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The NewFAMS Study Team

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Infant screen exposure links to toddlers' inhibition, but not other EF constructs: A propensity score study

Gabrielle McHarg[1] | **Andrew D. Ribner**[2] | **Rory T. Devine**[3] | **Claire Hughes**[1] | **The NewFAMS Study Team**

[1]Centre for Family Research, University of Cambridge, Cambridge, UK

[2]Department of Applied Psychology, New York University, New York, NY, USA

[3]Department of Psychology, University of Birmingham, Birmingham, UK

Correspondence
Gabrielle McHarg, Centre for Family Research, Free School Lane, University of Cambridge, Cambridge CB2 3RQ, UK.
Email: ggm25@cam.ac.uk

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Abstract
Technology is pervasive in homes of families with young children, despite evidence for negative associations between infant exposure to screen-based media and cognitive development that has led the American Academy of Pediatrics (AAP) to discourage parents from exposing children under the age of 18 months to any kind of screen time (AAP, 2016). Here, we apply a propensity score matching approach to estimate relations between electronic screen-based media use in infancy and executive function in early toddlerhood. In an international sample of 416 firstborn infants, parental report of regular exposure to screen-based media at 4 months predicted poorer performance on a test of inhibition at 14 months, but was unrelated to either cognitive flexibility or working memory at 14 months. Results of this study are therefore consistent with the view that early exposure to screen-based media adversely affects the development of executive function.

1 | INTRODUCTION

Parents and teachers often discuss how much television young children should watch, but the answer to this question remains unclear. Despite recommendations from the American Academy of Pediatrics that children under 2 years of age should have very limited screen exposure (AAP, 2016), access to electronic screen-based media is pervasive. Nearly 97% of households in the United States report having at least one television (Nielsen, 2017), and 95% of households with children between the ages of 0 and 8 have at least one smartphone (Common Sense Media, 2017). In addition, a recent UK study of 131 children aged 6–36 months found that 82% of the sample watched television daily, and 49% used mobile touchscreen devices daily (Taylor, Monaghan, & Westermann, 2018).

The evidence behind the AAP recommendation for very young children is limited, and potential long-term effects of very early electronic screen-based media use remain unknown. However, there is growing interest in the association between very early screen use and children's executive function (e.g., Lillard & Peterson, 2011). Executive function (EF; a multidimensional construct that broadly encompasses the ability to inhibit prepotent responses, keep multiple pieces of information in mind and manipulate them in working memory, and flexibly shift attention between multiple stimuli in pursuit of goals) develops throughout the lifespan and can be reliably measured as early as toddlerhood (e.g., Devine, Ribner, & Hughes, 2019; Johansson, Marciszko, Brocki, & Bohlin, 2016; Mulder, Hoofs, Verhagen, van der Veen, & Leseman, 2014). Supporting EF is critical, as it is implicated in the development of academic and interpersonal skills (Blair & Razza, 2007; Brock, Rimm-Kaufman, Nathanson, & Grimm, 2009; Devine & Hughes, 2014).

Exposure to electronic screen-based media might be particularly detrimental to the development of EF; however, evidence to date is mixed and differences in results might depend upon context or platform of viewing, media content, or child age. In groups of older children, increased time spent watching television is negatively associated with EF, perhaps due to its impact on attentional capacities (Nathanson, Alade, Sharp, Rasmussen, & Christy, 2014; Ribner, Fitzpatrick, & Blair, 2017). This has been shown experimentally: Lillard and Peterson (2011) found that 4-year-old children who watched a fast-paced cartoon, rather than either an educational cartoon or no television, performed significantly worse on EF tasks immediately after watching. These findings suggest that there could be temporary "state" effects on EF, but say nothing about effects on individual differences in chronic or lasting "traits." Results from a follow-up study identified that it was not pace, but on-screen fantastical elements, contrasted with on-screen real-life events, that seemed to negatively affect EF in 4- to 6-year-old children (Lillard, Drell, Richey, Boguszewski, & Smith, 2015). Huber, Yeates, Meyer, Fleckhammer, and Kaufman (2018) found that children were less likely to delay gratification after viewing a cartoon than after playing an educational app, suggesting not only content, but interactivity of screen time affects EF. Indeed, playing the app was associated with *increased* working memory.

What is even less clear is how children's EF is affected by screen exposure in the first 6 months of life. Young infants only view screens for 3–5 s at a time (for summary, see Kirkorian, Pempek, & Choi, 2017), and child-directed programming does not seem to be understood by until age two (Anderson & Subrahmanyam, 2017; Hipp et al., 2017). Before this, all television content can be understood as background television, especially in the very early months when parents are likely to be watching adult-directed content around their infants (Anderson & Subrahmanyam, 2017). For infants and toddlers 12 months and older, research suggests that adult-content and background screen exposure is detrimental for EF development (Linebarger, Barr, Lapierre, & Piotrowski, 2014). Indeed, Barr, Lauricella, Zack, and Calvert (2010) found that higher levels of exposure to adult screen content at 12–14 months of age were related to lower inhibitory self-control and metacognition skills at age four. However, it is unclear how adult-directed background television may affect young infants' cognitive development. In addition, 4-month-old infants are almost certainly not interacting with apps and games directly and therefore are not likely getting the EF benefits of interactive screen use.

In order to estimate the relations between screen exposure at 4 months of age and EF at 14 months, the current study exploits natural variation in whether parents exposed their young children to electronic screen-based media. We expect that screen exposure early in life will have adverse effects on

EF. We use a propensity score modeling approach in a large, longitudinal, international sample of firstborn children to estimate effects of exposure to screen-based media on EF at 14 months. Because we could not ethically ask some parents to expose their children to screens, propensity score matching was used to create post hoc experimental groups. Based on what we know about television and its immediate effect on EF in older children, it is possible there are detrimental long-term effects of very early regular screen exposure on inhibition, working memory, and set-shifting.

