The relation between executive functions and math intelligence in preschool children: A systematic review and meta-analysis. Psychological Bulletin, 148, 337-369.https://doi.org/10.1037/bul0000369

Erol, O., & Çırak, N. S. (2022). The effect of a programming tool scratch on the problem-solving skills of middle school students. *Education and Information Technologies*, *27*, 4065-4086.https://doi.org/ 10.1007/s10639-021-10776-w

Erümit, A. K. (2020). Effects of different teaching approaches on programming skills. *Education and Information Technologies*, *25*, 1013-1037.https://doi.org/ 10.1007/s10639-019-10010-8

Fard, A. E., Asgary, A., Sarami, G. R., & Zarekar, A. (2014). A Comparative Study of the Effect of Computer-Based Instruction and Problem-Solving Instruction on the Students' Creativity. *Journal of Education and Training Studies*, *2*, 105-113.

Feng, C. Y., & Chen, M. P. (2014). The effects of goal specificity and scaffolding on programming performance and self-regulation in game design. *British Journal of Educational Technology*, *45*, 285-302.https://doi.org/ 10.1111/bjet.12022

Friedman, S. L., Scholnick, E. K., & Cocking, R. R. (Eds.). (1987). *Blueprints for thinking: The role of planning in cognitive development*. Cambridge University Press.

Fuchs, L. S., Fuchs, D., Prentice, K., Burch, M., Hamlett, C. L., Owen, R., & Schroeter, K. (2003). Enhancing third-grade student'mathematical problem solving with self-regulated learning strategies. *Journal of educational psychology*, *95*, 306.

Hariton, E., & Locascio, J. J. (2018). Randomised controlled trials—The gold standard for effectiveness research. *BJOG: an international journal of obstetrics and gynaecology*, *125*. https://doi.org/10.1111/1471-0528.15199

Hayes, J., & Stewart, I. (2016). Comparing the effects of derived relational training and computer coding on intellectual potential in school-age children. *British Journal of Educational Psychology*, *86*, 397-411.https://doi.org/ 10.1111/bjep.12114

Higgins, J. P., Thomas, J., Chandler, J., Cumpston, M., Li, T., Page, M. J., & Welch, V. A. (Eds.). (2019). *Cochrane handbook for systematic reviews of interventions*. John Wiley & Sons.

Holyoak, K. J. (1990). Problem solving. *Thinking: An invitation to cognitive science*, *3*, 117-146.

Hu, C. C., Yang, Y. F., Cheng, Y. W., & Chen, N. S. (2023). Integrating educational robot and low-cost self-made toys to enhance STEM learning performance for primary school students. *Behaviour & Information Technology*, 1-22.https://doi.org/ 10.1080/0144929X.2023.2222308

Hubwieser, P., Armoni, M., & Giannakos, M. N. (2015). How to implement rigorous computer science education in K-12 schools? Some answers and many questions. ACM Transactions on Computing Education (TOCE), 15, 1-12.https://doi.org/10.1145/2729983

Jonassen, D. H. (2000). Toward a design theory of problem solving. *Educational technology research and development*, *48*, 63-85.https://doi.org/ 10.1007/BF02300500

Kalelioğlu, F. (2015). A new way of teaching programming skills to K-12 students: Code. org. *Computers in Human Behavior*, *52*, 200-210.https://doi.org/ 10.1016/j.chb.2015.05.047

Karaahmetoğlu, K., & Korkmaz, Ö. (2019). The effect of project-based arduino educational robot applications on students' computational thinking skills and their perception of Basic Stem skill levels. *Participatory Educational Research*, *6*, 1-14.https://doi.org/ 10.17275/per.19.8.6.2

Karsenti, T., & Bugmann, J. (2017). Exploring the Educational Potential of Minecraft: The Case of 118 Elementary-School Students. *International Association for Development of the Information Society*.

Keen, R. (2011). The development of problem solving in young children: A critical cognitive skill. *Annual review of psychology*, *62*, 1-21.https://doi.org/ 10.1146/annurev.psych.031809.130730

Kim, J. O., & Kim, J. (2020). Development and application of art based STEAM education program using educational robot. In *Robotic Systems: Concepts, Methodologies, Tools, and Applications* (pp. 1675-1687). IGI Global.

Klauer, K. J., Willmes, K., & Phye, G. D. (2002). Inducing inductive reasoning: does it transfer to fluid intelligence?. *Contemporary Educational Psychology*, *27*, 1-25.https://doi.org/ 10.1006/ceps.2001.1079

Kostousov, S. A., & Simonova, I. V. (2019, November). Visual modeling for exploratory problem solving on computer science lessons. In *16th International Conference on Cognition and Exploratory Learning in Digital Age, CELDA 2019* (pp. 265-272).

Kožuh, I., Krajnc, R., Hadjileontiadis, L. J., & Debevc, M. (2018). Assessment of problem solving ability in novice programmers. *PloS one*, *13*, 1-21.https://doi.org/ 10.1371/journal.pone.0201919

La Paglia, F., Francomano, M. M., Riva, G., & La Barbera, D. (2018). Educational Robotics to develop executive functions visual spatial abilities, planning and problem solving. In 2018 *Annual Review of Cybertherapy and Telemedicine*.80-86.

La Paglia, F., La Cascia, C., Francomano, M. M., & La Barbera, D. (2017). Educational robotics to improve mathematical and metacognitive skills. *Annual Review Of Cybertherapy And Telemedicine, 15*, 70-75.

La Paglia, F., Rizzo, R., & La Barbera, D. (2011). Use of robotics kits for the enhancement of metacognitive skills of mathematics: a possible approach. In 2011 *Annual Review of Cybertherapy and Telemedicine*. 22-25.

Lai, A. F., & Yang, S. M. (2011, September). The learning effect of visualized programming learning on 6 th graders' problem solving and logical reasoning abilities. In *2011 International Conference on Electrical and Control Engineering* (pp. 6940-6944). IEEE.

Langdon, D., McKittrick, G., Beede, D., Khan, B., & Doms, M. (2011, July). STEM: Good Jobs Now and for the Future. Washington, DC: US Department of Commerce, Economics and Statistics Administration. Retrieved from http://www.esa.doc.gov/sites/default/files/news/documents/stemfinalyjuly14.pdf

Liao, Y. K. C., & Bright, G. W. (1991). Effects of computer programming on cognitive outcomes: A meta-analysis. *Journal of Educational Computing Research*, *7*, 251-268.https://doi.org/ 10.2190/E53G-HH8K-AJRR-K69M

Liao, Y.-C. (2000, June). *A meta-analysis of computer programming on cognitive outcomes: An updated synthesis*. Paper presented at the Proceedings of World Conference on Educational Multimedia, Hypermedia and Telecommunications, Montreal, Québec, Canada. Retrieved from https://www.learntechlib.org/primary/p/16132/

Luciana, M., & Nelson, C. A. (2002). Assessment of neuropsychological function through use of the Cambridge neuropsychological testing automated battery: Performance in 4- to 12- year-old children. *Developmental Neuropsychology*, *22*, 595–624. https://doi.org/ 10.1207/S15326942DN2203_3

Lynn, R., Meisenberg, G., Mikk, J., & Williams, A. (2007). National IQs predict differences in scholastic achievement in 67 countries. *Journal of Biosocial Science*, *39*, 861-874.https://doi.org/ 10.1017/S0021932007001964

Macrides, E., Miliou, O., & Angeli, C. (2021). Programming in early childhood education: A systematic review. *International Journal of Child-Computer Interaction*, *32,* 100396. https://doi.org/ 10.1016/j.ijcci.2021.100396

Mayer, R. E. (1992). *Thinking, problem solving, cognition*. WH Freeman/Times Books/Henry Holt & Co.

McGuckian, T. B., Wilson, P. H., Johnston, R. D., Rahimi-Golkhandan, S., Piek, J., Green, D.,Rogers, J. M., Maruff, P., Steenbergen, B., & Ruddock, S. (2023). Development of complex executive function over childhood: Longitudinal growth curve modeling of performance on the Groton Maze Learning Task. *Child Development*, *94*, 648-658. https://doi.org/10.1111/cdev.13888

Merkouris, A., & Chorianopoulos, K. (2017, November). Programming Human-Robot Interactions in Middle School: The Role of Mobile Input Modalities in Embodied Learning. In *Interactive Mobile Communication, Technologies and Learning* (pp. 457-464). Springer, Cham.

Minzenberg, M. J., Laird, A. R., Thelen, S., Carter, C. S., & Glahn, D. C. (2009). Meta analysis of 41 functional neuroimaging studies of executive function in schizophrenia. *Archives of general psychiatry*, *66*(8), 811-822.

Montuori, C., Gambarota, F., Altoé, G., & Arfé, B. (2023). The cognitive effects of computational thinking: A systematic review and meta-analytic study. *Computers & Education*, 104961.

Moreno-León, J., & Robles, G. (2016). Code to learn with Scratch? A systematic literature review. In *2016 IEEE Global Engineering Education Conference (EDUCON)* (pp. 150-156). IEEE.https://doi.org/ 10.1073/pnas.1010076108

Morris, S. B. (2008). Estimating effect sizes from pretest-posttest-control group designs. *Organizational research methods*, *11*, 364-386.https://doi.org/ 10.1177/1094428106291059

Müller, U., & Kerns, K. (2015). The development of executive function. In R. Lerner, L. Liben, U. Müller (Eds.), *Cognitive and working memory training: Perspectives from* *psychology, neuroscience, and human development* (2nd ed., pp. 571-623). Hoboken, New Jersey: John Wiley & Sons, Inc.

Nam, D., Kim, Y., & Lee, T. (2010, November). The effects of scaffolding-based courseware for the Scratch programming learning on student problem solving skill. In *Proceedings of the 18th International Conference on Computers in Education* (pp. 723-727). Putrajaya, Malaysia: Asia-Pacific Society for Computers in Education.

Newell, A., & Simon, H. (1972). *Human problem solving.* Englewood Cliffs, NJ: Prentice Hall.

Özcan M. Ş., Çetinkaya E., Goksun T., & Kisbu Sakarya Y. (2021). Does Learning to Code Influence Cognitive Skills of Elementary School Children? Findings from a Randomized Experiment. *British Journal of Educational Psychology*

Pardamean, B., & Suparyanto, T. (2015). Improving problem-solving skills through Logo programming language. *Stanisław Juszczyk*, 52-64.https://doi.org/ 10.15804/tner.2015.41.3.04

Pellas, N., & Vosinakis, S. (2018). The effect of simulation games on learning computer programming: A comparative study on high school students' learning performance by assessing computational problem-solving strategies. *Education and Information Technologies*, *23*, 2423-2452.https://doi.org/ 10.1007/s10639-018-9724-4

Popat, S., & Starkey, L. (2019). Learning to code or coding to learn? A systematic review. *Computers & Education*, *128*, 365-376.https://doi.org/ 10.1016/j.compedu.2018.10.005

Psycharis, S., & Kallia, M. (2017). The effects of computer programming on high school students' reasoning skills and mathematical self-efficacy and problem solving. Instructional Science, 45, 583-602.https://doi.org/ 10.1007/s11251-017-9421-5

Rahman, M. (2019). 21st Century Skill" Problem Solving": Defining the Concept. *Online Submission*, *2*, 71-81.

Resing, W. C., Vogelaar, B., & Elliott, J. G. (2020). Children's solving of 'Tower of Hanoi'tasks: dynamic testing with the help of a robot. *Educational Psychology*, *40*, 1136-1163.https://doi.org/ 10.1080/01443410.2019.1684450

Resnick, M., Maloney, J., Monroy-Hernández, A., Rusk, N., Eastmond, E., Brennan, K., ... & Kafai, Y. (2009). Scratch: programming for all. *Communications of the ACM*, *52*, 60-67.https://doi.org/ 10.1145/1592761.1592779

Rideout, V. (2017). The Common Sense census: Media use by kids age zero to eight. *San Francisco, CA: Common Sense Media*, 263-283.

Rittle-Johnson, B., Loehr, A. M., & Durkin, K. (2017). Promoting self-explanation to improve mathematics learning: A meta-analysis and instructional design principles. ZDM, 49, 599-611.https://doi.org/10.1007/s11858-017-0834-z

Robledo-Castro, C., Hederich-Martínez, C., & Castillo-Ossa, L. F. (2023). Cognitive stimulation of executive functions through computational thinking. *Journal of Experimental Child Psychology*, *235*, 105738. https://doi.org/ 10.1016/j.jecp.2023.105738

Rodríguez-Martínez, J. A., González-Calero, J. A., & Sáez-López, J. M. (2020). Computational thinking and mathematics using Scratch: an experiment with sixth-grade students. *Interactive Learning Environments*, *28*, 316-327.https://doi.org/ 10.1080/10494820.2019.1612448

Rowland, G., & DiVasto, T. (2001). Instructional design and powerful learning. Performance Improvement Quarterly, 14, 7-36.https://doi.org/10.1111/j.1937-8327.2001.tb00207.x

Scherer, R., Siddiq, F., & Viveros, B. (2018). The Cognitive Benefits of Learning Computer Programming: A Meta-Analysis of Transfer Effects. *Journal of Educational Psychology*. Advance online publication. http://dx.doi.org/10.1037/edu0000314

Shaffril, H. A.M., Samsuddin, S. F., & Abu Samah, A. (2021). The ABC of systematic literature review: the basic methodological guidance for beginners. Quality & Quantity, 55, 1319-1346.https://doi.org/10.1007/s11135-020-01059-6

Siegle, D. (2017). Technology: Encouraging creativity and problem solving through coding. *Gifted Child Today*, *40*, 117-123.https://doi.org/ /10.1177/1076217517690861

Siegler, R. S. (1996).Emerging Minds: The Process of Change in Children's Thinking.New York, NY: Oxford University Press.

