Pediatric RESEARCH

CLINICAL RESEARCH ARTICLE

Screen media exposure in the first 2 years of life and preschool cognitive development: a longitudinal study

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BACKGROUND: Associations between screen media and child cognition are complex. This study aimed to examine whether age of onset of media exposure, cumulative effect of high media exposure, and verbal interaction during screen time in the first 2 years of life were associated with 4-year-old cognition by including parenting behaviors into the final construct.
METHODS: There were 274 healthy participants who were followed up until age 4 years. Screen media data were collected at age 6, 12, 18 months, and 2 years. Cognition or early learning composite (ELC) was evaluated at age 2, 3, and 4 years, where the latter variable was the primary outcome. Positive parenting was obtained by Parenting Styles and Dimensions Questionnaire.
RESULTS: ELC at age 2 years was associated with later age of onset of media exposure ($\beta = 0.113$, $p < 0.05$), fewer months of high media exposure above the upper quartile ($\beta = 0.282$, $p < 0.001$), and more months of verbal interaction during screen time ($\beta = 0.261$, $p < 0.001$). ELC at age 4 years was associated with ELC and positive parenting at earlier ages.
CONCLUSION: Delayed introduction of screen media, appropriate screen time, and increased verbal interaction during media use in the first 2 years of life were associated with better cognitive development in preschoolers.

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IMPACT:

- Associations between screen media exposure and children's cognitive development in existing literature mainly focused on duration of screen media viewing or the content of electronic media in which other factors are rarely explored.
- Earlier age of onset of media exposure, more months of excessive screen media exposure (>6.5 h/day), and fewer months of verbal interaction with children during media use in the first 2 years of life had associations with decreased preschool cognition.
- To mitigate undesirable effects of inappropriate screen media use on cognition, delayed introduction of screen media, appropriate electronic media exposure, and increased verbal interaction during media use with children should be recommended at health supervision visits.
- Lower positive parenting was a mediator for the relationship between cumulative months of high screen media exposure and decreased child cognition.

INTRODUCTION

Although American Academy of Pediatrics and World Health Organization discourage screen media exposure for children younger than 18–24 months,[1,2] such exposure in this age group is still high.[3,4] Previous studies have shown that screen media exposure and adult-oriented programs before the age of 2 years were associated with behavioral problems,[5–8] decreased parent–child interaction,[9,10] reduced toy play,[11] poorer executive function (EF),[12] delayed language,[10,13–16] cognitive,[13,14] and motor development[14] in toddlers and preschoolers in addition to lower subsequent cognition in school-age children.[17] However, such an association with cognitive development was not demonstrated in one study.[18] Additionally, previous studies on the effects of screen media exposure on children's cognitive development mainly focused on duration of screen media viewing[14,17,18] or the content of electronic screen media.[13] Nonetheless, there are still other media factors, which are rarely explored in the existing literature, especially the age of onset of media exposure, cumulative effect of high screen media exposure over time, and verbal interaction between children and their caregivers during screen time, which could potentially affect a child's cognition. Both age of onset and heavier lifetime television viewing were related to lower EF in preschoolers.[19] An adverse effect of electronic screen media exposure since 6 months of age on 14-month-old children's language development emerged only in those without mother–child verbal interactions during screen media exposure in another study.[20] As a result, such media variables were related to language development and EF that merits further examination in the context of cognitive outcome. However, the media variables, including the age of onset of media exposure, cumulative effect of high screen media exposure, and verbal interaction between children and their caregivers during screen time, should be simultaneously examined in the same analysis models since these media variables

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appeared to be highly correlated, reflecting the dynamic and complex associations among such predictors.

Moreover, relationships between early screen media exposure and subsequent cognitive outcomes are relatively sophisticated because there are several factors at the individual, parental, and contextual levels that come into play and potentially influence both screen media exposure and child cognition, especially in the preschool period where brain networks are rapidly developing.[21–23] As demonstrated in the context of EF, school-age children who had been exposed to background television and whose parents exhibited parental inconsistency were found to have reduced EF, whereas those children who had been exposed to educational television and were cared for by parents who were more responsive to their needs had better EF.[24] Previous studies also showed that parents' report of being more permissive towards their children or using punishment in response to the child's behaviors were associated with more screen media exposure in toddlers and preschoolers.[25,26] Therefore, parenting behaviors should also be taken into consideration in the context of the associations between the aforementioned screen media variables in the first two years of life and cognitive development at 4 years of age.

In sum, previous studies showed inconsistent findings, limited by the nature of a cross-sectional study and the lack of data on the age of onset of media exposure, cumulative effect of high screen media exposure across time, verbal interaction during screen media exposure, and the complexity of parental factors on screen media exposure and children's cognitive development. Our primary question of this current study was to investigate whether screen media variables in the first 2 years of life, including (1) age of onset of media exposure, (2) cumulative effect of high screen media exposure, and (3) verbal interaction between children and their caregivers during screen time, were associated with cognitive development at 4 years of age by also including positive parenting behaviors into the final construct. We hypothesized that children who had an earlier age of onset of media exposure, cumulative months of high screen media exposure, and decreased verbal interaction between children and their caregivers during screen time in the first 2 years of life were associated with lower cognitive development at 4 years of age. Furthermore, those who were cared for by parents with positive parenting were more likely to be associated with higher cognition at age 4 years.