2 | METHODS

2.1 | Participants

Participants were recruited as a part of a larger longitudinal study of parents and their firstborn children in the United Kingdom (UK), the United States (US), and the Netherlands (NL). To be eligible for the current study, potential participants had to (a) be first-time parents, (b) be expecting to deliver a healthy singleton baby, (c) be planning to speak the native language of the recruiting country (i.e., English or Dutch) as the child's primary language, and (d) have no history of severe mental illness (e.g., psychosis) or substance misuse. We recruited 474 expectant couples attending prenatal classes and appointments at local hospitals in the East of England and in New York City, and at maternity events in the Netherlands. An additional 10 families were recruited, but these families were not eligible for follow-up when the infants were 4 months old due to birth complications or having left the area. All remaining participants were born full term (after 36 weeks) and without birth complications. Of families recruited, 416 (93.3%; $N_{\text{England}} = 194$; $N_{\text{NYC}} = 100$; $N_{\text{Netherlands}} = 122$) families agreed to participate in a home visit when their infants (212 boys, 204 girls) were both 4 months ($M_{\text{Age}} = 4.26$ months, $SD = 0.45$ months, range: 2.97–6.23 months) and 14 months ($M_{\text{Age}} = 14.42$ months, $SD = 0.57$ months, range: 9.47–18.40 months of age). Of note, despite the seemingly large age range, age was not controlled for in analyses because it is not appropriate to control for post-treatment variables in propensity score analyses (described below) and there was no relation between age and EF variables at 14 months in the UK sample (see Devine et al., 2019).

All procedures performed were in accordance with the ethical standards of the institutional and/or national research committees involved and were acceptable according to the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The National Health Service (NHS UK) Research Ethics Committee (London Bloomsbury), and the University Committee on Activities Involving Human Subjects at New York University approved the study protocol (REF: 14/LO/1113).

2.2 | Measures

2.2.1 | Independent variable

Parents (mostly mothers) were asked to report the amount of time infants spent exposed to electronic screen-based media at 4 months of age. As a part of a comprehensive questionnaire completed either during or before the home visit, parents reported "Number of hours watching TV/DVDs or looking at iPADs or computer" on a typical weekday, weekend day, and on the day prior to completion of the questionnaire (adapted from Thompson, Adair, & Bentley, 2013). Responses were allowed to be given and were recorded in any unit (e.g., minutes, parts of hours) and were later converted to hours. Screen time on a typical weekday, weekend day, and the day prior to survey completion was highly correlated (all *r*s > .64; *p*s < .001); therefore, a single variable representing regular exposure to electronic screen-based media was computed according to whether the value for a typical weekday or weekend day was >0. If parents reported more than 0 hr on either a typical weekday or weekend day (i.e., the parent reported any regular screen use; $n = 276$), that child received a value of "1"; if both typical weekday and weekend day were exactly 0 (i.e., the parent reported the child did not use screen time regularly), that child received a value of "0" ($N = 111$).

2.2.2 | Outcome variables

At 14 months, toddlers completed a short series of tasks based on tasks which are reported and elaborated on in Devine et al., 2019. Infants were seated on a parent's lap across a table from the examiner, and parents were asked to remain silent during each task and not to influence their infant's behavior. Infants were monitored and provided with breaks between tasks if necessary, and were praised at the end of each task regardless of performance.

Inhibition

In the Prohibition task (Friedman, Miyake, Robinson, & Hewitt, 2011), toddlers were shown a glittery wand by the experimenter while the examiner verbally engaged the infant. Next, the examiner looked the toddler in the eye, raised their index finger, and said: "No, don't touch!". The wand was then placed within reaching distance of the toddler, and the examiner turned around for 30 s. The latency to the first time the toddler touched the wand was recorded (possible range: 0–30 s). Double coding of 60 of videos revealed high inter-rater agreement, ICC = 0.99, $p < .001$.

Working memory

In the Three Boxes task (Miller & Marcovitch, 2015), toddlers were asked to find red, yellow, and blue plastic cars hidden in matched-color garages. The toy was placed just out of reach of the toddler, and the examiner called attention to the process of putting the cars in the garages while doing so. Children were then given the chance to find cars in a series of searches, and, after each success, the child was allowed to play with the car briefly before it was very obviously placed behind the examiner. The door to the garage was then closed conspicuously. Between searches, there was a short delay in which the view of the garages was obstructed and the experimenter counted to 5. Since all garages contained a car, the toddler was always successful on the first trial. If toddlers pointed to an empty garage, the examiner opened the garage, looked inside, and said "Oh, it's not there. Let's have another go" and closed the door before starting the next trial. This continued until all cars were found or until the child made three consecutive errors. Scoring took place offline and double coding of 60 videos revealed perfect inter-rater reliability for each trial, Kappa = 1.00.

Scoring was adapted from Garon, Smith, and Bryson (2014) in a similar multi-location search task and created two scores: total number of searches to find the (a) second and (b) third cars (i.e., 0 = did not find; 1 = 3 searches; 2 = 2 searches; 3 = 1 search). A third score based on adult research on self-ordered search tasks (Owen, Downes, Sahakian, Polkey, & Robbins, 1990) was also created for efficiency. The strategy score recorded the approach used to search for the hidden cars with higher scores indicating a more efficient search strategy (i.e., 0 = starts in the middle, 1 = starts at either edge, 2 = starts at either edge and then selects middle but then repeats a search, 3 = starts at edge, then middle, then other edge).