Spiegel, J. A., Goodrich, J. M., Morris, B. M., Osborne, C. M., & Lonigan, C. J. (2021). Relations between executive functions and academic outcomes in elementary school children: A meta-analysis. Psychological bulletin, 147, 329-351.https://doi.org/10.1037/bul0000322

Sterne JAC, Hernán MA, Reeves BC, Savović J, Berkman ND, Viswanathan M, Henry D, Altman DG, Ansari MT, Boutron I, Carpenter JR, Chan AW, Churchill R, Deeks JJ, Hróbjartsson A, Kirkham J, Jüni P, Loke YK, Pigott TD, Ramsay CR, Regidor D, Rothstein HR, Sandhu L, Santaguida PL, Schünemann HJ, Shea B, Shrier I, Tugwell P, Turner L, Valentine JC, Waddington H, Waters E, Wells GA, Whiting PF, Higgins JPT. (2016) ROBINS-I: a tool for assessing risk of bias in non-randomized studies of interventions. BMJ 2016; 355; i4919; https://doi.org/ 10.1136/bmj.i4919.

Sterne JAC, Savović J, Page MJ, Elbers RG, Blencowe NS, Boutron I, Cates CJ, Cheng H-Y, Corbett MS, Eldridge SM, Hernán MA, Hopewell S, Hróbjartsson A, Junqueira DR, Jüni P, Kirkham JJ, Lasserson T, Li T, McAleenan A, Reeves BC, Shepperd S, Shrier

I, Stewart LA, Tilling K, White IR, Whiting PF, Higgins JPT. (2019) RoB 2: a revised tool for assessing risk of bias in randomised trials. *BMJ* 2019; 366: l4898.

Su, Y. S., Shao, M., & Zhao, L. (2022). Effect of mind mapping on creative thinking of children in scratch visual programming education. *Journal of Educational Computing Research*, *60*, 906-929. 10.1177/07356331211053383

Sun, Y., Chang, C. H., & Chiang, F. K. (2022). When Life Science Meets Educational Robotics. *Educational Technology & Society*, *25*, 166-178.

Ten Eycke, K.D.,&Dewey,D. (2016). Parent-report and performance-based measures of executive function assess different constructs. *Child Neuropsychology: A Journal on Normal and Abnormal Development in Childhood and Adolescence*, *22*, 889–906. https://doi.org/10.1080/09297049.

Trinchero, R., & Sala, G. (2016). Chess training and mathematical problem-solving: the role of teaching heuristics in transfer of learning. *Eurasia Journal of Mathematics, Science & Technology Education*, *12*, 655-668.

Vico, F., Molina, M., Orden, D., Ortiz, J., Garcia, R., & Masa, J. (2019). A coding curriculum for K-12 education: the evidence-based approach. In *Proceedings of the 11th annual International Conference on Education and New Learning Technologies* (pp. 7102-7106).

Wing, J. M. (2006). Computational thinking. *Communications of the ACM*, *49*, 33-35.https://doi.org/ 10.1145/1118178.1118215

Xiao, Y., & Watson, M. (2019). Guidance on conducting a systematic literature review. Journal of planning education and research, 39, 93-112.https://doi.org/10.1177/0739456X17723971

Zelazo, P. D., & Jacques, S. (1997). Children's rule use: Representation, reflection, and cognitive control. *Annals of child development*, *12*, 119-176.

Zelazo, P. D., & Müller, U. (2012). Executive function in typical and atypical development. In U. Goswami (Eds.), *The Wiley-Blackwell handbook of childhood cognitive development* (2nd ed., pp. 574-603). Wiley-Blackwell.

Zelazo, P. D., Carter, A., Reznick, J. S., & Frye, D. (1997). Early development of executive function: A problem-solving framework. *Review of general psychology*, *1*, 198-226.

CHAPTER 5

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Does Learning to Code Improve Cognitive Skills of Elementary School Children? Findings from a Randomized Experiment

Coding education is increasingly becoming a part of children's lives. In many countries, children learn how to code starting from an early age. Coding is one of the necessary 21st-century skills (Wing, 2006). The recent literature suggests that besides its practical benefits, learning to code improves the cognitive abilities of children (e.g., Popat & Starkey, 2019; Scherer, Siddiq, and Viveros, 2018). However, there are conflicting results in the literature. While some studies presented the significant positive effect of learning coding on different cognitive skills such as problem-solving (e.g., Akcaoglu & Koehler, 2014), reasoning (e.g., Psycharis & Kallia 2017), and planning (e.g., Arfé, Vardanega, Montuori, & Lavanga, 2019); others failed to do so for the same outcome variables (e.g., Kalelioglu, 2015; Lai & Yang, 2011). Moreover, earlier studies on the effectiveness of learning to code are based on a pretest-posttest design, which limits establishing causal effects. In this study, we investigate whether learning to code benefits different cognitive skills of elementary school children using a randomized experiment. In particular, we examine the impact of a 10-week learn-to-code education program (i.e., treatment of interest) on children's computational thinking, fluid intelligence, and spatial orientation skills, as compared to children receiving a 10-week math education program (i.e., another STEM-related comparison treatment) or a 10-week reading program (i.e., control).

Coding Training Tools for Children

Children spend substantial amounts of time with technological devices (Common Sense Media, 2020), yet they are usually in the consumer position of technology rather than the creators. Bers and Horn (2010) suggested that this might arise from the previous belief that children cannot understand the logic behind programming with complex syntax. During the 1970s and 1980s, many schools in the USA provided programming education to children (Moreno-León & Robles 2016; Pea & Kurland 1984), using software called LOGO (Papert, 1980). These early attempts faded in the 1990s (Moreno-León & Robles, 2016). They may not have been successful because the programming education was not integrated into the curricula of children outside the domains of mathematics and physics (Kafai & Burke, 2013). Resnick et al. (2009) listed some reasons for the failure of early attempts. First, programming languages were too challenging for children because of the complex syntaxes behind them. Second, the activities used in teaching programming were not attractive to children. Third, programming was usually introduced in a context where children did not have guidance for the activities. These reasons might explain why some earlier studies found benefits in learning programming (Battista & Clements, 1986; Kapa, 1999), but not others (e.g., Clements, 1986; Shaw, 1986).

In the last decade, the intention to teach programming to children has reemerged (Moreno-León & Robles, 2016). Scratch is one of these newer programming languages that has the advantage of eliminating the problems that were encountered in previous attempts. It is “more tinkerable, more meaningful, and more social” according to its creators (Resnick et al., 2009, p.4). Scratch allows children to personalize the programs they created using the interface with music, colors, or stories. It is social because children can share their codes or adopt other peoples’ codes from the Scratch community. Finally, Scratch eliminates the complex syntax problem that was encountered in previous attempts and enables children to focus on the created programs instead of getting overwhelmed with the complicated syntax (Kelleher, & Pausch, 2005; Mladenović, Krpan & Mladenović 2016). Copple and Bredekamp (2009) suggested that developmentally appropriate tools provide the most benefit. Duncan, Bell, and Tanimoto (2014) asserted that Scratch is one of the drag and drop programming tools for this age group. With the availability of more developmentally appropriate programming languages, many countries (e.g., USA, China, Finland) have started adding coding to their school curricula (Barr & Stephenson, 2011; Duncan & Bell, 2015; Sturman and Sizmur, 2011; Webb et al., 2016).

Programming and Cognitive Skills

Several studies were conducted to see the effects of the early attempts of teaching programming on young children (for a meta-analysis, see Liao & Bright, 1991). Some of those reported beneficial effects of learning to code compared to a control group on problem-solving, planning, cooperation skills (Kapa, 1999), operational competence, metacognitive skills, creativity (Clements, 1986), and executive-level problem-solving (Battista & Clements, 1986). However, some other studies found a null effect of learning programming on math and reading achievement test scores (Clements, 1986), problem-solving skills (Shaw, 1986), math achievement, and knowledge-based problem solving (Battista & Clements,1986). With these conflicting findings and efforts to make programming languages more developmentally appropriate for children, Scherer (2016) suggested that more research is needed to provide empirical evidence for the transferability of learning programming to cognitive skills. However, randomized studies investigating the effects of developmentally appropriate programming education on different cognitive skills are scarce. Popat and Starkey (2019) conducted a systematic review based on ten articles, investigating the educational outcomes of learning to code in students. They reported that children had other benefits such as mathematical problem-solving and critical thinking in addition to learning to code. However, the children's age range was vast in the reviewed studies, which might lead to imprecise information regarding effects at different age periods. Furthermore, the reviewed studies did not test the multiple cognitive skills by relying on the same study sample or education program. Scherer, Siddiq, and Viveros (2019) conducted a meta-analysis on the transferability effects of programming on cognitive skills, categorizing the cognitive skills into two: a near transfer effect (e.g., programming knowledge, computational thinking), and a far transfer effect (e.g., spatial reasoning, creative thinking). They defined near transfer effects as transferring the knowledge gained from the training to other contexts that require similar skills or strategies. The far transfer is, on the other hand, defined as transferring skills to contexts that require different cognitive skills or strategies. Their meta-analysis included both studies on early attempts of programming education and recent studies with diverse content targeting different skills. They found that there was a robust near transfer effect and a moderate far transfer effect. They suggested that far-transfer effects may selectively exist for some cognitive skills, such as creative thinking. Future studies should investigate the differential far transfer effects of specific programming training on different cognitive skills. By listing some methodological issues of previous studies, they suggested that an optimal study for this topic should include treated and untreated control groups and measure both programming skills and other cognitive skills with pre-test, post-test, and follow-up. In the current study, we implemented this methodology by having two comparison groups and measuring computational thinking (programming related skills), fluid intelligence, and spatial orientation (cognitive skills) with a randomized pre-test post-test design. We could not have a follow-up because children in the comparison conditions enrolled in the coding training after the data collection at post-test.

In our randomized study, we investigate whether a 10-week coding education program can benefit a variety of cognitive skills of elementary school children. We specifically investigate computational thinking, fluid intelligence, and spatial orientation, as these are conceptually related to learning programming (Francis, Khan, & Davis, 2016; Lye & Koh, 2014; Mladenović, Krpan, & Mladenović, 2016; Psycharis & Kallia, 2017; Scherer et al., 2019) as well as suggested to be essential for the development of 21^{st}-century skills

(Lynn, Meisenberg, Mikk & Williams, 2007; Uttal & Cohen, 2012; Wai, Lubinski & Benbow, 2009; Werner, Denner, Campe & Kawamoto, 2012). Moreover, using the same sample and education program and a randomized design, the current study examines both near (computational thinking) and far transfer effects (fluid intelligence and spatial reasoning) of a developmentally appropriate programming education to contribute to the knowledge on the differential effects of programming education on cognitive skills.

Computational thinking

In her pioneer work, Wing (2006) asserted that computational thinking is an essential skill for everyone and not just for people who are in computer sciences. She defined computational thinking as "solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science" (p.33). Its underlying mechanism involves problem representation, exploring solutions, and debugging (Barr & Stephenson, 2011; Bers, Flannery, Kazakoff, & Sullivan, 2014). Programming can create an environment to develop computational thinking through the practice of algorithms, manipulation, and computation (Barr & Stephenson, 2011). Therefore, we would expect that children will practice computational thinking skills while coding.

Computational thinking is suggested to be a general cognitive skill, like problem-solving, that individuals can use outside of computer sciences (Barr, Harrison, & Conery, 2011; Wing, 2006), and it is related to skills such as algorithmic thinking, creativity, and critical thinking (Durak & Saritepeci, 2018). For example, children practice conditionals while coding, and they can use these if/then statements in other situations where they encounter problems. Furthermore, visual programming languages such as Scratch can be especially beneficial for computational thinking because they allow children to see what they code as an animated object (Lye & Koh 2014). Therefore, we hypothesize that children who attend the learn-to-code education program will have higher computational thinking scores than children in math or reading groups.

Although a substantial number of studies reported that learning to code could improve computational thinking (Bers, Flannery, Kazakoff, & Sullivan, 2014; Brennan & Resnick, 2012; Duncan & Bell, 2015; Lye & Koh 2014; Tran, 2018; Webb, 2010; Werner, Denner, Campe & Kawamoto, 2012), none of these studies were randomized trials that can provide causal evidence. This can be partly due to measurement limitations. Several measures were developed to assess computational thinking (Brennan & Resnick, 2012; Webb, 2010; Werner, Denner, Campe & Kawamoto, 2012). For instance, trouble-shooting assessment requires children to fix the code sequences (i.e., debug) that were given at the end of a coding training (Webb, 2010). Most of the measures to assess computational thinking similarly require coding knowledge, making researchers unable to conduct pre-test, post-test, or randomized control group studies. Only one paper-based assessment of computational thinking was recently developed (Tran, 2018). With this questionnaire, researchers can evaluate different components of computational thinking: sequence, algorithm, loop, debug, and conditional. By using this measure, Tran (2018) found that a 10-week coding training significantly increased third-grade children's total computational thinking scores from pre-test to post-test, as expected. However, the study did not involve a control group. We also lack the knowledge of whether having training in another STEM field, such as mathematics, would lead to similar gains in computational thinking.

Fluid Intelligence (Matrix Reasoning)

Fluid intelligence (Gf) is an ability to adapt and solve novel problems without the use of previous experience or knowledge (Carpenter, Just, & Shell, 1990). Fluid intelligence is counted as one of the critical predictors of learning (Deary, Strand, Smith, & Fernandes, 2007) and academic success (Lynn, Meisenberg, Mikk & Williams, 2007). Moreover, fluid intelligence is also suggested to be one of the crucial predictors of problem-solving (Klauer, Willmes & Phye, 2002) and was even used as synonymous with problem-solving in Diamond (2013). For example, some creative problem-solving interventions targeted fluid intelligence as the outcome variable (Herrnstein, Nickerson, de Snchez & Swets, 1986; Klauer, Willmes & Phye, 2002; Stankov, 1986). Programming and problem-solving share similar mechanisms, such as analyzing a problem, planning the solution, choosing the solution, and checking the completed solution (Blume & Schonen, 1988; Siegle, 2017).