METHODS

Participants

From August 2012 to March 2014, 291 healthy infants with typical development were originally enrolled at age 6 months. Inclusion criteria were singleton full-term birth with birth weight of ≥2500 g; no pre-, peri-, and postnatal complications; no underlying medical illnesses; having normal growth and typical development documented by using the Cognitive Adaptive Test/Clinical Linguistic and Auditory Milestone Scale (CAT/CLAMS).[27] To replace those who were lost to follow-up (24/291, 8.2%) at age 2 years, 30 participants were later recruited at 3 years of age using the same eligibility criteria as the original cohort. Study participants were followed up at the age of 12, 18 months, 2, 3, and 4 years. This study was approved by the Institutional Review Boards of the Faculty of Medicine, Chulalongkorn University. Participants' parents provided informed consent.

Screen media exposure data

Screen media exposure data was collected in depth at each visit by using a 24-h media diary, which recorded an individual's screen media exposure while awake on a typical weekday and was utilized in previous research.[13,28] Media programs were classified as older child/adult, noneducational, and educational programs based on previous studies.[3,13,28] Total duration of all screen media exposure was then summed based on all exposure from any screen media devices. Main screen media exposure data in this study were (1) the age of onset of screen media exposure, (2) cumulative effect of high screen media exposure in months, and (3) verbal interaction between caregivers and children during screen time in the first 2 years of life. The age at which each participant began being exposed to screen media was collected at the age of 6 months and defined as the age of onset of screen media exposure. Participants who were enrolled later at age 3 years provided data on the age of onset of screen media exposure and duration of all screen media exposure for both 12 months and 3 years of age. Due to skewed distribution of the total duration of all screen media exposure data at each age, upper quartile of such variable at 6, 12, 18 months, and 2 years was computed based on the sample size at that age. High screen media exposure at each age was characterized by having total duration of all screen media exposure above the upper quartile cut-off at that age. Furthermore, verbal interaction between caregivers and children during screen time at each visit was also ascertained. Participants' caregivers were interviewed about whether they talked or sang with the child during media programs for ≥50% of total screen time. Such a variable was defined as having verbal interaction during screen time at that age. The duration in months of the two variables, verbal interaction between caregivers and children during screen time and high screen media exposure above the upper quartile in the first 2 years of life, was then finally computed based on available media data of ≥3 in four visits from age 6 months to 2 years.

Cognitive outcome

The Mullen Scales of Early Learning was utilized to assess cognitive development in study participants at 2, 3, and 4 years of age, where cognitive development at 4 years of age was our primary outcome.[29] The MSEL consisted of five subscales, including gross motor, fine motor, visual reception, receptive language, and expressive language. Raw scores of all developmental domains were converted to *T*-scores. A mean *T*-score of each developmental domain was 50 and the standard deviation (SD) was 10. An early learning composite (ELC) was finally computed based on summation of *T*-scores of all subscales, except for gross motor domain, with a mean of 100 and SD of 15.

Positive parenting behaviors

Parenting behaviors were rated by participants' mothers using the Parenting Styles and Dimensions Questionnaire-short version (PSDQ-short version) when participants were 3 and 4 years of age.[30] It consisted of 32 questions regarding how often the mother reported having particular parenting behaviors according to the 5-point Likert scale, including (1) never, (2) once in a while, (3) about half of the time, (4) very often, and (5) always towards the child.[30] There were three parenting styles, including authoritative, authoritarian, and permissive parenting style, respectively. To obtain overall authoritative, authoritarian, and permissive parenting behaviors, an average of those items specific to each parenting style was then calculated.[30] Positive parenting behaviors were then ultimately computed by subtracting permissive and authoritarian parenting from authoritative parenting style. A higher score was indicative of more positive parenting behaviors.

Demographic data

Demographic data, including child age, gender, birth order, primary caregivers, nursery and preschool attendance, parental age, education, occupation, and family income, were completed by primary caregivers at least 1 week before the 6-month-old visit and were updated at the 3-year-old visit.

Table 1. Demographic characteristics of study participants.

Characteristics	Total *n*	Age at 6 months *n* (%)	Total *n*	Age at 3 years *n* (%)
Child				
Age (months), median (IQR)	291	6.4 (6.2–6.6)	280	36.3 (36.1–36.5)
Birth weight (g), median (IQR)	285	3120.0 (2912.5–3360.0)	280	3120.0 (2901.3–3353.3)
Female gender	291	153 (52.6)	280	149 (53.2)
Firstborn	290	200 (69.0)	280	199 (71.1)
Primary caregiver	290		280	
Mother		141 (48.6)		137 (48.9)
Father		15 (5.2)		29 (10.4)
Grandparents		94 (32.4)		93 (33.2)
Others		40 (13.8)		21 (7.5)
Nursery/preschool attendance	286	47 (16.4)	278	197 (70.9)
Mother				
Age (years), median (IQR)	290	34.0 (30.0–36.0)	280	36.0 (33.0–39.0)
Education (years), median (IQR)	289	16.0 (16.0–18.0)	280	16.0 (16.0–18.0)
Occupation: company employee or government officer	288	185 (64.2)	280	191 (68.2)
Father				
Age (years), median (IQR)	283	35.0 (32.0–39.0)	277	38.0 (34.0–42.0)
Education (years), median (IQR)	286	16.0 (14.0–16.0)	279	16.0 (16.0–18.0)
Occupation: company employee or government officer	281	195 (69.4)	277	185 (66.8)
Family income (Baht/month), median (IQR)	285	60,000.0 (40,000.0–95,000.0)	276	60,000.0 (40,000.0–115,000.0)

