Exploring the Role of Digital Play in Child Development

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Abstract

Mobile devices and applications (apps) have become staples of Western childhood, irrespective of socioeconomic status (SES). Despite widespread usage, research assessing the content and design of children's apps is limited. Likewise, there is little research investigating how children of varying SES engage with apps, as well as how app usage relates to significant developmental capacities like executive functioning (EF). We examined if preschool-age children of varying SES differ in their daily duration of mobile device use, proportion of free apps installed, quantity of violent apps installed, and quality of educational apps played. We also examined how app design relates to child EF. SES included parents' levels of education and an income-to-needs ratio (ITN), calculated through household income and size. We used Kruskal-Wallis tests, Chi-Square tests, Spearman correlations, and linear regression to examine associations between mobile device and app variables, parent education, and ITN. Parent education and preschool attendance were negatively associated with average daily duration of mobile device use. Increased average daily duration of mobile device use was associated with weaker EF in bivariate models, but did not maintain significance in linear regression models. Given the critical cognitive and social development occurring during the preschool years, disparate use of mobile devices may sustain the present digital divide, with cascading implications for inequitable school readiness and later academic achievement. Future research should further evaluate quality differences in mobile device and app use according to SES, continuing to use objective measures of the duration and types of apps played by children.

Keywords: mobile devices, apps, child development, executive function, socioeconomic status, parent education, household income

Exploring the Role of Digital Play in Child Development

Media have become a ubiquitous aspect of early childhood, serving as digital playgrounds, educational spaces, and entertainment venues for young children. Over the past nine years, the media landscape has experienced rapid development, with increases in media ownership and adoption of new forms of media, namely mobile devices like smartphones and tablets, “across all levels of society” (Rideout, 2017, p. 3). A nationally representative survey found that “98% of children age eight and under live in a home with some type of mobile device,” a steep increase in mobile device ownership from 52% in 2011 (Rideout, 2017, p. 3, 23). Moreover, 45% of children surveyed had their own mobile device, compared to only three percent of children in 2011 (Rideout, 2017, p. 23). The overall amount of time spent using media has remained relatively constant for the past nine years; however young children have changed where they devote their screen time, spending approximately one hour per day using mobile devices in place of watching television (Rideout, 2017, p. 3, 24). Additionally, application (“app”) use is common, with tens of thousands of apps available for gameplay, educational instruction, and passive viewing.

Mobile Device Use according to Socioeconomic Status (SES)

Experts have expressed concerns regarding a “digital divide,” which may exacerbate opportunity gaps for children of lower-income families due to reduced access to various media (Rideout, 2017, p. 29). While gaps persist in home computer ownership and internet access, the gap in mobile device ownership has dramatically narrowed, as a greater number of lower-income families own smartphones (Rideout, 2017, p. 29). Kabali et al. (2015) found that nearly all children from a lower-income community had access to mobile devices (tablets: 83%, smartphones: 77%), consistent with the “Common Sense Census” (p. 1046). Presently, concerns regarding inequitable access to media have shifted, with a new emphasis on the varying uses of media, quality of media, and durations of media use based on SES.

Both children from higher-income households and those whose parents have received a college degree spend less time using mobile devices than children from lower-income households and whose parents have not graduated with a college degree (Rideout, 2017, p. 30). Importantly, children from lower-income households spend an average excess of 36 minutes per day using mobile devices than children from higher-income households. Likewise, children whose parents received a high school degree or less spend approximately 29 minutes longer per day using mobile devices than children whose parents received a college degree, according to parent-report surveys (Rideout, 2017, pp. 24–25). Updated research is needed to determine if SES differences exist in duration of mobile media use, based on updated methods for assessing child mobile device use objectively. Accordingly, the first question of this study asks: do children of varying SES differ in daily duration of mobile device use, as measured by mobile device sampling? Mobile device sampling is a novel approach that harnesses data already collected by devices. Child SES is defined by household income and parent educational attainment. Hypothesis One (H1): In continuation of previous demographic use patterns, children of lower-SES will use mobile devices for a longer duration compared to children of higher-SES.

Although SES differences have not been observed in parental reports of downloading apps for their child, significant SES differences exist in parental histories of paying for apps for their child. Forty-five percent of parents sampled in the “Common Sense Census” describe downloading exclusively free apps for their child, and approximately one quarter of parents report purchasing an app for their child (Rideout, 2017, p. 26). Notably, higher-income parents (29%) are significantly more likely to purchase an app for their child than lower-income parents

(14%) (Rideout, 2017, p. 26). Updated research is needed to determine if the quantity of free and paid apps downloaded differs based on SES, leading this study to question: do children of varying SES differ in the proportion of free apps installed on their mobile devices? Hypothesis Two (H2): Children of lower-SES will install a higher proportion of free apps than children of higher-SES.

Types of Media Programming and Implications

Children aged three years and older have the capacity to learn from "age-appropriate, child-directed television programs" (Anderson & Subrahmanyam, 2017, p. S59). Observational learning is one of the primary mechanisms by which children learn from media. Through observational learning, children acquire and may emulate behaviors and beliefs that they observe others performing. Observational learning is strongest when children identify with the individual modeling the observed practice, as well as when an action or belief is rewarded (Bushman & Huesmann, 2006). Accordingly, the American Academy of Pediatrics (AAP) Council on Communications and Media emphasizes that "content is crucial" when describing the influence of media programming on children's cognitive and socio-emotional development (2016a, p. 2).

Educational Programming

Analyses of educational television programs for a preschool-age audience have demonstrated a wide range of positive outcomes for viewers. Benefits have been documented for educational programming designed with expert guidance (i.e., Sesame Workshop and Public Broadcasting Service (PBS)) (AAP Council on Communications and Media, 2016a, p. 2). For example, viewing *Sesame Street* is associated with the development of foundational academic skills, such as numeracy and literacy, for preschool-age consumers; this association remained even after controlling for potential confounders like preschool enrollment and parent education

(Zill, 2000, p. 120). Moreover, viewing *Sesame Street* during the preschool years is associated with greater independence with reading, as well as reduced need for “special help for reading problems,” in early elementary school (Zill, 2000, p. 124). Additional benefits from viewing well-designed educational television programming during early childhood include increased vocabulary, improved problem-solving abilities on mathematics assessments, and “greater school readiness” (Anderson & Subrahmanyam, 2017, p. S59; Fisch, 2004).

Violent Media

Numerous studies support the conclusion that exposure to violent media increases the likelihood of aggression by viewers, often through an increase in “aggressive thoughts… angry feelings… and physiological arousal” (Bushman & Anderson, 2015, pp. 1814–1815). Exposure to violent media during early childhood is especially concerning, as indicated by theorized learning mechanisms. Through observational learning from media characters, children may incorporate the modeled aggressive behaviors and beliefs into their social scripts. Moreover, children may believe that aggression is a socially-acceptable means for interacting with others (Bushman & Huesmann, 2006, p. 349). Furthermore, viewing violent media during childhood may contribute to faster desensitization in “distress-related physiological reactivity” to witnessing violence (Bushman & Huesmann, 2006, pp. 349–350). Compared to adults, children are significantly more susceptible to accepting and imitating modeled aggression because they have fewer learned social scripts to replace (Bushman & Huesmann, 2006, p. 350).

Acceptance of aggressive actions and beliefs, as well as increased adaptation to depictions of violence, negatively influences children’s social and behavioral development. Specifically, in field studies, children were more likely to engage in physical violence and be verbally aggressive after viewing violent television programs or movies (Bushman & Anderson, 2015, p. 1815). Similarly, longitudinal studies have demonstrated that viewing large amounts of violent television content during childhood increases the likelihood of acting aggressively during adulthood (Bushman & Anderson, 2015, p. 1815). Exposure to violent video games has evidenced “decreased prosocial behavior and increased hostile attribution bias,” leading individuals to perceive neutral behaviors or comments from others as provocative and aggressive (Bushman & Anderson, 2015, p. 1818). Consequently, children may experience greater difficulties forming healthy relationships with others, with peer rejection cited as a frequently linked outcome of violent media exposure (Bushman & Anderson, 2015, p. 1818).

Furthermore, children engage in more explicitly dangerous behaviors following exposure to violent media. A recent clinical trial randomly assigned children to play or watch the video game *Minecraft*. Participants engaged with gun violence against monsters, sword violence against monsters, or a nonviolent version without monsters or weapons present. Those who were exposed to gun or sword violence were more likely to touch a real gun, hold it for a longer duration, and pull the trigger more times than participants who engaged with the nonviolent version of *Minecraft* (Chang & Bushman, 2019). Thus, the negative social and behavioral implications of exposure to violent media during childhood are well-researched and well-supported.

