Children, Executive Functioning, and Digital Media: A Review

Executive Summary

"Media is so pervasive that it should no longer be considered a nuisance variable that could affect development; rather, it should be seen as a fundamental part of the context in which development occurs." (Barr, 2019)

What is digital media?

When we use the term digital media, we are referring both to the physical devices—TV sets, smartphones, tablets, gaming consoles—and the content they provide, such as videos, interactive apps, and games.

As the world copes with the coronavirus pandemic, digital technology has taken center stage in children's homes. Today more than ever, children's digital access—or lack thereof—significantly determines whether children can continue their education, seek information, stay in touch with friends and family, and enjoy digital entertainment (Winther et al., 2020). And as jobs, schools, and even health care are moved online, for many, digital life has become the new normal. In this time, families are navigating uncharted waters as they increasingly rely on screens while trying to find balance with offline activities.

Digital technology has become both a constant and major presence in children's lives. Today, infants as young as 4 months are interacting with digital media, whereas 50 years ago regular television viewing didn't occur until age 4 (Chassiakos et al., 2016). Understanding how experiences with digital media may shape the developing brain is essential knowledge for those who work to support children's healthy brain development.

Decades of research demonstrate that early childhood is among the most critical times for children's brains (National Scientific Council on the Developing Child, 2020). Before children turn 2, their brains are forming more than 1 million new neural connections every second (National Scientific Council on the Developing Child, 2007; OECD, 2002). These neural connections are the basis for the information-processing networks of the brain that are responsible for all thoughts, sensations, feelings, and actions. The early experiences children have, and their relationships with the important people in their lives, literally build the brain's architecture, providing the foundation for future learning, health, and behavior (Galinsky, 2010; National Scientific Council on the Developing Child, 2007).

Executive function (EF) refers to a set of attention-regulation skills that originate in the prefrontal cortex. EF skills make it possible to consider alternative perspectives and think flexibly in response to changing circumstances (*cognitive flexibility*), to keep information in mind so it can be used (*working memory*), and to resist automatic and impulsive behaviors (*inhibitory control*) so that one can engage in goal-directed reasoning and problem-solving (Diamond, 2013; Galinsky et al., 2017; Garon et al., 2008; Rueda et al., 2005; Zelazo & Müller, 2002). Although individual variability exists, longitudinal studies have shown that children with better EF skills are more effective learners (Hassinger-Das et al., 2014), are more likely to graduate from college (McClelland et al., 2013), and are more likely to have better health and wealth in adulthood, regardless of their intelligence or social class at birth (Moffitt et al., 2011). In the absence of supportive relationships, children who experience excessive or prolonged amounts of stress (due to poverty, trauma, abuse, or neglect) are at greater risk of developing weaker EF skills (Evans & Kim, 2013; Farah et al., 2006; Haft & Hoeft, 2017; Shonkoff et al., 2012).

It is well established that EF skills develop through practice and positive, supportive relationships with adults (Galinsky, 2010). EF skills are also a promising and important target for early intervention (Blakey & Carroll, 2015; Diamond & Lee, 2011; Rueda et al., 2005; Zelazo & Lyons, 2012). Despite the value of developing young children's EF, these skills have not yet been fully embraced and routinely taught in early childhood settings, schools, or homes. This is perhaps due to the educational focus on children's learning content (the "what" of learning) versus skills (the "how" of learning). Nor has the role of children's experiences with digital media at home been explored in relation to EF development.

When it comes to screen time, researchers and policymakers historically have focused on trying to determine how much is too much, with less attention focused on figuring out how much is too little and the kinds of digital content that can support healthy development. In recent years, children's screen time has come to encompass behaviors as diverse as watching (i.e., video content), reading, writing, interactive play (i.e., gaming), video-chatting, and immersion in virtual worlds. Each of these activities can take place on a range of devices (e.g., TV sets, smartphones, tablets, e-readers, smartwatches, laptops, desktops, consoles, and handheld players). And each of these devices offers a different set of affordances (e.g., sound, motion, ease of portability, interactivity, touch sensitivity, or persuasive design that prolongs engagement). Additionally, the list of the different kinds of digital content children consume today is exhaustive: Screen content ranges from educational to entertaining, realistic to fantastical, child-directed to adult-directed, interactive to observational, and more.

The bulk of research exploring the link between digital media exposure and EF skill development looks at television and video exposure for two reasons:

- Television has been around much longer than other kinds of digital media, and research is slow compared to the rate at which new kinds of digital media are adopted (Wartella & Robb, 2008).
- Television and video are still the dominant types of content that young children consume on digital devices (Rideout & Robb, 2020).

Although the ways children experience television has expanded (i.e., video content is increasingly viewed through streaming services on interactive devices), the experience of watching television is generally similar despite the viewing platform: Audiovisual content unfolds in time independent of the viewer's presence or actions.

Research is beginning to look at the effects of interactive content and digital gaming devices on EF skills in younger children, yet it is still true that most of our insights about interactive media are based on research conducted with adolescents and adults (Christakis, 2014; Dale et al., 2020). Interactive digital media can be defined as experiences that require the user to interact with a digital device in a way that changes what content is presented (e.g., clicking a mouse button, touching a screen, moving in front of a sensor, and/or using voice input).

Yet the available research has several important limitations. First, there is a lack of research: The myriad digital media experiences available to young children today has meant that research in this field has not been able to keep up with the rate at which digital media has been incorporated into childhood. As such, many open questions remain about whether findings hold for children of different ages, with different risk profiles.

Another issue is the correlational nature of digital media research. Although a number of researchers have tried to address the problem of directionality by using a longitudinal approach, in many studies, a bidirectional relationship between digital media use and sample characteristics seems likely. Thus the majority of research available can only show that a relationship exists between digital media and a certain developmental outcome, and not that digital media causes a certain developmental outcome.

Obtaining reliable effect size estimates has also proven difficult as many studies are unable to take into account the number of demographic and contextual variables that moderate the effect of digital media (Ferguson & Donnellan, 2014; Ferguson & Kilburn, 2010; Foster & Watkins, 2010; Linebarger & Vaala, 2010). Finally, current statistical approaches used in digital media research often lack the sensitivity to detect more nuanced effects, such as nonlinear relationships and threshold effects (Foster & Watkins, 2010).

Despite these limitations, such research is often used to sway public opinion and policy regarding issues around children and digital media as well as to advocate for partially or fully limiting screen time for children (Elson et al., 2019). However, strict cutoffs, while convenient, neglect the following:

- They do not take into account *how* digital media are used and with *whom.*
- They overlook the convergence between online and offline play and alternate social spaces that children construct today (Marsh, 2014).
- One size does not fit all with respect to digital interactions: Individual differences in children, the diversity of families, and the context within which they live, all influence the level of risk and benefits digital media can pose.

The pandemic has made it clear that digital media are a necessary part of young children's lives. It is imperative stakeholders in early childhood understand how digital media interacts with children's brain development: When do digital media pose a risk, and how can digital media be used to foster important life skills and relationships? And it isn't only children's digital media consumption that requires examination; *parents'* digital media use could have a significant impact on the parent-child relationship, with implications for brain development. Thus there is an urgency to address the questions that these new realities have raised.

Report Summary

This research landscape analysis reviews the impact of digital media use on children's EF development. We focus specifically on young children's experiences with digital media at home, although we note that in today's world digital media has made formal schooling possible outside the physical bounds of the classroom. We restricted our literature search to scientific studies of children from birth to age 8. Recent data points to increased digital media use by younger children and an "ageing down" of first experiences with digital media (Hooft Graafland, 2018; Rideout & Robb, 2020). Furthermore, the early life period represents a critical window for brain development in which early experiences can have lasting and cascading impacts. We did not include studies about ebooks because children's ebook use constitutes a very small portion of children's media experiences (Rideout & Robb, 2020).

We reviewed more than 150 journal articles, press articles, industry papers, and books. Data was collected from global populations, and studies with people living in the United States were cited most frequently. Based on our literature review, we identified several trends in the growing body of research on EF skill development and children's digital media exposure. We have included below a summary of key findings that we believe are most relevant for various stakeholders working in early childhood education, public policy, and programs and services for children and families in lower-income households.

Key Trends

Digital media doesn't exist in a vacuum: Those with whom children experience digital media are key and can shape the extent to which digital media experiences will ultimately be beneficial to children's EF development.

- An "environment of relationships" is crucial for the development of a child's brain architecture (Galinsky, 2010).
- Through practicing joint media engagement, adults and peers can boost the educational value of digital media by scaffolding children's learning in a developmentally appropriate manner (Ewin et al., 2020).
- *Technoference* refers to the frequent disruptions that digital media can cause in interpersonal relationships (McDaniel & Coyne, 2016). Research suggests that technoference is a potential threat to sensitive and reliable caregiving, with implications for children's EF skill development (Radesky et al., 2015).
- Many studies have reported an association between high amounts of background television during infancy and early childhood and decreased EF skills later in life (Barr, 2010).
- The reasons parents and children engage with digital media are related and can have complex effects on EF skill development. For example, parents may try to soothe or manage more difficult children with screen time, which in turn exacerbates regulatory difficulties as a result of reduced parent-child interactions/exposure to inappropriate content (Radesky & Christakis, 2016).

Not all digital media content are created equally: Although high-quality, educational content can be used to foster EF skills, consuming developmentally inappropriate content has been linked to poorer EF skill development.

- High-quality content is engaging, encourages active involvement, is meaningful for the child, encourages social interaction, and has a clear learning goal (Hirsh-Pasek et al., 2015).
- High-quality, interactive digital media are a promising avenue for direct instruction of EF skills (Eichenbaum et al., 2014; Simons et al., 2016). However, games that use "bells and whistles" to increase interest may inadvertently distract players from the learning goal (Hirsh-Pasek et al., 2015).
- Children's performance on measures of EF skill appears to be reduced (temporarily) after viewing fantasy content (Rhodes et al., 2019). The long-term consequences of this effect require further investigation.

- For children younger than about age 3, there are limits on how much they can learn from screen-based media (transfer deficit) (Barr, 2010; Huber et al., 2016). This effect appears to be reduced when the content are interactive, when children are already familiar with the content, and/or when children have prior experience with screens.

High amounts of screen time are related to weaker EF skill development in young children. Yet what constitutes "high" amounts of screen time is unclear.

- Research points to multiple and non-mutually exclusive pathways through which high amounts of screen time could affect the developing brain and EF skills (i.e., by displacing more developmentally appropriate and brain-enriching activities, an increase in exposure to inappropriate content, disrupted sleep, and increased sedentary behavior). High amounts of screen time may also be a proxy variable for other factors (such as reduced access to sensitive caregiving, or to learning environments that promote and build EF skills).
- Children whose exposure to digital media occurred earlier in life are more likely to show poorer EF skills during the preschool years (Nathanson et al., 2014).
- There is an especially strong link between increased screen time and poorer attentional control. Sustained, high levels of digital media exposure (as opposed to single bouts of high digital media use throughout childhood) are related to poorer EF development (Mistry et al., 2007).
- *Exergames*, or video games that require active physical participation, have been shown to result in short-term benefits to cognitive function immediately after playing, similar to physical activity (Best, 2012).

Executive Function Skills

EF refers to a set of attention-regulation skills that originate in the prefrontal cortex (Diamond, 2013; Garon et al., 2008; Jones et al., 2016; Zelazo & Müller, 2002). EF typically comprises the following simple skills (sub-components):

- **Working memory**: This skill enables us to hold and mentally manipulate information in our minds and make connections between seemingly unrelated things. For example, working memory makes it possible for children to do addition and subtraction, follow a story, and remember the rules of a game.

- **Inhibitory control**: This skill enables us to make choices and achieve goals by suppressing a dominant response or impulse to do something to achieve a goal as well as resist distraction. For example, inhibitory control helps children focus their attention selectively, wait for their turn, and stop themselves (as best they can) from snatching a toy they want.