Note: Data presented as median (IQR) for continuous variables and percentage for categorical variables.
IQR interquartile range.

Statistical analysis

Characteristics were reported as median and interquartile ranges (IQR) for continuous variables and percentage for categorical variables. Simple correlations among demographic characteristics, including gender and maternal education; screen media variables: (1) the age of onset of screen media exposure, (2) duration of high screen media exposure in months, (3) duration of verbal interaction in months between caregivers and children during screen time; 3- and 4-year positive parenting behaviors; and ELC at the age of 2, 3, and 4 years were analyzed. Path analyses were finally conducted to account for multiple correlations and to explore effects for both the direct and indirect pathways of demographic characteristics, screen media variables, and positive parenting behaviors on ELC, adjusting for confounding factors, including chronological age, gender, primary caregivers, preschool attendance, parental age, maternal education, and family income. Standardized regression weights of relationships among such variables were demonstrated next to the arrows of pathways in the path analysis models. Sensitivity analyses were conducted for participants who were originally enrolled at the age of 6 months by excluding those who were recruited later at 3 years of age. *P* values noted were two-sided with $p < 0.05$ as the significance level. All statistical analyses were conducted with SPSS and Amos version 22 (IBM Inc., Bangkok, Thailand).

RESULTS

Demographic characteristics of study participants

There were 291 healthy participants originally enrolled at a median age of 6.4 (IQR 6.2–6.6) months. The median of participants' full-scale developmental quotient on the CAT/CLAMS was 103 (IQR 98–107.5) at 6 months of age. Of 291 participants, there were 265 (91.1%), 267 (91.8%), and 267 (91.8%) participants who were followed up at age 12, 18 months, and 2 years respectively. At the 3-year-old visit, 250 (85.9%) participants from the original cohort came to the follow-up along with 30 participants who were later recruited. There were no statistically significant differences in background characteristics between participants who were originally enrolled and those who were recruited later. There were 38 (13.1%) participants from the original cohort who were lost to follow-up at both the 3- and 4-year-old visits. Parents of those who were lost to follow-up were significantly younger and had less formal education than those not lost to follow-up. Finally, 274 participants (247 from the original cohort and 27 from the new recruitment at age 3 years) came for the 4-year-old visit. According to family income, our participants were in the middle to high socioeconomic status according to the Thai context. Other demographic characteristics of study participants at age 6 months and 3 years are displayed in Table 1.

Screen media exposure data

Participants were reported to start being exposed to any screen media devices at a median of 1 month (IQR 0–3). From age 6 months to 2 years, participants mostly spent time each day with television (80.8–89.0%), followed by hand-held devices (both tablets and smartphones) (7.8–16.7%), and computers (2.6–3.2%), respectively. Total duration of all electronic screen media exposure at different ages are shown in Fig. 1. Older child/adult programs were the most common type of program the participants had been exposed to from age 6 months to 2 years (74.6–87.9%, median 194–240 (IQR 90–381) min/day), followed by noneducational (11.6–23.9%, median 7–45 (IQR 0–108) min/day) and educational programs (0.2–1.5%, median 0 (IQR 0–0) min/day), respectively. Moreover, participants were likely to have been increasingly exposed to noneducational program as they grew older from the median of 7 (IQR 0–32), 15 (IQR 0–60), and 30 (IQR 5–90) min/day at 6, 12, and 18 months of age, respectively, to the

