Longitudinal Associations of Electronic Application Use and Media Program Viewing with Cognitive and Psychosocial Development in Preschoolers

Jade McNeill, MSc; Steven J. Howard, PhD; Stewart A. Vella, PhD; Dylan P. Cliff, PhD

From the Early Start and School of Education, Faculty of Social Sciences (J McNeill, SJ Howard, DP Cliff); Illawarra Health and Medical Research Institute (J McNeill and DP Cliff); and Early Start and School of Psychology, Faculty of Social Sciences (SJ Howard and SA Vella), University of Wollongong, New South Wales, Australia
The authors have no conflicts of interest to disclose.
Address correspondence to Jade McNeill, MSc, Early Start, Faculty of Social Sciences, University of Wollongong, Northfields Ave, Wollongong, NSW 2522, Australia (e-mail: jm866@uowmail.edu.au).

ABSTRACT

OBJECTIVE: To investigate associations of traditional (program viewing) and contemporary (electronic applications, or apps) electronic media use with preschoolers' executive function and psychosocial development 12 months later.

METHODS: We conducted an analysis of longitudinal data from 185 children (mean age, 4.2 ± 0.6 years). Parents reported children's weekly electronic media use: 1) viewing programs on television or other devices and 2) app and game play using tablets, computers, consoles, or other devices. Direct assessments of children's executive functions (working memory, inhibition, and shifting) and educator-reported psychosocial difficulties were also collected. Linear regression models assessed associations between baseline predictors and developmental outcomes 12 months later, adjusting for covariates, preschool clustering, and baseline levels of predictors.

RESULTS: Higher levels of program viewing at baseline were significantly associated with increases in externalizing behaviors ($\beta = 0.008$; 95% confidence interval [CI], 0.002−0.014; $P = .010$) and total difficulties ($\beta = 0.013$; 95% CI, 0.005−0.022; $P = .005$) at follow-up. High-dose app users ($\geq$30 min/d) had a significantly lower inhibition score (mean difference = −0.04; 95% CI: −0.09 to −0.00; $P = .044$) at follow-up compared to low-dose app users (1 to 29 min/d).

CONCLUSIONS: Limiting electronic app use to <30 min/d and limiting media program viewing may be positively associated with preschool children's cognitive and psychosocial development.

KEYWORDS: digital media use; executive function; mental health; preschool; program viewing

ACADEMIC PEDIATRICS 2019;19:520−528

WHAT'S NEW

Higher levels of program viewing were significantly associated with increases in externalizing behaviors and total psychological difficulties in preschoolers. High-dose app use ($\geq$30 min/d) was associated with lower inhibition capabilities compared to low-dose app use.

EXECUTIVE FUNCTIONS ARE higher order cognitive processes implicated in the ability to reason, problem solve, and plan through their enabling of manipulating information in the mind (working memory), resisting distractions and impulsive behaviors (inhibition), and flexibly switching between task demands (shifting).[1] Executive functioning in the preschool period, in particular, is associated with later school readiness, academic achievement,[2] risky life choices,[3] and psychosocial development.[4] These outcomes appear to be further influenced by the flow-on effect of negative trajectories in areas also influenced by executive functions, such as the health outcomes of poor psychosocial health (eg, depression).[5] Understanding determinants of executive functions and psychosocial health in preschoolers may provide targets for prevention or early intervention, with implications for broad health and developmental outcomes in later life.

Electronic media, particularly watching television (TV), has been linked with detrimental child health outcomes;[6] consequently, the United States, Australia, and Canada are consistent in recommending that children ages 2 to 5 years should engage in no more than 1 h/d of screen time.[7−9] Despite these guidelines, US national data indicate that 2- to 4-year-olds engage in, on average, almost 2.5 hours of electronic media use per day.[10] Although children's time engaging in electronic media use has remained relatively constant, exposure to and use of mobile devices tripled from 2011 to 2017 among 0- to 8-year-olds in the United States.[10] Yet, current guidelines are premised predominantly on studies of traditional electronic media behaviors (ie, TV/DVD viewing or electronic console gaming). There

is a scarcity of research on contemporary, interactive media, including electronic applications (apps).[6] Hypothesized mechanisms through which electronic media use might adversely affect young children include overstimulation of the developing brain or displacement of time from social interactions or other developmentally beneficial activities.[11,12] There is speculation that contemporary interactive media with touchscreen technologies may have different effects due to the potential for reactivity, interactivity, tailorability, progressiveness, promotion of joint attentions, and portability.[13] Further research is needed to understand if interactive media use may have different associations with young children's development.[6]

Of the 2 longitudinal studies that investigated the relationship between electronic media use and executive functions[14,15] and the 2 longitudinal studies that investigated the relationship between electronic media use and psychosocial health,[16,17] only associations with traditional forms of media use are available (with results inconsistent across media types). That is, evidence from these studies reported that TV time was not associated with executive functions or psychosocial health;[14–17] computer use was positively associated with emotion problems but not peer problems;[16] and electronic game use was positively associated with emotional health.[17]

Notably, no longitudinal studies have examined associations of executive functions or psychosocial health with contemporary media behaviors (eg, app use). As such, it is unclear whether associations for early contemporary interactive media use (apps) and traditional passive media use (TV program viewing) may differ in their associations with children's cognitive and psychosocial development. The current longitudinal study examined if electronic media use at 3 to 5 years of age (particularly total screen time, program viewing, and app use) was associated with cognitive and psychosocial development in children 12 months later.