Importantly, when violent television programming was replaced with prosocial or educational programming, preschool-age children exhibited improved social competence and fewer externalizing behaviors (Christakis et al., 2013). The AAP Council on Communications and Media (2016b) advises parents to regulate the types of television programs, movies, video games, and other media with which their children engage. Likewise, the AAP Council on Communications and Media (2016b) discourages exposure to violent media for children ages six and under, as “young children do not always distinguish fantasy from reality” (p. 3). Moreover, media that trivialize or humorously depict violence are strongly advised against, as are video games in which players are rewarded for inflicting harm on other characters; these forms of violent media exposure condition viewers “to associate pleasure and success” with aggressive behaviors (AAP Council on Communications and Media, 2016b, p. 3).

Comparison of Television to Mobile Devices

While the literature on the effects of prosocial and violent television programming is robust, research on the effects of app content is lacking. No studies have assessed the presence of violent content in apps, or the effects of violent in-app content on app users. Moreover, the differences between television and mobile devices may limit the degree to which findings on television effects can be generalized to that of apps.

Mobile devices differ in both format and the amount of content available for viewers. Primarily, mobile devices are interactive, requiring continuous action on behalf of the user to engage with the device (Anderson & Subrahmanyam, 2017, p. S58). Moreover, the progression of content delivery is contingent on the user’s previous action (Anderson & Subrahmanyam, 2017, p. S58), whereas television elicits passive viewing. Mobile devices also have the capacity to be personalized to the user, whereas the content in a television program remains the same regardless of who is watching it (Radesky et al., 2015). Moreover, a greater variety of programming (i.e., entertainment, games, educational instruction, passive viewing) is available from an expansive selection of apps (Anderson & Subrahmanyam, 2017). Thus mobile devices may differ—possibly having a stronger influence on child development given their portability, personalized features, and instant accessibility—than traditional television viewing. Yet there is little research investigating how the content and quality of apps are related to behavior and socio-emotional development for preschool-age children (Radesky et al., 2015).

To the best of our knowledge, this is the first study to examine violent content in children's apps. In addition to assessing app content for the presence of various forms of violence, this study will also investigate if children of varying SES differ in the amount of violent apps that they install on their personal devices. Hypothesis Three (H3): Children of lower-SES will play a higher number of apps with violent content.

App Content Analyses

Albeit growing, the extant literature on app content and design is limited. Many content analyses have focused on educational apps, reviewing the instructional quality of apps for a single domain, such as literacy and language skills. In a study of children's apps advertised for literacy instruction, "games, puzzles, and quizzes" were the most common activities available (Vaala et al., 2015, p. 27). These apps only permitted forced-choice responses, failing to incorporate flexible and unrestricted activities that encourage independent thinking by the user (Vaala et al., 2015). Another study reviewed popular math and literacy apps intended for preschool-age users from the Apple, Amazon, and Google Play app stores. Many of the sampled apps failed to incorporate evidence-based teaching strategies based on how preschool-age children learn. For example, if a player answered a question incorrectly, they were encouraged to retry the problem, without explanatory feedback that would guide the player to learn the instructed concepts. Moreover, apps rarely scaffolded challenge, failing to modify an activity's difficulty level based on a child's responses (Callaghan & Reich, 2018). In a content analysis of Greek Google Play apps with advertised educational claims, many apps encouraged problem-solving solely through simple "'trial and error' questions" (Papadakis et al., 2018, p. 151).

Moreover, the majority of apps drilled basic numeracy and phonic skills, and did not support more complex comprehension of instructed concepts (Papadakis et al., 2018, p. 155). Lastly, when compared to framework rooted in cognitive and developmental science, one study found overall low-quality in the top downloaded children's apps from the Google Play and Apple app stores, regardless of payment status. The study also evaluated apps played by preschool-age children on their personal mobile devices, containing similarly low-quality content and design features. Sampled apps did not provide activities that elicit a developmentally-appropriate degree of cognitive challenge. Moreover, apps contained overwhelming interactive features that detracted from an activity's learning objective, and failed to construct opportunities for social interaction (Meyer et al., 2020).

Other content analyses have described the distracting gameplay and learning environments of children's apps, highlighting overwhelming gamification via "hotspots" (Vaala et al., 2015, p. 30) and disruptive advertising practices (Meyer et al., 2019; Papadakis et al., 2018, p. 154). High rates of mobile advertising were found in the top downloaded free and paid apps of the Google Play store marketed to children ages five and under. Specifically, 95% of reviewed apps had at least one type of advertisement, including pop-up video advertisements and banner advertisements that interrupted gameplay (Meyer et al., 2019, p. 35). Despite a lack of comprehensive research on the content presented in apps marketed to children, 71% of parents have downloaded apps intended for their child's use (Rideout, 2017, p. 26).

Learning from Educational Apps

Although evidence suggests that learning from children's educational apps is possible, there is widespread agreement that most apps available in popular app stores are not designed to support meaningful learning and sustained engagement among young users. Children who played the PBS Kids app *Super Why* increased their early literacy skills, such as identifying rhymes; however, demonstrated gains differed based on the age of the user. For example, three-year-olds showed the greatest increase in early literacy skills after playing *Super Why*, averaging a 17% increase in score on a standard literacy assessment (Chiong & Shuler, 2010, p. 18). Conversely, older children only gained an average of eight-to-nine percent, likely because they were already proficient in introductory literacy skills like identifying letters and corresponding sounds (Chiong & Shuler, 2010, pp. 18–19). These findings highlight the need for "developmentally appropriate content" based on the age and education level of the child (Chiong & Shuler, 2010, p. 19). If an app does not meet an individually-optimal level of challenge, children will likely lose interest in the app. Young children may become discouraged if they are playing an app that is too difficult, whereas older children may grow bored if the instructed content is too easy (Chiong & Shuler, 2010). Creating developmentally-appropriate apps will leverage the instructional capabilities of educational apps, as well as sustain attention of app users. Unfortunately, the educational apps that are currently marketed to young children are not designed effectively, based on how children at varying developmental stages learn best (Hirsh-Pasek et al., 2015).

Experts have warned about the "largely unregulated" range of apps marketed to young children, leading Hirsh-Pasek et al. (2015) to establish a theoretical framework for evaluating apps based on evidence of children's learning processes from "the Science of Learning" (p. 3, 6). Titled the "Four Pillars," each Pillar describes a well-established principle about either the content of a given curriculum or the structure of a learning experience that facilitate optimal learning (Hirsh-Pasek et al., 2015, pp. 7–19). The Four Pillars were operationalized into a coding scheme to evaluate the content and quality of children's educational apps (Meyer et al., 2020). In this coding scheme, “Pillar 1 (Active Learning)” evaluates the degree of cognitive challenge elicited by an app’s activity. It examines whether app activities are merely facilitating a cause-and-effect reaction to on-screen stimuli, or if the player is able to generate responses. “Pillar 2 (Engagement in the Learning Process)” assesses the extent to which interactive design features support or distract from engaging in an app’s learning objectives. “Pillar 3 (Meaningful Learning)” questions whether the app activities are contextually meaningful in the digital setting, as well as if the learning objectives can be easily extended to the child’s life outside of the screen. “Pillar 4 (Social Interaction)” appraises the quality and format of social interaction promoted by an app’s activities, through parasocial relationships with characters, engagement with another player mediated by the device, or interaction with another player in-person around the screen (Meyer et al., 2020). A revised version of this coding scheme is used in the present study to evaluate apps played by study participants.

Implications of Media Quality for Preschool-Age Children

The preschool years are a crucial period for cognitive development. The subject matter and skills children establish between ages three and five serve as the “foundation for later academic success” (Callaghan & Reich, 2018, p. 280). Children from lower-income families are at greater risk than those from higher-income families for “lower scores on mental tests [and] higher rates of academic failure,” stemming from discrepancies in early learning experiences (Campbell et al., 2002, p. 42). Access to high-quality education during early childhood, such as preschool intervention programs like the Abecedarian Project, has demonstrated dramatic cognitive and academic benefits for lower-income children (Campbell et al., 2002).

Given widespread access to mobile devices (Rideout, 2017), educational apps may serve as a new venue for early learning experiences. Children from lower-income families exhibited more literacy and numeracy skills after viewing *Sesame Street*, compared to their higher-income counterparts (Zill, 2000, p. 121). When designed with evidence-based techniques for supporting how children learn best, educational apps hold palpable opportunities for similar developmental outcomes. Unfortunately, these benefits have not been realized yet in currently available educational apps (Meyer et al., 2020).

While educational apps could increase access to early learning opportunities for preschool-age users, they likewise have the potential to exacerbate the opportunity gap. Kabali et al. (2015) questioned whether inequitable access to high-quality media persisted amidst an otherwise decreasing digital divide (p. 1049). It is currently unclear whether meaningful differences exist between free and paid apps. One study identified significantly more disruptive advertising and distracting interactive design features in the top-downloaded free educational apps, compared to those requiring payment, from the Google Play and Apple app stores. The majority of free and paid apps sampled were considered low-quality; however more free apps were deemed low-quality than paid apps, albeit a difference that was not statistically significant (Meyer et al., 2020). Should free apps present lower-quality content and design features, and lower-income children more frequently use free apps, the aforementioned equity concerns may be realized. Thus, this study will examine if children of varying SES differ in the quality of educational apps that they play. Educational quality of apps will be assessed through the aforementioned refined coding scheme based on the Four Pillars. Hypothesis Four (H4): Children of lower-SES will play apps with lower educational quality scores.