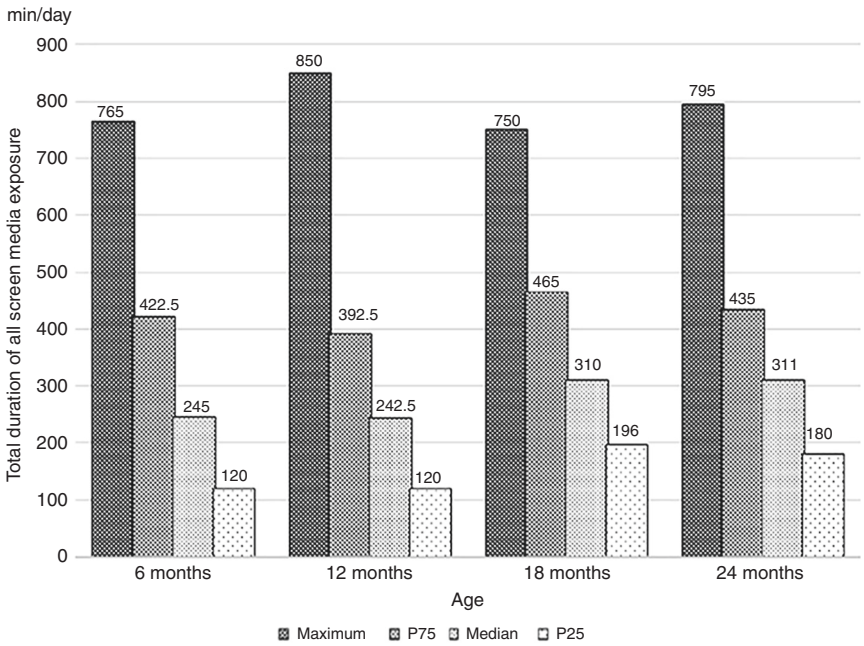

Fig. 1 Total duration of all electronic screen media exposure at different ages.

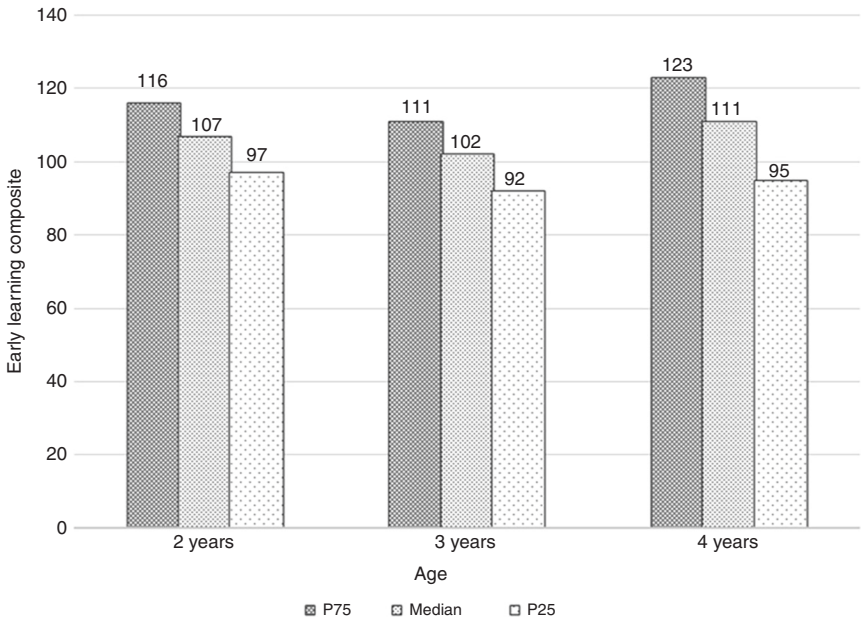

Fig. 2 Early learning composite scores at age 2, 3, and 4 years.

median of 45 (IQR 12–108) min/day at age 2 years. Proportions of verbal interaction between caregivers and children during screen time were likely to decrease over time from 73.8%, 61.9%, and 53.9% at 6, 12, and 18 months of age, respectively, to 51.7% at age 2 years. Regarding the duration in months of high screen media exposure during the first 2 years of life, there were 270 out of 291 participants who had screen media exposure data of ≥3 in 4 visits from age 6 months to 2 years. There were 146 (54.1%) participants who had never been exposed to high screen media, whereas 44 (16.3%), 36 (13.3%), 29 (10.7%), and 15 (5.6%) participants had been exposed to high screen media of ≥6, 12, 18 months, and 2 years, respectively. With respect to the duration of verbal interaction in months between caregivers and children during screen time, 21 (7.8%) participants did not have verbal interaction with their caregivers during screen time in the first 2 years of life. However, there were 49 (18.1%), 66 (24.4%), 71 (26.3%), and 63 (23.3%) participants who had verbal interaction with their caregivers during screen time of ≥6, 12, 18 months, and 2 years, respectively.

Cognitive development and positive parenting behaviors

Almost all participants in this cohort had normal cognitive development and all subscales at the age of 2 to 4 years. There were 5 (1.9%), 7 (2.5%), and 7 (2.6%) participants with cognitive impairment (ELC scores ≤ 70) at 2, 3, and 4 years of age, respectively. P75, median, and P25 of ELC at 2, 3, and 4 years of age are illustrated in Fig. 2. Other developmental subscales on the MSEL and positive parenting behaviors of study participants at each age are presented in Supplementary Table S1 (online).

Table 2. Simple correlations among demographic characteristics, positive parenting behaviors, screen media variables, and ELC.