METHODS

CENTER RECRUITMENT

Data were drawn from the Preschool Activity, Technology, Health, Adiposity, Behaviour and Cognition study,[18] which had University of Wollongong Health and Medical Human Research Ethics Committee approval (HE14/310). Preschools were recruited based on a stratified sampling process from the Illawarra region of New South Wales, Australia. Preschools (long daycares and preschools) in the region were categorized according to the 2011 Socio-Economic Indexes for Areas Index of Relative Socio-Economic Advantage and Disadvantage as low (deciles 1–4), medium (deciles 5–7), or high (deciles 8–10) socioeconomic areas. The number of preschools invited to participate from each socioeconomic group was proportional to the population distribution. Baseline data were collected in preschools (n = 18) between April and December 2015. Follow-up data were collected between April and December 2016 at preschools (n = 17) or the child's primary school (n = 51).

SAMPLE

Children were eligible to participate if they were 3 to 5 years of age, generally healthy, and developing typically. Children could not participate if they had a learning or physical disability, known motor delay, or diagnosed medical or psychological condition that was pertinent to the study's outcome variables (eg, conduct disorder). At baseline, 490 eligible participants were recruited, 243 had missing data, and 12 did not consent to follow-up; thus, 235 participants provided complete data. Of the 235 participants with complete data, 15 did not agree to be reconsented and 35 could not be contacted (Figure); therefore, 185 participants were included in the analytic sample. Participant characteristics are reported in Table 1. However, due to incomplete data for cognitive and psychosocial variables, sample sizes for the individual analyses varied (Table 2).

MEASURES

PREDICTORS: ELECTRONIC MEDIA USE

Parents reported the total number of electronic media devices in the house and, of those, how many were available to the child at 3 to 5 years of age. Also reported was the total time a child spent engaging in electronic media behaviors separately for weekdays and weekend days during a typical week, as well as by the following types of media use: 1) program viewing on traditional devices, such as TV or DVDs; 2) program viewing on non-traditional devices, such as a tablet, DVD in the car, computer, laptop, or mobile phone; 3) apps on portable handheld devices or laptop/computer, such as a tablet, mobile phone, or handheld game system; 4) non-active console games, such as PlayStation or Xbox; and 5) active console games, such as Wii or Xbox Kinect. The total time in each behavior was averaged to calculate an average daily time of engagement in each behavior and then summed to calculate daily total electronic media time. Averages for traditional (eg, TV) and non-traditional (eg, tablet) program viewing were summed to calculate average daily total program viewing and analyzed as a continuous variable. A large proportion of children did not engage in app use (11%); consequently, due to data distributions, app use on portable devices was analyzed categorically, with daily estimates categorized as 1) non-users (0 min/d); 2) low-dose users (1–29 min/d); or 3) high-dose users (≥30 min/d). A limit of 30 min/d was chosen because it aligned with the lower pragmatic limit identified by Christakis,[19] a leading expert in the field, for young children's app use. Average daily minutes using active consoles and non-active consoles were combined to calculate average daily console use, as a continuous variable.

OUTCOMES: COGNITIVE DEVELOPMENT

Executive functions were assessed at baseline and follow-up using measures drawn from the Early Years Toolbox (EYT).[20] The EYT, based on the iPad (Apple; Cupertino, Calif), has been validated for use with young children, is
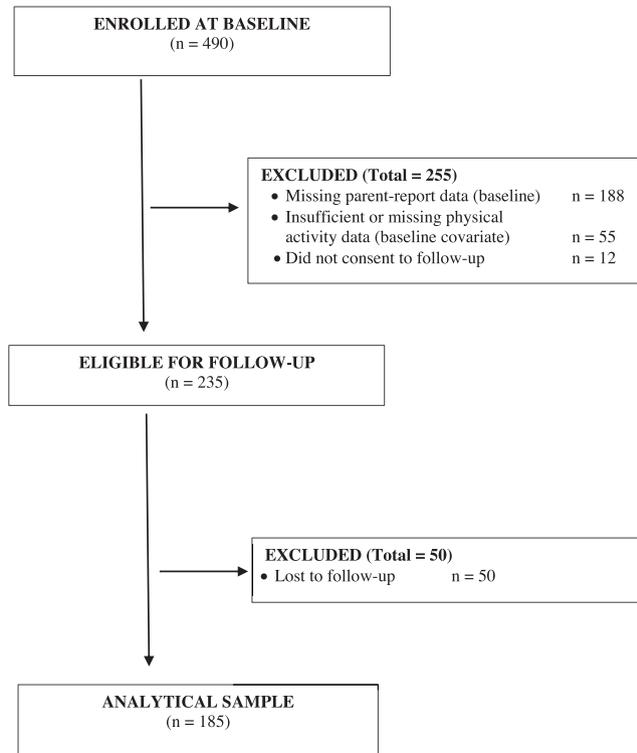
Figure. *Flowchart of participants (3−5 and 4−6 years of age) in the Preschool Activity, Technology, Health, Adiposity, Behaviour and Cognition study.*