Cognitive flexibility

The Ball Run task was based on the Trucks task developed by Hughes and Ensor (2005). A toy that had three circular holes on the top running from left to right (i.e., green, yellow, red) and a metal chute that allowed a ball to roll down through the toy was introduced to the infant. The middle hole (yellow) was sealed for the whole task, and the two holes on either end could be sealed or opened. The bottom of the toy was fitted with a pressure-activated speaker programmed to play 5 s of a nursery song ("The Wheels on the Bus") when pressed by the ball. There were three phases: In the rule learning phase, the examiner introduced the toy to the toddler and illustrated how to play, either by green ball in the green hole (on the left-hand side of the toy) or the red ball in the red hole (on the right-hand side of the toy; counterbalanced across children). In the second phase, the examiner handed the ball to the toddler directly over the middle of the toy and looking at the infant and said, "Now you try!". Toddlers were praised for each correct placement and reinforced through activation of the musical switch, and incorrect tries were met with "Oh, it didn't work!" and were followed by the next of six trials.

For those children who placed the ball correctly four or more times ($n = 159$), a rule-reversal phase was carried out. To begin, the researcher placed the ball that had been used (e.g., the green ball) and conspicuously put it away. Next, the examiner got the other ball (e.g., the red ball) and swapped the brackets to open the corresponding hole and closing the hole for the ball that was put away. One example was shown to the child, and the examiner then repeated the experiment in the same way as the second phase with the new ball. Scoring took place offline, and double coding of 60 videos revealed perfect inter-rater reliability for each trial, Kappa = 1.00. Children received one point for each correct placement. Toddlers who did not place 4 or more balls correctly in the learning phase received a score of 0 on each trial of the reversal phase.

Factor score estimation

A model was estimated in which each of the task indicators loaded onto separate latent factors representing working memory and cognitive flexibility. As the inhibition task was comprised of just one indicator, we did not estimate a latent factor for this task. The two latent factors for each working memory and cognitive flexibility, as well as the indicator for inhibition, were allowed to correlate. This model provided a good fit to the data, χ^2 (100) = 195.320, $p < .0001$, RMSEA = 0.047, 90% CI [0.038, 0.057], CFI = 0.977, TLI = 0.973. Detailed information about item-level task performance and latent variable estimation and reliability is reported elsewhere (Devine et al., 2019). To reduce model complexity and capitalize on the benefits of latent variable modeling, Bayesian plausible latent factor scores were estimated using multiple imputations (Asparouhov & Muthen, 2010).

2.2.3 | Propensity score covariates

To control for possible selection effects that might be associated with child electronic screen-based media use, a range of control variables (all measured before 4 months) were entered into a logit model predicting regular screen use at 4 months. For both parents, the following variables were included from report when mothers were in their last month of pregnancy: parent age at time of childbirth, educational attainment, general well-being, anxiety, depression, life satisfaction, couple's satisfaction, self-efficacy in the nurturing role, and social support. Child attention and temperament, both collected at 4 months of age, were also included as propensity score covariates. Additional variables were included for child gender and country of recruitment with the UK as reference group.

Parent well-being

Parents completed the General Health Questionnaire (Goldberg et al., 1997); higher values indicate more concerns with general well-being. Questionnaire items showed adequate internal consistency for mothers ($\alpha = .74$) and fathers ($\alpha = .79$). Parents completed the State-Trait Anxiety Inventory (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983); higher values indicate higher levels of anxiety symptomatology. Items showed adequate internal consistency for mothers ($\alpha = .77$) and fathers ($\alpha = .73$). Parents completed the Center for Epidemiological Study-Depression Scale (Radloff, 1977); higher values indicate higher levels of depression symptomatology. Items showed adequate internal consistency for mothers ($\alpha = .80$) and fathers ($\alpha = .83$). Parents completed the Satisfaction with Life scale (Diener, Emmons, Larsen, & Griffin, 1985); higher values indicate lower levels of satisfaction (higher levels of dissatisfaction) with the respondent's own life. Items showed adequate internal consistency for mothers ($\alpha = .89$) and fathers ($\alpha = .88$).

Couple's satisfaction

Parents completed the Couple's Satisfaction Inventory (Funk & Rogge, 2007); higher values indicate higher levels of satisfaction in the respondent's partnership. Items showed adequate internal consistency for mothers ($\alpha = .96$) and fathers ($\alpha = .94$).

Self-efficacy in the nurturing role

Parents completed the Self-Efficacy in the Nurturing Role scale (Pederson, Bryan, Huffman, & Del Carmen, 1989); higher values indicate higher levels of comfort and confidence as a parent of a young child. Items showed adequate internal consistency for mothers ($\alpha = .87$) and fathers ($\alpha = .87$).

Social support

Parents completed the Multidimensional Scale of Perceived Social Support (Zimet, Dahlem, Zimet, & Farley, 1988); higher values indicate higher levels of perceived social support from family and friends. Items showed adequate internal consistency for mothers ($\alpha = .94$) and fathers ($\alpha = .92$).

Subjective social status

Parents completed the Subjective Social Status Ladder (Singh-Manoux, Adler, & Marmot, 2003). Higher values indicate participants view themselves as having higher social status.

Attention

We measured infant visual attention at 4 months (Cuevas & Bell, 2014). Infants were seated on a parent's lap facing the examiner (seated approximately 1 m from the infant). The examiner rattled an attractive toy three times and held it up to his/her right or left (counterbalanced across infants). The examiner held the stimulus in position until the infant looked away for at least 3 s. At this point, the examiner lowered the toy and repeated the procedure for three further trials. Child gaze was recorded using a camera placed on a tripod behind the examiner. The footage was coded offline using JHab Java Habituation Software (version 1.0.0) (Casstevens, 2007). Amount of time spent looking at the stimulus on each trial was recorded. Inter-rater reliability based on 45 cases was acceptable, for all four trials $0.77 < \text{ICC} < 0.98$. Median looking duration across the four trials of the task was used.