Development of Executive Functions (EFs) during Preschool

EFs are higher-order, effortful cognitive processes that manage automatized, reflexive thoughts (Garon et al., 2016). Recent research supports an integrated approach for conceptualizing EFs, in which working memory, inhibitory control, and set shifting are interrelated, yet independent processes (Garon et al., 2008, p. 32). Set shifting has also been referred to as attention flexibility (Linebarger et al., 2014) and cognitive flexibility (Rosas et al., 2019). Through managing automatized thoughts and behaviors, EFs facilitate “adaptive, goal-directed behaviors,” such as planning, careful decision-making, and problem-solving (Garon et al., 2008, p. 31; Linebarger et al., 2014).

Working memory, inhibitory control, and attention flexibility have distinct roles in supporting EF processes at large. Working memory entails short-term storage of information, as well as enables processing and incorporating new information into existing mental schema. Inhibitory control allows individuals to restrain reflexive thoughts and behaviors, delay gratification, and intentionally attend to task-relevant stimuli (Garon et al., 2008; Rosas et al., 2019). Attention flexibility facilitates transition between “mental set[s],” and enables individuals to adapt to multiple situational demands (Garon et al., 2008, p. 43; Rosas et al., 2019).

The preschool years (ages three through five) are a critical period for EF development. Prior to age three, foundational working memory, inhibitory control, and attention flexibility begin to develop. During the preschool years, these EF components continue to advance, both independently and in coordination with one another; this facilitates completion of more complex tasks as children grow. Notably, the capacity to manage contradictory input during information processing is a defining characteristic of EF development among preschool-age children (Garon et al., 2008).

Additionally, EF development during the preschool years has significant, cascading implications for later cognitive development. EF is consistently associated with school readiness and later academic achievement (Blair & Razza, 2007). On the one hand, low EF scores in preschool are predictive of worse math performance in elementary school. Preschool children who scored low on measures of EF competencies, especially working memory, performed worse on math tasks in elementary school than preschoolers with higher EF scores (Usai et al., 2018). On the other hand, greater EF competencies may support learning and improve later academic performance. For preschoolers with limited math skills, stronger EF may “compensate for their limited domain-specific prerequisite skills” (Usai et al., 2018, p. 414). Additionally, preschool EF is associated with literacy skills (Blair & Razza, 2007). Moreover, productive participation in school overall requires following directions, inhibiting impulses, and sustained attention on schoolwork, all of which demand strong EF skills (Linebarger et al., 2014, p. 367).

Preschool EF likewise has implications for social and behavioral development. All three EF constructs are associated with problematic externalizing behaviors, with the greatest effect size found for inhibitory control and among older preschoolers (aged four-and-a-half through six years) (Shoemaker et al., 2012). Deficits in EF skills may contribute to problematic behaviors, including difficulties in following classroom and parental rules, regulating emotions and impulses, and staying on task (Nathanson et al., 2014, p. 1497). Low EF during the preschool period may have negative cascading effects on the ability to develop healthy relationships with one’s teachers and peers, and may impede development of socio-emotional competence (Blair & Razza, 2007).

Media Exposure and EF

Television Exposure

Associations of EF and television exposure during early childhood vary based on the type of television programming. Entertainment programming and adult-appropriate programming are typically associated with weaker EF performance. Conversely, PBS programming is positively associated with EF performance, compared to educational cartoons. The variation in EF performance related to type of programming has been attributed to the presence of commercials mid-story, which disrupt children's sustained attention to a program's narrative, as PBS programs do not contain commercials mid-episode (Nathanson et al., 2014, p. 1503). Moreover, pace of content presentation may contribute to EF development. Entertainment and adult-appropriate programming are often fast-paced; this may curb more effortful, judicious information processing by viewers, instead encouraging reflexive, automatic responses (Nathanson et al., 2014, p. 1498).

Moreover, quantity and degree of direct exposure to television are differentially associated with EF development and performance. Children who began watching television at younger ages performed worse on EF assessments than children who began watching television at an older age (Nathanson et al., 2014, p. 1503). Similarly, children with greater cumulative television exposure exhibited weaker EF than children who viewed fewer overall hours of television (Nathanson et al., 2014, p. 1502). Lastly, greater indirect television exposure, or "background television" exposure, is negatively associated with EF competencies (Linebarger et al., 2014, p. 375).

App Exposure

The literature is sparse about how user engagement with apps influences developmental outcomes. Only one study has evaluated how the duration of app use is associated with preschoolers' EF development, suggesting a relationship between high durations of app play ($\geq$ 30 minutes per day) and greater difficulty with impulse inhibition (McNeill et al., 2019). However, McNeill et al. (2019) did not evaluate the content or quality of app design. Moreover, McNeill et al. (2019) did not directly measure child app use, as the study relied solely on parent report of the participant's media use. Research on the relationship between quality of app design and developmental outcomes for children is needed. Accordingly, this study will examine how the content and design of apps is associated with child EF. Hypothesis Five (H5): Children who play lower quality apps will have weaker parent-reported EF.

Summary of Study Significance

This study aims to clarify how children of varying SES engage with their personal mobile devices. While survey-based statistics are available detailing the demographics and amount of mobile device use among young children, there has yet to be research connecting these social identifiers of preschool-age app users to objectively measured duration, content, and quality of apps actually used by preschool-age children. It is important to understand if differences exist in the aforementioned forms of user engagement based on SES, as these differences may contribute to a digital divide, characterized by inequities in access or use of the types of media known to improve child outcomes.

Additionally, this study aims to identify modern passages or barriers to productive cognitive and socio-emotional development for contemporary preschoolers, who are among the first generation to be exposed to mobile devices since birth. The content and quality of apps may have significant developmental implications for preschool-age children, especially if anti-social behaviors and beliefs are modeled by app characters. Moreover, the duration of mobile device usage may play a crucial role in a child's overall development, when considering both the types of apps used and the potential activities displaced by excess mobile device use. Given the foundational skills established during the preschool period, it is important for research to elucidate the developmental outcomes associated with mobile device use by preschoolers (AAP Council on Communications and Media, 2016a).

Method

Overall Study Design

This study included original data collection and content analysis of 430 children's apps, as well as secondary analysis of data from a six-month longitudinal study, titled the Preschooler Tablet Study (PTS). PTS was funded by the National Institute of Child Health and Development (NICHD R21HD094051). The University of Michigan Medical School Institutional Review Board approved PTS through the Radesky Lab and did not require human subjects review for the present content analysis.

Participants

PTS recruited 365 parent-child dyads from Southeast Michigan. At three separate time-points, parents completed an online survey containing a standardized measure of their child's EF; they also reported their highest level of educational attainment, household income, and household size. Additionally, participants completed seven-to-ten days of mobile device sampling, which involved installing a passive-sensing app (*Chronicle*) for Android devices or collecting battery screenshots for Apple devices.

The present analysis used data from the baseline wave of children who had their own mobile devices (n = 121, 33% of the full sample). The other 244 children either shared a device with parents or siblings (n = 225) or never used a mobile device (n = 19); therefore, their duration of daily mobile device use could not be calculated, due to inability to distinguish parent versus child use of popular apps. Participants' ages ranged from 3.01–5.00 years (M = 3.86, SD = 0.55). There were 67 male (55%) and 54 female (45%) participants. Ninety-two participants (77%) identified as non-Hispanic White. Parents' ages ranged from 23.98–45.28 years (M = 34.20, SD = 4.55).

Twenty-nine participants were excluded from the educational quality analysis (H4 and H5) because they solely used apps that could not be evaluated with the coding scheme. Among participants who own Android devices, nine were excluded because they used only video streaming apps (e.g., *Netflix, YouTube*) and/or standard mobile device apps (e.g., *Clock, Weather, Samsung Memos*). Among participants who own Apple devices, 20 were excluded. Fifteen of these participants used only video steaming apps (e.g., *Hulu, PBS Watch Videos*), standard mobile device apps (e.g., *Settings, Phone, Safari, Home & Lock Screen*), or social media apps (e.g., *Messenger*). Two participants used exclusively video streaming apps, and one participant only used standard mobile device apps. Two participants used video streaming apps, standard mobile device apps, and apps that required connection to an external toy that must be purchased.

Measures from PTS

Mobile sampling output provided both the names of apps used and data regarding the daily duration of app usage by each participant. For Android users, parents were instructed on how to install *Chronicle* onto the smartphone or tablet their child used most frequently. *Chronicle* is an app developed by the Radesky Lab that records the names of apps used and timestamps the start and stop times for each app, from which daily usage of each app is calculated. Apple users were instructed on capturing similar usage data through taking screenshots of their battery usage from the *Settings* app. Research assistants transferred this data to Excel files for each participant, and average duration of daily use was calculated for each app. From both *Chronicle* and screenshot output, a list of apps played by participants with their own mobile devices was generated (Radesky et al., in press).