Only a few studies tested the effects of learning to code on fluid intelligence (Lai & Yang, 2011; Psycharis & Kallia, 2017). While one of them showed a significant positive effect of learning to code (Psycharis & Kallia, 2017), the other one failed to find a significant effect. In addition to those studies, several studies focused on improving problem-solving via programming (e.g., Akcaoglu, & Koehler, 2014; Fessakis, Gouli, & Mavroudi, 2013; Kalelioglu & Gulbahar, 2014; Mladenović, Krpan, & Mladenović, 2016; Shaw, 1986;). For example, children who were in a game design and learning group (i.e., an after-school program where children learn the principles of game design, basics of programming, producing digital media, and problem-solving skills in a game design context) had higher PISA scores compared to children in a control group (Akcaoglu, & Koehler, 2014). Another study revealed that children who have lower levels of problem-solving skills before learning programming could benefit more from a visual programming language like Scratch compared to a traditional programming language like Python (Mladenović, Krpan, & Mladenović, 2016). Other studies, however, failed to confirm the positive effects of learning to program on problem-solving (e.g., Shaw, 1986; Kalelioglu & Gulbahar, 2014). One reason for the inconsistent results might stem from the fact that these studies focused on different types of problem-solving skills, such as general problem-solving and math problem-solving. Focusing on creative problem solving, as in fluid intelligence tasks, might show us that learning programming can contribute to a specific problem-solving type. Even though fluid intelligence develops with time during childhood (Horn, Donaldson, & Engstrom, 1981; Schroeders, Schipolowski, & Wilhelm, 2015), if programming education has a far transfer effect on fluid intelligence, we would expect that the improvement will be more pronounceable for children in the learn to code education program. Thus, we hypothesize that children in the coding group will have higher fluid intelligence scores than children in the math or reading groups.

Spatial Reasoning/Orientation

Spatial reasoning is one of the necessary skills in pursuing careers in STEM fields (Uttal & Cohen, 2012; Wai, Lubinski & Benbow, 2009). People who have higher spatial reasoning skills are more successful in STEM-related domains (e.g., Gilligan, Flouri, & Farran, 2017; Hegarty et al., 2007; Uttal, Miller, Nora, & Newcombe, 2013). Moreover, spatial reasoning skills strongly predict STEM-related career attainment (Benbow & Stanley, 1982; Shea, Lubinski, & Benbow, 2001; Wolfgang, Stanndard, & Jones, 2003). A report from the U.S. Department of Commerce indicated that from 2000 to 2010, STEM employment increased three times compared to non-STEM jobs (Langdon, McKittrick, Beede, Khan, & Doms, 2011). Therefore, finding ways to improve the spatial reasoning of children is an important pursuit.

Learning Scratch triggers imagining, visualizing, and locating and has the potential to improve spatial skills (Francis, Khan, & Davis, 2016). For example, while programming in Scratch, children need to think from the physical perspective of the characters in the project. Therefore, they can practice spatial thinking skills while coding in Scratch. Although there is no recent study conducted with more developmentally appropriate programming languages, early studies showed that programming education could improve spatial skills (e.g., Miller, Kelly, & Kelly, 1988). Some studies also emphasize a relationship between spatial reasoning and mathematics ability (e.g., Cheng & Mix, 2014; Lowrie, Logan & Ramful, 2017). We hypothesize that children in the learn-to-code and math education programs will have higher spatial orientation scores than children in the reading group.

The Present Study

Using a pretest-posttest randomized experiment, the current study investigates whether participating in a 10-week coding education program (i.e., treatment of interest), compared to another 10-week math education program (i.e., another STEM-related comparison treatment), and a 10-week reading program (i.e., control), improves the computational thinking, fluid intelligence, and spatial orientation skills of elementary school children. As suggested by the meta-analysis of Scherer et al. (2019), we examine "near transfer" with computational thinking and "far transfer" with fluid intelligence and spatial orientation. As a summary, we address three primary expectations with the present study. First, because learning to code education program includes activities where children can learn computational thinking related components such as debugging or conditionals (Barr & Stephenson, 2011; Bers, Flannery, Kazakoff, & Sullivan, 2014; Duncan & Bell, 2015; Tran, 2018), it will enable children to practice computational thinking skills with a concrete object as compared to math or reading education programs (Lye & Koh, 2014). Therefore, we expect that children who are in the learn-to-code education program will have higher computational thinking scores at the post-test than children in math or reading groups. Second, learning to code can enhance fluid intelligence as it is related to creative problem solving (Mladenović, Krpan & Mladenović 2016). Thus, while children in all groups may have improvements in fluid intelligence over time, we expect that children in the learn-to-code education program will have higher fluid intelligence scores at the post-test compared to children in math or reading groups. Third, children in both learn-to-code and mathematics education programs practice spatial reasoning. Therefore, we expect children who attend the learn-to-code and math education programs will have higher spatial orientation scores than children in the reading group.

Method

Participants and design

Our participants were socioeconomically disadvantaged children who attended a 10-week structured educational program (i.e., coding, math, and reading) offered by a well-established education NGO (Turkish Educational Volunteers Foundation, TEGV) in Turkey. We conducted the current study with fourth-grade children. One main reason for choosing this age group is that our participants were Turkish, and in Turkey, as of 2018, learning to code was added to the mandatory school curriculum starting from the 5^{th} grade (T.C. Millî Eğitim Bakanlığı Bilgi İşlem Dairesi Başkanlığı ve İnternet Hizmetleri Daire Başkanlığı - Internet Services and Data Processing Departments of the Ministry of National Education of the Republic of Turkey, 2017). Data were collected from three TEGV locations in three cities, Istanbul, Eskisehir, and Sakarya. One hundred eighty-two children participated in our study. Two of them were excluded from the data because they were students with learning disabilities. Scores for four children were deleted from the dataset because they got zero scores at the post-test, even though they had higher scores in the pre-test, which led us to think that they did not read the questions during the post-test. We kept ourselves blind to the programs of the children during the exclusion decision. Two children were missing at either pre-test or post-test. The final sample consisted of 174 fourth-grade students (M_{age}=10.01, SD_{age}=.39). The study had a pretest-posttest experimental design. Children were randomly assigned to one of the three education program conditions. Fifty-eight students were in the learn-to-code condition (27 girls, M_{age}=10.10, SD_{age}=.44), 52 students were in the mathematics condition (23 girls, M_{age}=9.93, SD_{age}=.35), and 64 students were in the reading condition (31 girls, M_{age}=10.01, SD_{age}=.37).

Materials

Matrix reasoning task

To measure fluid intelligence, the matrix reasoning task from the Wechsler Abbreviated Scale of Intelligence Measurement was used (see Figure 1b for sample item). Matrix reasoning task materials were 32 cards; each had one incomplete matrix figure and five possible options for the missing piece. It consisted of 2 practice questions and 30 main questions. Each correct answer that the children gave counted as one point. Therefore, the highest point a child could get was thirty, and the lowest was zero. The questions were progressive, which means that they became more complicated as children progressed on the task. The task starts with the 4^{th} question. Each child should answer the fourth and fifth questions correctly. If they did not answer either of them correctly, the previous three questions were asked until the child had two consecutive correct answers. If there were no two consecutive correct answers in the first five questions, the task was ended. If children had two consecutive correct answers, then the task started; and it ended when the child made four consecutive errors. In each question, there was a figure consisting of a one-part missing pattern. There were four options below to fill the missing pattern. Children were asked to choose one of the four options to fill the missing pattern. The matrix reasoning task was administered by our research team, and answers were scored as correct or incorrect during the administration of the task. The internal reliability of the task in the current study was .8. The task lasted approximately 5 to 10 minutes; the time varied according to how many questions a child answered.

Computational thinking

The computational thinking scale was taken from Tran (2018) (see Figure 1a for sample item). There were ten items in total, measuring sequence, algorithm, loop, debug, and conditional. In sequence questions, children were asked to complete the shown maze using directions. Children needed to order the given mixed-up sequences for the algorithm questions. In the loop questions, children needed to answer the questions by understanding the repeating patterns. Debug questions required children to find the wrong step in a sequence. In the conditional questions, children should understand the “if” command and answer accordingly. The questions have one correct answer, and the graduate research assistant scored each question as 0 or 1. Therefore, the highest point a child could get was ten, and the lowest was zero. The internal reliability of the test with ten binary item scores was .6. The task was delivered in paper and pencil format and lasted approximately 15 minutes.

Spatial orientation scale

The spatial orientation scale was a subtest of the spatial reasoning task (Ramful et al., 2017) (see Figure 1c for sample item). In each question, children were shown a figure and were asked the following question related to that figure. The task was delivered in paper and pencil format. There were ten items. However, item 6 was deleted due to low reliability. Therefore, nine questions were included in the final analyses. Each correct answer was counted as one point. Therefore, possible scores ranged from 0 to 9. The internal reliability of the test with nine binary item scores was .5. This task lasted approximately 10 minutes.

Figure 1a

Sample item from the computational thinking scale.

7. Circle the wrong steps in the sequence.

- Wake up.
- Get dressed and eat breakfast.
- Drive to school.
- Put on your backpack for school.
- Get in the car.
- Walk into the classroom.

8. Rewrite the sequence from above to make it correct

____

_______________________________________.

Figure 1b

Sample item from the matrix reasoning task.

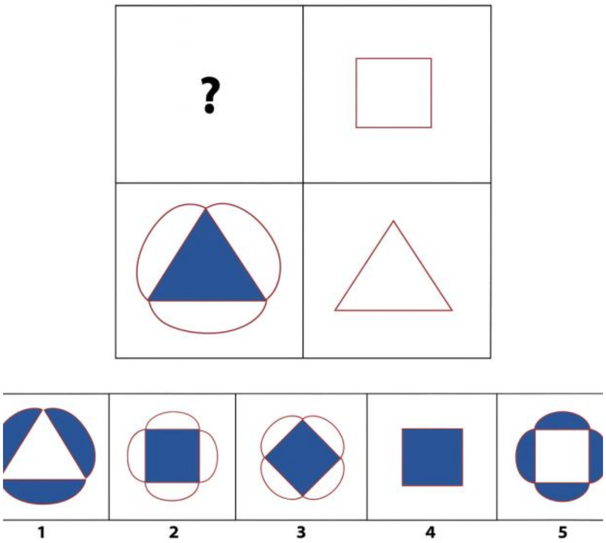
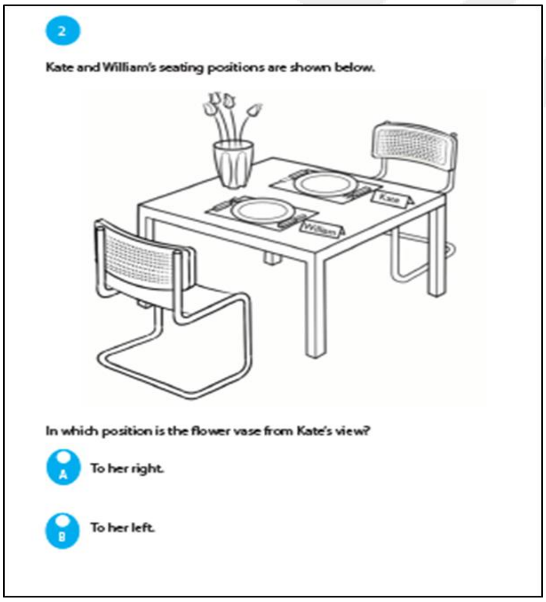


Figure 1c

Sample item from the spatial orientation test.



Procedure

After receiving ethical approval from the University Institutional Review Board, the current study was implemented in the above-mentioned NGO locations. Children were transported to NGO locations from their schools during their recess hours twice a week for one hour. They received 20 hours of intervention in total. In the first week, when children came to NGO locations, they were individually randomly assigned to one intervention condition. When, for example, 30 students from the same school arrived, they were randomly assigned to each condition. Children received the three interventions in different classrooms at the NGO location. Therefore, students in different conditions did not interact with each other during the intervention delivery. They have interacted in other times as some of them were classmates in their schools. However, diffusion of treatment is unlikely as children in the coding condition cannot deeply explain the coding activities to their peers without the coding platform or the game-based activities. Moreover, children would need guidance to successfully continue learning coding with those activities. We also asked the participants at both pre-and post-test whether that they have practiced coding in other settings. Children in both reading ($t(52) = -1.45$, $p = .15$) and math conditions ($t(44) = 1.00$, $p = .32$) did not have an increase in their practice of coding from pre-test to post-test.

The study had three different phases: pre-test, delivery of the education programs, and the post-test.

Pre-Test

Our research team administered the matrix reasoning test to each child separately during the first week of the program. The administrators who were experienced in data collection with children brought each child into a silent room and ran the task, and the child returned to the class upon the completion of the task. The first week of the education programs consisted of a general introduction. Students completed the computational thinking and spatial orientation scales independently in a paper and pencil format at the beginning of the second-week class.

Education Programs

Children were randomly assigned to one of the three education program conditions: a) Learn-to-code program, b) Reading program, and c) Math program. TEGV has already implemented education programs for several years. Therefore, the current study did not intend to design an education program. Instead, we aimed to evaluate their effects on several cognitive skills. Children came to TEGV locations to participate in the programs. During that time, each child only participated in his/her assigned education program. The courses were taught by volunteers who were extensively trained on the subject matter by the NGO. The topics that are covered were first explicitly taught by the volunteers to children. Then, children completed activities either by themselves or as a group depending on the content of the activity. The summaries for all three education programs are provided below.

Learn-to-code Program. In the first week**,** children received the introduction session for their assigned programs. In the following eight weeks, they learned about the logic behind coding and algorithms (see Table 1 for topics and learning goals). In the beginning, they learned these concepts by playing with Algo Digital, which is a coding platform that was designed by the TEGV team and funded by Google.org (https://algodijital.com/). In the following weeks, they learned more complex features of coding through Scratch (see Figures 2a-2c for example activities). Scratch is a coding language, which has drop and drag features and eliminates the writing of a complex syntax reported to be perceived as problematic (Resnick et al. 2009). Towards the end of the education program, children had developed their coding projects in Scratch.