- **Cognitive flexibility**: This skill enables us to "switch gears" when we need to, consider different perspectives and strategies, and shift attention from one source to another. For example, cognitive flexibility helps children problem solve, be creative, and think critically.

While researchers can measure each of these simple skills independently, in reality, they work together to make up EF skills. Furthermore, complex life skills (such as problem-solving, regulating emotions, and planning) typically involve EF skills as well as other skills and knowledge (Jones et al., 2016).

EF skills vary along a continuum from "cool" to "hot" (Zelazo & Müller, 2002). Cool EF refers to skills engaged in relatively emotionally neutral contexts (e.g., using inhibitory control during a Stroop Test to say the color of a word, like "green," instead of reading the word "red"). Hot EF refers to skills engaged in situations that are emotionally and/or motivationally significant (e.g., using inhibitory control to delay reaching for a piece of chocolate).

It is important to distinguish EF skills from related yet distinct constructs (e.g., attention, effortful control, self-control, emotion regulation, self-regulation, and planning, among others). Often these are incorrectly used interchangeably in the literature, obscuring the differences that exist in terms of when and how each skill develops, when is the most important time to focus on it in development, how easy or difficult it is to change, what strategies are shown to improve it, and how strongly it predicts short- and long-term outcomes (social, health, education) (Jones et al., 2016).

Executive function skill development: Birth to age 8

The scientific evidence on the development and consequences of EF skills in the earliest years of life conveys several important messages (Center on the Developing Child at Harvard University, 2011):

1. **EF skill development follows a protracted course.** The fact that young children have a difficult time staying on tasks, remembering multistep instructions, or deviating from routines, is of course no surprise to anyone who has been around a young child. Children go from reacting to their world around them in a reflexive way to developing more goal-directed, self-regulatory behaviors. As a child's ability to engage in reflective thinking improves, EF skills are more likely to be engaged (Zelazo, 2015). When a child can notice challenges, pause, consider the options, and put things into context before responding, they are in a better position to use EF skills appropriately. It is when a child responds to a situation reactively, without reflecting upon their current behavior, classic failures of EF skills occur (i.e., children proceed on "autopilot").

   During the second half of the first year, infants are increasingly capable of remembering one or two objects that have been hidden from view (*working memory*) and inhibit the tendency to search for a desirable toy at an old hiding location (*inhibitory control*). During the preschool period, EF skills are rudimentary. However, they serve an essential role in children's increasing ability to learn and act independently. Preschool-age children show changes in their ability to remain focused despite distracting alternatives (e.g., pulling out one toy to play with for a short time rather than all of the toys at once) (*inhibitory control*), and thinking about objects flexibly (e.g., using wooden blocks like a train) (*cognitive flexibility*). By the time children turn 7 or 8, aspects of their developing EF skills are comparable to adults, even though EF skills continue to develop well into the adolescent years and beyond.

2. **Genes provide the blueprint for EF skill development, yet the malleability of the brain during the early life period means early experiences can produce lasting impacts on EF skill development.** Scientists use the term "plasticity" to refer to the capacity of the brain to change as a function of experience (Kolb et al., 2013). Plasticity is greatest early in life and adolescence but then decreases with age. Although windows of opportunity remain open for many years, trying to change behavior or build new skills later in life requires more time and effort—for both the individual and society (National Scientific Council on the Developing Child, 2005; Shonkoff et al., 2012).

3. **An environment of relationships is crucial for the development of a child's brain architecture** (Galinsky, 2010; National Scientific Council on the Developing Child, 2004). Growth-promoting relationships allow children to engage in meaningful and supportive interactions and provide ample opportunities for children to extend their developing EF skills through practice and age-appropriate challenges. When children are not provided with reliable, responsive, and sensitive caregiving, it can and does affect brain development. Without supportive relationships, ongoing, severe stress during the early life period (due to poverty, violence, abuse, or neglect) can disrupt the brain's developing architecture and increase the risk for linguistic, cognitive, and social and emotional problems, though repair is possible (Evans & Kim, 2013; Farah et al., 2006; National Scientific Council on the Developing Child, 2007).

   During infancy, attention to an infant's cues is important for supporting what researchers call the "serve-and-return" interactions that build strong neural connections in the developing brain. For example, infants naturally seek social interaction through babbling, facial expressions, and gestures (serve), and responsive adults will answer this behavior with similar kinds of vocalizing and behaviors (return). As children become toddlers, preschoolers, and elementary schoolers, it is necessary for primary caregivers to help shape experiences that both promote EF skills and help children practice their developing EF skills (National Scientific Council on the Developing Child, 2004). Adaptive support, or scaffolding, is one way primary caregivers can do this. First, children are given "just enough" help from an adult or peer when they are faced with a challenge, so that they can learn by doing. Then this support is gradually decreased as children improve their skills, learn from their mistakes, and acquire the tools they need to succeed more independently (Hammond et al., 2012).

   As children grow older, their EF skill development benefits from participation in less-structured activities (i.e., ones in which the child, rather than the adult, has increasing decision-making and problem-solving responsibilities). For example, on a visit to a museum, a child may practice engaging self-directed forms of EF by establishing goals and plans, keeping them in mind, and carrying them out. ("First I want to see the dinosaur exhibit, and then I want to learn about rocks.") (Barker et al., 2014).

4. **There is increasing evidence that interventions targeting EF skills are effective** (Diamond & Lee, 2011; Rueda et al., 2005). In particular, school-based social and emotional programs and professional development for teachers have been shown to have a positive effect on children's EF and regulation-related skills as well as a positive impact on academic and behavior outcomes (Bierman et al., 2008; Riggs et al., 2006; Zelazo & Lyons, 2012). Often these programs show the largest effects among children at-risk for academic and behavioral problems (e.g., Jones et al., 2011). Fostering the healthy development of EF skills, and in turn, coping skills such as emotional regulation, reflection, and problem-solving may also protect at-risk children (Buckner et al., 2003, 2009).

Exploring the Literature: Digital Media Experiences and Children's EF Skills

Screen time today is no longer as simple as watching a show on television—digital devices, such as smartphones, tablets, TV sets, and gaming consoles—have multiple affordances (e.g., streaming, interactive gaming, video-chatting, instant messaging, tailoring and recommending content), and the line between video content and interactive content is becoming increasingly blurred. Furthermore, as children spend increasing amounts of time with digital media, their play activities and social relationships transcend digital and nondigital contexts (Fleer, 2018; Follmer et al., 2010; Marsh, 2014; Richards & Calvert, 2017).

A recent report by Common Sense Media summarized the results of a national study documenting media-use patterns among children from birth to age 8 in America (Rideout & Robb, 2020). Watching videos is the dominant screen activity among children age 8 and younger, taking up nearly three-quarters (73%) of all screen time. By contrast, gaming accounts for 16% of young children's screen time. Other activities, like video-chatting, electronic reading, or doing homework on a computer or mobile device, each account for less than 3% of children's screen time. Nearly half (49%) of children age 8 or under "often" or "sometimes" watch television or videos or play video games in the hour before bedtime, and 39% of parents say the TV set is on "always" or "most of the time" in their home, whether anyone is watching or not.

Children younger than 2 engage with screens for an average of 49 minutes a day. By contrast, children age 2 and older consume, on average, two and a half to three hours of screen time daily, despite arguably large differences in children's daily activities (e.g., stay at home vs. attend school) or the amount of digital media activities available to them (e.g., watching television vs. internet browsing). An earlier report found that exposure to background television declines from 3.88 hours in preschool to 2.70 hours as children enter formal schooling (Lapierre et al., 2012).

Eighty-four percent of parents watch television with their child at least some of the time; 29% say they do so "most of the time" the child watches. Fewer say they watch online videos with their child (74% at least sometimes), play games or use apps on a mobile device (63% at least sometimes), or play console video games (54%). The majority of children younger than 8 have used general-audience video platforms like YouTube, where (a) content may be age inappropriate, (b) prolonged viewing is encouraged through autoplay, and (c) tailored recommendations and user-generated content may have low educational quality and high commercialism.

Importantly, there are large differences in screen time by household income and race/ethnicity. Children in lower-income households spend an average of nearly two hours a day more with screen media than those in higher-income homes (three hours, 48 minutes vs. one hour, 52 minutes). Similarly, Hispanic/Latinx (three hours, three minutes) and Black (four hours, nine minutes) children spend more time with screen media per day than White (one hour, 52 minutes) children do. There are similar differences with screen use by parent education (Rideout & Robb, 2020). Children from homes with lower parent education are more likely to have their data collected and shared with third-party companies (Zhao et al., 2020).

Additionally, the Common Sense Media report found a gap of 32 percentage points in home computer access and a gap of 20 percentage point in high-speed internet access at home between children in lower- and higher-income households (63% vs. 95% for a home computer, and 74% vs. 94% for high-speed internet). Children in lower-income families are as likely as children in higher-income families to own a tablet device (40% from each group, and 45% of those in the middle-income group).

1. Relationships, Digital Media, and EF Skills

When considering the link between children's EF skills and digital media, those with *whom* children consume digital media—or *what interpersonal processes* media interrupts—are key. The practices caregivers engage in to manage and regulate children's experience while using digital media can shape the extent to which digital media experiences will ultimately be positive or negative. At the same time, digital media experiences can promote or disrupt important peer relationships: Learning to share with others, engaging in reciprocal exchanges, managing impulses, and considering others, are all EF-related skills that young children practice during social interactions with one another.

Technoference and digital media use

There is growing concern over technoference in adult-child relationships (i.e., the frequent, daily disruptions that digital media can cause in interpersonal relationships) (McDaniel & Coyne, 2016). In an observational study, researchers recorded the behaviors of 55 parents eating at a fast food restaurant in Boston. They found that out of 55 parents, 40 used a mobile device during the meal, and the more time parents spent with their mobile devices, the more likely their children were likely to show externalizing behaviors, like acting out and trying to get the parents' attention (Radesky et al., 2014).

Parents have been estimated to use digital media an average of nine hours per day, with approximately three hours per day of smartphone use (Lauricella et al., 2016; Wartella et al., 2015). At the same time, primary caregivers, the people with whom children form their strongest relationships, are children's first and most important teachers. It is through serve-and-return interactions with important people in children's lives that infants' and children's brains develop a foundation for future learning, health, and behavior.

While researchers agree that occasional inattention is not cause for concern, the brief yet repeated and unpredictable interruptions that digital technology creates when primary caregivers and children are together could be displacing important opportunities for bonding and learning. In one study, researchers asked whether a disruption as simple as a phone call could interfere with young children's learning (Reed et al., 2017). Mothers were asked to teach their toddlers two novel words; sometimes mothers received a phone call that interrupted them while teaching one of the words. Children were significantly less likely to learn the novel word when their mother was interrupted by the phone call than in the uninterrupted situation, despite the researchers ensuring that the amount of exposure to each word was similar.

The relationship between adult digital media use and children may be transactional (i.e., there may be bidirectional associations between parental digital media behaviors and children's behaviors). One possibility is that parents rely on digital technology for personal stress-relieving purposes. In one study, researchers found that parents who report being stressed by their child's difficult behavior, are more likely to withdraw from parent-child interactions with technology (e.g., using mobile media while with a child) (McDaniel & Radesky, 2018). Furthermore, higher amounts of difficult behavior predicted greater parenting stress, while higher technology use during parent-child interactions predicted greater child self-regulatory problems over time. Parents who use mobile devices frequently when with their young children have more difficulty "repairing" with their infants after disrupted interaction (Myruski et al., 2018), and have less sensitive and reflective mental working models of their children (Radesky et al., 2018), both of which are important for children's burgeoning EF skills.

Background television

Numerous studies have reported an association between high amounts of background television during infancy and early childhood, and decreased EF skills later in life (Barr et al., 2010; Ribner et al., 2020; Schmidt et al., 2008). Recently, one study also showed that increased background television was negatively associated with increased self-regulation problems, which was subsequently linked to poorer language and literacy outcomes (Ribner et al., 2020).

