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Early-Life Digital Media Experiences and Development of Atypical Sensory Processing

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Supplemental content

IMPORTANCE Atypical sensory processing is challenging for children and families, yet there is limited understanding of its associated risk factors.

OBJECTIVE To determine the association between early-life digital media exposure and sensory processing outcomes among toddlers.

DESIGN, SETTING, AND PARTICIPANTS This multicenter US study used data that were analyzed from the National Children's Study (NCS), a cohort study of environmental influences on child health and development, with enrollment from 2011 to 2014. Data analysis was performed in 2023. The study included children enrolled in the NCS at birth whose caregivers completed reports of digital media exposure and sensory processing.

EXPOSURES Children's viewing of television or video at 12 months (yes or no), 18 months, and 24 months of age (hours per day).

MAIN OUTCOMES AND MEASURES Sensory processing was reported at approximately 33 months of age on the Infant/Toddler Sensory Profile. Quadrant scores (low registration, sensation seeking, sensory sensitivity, and sensation avoiding) were categorized into groups representing typical, high, and low sensory-related behaviors, and multinomial regression analyses were performed.

RESULTS A total of 1471 children (50% male) were included. Screen exposure at 12 months of age was associated with a 2-fold increased odds of being in the high category of low registration (odds ratio [OR], 2.05; 95% CI, 1.31-3.20), while the odds of being in the low category instead of the typical category decreased for sensation seeking (OR, 0.55; 95% CI, 0.35-0.87), sensation avoiding (OR, 0.69; 95% CI, 0.50-0.94), and low registration (OR, 0.64; 95% CI, 0.44-0.92). At 18 months of age, greater screen exposure was associated with increased risk of high sensation avoiding (OR, 1.23; 95% CI, 1.03-1.46) and low registration (OR, 1.23; 95% CI, 1.04-1.44). At 24 months of age, greater screen exposure was associated with increased risk of high sensation seeking (OR, 1.20; 95% CI, 1.02-1.42), sensory sensitivity (OR, 1.25; 95% CI, 1.05-1.49), and sensation avoiding (OR, 1.21; 95% CI, 1.03-1.42).

CONCLUSIONS AND RELEVANCE In this cohort study, early-life digital media exposure was associated with atypical sensory processing outcomes in multiple domains. These findings suggest that digital media exposure might be a potential risk factor for the development of atypical sensory profiles. Further research is needed to understand the relationship between screen time and specific sensory-related developmental and behavioral outcomes, and whether minimizing early-life exposure can improve subsequent sensory-related outcomes.

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Key Points

Question Is early-life digital media exposure associated with subsequent atypical sensory processing?

Findings In this cohort study, early-life television or video exposure was associated with atypical sensory processing in low registration, sensation seeking, sensory sensitivity, and sensation avoiding domains of the Infant-Toddler Sensory Profile, after controlling for perinatal and demographic variables; results differed by age at exposure.

Meaning Greater early-life digital media exposures may be associated with atypical sensory processing. Further research is needed to understand why early media exposure is associated with specific sensory-related behaviors, including those seen in autism spectrum disorder, and if minimizing screen media at a young age can improve subsequent sensory-related outcomes.

Early-life exposure to digital media (ie, screens) is a relatively new phenomenon in human history, with little understanding of its impact on sensory processing. Screen time reduces meaningful play[1] and social interactions,[2] which may have significant implications for the development of typical sensory processing and overall level of daily function. Studies in neuroplasticity show that altering sensory exposures produces changes in brain connectivity that subsequently shape behaviors, potentially leading to maladaptive behaviors.[3] Therefore, high early-life digital media exposure could directly impact neurodevelopment,[4,5] while also displacing other developmentally important sensory and motor experiences.

Sensory processing abilities refer to the integration of information received from the body's sensory systems (eg, auditory, visual, tactile, oral sensory, and vestibular) to form appropriate and efficient behavioral responses. Poor sensory processing may impact children's daily functioning or well-being. There is substantial evidence of a relationship between atypical sensory findings and developmental disability, particularly among children with attention-deficit/hyperactivity disorder (ADHD),[6] autism spectrum disorder (ASD),[7,8] and developmental coordination disorder.[9]

Among children with disabilities, atypical sensory processing is associated with significant challenges, both for the children and their caregivers.[10] Greater sensation seeking, sensation avoiding, sensory sensitivity, and low registration among children with ASD have been associated with increased irritability, hyperactivity, restricted and repetitive behaviors, aggressive behaviors, emotional dysregulation, eating and sleeping problems, and social deficits.[11-15] In children with ADHD, atypical sensory processing is associated with poorer executive function, higher anxiety, and lower quality of life.[16] Sensory hypersensitivity is associated with greater restricted and repetitive behaviors in children with and without ASD.[17] Sensory-related behaviors in children with ASD can interfere with family members' participation in work, family, and leisure activities.[10] Additionally, children's atypical sensory processing is associated with greater caregiver stress.[18,19]