Variables	1	2	3	4	5	6	7	8	9	10	11	12
1. Age at 3 years (months)	–											
2. Gender	−0.05	–										
3. Mother's education (years)	0.14*	−0.16**	–									
4. Family income (Baht/month)	0.12	−0.04	0.50**	–								
5. Positive parenting behaviors at 3 years of age	0.13*	−0.11	0.28**	0.21**	–							
6. Positive parenting behaviors at 4 years of age	0.05	−0.07	0.26**	0.18**	0.67**	–						
7. Age of onset of media exposure (months)	−0.04	−0.03	0.21**	0.06	0.06	0.01	–					
8. Duration of high screen media exposure above the upper quartile (months)	−0.03	0.03	−0.20**	−0.08	−0.21**	−0.19**	−0.17**	–				
9. Duration of verbal interaction between caregivers and children during screen time (months)	0.11	−0.17**	0.21**	0.11	0.10	0.22**	0.02	−0.21**	–			
10. ELC at 2 years of age	−0.05	−0.19**	0.29**	0.20**	0.17*	0.15*	0.08	−0.41**	0.35**	–		
11. ELC at 3 years of age	−0.05	−0.20**	0.35**	0.28**	0.22**	0.22**	0.09	−0.26**	0.21**	0.71**	–	
12. ELC at 4 years of age	−0.04	−0.16**	0.32**	0.28**	0.27**	0.27**	0.14*	−0.28**	0.18**	0.66**	0.78**	–

ELC early learning composite.
*$p < 0.05$.
**$p < 0.01$.

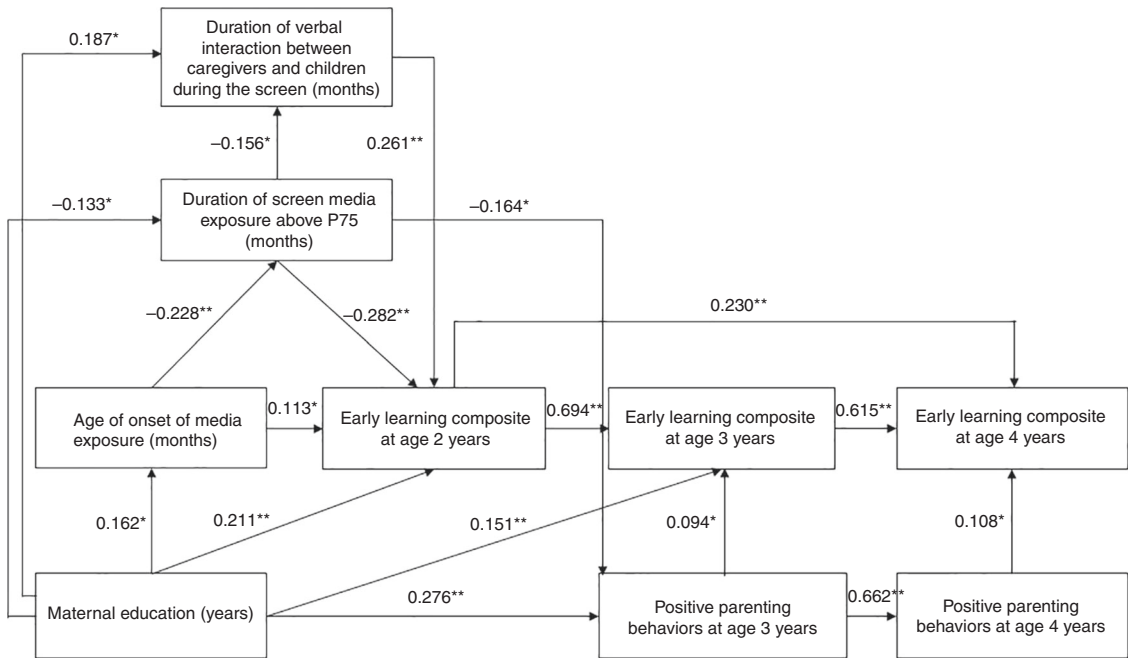

Fig. 3 Path analysis model for overall cognitive development adjusting for child age, gender, primary caregivers, preschool attendance, parental age, maternal education, and family income. $\chi^2 = 22.910$ (d.f. 18), $p = 0.194$, comparative fit index (CFI) = 0.994, root mean square error of approximation (RMSEA) = 0.029, normed fit index (NFI) = 0.974. *$p < 0.05$ and **$p < 0.001$.

Simple correlations among demographic characteristics, positive parenting behaviors, screen media variables, and ELC

Mother's education and family income were associated with positive parenting behaviors and ELC. Mother's education was also related to a later age of onset of screen media exposure, fewer months of high screen media exposure, and more months of verbal interaction between caregivers and children during screen time. ELC was also associated with positive parenting behaviors, fewer months of high screen media exposure, more months of verbal interaction between caregivers and children during screen time, and a later age of onset of screen media exposure. Simple correlations among such variables are shown in Table 2.