Researchers have proposed three primary and non-mutually exclusive mechanisms through which background television could negatively impact EF development. The first is through disruption of play, a fundamental ingredient for healthy brain development and learning (Courage & Howe, 2010; Ginsburg, 2007; Golinkoff et al., 2003; Schmidt et al., 2008). The second is through technoference and diminished quality of adult-child interactions (Kirkorian et al., 2009; Masur et al., 2016; Pempek et al., 2014). The third is through exposure to developmentally inappropriate content (Tomopoulos et al., 2014) For example, even child-directed content an older sibling watches might be inappropriate for a younger child.

Joint media engagement

Early childhood experts have long advocated for the importance of joint attention for learning and meaning-making (Bruner, 1983; Carpenter & Tomasello, 1995; Galinsky, 2010; Tomasello, 2009). *Joint media engagement (JME)* refers to how adults and children interact with each other when engaging in digital media. JME includes viewing, playing, searching, reading, contributing, and creating—with either digital or traditional media—together (Stevens & Penuel, 2010). Research shows that JME may boost the educational value of digital media experiences (Anderson & Hanson, 2017; Ewin et al., 2020; Takeuchi & Stevens, 2011). When adults or peers engage with digital media with children, they can help children draw connections between what they see on a screen and the real world, respond to questions, share their perspective, and model appropriate responses and behaviors as well as physically assist children with a digital device.

For example, in one study, children age 6 to 18 months showed longer looking times to a screen (a measure of attention) and greater responsiveness when their parents provided verbal cues (such as labels or questions) while coviewing (Fidler et al., 2010). In another study, children age 2 to 6 years either watched or did not watch 10 episodes of *Daniel Tiger's Neighborhood* over two weeks (Rasmussen et al., 2016). *Daniel Tiger's Neighborhood* is a cartoon designed for preschoolers that employs a social and emotional curriculum (similar to *Mister Rogers' Neighborhood*), where each episode targets a particular social, emotional, or life skill. Preschoolers who watched the program and whose parents frequently engaged in conversations about the content exhibited higher levels of empathy, self-efficacy, and emotion recognition—all of which depend heavily on EF skills. The effects were more pronounced for younger preschoolers and preschoolers from lower-income families. Similar improvements in content comprehension have previously been reported by researchers examining coviewing and *Sesame Street* (Reiser et al., 1984).

Video chat

Video chat is one way digital media can be used to foster important social relationships necessary for building EF skills (McClure et al., 2015). When parents or caregivers are physically present with young children during a video chat, adults can model appropriate ways of interacting with a chat partner and help children make sense of the situation. In one study, toddlers participated in a video chat while their coviewer was responsive or unresponsive (Myers et al., 2018). Toddlers whose coviewer was responsive looked longer at the screen and made more vocalizations.

Furthermore, research shows that video chat may be a more appropriate platform for younger children to connect with others than phone calls (Follmer et al., 2010). First, video chat allows children and their conversation partners to communicate through actions, rather than with words, which is especially important for younger children who have weaker language skills. Secondly, even older children may require a high level of prompting and scaffolding when using a telephone, as they are still developing the skill of conversation. Third, and perhaps most importantly, video chat allows for a greater degree of social contingency: Social cues, such as eye gaze, gestures, and facial expressions, are important for children's comprehension of social situations, and video chat partners can respond to each other in real-time (Kirkorian et al., 2016; Roseberry et al., 2014).

2. Digital Media Content and EF Skills

The sheer volume of digital media content targeted at young children is staggering. Most (but not all) child-directed content is created by developers who are not experts in cognitive development, and content marketed as "educational" is not necessarily so (Zosh et al., 2017). Yet high-quality, educational content does exist and offers the opportunity for children living in different socioeconomic contexts to access the same learning experiences (Rideout & Katz, 2016). Currently, open questions remain about the extent to which high-quality digital media can improve EF skills (e.g., by how much, for whom, and how long do the effects last) and whether these improvements transfer to other skills known to depend on EF skills (e.g., perspective-taking, academic performance, critical thinking) (Hampshire et al., 2019; Rossignoli-Palomeque et al., 2018; Simons et al., 2016).

High-quality content

Researchers examining how children learn best have identified a number of features that distinguish high-quality digital media content (Hirsh-Pasek et al., 2015; Zosh et al., 2017):

1. **Engaging**: Children learn best when they are engaged with the content. Engaging content is media content designed to help children focus on a specific learning goal without distractions unrelated to the learning objective. Engaging content also includes media that facilitate or encourage contingent interaction, provide extrinsic motivation or feedback, or feature design that evokes intrinsic motivation (i.e., kids' unique abilities, passions, and interests, matched to their developmental level).

2. **Actively involved**: Media that encourage children's active involvement engages children in "minds-on" experiences, sparking their motivation to engage fully with the content. Content that promotes active involvement encourages children to participate in thinking about problems or coming up with ideas, rather than passively following along.

3. **Meaningful**: Children learn best when they can connect new information to previously learned information or experiences. Children also learn when information is presented in a meaningful context, such as a story. Thus, content should be meaningful and relevant to your own child's interests

4. **Socially interactive**: Research shows that learning is enhanced when content engages the child in an interaction with a peer or caregiver as part of the screen experience. Caregivers can also facilitate this kind of experience even when the content does not explicitly require social interaction. They can do so by asking questions, labeling objects, providing descriptions of what is on the screen, and/or talking about or performing actions related to the storyline.

5. **Learning goal**: Screen time should have a purpose, whether it is to build content knowledge or practice a skill. High-quality educational content promotes children's attention and engagement with features that are specific to the learning goal rather than generally boosting engagement through bells and whistles.

There is evidence that children who consume high-quality content are more likely to develop strong EF skills. A recent meta-analysis synthesizing the results of 24 studies, conducted with more than 10,000 children in 15 countries, examined the effects of children's exposure to international coproductions of *Sesame Street* (Mares & Pan, 2013). The researchers found widespread cognitive, social, and emotional benefits in terms of developing content knowledge, life skills, and prosocial behavior.

In another study, researchers examined the effect of watching *Blue's Clues* on children age 3 to 5 (Anderson et al., 2000). *Blue's Clues* is a TV series designed for preschoolers and aims to promote mastery of thinking and problem-solving skills through a think-along/play-along style. *Blue's Clues* also features episode repetition (when viewed live), which is intended to improve comprehension while holding attention and increasing children's participation. The researchers found that regular viewers of *Blue's Clues* performed better on parental report measures of flexible thinking, problem-solving, and social skills—all of which depend heavily on EF.

Commercials may reduce the educational value of high-quality content. In one study, the amount of PBS viewing was positively related to preschoolers EF skills, whereas the amount of "educational cartoon" viewing was negatively related to preschoolers EF skills (Nathanson et al., 2014). The researchers speculated that a potential explanation for the different effects was due to the lack of commercials on PBS, which meant less frequent attention-grabbing interruptions to the storyline.

Transfer deficit

For children younger than about age 3, there are limits on how much they can learn from screen-based media: Infants and toddlers learn more effectively from real-life interactions with people and objects compared to screens. This effect has been termed the "transfer deficit" (Anderson & Pempek, 2005) and is, in fact, a general principle that describes how very young children's brains' learn. Information learned or acquired in one context is more likely to be applied in a new context if the new context is highly similar (Barr, 2010). This means that, for very young children, the two-dimensional context of screens can be too dissimilar to the 3D context of the real world, resulting in little transfer of learning between the two.

There is some evidence, for example, that infants and toddlers are capable of imitating a series of actions observed on television and recall these actions at a later point in time. However, the rate of learning is faster when the same series of actions is observed through a real-life demonstration (Barr et al., 2007; Barr & Hayne, 1999; Brito et al., 2012). However, there is also evidence that the transfer deficit can be reduced. For example, one study showed that 2-year-olds who previously experienced a video-chat scenario were subsequently more likely to use information delivered to them by screen to find a toy than children who did not (Troseth et al., 2006), suggesting that prior experience interacting with screens may be important. In another study, children age 1 to 5 years showed greater imitation of an action sequence when the video was viewed multiple times (Barr et al., 2007), suggesting repetition of content may aid screen-based learning. Lastly, there is evidence that toddlers learn more effectively from screens when familiar characters are in charge of teaching (such as a friend, relative, or beloved TV character, like Elmo) (Gola et al., 2013).

Digital worlds and fantastical content

From a young age, infants show expectations about the physical world and how it works, a phenomenon referred to as "naïve physics" (Spelke, 1994). For example, 5-month-old infants expect humans, like all material objects, to be solid and are surprised when a hand passes through a wall (Saxe et al., 2006). As such, young children are highly attuned to situations that violate their expectations about the world and use these situations to guide learning (Stahl & Feigenson, 2019).

Researchers have suggested that digital media content that frequently violates young children's expectations of the real world may result in a kind of "mental overload," similar to the mental exhaustion students can experience after taking a challenging exam (Lerner & Barr, 2015). The clearest evidence of this comes from experimental studies examining the effects of watching fantastical content on EF skill performance in children. In a series of studies, researchers compared EF skill performance immediately after 4- and 6-year-old children watched either a fantastical cartoon (e.g., *SpongeBob SquarePants*) or a realistic cartoon (e.g., *Caillou*) (Lillard et al., 2015; Lillard & Peterson, 2011). Children who viewed fantastical content performed worse than their peers who viewed realistic content. The researchers also investigated whether pacing of the content interacted with the degree of fantastical content, and found pacing was not a significant factor.

It is important to note that in the aforementioned studies, baseline EF skill performance was not measured, so it is unclear whether the fantastical content impaired EF skills, or the more realistic content improved EF skills. However, using a similar paradigm, a more recent study found that EF skills were impaired immediately after viewing fantastical content in a group of 5- and 6-year-old children (Rhodes et al., 2019). Future research is needed to determine what (if any) are the longer-term consequences of repeated bouts of reduced EF skill performance immediately after viewing nonrealistic digital media content. Currently it is unclear whether nonrealistic digital content actually reduces EF skills versus reduces EF performance. For example, children may continue to think about the (potentially more interesting) nonrealistic content, and so are distracted when their EF skills are measured right after watching this content, even if their EF capabilities are still intact.

Interactive content may have the potential to mitigate some of the negative effects of unrealistic content on EF skills. In one study, 4- to 6-year old children who played an interactive app that contained fantastical content showed no change in inhibitory control, whereas children who watched fantastical content showed poor inhibitory control as measured by a go/no-go task (Li et al., 2018). Interacting with fantastical events in a physical way (i.e., by touching the screen) may make fantastical events more "real." Indeed, when the researchers asked the children whether the events in the video or game could happen in real life or only in a video or game, children in the interactive condition were more likely to respond that the fantastical events could happen in real life.

Fast-paced images and sounds

A concern that is often raised about digital media and very young children is exposure to "non-normative" stimulation (Anderson et al., 1977; Christakis et al., 2018). For example, researchers analyzed 59 DVDs designed for children younger than 3 years and found that most of the content contained high concentrations of perceptually salient features (e.g., rapid pace and camera cuts), which can be difficult even for older children to understand (Goodrich et al., 2009).

Furthermore, concentrations of reflective features which provide opportunities to rehearse content (e.g., singing, rhyming, camera zooms, and moderate character action) were relatively rare. The suggestion is that this kind of content compels children to sustain attention to the screen longer than natural and increases children's desire to be constantly stimulated without mental effort, thereby potentially disrupting attentional regulatory abilities (Pempek et al., 2010).