Child EF was measured through the Behavior Rating Inventory of Executive Function – Preschool (BRIEF-P) scale included in the online surveys. BRIEF-P assesses both inhibitory control and metacognitive functions of children aged two to five, and it has demonstrated construct validity and reliability through strong correlations with experimental measures of preschooler EF (Garon et al., 2016).

Additional App Selection Conditions

Subscription Apps

Ten apps required subscriptions (e.g., *ABC Mouse, Homer*), and necessitated signing up for free trials to assess the apps. Enrollment in free trials only occurred if it was the sole means for accessing an app's activities. We did not elect to enroll in the free trial for apps that provided some unlocked activities without a subscription; this process reflected how the average child would engage with the same app, as enrolling in a free trial commonly required input of credit card information.

Apps Excluded from Educational Coding

Overall, of a total of 559 apps played by participants during the sampling week, 129 apps were excluded from the educational quality analysis. Seventy-two apps collected via *Chronicle* were excluded because they contained features that could not be evaluated with the coding scheme, or were unable to be installed on the lab tablet for review. Apps incompatible with the coding scheme included modification apps for other games (e.g., *furniture mod, Toolbox for Minecraft: PE*), platforms for playing other apps (e.g., *Samsung Kids, Google Play Games*), social media platforms (e.g., *TikTok*), and apps requiring access to a child's school's subscription (e.g., *Tumblebooks*). Many apps were no longer available for download from the Google Play Store (e.g., *Tron Racer, Puppy Life – Secret Pet Party*), or could not be identified from the app package name in *Chronicle* output. One app (*Cartoon Network Arcade*) was excluded due to playback errors.

Fifty-seven apps collected through Apple screenshots were excluded. These apps required connection to an external toy that must be purchased (e.g., *Shop 'n Learn Smart Checkout, Osmo Tangram*), or could not be identified in the Apple app store (e.g., *Food, Mommy, Cars*). For both operating systems, standard mobile device apps (e.g., *Clock, Calendar, Messages*) were excluded, as these apps did not contain educational or entertainment content to be evaluated. Lastly, video streaming apps (e.g., *PBS KIDS Video, Netflix*) were excluded, as these apps presented solely movies, television episodes, or music videos for passive viewing by users. To maintain consistency with this exclusion criterion, videos presented in other apps were not considered when determining an app's overall Pillar 1 (Active Learning) and Pillar 2 (Engagement in the Learning Process) scores.

Refinement of the Four Pillars Coding Scheme

In a previous study by the Radesky Lab at the University of Michigan Medical School, I led the development of a four-tier coding scheme to evaluate the quality of children's apps marketed as educational (Meyer et al., 2020). This coding scheme was based on the Four Pillars, a widely influential framework for determining whether apps are designed with features that promote effective learning (Hirsh-Pasek et al., 2015). To accommodate the large sample of apps and the amount of time required to code each app, I refined the coding scheme to include Pillar 1 (Active Learning) and Pillar 2 (Engagement in the Learning Process). These Pillars represent the greatest source of design variability in apps scored to date (Meyer et al., 2020), and are rooted in theory most relevant to EF. Pillar 1 (Active Learning) assesses the extent to which a child is encouraged to actively plan, generate responses, and make decisions about their gameplay, compared to passively following activity prompts. Likewise, Pillar 2 (Engagement in the Learning Process) evaluates the extent to which the interactive design features affect a child's ability to attend to an app's learning objectives. Interrater reliability was high for Pillar 1 (Active Learning) (ICC = .87) and Pillar 2 (Engagement in the Learning Process) (ICC = .95). Appendix A and Appendix B summarize the coding criteria for each Pillar, respectively.

Evaluation of App Quality

Between September 10, 2019 and February 20, 2020, I downloaded, played, and assessed 430 apps (240 Google Play apps and 190 Apple apps) using the refined coding scheme. In the refined coding scheme, apps earned a score from zero to three for each Pillar; zero served as the lowest score and three served as the highest score. A score of zero or one indicated a low-quality app, with design features that diminished an app's intended learning objectives. Conversely, a score of two or three indicated a higher-quality app, consisting of design features that supported an app's intended learning objective.

I played each app for approximately 20 minutes, or until all activities were observed, and recorded notes on the gameplay experience and design features. I then assigned a score for Pillar 1 (Active Learning) and Pillar 2 (Engagement in the Learning Process). I likewise recorded my rationale for each score, describing how each Pillar's criteria corresponded with observations from gameplay.

Post-Hoc Coding Modifications

Violent Content

Upon downloading and playing apps, I realized a surprising amount of apps contained violent or mature content that would be inappropriate for a preschooler, despite being played by participants on their own devices. While evaluating apps against the educational coding scheme, I flagged apps that included violent content, and recorded notes about observed features. Given the robust literature detailing serious negative implications from early exposure to violent media, I developed a formal coding process to evaluate violence in children's apps.

I created a binary coding scheme to assess the presence of violent or aggressive content in apps, based on the criteria used for coding violence in television programs and movies from the Panel Study of Income Dynamics Child Development Supplement (University of Michigan Institute for Social Research, 2018). Two research assistants played 20 apps from the Google Play store, achieving high reliability (kappa = .90). Apps scored a zero if there were no depictions of violence or aggressive behavior; the player did not engage in acts of violence or aggression; there were no depictions of weapons; and there were no depictions of graphic injuries, blood, or gore. All four criteria must be met for an app to score a zero. Conversely, an app scored a one if there was at least one depiction of violence or aggressive behavior; the player was prompted to engage in acts of violence or aggression, with the objective of gameplay to harm another character or sentient being; or if the player was rewarded for violent or aggressive actions. Only one of the aforementioned criteria was required for an app to score a one. Uncertainties were resolved through discussion and consensus in weekly meetings. Appendix C summarizes the coding criteria.

From January 28, 2020 to February 20, 2020, I re-installed and played 402 apps (221 Google Play apps and 181 Apple apps) for up to five minutes, to ascertain whether violence or aggression was present in the app. I scored each app against the aforementioned criteria, assigning a score of zero or one. When present, examples of violent or aggressive content were recorded. Twenty-eight of the original apps (19 Google Play apps and nine Apple apps) were no longer available for download in the app stores (e.g., *3D Piano Keyboard*, *Doc McStuffins: Baby Nursery*), and were scored according to previous notes about violent content.

Notably, the content of violent apps was qualitatively different from the other sampled apps. The main gameplay narratives were violent, with no clear educational or strategy objectives, thereby not fitting well with the educational coding scheme criteria. For example, *Kick the Buddy* involves harming a talking doll through tossing it around the screen, throwing objects at it, or using various weapons. The player sees the doll endure physical injuries as a direct result of their actions against it, and hears the doll react in pain. The player also earns app currency for harming the doll, which could then be used to purchase more weapons to further hurt it. In contrast, apps such as *Trace Letters & Sight Words* and *Pepi Bath* promoted age-appropriate educational goals of phonics practice and pretend-play exploration, respectively, which could be scored against the educational coding scheme. Consequently, most violent apps were not assigned Pillar 1 (Active Learning) and Pillar 2 (Engagement in the Learning Process) scores.

Platform Apps

Twenty-one apps—considered platform apps—contained numerous activities, and were initially excluded from this analysis. The refined coding scheme is intended for apps that contain no more than twenty activities, with an optimal amount of less than five activities given the time-intensive nature of coding each activity. However, platform apps comprised a substantial amount of the app activity of several participants. Thus, we risked systematically biasing our results by excluding these apps, and needed to establish a comparable method for evaluating the curricular materials, instructed skills, and design features of these apps. Accordingly, two standardized methods were developed, varying based on the structure of the app. If the app contained a learning pathway, in which the player was encouraged to follow a preset sequence of activities, I followed the pathway for 20 minutes. If the app did not contain a learning pathway, I played up to the first 20 activities that were presented, as this would mirror what a child would experience upon downloading the same app.

Data Analysis

Survey responses of parental level of education, household income, and household size informed SES analyses. Parent education was divided into three categories: high school and/or some college, four-year college degree, and more than a four-year college degree. Household income and household size were used to create an income-to-needs ratio (ITN), which was calculated as a continuous variable and then split into three categories (< 2.0, 2.0–4.0, > 4.0). An ITN of < 2.0 refers to less than 200% of the federal poverty level, which is the cutoff for public services like Medicaid for many states.

Chronicle output and battery screenshots were used to calculate each participant's average daily duration of mobile device use for Android and Apple devices, respectively. We had intended to calculate the proportion of apps used by each child that were free, but variability was too low in this sample, so a dichotomous variable was created to indicate if the participant ever used a paid app. Only 43 paid apps (10%) were installed by the sample overall.