brief to administer, and offers a number of pragmatic advances (eg, data capture, standardization, engaging for young children).[20] Measures were administered in 2 assessment sessions grouped by outcomes: physical health and cognitive development. The EYT assessments adopted index visual-spatial working memory ("Mr. Ant"), phonological working memory ("Not This"), inhibition ("Go/No-Go") and shifting ("Dimensional Change Card Sort"). Full details of the EYT methodology, reliability, and validity have been reported elsewhere.[20]

Table 1. Descriptive Data on Participant Characteristics, Physical Activity, and Covariates at 3 to 5 Years

Characteristics	Boys (n = 112)	Girls (n = 73)	Total Sample (N = 185)
Age at enrollment into study (y), mean (SD)	4.32 (0.66)	3.99 (0.57)	4.19 (0.64)**
Socioeconomic status (IRSAD)	1027.20 (60.00)	1020.33 (55.02)	1024.0 (57.35)
Home learning environment	26.47 (9.28)	28.26 (9.17)	27.18 (9.25)
Sleep (hr/d), mean (SD)	10.52 (1.00)	10.62 (0.81)	10.56 (0.93)
Parental education, n (%)			
Less than Year 12 of high school	10 (8.9)	21 (28.8)	31 (16.8)**
Year 12 high school or trade/diploma	36 (32.1)	10 (13.7)	46 (24.9)**
Degree/postgraduate	66 (58.9)	42 (57.5)	108 (58.4)
Participant education sector follow-up, n (%)			
Preschool	62 (55.4)	51 (69.9)	113 (61.1)
Primary school	50 (44.6)	22 (30.1)	72 (38.9)
Electronic media average (min/d), mean (SD)			
Total electronic media	145.45 (80.64)	143.70 (79.32)	145.04 (79.91)
Total program viewing TV	118.75 (64.83)	127.36 (74.30)	122.15 (68.65)
Total program viewing (traditional devices)	94.88 (48.87)	101.42 (61.38)	97.46 (54.09)
Total program viewing (non- traditional devices)	23.87 (33.40)	25.94 (33.74)	24.69 (33.46)
Apps use	22.79 (27.88)	13.55 (18.35)	19.15 (24.93)
Console use (combined)	3.91 (12.85)	2.79 (19.68)	3.74 (15.73)
Active console use	0.91 (4.36)	0.23 (1.41)	2.82 (14.82)
Non-active console use	3.0 (10.65)	2.56 (19.66)	0.65 (3.51)
App use, n (%)			
Non-users (0 min/d)	27 (24.1)	27 (37.0)	54 (29.2)
Low-dose users (>1−29 min/d)	52 (46.4)	35 (47.9)	87 (47.0)
High-dose users (≥30 min/d)	33 (29.5)	11 (15.1)	44 (23.8)*

IRSAD indicates Index of Relative Socio-Economic Advantage and Disadvantage; SD, standard deviation.

*P < .05.

**P < .01.

Table 2. Associations of Media Use and Program Viewing at 3−5 Years and Associations Among Executive Functions, Strengths and Difficulties Questionnaire Subscales, and Total Difficulties Scores at 4−6 Years[†]

	n	Total Electronic Media Use		Program Viewing[‡]	
		β (95% CI)	P Value	β (95% CI)	P Value
Executive function					
Visual-spatial working memory	185	0.000 (−0.001, 0.002)	.766	0.000 (−0.001, 0.002)	.662
Phonological working memory	181	0.000 (−0.001, 0.001)	.945	−0.000 (−0.002, 0.002)	.858
Inhibition	185	0.000 (−0.000, 0.000)	.475	0.000 (−0.000, 0.001)	.171
Shifting	185	0.003 (−0.003, 0.010)	.303	0.004 (−0.004, 0.012)	.289
Psychosocial development					
Prosocial behaviors	156	−0.002 (−0.004, 0.001)	.175	−0.003 (−0.006, 0.001)	.150
Internalizing problems	156	0.002 (−0.003, 0.008)	.371	0.005 (0.000, 0.010)	.051*
Externalizing problems	156	0.004 (−0.001, 0.009)	.082	0.008 (0.002, 0.014)	.010*
Total difficulties	156	0.007 (−0.002, 0.016)	.117	0.013 (0.005, 0.022)	.005*

Linear regression models are adjusted for age, sex, suburb-level socioeconomic status, parental education, participation in sports, physical activity duration, home learning environment, sleep duration, total program viewing, and childcare-level clustering.
†Controlling for executive functions, Strengths and Difficulties Questionnaire subscales, and total difficulties scores at 3−5 years; adjusted for covariates.
‡Additionally adjusted for app use.
*$P < .05$.