However, two studies specifically investigated the effect of pacing and editing on preschool children's EF skills and found no differences in EF skills between children exposed to fast-paced or slow-paced clips of *Sesame Street* or a video of an adult reading a story (Anderson et al., 1977; Cooper et al., 2009). Brain-imaging studies and studies that measure physiological responses while engaging with digital media are needed to further evaluate to what extent and at what age the formal features of digital media might significantly disrupt children's attentional processing and learning. For example, highly salient content might elicit attention but also distract children from allocating mental resources to learning meaningful content, thereby reducing the value of the content (Barr et al., 2018).

Violent and other negative content

Research indicates that children's consumption of violent and sexually charged content is related to increased displays of aggression, antisocial behavior, and poorer academic achievement (Bushman & Huesmann, 2006; Common Sense Media, 2013; Friedrich & Stein, 1973). Such content has also been linked to attentional problems in young children. In one experimental study, 4- and 5-year-old children watched an episode of *Mr. Rogers' Neighborhood* or *Mighty Morphin Power Rangers* and then were observed for 30 minutes in a playroom with seven activity centers. (The control group went straight to the playroom.) (Geist & Gibson, 2000). Children who viewed *Mighty Morphin Power Rangers* spent less time at each activity center and switched between the activity centers more frequently, potentially indicating reduced ability or inclination to sustain attention on one task.

By contrast, the children who watched *Mr. Rogers' Neighborhood* did not differ significantly in their play behavior to the control group. In another study conducted with younger children, each hour of viewing violent content (e.g., Looney Tunes) before age 3 was associated with approximately double the odds for attentional problems in childhood (Zimmerman & Christakis, 2007). Nonviolent entertainment content (e.g., *The Aristocats*) was also associated with increased odds for attentional problems, but less so. By contrast, viewing educational content (e.g., *Sesame Street*) before age 3 was not associated with an increased odds of attentional problems five years later.

Interactive content and digital games

There is good reason to think that interactive content is less akin to more passive forms of digital media (like watching video content) and more similar to children's real-world toy play: Both interactive digital content and real-world toys often can respond to something a child does (*reactivity*), can prompt reactions from a child based on actions that he or she took (*interactivity*), can be manipulated differently based on the age of the child (*tailorability*), can build upon or scaffold a child's learning through increasing challenges and complexity (*progressiveness*), and can promote social interaction (*joint attention*) (Christakis, 2014).

Today, interactive apps and video games incorporate many features that psychologists, neuroscientists, and educators believe are critical for learning, such as active engagement, motivation, reward, and contingent feedback (Eichenbaum et al., 2014; Flynn et al., 2019; Kirkorian, 2018). However, whether and when the influence of digital games on the brain is positive or negative is hotly debated (Eichenbaum et al., 2014; Gorman & Green, 2017; Halbrook et al., 2019; Kovess-Masfety et al., 2016; Kulman et al., 2014).
Some researchers have also questioned whether the highly publicized negative effects of video game play are large enough to warrant concern. For example, a meta-analysis of 101 studies of children between age 5 and 17 found only weak evidence for a relationship between gaming and aggression, reduced prosocial behavior, reduced academic performance, depressive symptoms, and attention deficit symptoms (Ferguson, 2015). Complicating matters is the fact that even a single game, like Grand Theft Auto, could potentially have positive (improved visual processing) and negative effects (increased aggressive thoughts and feelings) on players (Prot et al., 2012).

To date, the majority of research on video games has considered the effects of the "action" genre (typically first- or third-person shooter games) in adolescents and adults (Dale et al., 2020). However, a small number of studies have considered the impact of commercial video games on EF development in children younger than 8. For more general review, see Blumberg et al. (2013).

In one study, researchers investigated EF skills in 2- and 3-year-old children before and after exposure to one of three different touchscreen-based interventions: (a) a noneducational cartoon (*Penguins of Madagascar*), (b) an educational video (*Sesame Street*) or (c) an educational app (Shiny Party) (Huber et al., 2018). The researchers found that inhibitory control and working memory improved only for children in the educational app condition.

In another study, 4- to 6-year-olds played either (a) the arcade game Whac-A-Mole[1], (b) Talking Tom Gold Run[2], or (c) no game for five minutes a day, for five days (Liu et al., 2019). Both video games require children, in one way or another, to focus on selecting target items (i.e., the mole or gold) while avoiding nontarget items (i.e., bombs or obstacles). At the end of the five-day period, children who played video games performed better on a measure of inhibitory control measure relative to the control group.

While it is clear that digital games can be powerful teaching tools (Green & Bavelier, 2012; Levine & Vaala, 2013; Prot et al., 2012), not all interactive content designed for children is necessarily high quality. For example, interactive features can be used to direct attention toward a relevant learning goal or increase motivation. Interactive features can also present a learning challenge in themselves (e.g., requiring a complex button press), derailing a young child's attention and learning (Bus et al., 2015). Similarly, commercially available games often include bells and whistles designed to increase interest but might also distract young children from a learning goal (Hirsh-Pasek et al., 2015).

Lastly, some research has suggested that interactive content may, at times, discourage joint media engagement, while user-paced games that allow multitouch input may support JME (Hiniker et al., 2018). For example, when digital games provide feedback to scaffold a child's behavior, parents may be more likely to let the device do the teaching, so to speak. Also, the handheld design affordances of tablets may lead to children using them in a more solitary way, positioning their body in a manner that precludes JME (Munzer et al., 2019).

3. Digital Media Balance, Screen Time, and EF Skills

It is a common and long-standing concern among parents, practitioners, and policymakers that children are spending too much time in front of a screen (Chassiakos et al., 2016; Council on Communications and Media, 2016). Time spent with screen media has been suggested to displace activities that would otherwise provide a better forum for children to develop, practice, and strengthen EF skills (Calvert & Wilson, 2010).

[1] The goal of Whac-A-Mole is to force the moles that have popped up back into their holes by whacking them with a mallet, and to avoid hitting other objects, such as bombs.
[2] The goal of Talking Tom Gold Run is to make characters (such as Talking Tom) run as far as possible on each level while avoiding obstacles and collecting items (e.g., gold bars).

However, there are alternatives to the displacement hypothesis. It could be the case that as screen time increases, the amount of inappropriate content consumed also increases. It could also be that children who experience increased screen time have other obstacles to developing EF skills, such as less access to sensitive caregiving or learning environments that build EF skills. Another possibility is that children with weaker EF skills may be more likely to seek out screen time. Or that families experiencing more stress rely on screen time more.

It is important to note that the studies reviewed below should be interpreted with caution: Although screen time is a useful measure, it does not take into account the content children are consuming, including the quality of programming, how interactive the experience is, and those with whom children are sharing the experience.

High amounts of screen time

Several cross-sectional and longitudinal studies have found a link between the amount of screen time and attentional control (Acevedo-Polakovich et al., 2006; Christakis et al., 2004; Courage, 2017; Ferguson, 2011; Gentile et al., 2012; Hofferth, 2010; Johnson et al., 2007; Miller et al., 2006; Swing et al., 2010). In one study, researchers found that children who viewed more television at age 7 were more likely to show weaker attentional focus at age 8 (Acevedo-Polakovich et al., 2006). In another study, researchers looked at video game playing in a large sample of children age 6 to 12 and compiled teacher reports of attentional problems (e.g., difficulty staying on task, difficulty paying attention, or frequently interrupting other children).

Increased video game playing was associated with higher attentional problems on the teacher-reported measure, and this effect was similar in magnitude to the association between attentional problems and television viewing. In another study, conducted with older children (age 8 to 17), time spent playing video games was a more robust predictor of attentional problems three years later than playing video games with violent content (although this was also significant) (Gentile et al., 2012).

High levels of digital media exposure *throughout* childhood are more strongly related to poor EF skill development compared to high levels at a single point in childhood. For example, one study reported that watching more than two hours of television daily at age 2 was not linked to attentional problems at age 5 (Mistry et al., 2007). However, for children for whom this high level of exposure to television was sustained (i.e., was greater than two hours a day at both age 2 and 5), exposure to television predicted greater attentional problems at age 5, in addition to more sleep problems, aggressive behavior, and externalizing behavior.

Children with poorer attentional control may be more likely to consume greater amounts of digital media, indicating a bidirectional relationship between screen time and this specific EF skill (Acevedo-Polakovich et al., 2006; Gentile et al., 2012). However, further research is needed to determine why because a number of child- and context-specific factors could explain this effect. For example, it could be that children seek this kind of activity themselves, or that parents opt for digital media as a way to manage difficult behaviors. It could also be that high amounts of digital media consumption is a proxy for high parental media consumption and interference of digital media in the home and family relationships.

Evidence for a relationship between screen time and core EF skills (i.e., working memory, inhibitory control, and cognitive flexibility) is mixed—some studies have reported linear relationships between core EF skills and high amounts of digital media use, while others have found no relationship (Jusienė et al., 2020; Munzer et al., 2018; Nathanson et al., 2014; Zimmerman & Christakis, 2005). For example, one study found a link between the amount of TV exposure before age 3, and poorer working memory at age 6 (Zimmerman & Christakis, 2005). Another study found increased screen time at 4 months was related to poorer inhibitory control at 14 months, but not working memory or cognitive flexibility (McHarg et al., 2020).

However, an outstanding question is what constitutes a *high* amount of screen time? For example, in one study, every hour of television viewed per day at age 1 and 3 was associated with higher odds of attentional problems at age 7 (Christakis et al., 2004). However, a different group of researchers analyzed the same dataset using different criteria and found that only children who watched very high amounts of television (more than seven hours daily, 10% of the sample) were more likely to show attentional problems at age 7 (Foster & Watkins, 2010). These researchers also found that when poverty status and maternal efficacy were included in the analysis, there was no statistically significant link between watching television before age 3 and attentional problems at age 7.

Similarly, another study that investigated digital media use in 4-year-olds found the relationship between screen time and EF skill development was only significant at higher amounts of screen time: "High-dose app users" (i.e., 30 minutes or more per day) had significantly lower inhibitory control scores 12 months later compared to "low-dose app users" (i.e., one to 29 minutes per day) (McNeill et al., 2019). Research that investigates whether there are threshold effects above which a deleterious relationship between screen time and core EF skills exists in very young children is greatly needed.

Age of onset

Today, infants as young as 4 months are interacting with digital media, whereas 50 years ago regular television viewing didn't occur until age 4 (Chassiakos et al., 2016). Most people have watched in wonder as a child too young to hold a book deftly swipes across a touchscreen, or sits silently at a restaurant, engrossed in the show playing on their parents' iPad. Recently researchers have begun to investigate whether the age at which infants begin being exposed directly to digital media (including background television) has an impact on brain development. Currently only a few correlational studies exist, although their findings are similar: Children whose exposure to digital media occurred earlier in life were more likely to show poorer EF skills during the preschool years (Cheng et al., 2010; Madigan et al., 2020; Nathanson et al., 2014; Supanitayanon et al., 2020). More research is needed to disentangle why the relationship between early screen exposure and poorer EF development exists.

Using digital media as a coping strategy

Self-regulation refers to a child's increasing skill in managing his or her emotions, behaviors, and attention in order to achieve goals. This includes not only intentional modification (like deep breathing when feeling anxious), but also unintentional, involuntary processes, like shivering to increase body temperature. In infancy, most self-regulation occurs automatically. As children age, self-regulation becomes increasingly intentional. When it is intentional, self-regulation draws on EF skills, especially in situations when individuals purposefully control their behavior, emotional reactions, or social interactions to achieve a goal (Hofmann et al., 2012)

Infants and toddlers with self-regulation difficulties (i.e., problems with self-soothing, sleep, emotional regulation, and attention) are more likely to view more media at age 2 (Munzer et al., 2018; Raman et al., 2017), and are more likely to be given media to calm down (Radesky et al., 2016). It is unclear why this is the case. Researchers are investigating whether there is a bidirectional link between self-regulation and children's media use: Parents may try to soothe or manage more difficult children with screen time, which in turn exacerbates regulatory difficulties as a result of reduced parent-child interactions and potential exposure to inappropriate content (Cliff et al., 2018; McDaniel & Radesky, 2018; Radesky & Christakis, 2016). Currently, this is an important area for future research.