Child app content was defined in several ways. First, we calculated the number of apps played by each child that were coded as violent. We then calculated a weighted Pillar 1 (Active Learning), Pillar 2 (Engagement in the Learning Process), and total Pillar score for each child. The total Pillar score is the sum of the weighted Pillar 1 (Active Learning) and Pillar 2 (Engagement in the Learning Process) scores.

Weighting was needed to account for the variation in duration of usage by app for each participant, as we wanted the variable to reflect both the quality and quantity of app usage over the sampling week. Rather than averaging the Pillar scores for all apps a participant used, a weighted average Pillar score would accurately reflect the amount of time a participant spent on each app, whereby apps that are played more were weighted more. The weighted average of Pillar 1 (Active Learning) was calculated as follows: for all apps that a participant played with Pillar scores, each app's Pillar 1 (Active Learning) score was multiplied by the total duration of each app use for that participant. The sum of this variable was then divided by the sum of total durations for all apps that a participant played with Pillar scores. The weighted average of Pillar 2 (Engagement in the Learning Process) was calculated through the same procedure, using Pillar 2 (Engagement in the Learning Process) scores in place of Pillar 1 (Active Learning) scores.

We used the UNIVARIATE Procedure to examine daily duration of mobile device use and the distribution of Pillar scores. To investigate associations between parent education, ITN, app payment status, and presence of violent content, we used Chi-Square tests. We used Kruskal-Wallis tests to examine associations between weighted Pillar scores, parent education, and ITN. We used Spearman's correlation coefficients to examine associations between BRIEF-P t-scores, amount of time spent on a mobile device, parent education, and ITN. Additionally, we used Kruskal-Wallis tests to compare parent education and ITN to BRIEF-P t-scores.

For each research question, when there was a significant bivariate association identified between the independent variable and dependent variable, we built multivariate models using the following procedure. We included all potential confounders that showed a bivariate association with the independent variable or dependent variable at $p < .20$. Once these variables were in the regression model, we performed backward elimination to retain only statistically significant variables ($p < .05$).

Given the Normal distribution of BRIEF-P t-scores, we created linear regression models. Although daily duration of mobile device use was skewed, the residuals were normally distributed, thereby making linear regression appropriate.

Results

Table 1 displays participants' SES characteristics. Table 2 summarizes child mobile device use characteristics; children used their mobile devices for an average of two hours per day, ranging from less than one minute to more than 10 hours per day. During their sampling week, participants played between 1–85 apps.

Research Question One: Do children of varying SES differ in the amount of time spent on a mobile device, whereby child SES is determined through measures of parent education and household income?

We hypothesized that children of lower-SES will use mobile devices for a longer duration compared to children of higher-SES; this hypothesis was partially supported. Children whose parents attained lower levels of education had higher average daily durations of mobile device use than children whose parents attained higher levels of education, $H(2) = 10.45$, $p = .0054$. Children whose parents completed high school or some college spent an average of 155.19 minutes ($SD = 137.40$) per day on their mobile device, whereas children whose parents completed more than a four-year college degree spent an average of 82.30 minutes ($SD = 74.68$) per day. Children whose parents completed a four-year college degree spent 79.34 minutes ($SD = 81.66$) per day on their mobile device. However, children from lower-income families did not significantly differ in the average daily duration of mobile device use compared to children from higher-income families, $H(2) = 2.94$, $p = .2297$.

In multiple linear regression models adjusting for child preschool attendance, parents in the lowest educational attainment category had children with significantly higher daily durations of mobile device use, $p = .0284$. Specifically, children whose parents completed high school or some college spent approximately 57.61 more minutes per day using mobile devices compared to children whose parents earned more than a four-year college degree, 95% CI [6.19, 109.02]. Children whose parents earned a four-year college degree spent on average 23.03 fewer minutes per day using mobile devices, although this difference was not statistically significant, $p = .4295$, 95% CI [-80.61, 34.54].

Preschool attendance also predicted the average daily duration of mobile device use by children, independent of parent educational attainment. Children who attended a center-based preschool program, such as Head Start, KinderCare, or a Montessori program, spent approximately 61.82 fewer minutes per day using mobile devices compared to children who stayed home with a caregiver, $p = .0117$, 95% CI [-109.58, -14.05]. Children who attended a home-based childcare, such as an in-home daycare, spent on average 47.92 fewer minutes per day using mobile devices than children who stayed home with a caregiver; however, this difference was not statistically significant, $p = .3323$, 95% CI [-145.44, 49.61]. The multiple linear regression model explained 15.8% of the variance in average daily duration of mobile device use, $F(4, 109) = 5.12$, $p = .0008$. Thus, both level of education attained by parents and preschool attendance were independently associated with the average daily duration of mobile device use by children.

Research Question Two: Do children of varying SES differ in the quantity of free apps installed on their mobile devices compared to paid apps?

We hypothesized that children of lower-SES will install a higher proportion of free apps than children of higher-SES. This hypothesis was not supported, as neither level of parental education, $\chi^2(2) = 0.45$, $p = .7994$, nor ITN, $\chi^2(2) = 3.12$, $p = .2103$, were significantly related to the likelihood of children ever playing paid apps. Interestingly, it was rare for participants to have installed a paid app on their personal device; only 26 participants (21%) ever used a paid app. In contrast, 95 of the 121 participants (79%) used only free apps (see Figure 1).

Research Question Three: Do children of varying SES differ in the number of violent apps that they play?

Of the 430 evaluated apps, 122 apps (85 Google Play apps and 37 Apple apps) contained violent content. Common themes included fighting, killing, and/or using various weapons to harm characters. Violence was often the objective of gameplay, with players rewarded for harming a character or causing destruction (see Figure 2).

We hypothesized that children of lower-SES will install more violent apps compared to children of higher-SES; this hypothesis was not supported. The proportion of children who ever played a violent app did not significantly differ according to level of parental education, $\chi^2(2) = 3.77$, $p = .1521$, nor ITN, $\chi^2(2) = 0.69$, $p = .7088$. Notably, many of our preschool-age participants (n = 37, 31%) played a violent app during their sampling week.

Research Question Four: Do children of varying SES differ in the quality of educational apps played, whereby educational quality is determined through weighted average Pillar scores?

Table 2 summarizes weighted average Pillar 1 (Active Learning), Pillar 2 (Engagement in the Learning Process), and total Pillar scores. Common themes included foundational phonics instruction, simple addition and subtraction practice, pattern identification and matching, creative expression, and pretend-play caring for a character (see Figure 3). The majority of apps (320 apps, 74%) scored a zero or one for Pillar 1 (Active Learning); this suggests that the apps selected and played by participants were largely closed-loop in structure, and failed to engage the child in learning experiences in which they could generate responses and be cognitively challenged. Likewise, the majority of apps (322 apps, 75%) were considered low-quality when evaluated against Pillar 2 (Engagement in the Learning Process) criteria, scoring a zero or one. Low Pillar 2 (Engagement in the Learning Process) scores suggest high levels of disruptive advertising and over-stimulating feedback mechanisms during gameplay.

We hypothesized that children of lower-SES will use lower-quality educational apps compared to children of higher-SES, which was not supported. Weighted average Pillar 1 (Active Learning) scores were not significantly correlated with parental education status, $H(2) = 2.84$, $p = .2417$, nor ITN, $H(2) = 4.36$, $p = .1131$. Likewise, weighted average Pillar 2 (Engagement in the Learning Process) scores were not significantly correlated with parental education status, $H(2) = 0.63$, $p = .7300$, nor ITN, $H(2) = 4.76$, $p = .0925$. Lastly, total weighted average Pillar scores were not significantly associated with parental education status, $H(2) = 1.25$, $p = .5350$, nor ITN, $H(2) = 1.56$, $p = .4591$.

Research Question Five: How is the design of apps associated with child EF?

We hypothesized that lower-quality apps will be associated with worse EF scores; this hypothesis was not supported. Weighted average Pillar 1 (Active Learning) scores were not significantly associated with BRIEF-P t-scores, $r_s = .19$, $p = .0748$, N = 89. Likewise, weighted average Pillar 2 (Engagement in the Learning Process) scores were not significantly associated with BRIEF-P t-scores, r_s = -.08, p = .4584, N = 89. Weighted average total Pillar scores were also not significantly correlated with BRIEF-P t-scores, r_s = .05, p = .6183, N = 89. Although not a measure of design quality, children who had higher average daily durations of mobile device use had significantly higher BRIEF-P t-scores, r_s = .18, p = .0434, N = 120, suggesting weaker EF.

In simple linear regression models examining associations between average daily duration of mobile device use and BRIEF-P t-scores, results were non-significant, β = 0.009, R^2 = .0062, $F(1, 118) = 0.73$, p = .3945, 95% CI [-0.01, 0.03]. When potential cofounders were added to the linear regression model, such as level of education attained by parents, results were unchanged.