Child temperament

Mothers completed the Infant Behavior Questionnaire-Very Short Form (IBQ) (Putnam, Helbig, Garstein, Rothbart, & Leerkes, 2014), a widely used parent-report assessment to characterize infant temperament. Temperament was represented by three scale scores, all of which demonstrated adequate internal consistency: Distress to Limitations (α = .83), Duration of Orienting (α = .75), and Distress to Approach (α = .77).

2.2.4 | Analysis plan

For ethical reasons, it was not feasible to use randomized control trials—the gold standard for estimating causal effects—when studying effects of screen-based media use for young children. Thus, one increasingly common method to address this and estimate causal effects by identifying comparable groups is propensity score analysis (Schneider, Carnoy, Kilpatrick, Schmidt, & Shavelson, 2007). Propensity score analysis relies on a model of treatment assignment to match individuals on the basis of the probability of receiving "treatment" (i.e., regular exposure to screen-based media). Such models are estimated using standard logistic regression, where the outcome is the treatment indicator and the predictors are covariates. A match for each observation who received "treatment" is then assigned by choosing the control observation with the closest propensity score. Propensity score matching may be practically useful because it does not hold as strict assumptions about the linearity of the data as required for traditional regression models. Because this method uses a matching procedure, it is also helpful for identifying clear treatment and counterfactual groups about whom to interpret findings (Gelman & Hill, 2007).

We sought to examine the relation between regular electronic screen-based media use in infancy with each inhibition, working memory, and cognitive flexibility in early toddlerhood. To do this, we estimated weights representing each infant's propensity to be exposed to screen-based media using a logit model with regular screen use as the outcome variable and covariates specified above as predictors. Based on these predicted probabilities, we applied a genetic-matching algorithm to match infants who did not regularly use screens with those who did based on similar propensity to use screens according to covariates. Each individual EF measure was then regressed on the treatment variable and covariates using propensity scores as sample weights (Rosenbaum & Rubin, 1983). All analyses were performed in *RStudio* using the *matchit* package (Ho, Imai, King, & Stuart, 2011).

Replacements for missing data were estimated with multiple imputation using chained equations prior to matching. All cases for whom regular media use was reported (n = 387) were included in analysis; missing data for cases for whom regular media use was reported ranged from 17.4 (n = 67) to 0%; and on average, variables were missing <5% of data (4.3%, n = 16.81 data points missing). Five datasets were estimated using the *mi* package (Su, Gelman, Hill, & Yajima, 2011). Propensity scores were estimated for each dataset sequentially, and regression analyses were performed on each dataset. Coefficients were pooled manually using Rubin's (1987) rules.

3 | RESULTS

Tables 1 and 2 show descriptive statistics and the extent to which data were missing for each variable. Regular use of electronic screen-based media differed by country ($F(2, 384) = 10.10$, $p < .001$) such that children from the UK (81.9%, n = 145) were more likely to be regularly exposed to electronic screen-based media than were children in either the United States (65.8%, n = 75; $p < .001$) or the Netherlands (58.3%, p = 56; p = .008). Pre-matching balance and post-matching balance for one dataset are shown in Table 2. Propensity score balance for the no-screen time group and the regular screen time group is shown in Figure 1 (Table 3).

TABLE 1 Descriptive statistics of continuous variables included in regressions

	N	Mean	*SD*	Range
Infant age 4 months	414	4.24	0.45	2.97–6.23
Infant attention 4 months	400	7.29	4.79	0.00–26.89
Mom SSS	404	7.32	1.09	3.75–10.00
Dad SSS	404	7.29	1.16	2.84–10.00
Mom well-being	396	1.98	2.18	0–12
Dad well-being	378	1.39	2.03	0–11
Mom STAI	396	10.40	2.99	3–22
Dad STAI	376	10.85	2.81	6–20
Mom CES-D	396	29.66	5.83	20–54
Dad CES-D	376	27.31	6.06	19–54
Mom SLS	396	10.20	4.71	5–35
Dad SLS	376	12.18	5.75	5–35
Mom CSI	396	88.73	7.62	52–97
Dad CSI	376	87.61	8.39	52–97
Mom SEN	395	86.47	12.55	46–112
Dad SEN	375	84.89	13.11	38–112
Mom social support	395	70.99	11.83	12–84
Dad social support	374	65.99	13.04	12–84
Media use per day (hours)	387	0.88	1.25	0.00–8.61
Inhibition	342	14.14	12.42	0–30
Working memory	402	0.12	0.74	−0.79 to 1.74
Cognitive flexibility	402	0.01	0.58	−0.79 to 1.57
Distress to limitations	424	3.41	0.92	1.50–6.29
Duration of orienting	424	4.21	0.93	1.83–7.00
Approach	424	2.01	0.76	1.00–7.00

Abbreviations: CES-D, Center for Epidemiological Studies-Depression Scale; CSI, Couple's Satisfaction Index; SEN, Self-efficacy in the Nurturing Role; SLS, Satisfaction with Life Scale; SSS, Subjective Social Status; STAI, State-Trait Anxiety Inventory.