Table 1

Topics and learning goals of the learn-to-code education program

Week	Topic	Learning Goals
1a	Introduction	A brief overview of the education program.
1b	Computer use	Learns the usage of computer peripherals such as the mouse and keyboard.
2a	Learning the term "algorithm"	Knows to reach a goal, there are steps to follow, and there may exist different solutions for the same problem. Learns the term algorithm and recognizes an algorithm should be written step by step.
2b	Code.org applications	Chooses necessary steps for the character to reach a goal. Understands where the character is going by

		looking at the algorithm steps. Lists the steps to reach the goal.
3a	Tower of Hanoi	Writes the algorithm for a specific goal.
3b	Introducing Algo Dijital learn to code software	Understands the Algo Dijital learn to code platform. Able to sequence the blocks to reach a goal.
4a	Introducing Scratch learn to code software	Knows seven functions within the Scratch interface. Knows how to personalize the background and the character.
4b	Event and motion blocks	Recognizes and uses the event and motion code blocks in Scratch.
5a	Loop	Understands that with the loop function, fewer blocks are needed to achieve the same goal.
5b	Loop	Uses repeat, loop, nested loop functions to reach a goal.
6a	Loop	Understands that with the loop function, fewer blocks are needed to achieve the same goal, using Algo Dijital.
6b	If and sensing blocks	Uses if and sensing blocks to reach the goal, in Scratch.
7a	Sound blocks	Uses sound blocks and chooses sound from the music library in Scratch.
7b	Writing code	Learns the importance of writing a code that can be easily understood by others.
8a	Application	Writes the code in steps to create a given picture. Creates the picture in Scratch.
8b	Troubleshooting	Fixes a coding sequence that has missing or wrong blocks in the sequence.
9a	General Recap	Recap of the previous 8-weeks.
9b	Project	Understands that the preparation of a coding sequence is necessary to create an animation in Scratch.
10a	Project	Coding project application in Scratch.
10b	Project	Coding project application in Scratch.

Figure 2a

Example activity from Code.org that was used in learn-to-code education program: Troubleshooting to fix the code sequence.

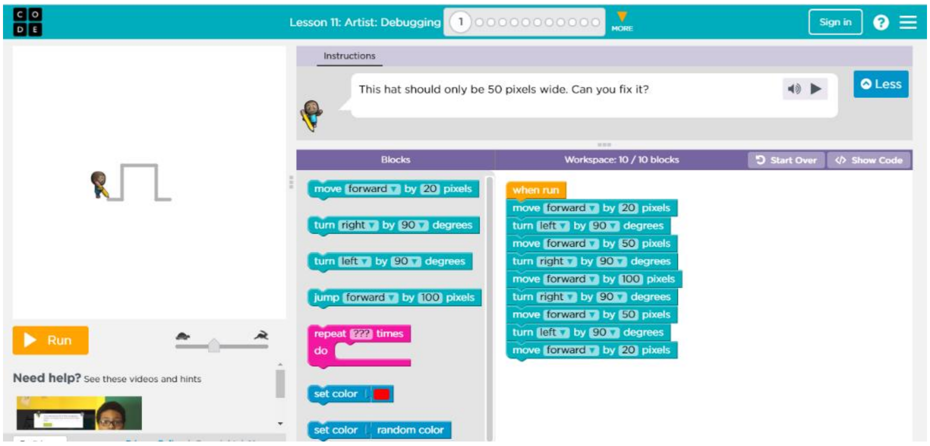


Figure 2b

Example activity from Algo Dijital that was used in learn-to-code education program: Multiple solutions are present to achieve the same goal.

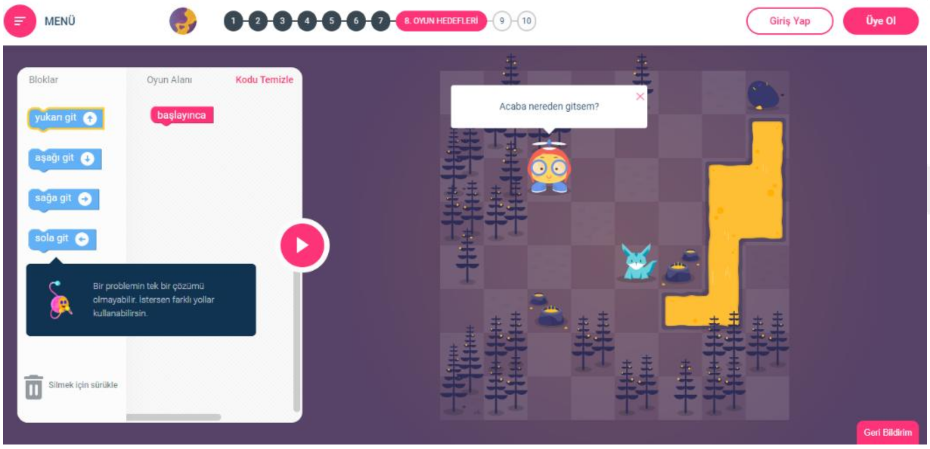
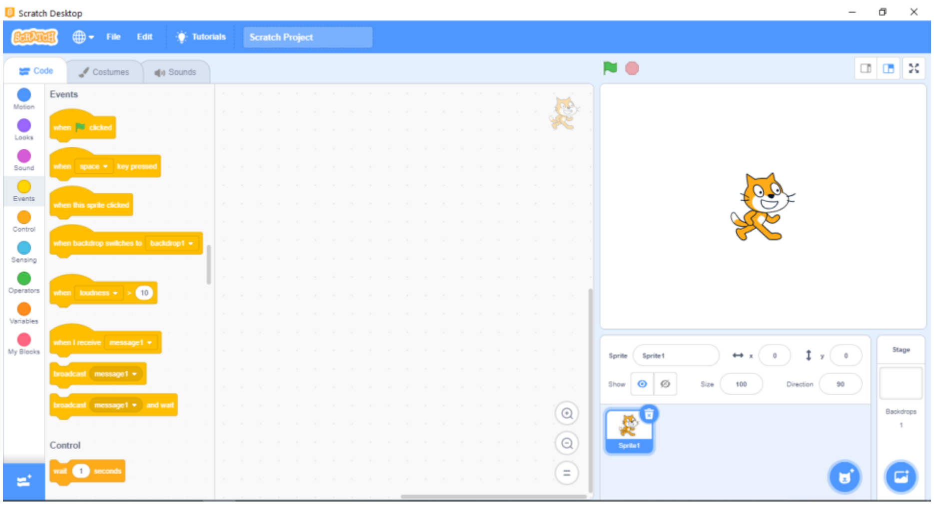


Figure 2c

Example activity from Scratch that was used in learn-to-code education program: Event blocks to sense events and trigger scripts.



Math Program. Children first participated in an introduction session. Then, each week, children learned different math topics: four operations, fractions, angles, shapes, circumference and area of shapes, patterns, symmetry, measuring units, charts, and tables in a play and learn format. TEGV chose these games and topics in light of the national school curriculum. For example, in the second week, children learned simple calculations with a game called "shopping." Children pretended that they were shopping and did some calculations while shopping.

Reading Program. Children in this program also participated in an introduction session for their program in their first week. Each week had a different theme developed following the assigned reading of the week. Children first played a game referring to that theme, then they looked at some pictures and prepared role-playing that was inspired by the picture. Later, the teacher read the assigned reading of the week to the children and asked them to find the similarities between the pictures and the reading. Finally, each child drew a picture that was inspired by the reading. Moreover, each child commented on his/her friends' drawings.

Post Test

During the last two weeks of the education programs, children completed the same assessment materials they completed at the pre-test, using the same procedures.

Results

Outcomes at baseline

One-way analysis of variance (ANOVA) results showed that groups were balanced at baseline in their computational thinking, matrix reasoning, and spatial orientation scores ($F(2,162)=.148$, $p = .86$, $\eta^2 =.006$; $F(2,171)=.529$, $p = .59$, $\eta^2=.004$; $F(2,160)=.373$, $p = .69$,

η^2=.005, respectively). Correlations between study variables are presented in Table 1, indicating that all outcomes were significantly correlated with each other.

Table 2

Correlations among the variables

Measures	*N*	*M*	*SD*	*1*	*2*	*3*	*4*	*5*
1. Computational Thinking Pre-test	165	3.16	1.62					
2. Fluid Intelligence Pre-test	174	12.01	4.62	.376**				
3. Spatial Orientation Pre-test	163	3.74	1.66	.161*	.204**			
4. Computational Thinking Post-test	153	3.41	1.93	.485**	.389**	.202*		
5. Fluid Intelligence Post-test	156	13.88	4.76	.349**	.653**	.271**	.417**	
6. Spatial Orientation Post-test	151	4.02	1.86	.223**	.289**	.358**	.372**	.261**

*p<.05, **p<.01, ***p<.001

Main analyses

Computational thinking

Levene's test for computational thinking measure indicated that the homogeneity of variance assumption was not violated in both the pre-test and post-test, ($F(2, 143)=.262$, $p=.77$, $F(2,143)=1.224$, $p=.30$, respectively). Mixed ANOVA results showed that there was a significant interaction between time and group status in predicting children's computational thinking scores, $F(2,143) = 3.24$, $p = .04$, $\eta_p^2=.04$. Children in the coding condition had significantly higher scores at post-test (M=3.67, SD=2.14) compared to pre-test (M=3.08, SD=1.71), p=.04, d=.29 (Figure 3). Similarly, children in the math condition had higher scores at post-test (M=3.56, SD=1.84) compared to pre-test (M=3.11, SD=1.58), but the difference was not significant, p=.10, d=.26. Children in the reading condition did not have significantly higher scores at post-test (*M*=3.26, *SD*=1.64) compared to pre-test (*M*=3.00, *SD*=1.77), *p*=.26, *d*=.15. There were no main effects of time, $F(1,143) = 2.91$, $p = .09$, η_p^2=.02. and group status on computational thinking scores, $F(2,143) = .36$, $p = .70$, η_p^2=.005.

Fluid Intelligence

Levene's test indicated that the homogeneity of variance assumption was not violated in both the pre-test and post-test, ($F(2, 153)$=2.226, *p*=.11, $F(2,153)$=.062, *p*=.94, respectively). There was no interaction between time and condition in predicting children's matrix reasoning scores, $F(2,153) = .47$, $p = .63$, η_p^2=.006. However, there was a main effect of time on fluid intelligence, $F\ (1.153) = 33.16$, $p < .001$, η_p^2=.18. As shown in Figure 4, in all conditions, children's scores significantly increased from pre-test to post-test (p<.05) for all groups). Children in the coding condition had significantly higher scores at post-test (*M*=13.74, *SD*=4.91) compared to pre-test (*M*=11.52, *SD*=4.17), p<.001, *d*=.49. Children in the math condition had significantly higher scores at post-test (*M*=13.50, *SD*=4.79) compared to pre-test) (*M*=11.79, *SD*=5.34), p<.001, *d*=.33. Children in reading condition had significantly higher scores at post-test (*M*=14.31, *SD*=4.65) compared to pre-test (*M*=12.81, *SD*=4.23), *p*=002, *d*=.34. There was no main effect of group status, $F(2,153) = .86$, $p = .43$, η_p^2=.01.

Spatial Orientation

Levene's test indicated that the homogeneity of variance assumption was not violated in both the pre-test and post-test ($F(2, 139)$=.121, *p*=.87, $F(2,139)$=.919, *p*=.40, respectively). There was no interaction between time and group status in predicting children's spatial orientation scores, $F(2,139) = .550$, $p = .58$, η_p^2=.008. (Figure 5). There was no main effect of time, $F(1.139) = 3.56$, $p = .06$, η_p^2=.03. There was no main effect of group status on spatial orientation scores, $F(2,139) = 1.42$, $p = .25$, η_p^2=.02. Children in the coding condition did not have significantly higher scores at post-test (*M*=3.66, *SD*=1.98) compared to pre-test (*M*=3.60, *SD*=1.57), *p*=.83, *d*=.034 (Figure 5). Children in the math condition did not have significantly higher scores at post-test (*M*=4.02, *SD*=1.72) compared to pre-test (*M*=3.54, *SD*=1.55), *p*=.16, *d*=.29 (see Figure 5.). Children in reading condition did not have significantly higher scores at post-test (*M*=4.32, *SD*=1.91) compared to pre-test (*M*=3.90, *SD*=1.78), *p*=.09, *d*=.23 (see Figure 5.).

Figure 3

Computational thinking scores for each group at pre-test and post-test.

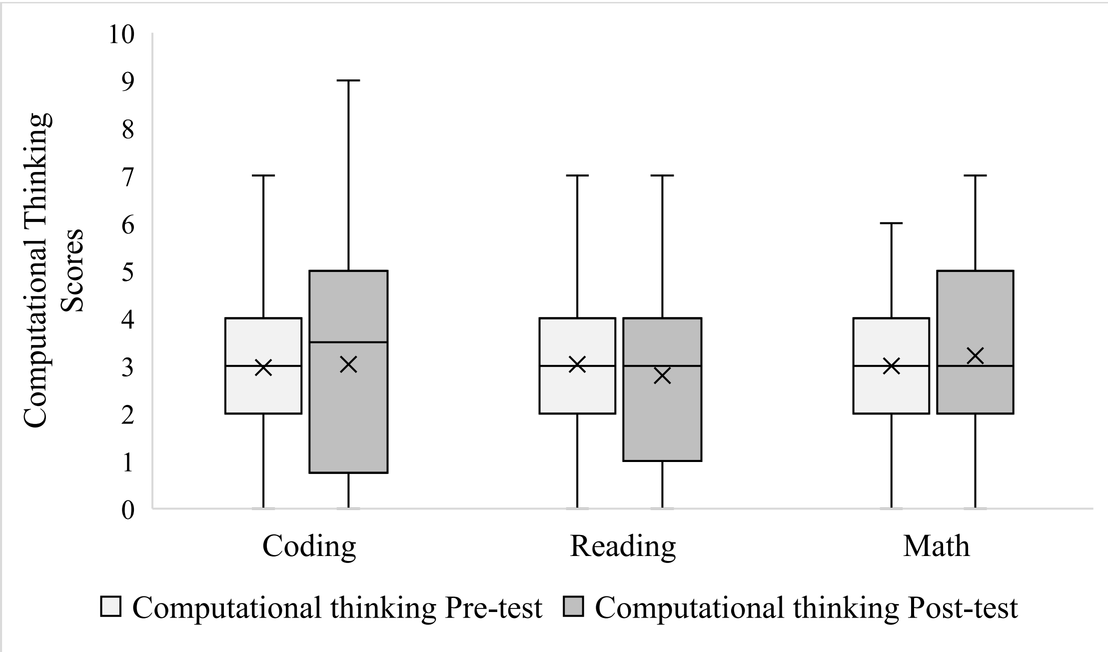


Figure 4

Fluid intelligence scores for each group at pre-test and post-test.