Discussion

The present study explored how children of varying SES engage with their own mobile devices. We found that children whose parents attained lower levels of education spent a longer average amount of time daily on their mobile devices than children whose parents attained higher levels of education; this relationship remained significant after controlling for confounding variables in linear regression models. Moreover, we found that preschool attendance was associated with less time spent by children using a mobile device each day, independent of parent educational attainment. Statistically significant differences were not observed in the number of violent apps played, nor the quality of educational apps played, based on child SES. Unexpectedly, we found that average daily duration of mobile device use was associated with BRIEF-P t-scores, whereby greater amounts of time spent on mobile devices were associated with weaker EF. However, this association was no longer significant when examined through linear regression models.

Research Question One: Do children of varying SES differ in the amount of time spent on a mobile device?

Average daily duration of mobile device use was higher among participants from lower-education households compared to those from higher-education households; however, average daily use did not differ significantly among participants based on income. These findings are partially consistent with previous research, which reported that children whose parents did not receive a college degree spent more time on their mobile devices than children whose parents graduated from college (Rideout, 2017, p. 30). In contrast to our findings, extant research maintains that children from higher-income households spend less time using mobile devices than children from lower-income households (Rideout, 2017, p. 30).

It is possible that parents with lower levels of educational attainment may encourage greater media consumption for their children than parents with higher levels of education. When interviewed about their attitudes toward mobile device use by their child, parents and guardians commonly expressed confidence in the potential for their child to learn from educational apps. There was widespread agreement that apps would teach their children new concepts, or at a minimum strengthen their understanding of previously-learned concepts (Chiong & Shuler, 2010, p. 21). Parents perceived learning from educational apps to be more intrinsically motivating, and described the potential for development of fine motor skills through using devices with a touchscreen. They also described fears that their child would fall behind without exposure to mobile devices, given the universality and importance of technology to present-day life (Radesky et al., 2016a). Moreover, parents with higher levels of education may have greater awareness of the AAP Council on Communications and Media's (2016a) recommended screen time limits.

On the one hand, greater average daily use of mobile devices by children from lower-education families may be an encouraging sign of a decreasing digital divide. Firstly, this finding supports previous research reporting a reduction in the socioeconomic gap in access to mobile devices (Kabali et al., 2015). Additionally, if children from lower-education households have access to high-quality content on their mobile devices, this may provide more opportunities for learning and practicing foundational academic skills, which children from higher-education households more readily access through non-digital opportunities structured by their parents. For example, it is possible that high-quality reading apps could help children from lower-education households develop literacy skills before entering grade school—skills that children from higher-education households may develop through easier access to reading materials in their home environment (e.g., increased number of physical books available, structured reading time with parents) (Aikens & Barbarin, 2008; Davis-Kean, 2005).

On the other hand, greater average daily use of mobile devices by children from lower-education families is concerning when considered holistically. Development of foundational academic skills like phonics and numeracy, as emphasized in children's educational apps, is only one component of cognitive development. Higher-order cognitions such as EFs, as well as socio-emotional skills, are best developed through reciprocal communications with other people and through "unstructured and social (not digital) play" (AAP Council on Communications and Media, 2016a, p. 2). If time spent using mobile devices is displacing parent-child interactions or imaginative social play, these children may be at increased risk of not achieving well-rounded cognitive and social development.

In addition to level of education attained by parents, preschool attendance was associated with the average daily duration of mobile device use by children. Compared to children who stayed home with a caregiver, children who attended a center-based preschool program used mobile devices for approximately one hour less per day. Center-based preschool programs, such Montessori and Head Start, follow regimented curriculums and adhere to structured daily schedules, likely with greater restrictions on media use. Moreover, children who attend a structured preschool program have less time at home to spend using digital media. Parents describe giving their children mobile devices to keep them occupied while trying to complete household chores, or to keep their children quiet during public events like dance recitals (Kabali et al., 2015; Radesky et al., 2016a); this may be one explanation for our finding that preschool-age children who stay home with caregivers have more mobile device use than children in center-based preschools. Lastly, children who do not attend preschool programs may play more apps marketed as educational, such as the popular platform *ABCMouse*, in attempt by their caregivers to provide learning experiences. Future research should examine the types of media experiences offered daily in structured preschool programs, compared to those used by children who stay home with their caregivers.

Research Question Two: Do children of varying SES differ in the quantity of free apps installed on their mobile devices compared to paid apps?

Our hypothesis, that children of lower-SES will install a higher proportion of free apps than children of higher-SES, was not supported. An overwhelming majority of participants used only free apps, to the extent that we needed to change our statistical analysis plans to accommodate the low variability in payment status. Although more parents of higher-SES report installing paid apps for their children than parents of lower-SES, parents of all levels of SES likewise report installing free apps for their children (Rideout, 2017). Thus, there was no difference in the proportion of free versus paid apps installed based on SES for our sample likely because of how easily accessible free apps are to any consumer; everyone uses free apps, regardless of educational background and income.

This study was limited in that it only used baseline data from the longitudinal PTS. A greater variety of apps may have been collected across all six months of the study, which may have yielded significant differences in the quantity of free and paid apps installed based on SES. However, given how few paid apps were played overall (43 apps, 10%) and how few participants played paid apps (26 children, 21%), a similar pattern would likely present across the remaining waves of data collection. Nonetheless, future studies should continue to evaluate differences in app payment status according to participant SES; this research should be conducted alongside evaluations of the quality of app content, as well as examinations of the collection and sharing of persistent identifiers from children's apps, which have been documented in prior research (Binns et al., 2018).

Research Question Three: Do children of varying SES differ in the number of violent apps that they play?

The number of violent apps played was not significantly different based on participant SES. Similar to the lack of differences in the quantity of free apps installed by participants, the lack of differences in the quantity of violent apps installed by participants is likely a matter of accessibility. The majority of violent apps played by participants were free (118 apps, 97%). Thus, children of all SES backgrounds could download violent apps without payment barriers.

To the best of our knowledge, this is the first study to examine the presence of violent content in children's apps. Of the 430 apps reviewed, 122 apps (28%) contained explicitly violent content, including fighting, killing, and assaulting characters. The presence of weapons, including guns, explosives, and cold weapons, was common. In addition to viewing weapons in the app setting, the user was often engaging in first-person use of the weapon as well. Moreover, acts of violence were commonly rewarded, such as through gameplay currency.

Thirty-seven participants (31%) played at least one of these violent apps; this finding is especially concerning given the young age of the sample. Observational learning posits that individuals establish a personalized understanding about appropriate behaviors and beliefs based on the actions and beliefs they view other people exhibiting, both in-person and mediated by screens. Moreover, social learning theory asserts that these beliefs are strengthened if the individual identifies with the actor, or if the actor is rewarded for their behavior (Bushman & Huesmann, 2006). Through repeated viewing and/or engaging in acts of violence in the app setting, children may develop beliefs that violence is appropriate and accepted in their everyday lives. Moreover, children may identify more strongly with modeled in-app violence, as they are the aggressor through first-person gameplay. Furthermore, children's acceptance of violence as normative behavior may be further strengthened given how frequently violence is rewarded during gameplay. Similar to associated behaviors following exposure to violent television programming (Bushman & Anderson, 2015), children may develop more aggressive thoughts and behaviors following exposure to in-app violence. Longitudinal and experimental research is severely needed to investigate the short-term and long-term effects of playing violent apps, especially during the formative preschool years.

The present study was limited by the dichotomous nature of the violent content coding scheme. Explicit representations of violence were clearly distinguished, such as fighting and killing with a weapon; however, acts of humorous violence (e.g., bopping a dinosaur on the head with a mallet) and accidental injuries (e.g., flipping a jet ski) were also common. Slapstick violence was often used as a way to engage viewers. Likewise, accidental injuries and destruction of property through car crashes were common in racing games, and resulted in losing the game and needing to restart the level. Although these apps did not display intentional harm to characters, it does not mean acts of accidental violence should be considered appropriate for preschool-age users. Moreover, unintentional acts of violence still have the potential to influence normative beliefs of app users. The intention behind the violent action and degree of gore depicted were the decision rule for this coding scheme; however future research should aim to develop a continuous coding scheme that accommodates the range of intentionality and violence depicted in apps.

The present study was likewise limited in that it only evaluated the violent content displayed during gameplay. Many apps contained advertisements for violent apps, often showing videos of violent gameplay or requiring a user to engage in a demo version of the app. Future research should continue to evaluate the types of violent content presented in apps during both gameplay and advertising disruptions. Ultimately, more research is needed to expand our understanding of the breadth of violent content that children are exposed to in apps, as well as how this content influences the socio-emotional and behavioral development of children at varying ages.

Research Question Four: Do children of varying SES differ in the quality of educational apps played, whereby educational quality is determined through weighted average Pillar scores?