Sedentary behavior, screen time, and executive function

Physical activity is essential for healthy brain function and has both short- and long-term benefits for cognitive performance (Etnier & Chang, 2009; Loprinzi et al., 2013). Many studies have linked high amounts of screen time to increased sedentary behavior in young children (Byun et al., 2011; Carson et al., 2015). Video games that get players moving, known as exergames, might be one way to reduce sedentary behavior (O'Leary et al., 2011; Staiano & Calvert, 2011). Even short bouts of physical activity can increase physiological arousal resulting in positive short-term effects on EF skill performance. For example, in one study 6- to 10-year-olds who played a physically active video game outperformed children who engaged in a cognitively engaging but sedentary video game on a test of EF skills (Best, 2012). However, despite such benefits, many researchers agree that exergames should be used as a fun addition to alternative forms of physical activity, rather than as a substitute.

Sleep, screen time, and executive function

The amount of sleep infants and young children get is directly related to brain development and learning. During sleep, important processes, such as memory consolidation and synaptic pruning, take place (Astill et al., 2012). Screen time may disrupt sleep (Magee et al., 2014), which in turn disrupts the development of EF skills. Children who lack adequate sleep may be less able to engage actively with digital media (compared to children who have adequate sleep) and instead consume digital media passively, reducing opportunities for engaging in learning. For example, researchers observed a negative relation between preschoolers' tablet time and hot EF skills (Nathanson & Beyens, 2018). However, this relationship only existed for preschoolers who slept for less than about 10.5 hours each night (approximately 40% of children in the study). By contrast, for children who slept for more than about 10.5 hours each night, handheld game playing was positively related to hot EF skills.

Implications and Future Research

Important research and programmatic work is still needed to build a robust body of knowledge about the role of digital media in young children's EF skill development. Based on our literature review, we identified a number of questions and assumptions that researchers have not yet addressed or answered. These questions suggest cautions for how research is interpreted, and point to future directions for children's digital media research.

Before turning to gaps in the literature, we wish to highlight the following: The sheer volume of digital media experiences available to young children and families, and the multitude of variables that determine healthy brain development make it implausible for researchers to carry out scientific studies that evaluate the impact of every digital media scenario on EF skill development. Rather than getting lost in the details of each unique digital media experience, we suggest digital media research should focus on the ways families can use their experiences with media and technology as "everyday" moments that can be used to strengthen parent-child relationships as well as children's development of essential life skills.

We identified the following gaps in the literature, organized by major priorities and questions for the field:

Research

- What populations are most at risk/benefit most from digital media?
- What is the "threshold" for too much media use, and what are the key factors that serve as protective factors to mitigate negative effects? What are the long-term effects of exposure to digital media?
- What frequency of ads in apps, YouTube videos, and other platforms interferes with child comprehension or learning?
- How do children understand and react to mobile advertising, persuasive design, or other design features that interact with aspects of EF such as impulse inhibition? Why do children with poorer attentional focus use more digital media?
- Longitudinal associations between technoference and child EF skill: Is there a relationship, and is it stronger/weaker in children/parents who have weak EF skills? Is it moderated by overall parenting sensitivity, autonomy support, or frequency of other EF-building activities?
- Do children orient differently to different types of interactive designs? That is, is there evidence that children are more minds-on with certain types of design/content, and more passive with others (e.g., frictionless feeds, more subtle nudges)?

- General need for more research on modern media (YouTube, SVOD) and contexts (bedtime, other daily routines in which EF skills/self-regulation are practiced)

- Experimental/interventional work that doesn't rely on behavior change from exhausted parents—many of whom also have EF deficits (e.g., Wi-Fi settings or smart TV settings that elevate positive content, designs that encourage JME/parent involvement, and designs that encourage transfer to 3D life and nudge children off).

Policy

- What content should we be encouraging children to use, and at what ages?

- Given the small effect sizes reported in the literature, how concerned should parents, practitioners, and policymakers be, and how should digital media use be prioritized relative to other child development concerns?

- Under what conditions does digital media make a positive difference? How do we support systems that maximize the beneficial effects of digital media and minimize the negative effects?

- How can stakeholders in children's lives increase the extent to which skills learned in the context of digital media will transfer to nondigital contexts?

- How can families from all socioeconomic (SES) backgrounds make the most out of joint media experiences? For example, families from high SES backgrounds may have more time or resources to curate joint media experiences with children than low SES families. However, children from low SES backgrounds, or with less-educated mothers tend to watch more television than children from higher SES backgrounds, and presumably would benefit most from joint media experiences.

- What sort of expectations should parents have around the role of educational content in teaching EF skills? Do those EF skills generalize to everyday behaviors?

- What are the best strategies in helping parents and children use media to cope with stress?

- Can children's (or parents') EF abilities be inferred from their app/gameplay, and how can this data be protected and not exploited?

The findings reviewed here have practical implications for multiple stakeholders, including program developers, service providers, researchers, evaluators, educators, practitioners, and policymakers. In addition, they allow each stakeholder to consider their own role in communicating the role of digital media in young children's EF skill development with more accuracy and transparency.

References

Acevedo-Polakovich, I. D., Lorch, E. P., Milich, R., & Ashby, R. D. (2006). Disentangling the relation between television viewing and cognitive processes in children with attention-deficit/hyperactivity disorder and comparison children. *Archives of Pediatrics & Adolescent Medicine*, *160*(4), 354–360. https://doi.org/10.1001/archpedi.160.4.354

Anderson, D. R., Bryant, J., Wilder, A., Santomero, A., Williams, M., & Crawley, A. M. (2000). Researching Blue's Clues: Viewing behavior and impact. *Media Psychology*, *2*(2), 179–194.

Anderson, D. R., & Hanson, K. G. (2017). Screen media and parent–child interactions. In R. Barr & D. N. Linebarger (Eds.), *Media exposure during infancy and early childhood: The effects of content and context on learning and development* (pp. 173–194). https://doi.org/10.1007/978-3-319-45102-2_11

Anderson, D. R., Levin, S. R., & Lorch, E. P. (1977). The effects of TV program pacing on the behavior of preschool children. *AV Communication Review*, *25*(2), 159–166.

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

Astill, R. G., Van der Heijden, K. B., Van Ijzendoorn, M. H., & Van Someren, E. J. W. (2012). Sleep, cognition, and behavioral problems in school-age children: A century of research meta-analyzed. *Psychological Bulletin*, *138*(6), 1109–1138. https://doi.org/10.1037/a0028204

Barker, J. E., Semenov, A. D., Michaelson, L., Provan, L. S., Snyder, H. R., & Munakata, Y. (2014). Less-structured time in children's daily lives predicts self-directed executive functioning. *Frontiers in Psychology*, *5*. https://doi.org/10.3389/fpsyg.2014.00593

Barr, R. (2010). Transfer of learning between 2D and 3D sources during infancy: Informing theory and practice. *Developmental Review*, *30*(2), 128–154. https://doi.org/10.1016/j.dr.2010.03.001

Barr, R. (2019). Growing up in the digital age: Early learning and family media ecology. *Current Directions in Psychological Science*, *28*(4), 341–346. https://doi.org/10.1177/0963721419838245

Barr, R., & Hayne, H. (1999). Developmental changes in imitation from television during infancy. *Child Development*, *70*(5), 1067–1081. https://doi.org/10.1111/1467-8624.00079

Barr, R., Lauricella, A., Zack, E., & Calvert, S. (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*(1), 21–48. https://doi.org/10.1353/mpq.0.0038

Barr, R., McClure, E., & Parlakian, R. (2018). *What the research says about the impact of media on children aged 0-3 years old*. Retrieved from Zero to Three website: https://www.zerotothree.org/resources/2536-screen-sense-what-the-research-says-about-the-impact-of-media-on-children-aged-0-3-years-old

Barr, R., Muentener, P., & Garcia, A. (2007). Age-related changes in deferred imitation from television by 6- to 18-month-olds. *Developmental Science*, *10*(6), 910–921. https://doi.org/10.1111/j.1467-7687.2007.00641.x

Best, J. R. (2012). Exergaming immediately enhances children's executive function. *Developmental Psychology*, *48*(5), 1501–1510. https://doi.org/10.1037/a0026648

Bierman, K. L., Domitrovich, C. E., Nix, R. L., Gest, S. D., Welsh, J. A., Greenberg, M. T., Blair, C., Nelson, K. E., & Gill, S. (2008). Promoting academic and social-emotional school readiness: The Head Start REDI program. *Child Development*, *79*(6), 1802–1817.

Blakey, E., & Carroll, D. J. (2015). A short executive function training program improves preschoolers' working memory. *Frontiers in Psychology*, *6*. https://doi.org/10.3389/fpsyg.2015.01827

Blumberg, F. C., Altschuler, E. A., Almonte, D. E., & Mileaf, M. I. (2013). The impact of recreational video game play on children's and adolescents' cognition. *New Directions for Child and Adolescent Development*, *2013*(139), 41–50. https://doi.org/10.1002/cad.20030

Brito, N., Barr, R., McIntyre, P., & Simcock, G. (2012). Long-term transfer of learning from books and videos during toddlerhood. *Journal of Experimental Child Psychology*, *111*(1), 108–119. https://doi.org/10.1016/j.jecp.2011.08.004

Bruner, J. S. (1983). Education as social invention. *Journal of Social Issues*, *39*(4), 129–141. https://doi.org/10.1111/j.1540-4560.1983.tb00179.x

Buckner, J. C., Mezzacappa, E., & Beardslee, W. R. (2003). Characteristics of resilient youths living in poverty: The role of self-regulatory processes. *Development and Psychopathology*, *15*(1), 139–162.

Buckner, J. C., Mezzacappa, E., & Beardslee, W. R. (2009). Self-regulation and its relations to adaptive functioning in low income youths. *American Journal of Orthopsychiatry*, *79*(1), 19–30.

Bus, A. G., Takacs, Z. K., & Kegel, C. A. T. (2015). Affordances and limitations of electronic storybooks for young children's emergent literacy. *Developmental Review*, *35*, 79–97. https://doi.org/10.1016/j.dr.2014.12.004

Bushman, B. J., & Huesmann, L. R. (2006). Short-term and long-term effects of violent media on aggression in children and adults. *Archives of Pediatrics & Adolescent Medicine*, *160*(4), 348–352. https://doi.org/10.1001/archpedi.160.4.348

Byun, W., Dowda, M., & Pate, R. R. (2011). Correlates of objectively measured sedentary behavior in US preschool children. *Pediatrics*, *128*(5), 937–945. https://doi.org/10.1542/peds.2011-0748

Calvert, S. L., & Wilson, B. J. (2010). *The handbook of children, media, and development*. Thousand Oaks, CA: Sage Publishing.

Carpenter, M., & Tomasello, M. (1995). Joint attention and imitative learning in children, chimpanzees, and enculturated chimpanzees. *Social Development*, *4*(3), 217–237.

Carson, V., Kuzik, N., Hunter, S., Wiebe, S. A., Spence, J. C., Friedman, A., Tremblay, M. S., Slater, L. G., & Hinkley, T. (2015). Systematic review of sedentary behavior and cognitive development in early childhood. *Preventive Medicine*, *78*, 115–122. https://doi.org/10.1016/j.ypmed.2015.07.016

Chassiakos, Y. R., Radesky, J. S., Christakis, D., Moreno, M. A., Cross, C., & Council on Communications and Media. (2016). Children and adolescents and digital media. *Pediatrics*, *138*(5). https://doi.org/10.1542/peds.2016-2593

Cheng, S., Maeda, T., Yoichi, S., Yamagata, Z., Tomiwa, K., & Japan Children's Study Group. (2010). Early television exposure and children's behavioral and social outcomes at age 30 months [Supplement 2]. *Journal of Epidemiology*, *20*, S482–489. https://doi.org/10.2188/jea.je20090179

Christakis, D. A. (2014). Interactive media use at younger than the age of 2 years: Time to rethink the American Academy of Pediatrics guideline? *JAMA Pediatrics*, *168*(5), 399–400. https://doi.org/10.1001/jamapediatrics.2013.5081

Christakis, D. A., Ramirez, J. S. B., Ferguson, S. M., Ravinder, S., & Ramirez, J.-M. (2018). How early media exposure may affect cognitive function: A review of results from observations in humans and experiments in mice. *Proceedings of the National Academy of Sciences*, *115*(40), 9851–9858. https://doi.org/10.1073/pnas.1711548115

Christakis, D. A., Zimmerman, F. J., DiGiuseppe, D. L., & McCarty, C. A. (2004). Early television exposure and subsequent attentional problems in children. *Pediatrics*, *113*(4), 708–713.