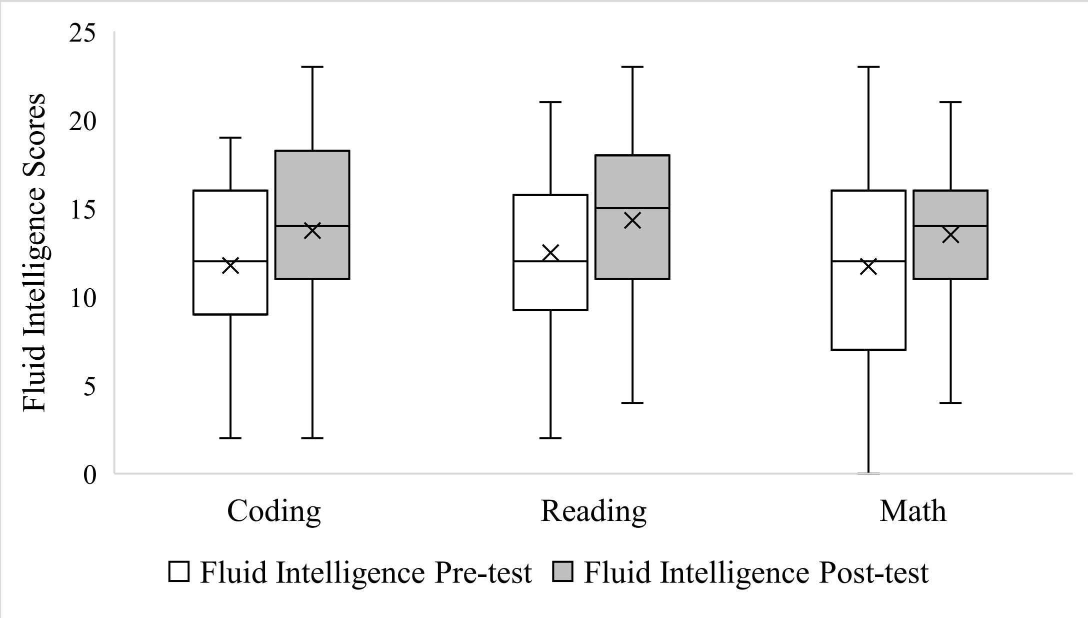
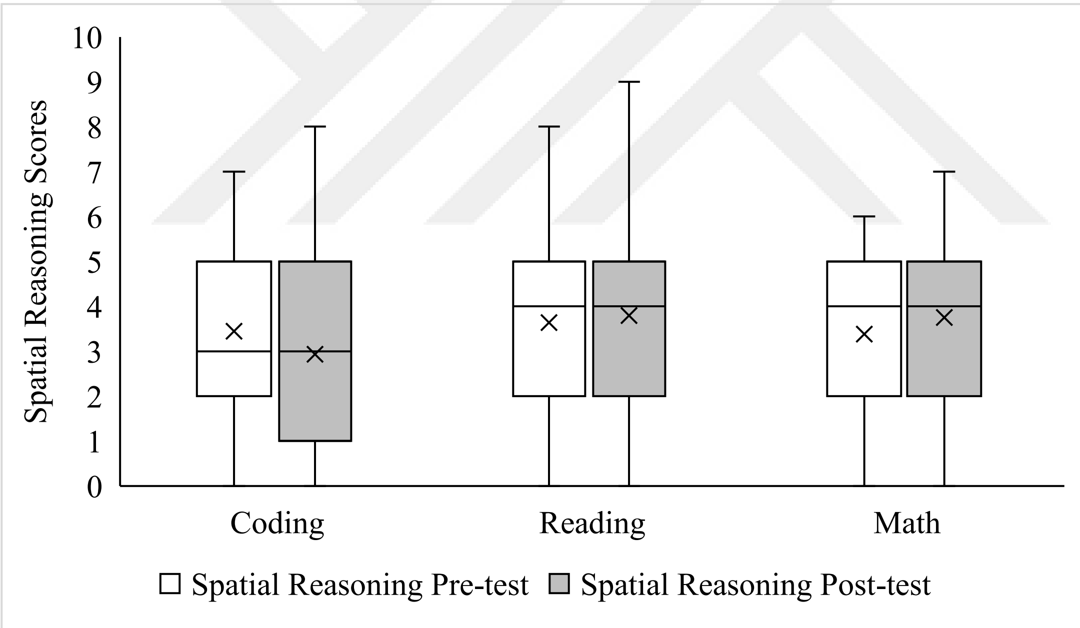


Figure 5

Spatial orientation scores for each group at pre-test and post-test.



Discussion

The present study examines the effects of learning to code on different cognitive skills of elementary school-aged children. We found that only the learn-to-code education program significantly increased computational thinking scores from pre-test to post-test compared to the control group. Fluid intelligence significantly improved from pre-test to post-test in all groups. Spatial orientation scores of children did not significantly increase in any of the groups. We showed the "near transfer" (computational thinking), but we did not find the "far transfer" (fluid intelligence and spatial orientation) effect of the learn to code intervention. In the following sections, we separately discuss the results for each outcome variable.

Several researchers suggested that learning to code improves the computational thinking skills of children (e.g., Bers, Flannery, Kazakoff, & Sullivan, 2014; Brennan & Resnick, 2012; Duncan & Bell, 2015; Lye & Koh 2014; Tran, 2018). The current randomized study provided empirical causal evidence for this effect. As demonstrated in many examples in developmental psychology (e.g., spatial learning; Lowrie, Logan, & Ramful, 2017; Sorby et al., 2013, perspective-taking: Mori & Cigala, 2019), findings from studies showing the effects of specific trainings on specific outcomes like in the current study are very valuable. The question is whether children transfer the skills they learn in training to other situations that require similar skills. This idea is in line with the near transfer effects in Scherer et al. (2019). Authors defined near transfer effects as transferring skills learned in a specific setting to contexts that require similar skills and strategies. As suggested, measuring near effects with tasks that do not share similar surface features with the training provides information on gains in targeted variables rather than practice effects (e.g., Alloway, Bibile, & Lau, 2013; Bergman Nutley et al. 2011). For example, in our study, children trained on computers using a programming software with game features and tested with paper and pencil format questions that were different in terms of the surface features such as presentation of the questions. Our results confirm a near transfer effect of learning to code on computational thinking. Improving computational thinking can help other areas outside of computer sciences (Barr, Harrison, & Conery, 2011; Wing, 2006). We also showed that even though some cognitive skills may develop as a function of time, coding education can improve computational thinking over and above the normal function of time. Yet, the effect size was small. Therefore, more studies are needed to see which components of coding education may yield larger effects. Children in the math program condition also showed improvement in their computational thinking scores from pre- to post-test, but this increase was not statistically significant. However, the effect sizes of the coding and math groups were similar. This can be explained by the fact that coding and mathematics share similar underlying mechanisms where children need to break down the problem into smaller parts, look at the relationship between those steps, and solve step by step by using an algorithm (Barr & Stephenson, 2011; Wing, 2006). Therefore, children in the math program might practice breaking down problems, abstraction, and developing algorithms, which lead to an improvement in their computational thinking.

Regarding fluid intelligence, we hypothesized that although there can be an improvement for every group over time, the enhancement will be more pronounced for the learn-to-code group. However, the results showed that fluid intelligence scores similarly improved in all the conditions. This result was contradictory to the existing findings in the literature. Not finding the expected results might be due to a practice effect. Fluid intelligence was measured with a face-to-face task. Children in our study came from disadvantaged neighborhoods. Likely, they were not familiar with face to face tasks, and at the post-test, they all scored higher on the task due to a possible practice effect. Another alternative explanation is that even though fluid intelligence seems to be related to creative thinking and problem-solving (Herrnstein, Nickerson, de Snchez & Swets, 1986; Klauer, Willmes & Phye, 2002; Stankov, 1986), all the programs children took designed for teaching children the topics in a creative way. Therefore, these programs may provide room for thinking creatively, and the beneficial effects on fluid intelligence were not necessarily specific to coding.

Although children practice spatial reasoning skills while coding in Scratch, we did not find any significant improvement in students' spatial orientation skills in any of the conditions. We chose a spatial orientation subtest to measure the spatial reasoning ability since a previous pilot pretest-posttest study conducted with a similar sample showed the most improvement and variance in this subtest. Previous research mostly focused on younger children's spatial development using mental rotation tasks (e.g., De Lisi & Wolford, 2002; Ehrlich, Levine & Goldin-Meadow, 2006). Thus, we know less about the details on improving spatial orientation. First, spatial orientation may be difficult to improve in only ten weeks. Children at this age particularly may need more prolonged and more frequent STEM-related training to enhance their spatial orientation skills. Moreover, in this task, we assumed that children knew the spatial concepts of left-right. However, we did not explicitly test their knowledge. Although only three out of ten trials require the knowledge of left-right concepts, future research should assess children's broader knowledge of spatial relations for spatial orientation.

It is also possible that other spatial skills, such as mental rotation, can be more malleable than spatial orientation. Second, to improve spatial reasoning, one may need to tap into spatial skills directly. Previous studies usually aimed to improve spatial reasoning and assess its consequences on mathematics or other STEM topics (e.g., Cheng & Mix, 2014; Lowrie, Logan & Ramful, 2017). Therefore, we do not have much information regarding indirectly improving spatial reasoning with training such as coding. Last, spatial reasoning tasks are usually administered face-to-face in a silent room (e.g., Ehrlich, Levine & Goldin-Meadow, 2006; Klein, Adi-Japha, & Hakak-Benizri, 2010). In our study, we were not able to provide those conditions due to time limits. Also, we could not provide different subtests of spatial reasoning like mental rotation, as children could experience a fatigue effect. Therefore, the reason for not finding the expected results might be due to the measurement choice.

Limitations and Future Implications

Even though our study is one of the first comprehensive attempts to assess how learning to code results in changes in several cognitive outcomes, we have a few limitations that need to be considered. First, the sample only consists of children who are coming from disadvantaged neighborhoods. Our results might not be generalizable to children living in more nourished environments with technological devices available. Future studies should investigate the effects of learning programming on children's cognitive skills with diverse socioeconomic status backgrounds. This would allow considering the moderating effect of previous experience with technology and coding on the links between learning to code and cognitive skills. Second, the programs in our study lasted for ten weeks. However, cognitive abilities such as spatial orientation might not be enhanced only in ten weeks. Future studies investigating more extended education programs might reveal improvements in those cognitive skills. Moreover, future studies on cognitive skills that could be improved in shorter periods are needed to expand our understanding of the effects of learning to code. Finally, we found improvement (although not significant) in computational thinking for the math condition as well, which might happen because children also practiced computational thinking during the math program. Future studies should investigate deeper how math education may also affect computational thinking and how coding education contributes to the development of computational skills beyond math training.

Conclusions

The current study is one of the first randomized studies where the effect of learning to code on multiple cognitive skills of elementary school children was examined. Results demonstrated that a coding education program significantly increased computational thinking scores but not fluid intelligence or spatial orientation scores, as compared to a control condition. With our current results, it seems that the skills that are learned in coding education are better transferable to "near transfer skills" than to "far transfer skills" (Scherer, Siddiq, & Viveros, 2019), such as spatial reasoning. However, our null findings might be due to other factors such as not having experience with face-to-face tasks or investigating a cognitive skill that is difficult to change in ten weeks. Therefore, future randomized studies are needed to examine the transferability of coding education to other cognitive skills. As presented in this study, many possible research questions are worth pursuing to expand our understanding of the effects of learning to code on children's lives.

References

Akcaoglu, M., & Koehler, M. J. (2014). Cognitive outcomes from the Game-Design and Learning (GDL) after-school program. *Computers & Education, 75,* 72-81. doi: 10.1016/j.compedu.2014.02.003

Alloway, T. P., Bibile, V., & Lau, G. (2013). Computerized working memory training: Can it lead to gains in cognitive skills in students?. *Computers in Human Behavior*, *29*, 632-638.doi: 10.1016/j.chb.2012.10.023

Arfé, B., Vardanega, T., Montuori, C., & Lavanga, M. (2019). Coding in primary grades boosts children's executive functions. *Frontiers in Psychology*, *10*. doi: 10.3389/fpsyg.2019.02713

Barr, D., Harrison, J., & Conery, L. (2011). Computational thinking: A digital age skill for everyone. *Learning & Leading with Technology*, *38*, 20-23.