Media use was associated with lower inhibition, such that infants who were regularly exposed to electronic screen-based media touched the wand over 5 s earlier in the delay task than did those were not regularly exposed to electronic screen-based media ($b = -4.26$, $p = .008$). This association between propensity for media use and inhibition is shown graphically in Figure 2. Media use was not significantly associated with working memory (as measured by performance on the Multi-location Search task; $p = .905$) or cognitive flexibility (as measured by the Ball Run task; $p = .917$). Unweighted regressions with the same covariates were also estimated using a continuous measure of screen-based media use on an average day to examine whether the relations between exposure to electronic screen-based media and EF were linear in nature. Time spent watching media was not linearly associated with inhibition ($b = -0.02$, $p = .437$). Table 4 reports the results of the weighted regressions predicting EF.

TABLE 2 Frequencies of categorical variables

	Frequency	%	χ^2 (media vs. non-media) non-matched	χ^2 matched
Child female	204	49.0	0.25	0.14
Mom employment	397		1.73	3.15
Full time	302	76.1		
Part time	62	15.6		
Home maker	9	2.3		
Student	13	3.3		
Seeking employment	11	2.8		
Dad employment	397		2.90	1.79
Full time	369	92.9		
Part time	15	3.8		
Student	8	2		
Seeking employment	5	1.3		
Mom history of depression/anxiety	396		2.25**	3.58*
No	327	82.6		
Depression	32	8.1		
Anxiety	22	5.6		
Depression and anxiety	15	3.8		
Dad history of depression/anxiety	397		11.80	6.46
No	353	88.9		
Depression	22	5.5		
Anxiety	14	3.5		
Depression and anxiety	8	2		
Mom Age at enrollment	404		1.70	1.61
21–24	15	3.7		
25–29	116	28.7		
30–34	186	46		
35+	87	21.5		
Dad age at enrollment	404		0.50	1.61
21–24	4	1		
25–29	77	19.1		
30–34	187	46.3		
35+	136	33.7		
Mom education	398		15.89	14.74
Upper secondary	20	5		
Post-secondary not tertiary	13	3.3		
Short-cycle tertiary	32	8		
Bachelors	146	36.7		
Masters	126	31.7		

(Continues)

TABLE 2 (Continued)

	Frequency	%	χ^2 (media vs. non-media) non-matched	χ^2 matched
Doctoral	52	13.1		
Other	9	2.3		
Dad education	379		27.17	19.00
Primary	1	0.3		
Lower secondary	8	2.1		
Upper secondary	29	7.7		
Post-secondary not tertiary	22	5.8		
Short-cycle tertiary	33	8.7		
Bachelors	140	36.9		
Masters	90	23.7		
Doctoral	46	12.1		
Other	10	2.7		

*$p < .05$;
**$p < .01$.

4 | DISCUSSION

Inhibition at 14-months of age was negatively associated with screen exposure at 4 months. The inverse relation between screen time and inhibition mirrors previous findings (Barr et al., 2010; Lillard & Peterson, 2011), but in a much younger sample over a longer period of time. Our results therefore extend prior findings by suggesting a longitudinal association between screen exposure and inhibition, rather than a simple short-term effect.

Notably, 4-month-old infants are not mobile and their screen time is at the discretion of their parents and caregivers. Additionally, the current study investigated the associations between overall screen exposure and EF, rather than interest in or attention to screens. Therefore, it is not likely that the inverse relation between screen exposure and inhibition is reflective of infants with lower inhibition being drawn to screens at this early age.

Notably, the association between screen exposure and inhibition was found over and above parent characteristics. In other words, even if parents who are struggling to cope are especially likely to expose their infants to screens, this early exposure to screens has a specific and negative association with toddler EF even when mental health problems or couple conflict is considered. This is particularly important when considering the directionality of findings; it is not likely that parents who were unable to cope with their impulsive infants at 4 months of age were exposing those infants to more screens, but that infants who were exposed to more screen time had lower inhibition 10 months later. Importantly, however, this relation may reflect a greater exposure to screens among more impulsive children, perhaps because their parents are struggling to find ways to soothe them, even if it did not impact those parents' mental well-being.

In addition, the quality of parental attention is related to EF (Hughes & Devine, 2017). Screens may take parents' attention away from their children, which in turn may decrease positive parent–child interactions and impact later EF. Another possibility is that parents with low levels of inhibitory control themselves might be more likely to leave screens on or watch television themselves, such that genetic factors might mediate the apparently environmental influence of screens. Indeed, parent exposure to