Cliff, D. P., Howard, S. J., Radesky, J. S., McNeill, J., & Vella, S. A. (2018). Early childhood media exposure and self-regulation: Bidirectional longitudinal associations. *Academic Pediatrics*, *18*(7), 813–819. https://doi.org/10.1016/j.acap.2018.04.012

Common Sense Media. (2013). *Media and violence: An analysis of current research*. Retrieved from Common Sense Media website: https://www.commonsensemedia.org/research/media-and-violence-an-analysis-of-current-research

Cooper, N. R., Uller, C., Pettifer, J., & Stolc, F. C. (2009). Conditioning attentional skills: Examining the effects of the pace of television editing on children's attention. *Acta Paediatrica*, *98*(10), 1651–1655. https://doi.org/10.1111/j.1651-2227.2009.01377.x

Council on Communications and Media. (2016). Media and young minds. *Pediatrics*, *138*(5). https://doi.org/10.1542/peds.2016-2591

Courage, M. L. (2017). Screen media and the youngest viewers: Implications for attention and learning. In *Cognitive Development in Digital Contexts* (pp. 3–28). https://doi.org/10.1016/B978-0-12-809481-5.00001-8

Courage, M. L., & Howe, M. L. (2010). To watch or not to watch: Infants and toddlers in a brave new electronic world. *Developmental Review*, *30*(2), 101–115.

Dale, G., Joessel, A., Bavelier, D., & Green, C. S. (2020). A new look at the cognitive neuroscience of video game play. *Annals of the New York Academy of Sciences*, *1464*(1), 192–203. https://doi.org/10.1111/nyas.14295

Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, *64*(1), 135–168. https://doi.org/10.1146/annurev-psych-113011-143750

Diamond, A., & Lee, K. (2011). Interventions shown to aid executive function development in children 4–12 years old. *Science (New York, N.Y.)*, *333*(6045), 959–964. https://doi.org/10.1126/science.1204529

Eichenbaum, A., Bavelier, D., & Green, C. S. (2014). Video games: Play that can do serious good. *American Journal of Play*, *7*(1), 50–72.

Elson, M., Ferguson, C. J., Gregerson, M., Hogg, J. L., Ivory, J., Klisanin, D., Markey, P. M., Nichols, D., Siddiqui, S., & Wilson, J. (2019). Do policy statements on media effects faithfully represent the science? *Advances in Methods and Practices in Psychological Science*, *2*(1), 12–25.

Etnier, J. L., & Chang, Y.-K. (2009). The effect of physical activity on executive function: A brief commentary on definitions, measurement issues, and the current state of the literature. *Journal of Sport and Exercise*

Psychology, *31*(4), 469–483. https://doi.org/10.1123/jsep.31.4.469

Evans, G. W., & Kim, P. (2013). Childhood poverty, chronic stress, self-regulation, and coping. *Child Development Perspectives*, *7*(1), 43–48.

Ewin, C. A., Reupert, A. E., McLean, L. A., & Ewin, C. J. (2020). The impact of joint media engagement on parent–child interactions: A systematic review. *Human Behavior and Emerging Technologies*, *n/a*(n/a), 1–25. https://doi.org/10.1002/hbe2.203

Farah, M. J., Shera, D. M., Savage, J. H., Betancourt, L., Giannetta, J. M., Brodsky, N. L., Malmud, E. K., & Hurt, H. (2006). Childhood poverty: Specific associations with neurocognitive development. *Brain Research*, *1110*(1), 166–174. https://doi.org/10.1016/j.brainres.2006.06.072

Ferguson, C. J. (2011). The influence of television and video game use on attention and school problems: A multivariate analysis with other risk factors controlled. *Journal of Psychiatric Research*, *45*(6), 808–813. https://doi.org/10.1016/j.jpsychires.2010.11.010

Ferguson, C. J. (2015). Do Angry Birds make for angry children? A meta-analysis of video game influences on children's and adolescents' aggression, mental health, prosocial behavior, and academic performance. *Perspectives on Psychological Science*, *10*(5), 646–666. https://doi.org/10.1177/1745691615592234

Ferguson, C. J., & Donnellan, M. B. (2014). Is the association between children's baby video viewing and poor language development robust? A reanalysis of Zimmerman, Christakis, and Meltzoff (2007). *Developmental Psychology*, *50*(1), 129–137. https://doi.org/10.1037/a0033628

Ferguson, C. J., & Kilburn, J. (2010). Much ado about nothing: The misestimation and overinterpretation of violent video game effects in Eastern and Western nations: Comment on Anderson et al. (2010). *Psychological Bulletin*, *136*(2), 174–178. https://doi.org/10.1037/a0018566

Fidler, A. E., Zack, E., & Barr, R. (2010). Television viewing patterns in 6-to 18-month-olds: The role of caregiver-infant interactional quality. *Infancy*, *15*(2), 176–196.

Fleer, M. (2018). Digital animation: New conditions for children's development in play-based setting. *British Journal of Educational Technology*, *49*(5), 943–958. https://doi.org/10.1111/bjet.12637

Flynn, R. M., Richert, R. A., & Wartella, E. (2019). Play in a digital world: How interactive digital games shape the lives of children. *American Journal of Play*, *12*(1), 54–73.

Follmer, S., Raffle, H., Go, J., Ballagas, R., & Ishii, H. (2010). Video play: Playful interactions in video conferencing for long-distance families with young children. *Proceedings of the 9th International Conference on Interaction Design and Children*, 49–58. https://doi.org/10.1145/1810543.1810550

Foster, E. M., & Watkins, S. (2010). The value of reanalysis: TV viewing and attention problems. *Child Development*, *81*(1), 368–375. https://doi.org/10.1111/j.1467-8624.2009.01400.x

Friedrich, L. K., & Stein, A. H. (1973). Aggressive and prosocial television programs and the natural behavior of preschool children. *Monographs of the Society for Research in Child Development*, *38*(4), 1–64. https://doi.org/10.2307/1165725

Galinsky, E. (2010). *Mind in the making: The seven essential life skills every child needs*. New York, NY: HarperStudio.

Galinsky, E., Bezos, J., McClelland, M., Carlson, S. M., & Zelazo, P. (2017). Civic science for public use: Mind in the Making and Vroom. *Child Development*, *88*(5), 1409–1418. https://doi.org/10.1111/cdev.12892

Garon, N., Bryson, S. E., & Smith, I. M. (2008). Executive function in preschoolers: A review using an integrative framework. *Psychological Bulletin*, *134*(1), 31–60. https://doi.org/10.1037/0033-2909.134.1.31

Geist, E. A., & Gibson, M. (2000). The effect of network and public television programs on four and five year olds ability to attend to educational tasks. *Journal of Instructional Psychology*, *27*(4), 250–250.

Gentile, D. A., Swing, E. L., Lim, C. G., & Khoo, A. (2012). Video game playing, attention problems, and impulsiveness: Evidence of bidirectional causality. *Psychology of Popular Media Culture*, *1*(1), 62–70. https://doi.org/10.1037/a0026969

Ginsburg, K. R. (2007). The importance of play in promoting healthy child development and maintaining strong parent-child bonds. *Pediatrics*, *119*(1), 182–191. https://doi.org/10.1542/peds.2006-2697

Gola, A. A. H., Richards, M. N., Lauricella, A. R., & Calvert, S. L. (2013). Building meaningful parasocial relationships between toddlers and media characters to teach early mathematical skills. *Media Psychology*, *16*(4), 390–411. https://doi.org/10.1080/15213269.2013.783774

Golinkoff, R. M., Hirsch-Pasek, K., & Ever, D. (2003). *Einstein never used flashcards*. New York, NY: Rodale.

Goodrich, S. A., Pempek, T. A., & Calvert, S. L. (2009). Formal production features of infant and toddler DVDs. *Archives of Pediatrics & Adolescent Medicine*, *163*(12), 1151–1156.

Gorman, T. E., & Green, C. S. (2017). Young minds on video games. In F. C. Blumberg & P. J. Brooks (Eds.), *Cognitive development in digital contexts* (pp. 121–143). https://doi.org/10.1016/B978-0-12-809481-5.00006-7

Green, C. S., & Bavelier, D. (2012). Learning, attentional control and action video games. *Current Biology*, *22*(6), R197–R206. https://doi.org/10.1016/j.cub.2012.02.012

Haft, S. L., & Hoeft, F. (2017). Poverty's impact on children's executive functions: Global considerations. *New Directions for Child and Adolescent Development*, *2017*(158), 69–79. https://doi.org/10.1002/cad.20220

Halbrook, Y. J., O'Donnell, A. T., & Msetfi, R. M. (2019). When and how video games can be good: A review of the positive effects of video games on well-being. *Perspectives on Psychological Science*, *14*(6), 1096–1104.

Hammond, S. I., Müller, U., Carpendale, J. I., Bibok, M. B., & Liebermann-Finestone, D. P. (2012). The effects of parental scaffolding on preschoolers' executive function. *Developmental Psychology*, *48*(1), 271.

Hampshire, A., Sandrone, S., & Hellyer, P. J. (2019). A large-scale, cross-sectional investigation into the efficacy of brain training. *Frontiers in Human Neuroscience*, *13*. https://doi.org/10.3389/fnhum.2019.00221

Hassinger-Das, B., Jordan, N. C., Glutting, J., Irwin, C., & Dyson, N. (2014). Domain-general mediators of the relation between kindergarten number sense and first-grade mathematics achievement. *Journal of Experimental Child Psychology*, *118*, 78–92. https://doi.org/10.1016/j.jecp.2013.09.008

Hiniker, A., Lee, B., Kientz, J. A., & Radesky, J. S. (2018). Let's play! Digital and analog play between preschoolers and parents. *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, 1–13.

Hirsh-Pasek, K., Zosh, J. M., Golinkoff, R. M., Gray, J. H., Robb, M. B., & Kaufman, J. (2015). Putting education in "educational" apps: Lessons from the science of learning. *Psychological Science in the Public Interest*, *16*(1), 3–34. https://doi.org/10.1177/1529100615569721

Hofferth, S. L. (2010). Home media and children's achievement and behavior. *Child Development*, *81*(5), 1598–1619. https://doi.org/10.1111/j.1467-8624.2010.01494.x

Hofmann, W., Schmeichel, B. J., & Baddeley, A. D. (2012). Executive functions and self-regulation. *Trends in Cognitive Sciences*, *16*(3), 174–180. https://doi.org/10.1016/j.tics.2012.01.006

Hooft Graafland, J. (2018). *New technologies and 21st century children: Recent trends and outcomes* (OECD Education Working Paper No. 179). Organisation for Economic Cooperation and Development. https://doi.org/10.1787/e071a505-en

Huber, B., Tarasuik, J., Antoniou, M. N., Garrett, C., Bowe, S. J., & Kaufman, J. (2016). Young children's transfer of learning from a touchscreen device. *Computers in Human Behavior*, *56*, 56–64. https://doi.org/10.1016/j.chb.2015.11.010

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

Johnson, J. G., Cohen, P., Kasen, S., & Brook, J. S. (2007). Extensive television viewing and the development of attention and learning difficulties during adolescence. *Archives of Pediatrics & Adolescent Medicine*, *161*(5), 480–486.