PSYCHOSOCIAL HEALTH

Psychosocial health was assessed at baseline and follow-up using the educator-reported version of the Strengths and Difficulties Questionnaire (SDQ),[21] which has been validated for use with Australian preschoolers.[22] The SDQ is comprised of 25 items assessing 5 psychosocial domains: 1) conduct problems, 2) hyperactivity, 3) emotional problems, 4) peer problems, and 5) prosocial behavior. Educators rate the typicality of each target behavior (ie, item) on a 3-point Likert scale ranging from 0 (not true) to 2 (certainly true). In low-risk and general populations, a 3-subscale model of the SDQ is appropriate and is comprised of 1) internalizing problems (sum of emotional problems and peer problems subscales); 2) externalizing problems (sum of conduct problems and hyperactivity subscales); and 3) prosocial behaviors. Total psychological difficulties were also calculated by summing the 20 items pertaining to psychosocial problems (ie, conduct problems, hyperactivity, emotional symptoms, and peer problems).

CHILD AND PARENT DEMOGRAPHICS AND COVARIATES

Data on child and parent demographics and covariates were collected via parent-report survey. These covariates were child age, child sex, area-level socioeconomic status (Socio-Economic Indexes for Areas),[23] and primary caregiver education (categorized as less than Year 12 high school, Year 12 high school completion or trade, or tertiary qualification). In addition, due to evidence of their associations with children's cognitive and psychosocial development, further covariates collected and considered were parent-reported average sleep time,[24] sports participation,[25] moderate-to-vigorous physical activity,[25] and educational and extracurricular experiences as an index of the quality of the home learning environment.[26] Parents reported children's average daily sleep duration (hours),[18] sports participation (participant or non-participant),[25] and the quality of the home learning environment (ie, frequency with which parents engaged their children in going to the library,

reading, listening to the child read, practicing numbers, or teaching them songs).[26] Children's moderate-to-vigorous physical activity was assessed using accelerometry.[18,25]

ANALYTICAL STRATEGY

Analyses were conducted in STATA/IC 13.1 (StataCorp; College Station, Tex). Differences between the analytical sample and those excluded due to missing data were tested using independent samples *t*-tests. It was determined that the level of missing data was too high for confident imputation, as such complete case analysis was used, and the resultant sample was investigated for any evidence of bias. Children with missing data had lower Index of Relative Socio-Economic Advantage and Disadvantage scores ($P = .003$) and lower phonological working memory scores at baseline ($P = .028$). Separate linear regression models were conducted, due to expected multicollinearity, to examine the associations of total electronic media use, program viewing, and app use at baseline with each executive function or psychosocial development subscale at follow-up. All models controlled for age, sex, area-level socioeconomic status, parental education, sleep, participation in sport, moderate-to-vigorous physical activity, home learning environment quality, preschool-level clustering, participants' educational setting at follow-up (ie, preschool or primary school), and the baseline levels of the outcome variable. The model examining program viewing also controlled for app use and the model examining app use controlled for total program viewing, due to these being the predominant forms of electronic media use in young children. Assumptions of normality for linear regression were assessed by examining distributions of residuals for each model, no-variable-required transformation. Participant characteristics are presented as means ± standard deviation (SD), and distributions of the sample are presented as percentages. Regression results are presented as unstandardized beta coefficients (β) and 95% confidence intervals (CIs) for continuous variables

and as mean differences (MDs) and 95% CIs for categorical variables. Unstandardized β coefficients describe the unit change in the dependent variable given a 1-unit change in the independent variable and indicate the effect size for continuous associations.[27] For significant categorical associations, Cohen's d standardized effect size is reported, where effect sizes of approximately 0.2, 0.5, and 0.8 are generally considered small, medium, and large effects, respectively.[28] Significance was set at $P < .05$.

RESULTS

On average, children spent ~2.4 h/d engaging with electronic media at baseline (3 to 5 years of age), with the majority of this time (122 min/d; 85%) spent in program viewing and 13% (19 min/d) and 2% (3 min/d) of the total time spent using apps and console devices, respectively. There were, on average, 10 (SD, 3.4) electronic media devices in children's homes, with 4 (SD, 2.7) available for children to use. Compared to boys, girls experienced fewer externalizing behavior problems ($P = .014$), and fewer girls spent ≥30 min/d using apps ($P = .033$); remaining gender differences are reported in Table 1. Children's mean executive function scores were in line with preliminary norms derived from EYT validation.[20] Mean scores for internalizing and externalizing subscales, prosocial scores, and total difficulties scores for the SDQ fell within the normal ranges.[29] From 3−5 years to 4−6 years of age, significant improvements were found for all executive functions domains ($P < .001$) and for total difficulty scores ($P = .033$) (Table 3), but not for other SDQ subscales.