Barr, V., & Stephenson, C. (2011). Bringing computational thinking to K-12: What is involved and what is the role of the computer science education community?. *Acm Inroads*, *2*, 48-54.doi: 10.1145/1929887.1929905

Battista, M. T., & Clements, D. H. (1986). The effects of Logo and CAI problem-solving environments on problem-solving abilities and mathematics achievement. *Computers in Human Behavior*, *2*, 183-193.doi: 10.1016/0747-5632(86)90002-6

Benbow, C., & Stanley, J. (1982). Intellectually talented boys and girls: Educational profiles. *Gifted Child Quarterly, 26*, 82-88.doi: 10.3102/00028312019004598

Bergman Nutley, S., Söderqvist, S., Bryde, S., Thorell, L. B., Humphreys, K., & Klingberg, T. (2011). Gains in fluid intelligence after training non-verbal reasoning in 4-year-old children: A controlled, randomized study. *Developmental science*, *14*, 591-601.doi: 10.1111/j.1467-7687.2010.01022.x

Bers, M. U. & Horn, M. S. (2010). Tangible programming in early childhood: Revisiting developmental assumptions through new technologies. In I. R. Berson, & M. J. Berson (Eds.), *High-Tech Tots: Childhood in a Digital World*, 49–70.

Bers, M. U., Flannery, L., Kazakoff, E. R., & Sullivan, A. (2014). Computational thinking and tinkering: Exploration of an early childhood robotics curriculum. *Computers & Education*, *72*, 145-157.doi: 10.1016/j.compedu.2013.10.020

Blume, G. W., & Schoen, H. L. (1988). Mathematical problem-solving performance of eighth-grade programmers and nonprogrammers. *Journal for Research in Mathematics Education*, *19,* 142-156.doi: 10.2307/749408

Brennan, K., & Resnick, M. (2012). New frameworks for studying and assessing the development of computational thinking. In *Proceedings of the 2012 annual meeting of the American Educational Research Association, Vancouver, Canada,1*,1-25.

Carpenter, P. A., Just, M. A., & Shell, P. (1990). What one intelligence test measures: A theoretical account of the processing in the raven progressive matrices test. *Psychological Review*, *97*, 404-431.doi: 10.1037/0033-295X.97.3.404

Cheng, Y. L., & Mix, K. S. (2014). Spatial training improves children's mathematics ability. *Journal of Cognition and Development*, *15*, 2-11.doi: 10.1080/15248372.2012.725186

Clements, D. H. (1986). Effects of Logo and CAI environments on cognition and creativity. *Journal of Educational Psychology*, *78*, 309-318.doi: 10.1037/0022-0663.78.4.309

Common Sense Media. (2013). Zero to eight: Children's media use in America 2013.

Copple, C. & Bredekamp, S. (2009). Developmentally appropriate practice in early childhood programs: serving children from birth through age 8 (3rd ed.). National Association for the Education of Young Children.

Deary, I. J., Strand, S., Smith, P., & Fernandes, C. (2007). Intelligence and educational achievement. *Intelligence*, *35*, 13-21.doi: 10.1016/j.intell.2006.02.001

De Lisi, R., & Wolford, J. L. (2002). Improving children's mental rotation accuracy with computer game playing. *The Journal of Genetic Psychology*, *163*, 272-282. doi: 10.1080/00221320209598683

Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, *64*, 135-168. doi: 10.1146/annurev-psych-113011-143750

Duncan, C., & Bell, T. (2015). A pilot computer science and programming course for primary school students. In *Proceedings of the Workshop in Primary and Secondary Computing Education*, 39-48.doi: 10.1145/2818314.2818328

Duncan, C., Bell, T., & Tanimoto, S. (2014). Should your 8-year-old learn coding?. In *Proceedings of the 9th Workshop in Primary and Secondary Computing Education*, 60-69.doi: 10.1145/2670757.2670774

Durak, H. Y., & Saritepeci, M. (2018). Analysis of the relation between computational thinking skills and various variables with the structural equation model. *Computers & Education*, *116*, 191-202.doi: 10.1016/j.compedu.2017.09.004

Ehrlich, S. B., Levine, S. C., & Goldin-Meadow, S. (2006). The importance of gesture in children's spatial reasoning. *Developmental Psychology*, *42*, 1259-1268.doi: 10.1037/0012-1649.42.6.1259

Fessakis, G., Gouli, E., & Mavroudi, E. (2013). Problem solving by 5–6 years old kindergarten children in a computer programming environment: A case study. *Computers & Education*, *63*, 87-97.doi: 10.1016/j.compedu.2012.11.016

Francis, K., Khan, S., & Davis, B. (2016). Enactivism, spatial reasoning and coding. *Digital Experiences in Mathematics Education*, *2*, 1-20.doi: 10.1007/s40751-015-0010-4

Gilligan, K. A., Flouri, E., & Farran, E. K. (2017). The contribution of spatial ability to mathematics achievement in middle childhood. *Journal of experimental child psychology*, *163*, 107-125.doi: 10.1016/j.jecp.2017.04.016

Hegarty, M., Keehner, M., Cohen, C., Montello, D. R., & Lippa, Y. (2007). The role of spatial cognition in medicine: Applications for selecting and training professionals. In G. Allen (Ed.), *Applied Spatial Cognition*. Mahwah, NJ: Lawrence Erlbaum Associates.

Herrnstein, R.J., Nickerson, R.S., de Snchez, M., & Swets, J.A. (1986). Teaching thinking skills. *American Psychologist, 41*, 1279–1289.doi: 10.1037/0003-066X.52.10.1125

Horn, J. L., Donaldson, G., & Engstrom, R. (1981). Apprehension, memory, and fluid intelligence decline in adulthood. Research on Aging, 3, 33-84.doi:10.1177/016402758131002

Kafai, Y. and Burke, Q. (2013) "Computer programming goes back to school". *Phi Delta Kappan, 95*, 61–65.doi: 10.1177/003172171309500111

Kalelioğlu, F. (2015). A new way of teaching programming skills to K-12 students: Code. org. *Computers in Human Behavior*, *52*, 200-210.doi: 10.1016/j.chb.2015.05.047

Kalelioglu, F., & Gülbahar, Y. (2014). The effects of teaching programming via Scratch on problem solving skills: A discussion from learners' perspective. *Informatics in Education*, 13, 33-50.

Kapa, E. (1999). Problem solving, planning ability and sharing processes with LOGO. *Journal of Computer Assisted Learning*, *15*, 73-84.doi: 10.1046/j.1365-2729.1999.151077.x

Kelleher, C., & Pausch, R. (2005). Lowering the barriers to programming: A taxonomy of programming environments and languages for novice programmers. *ACM Computing Surveys*, *37*, 83-137.doi: 10.1145/1089733.1089734

Klauer, K. J., Willmes, K., & Phye, G. D. (2002). Inducing inductive reasoning: does it transfer to fluid intelligence?. *Contemporary Educational Psychology*, *27*, 1-25.doi: 10.1006/ceps.2001.1079

Klein, P. S., Adi-Japha, E., & Hakak-Benizri, S. (2010). Mathematical thinking of kindergarten boys and girls: Similar achievement, different contributing processes. *Educational Studies in Mathematics*, *73*, 233-246. doi: 10.1007/s10649-009-9216-y

Lai, A. F., & Yang, S. M. (2011). The learning effect of visualized programming learning on 6 th graders' problem solving and logical reasoning abilities. In *2011 International Conference on Electrical and Control Engineering*, 6940-6944. doi: 10.1109/ICECENG.2011.6056908

Langdon, D., McKittrick, G., Beede, D., Khan, B., & Doms, M. (2011, July). STEM: Good Jobs Now and for the Future. Washington, DC: U.S. Department of Commerce, Economics and Statistics Administration. Retrieved from http://www.esa.doc.gov/sites/default/files/news/documents/stemfinalyjuly14.pdf

Liao, Y. K. C., & Bright, G. W. (1991). Effects of computer programming on cognitive outcomes: A meta-analysis. *Journal of Educational Computing Research*, *7*, 251-268.doi: 10.2190/E53G-HH8K-AJRR-K69M

Lowrie, T., Logan, T., & Ramful, A. (2017). Visuospatial training improves elementary students' mathematics performance. *British Journal of Educational Psychology*, *87*, 170-186.doi: 10.1111/bjep.12142

Lye, S. Y., & Koh, J. H. L. (2014). Review on teaching and learning of computational thinking through programming: What is next for K-12?. *Computers in Human Behavior*, *41*, 51-61.doi: 10.1016/j.chb.2014.09.012

Lynn, R., Meisenberg, G., Mikk, J., & Williams, A. (2007). National IQs predict differences in scholastic achievement in 67 countries. *Journal of Biosocial Science*, *39*, 861-874.doi: 10.1017/S0021932007001964

Miller, R. B., Kelly, G. N., & Kelly, J. T. (1988). Effects of Logo computer programming experience on problem solving and spatial relations ability. *Contemporary Educational Psychology, 13,* 348–357. doi: 10.1016/0361-476X(88)90034-3

Mladenović, M., Krpan, D., & Mladenović, S. (2016). Introducing programming to elementary students novices by using game development in python and scratch. In *International Conference on Education and New Learning Technologies*, 1622-1629.

Moreno-León, J., & Robles, G. (2016). Code to learn with Scratch? A systematic literature review. In *2016 IEEE Global Engineering Education Conference (EDUCON)* (pp. 150-156). IEEE.

Mori, A., & Cigala, A. (2019). 'Putting oneself in someone else's shoes during childhood: How to learn it'Training for preschool age children. *British Journal of Educational Psychology*, *89*, 750-766.doi: 10.1111/bjep.12255

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. New York, NY: Basic Books.

Pea, R. D., & Kurland, D. M. (1984). On the cognitive effects of learning computer programming. *New ideas in psychology*, *2*, 137-168.doi: 10.1016/0732-118X(84)90018-7

Popat, S., & Starkey, L. (2019). Learning to code or coding to learn? A systematic review. *Computers & Education*, *128*, 365-376.doi: 10.1016/j.compedu.2018.10.005

Psycharis, S., & Kallia, M. (2017). The effects of computer programming on high school students' reasoning skills and mathematical self-efficacy and problem solving. *Instructional Science*, *45*, 583-602.doi: 10.1007/s11251-017-9421-5

Ramful, A., Lowrie, T., & Logan, T. (2017). Measurement of spatial ability: Construction and validation of the spatial reasoning instrument for middle school students. *Journal of Psychoeducational Assessment, 35*, 709–727. doi:10.1177/0734282916659207

Resnick, M., Maloney, J., Monroy-Hernández, A., Rusk, N., Eastmond, E., Brennan, K., ... & Kafai, Y. (2009). Scratch: programming for all. *Communications of the ACM*, *52*, 60-67.doi: 10.1145/1592761.1592779

Scherer, R. (2016). Learning from the past–The need for empirical evidence on the transfer effects of computer programming skills. *Frontiers in Psychology*, *7*, 1390-1393.doi: 10.3389/fpsyg.2016.01390

Scherer, R., Siddiq, F., & Sánchez Viveros, B. (2019). The cognitive benefits of learning computer programming: A meta-analysis of transfer effects. *Journal of Educational Psychology*, *111*(5), 764.doi: 10.1037/edu0000314

Schroeders, U., Schipolowski, S., & Wilhelm, O. (2015). Age-related changes in the mean and covariance structure of fluid and crystallized intelligence in childhood and adolescence. Intelligence, 48, 15-29.doi:10.1016/j.intell.2014.10.006

Siegle, D. (2017). Technology: Encouraging creativity and problem solving through coding. *Gifted Child Today*, *40*, 117-123.doi: /10.1177/1076217517690861

Shaw, D. G. (1986). Effects of learning to program a computer in BASIC or Logo on problem-solving abilities. *AEDS Journal*, *19*, 176-189. doi: 10.1080/00011037.1986.11008422

Shea, D. L., Lubinski, D., & Benbow, C. P. (2001). Importance of assessing spatial ability in intellectually talented young adolescents: A 20-year longitudinal study. *Journal of*

Educational Psychology, *93*, 604.doi: 10.1037/0022-0663.93.3.604

Sorby, S., Casey, B., Veurink, N., & Dulaney, A. (2013). The role of spatial training in improving spatial and calculus performance in engineering students. *Learning and Individual Differences*, *26*, 20-29.doi: 10.1016/j.lindif.2013.03.010

Stankov, L. (1986). Kvashchev's experiment: can we boost intelligence? *Intelligence, 10*, 209–230. doi: 10.1016/0160-2896(86)90016-4

Sturman, L., and Sizmur, J. (2011). International Comparison of Computing in Schools. *Slough: National Foundation for Educational Research*.

Tran, Y. (2018). Computational thinking equity in elementary classrooms: What third-grade students know and can do. *Journal of Educational Computing Research,* 57. 3-31. doi: 10.1177/0735633117743918

T.C. Millî Eğitim Bakanlığı Bilgi İşlem Dairesi Başkanlığı ve İnternet Hizmetleri Daire Başkanlığı (Information Technology and Internet Services Department of Ministry of National Education of the Republic of Turkey). (2017, October 5). "Kodlama" dersinin eğitim materyalleri hazır (The materials for coding course are ready). Retrieved from https://meb.gov.tr/quotkodlamaquot-dersinin-egitim-materyalleri-hazir/haber/14659/tr.

Uttal, D. H., & Cohen, C. A. (2012). Spatial thinking and STEM education: When, why, and how?. In *Psychology of learning and motivation*, 57, 147-181. doi: 10.1016/B978-0-12-394293-7.00004-2

Uttal, D. H., Miller, D. I., & Newcombe, N. S. (2013). Exploring and enhancing spatial thinking: Links to achievement in science, technology, engineering, and mathematics?. *Current Directions in Psychological Science*, *22*, 367-373.doi: 10.1177/0963721413484756

Wai, J., Lubinski, D., & Benbow, C. P. (2009). Spatial ability for STEM domains: Aligning over 50 years of cumulative psychological knowledge solidifies its importance. *Journal of Educational Psychology*, *101*, 817-835. doi: 10.1037/a0016127

Webb, D. C. (2010). Troubleshooting assessment: An authentic problem solving activity for it education. *Procedia-Social and Behavioral Sciences*, *9*, 903-907.doi: 10.1016/j.sbspro.2010.12.256

Webb, M., Davis, N., Bell, T., Katz, Y. J., Reynolds, N., Chambers, D. P., et al. (2016). Computer science in K-12 school curricula of the 2lst century: Why, what and when? *Education and Information Technologies, 22,* 445-468. doi: 10.1007/s10639-016-9493-x

Wechsler, D. (2011). Wechsler Abbreviated Scale of Intelligence–Second Edition (WASI-II). San Antonio, TX: NCS Pearson.