Path analysis for cognitive development

Figure 3 illustrates the path analysis model of complex associations among maternal education, screen media variables, positive parenting behaviors, and ELC adjusting for age, gender, primary caregivers, preschool attendance, parental age, maternal education, and family income. Variables that did not demonstrate robust and significant relationships with main variables of interest were not shown in the final model. Maternal education was associated with a later age of onset of screen media exposure, fewer months of high screen media exposure, more months of verbal interaction between caregivers and children during screen time, positive parenting behaviors at age 3 years, and ELC at 2 and 3 years of

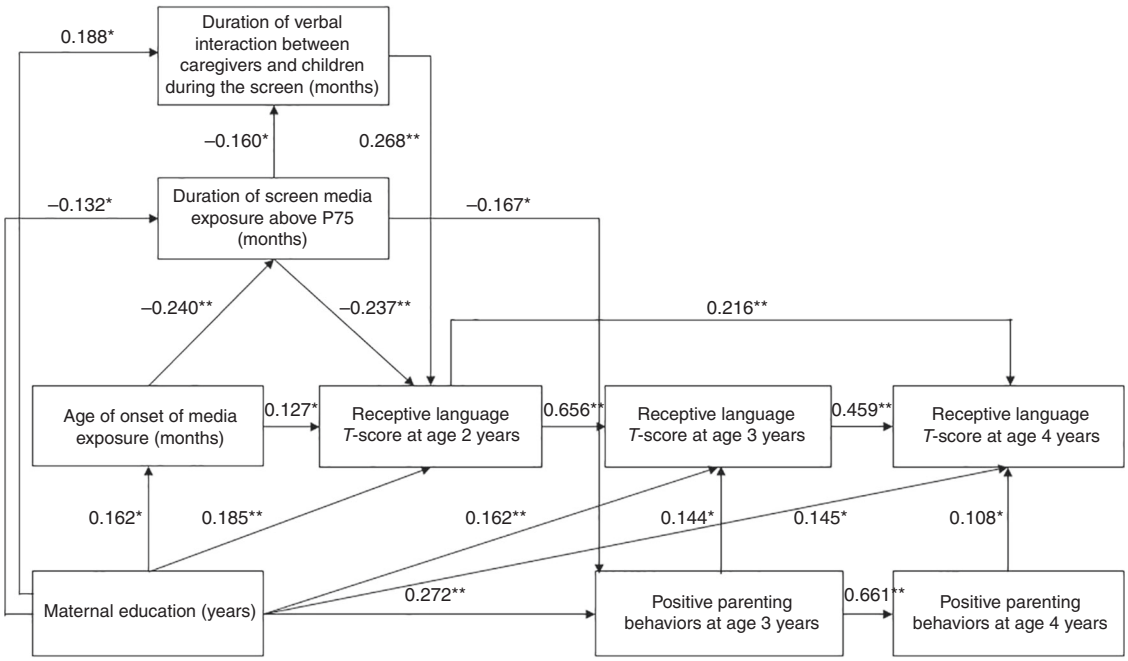

Fig. 4 Path analysis model for receptive language development adjusting for child age, gender, primary caregivers, preschool attendance, parental age, maternal education, and family income. $\chi^2 = 29.730$ (d.f. 17), $p = 0.028$, CFI = 0.981, RMSEA = 0.048, NFI = 0.959. $^*p < 0.05$ and $^{**}p < 0.001$.

age. ELC at 2 years of age was related to a later age of onset of screen media exposure, fewer months of high screen media exposure, and more months of verbal interaction between caregivers and children during screen time. Later age of onset of screen media exposure was also indirectly associated with ELC at age 2 years, which was mediated through fewer months of high screen media exposure. The latter variable also had an indirect association with ELC at 2 years of age, which was mediated via more months of verbal interaction between caregivers and children during screen time. Moreover, fewer months of high screen media exposure had an indirect association with higher ELC at 3 years of age via positive parenting behaviors at the same age. ELC at age 4 years was associated with ELC at earlier ages and positive parenting behaviors at age 4. Positive parenting behaviors at 3 years of age was also indirectly related to ELC at age 4 years through positive parenting behaviors at 4 years of age.

Path analysis for each developmental domain

The findings on associations between maternal education and screen media variables, positive parenting behaviors at age 3 years, and each developmental stream at 2 and 3 years of age were similar to the path analysis for cognitive development model as shown in Fig. 3. More months of high screen media exposure but fewer months of verbal interaction between caregivers and children during screen time had direct associations with lower fine motor, visual reception, receptive language, and expressive language development. More months of high screen media exposure had a stronger association with decreased fine motor and visual reception, whereas fewer months of verbal interaction between caregivers and children during screen time was associated with lower language *T*-scores. Furthermore, earlier introduction of screen media exposure was directly associated with lower receptive and expressive language *T*-scores, but not other developmental domains. However, an earlier age of onset of screen media exposure had an indirect association with lower *T*-scores of all developmental streams at 2 years of age via more months of high screen media exposure. In addition, more months of high screen media exposure was also indirectly associated with lower visual reception and receptive language *T*-scores at age 3 years via diminished positive parenting behaviors at the same age. Other associations between positive parenting behaviors and cognitive subdomains varied among each developmental domain as illustrated in Figs. 4 and 5 and Supplementary Figs. S1 and S2 (online).

Sensitivity analyses

Path analyses were only conducted for participants who were originally enrolled at the age of 6 months. The main findings were similar to the path analyses for the whole sample, except for the lack of a direct path from a later age of onset of screen media exposure on cognitive development and developmental subdomains. Furthermore, findings on the path analysis for older child/adult programs were comparable to the path analysis model for all screen media exposure, except for the absence of a direct association between maternal education and months of high screen media exposure on older child/adult programs above the upper quartile. Nonetheless, months of high screen media exposure on noneducational programs had a slightly direct association with lower receptive and expressive language *T*-scores, but not other developmental subdomains.