Program Viewing and Total Electronic Media Use

Higher levels of program viewing at baseline were associated with more externalizing problems at follow-up ($\beta = 0.008$; 95% CI, 0.002−0.014; $P = 0.010$) (Table 2). Higher levels of program viewing at baseline were associated with higher total difficulties at follow-up ($\beta = 0.013$; 95% CI, 0.005−0.022; $P = 0.005$). A 68 min/d (1 SD; see Table 1) lower exposure to program viewing at 3 to 5 years equated to a 12% to 20% lower risk of being diagnosed with a psychiatric disorder within 3 years.[29] Higher levels of program viewing at 3 to 5 years were also marginally associated with higher internalizing behaviors at follow-up

($\beta = 0.005$; 95% CI, 0.000−0.010; $P = .051$). Total electronic media use and program viewing at baseline were not significantly associated with executive functions or prosocial behaviors at follow-up.

Application Use

High-dose app users (≥30 min/d) at baseline had a significantly lower inhibition score (MD = −0.04; 95% CI, −0.09 to −0.00; $P = 0.044$; $d = −0.19$) at follow-up than low-dose app users (1−29 min/d) (Table 4). This difference equates to ~2.7 months of normal development[20] and represented a small effect ($d = −0.19$). There were no significant differences among non-users, low-dose app users, or high-dose app users in visual-spatial or phonological working memory, shifting, or psychosocial development at follow-up.

DISCUSSION

This longitudinal study sought to investigate associations of traditional and contemporary habitual electronic media use with executive functions and psychosocial development 12 months later in preschoolers. Higher levels of program viewing (eg, TV or internet programs on any device) at age 3 to 5 years were associated with increases in externalizing behavior problems and total psychological difficulties 12 months later. Similarly, high-dose app users (≥30 min/d) at ages 3 to 5 years had lower inhibition 12 months later compared to low-dose app users (1−29 min/d). Traditional forms of media use exerted detrimental associations with subdomains of psychosocial health, which is consistent with the broader literature.[6] Whereas no associations were observed for low-dose app use (1−29 min/d) with developmental outcomes, some evidence suggests that high-doses of app use (≥30 min/d) exerted a detrimental effect on inhibition. These findings indicate that different types of electronic media use may exert independent effects on health and development and further support recommendations to limit young children's electronic media use to avoid overexposure. Such recommendations might be beneficial for a child's future cognitive development, particularly their ability to control impulsive behavior, and for their psychosocial health.

Table 3. Executive Functions and Strengths and Difficulties Questionnaire Subscale Scores at 3−5 Years and 4−6 Years

Developmental Outcomes	3−5 Years Mean (SD)	4−6 Years Mean (SD)
Executive function		
Visual-spatial working memory (score range, 0−8)	1.29 (1.02)	2.25 (0.92)*
Phonological working memory (score range, 0−8)	1.80 (0.79)	2.17 (0.71)*
Inhibition (score range, 0−1)	0.56 (0.21)	0.73 (0.16)*
Shifting (score range, 0−12)	4.51 (4.35)	7.64 (3.64)*
Psychosocial development		
Internalizing problems (score range, 0−20)	3.22 (2.85)	2.83 (3.17)
Externalizing problems (score range, 0−20)	5.27 (4.54)	4.41 (4.44)
Prosocial behaviors (score range, 0−10)	7.23 (2.61)	7.49 (2.35)
Total difficulties (score range, 0−40)	8.50 (5.78)	7.24 (6.22)*

SD indicates standard deviation.
*$P < .05$.

Table 4. Associations Between Dose of Engagement in Apps at 3−5 years and Associations Among Executive Functions, Strengths and Difficulties Questionnaire Subscales, and Total Difficulties Scores at 4−6 Years[†]