The majority of apps sampled were considered low-quality. Most apps (320 apps, 74%) scored a one or less for Pillar 1 (Active Learning), as the structure of these apps did not elicit deep cognitive processing by the child in order to engage with the learning objectives. Many of the activities involved simple, closed-loop responses, whereby the user would tap the correct answer to complete the activity, mirroring an online workbook that drills academic skills. Moreover, most apps (322 apps, 75%) scored a one or less for Pillar 2 (Engagement in the Learning Process). Gameplay was frequently interrupted by pop-up advertisements, or the user was distracted from the app's learning objectives by embedded video advertisements (e.g., earning gameplay currency for watching an advertisement). Additionally, these apps commonly incorporated multiple feedback mechanisms (e.g., a combination of auditory feedback mechanisms like cheering, music, and applause, with visual feedback of written affirmations, character reactions, and confetti). Through narrowing a user's attention to receiving continued praise, excessive feedback may distract the user from an app's learning objectives, or may diminish their intrinsic motivation for learning (Hirsh-Pasek et al., 2015).

When evaluated according to Pillar 1 (Active Learning) and Pillar 2 (Engagement in the Learning Process) criteria, the quality of educational apps did not differ significantly based on SES. As aforementioned, the majority of apps played by participants were considered low-quality. Thus, the lack of differences in quality of educational app based on SES may not reflect true differences in the types of educational apps used by children of varying SES. Rather, this finding likely reflects the overall low-quality of educational apps marketed to children in the Google Play and Apple app stores, which are available to users of all SES.

The lack of significant differences in quality of educational apps may have less to do with who is downloading and playing these apps, instead having greater implications for app designers at large. App designers must begin creating apps based on evidence of how children actually learn, through creating developmentally-appropriate curriculum, building in scaffolded learning opportunities, and minimizing design features that distract from the primary learning goals (Hirsh-Pasek et al., 2015; Meyer et al., 2020).

Research Question Five: How is the design of apps associated with child EF?

Quality of apps was not significantly associated with EF scores. It was surprising that low Pillar 2 (Engagement with the Learning Process) scores were not associated with weaker EF, as both variables are associated with sustained attention. Specifically, the ability to select a task, disregard tangential stimuli, and maintain attention to one task over a period of time supports the development of EFs (Garon et al., 2008). Pillar 2 (Engagement in the Learning Process) captures the extent to which advertisements, feedback, and gamification mechanisms support or undermine sustained attention on the app's learning objective. If an app contained many disruptions or overly-engaging rewards that distracted the user from attending to the learning objective, then it would score low on Pillar 2 (Engagement in the Learning Process). Moreover, consistent rewards may negatively affect a child's ability to delay gratification and inhibit responses in other non-digital activities. It is possible that participants played low-quality apps for such short durations each day that overall exposure to low-quality apps contributed to negligible variance of EFs, compared to other daily activities. Given the social desirability and response biases associated with surveys, future research should consider more objective, in-person evaluations of EF to examine associations between app quality and EF.

In bivariate analyses, average daily duration of mobile device use was significantly associated with BRIEF-P t-scores, whereby greater amounts of time spent using mobile devices were correlated with slightly weaker EF. However, this association was no longer significant when examined through linear regression models. This difference in findings likely reflects differences in statistical analysis methods, as Spearman correlations are not comparable to linear regression. Rather than assessing the linear relationship between two variables, Spearman correlations assess monotonic relationships, illustrating how variables may change together, but not necessarily at a constant rate. These regression findings differ from one published study on app use and child EF, which reported that children who used apps for 30 minutes or more per day demonstrated worse inhibitory control than children who used apps for less than 30 minutes per day (McNeill et al., 2019, p. 524).

This study did not differentiate between the three EF constructs, serving as an important limitation given potential independent associations between working memory, inhibitory control, attention flexibility, and mobile device use. Future research should examine whether on-demand access to mobile devices associates with weak inhibitory control, similar to the findings of McNeill et al. (2019). Additionally, future research should assess whether difficulty transitioning away from mobile devices to attend to other situational demands reflects set shifting weaknesses; it could likewise reflect difficulty with delaying gratification, as children may choose to continue the instantaneously rewarding experience of using their mobile devices in place of other activities. More research is needed to clarify which of the EF constructs may be most strongly related to mobile device use.

Moreover, this study is limited in that few behavioral media use characteristics were surveyed. Use of media for calming purposes (Radesky et al., 2016b), displacement of other activities (Vandewater et al., 2006), or presence of parent mediation practices (Nikken & Schols, 2015) may determine whether mobile device use influences EF. These behavioral constructs should be examined in future research.

Conclusion

The present study highlighted two crucial characteristics of childhood media use. Firstly, average daily duration of mobile device use was significantly related to parent education, whereby children from lower-education households spent more time using mobile devices each day than children from higher-education households. Secondly, average daily duration of mobile device use was significantly correlated with preschool attendance, whereby children who attended center-based preschool programs spent less time using mobile devices each day than children who stayed at home with a caregiver. Further research is needed to clarify the types of activities that children from lower-education households and children who do not attend a structured preschool program are engaging with during their long periods of gameplay. If children are downloading and playing high-quality apps, with productive educational goals or imaginative play opportunities, these apps may serve as an additional means for effective cognitive and social development. However, if children are playing low-quality apps or displacing other productive forms of social engagement, the increased amount of time on mobile devices may serve as a barrier for productive cognitive and social development; this possibility is especially concerning in light of the shocking amount of violent content documented in apps played by young children. Given that preschool is a period of critical development, disparate uses of mobile devices during these years may intensify academic opportunity gaps before children even attend elementary school.

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Table 1

SES Characteristics

SES Variable	N (%)
Parent Education	
High School/Some College	56 (46%)
Four-Year College Degree	32 (26%)
More than Four-Year College Degree	33 (27%)
ITN Ratio	
< 200% of Federal Poverty Level	34 (29%)
200–400% of Federal Poverty Level	54 (45%)
> 400% of Federal Poverty Level	31 (26%)

Note. ITN data was missing for two participants.

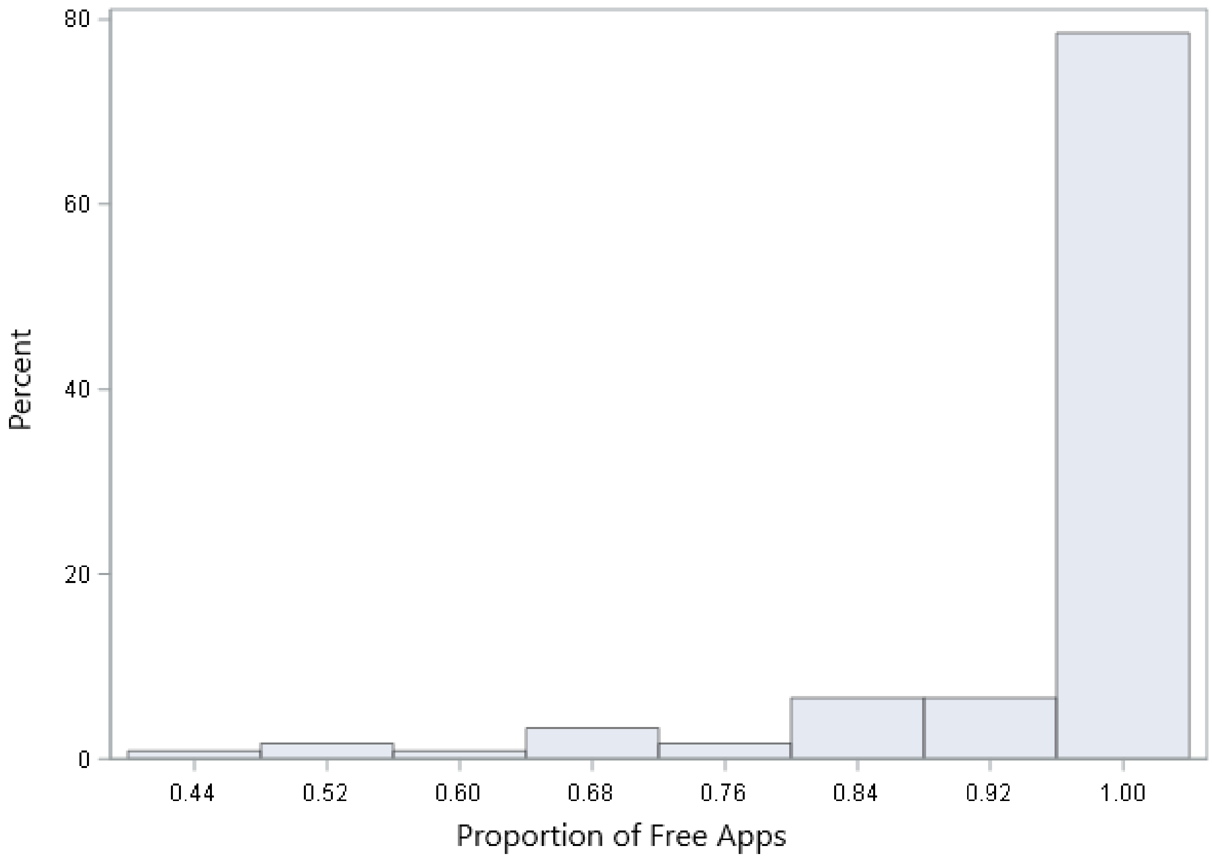
Table 2

Child Mobile Device Use Characteristics

Child Mobile Device Use Variable	Mean (SD)	Median (IQR)	Range
Average daily mobile device use (minute/day)	115.25 (115.11)	77.20 (127.11)	0.20 – 632.45
Weighted Average Pillar 1 Score	1.03 (0.40)	1.00 (0.05)	0.00 – 2.86
Weighted Average Pillar 2 Score	0.90 (0.61)	1.00 (0.56)	0.00 – 3.00
Total Weighted Average Pillar Score	1.93 (0.88)	2.00 (0.80)	0.49 – 5.77