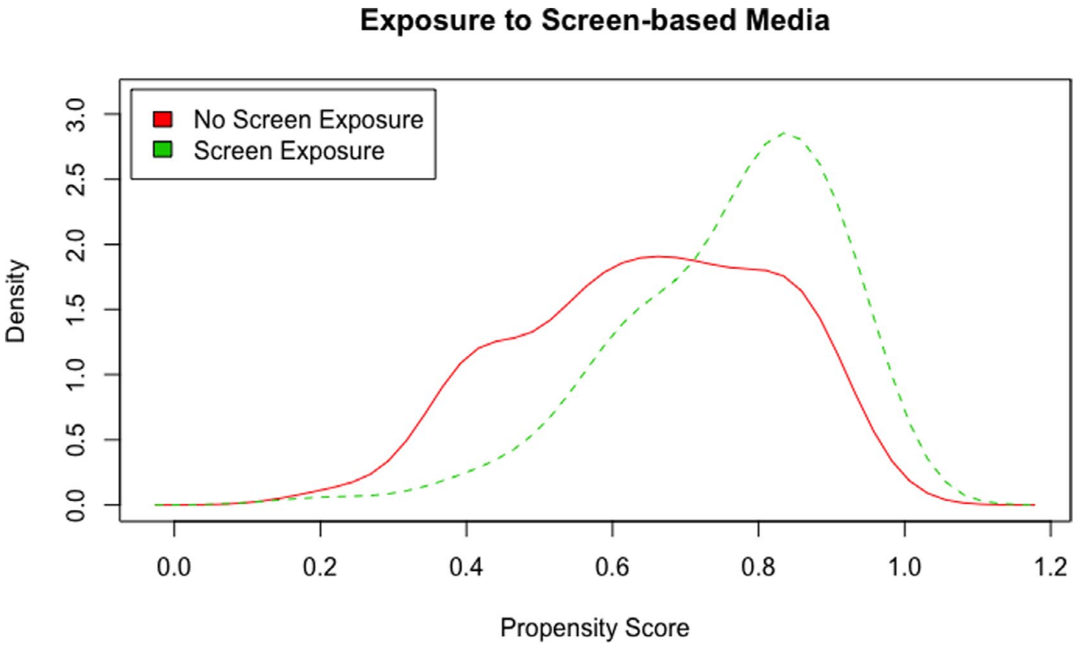

FIGURE 1 Propensity score overlap for regular screen exposure and no-screen exposure groups. The goal of the propensity score approach is to match participants as closely as possible to one another across groups such that biggest difference is whether or not children used screens, and good propensity score matching was achieved

screens is a strong predictor of child screen exposure (Beyens & Eggermont, 2014) and EF is related inter-generationally (Cuevas et al., 2014; Ellefson, Ng, Wang, & Hughes, 2017). Future research using cross-lagged designs and inter-generational measures of EF is needed to test these hypotheses.

Whether screen time is directly inversely related to inhibition or indirectly related due to parental attention or both, this finding is striking. Even when infants are likely getting very little entertainment or content out of their screen exposure, this screen time is related to less positive outcomes in cognitive development. Notably, there was not a linear relationship between screen exposure and latency to touch, suggesting that it is not massed amounts of screen exposure, but instead any regular exposure that seems to have a detrimental effect.

Note that the present study contrasted with the findings reported by Barr et al. (2010) in showing no relation between media use and either working memory or cognitive flexibility. However, this null effect could reflect infants' lack of active viewing; the mechanics behind negative effects of television on EF might be content specific or about engagement with on-screen interactions. Importantly, our results with regard to inhibition are in line with Huber et al. (2018), who found that passive viewing was related to lower inhibition more so than active engagement with an app, and who found a positive association between playing on the app and working memory. Thus, our findings support the idea that interactivity might make an impact. Content may matter as well; indeed, screen exposure in early infancy is likely to involve television for adults and hence show more life-like events than the fantastical events that Lillard et al. (2015) found to be especially detrimental. In addition, these findings suggest that the effects of screen exposure may not be global, affecting all aspects of cognition, but specific, affecting selected domains.

Importantly, there were differences in screen exposure by country, whereby children in the UK were more likely to be regularly exposed to electronic screen-based media than children in the Netherlands or in the USA. One possible explanation for this difference may be that parents in the

TABLE 3 Pre- and post-matching mean differences

	Unmatched				Matched			
	No screens	Screens	*t*	*p*-value	No screens	Screens	*t*	*p*-value
Infant Age	4.27	4.24	0.60	.546	4.21	4.24	−0.43	.670
Mom well-being	1.33	1.51	−0.88	.382	1.10	1.51	−2.06	.040
Mom SSS	7.38	7.26	0.82	.415	7.53	7.26	1.97	.049
Mom STAI	10.18	10.42	−0.59	.554	9.80	10.42	−1.54	.125
Mom CES-D	29.21	29.39	−0.23	.815	28.07	29.39	−1.81	.071
Mom SLS	9.78	10.18	−0.64	.522	9.35	10.18	−1.36	.176
Mom CSI	87.28	88.79	−1.30	.194	88.65	88.79	−0.12	.902
Mom SEN	87.39	84.54	1.42	.157	85.30	84.54	0.38	.704
Mom social support	71.33	70.54	0.48	.634	72.68	70.54	1.29	.198
Dad well-being	1.07	1.12	−0.21	.835	1.05	1.12	−0.31	.760
Dad STAI	10.64	11.35	−1.60	.111	10.76	11.35	−1.35	.177
Dad CES-D	28.19	27.13	1.27	.206	27.81	27.13	0.81	.419
Dad SSS	7.46	7.22	1.59	.114	7.49	7.22	1.86	.064
US (vs. UK)	1.28	1.20	1.30	.193	1.20	1.20	−0.13	.894
NL (vs. UK)	1.33	1.27	1.01	.312	1.30	1.27	0.42	.675
Dad SLS	11.77	12.74	−1.17	.243	11.59	12.74	−1.36	.173
Dad CSI	88.59	88.20	0.34	.731	88.78	88.20	0.51	.611
Dad SEN	82.92	85.29	−1.33	.186	82.26	85.29	−1.71	.089
Dad social support	66.08	66.03	0.03	.978	67.93	66.03	1.07	.287
Infant attention	7.83	7.10	1.10	.273	7.34	7.10	0.37	.709
Distress to limitations	3.37	3.45	−0.66	.507	3.45	3.45	0.04	.966
Duration of orienting	4.14	4.25	−0.90	.367	4.22	4.25	−0.30	.761
Approach	1.99	2.05	−0.59	.558	1.92	2.05	−1.25	.211

Abbreviations: CES-D, Center for Epidemiological Studies-Depression Scale; CSI, Couple's Satisfaction Index; NL, Netherlands; SEN, Self-efficacy in the Nurturing Role; SLS, Satisfaction with Life Scale; SSS, Subjective Social Status; STAI, State-Trait Anxiety Inventory; UK, United Kingdom; US, United States.