	n	Non-Users (0 min/d) Mean (95% CI)	Low-Dose Users (>1−29 min/d) Mean (95% CI)	High-Dose Users (≥30 min/d) Mean (95% CI)	Low-Dose Users vs Non-Users		High-Dose Users vs Non-Users		High-Dose Users vs Low-Dose Users	
					Mean (95% CI)	P Value	Mean (95% CI)	P Value	Mean (95% CI)	P Value
Executive Functions										
Visual-spatial working memory	185	2.14 (1.83, 2.45)	2.31 (2.16, 2.47)	2.29 (1.89, 2.68)	0.17 (−0.13, 0.48)	.244	0.14 (−0.32, 0.61)	.518	−0.03 (−0.36, 0.30)	.856
Phonological working memory	185	2.21 (1.96, 2.45)	2.14 (1.98, 2.30)	2.27 (2.03, 2.51)	−0.06 (−0.29, 0.16)	.547	0.06 (−0.24, 0.37)	.668	0.13 (−0.10, 0.36)	.256
Inhibition	181	0.73 (0.68, 0.79)	0.76 (0.72, 0.79)	0.71 (0.67, 0.75)	0.02 (−0.05, 0.09)	.509	−0.02 (−0.11, 0.06)	.594	-0.04 (−0.09, −0.00)	.044[*]
Shifting	185	7.53 (6.54, 8.52)	7.77 (7.20, 8.33)	7.70 (6.44, 8.96)	0.24 (−0.95, 1.42)	.679	0.16 (−1.39, 1.72)	.826	−0.07 (−1.28, 1.14)	.903
Psychosocial Development										
Internalizing problems	156	2.98 (1.50, 4.47)	3.01 (2.38, 3.64)	2.38 (1.32, 3.44)	0.03 (−1.37, 1.43)	.965	−0.61 (−2.28, 1.07)	.455	−0.64 (−1.62, 0.35)	.190
Externalizing problems	156	4.70 (3.45, 5.94)	4.48 (3.06, 5.90)	4.26 (3.13, 5.39)	−0.22 (−1.15, 0.72)	.629	−0.44 (−2.23, 1.36)	.612	−0.22 (−1.91, 1.46)	.785
Prosocial behaviors	156	7.32 (6.72, 7.92)	7.67 (7.01, 8.32)	7.44 (6.68, 8.21)	0.35 (−0.31, 1.01)	.278	0.12 (−0.71, 0.95)	.756	−0.22 (−1.14, 0.69)	.611
Total difficulties	156	7.62 (5.36, 9.88)	7.53 (5.64, 9.43)	6.63 (5.01, 8.26)	−0.08 (−1.91, 1.74)	.924	−0.98 (−3.51, 1.54)	.424	−0.90 (−2.78, 0.98)	.320

Linear regression models are adjusted for age, sex, suburb-level socioeconomic status, parental education, participation in sports, physical activity duration, home learning environment, sleep duration, total program viewing, and childcare-level clustering.

†Controlling for executive functions, Strengths and Difficulties Questionnaire subscales, and total difficulties scores at 3−5 years; adjusted for covariates.

*P < .05.

The negative associations we observed between program viewing and psychological development are generally consistent with the broader evidence base indicating that program viewing (combining TV and movies) may be detrimental to young children's psychological health.[6,30] However, not all studies conform to these findings. Hinkley et al[16] reported that TV viewing during the preschool years was not associated with an increased risk of emotional or peer problems 2 years later (internalizing problems), and another study found no associations with social and emotional skills 3 years later.[17] Although Hinkley et al[16] also used SDQ items, they investigated associations separately for emotional or peer problem subscales rather than their aggregate. Further, the current study examined had a shorter follow-up period (12 months) and narrower age range (3 to 5 years), which may account for the discrepancies observed. In contrast, these detrimental associations were not observed for contemporary electronic media use.

To our knowledge, no published longitudinal studies have examined associations between app use during the preschool years and later executive function development.[6,31] Conceptually, app use on portable handheld devices may differ fundamentally in nature from traditional media use (in a way that could support executive function development), in its active engagement of children, reactivity to children's levels of competence, and promotion of joint attention and interaction.[19] In support of this possibility, a review by Herodotou[31] reported positive effects of tablets with learning and development in young children. Similarly, improvements in problem solving, planning ability, and executive functioning were observed in children ages 4 to 6 years after practicing with a tablet-based Tower of Hanoi puzzle and then applying this learning to a physical version.[32]

Despite this, our study found no associations for low-dose app use at baseline (1−29 min/d) and executive functions at follow-up, but high-dose app users (≥30 min/d) at baseline displayed lower inhibition capabilities than low-dose app users (1−29 min/d), equating to 2.7 months of functional developmental; however, the effect size was small. This might suggest that the effects of some electronic media use (ie, app use) might be curvilinear. For example, limited app use (<30 min/d of educational, interactive use with sound education content) may at best not be developmentally harmful; yet, beyond a 30-min/d threshold, app use may begin to reduce other developmentally boosting activities, potentially harming a child's development. One cross-sectional study in preschoolers (n = 100) has examined associations for media other than TV viewing—specifically, playing video/computer games—with executive functions, and null associations were reported.[33] Differences in media exposure classification, executive function measures, and study design may potentially contribute to the discrepancies in findings among studies. Our novel findings suggest that, although mild levels of app use may not be detrimentally associated with a child's executive function, higher durations (≥30 min/d) may be harmful to aspects of early executive function development. These findings provide evidence of contemporary media use to support the proposed pragmatic limit for young children of <30 min/d of app use,[19] ideally involving developmentally appropriate, educational content.