Jones, S. M., Bailey, R., Barnes, S. P., Partee, A. (2016). *Executive function mapping project: Untangling the terms and skills related to executive function and self-regulation in early childhood*. Retrieved from U.S. Department of Health and Human Services Office of Planning, Research and Evaluation website: https://www.acf.hhs.gov/sites/default/files/opre/efmapping_report_101416_final_508.pdf

Jones, S. M., Brown, J. L., & Aber, J. L. (2011). Two-year impacts of a universal school-based social-emotional and literacy intervention: An experiment in translational developmental research. *Child Development*, *82*(2), 533–554. https://doi.org/10.1111/j.1467-8624.2010.01560.x

Jusienė, R., Rakickienė, L., Breidokienė, R., & Laurinaitytė, I. (2020). Executive function and screen-based media use in preschool children. *Infant and Child Development*, *29*(1), e2173. https://doi.org/10.1002/icd.2173

Kirkorian, H. L. (2018). When and how do interactive digital media help children connect what they see on and off the screen? *Child Development Perspectives*, *12*(3), 210–214. https://doi.org/10.1111/cdep.12290

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.

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

Kolb, B., Mychasiuk, R., Muhammad, A., & Gibb, R. (2013). Brain plasticity in the developing brain. In M. M. Merzenich, M. Nahum, & T. M. Van Vleet (Eds.), *Progress in Brain Research* (Vol. 207, pp. 35–64). https://doi.org/10.1016/B978-0-444-63327-9.00005-9

Kovess-Masfety, V., Keyes, K., Hamilton, A., Hanson, G., Bitfoi, A., Golitz, D., Koç, C., Kuijpers, R., Lesinskiene, S., Mihova, Z., Otten, R., Fermanian, C., & Pez, O. (2016). Is time spent playing video games associated with mental health, cognitive and social skills in young children? *Social Psychiatry and Psychiatric Epidemiology;*

Heidelberg, *51*(3), 349–357. https://doi.org.ezproxy.lib.monash.edu.au/10.1007/s00127-016-1179-6

Kulman, R., Slobuski, T., & Seitsinger, R. (2014). Teaching 21st century, executive-functioning, and creativity skills with popular video games and apps. In Schrier, K. (Ed.), *Learning, education and games, volume 1* (pp. 159–174). Pittsburg, PA: ETC Press.

Lapierre, M. A., Piotrowski, J. T., & Linebarger, D. L. (2012). Background television in the homes of US children. *Pediatrics*, *130*(5), 839–846.

Lauricella, A. R., Cingel, D. P., Beaudoin-Ryan, L., Robb, M. B., Saphir, M., & Wartella, E. A. (2016). *The Common Sense census: Plugged-in parents of tweens and teens*. Retrieved from Common Sense Media website: https://www.commonsensemedia.org/sites/default/files/uploads/research/common-sense-parent-census_whitepaper_new-for-web.pdf

Lerner, C., & Barr, R. (2015). Screen sense: Setting the record straight–research-based guidelines for screen use for children under 3 years old. *Zero to Three*, *35*(4), 1–10.

Levine, M. H., & Vaala, S. E. (2013). Games for learning: Vast wasteland or a digital promise? *New Directions for Child and Adolescent Development*, *2013*(139), 71–82. https://doi.org/10.1002/cad.20033

Li, H., Subrahmanyam, K., Bai, X., Xie, X., & Liu, T. (2018). Viewing fantastical events versus touching fantastical events: Short-term effects on children's inhibitory control. *Child Development*, *89*(1), 48–57. https://doi.org/10.1111/cdev.12820

Lillard, A. S., Drell, M. B., Richey, E. M., Boguszewski, K., & Smith, E. D. (2015). Further examination of the immediate impact of television on children's executive function. *Developmental Psychology*, *51*(6), 792.

Lillard, A. S., & Peterson, J. (2011). The immediate impact of different types of television on young children's executive function. *Pediatrics*, *128*(4), 644–649.

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

Liu, X., Liao, M., & Dou, D. (2019). Video game playing enhances young children's inhibitory control. In X. Fang (Ed.), *HCI in Games* (pp. 141–153). https://doi.org/10.1007/978-3-030-22602-2_12

Loprinzi, P. D., Herod, S. M., Cardinal, B. J., & Noakes, T. D. (2013). Physical activity and the brain: A review of this dynamic, bi-directional relationship. *Brain Research*, *1539*, 95–104. https://doi.org/10.1016/j.brainres.2013.10.004

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*. https://doi.org/10.1001/jamapediatrics.2020.0327

Magee, C. A., Lee, J. K., & Vella, S. A. (2014). Bidirectional relationships between sleep duration and screen time in early childhood. *JAMA Pediatrics*, *168*(5), 465–470. https://doi.org/10.1001/jamapediatrics.2013.4183

Mares, M.-L., & Pan, Z. (2013). Effects of Sesame Street: A meta-analysis of children's learning in 15 countries. *Journal of Applied Developmental Psychology*, *34*(3), 140–151. https://doi.org/10.1016/j.appdev.2013.01.001

Marsh, J. (2014). The relationship between online and offline play: Friendship and exclusion. In A. Burn & C. Richards (Eds.), *Children's games in the new media age: Childlore, media and the playground* (109–132). Farnham, United Kingdom: Ashgate Publishing.

Masur, E. F., Flynn, V., & Olson, J. (2016). Infants' background television exposure during play: Negative relations to the quantity and quality of mothers' speech and infants' vocabulary acquisition. *First Language*, *36*(2), 109–123. https://doi.org/10.1177/0142723716639499

McClelland, M. M., Acock, A. C., Piccinin, A., Rhea, S. A., & Stallings, M. C. (2013). Relations between preschool attention span-persistence and age 25 educational outcomes. *Early Childhood Research Quarterly*, *28*(2), 314–324. https://doi.org/10.1016/j.ecresq.2012.07.008

McClure, E. R., Chentsova-Dutton, Y. E., Barr, R. F., Holochwost, S. J., & Parrott, W. G. (2015). "Facetime doesn't count": Video chat as an exception to media restrictions for infants and toddlers. *International Journal of Child-Computer Interaction*, *6*, 1–6.

McDaniel, B., & Radesky, J. S. (2018). Technoference: Longitudinal associations between parent technology use, parenting stress, and child behavior problems. *Pediatric Research*, *84*(2), 210–218. https://doi.org/10.1038/s41390-018-0052-6

McDaniel, B. T., & Coyne, S. M. (2016). "Technoference": The interference of technology in couple relationships and implications for women's personal and relational well-being. *Psychology of Popular Media Culture*, *5*(1), 85–98. https://doi.org/10.1037/ppm0000065

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*(5), 520–528. https://doi.org/10.1016/j.acap.2019.02.010

Miller, C. J., Marks, D. J., Miller, S. R., Berwid, O. G., Kera, E. C., Santra, A., & Halperin, J. M. (2006). Brief report: Television viewing and risk for attention problems in preschool children. *Journal of Pediatric Psychology*, *32*(4), 448–452. https://doi.org/10.1093/jpepsy/jsl035

Mistry, K. B., Minkovitz, C. S., Strobino, D. M., & Borzekowski, D. L. G. (2007). Children's television exposure and behavioral and social outcomes at 5.5 years: Does timing of exposure matter? *Pediatrics*, *120*(4), 762–769. https://doi.org/10.1542/peds.2006-3573

Moffitt, T. E., Arseneault, L., Belsky, D., Dickson, N., Hancox, R. J., Harrington, H., Houts, R., Poulton, R., Roberts, B. W., & Ross, S. (2011). A gradient of childhood self-control predicts health, wealth, and public safety. *Proceedings of the National Academy of Sciences*, *108*(7), 2693–2698.

Munzer, T. G., Miller, A. L., Peterson, K. E., Brophy-Herb, H. E., Horodynski, M. A., Contreras, D., Sturza, J., Lumeng, J. C., & Radesky, J. S. (2018). Media exposure in low-income preschool-aged children is associated with multiple measures of self-regulatory behavior. *Journal of Developmental and Behavioral Pediatrics*, *39*(4), 303–309. https://doi.org/10.1097/DBP.0000000000000560

Munzer, T. G., Miller, A. L., Weeks, H. M., Kaciroti, N., & Radesky, J. (2019). Parent-toddler social reciprocity during reading from electronic tablets vs print books. *JAMA Pediatrics*. https://doi.org/10.1001/jamapediatrics.2019.3480

Myers, L. J., Crawford, E., Murphy, C., Aka-Ezoua, E., & Felix, C. (2018). Eyes in the room trump eyes on the screen: Effects of a responsive co-viewer on toddlers' responses to and learning from video chat. *Journal of Children and Media*, *12*(3), 275–294. https://doi.org/10.1080/17482798.2018.1425889

Myruski, S., Gulyayeva, O., Birk, S., Perez-Edgar, K., Buss, K. A., & Dennis-Tiwary, T. A. (2018). Digital disruption?: Maternal mobile device use is related to infant social-emotional functioning. *Developmental Science*, *21*(4), e12610. https://doi.org/10.1111/desc.12610

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*(5), 1497–1506. https://doi.org/10.1037/a0035714

Nathanson, A. I., & Beyens, I. (2018). The role of sleep in the relation between young children's mobile media use and effortful control. *British Journal of Developmental Psychology*, *36*(1), 1–21.

National Scientific Council on the Developing Child. (2004). *Young children develop in an environment of relationships*

(NSCDC Working Paper No. 1). Center for the Developing Child at Harvard University. https://developingchild.harvard.edu/resources/wp1/

National Scientific Council on the Developing Child. (2005). *Excessive stress disrupts the architecture of the developing brain* (NSCDC Working Paper No. 2). Center for the Developing Child at Harvard University. https://developingchild.harvard.edu/wp-content/uploads/2005/05/Stress_Disrupts_Architecture_Developing_Brain-1.pdf

National Scientific Council on the Developing Child. (2007). *The timing and quality of early experiences combine to shape brain architecture* (NSCDC Working Paper No. 5). Center for the Developing Child at Harvard University. https://developingchild.harvard.edu/resources/the-timing-and-quality-of-early-experiences-combine-to-shape-brain-architecture/

National Scientific Council on the Developing Child. (2011). *Building the brain's "air traffic control" system: How early experiences shape the development of executive function* (NSCDC Working Paper No. 11). Center on the Developing Child at Harvard University. https://developingchild.harvard.edu/resources/building-the-brains-air-traffic-control-system-how-early-experiences-shape-the-development-of-executive-function/

National Scientific Council on the Developing Child. (2020). *Connecting the brain to the rest of the body: Early childhood development and lifelong health are deeply intertwined* (NSCDC Working Paper No. 15). Center for the Developing Child at Harvard University. https://developingchild.harvard.edu/resources/connecting-the-brain-to-the-rest-of-the-body-early-childhood-development-and-lifelong-health-are-deeply-intertwined/

Organization for Economic Co-operation and Development. (2002). *Understanding the brain: The birth of a learning science*. Paris, France: OECD Publishing.