Werner, L., Denner, J., Campe, S., & Kawamoto, D. C. (2012). The fairy performance assessment: measuring computational thinking in middle school. *In Proceedings of the 43rd ACM technical symposium on Computer Science Education*, 215-220.

Wing, J. M. (2006). Computational thinking. *Communications of the ACM*, *49*, 33-35.doi: 10.1145/1118178.1118215

Wolfgang, C., Stannard, L., & Jones, I. (2003). Advanced constructional play with LEGOs among preschoolers as a predictor of later school achievement in mathematics. *Early Child Development and Care*, *173*, 467-475.doi: 10.1080/0300443032000088212

CHAPTER 6

General Discussion

This dissertation investigated the role of children's interaction with digital technologies, both as consumers and producers, in relation to the development of executive functions (EFs). Grounded in the Dynamic, Relational, Ecological Approach to Media Effects Research (DREAMER; Barr et al., 2024), the four empirical studies presented here offer a comprehensive and theoretically informed examination of how technology-related experiences influence EF development. This chapter synthesizes the findings across these studies, discusses their theoretical implications, evaluates the strengths and limitations of the research, and outlines recommendations for future research and practice.

Theoretical Integration: Applying the DREAMER Framework

The DREAMER framework posits that the developmental impact of media is shaped not by screen time alone, but through the interaction of content, context, and relational processes. Although not every study in this dissertation explicitly operationalized all three components, the framework served as a guiding lens throughout the research.

Chapter Two, a meta-analysis of 30 studies, demonstrated that the relationship between media use and EF in early childhood is moderated by both the type and duration of exposure. Specifically, low-duration interactive media use was positively associated with EF, while high-duration receptive media use was negatively associated. These findings emphasize the importance of moving beyond aggregate screen time metrics and align closely with DREAMER's emphasis on media type and intensity.

Chapter Three extended these findings through an empirical study with preschool-aged children, examining media type alongside contextual moderators such as educational quality and parental mediation, as well as potential mediators including sustained attention and the displacement of activities. Results indicated that playing digital games was positively associated with EF, whereas watching videos was not significantly related. Mediation analyses showed no significant indirect effects, suggesting that sustained attention and activity displacement did not account for the observed associations. Of the tested moderators, only child temperament, specifically negative affectivity, was significant, revealing nuanced interaction patterns for both media types. This study closely aligned with DREAMER's focus on context and relational processes, reinforcing the model's relevance to early childhood media use.

Chapter Four shifted the focus to the producer role through a systematic review of programming education studies. Across 18 studies, programming interventions were generally associated with improvements in higher-order EF skills such as planning, reasoning, and problem-solving. However, methodological limitations, including the limited use of randomized trials and variation in intervention designs, posed challenges for drawing conclusions. While relatively few studies explicitly addressed relational components, elements such as instructional scaffolding and pedagogical strategies reflected DREAMER's contextual dimension.

Chapter Five addressed several of these limitations through a randomized controlled trial comparing a coding intervention to mathematics and reading interventions among fourth-grade students. While coding instruction significantly improved computational thinking, a skill linked to EF domains such as planning and reasoning, it did not yield improvements in far-transfer outcomes such as spatial orientation or fluid intelligence. These findings suggest that structured programming instruction may support near-transfer cognitive gains, but broader EF development may require more intensive or prolonged engagement.

Taken together, these four studies illustrate the flexibility of the DREAMER framework in guiding research across both naturalistic and structured technology-related experiences. In consumer-focused studies, media content and exposure duration emerged as central factors, while in studies of coding, instructional design and contextual support played a more prominent role. These findings demonstrate that the DREAMER framework can be extended beyond traditional media consumption to include children's active participation in digital environments, offering a robust conceptual model for understanding the cognitive implications of diverse technology experiences.

Key Findings and Contributions

The four studies presented in this dissertation collectively illustrate the complex and context-sensitive relationship between children's digital technology use and the development of EFs. A central finding across these studies is that not all media interactions are equally beneficial or harmful. The meta-analysis revealed that low-duration interactive media were positively associated with EF outcomes in young children, whereas extended exposure to receptive media was negatively related to EF. These results demonstrate that both the quality and quantity of media use matter significantly for early cognitive development. This conclusion was further supported by the empirical study in Chapter Three, which found that playing digital games was positively associated with EF, whereas watching videos showed no significant relationship. The study also revealed that these associations varied depending on child temperament, specifically negative affectivity, highlighting that individual differences shape the cognitive implications of media use.

A second major contribution of this dissertation is the finding that media interactions do not have uniform effects across all cognitive domains. Programming education, for example, was associated with near-transfer skills that closely resembled the tasks taught during instruction. The systematic review and randomized controlled trial both showed that, while children gained domain-specific cognitive skills through coding interventions, these gains did not extend to far-transfer outcomes such as spatial orientation or fluid intelligence.

These findings suggest that promoting broad EF development may require more intensive, sustained, or strategically integrated instructional approaches.

A third key insight is that the DREAMER framework effectively accounts for these differential outcomes. Across both consumer and producer contexts, DREAMER helped conceptualize the role of media content, context of use, and relational processes in shaping cognitive development. In the media consumption studies, media type and duration were critical, whereas in the coding-focused studies, instructional design and social interaction (e.g., scaffolding, teacher support) played a prominent role.

In summary, this dissertation contributes to the growing body of research suggesting that technology use is neither inherently beneficial nor harmful. Rather, its developmental impact depends on the nature of children's engagement, specifically, how they interact with digital media, what types of content they encounter, and with whom these interactions occur. The findings offer nuanced evidence that both supports and extends the DREAMER framework, reinforcing its value as a conceptual tool for examining the intersection of digital technology and cognitive development. By addressing both media consumption and production, this work provides a deeper understanding of how varied digital experiences influence the development of executive functions across early and middle childhood.

Strengths and Limitations

This dissertation offers several important strengths. Foremost is its multi-method design, which integrates a meta-analysis, an empirical study, a systematic review, and a randomized controlled trial. This methodological breadth allowed for a comprehensive examination of the research questions from multiple angles and enhanced the validity of the findings through triangulation. Another strength is the dual focus on both naturalistic media exposure and structured educational interventions, which provided a unique perspective on children's digital experiences.

Despite these contributions, several limitations should be acknowledged. Not all components of the DREAMER framework, particularly relational processes, were fully operationalized in every study. For instance, social dynamics could not be incorporated into the experimental design of Chapter Five. The generalizability of the findings is also limited by the relatively homogeneous participant samples, which restricts insight into cultural and socioeconomic variability. In some cases, measures of media use relied on parent reports, potentially introducing bias. Lastly, none of the studies included long-term follow-ups, limiting the ability to determine whether the observed effects were sustained over time.

Implications for Research and Practice

The findings of this dissertation support moving beyond simplistic screen time metrics toward a more nuanced understanding of how digital technology can support or hinder development. For researchers, this work emphasizes the importance of grounding studies in theoretical frameworks such as DREAMER and designing research that accounts for media content, usage context, and relational dynamics. Incorporating these elements can contirbute to more precise and meaningful interpretations of how digital media influences executive function development.

For educators and policymakers, the results highlight the potential of high-quality, interactive media and well-structured programming curricula to promote meaningful cognitive outcomes, particularly in executive functioning. These findings suggest that interventions should be both intentional and contextually sensitive, considering the developmental stage, individual differences, and the social environment in which technology is used. By focusing on the quality of content and the structure of instructional experiences, practitioners can better harness the benefits of digital technology while minimizing potential drawbacks.

Future Directions

Several directions for future research emerge from this dissertation. First, longitudinal designs are needed to examine whether the cognitive effects of media use and programming education persist over time and extend to far-transfer outcomes. Such studies would also clarify developmental trajectories in executive functions and related skills across different types of digital engagement.

Second, expanding DREAMER-guided research to include more culturally and socioeconomically diverse populations is essential for understanding how broader ecological contexts shape media experiences and developmental outcomes. This would strengthen the generalizability of findings and reveal potential equity considerations in access to high-quality digital resources.

Finally, future studies should explore emerging digital modalities, such as AI-based tutoring systems, augmented reality, and co-play with intelligent agents. These technologies introduce novel forms of content, context, and relational interaction, making them especially relevant for testing and extending theoretical models like DREAMER. By investigating these evolving platforms, researchers can anticipate and address the opportunities and challenges of children's digital futures.

Conclusion

This dissertation contributes to the growing body of research examining how children's engagement with digital technologies shapes cognitive development. By addressing both media consumption and technology production through the lens of the DREAMER framework, it offers a comprehensive, theory-driven perspective on when and how digital experiences support or hinder the development of executive functions. The findings underscore that technology use is not inherently beneficial or harmful; rather, its developmental impact depends on the nature of the interaction, what children do with technology, the quality of the content, the context of use, and the relational processes involved.

By integrating insights from meta-analysis, empirical research, systematic review, and experimental design, this work provides a nuanced understanding of the complex, context-sensitive relationship between technology use and cognitive development. The results not only extend the applicability of DREAMER beyond traditional media consumption but also inform the design of developmentally informed, contextually sensitive educational practices and policies. Ultimately, this dissertation lays the groundwork for future research aimed at leveraging digital technologies in ways that help children thrive in an increasingly digital world.

Appendices

Chapter 2 Appendix.

Appendix Table 1

Study, sample, and measurement characteristics included in the meta-analysis

		Study characteristics				Sample characteristics					Measurement characteristics		
Authors	**Publication Year**	**Country**	**Publication status**	**Design**	**Sample size**	**Mean age (months)**	**Age category**	**Percentage of girls**	**Screen type**	**Interactivity**	**Frequency Category (minutes)**	**EF measure**	**Correlation**
Altun	2022	Turkey	Published	Cross Sec	201	59.82	Preschooler	49%	-	Receptive	High 96.04	EF Composite -PETA	-.39
									-	Interactive	Low 54.97	EF Composite -PETA	.43
Barr et al.	2010	US	Published	Long	53	15.77	Infant	-	TV	Receptive	High 103	Flexibility -Shape School	0
				Cross Sec	54	49.42	Preschooler	-	TV	Receptive	High 79.8	Flexibility -Shape School	-.09
Blankson et al.	2015	US	Published	Long	244	42	Preschooler	52.%	TV	Receptive	High 82.97	Inhibition -Stroop	-.12
												WM -Kaufmann Number Recall	-.18
												EF Combined	-.19
Blankson et al.	2015	US	Published	Long	228	54	Preschooler	52%	TV	Receptive	High 89.48	Inhibition -Stroop	-.11
												WM -Kaufmann Number Recall	-.1
												EF Combined	-.13
Bukhalenkova et al.	2023	Russia	Published	Cross	453	65.14	Preschooler	48%		Receptive	High 106.67	Inhibition NEPSY-II	.034
												Inhibition NEPSY-II	.045
												WM NEPSY-II	-.049
												WM NEPSY-II	.018
												Flexibility NEPSY-II	.12
										Interactive	High 75.39	Inhibition NEPSY-II	.072

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Authors	**Publication Year**	**Country**	**Publication status**	**Design**	**Sample size**	**Mean age (months)**	**Age category**	**Percentage of girls**	**Screen type**	**Interactivity**	**Frequency Category (minutes)**	**EF measure**	**Correlation**
												Inhibition NEPSY-II	.163
												WM NEPSY-II	.057
												WM NEPSY-II	.098
												Flexibility NEPSY-II	-.16
Bukhalenkova et al.	2023	Russia	Published	Long	445	77.4	Kindergarten	48%		Receptive	High 106.67	Inhibition NEPSY-II	.021
												Inhibition NEPSY-II	.036
												WM NEPSY-II	.222
												WM NEPSY-II	-.005
												Flexibility NEPSY-II	-.115
										Interactive	High 75.39	Inhibition NEPSY-II	.088
												Inhibition NEPSY-II	..085
												WM NEPSY-II	.146
												WM NEPSY-II	.067
												Flexibility NEPSY-II	-.11
Carson & Kuzik	2021	Canada	Published	Cross Sec	100	54	Preschooler	29%	Total	Uncategorized	High 93.2	Inhibition -Go/No-Go	-.25
												WM -Mr. Ant Task	.15
Chiu et al.	2022	Australia	Published	Cross Sec	162	87.6	Kindergartener	41%	TV	Receptive	Low [a]	Inhibition -Go/No-Go	.08
												Reasoning	.08

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												-Raven's colored matrices	
									Tablet	Uncategorized	Low [a]	Inhibition -Go/No-Go	-.05
												Reasoning -Raven's colored matrices	-.05
Chiu et al.	2022	Australia	Published	Cross Sec	162	87.6	Kindergartener	41%	Phone	Uncategorized	Low [a]	Inhibition -Go/No-Go	-.069
												Reasoning -Raven's colored matrices	-.02
									Videogames	Interactive	Low [a]	Inhibition -Go/No-Go	.072
												Reasoning -Raven's colored matrices	.03
Choe et al.	2022	US	Published	Cross Sec	56	38.02	Preschooler	56%	TV	Receptive	High 109	Inhibition -Snow/Grass	-.238
												Inhibition -Day/Night	-.45
												Inhibition -Whisper	-.247
Choe et al.	2022	US	Published	Cross Sec	56	38.02	Preschooler	56%	TV	Receptive	High 109	Inhibition -Walk a line	-.416
												Inhibition -Drawing circle	.038
												Inhibition -Turtle rabbit	-.077
Choi et al.	2018	US	Published	Cross Sec	0	30	Toddler	%45	Overall	Uncategorized	Low 55	WM -Spin the pots	.06
									TV	Receptive	Low 47.64	WM -Spin the pots	.03
									Videogames	Interactive	Low 6.5	WM -Spin the pots	.13

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Study, sample, and measurement characteristics included in the meta-analysis