Figure 1

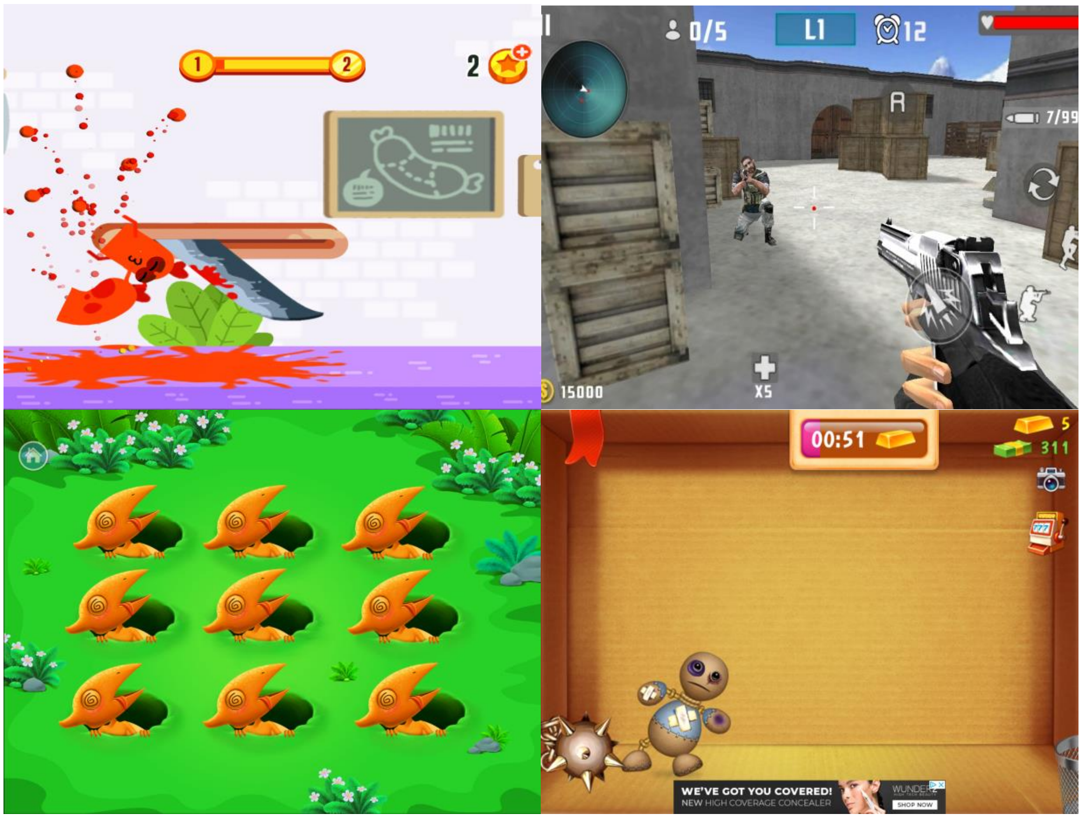
Distribution of the Proportion of Free Apps Installed



Note. The proportion of free apps played by the 121 sampled participants. Ninety-five participants (79%) played only free apps.

Figure 2

Violent Content Observed in Sampled Apps



Note. Examples of violent content in *Run Sausage Run!, Terrorist Shooter, Dinosaur Games - Jurassic Dino Simulator for Kids,* and *Kick the Buddy*, respectively.

Figure 3

Educational Content Observed in Sampled Apps

Note. Examples of educational themes observed in *Endless Learning Academy, Preschool Games, Caboose Express: Patterns and Sorting,* and *PaintSparkle,* respectively.

Appendix A

Pillar 1 – Active Learning (Reliability ICC = .87)	
Score	Description
0	Pillar objectives not met. App includes: • Activities that can be completed with little mental effort; and/or • Activities elicit simple "stimulus-response reactions to on-screen actions;" and/or • Passively following instructions with extremely constrained design that involves tapping the screen to make pages advance.
1	Activities have some learning objective, but are structurally closed-loop or repetitive. • There are many hints, demonstrations, or prompts to tell the child what to do; and/or • App drills skills, and feels like an online workbook; and/or • App forces activities to automatically advance from one activity to the next.
2	Activities have a learning objective, with some degree of flexibility or child-led problem-solving to complete them. • There is a mild degree of mental challenge to activities, such as having the player actively follow the programmed instructions to complete the learning objective. • Choices for completing the task may be constrained.
3	Pillar objectives met. App is a "minds-on" game, and includes activities "that require thinking and intellectual manipulation." • Activities allow the player to generate responses and incrementally increase challenge. • There may be several steps for the child to follow; however the steps are not spoon-fed to them, and hints are subtle or appropriate.

Appendix B

Pillar 2 – Engagement in the Learning Process (Reliability ICC = .95)					
Score	Distracting Advertising		Distracting Feedback		Gamification
0	• Embedded ad videos in gameplay; and/or • If pop-up ad interrupts mid-gameplay (e.g., in the middle of making a dessert, but not after completing one puzzle – must interrupt gameplay) more than one time; and/or • Four or more types of disruptive advertising present.	AND	• Object feedback provided after each action (e.g., earning a coin and seeing it put in the piggy bank and hearing a “cha-ching” noise after each step in an activity, such as after spraying water on a shirt to be ironed).	AND	• No active learning. Design features are purely for entertainment purposes.
1	• One-to-three types of disruptive advertising (includes pop-up ads, banner ads, hidden ads, rating prompts, social media prompts, and in-app purchases).	AND	• Feedback at the end of the game and/or after each action. • Six or more feedback mechanisms, and one or more object reward.	AND	• Extraneous visual and sound effects, which may distract the user from the game.

2	• Only in-app purchases allowed to be present. • No disruptive advertising should be present. • If character promotes in-app purchases, give a zero code for emotional manipulation. AND	• Feedback at the end of the game only. • Four-to-five types of feedback provided, of which only one should be an object reward. • If more than one object reward (e.g., potential to earn coins and a sticker), give a one code. AND	• See criteria for a score of one.
3	• No advertising present. AND	• Feedback at the end of the game only. • Very minimal – three or fewer types of feedback, of which only one should be an object reward. AND	• Visual and sound effects included only to enhance learning and engagement in the game.

Appendix C

Violent Content Coding Scheme (kappa = .90)	
Score	Non-Violent Content – All criteria must be met to score a zero

0	• There are no depictions of violence or aggressive behaviors.
	• The player does not engage in acts of violence or aggressive behaviors.
	• There are no depictions of weapons.
	    ◦ NOTE: The presence of knives or related potential weapons does not count as violent when used exclusively for cooking.
	• There are no depictions of graphic injuries, blood, or gore.
	• Examples:
	    ◦ A pretend-play app, in which the player takes care of an animal and gives it medicine by means of a shot.
	    ◦ A cooking app, in which the player is guided through a recipe to create a dish, including cutting vegetables with a knife.

Score	Violent Content – One of the following must be met to score a one

1	• There is at least one depiction of violence or aggressive behavior, including:
	    ◦ Depictions of victimization of crime
	    ◦ Depictions of graphic injuries or death
	    ◦ Depictions of fighting, beating, torture, or killing
	    ◦ Portrayal of weapons
	    ◦ NOTE: The player can observe these happening to other characters, or be on the receiving end of the violence.

	• The player is prompted to engage in acts of violence or aggressive behavior. The objective of the activity is to harm another character or sentient being, and the player is causing the harm with their actions. Includes:
	    • Fighting, beating, or torturing another character/sentient being
	    • Killing another character/sentient being
	    • Causing another character/sentient being to be physically harmed, and seeing the resulting graphic injuries (especially if blood or gore is shown)
	    • Engaging in antisocial actions (e.g., burglary, robbing, mugging)
	• The player is rewarded for violent or aggressive actions.
	    • Including through points, currency, gameplay boosts (e.g., a new weapon)
	• Does NOT include:
	    • Minor acts of comedic violence (e.g., making a character eat hot sauce)
	    • Sports violence, in which fighting with another character is needed to score, such as hockey or football
	        • NOTE: Must be in the context of a sports activity or app
	    • Activities that involve destruction but do not cause harm to another
	• Examples:
	    • An app in which the objective is to harm a character as a form of stress relief.
	    • An app simulating war, in which the player is in a war setting and shooting at opponents.