A number of mechanistic pathways could explain the detrimental or null associations observed for the different types of media use in this study. Engaging in program viewing (activities that are passive in nature) may have little developmental benefit to young children's executive functions, as observed in the predominantly null findings. Time spent engaging in this type of behavior may displace opportunities for interaction or activities that support aspects of health, such as engaging in play and socialization with adults, siblings, or peers; real-world experiences;[34] or active or interactive play,[35] thus providing one explanation for the detrimental associations for psychosocial health. Contrastingly, similar associations were not observed when examining contemporary media use. No developmental gains or detrimental associations were observed longitudinally for working memory, shifting, or psychosocial subdomains; however, high app exposure was detrimental to inhibition, relative to low-dose exposure. High levels of app exposure may impact a child's inhibition through neurobiological pathways. Extensive technology use can stimulate physiological arousal and the secretion of dopamine to cortical regions of the brain that are sensitive to reward and reinforcement, particularly when playing games and apps.[36] Therefore, it could be speculated that a dose-response effect may be one part of this complex relationship. For example, no effects were observed for low-dose exposure to contemporary media use with executive functions, but high exposure may result in time being taken away from other development-boosting activities which becomes detrimental. Alternatively, another plausible mechanism is that the child may become driven by external stimulus and instant reward and feedback, resulting in the child becoming unable to control their own attention or self-regulatory behaviors.[12] Thus, it is plausible that app use of higher exposures may be associated with neurochemical pathways that underpin executive functions, leading to impaired impulse control.

A strength of this study is the direct assessment of executive functions, using a battery that has strong validity, reliability, and developmental sensitivity.[20] Including covariates that have been associated with the developmental outcomes adds further weight to the suggestion that associations are robust, rather than a consequence of other related factors. Although this study used a representative sampling approach, participants with missing data were of lower suburb-level socioeconomic status and had lower phonological working memory at baseline than those in the analytic sample, which may influence the generalizability of the findings. Additionally, this study examined the dose and type of electronic media use; other characteristics, such as educational content[37] or social interaction,[12,38] may also influence developmental outcomes but were not possible to investigate with the current data. Although the average time children spent

engaging in traditional and contemporary media use was relatively consistent with another study reported in Australian children,[39] future research might consider adopting a more objective approach to capture the dynamic and flexible use of apps among preschoolers (eg, using an app that tracks time of use). Further, it is possible that associations between app use and inhibition may have occurred by chance, given the large number of outcome variables assessed in the study. Additional research is needed to confirm this finding. Finally, due to the observational nature of this study, causality cannot be established. Additional experimental evidence is needed to identify mechanistic pathways.

CONCLUSION

In terms of more traditional media use, program viewing at 3 to 5 years of age was detrimentally associated with changes in externalizing problems and total difficulties 1 year later, in line with some previous studies. This study demonstrated for the first time that high-dose app use ($\geq$30 min/d) was associated with lower inhibition performance 12 months later compared to low-dose use (1−29 min/d). Although further research is needed to investigate the exact nature of these media-use behaviors and their potentially differing effects, the current results provide initial evidence that reducing media program viewing and limiting electronic app use may be positively associated with preschool children's psychosocial and cognitive development.

ACKNOWLEDGMENTS

REFERENCES

1. Miyake A, Friedman NP, Emerson MJ, et al. The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: a latent variable analysis. *Cogn Psychol*. 2000;41:49–100.
2. Blair C, Razza RP. Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. *Child Dev*. 2007;78:647–663.
3. Moffitt TE, Arseneault L, Belsky D, et al. A gradient of childhood self-control predicts health, wealth, and public safety. *Proc Natl Acad Sci USA*. 2011;108:2693–2698.
4. Benavides-Nieto A, Romero-López M, Quesada-Conde AB, et al. Basic executive functions in early childhood education and their relationship with social competence. *Procedia Soc Behav Sci*. 2017;237:471–478.
5. Meagher SM, Arnold DH, Doctoroff GL, et al. Social-emotional problems in early childhood and the development of depressive symptoms in school-age children. *Early Educ Dev*. 2009;20:1–24.
6. Poitras VJ, Gray CE, Janssen X, et al. Systematic review of the relationships between sedentary behaviour and health indicators in the early years (0-4 years). *BMC Public Health*. 2017;17:868.
7. American Academy of Pediatrics. American Academy of Pediatrics Announces New Recommendations for Children's Media Use.