DISCUSSION

To our knowledge, this was the first study investigating the complex relationships between screen media variables, particularly age of onset of screen media exposure, cumulative effect of high screen media exposure, and verbal interaction between caregivers and children during screen time in the first 2 years of life, and cognitive development in preschoolers by including maternal education and positive parenting behaviors into the final construct, adjusting for age, gender, primary caregivers, preschool attendance, parental age, maternal education, and family income. Children with earlier screen media exposure, more months of excessive screen media exposure (>6.5 h/day), and fewer months of verbal interaction between caregivers and children during screen time in the first 2 years of life were more likely to have

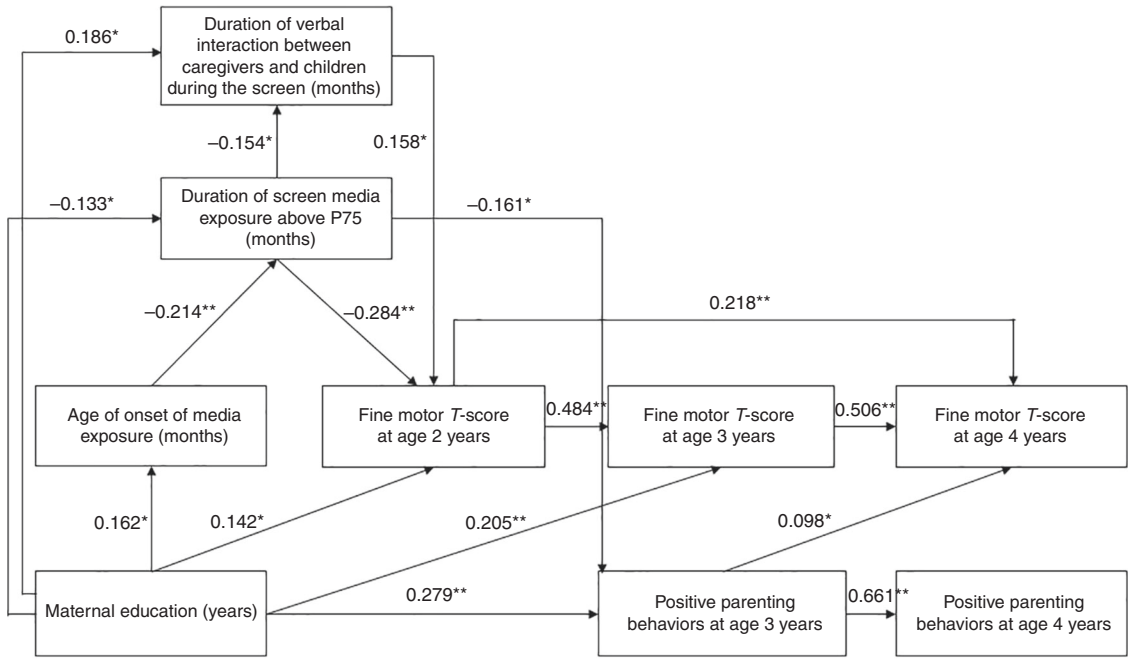

Fig. 5 Path analysis model for fine motor development adjusting for child age, gender, primary caregivers, preschool attendance, parental age, maternal education, and family income. $\chi^2 = 28.486$ (d.f. 20), $p = 0.098$, CFI = 0.983, RMSEA = 0.036, NFI = 0.948. *$p < 0.05$ and **$p < 0.001$.

lower cognition and language development in their preschool years. High cumulative months of excessive screen media exposure and fewer months of verbal interaction between caregivers and children during screen time were also related to lower fine motor and visual reception domains. The former factor had stronger associations with fine motor, visual reception, and cognitive development, whereas the latter variable was more associated with language outcomes, suggesting that parent–child verbal interaction, even during screen time was very important for enhancing child language development.[20,28] Cumulative months of high screen media exposure also had an indirect association with decreased cognitive development and all developmental subdomains, stemming from fewer months of verbal interaction between caregivers and children during screen time. As a result, parents should be aware of the protective effects of verbal interaction between caregivers and children during screen time on promoting cognitive outcomes in their children. Moreover, interventions aimed at enhancing parent–child interaction via interactive daily activities, shared book reading, hands-on, unstructured, and social play since early childhood are extremely helpful to lessen excessive digital media use and possibly mitigate the undesirable effects of inappropriate screen media exposure on child development.[1,28]