		Study characteristics				Sample characteristics				Measurement characteristics			
Authors	**Publication Year**	**Country**	**Publication status**	**Design**	**Sample size**	**Mean age (months)**	**Age category**	**Percentage of girls**	**Screen type**	**Interactivity**	**Frequency Category (minutes)**	**EF measure**	**Correlation**
Choi et al.	2021	US	Published	Cross Sec	134	30.0	Toddler	48%	Overall	Uncategorized	Low 37.5	WM -Spin the pots	.17
									TV/Video	Receptive	Low 29.0	WM -Spin the pots	.10
									-	Interactive	Low 12.6	WM -Spin the pots	.10
									Touchscreen	Uncategorized	Low 9.9	WM -Spin the pots	.12
Corkin et al.	2021	New Zeeland	Published	Long	3506	24	Toddler	-	TV	Receptive	High 72	Inhibition -Hand clap	-.081
Dolgikh et al.	2023	Russia	Published	Cross sec	151	78	Kindergartener	%83		Receptive	Low 112	Inhibition NEPSY-II	-.03
												Inhibition NEPSY-II	.043
												WM NEPSY-II	.115
												WM NEPSY-II	-.062
												Flexibility NEPSY-II	-.145
										Interactive	Low 55.56	Inhibition NEPSY-II	.035
												Inhibition NEPSY-II	-.093
												WM NEPSY-II	.176
												WM NEPSY-II	.147
												Flexibility NEPSY-II	-.099
Esteraich	2018	US	Unpublished	Cross Sec	25	50.5	Preschooler	43%	Touchscreen	Uncategorized	High 92.4	Composite -Minnesota Executive Function Scale	-.002
Gashaj et al.	2021	Switzerland	Published	Long	97	77	Kindergartener	47%	Touchscreen games	Interactive	Low -	Inhibition -Flanker	.09
												Flexibility	.14

Appendix Table 1
Study, sample, and measurement characteristics included in the meta-analysis

		Study characteristics			Sample characteristics				Measurement characteristics				
Authors	**Publication Year**	**Country**	**Publication status**	**Design**	**Sample size**	**Mean age (months)**	**Age category**	**Percentage of girls**	**Screen type**	**Interactivity**	**Frequency Category (minutes)**	**EF measure**	**Correlation**
												-Modified flanker	
												WM -Matrix task	-.16
												WM -Backward color span task	.09
Gashaj et al.	2021	Switzerland	Published	Long	97	77	Kindergartener	47%	Video games	Interactive	Low 23.3	Inhibition -Flanker	.13
												Flexibility -Modified flanker	.12
												WM -Matrix task	-.015
												WM -Backward color span task	-.07
Gashaj et al.	2021	Switzerland	Published	Long	97	77	Kindergartener	47%	Touchscreen games	Interactive	Low -	Inhibition -Flanker	.03
												Flexibility -Modified flanker	-.14
												WM -Matrix task	.00
												WM -Backward color span task	-.07
Gashaj et al.	2021	Switzerland	Published	Long	97	77	Kindergartener	47%	Video games	Interactive	Low 23.3	Inhibition -Flanker	.16
												Flexibility -Modified flanker	.00
												WM -Matrix task	.07
												WM -Backward color span task	-.09

Appendix Table 1
Study, sample, and measurement characteristics included in the meta-analysis

		Study characteristics				Sample characteristics					Measurement characteristics		
Authors	**Publication Year**	**Country**	**Publication status**	**Design**	**Sample size**	**Mean age (months)**	**Age category**	**Percentage of girls**	**Screen type**	**Interactivity**	**Frequency Category (minutes)**	**EF measure**	**Correlation**
Harmon	2021	US	Unpublished	Cross Sec	72	54	Preschooler	59%	Mobile media	Uncategorized	High 82.97	Inhibition -Bear Dragon	-.26
					72	54			TV	Receptive	High 95.66	Inhibition -Bear Dragon	-.11
Hu et al.	2020	China	Published	Cross Sec	579	60.66	Preschooler	-	Program viewing	Receptive	High 129.6	Inhibition -Head, toes, knees shoulders	-.236
									Games	Interactive	High 64	Inhibition -Head, toes, knees shoulders	.031
Jin & Lin	2021	Taiwan	Published	Cross Sec	75	66.12	Preschooler	45%	Touchscreen	Uncategorized	Low 11.4	-Inhibition ANT-C	.255
Jin & Lin	2021	Taiwan	Published	Cross Sec								-Inhibition ANT-C	.045
Jusiené et al.	2020	Lithuania	Published	Cross Sec	190	58.75	Preschooler	44%	TV	Receptive	Low 50.10	Inhibition -Head, toes, knees shoulders	-.055
												WM -Missing span	.089
												Flexibility -Shape school task	.149
												Reasoning -Raven's colored matrices	
Jusiené et al.	2020	Lithuania	Published	Cross Sec	190	58.75	Preschooler	44%	Smartphone	Uncategorized	Low 20.45	Inhibition -Head, toes, knees shoulders	.006
												WM -Missing span	.097
												Flexibility -Shape school task	.006

Appendix Table 1
Study, sample, and measurement characteristics included in the meta-analysis

		Study characteristics			Sample characteristics				Measurement characteristics				
Authors	**Publication Year**	**Country**	**Publication status**	**Design**	**Sample size**	**Mean age (months)**	**Age category**	**Percentage of girls**	**Screen type**	**Interactivity**	**Frequency Category (minutes)**	**EF measure**	**Correlation**
												Reasoning -Raven's colored matrices	
Jusiené et al.	2020	Lithuania	Published	Cross Sec	190	58.75	Preschooler	44%	Touchscreen	Uncategorized	Low 18.53	Inhibition -Head, toes, knees, shoulders	.081
												WM -Missing span	.034
												Flexibility -Shape school task	.031
												Reasoning -Raven's colored matrices	
Jusiené et al.	2020	Lithuania	Published	Cross Sec	190	58.75	Preschooler	44%	Computer	Uncategorized	Low 10.54	Inhibition -Head, toes, knees shoulders	.073
												WM -Missing span	.05
												Flexibility -Shape school task	.022
												Reasoning -Raven's colored matrices	
Li et al.	2021	China	Published	Cross Sec	38	60	Preschooler	45%	Touchscreen	Uncategorized	Low 17.98	Flexibility -DCCS	-.03
Lui et al.	2021	UK	Published	Cross Sec	163	10	Infants	48%	Touchscreen	Uncategorized	High[a]	Inhibition -Toy inhibition	.02
Martins et al.	2020	Brazil	Published	Cross Sec	42	45,12	Preschooler	43%	Overall	Uncategorized	High[a]	Inhibition -Go/No-Go	.101
McHarg et al.	2020	UK	Published	Cross Sec	179	24.29	Toddler	44%	Overall	Uncategorized	High 84:95	-Composite	-.05

Appendix Table 1
Study, sample, and measurement characteristics included in the meta-analysis

	Study characteristics				Sample characteristics					Measurement characteristics			
Authors	**Publication Year**	**Country**	**Publication status**	**Design**	**Sample size**	**Mean age (months)**	**Age category**	**Percentage of girls**	**Screen type**	**Interactivity**	**Frequency Category (minutes)**	**EF measure**	**Correlation**
												Inhibition, WM, Flexibility	
				Long	163	34.79	Preschooler	-	Overall	Uncategorized	High 84:95	-Composite Inhibition, WM, Flexibility	-.12
				Cross sec	163	34.79	Preschooler	-	Overall	Uncategorized	High 116:18	-Composite Inhibition, WM, Flexibility	.06
Meng et al.	2024	China	Published	Cross sec	188	37.47	Preschooler	%48	Overall	Uncategorized	High	Inhibition Day-Nigh	-.22
					42	41.24	Preschooler	%57	Overall	Uncategorized	Low	Inhibition Day-Night	-.31
Nathanson et al.	2014	US	Published	Cross sec	107	53.37	Preschooler	49%	TV	Receptive	High 171.98	-Composite Inhibition, WM, Flexibility	-.26
Portugal et al.	2021	UK	Published	Long	46	12	Infant	43%	Touchscreen	Uncategorized	High 25.58	Inhibition -Go/No-Go	.132
												WM -Delayed alternation	.202
												WM -Spin the pots	.160
												Flexibility -DCCS	.019
Portugal et al.	2023	UK	Published	Cross Sec	46	41.28	Preschooler	50%	Touchscreen	Uncategorized	Low 38.40	Inhibition -Go/No-Go	.021
												WM -Delayed alternation	.020
												WM -Spin the pots	-.033

Appendix Table 1

Study, sample, and measurement characteristics included in the meta-analysis

		Study characteristics					Sample characteristics				Measurement characteristics		
Authors	**Publication Year**	**Country**	**Publication status**	**Design**	**Sample size**	**Mean age (months)**	**Age category**	**Percentage of girls**	**Screen type**	**Interactivity**	**Frequency Category (minutes)**	**EF measure**	**Correlation**
Ribner et al.	2017	US	Published	Cross Sec	552	68.86	Kindergartener	50%	Program viewing	Receptive	High 131.4	Flexibility -DCCS	.059
												Composite -Inhibition, WM, Flexibility	-.158
												Reasoning -Raven's colored matrices	-.194
Suggate et al.	2020	Germany	Published	Cross Sec	109	55.76	Preschooler	49%	Overall	Uncategorized	High 78.34	WM -Backward digit span	-.04
									TV	Receptive	Low 40.37	WM -Backward digit span	-.02
									Other devices	Uncategorized	Low 39.17	WM -Backward digit span	-.05
Sumer	2018	Turkey	Unpublished	Cross Sec	82	61.98	Preschooler	55%	TV	Receptive	High[a]	Flexibility -DCCS	.078
												Inhibition -Tapping task	.177
												Inhibition -Day Night	-.096
Sumer	2018	Turkey	Unpublished	Cross Sec	82	61.98	Preschooler	55%	Mobile devices	Uncategorized	Low[a]	Flexibility -DCCS	-.153
												Inhibition -Tapping task	.067
												Inhibition -Day Night	-.069
Yang et al.	2017	China	Published	Cross Sec	119	55.68	Preschooler	51%	Program viewing	Receptive	High 73.2	Composite -Inhibition, WM, Planning	.12
Yang et al.	2020	China	Published	Cross Sec	119	55.68	Preschooler	51%	Videogames	Interactive	Low 30	Composite -Inhibition, WM, Planning	.26

Notes: a denotes screen exposure measured with categories.

Chapter 4 Appendix

Program and Study Design

Study	Programming language	Content	Control group	Random assignment	Curricular or extracurricular	Country	Publication status
Donley (2018)	Scratch	Creative computing. Both computerized and non-computerized programming activities like debugging.	Waitlist. Other camp activities.	No	Summer school, Extracurricular	USA	Thesis
Akcaoglu & Koehler (2014)	Microsoft Kodu	The Game-Design and Learning program. Game design, problem-solving, and programming activities.	Waitlist.	No	After school or summer camp, Extracurricular	Turkey and USA	Published
Nam, Kim, & Lee (2010)	Scratch	Scaffolding-based courseware. Programming concepts such as if-else were taught by	Typical coding lessons (doing alone).	N/A	N/A	Korea	Conference

		providing scaffolding when necessary.					
Pardamean &Suparyanto, (2015)	LOGO	Teaching programming concepts with LOGO.	Another experimental group (same intervention but taken after the first post-test) and pure control group.	No	Curricular	Indonesia	Published
Brown et al., (2013)	Scratch	Solving and evaluating math problems using computer science techniques.	N/A	No	Curricular	USA	Published
Psycharis & Kallia (2017) (Problem-solving)	Computer science integrated math course	Solving math problems by transferring to Matlab and creating general solutions.	Regular math class.	No	Curricular	Greece	Published
Psycharis & Kallia (2017) (Reasoning)	Development of Applications in Computer-Programming Environments	Regular computer programming course.	Technology orientation group.	No	Curricular	Greece	Published

Rodríguez-Martínez et al. (2020)	Scratch	Learning programming with an emphasis on math problem-solving	Learning programing concepts	No	Curricular	Spain	Published
La Paglia et al. (2017)	LEGO Mindstorms	Program and observe the robot's behavior.	N/A	Yes	Extracurricular	Italy	Published
Lai & Yang (2011)	Scratch	Learning basic computer operations with Scratch. Problem-solving activities and scaffolding.	N/A	No	Curricular	Taiwan	Conference
Özcan et al. (2021)	Scratch	Learning programming concepts with Scratch. Designing their program in Scratch.	Math program and reading program	Yes	During school. Extracurricular	Turkey	Published
Hayes & Stewart (2016)	Scratch	Learning programming concepts to create games.	Derived relational training.	Yes	Curricular.	Ireland	Published
Atasoy & Özden (2020)	Scratch	Learning programming with an emphasis on spatial concepts.	Regular school activities.	Yes	Curricular	North Cyprus Turkish Republic	Published

La Paglia et al., (2018)	LEGO Mindstorm	Program and observe the robot's behavior.	Regular school activities.	Yes	During school. Extracurricular.	Italy	Published
Arfé, Vardanega, & Ronconi, (2020)	Code.org	Solving coding problems in the code.org platform. Learning basic programming concepts while solving those problems.	Clustered. Standard STEM condition.	Yes	During school. Extracurricular.	Italy	Published
Arfé et al., (2019) (Study 1)	Code.org	Solving coding problems in the code.org platform. Learning basic programming concepts while solving those problems.	Clustered randomized control trial. Waitlist.	Yes	During school. Extracurricular.	Italy	Published
Arfé et al. (2019) (Study 2)	Code.org	Solving coding problems in the code.org platform. Learning basic programming concepts while solving those problems.	Randomized control trial. Waitlist.	Yes	During school. Extracurricular.	Italy	Published

Robledo-Castro et al. (2023)	Unplugged activities and MakeCode	Learning principles of CT with unplugged and plugged activities. Testing the algorithms on a micro: bit device.	Regular technology class activities.	Yes	Curricular	Colombia	Published