O'Leary, K. C., Pontifex, M. B., Scudder, M. R., Brown, M. L., & Hillman, C. H. (2011). The effects of single bouts of aerobic exercise, exergaming, and videogame play on cognitive control. *Clinical Neurophysiology*, *122*(8), 1518–1525. https://doi.org/10.1016/j.clinph.2011.01.049

Pempek, T. A., Kirkorian, H. L., & Anderson, D. R. (2014). The effects of background television on the quantity and quality of child-directed speech by parents. *Journal of Children and Media*, *8*(3), 211–222.

https://doi.org/10.1080/17482798.2014.920715

Pempek, T. A., Kirkorian, H. L., Richards, J. E., Anderson, D. R., Lund, A. F., & Stevens, M. (2010). Video comprehensibility and attention in very young children. *Developmental Psychology*, *46*(5), 1283–1293. https://doi.org/10.1037/a0020614

Prot, S., McDonald, K. A., Anderson, C. A., & Gentile, D. A. (2012). Video games: Good, bad, or other? *Pediatric Clinics*, *59*(3), 647–658. https://doi.org/10.1016/j.pcl.2012.03.016

Radesky, J., Leung, C., Appugliese, D., Miller, A. L., Lumeng, J. C., & Rosenblum, K. L. (2018). Maternal mental representations of the child and mobile phone use during parent-child mealtimes. *Journal of Developmental and Behavioral Pediatrics*, *39*(4), 310–317. https://doi.org/10.1097/DBP.0000000000000556

Radesky, J. S., & Christakis, D. A. (2016). Increased screen time: Implications for early childhood development and behavior. *Pediatric Clinics*, *63*(5), 827–839. https://doi.org/10.1016/j.pcl.2016.06.006

Radesky, J. S., Kistin, C. J., Zuckerman, B., Nitzberg, K., Gross, J., Kaplan-Sanoff, M., Augustyn, M., & Silverstein, M. (2014). Patterns of mobile device use by caregivers and children during meals in fast food restaurants. *Pediatrics*, *133*(4), e843–e849.

Radesky, J. S., Miller, A. L., Rosenblum, K. L., Appugliese, D., Kaciroti, N., & Lumeng, J. C. (2015). Maternal mobile device use during a structured parent–child interaction task. *Academic Pediatrics*, *15*(2), 238–244. https://doi.org/10.1016/j.acap.2014.10.001

Radesky, J. S., Peacock-Chambers, E., Zuckerman, B., & Silverstein, M. (2016). Use of mobile technology to calm upset children: Associations with social-emotional development. *JAMA Pediatrics*, *170*(4), 397–399. https://doi.org/10.1001/jamapediatrics.2015.4260

Raman, S., Guerrero-Duby, S., McCullough, J. L., Brown, M., Ostrowski-Delahanty, S., Langkamp, D., & Duby, J. C. (2017). Screen exposure during daily routines and a young child's risk for having social-emotional delay. *Clinical Pediatrics*, *56*(13), 1244–1253. https://doi.org/10.1177/0009922816684600

Rasmussen, E. E., Shafer, A., Colwell, M. J., White, S., Punyanunt-Carter, N., Densley, R. L., & Wright, H. (2016). Relation between active mediation, exposure to Daniel Tiger's Neighborhood, and US preschoolers' social and emotional development. *Journal of Children and Media*, *10*(4), 443–461. https://doi.org/10.1080/17482798.2016.1203806

Reed, J., Hirsh-Pasek, K., & Golinkoff, R. M. (2017). Learning on hold: Cell phones sidetrack parent-child interactions.

Developmental Psychology, *53*(8), 1428.

Reiser, R. A., Tessmer, M. A., & Phelps, P. C. (1984). Adult-child interaction in children's learning from "Sesame Street." *Educational Communication and Technology*, *32*(4), 217–223. https://doi.org/10.1007/BF02768893

Rhodes, S. M., Stewart, T. M., & Kanevski, M. (2019). Immediate impact of fantastical television content on children's executive functions. *British Journal of Developmental Psychology*, *n/a*(n/a). https://doi.org/10.1111/bjdp.12318

Ribner, A. D., Barr, R. F., & Nichols, D. L. (2020). Background media use is negatively related to language and literacy skills: Indirect effects of self-regulation. *Pediatric Research*, 1–7. https://doi.org/10.1038/s41390-020-1004-5

Richards, M. N., & Calvert, S. L. (2017). Media characters, parasocial relationships, and the social aspects of children's learning across media platforms. In R. Barr & D. N. Linebarger (Eds.), *Media exposure during infancy and early childhood: The effects of content and context on learning and development* (pp. 141–163). https://doi.org/10.1007/978-3-319-45102-2_9

Rideout, V. (2017). *The Common Sense census: Media use by kids zero to eight*. Retrieved from Common Sense Media website: **https://www.commonsensemedia.org/research/the-common-sense-census-media-use-by-kids-age-zero-to-eight-2017**

Rideout, V., & Katz, V. S. (2016). *Opportunity for all? Technology and learning in lower-income families.* Retrieved from Joan Ganz Cooney Center website: https://joanganzcooneycenter.org/publication/opportunity-for-all-technology-and-learning-in-lower-income-families/

Rideout, V., & Robb, M. R. (2020). *The Common Sense census: Media use by kids zero to eight.* Retrieved from Common Sense Media website: **https://www.commonsensemedia.org/research/the-common-sense-census-media-use-by-kids-age-zero-to-eight-2020**

Riggs, N. R., Jahromi, L. B., Razza, R. P., Dillworth-Bart, J. E., & Mueller, U. (2006). Executive function and the promotion of social–emotional competence. *Journal of Applied Developmental Psychology*, *27*(4), 300–309. https://doi.org/10.1016/j.appdev.2006.04.002

Roseberry, S., Hirsh-Pasek, K., & Golinkoff, R. M. (2014). Skype me! Socially contingent interactions help toddlers learn language. *Child Development*, *85*(3), 956–970. https://doi.org/10.1111/cdev.12166

Rossignoli-Palomeque, T., Perez-Hernandez, E., & González-Marqués, J. (2018). Brain training in children and adolescents: Is it scientifically valid? *Frontiers in Psychology*, *9*. https://doi.org/10.3389/fpsyg.2018.00565

Rueda, M. R., Rothbart, M. K., McCandliss, B. D., Saccomanno, L., & Posner, M. I. (2005). Training, maturation, and genetic influences on the development of executive attention. *Proceedings of the National Academy of Sciences*, *102*(41), 14931–14936.

Saxe, R., Tzelnic, T., & Carey, S. (2006). Five-month-old infants know humans are solid, like inanimate objects. *Cognition*, *101*(1), B1–B8. https://doi.org/10.1016/j.cognition.2005.10.005

Schmidt, M. E., Pempek, T. A., Kirkorian, H. L., Lund, A. F., & Anderson, D. R. (2008). The effects of background television on the toy play behavior of very young children. *Child Development*, *79*(4), 1137–1151. https://doi.org/10.1111/j.1467-8624.2008.01180.x

Shonkoff, J. P., Garner, A. S., Committee on Psychosocial Aspects of Child and Family Health, Committee on Early Childhood, Adoption, and Dependent Care, and Section on Developmental and Behavioral Pediatrics, Siegel, B. S., Dobbins, M. I., Earls, M. F., Garner, A. S., McGuinn, L., Pascoe, J., & Wood, D. L. (2012). The lifelong effects of early childhood adversity and toxic stress. *Pediatrics*, *129*(1), e232–e246. https://doi.org/10.1542/peds.2011-2663

Simons, D. J., Boot, W. R., Charness, N., Gathercole, S. E., Chabris, C. F., Hambrick, D. Z., & Stine-Morrow, E. A. L. (2016). Do "brain-training" programs work?: *Psychological Science in the Public Interest*. https://doi.org/10.1177/1529100616661983

Spelke, E. (1994). Initial knowledge: Six suggestions. *Cognition*, *50*(1), 431–445. https://doi.org/10.1016/0010-0277(94)90039-6

Stahl, A. E., & Feigenson, L. (2019). Violations of core knowledge shape early learning. *Topics in Cognitive Science*, *11*(1), 136–153. https://doi.org/10.1111/tops.12389

Staiano, A. E., & Calvert, S. L. (2011). Exergames for physical education courses: Physical, social, and cognitive benefits. *Child Development Perspectives*, *5*(2), 93–98. https://doi.org/10.1111/j.1750-8606.2011.00162.x

Stevens, R., & Penuel, W. R. (2010). *Studying and fostering learning through joint media engagement*. Paper presented at the Principal Investigators Meeting of the National Science Foundation's Science of Learning Centers, Arlington, Virginia.

Supanitayanon, S., Trairatvorakul, P., & Chonchaiya, W. (2020). Screen media exposure in the first 2 years of life and preschool cognitive development: A longitudinal study. *Pediatric Research*. https://doi.org/10.1038/s41390-020-0831-8

Swing, E. L., Gentile, D. A., Anderson, C. A., & Walsh, D. A. (2010). Television and video game exposure and the development of attention problems. *Pediatrics*, *126*(2), 214–221.

Takeuchi, L., & Stevens, R. (2011). *The new coviewing: Designing for learning through joint media engagement*. Retrieved from the Joan Ganz Cooney Center website: https://www.joanganzcooneycenter.org/wp-content/uploads/2011/12/jgc_coviewing_desktop.pdf

Tomasello, M. (2009). *The cultural origins of human cognition*. Cambridge, MA: Harvard University Press.

Tomopoulos, S., Brockmeyer Cates, C., Dreyer, B. P., Fierman, A. H., Berkule, S. B., & Mendelsohn, A. L. (2014). Children under the age of two are more likely to watch inappropriate background media than older children. *Acta Paediatrica*, *103*(5), 546–552. https://doi.org/10.1111/apa.12588

Troseth, G. L., Saylor, M. M., & Archer, A. H. (2006). Young children's use of video as a source of socially relevant information. *Child Development*, *77*(3), 786–799. https://doi.org/10.1111/j.1467-8624.2006.00903.x

Wartella, E., Rideout, V., & Lauricella, A. (2014). *Parenting in the age of digital technology*. Center on Media and Human Development School of Communication Northwestern University.

Wartella, E., & Robb, M. (2008). Historical and recurring concerns about children's use of the mass media. In *The handbook of children, media, and development* (pp. 7–26). https://doi.org/10.1002/9781444302752.ch1

Winther, D. K., Twesigye, R., Zlámal, R., Saeed, M., Smahel, D., Stoilova, M., & Livingstone, S. (2020). *Digital connectivity during COVID-19: Access to vital information for every child* (Innocenti Research Briefs). Retrieved from UNICEF website: https://www.unicef-irc.org/publications/1099-digital-connectivity-during-covid-19-access-to-vital-information-for-every-child.html

Zelazo, P. (2015). Executive function: Reflection, iterative reprocessing, complexity, and the developing brain. *Developmental Review*, *38*, 55–68. https://doi.org/10.1016/j.dr.2015.07.001

Zelazo, P., & Lyons, K. E. (2012). The potential benefits of mindfulness training in early childhood: A developmental social cognitive neuroscience perspective. *Child Development Perspectives*, *6*(2), 154–160.

https://doi.org/10.1111/j.1750-8606.2012.00241.x

Zelazo, P., & Müller, U. (2002). Executive function in typical and atypical development. In *Blackwell handbook of childhood cognitive development* (pp. 445–469). https://doi.org/10.1002/9780470996652.ch20

Zhao, F., Egelman, S., Weeks, H. M., Kaciroti, N., Miller, A. L., & Radesky, J. S. (2020). Data collection practices of mobile applications played by preschool-aged children. *JAMA Pediatrics*, e203345–e203345. https://doi.org/10.1001/jamapediatrics.2020.3345

Zimmerman, F. J., & Christakis, D. A. (2005). Children's television viewing and cognitive outcomes: A longitudinal analysis of national data. *Archives of Pediatrics & Adolescent Medicine*, *159*(7), 619–625.

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

Zosh, J. M., Lytle, S. R., Golinkoff, R. M., & Hirsh-Pasek, K. (2017). Putting the education back in educational apps: How content and context interact to promote learning. In R. Barr & D. N. Linebarger (Eds.), *Media exposure during infancy and early childhood: The effects of content and context on learning and development* (pp. 259–282). https://doi.org/10.1007/978-3-319-45102-2_17

Suggested Citation

Smith, H. (2020). *Children, executive functioning, and digital media: A review*. https://www.commonsensemedia.org/research/children-executive-functioning-and-digital-media-a-review-2020