The relationships between screen media variables and cognitive development mentioned above were more robust for older child/adult programs, but to a lesser extent for noneducational programs, which demonstrated associations with only language development. Our main findings were comparable to previous longitudinal studies on the associations between duration of early foreground traditional media or total exposure,[13,17] adult content of electronic media,[13] and the absence of parent–child verbal interaction with lower language and cognitive development in early childhood.[20] However, this study demonstrated such associations by taking into account the various screen media variables simultaneously in the models, thereby capturing the more complicated and dynamic nature of screen media exposure at a very young age on overall cognition and developmental subdomains. Furthermore, this study also underscored the importance of the relationship between an earlier age of onset of screen media exposure and decreased language and cognitive development. Such findings supported our previous cross-sectional studies where toddlers and preschoolers with autism spectrum disorder were more likely to begin watching television at a younger age than typical controls.[15,31] Despite being typically developing at enrollment, our participants who had been exposed to screen media at an earlier age would have consumed excessive screen media cumulatively, which ultimately could put them at risk for lower developmental scores. Early childhood cognitive development is generally enhanced by person-to-person interaction rather than device-to-person exchange, thereby limiting learning abilities for young individuals, particularly if they were immersed since early infancy in environments with background media that mostly contained inappropriate content for age and were too difficult for them to understand.[1,32] An earlier age of onset of screen media exposure, excessive and inappropriate digital media exposure, and the absence of responsive caregivers to foster verbal interaction during screen time, may be detrimental to those individuals' neuronal structure and function that subsequently affect their cognition.[23,33] Such a finding was demonstrated in a recent article where preschoolers with greater screen-based media use than the American Academy of Pediatrics recommendations were correlated with lower microstructural integrity of brain white matter tracts supporting language, EF, and emergent literacy abilities.[23]

Another interesting finding of this study was positive parenting as a mediator for the relationship between cumulative months of high screen media exposure and cognitive development. Children with more cumulative months of high screen media exposure were associated with decreased positive parenting behaviors at 3 years of age that were subsequently related to lower cognitive development and developmental subdomains at age 3 or 4 years. Early excessive media exposure was associated with poor self-control,[34] lower EF,[19] behavioral problems,[5,6] decreased parent–child interaction,[9,35] and elevated parent's own media use.[36] Such problems possibly shaped parenting styles and behaviors afterwards where parents either controlled their

children without reasoning or allowed their children to spend more time on digital media without discipline as demonstrated in our previous study.[26] As such, decreased positive parenting might be associated with lower language and cognitive development as reported in previous studies.[37,38] Moreover, positive parenting and parent–child verbal interaction indicative of sensitive and responsive caregivers also had direct associations with cognitive development and all developmental subdomains mentioned above. Such findings were supported by a recent meta-analysis where children whose caregivers exhibited higher sensitive responsiveness and warmth had a nearly threefold increased likelihood of having better language skills, compared with those whose parents showed less responsiveness and warmth.[39]

Moreover, higher maternal education had associations with positive parenting behaviors, children's appropriate screen media use, and cognitive development. These findings highlighted the importance of the primary caregiver playing a pivotal role through parenting behaviors and disciplining children by setting up regulations of appropriate screen media use in the family.[1] The path analysis models for child development shown in this study also underscored the transactional relationships between genetics and environment in addition to gene–environment interaction. Children with higher maternal education were likely reflective of their genetic underpinning on cognition. However, optimal screen media exposure and positive parenting created a nurturing environment and safe opportunities for learning activities, plausibly contributing to the child's cognitive development.[40]

Nonetheless, there were several limitations of this study that need to be mentioned. First, screen media exposure and parenting behaviors variables were obtained by parental report. Parents may have been inclined to answer questions in a manner that would be viewed favorably by others. However, the method of screen media and parenting data ascertainment were generally utilized in previous studies. Second, there were other unmeasured variables especially parent–child interaction, earlier parenting behaviors, shared book reading, play, and activities with caregivers and friends out of the context of screen media exposure that could potentially promote the child's literacy and cognitive development. Third, our participants were relatively in the middle to high socioeconomic status according to the Thai context. Therefore, our findings could not be generalized to other settings, although those with lower socioeconomic backgrounds were more likely to be exposed to screen time inappropriately and may be raised with negative parenting. As a result, we postulated that the associations of studied variables could be stronger in such a background. Fourth, maternal intelligence was not measured in this study, where such a variable would be better reflective of genetic influence on cognition rather than maternal education. Future studies should consider taking such variables into account when investigating the child's cognition. However, the strengths of this study were in the nature of the longitudinal cohort, the use of standardized cognitive assessment, the comprehensive ascertainment of both traditional and new digital media representing evolving technology, the age of onset of screen media exposure, cumulative duration of excessive screen media exposure, types of the programs, and the context of media use, especially the verbal interaction between caregivers and children during screen time.

In summary, an earlier age of onset of screen media exposure, cumulative months of excessive screen media exposure, and fewer months of verbal interaction between caregivers and children during screen media use in the first 2 years of life were associated with lower cognitive outcomes. To mitigate undesirable effects of inappropriate screen media use on cognition, delayed introduction of screen media, appropriate electronic media exposure, and increased verbal interaction during media use with children should be recommended at health supervision visits.

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AUTHOR CONTRIBUTIONS

S.S.: had responsibility for interpretation of data, drafted the article, and finally approved the version to be published. P.T.: participated in data interpretation, revised the article critically for important intellectual content, and finally approved the version to be published. W.C.: had substantial contributions to conception and design, acquisition of data, analysis and interpretation of data; drafted the article and revised it critically for important intellectual content; and finally approved the version to be published.

ADDITIONAL INFORMATION

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