UK are regularly granted longer parental leave than parents in the USA and therefore may have screens on for more hours of the day with their infants than parents in the USA. However, since there is generous parental leave in the Netherlands, as well, this cannot be the only explanation. It may be that there are characteristics of the locations of each of the samples that contribute to varied screen time or that parents who are likely to participate in longitudinal studies have different characteristics in each country. There are likely several cultural differences at play across the three countries that lend themselves to using more or less screens, especially with their infants present, and this should be examined in future research. Notably, these differences were accounted for in propensity score matching, such that, where possible, children were matched with a child in the other group with someone in the same country.

TABLE 4 Results of weighted regressions predicting EF

	Latency to touch				Multi-location search task				Ball run			
	b	*SE*	*t*	*p*	*b*	*SE*	*t*	*p*	*b*	*SE*	*t*	*p*
(Intercept)	0.80	20.16	0.04	.972	0.22	1.15	0.20	.839	−0.23	0.92	−0.23	.818
Media use	−4.26	1.80	−2.69	.008**	0.04	0.10	0.12	.905	−0.03	0.08	−0.10	.917
Infant age	2.93	1.90	1.63	.103	−0.10	0.11	−0.32	.752	0.09	0.09	0.30	.762
Infant female	1.54	1.51	0.75	.453	0.00	0.09	0.02	.988	−0.13	0.07	−0.48	.635
Mom employed PT	1.89	4.07	0.33	.739	−0.04	0.23	−0.08	.938	−0.21	0.19	−0.46	.646
Mom homemaker	−8.14	4.58	−2.20	.029*	−0.22	0.26	−0.42	.676	−0.04	0.21	−0.09	.925
Mom student	−7.47	3.78	−2.19	.029*	−0.08	0.22	−0.16	.873	0.01	0.17	0.01	.988
Mom unemployed	−1.99	4.81	−0.62	.534	0.34	0.27	0.66	.512	−0.13	0.22	−0.28	.783
Mom anxiety	1.49	2.72	0.44	.660	−0.30	0.16	−0.77	.443	−0.09	0.12	−0.26	.796
Mom depression	1.29	2.76	0.55	.580	−0.11	0.16	−0.27	.786	−0.03	0.13	−0.08	.940
Mom Dep & Anx	−1.51	2.92	−0.75	.455	−0.12	0.17	−0.29	.771	0.17	0.13	0.47	.639
Mom well-being	0.91	0.61	1.01	.316	0.02	0.03	0.12	.907	−0.03	0.03	−0.19	.847
Mom SSS	−1.13	0.95	−1.06	.289	0.00	0.05	0.01	.991	0.00	0.04	0.00	.997
Mom age 25–29	−8.30	3.91	−2.68	.008**	0.04	0.22	0.09	.932	0.02	0.18	0.05	.962
Mom age 30–34	3.37	2.71	1.35	.178	−0.05	0.15	−0.13	.898	−0.08	0.12	−0.24	.812
Mom age 35+	−1.49	1.60	−0.83	.405	−0.08	0.09	−0.28	.783	0.09	0.07	0.32	.748
Dad age 25–29	11.96	5.74	3.43	.001**	−0.31	0.33	−0.53	.598	0.27	0.26	0.53	.600
Dad age 30–34	−5.19	4.13	−2.38	.018*	−0.06	0.24	−0.13	.896	−0.02	0.19	−0.05	.957
Dad age 35+	3.40	2.23	1.60	.110	0.11	0.13	0.31	.758	−0.03	0.10	−0.08	.936
Mom education	0.01	0.70	0.01	.991	0.08	0.04	0.42	.677	0.03	0.03	0.16	.870
Mom STAI	−0.05	0.29	−0.08	.936	−0.02	0.02	−0.13	.896	−0.01	0.01	−0.07	.941
Dad employed PT	−4.14	4.15	−1.38	.168	0.06	0.24	0.12	.902	−0.05	0.19	−0.11	.913
Dad student	−3.94	4.95	−1.24	.217	0.21	0.28	0.37	.708	−0.34	0.23	−0.70	.485
Dad unemployed	−3.48	5.79	−1.20	.230	0.25	0.33	0.41	.682	0.12	0.26	0.23	.820
Dad anxiety	−1.29	3.74	−0.61	.545	0.16	0.21	0.35	.729	−0.30	0.17	−0.72	.473
Dad depression	0.93	3.56	0.28	.778	−0.10	0.20	−0.22	.827	−0.23	0.16	−0.55	.586
Dad Dep & Anx	1.57	3.53	0.42	.676	0.07	0.20	0.16	.874	0.04	0.16	0.10	.918

(Continues)

TABLE 4 (Continued)