Available at: https://www.aap.org/en-us/about-the-aap/aap-press-room/Pages/American-Academy-of-Pediatrics-Announces-New-Recommendations-for-Childrens-Media-Use.aspx. Accessed June 12, 2018.
8. Okely AD, Ghersi D, Hesketh KD, et al. A collaborative approach to adopting/adapting guidelines - The Australian 24-Hour Movement Guidelines for the early years (Birth to 5 years): an integration of physical activity, sedentary behavior, and sleep. *BMC Public Health*. 2017;17(Suppl 5):869.
9. Tremblay MS, Chaput JP, Adamo KB, et al. Canadian 24-Hour Movement Guidelines for the early years (0-4 years): an integration of physical activity, sedentary behaviour, and sleep. *BMC Public Health*. 2017;17(suppl 5):874.
10. Common Sense Media. Common Sense Research: The Common Sense Census: Media Use by Kids Age Zero to Eight. Available at: https://www.commonsensemedia.org/research. Accessed February 26, 2018.
11. Radesky JS, Christakis DA. Increased screen time: implications for early childhood development and behavior. *Pediatr Clin North Am*. 2016;63:827–839.
12. Radesky JS, Schumacher J, Zuckerman B. Mobile and interactive media use by young children: the good, the bad, and the unknown. *Pediatrics*. 2015;135:1–3.
13. Christakis DA. Interactive media use at younger than the age of 2 years: time to rethink the American Academy of Pediatrics Guideline ? *JAMA Pediatr*. 2014;168:229–340.
14. Blankson AN, O'Brien M, Leerkes EM, et al. Do hours spent viewing television at ages 3 and 4 predict vocabulary and executive functioning at age 5? *Merrill Palmer Q*. 2015;61:264.
15. Zimmerman FJ, Christakis DA. Children's television viewing and cognitive outcomes: a longitudinal analysis of national data. *Arch Pediatr Adolesc Med*. 2005;159:619–625.
16. Hinkley T, Verbestel V, Ahrens W, et al. Early childhood electronic media use as a predictor of poorer well-being: a prospective cohort study. *JAMA Pediatr*. 2014;168:485–492.
17. Hinkley T, Timperio A, Salmon J, et al. Does preschool physical activity and electronic media use predict later social and emotional skills at 6 to 8 years? A cohort study. *J Phys Act Heal*. 2017;14:308–316.
18. Cliff DP, McNeill J, Vella S, et al. The Preschool Activity, Technology, Health, Adiposity, Behaviour and Cognition (PATH-ABC) cohort study: rationale and design. *BMC Pediatr*. 2017;17:1–9.
19. Christakis DA. Interactive media use at younger than the age of 2 years. *JAMA Pediatr*. 2014;168:399–400.
20. Howard SJ, Melhuish E. An Early Years Toolbox for assessing early executive function, language, self-regulation, and social development. *J Psychoeduc Assess*. 2017;35:225–275.
21. Goodman R. The Strengths and Difficulties Questionnaire: a research note. *J Child Psychol Psychiatry*. 1997;38:581–586.
22. Hawes DJ, Dadds MR. Australian data and psychometric properties of the Strengths and Difficulties Questionnaire. *Aust N Z J Psychiatry*. 2004;38:644–651.
23. Australian Bureau of Statistics. Information Paper: An Introduction to Socio-Economic Indexes for Areas (SEIFA) (cat. no. 2039.0). Available at: http://www.abs.gov.au/ausstats/abs@.nsf/mf/2039.0. Accessed June 12, 2015.
24. Chaput J-P, Gray CE, Poitras VJ, et al. Systematic review of the relationships between sleep duration and health indicators in the early years (0-4 years). *BMC Public Health*. 2017;17:855.
25. McNeill J, Howard SJ, Vella SA, et al. Physical activity and modified organized sport among preschool children: associations with cognitive and psychosocial health. *Ment Health Phys Act*. 2018;15:45–52.
26. Sammons P, Toth K, Sylva K, et al. The long-term role of the home learning environment in shaping students' academic attainment in secondary school. *J Child Serv*. 2015;10:189–201.
27. Schroeder LD, Sjoquist DL, Stephan PE. Understanding Regression Analysis: An Introductory Guide. Los Angeles, Calif: Sage; 2016.
28. Cohen J. Statistical Power Analysis for the Behavioral Sciences. Hillsdale, NJ: Lawrence Erlbaum Associates; 1988.

29. Goodman A, Goodman R. Strengths and Difficulties Questionnaire as a dimensional measure of child mental health. *J Am Acad Child Adolesc Psychiatry*. 2009;48:400–403.

30. Hinkley T, Teychenne M, Downing KL, et al. Early childhood physical activity, sedentary behaviors and psychosocial well-being: a systematic review. *Prev Med*. 2014;62:182–192.

31. Herodotou C. Young children and tablets: a systematic review of effects on learning and development. *J Comput Assist Learn*. 2018;34:1–9.

32. Huber B, Tarasuik J, Antoniou MN, et al. Young children's transfer of learning from a touchscreen device. *Comput Human Behav*. 2016;56:56–64.

33. Carson V, Rahman AA, Wiebe SA. Associations of subjectively and objectively measured sedentary behavior and physical activity with cognitive development in the early years. *Ment Health Phys Act*. 2017;13:1–8.

34. Moreno MA. Supporting child play. *JAMA Pediatr*. 2016;170:184.

35. Golinkoff RM, Hirsh-Pasek K, Singer DG. Why play = learning: a challenge for parents and educators. In: Singer DG, Golinkoff RM, Hirsch-Pasek K, eds. Play = Learning: How Play Motivates and Enhances Children's Cognitive and Social-Emotional Growth, Oxford, UK: Oxford University Press; 2006:3–12.

36. Green CS, Bavelier D. Learning, attentional control, and action video games. *Curr Biol*. 2012;22:R197–R206.

37. Huber B, Yeates M, Meyer D, et al. The effects of screen media content on young children's executive functioning. *J Exp Child Psychol*. 2018;170:72–85.

38. Christakis DA, Garrison MM, Herrenkohl T, et al. Modifying media content for preschool children: a randomized controlled trial. *Pediatrics*. 2013;131:431–438.

39. Neumann MM. Young children and screen time: creating a mindful approach to digital technology. *Aust Educ Comput*. 2015;30:1–15.