	Latency to touch				Multi-location search task				Ball run			
	b	*SE*	*t*	*p*	*b*	*SE*	*t*	*p*	*b*	*SE*	*t*	*p*
Dad well-being	−0.73	0.47	−0.98	.326	−0.04	0.03	−0.25	.800	0.03	0.02	0.22	.823
Mom CES-D	−0.17	0.19	−0.36	.721	0.00	0.01	−0.02	.981	0.00	0.01	0.03	.976
Mom SLS	−0.09	0.19	−0.19	.849	0.01	0.01	0.11	.909	0.01	0.01	0.06	.956
Mom CSI	0.02	0.10	0.05	.961	0.00	0.01	0.04	.968	0.00	0.00	−0.02	.982
Mom SEN	0.07	0.06	0.30	.765	0.00	0.00	−0.07	.945	0.00	0.00	−0.04	.965
Mom social support	−0.04	0.07	−0.13	.894	0.00	0.00	−0.02	.986	0.00	0.00	0.05	.963
Dad SSS	0.92	0.77	0.98	.330	0.01	0.04	0.06	.951	0.00	0.04	0.01	.996
US (vs. UK)	−2.27	2.28	−0.78	.436	−0.12	0.13	−0.35	.730	0.17	0.10	0.53	.598
NL (vs. UK)	−8.93	2.29	−3.65	.000***	0.06	0.13	0.16	.871	0.09	0.10	0.27	.784
Dad SLS	0.25	0.13	0.68	.499	0.00	0.01	0.04	.969	−0.01	0.01	−0.07	.946
Dad CSI	0.07	0.11	0.20	.844	−0.01	0.01	−0.09	.931	0.00	0.00	0.03	.973
Dad SEN	0.04	0.06	0.16	.876	0.01	0.00	0.11	.915	0.00	0.00	−0.07	.946
Dad social support	0.03	0.06	0.13	.895	0.00	0.00	0.01	.990	0.00	0.00	0.00	.999
Infant attention	−0.03	0.16	−0.07	.944	−0.02	0.01	−0.19	.848	0.02	0.01	0.18	.854
Distress to limitations	−0.86	0.93	−0.76	.449	−0.04	0.05	−0.17	.867	−0.05	0.04	−0.23	.818
Duration of orienting	−0.99	0.84	−0.95	.343	0.03	0.05	0.14	.888	−0.01	0.04	−0.03	.977
Approach	0.34	1.00	0.26	.796	0.09	0.06	0.39	.697	−0.03	0.05	−0.16	.874

Abbreviations: CSI, Couple's Satisfaction Index; Dep & Anx, History of Anxiety or Depression; NL, Netherlands; PT, Part Time; SEN, Self-efficacy in the Nurturing Role; SLS, Satisfaction with Life Scale; SSS, Subjective Social Status; UK, United Kingdom; US, United States.

*$p < .05$;

**$p < .01$;

***$p < .10$.

Several key limitations to this study deserve note. Although propensity score methods provide a basis for causal inference, the design of the study is not experimental, and many household variables, such as why infants are exposed to screens in the first place, could not be controlled. In addition, all assumptions made about content are strictly speculative.

Additionally, there are a number of other unmeasured parent and child characteristics that might be associated with either child screen exposure or child EF (or both), including parent media habits and parent EF. As these data are a part of a larger longitudinal study, there are limitations to the amount of data that could be collected from parents of very young children without placing undue burden upon the family; further, for data that are available at later timepoints in the same dataset (e.g., parent EF is available when children are 14 months of age), including these in models would be in violation of the assumptions of propensity score modeling, specifically that all control variables be from prior to "treatment" (i.e., media exposure).

In sum, screen exposure at 4 months of age appears to be negatively associated with inhibition 10 months later (over and above early levels of attention and individual differences in temperament).

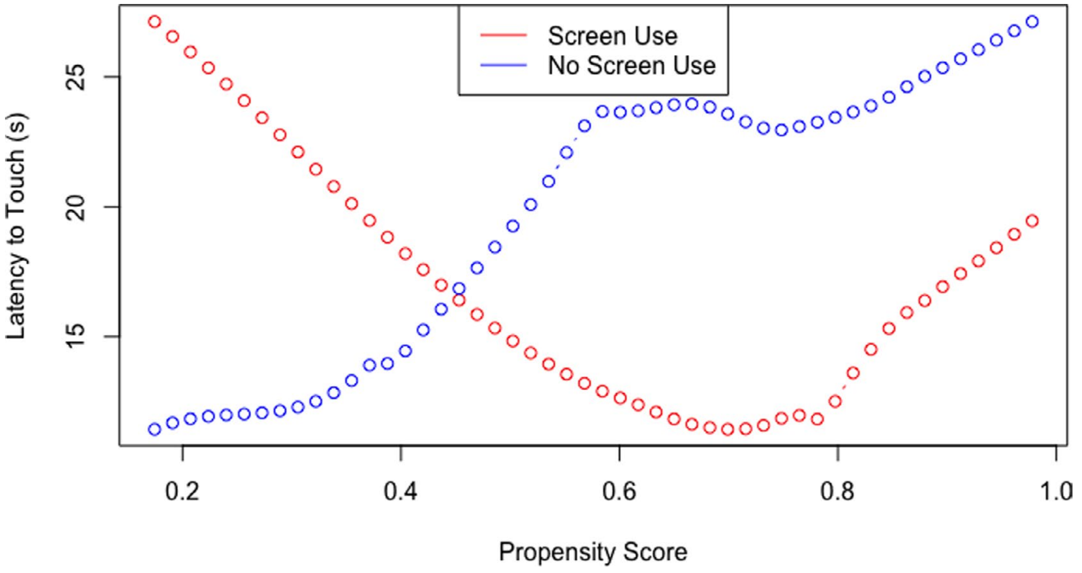

FIGURE 2 Relations between propensity for media use and inhibition. There was a statistically significant difference in inhibition at 14 months between the screen use and no-screen use groups at 4 months, such that infants exposed to screens were more likely to be less inhibited than infants not exposed to screens

This suggests there may be further long-term negative effects of very early screen exposure. In all, the current study expands the research on screen time and executive functioning by investigating longitudinal relations from a very young age. There appear to be specific relations between early screen exposure and later inhibition; these relations are not linear, but suggest that any regular exposure to screens may be detrimental. In contrast, there were no relations between screen time and set-shifting or working memory, contrary to previous findings in older children. Parents and other caregivers should take care when making decisions about screen time for infants, as the current research suggests there could be detrimental effects on later EF.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest in relation to the funding bodies involved in the current study.

ORCID

Gabrielle McHarg https://orcid.org/0000-0002-2239-7294
Andrew D. Ribner https://orcid.org/0000-0001-7188-223X

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