Because of the functional and behavioral difficulties associated with atypical sensory profiles,[12] it is important to consider potential risk factors and mechanisms of impact on sensory development. In addition to genetic factors, nongenetic factors, such as prematurity, socioeconomic status, and fetal alcohol spectrum disorder, may contribute to atypical sensory profiles.[20-23] It is also important to identify potentially modifiable risk factors for atypical sensory processing, such as digital media exposure, especially since early screen exposure is associated with ASD symptoms and diagnosis,[24,25] symptoms of which are highly associated with atypical sensory profiles.[11,13,14] Atypical sensory processing is also associated with sleep problems,[26] ADHD,[27] emotional dysregulation,[28] lower executive function,[16] and behavioral problems,[29] all of which are also associated with greater early-life digital media exposure.[30-34] Additionally, brain findings of disrupted white matter integrity are seen both in children with high screen exposure and in those with atypical sensory processing.[35-37]

The close association between atypical sensory processing and these developmental, behavioral, and brain findings suggests atypical sensory processing may possibly be a factor in the pathophysiology of these outcomes. Understanding modifiable risk factors for atypical sensory processing could potentially lead to improved outcomes in both sensory processing and these associated outcomes. The current study uses data from the National Children's Study (NCS)[38] to examine the association between early digital media exposures and subsequent caregiver-reported sensory profiles using the Infant/Toddler Sensory Profile (ITSP).[39]

Methods

Data Source and Study Sample

The NCS was a cohort study designed to investigate the effects of environmental factors on child health and development in the US.[38] Participants in the NCS were enrolled at birth between 2011 and 2014. Initially intended to observe 100 000 children from preconception to age 21 years, the NCS was closed by the National Institutes of Health after enrolling approximately 5000 children. In the current report, children whose caregiver completed an ITSP prior to NCS termination were included, excluding all children who were not yet of age for when the ITSP was administered. When multiple children from a single family participated, only data from the first enrolled child were used. This study was deemed exempt from Drexel University institutional review board review, as the NCS data contained no personally identifying information. This study followed Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guidelines and was preregistered with Open Science Foundation on November 30, 2021.[40]

Outcomes and Measures

The outcomes of interest are sensory behaviors measured using the ITSP questionnaire, a 48-item validated tool for measuring sensory processing in children aged 7 to 36 months.[41] Parents or caregivers rated their children's behavior using the ITSP's 5-point scale ranging from almost always (score of 1) to almost never (score of 5) when the children were approximately 30 months old (mean [SD] age, 32.7 [1.9] months). Thus, a lower score on an item indicates that the child more frequently exhibits the sensory-related behavior described in that item.

ITSP items are categorized into 5 sensory processing domains: auditory, visual, tactile, vestibular, and oral sensory. For example, the auditory subscale includes items such as "My child finds ways to make noise with toys" and "My child tries to escape from noisy environments." ITSP items are regrouped into 4 classes representing different patterns of sensory processing[41] to obtain quadrant scores based on Dunn's Model of Sensory Processing, which proposes that sensory-related responses are directly related to a person's interaction of neurological thresholds for noticing sensory events (high vs low) combined with self-regulation strategies (active vs passive).[42] The 4 patterns of Dunn's Model of Sensory Processing are: (1) low registration (high threshold and passive self-regulation; eg, a child who fails to notice obvious stimuli in the environment and may be slow to respond), (2) sensation seeking (high threshold and active self-regulation strategies; eg, a child who actively seeks sensory stimuli throughout the day, such as excessively touching or smelling objects or repetitively spinning items while staring at them), (3) sensory sensitivity (low threshold and passive self-regulation; eg, a child who is overly irritated or upset by lights, textures, or noises), and (4) sensation avoiding (low threshold and active self-regulation; eg, a child who actively tries to control the environment to limit sensory exposure, such as resisting having hair washed).[39,42] Children with atypical sensory processing frequently exhibit atypicality in multiple quadrants of sensory processing, such as sensory seeking of visual stimuli (including staring at lights, fans, or spinning wheels on a toy car) and also sensory sensitivity or sensation avoidance to loud noises, scratchy tags in clothing, or certain food textures.[42] Consistent with prior research and clinical use of the ITSP, quadrant scores were categorized into 3 groups based on age-specific cutoffs, as proposed by the ITSP.[41,43-45] The typical range included scores within 1 SD of the mean of age-corrected ITSP norms for each subtest.[41] Those with scores more than 1 SD below the mean were grouped as high, meaning that they exhibit more frequent sensory-related behaviors. Similarly, those with scores greater than 1 SD above the mean were grouped as low, meaning that they less frequently exhibit sensory-related behaviors. These categories of quadrant scores, which represent the overall patterns of sensory processing, are the outcome variables in the study. The cutoffs used in the categorization are provided in eTable 1 in Supplement 1.

The primary exposure variables of interest were children's screen exposure at 12, 18, and 24 months of age. Screen exposure at 12 months was based on caregiver responses to "Does your child watch TV or DVDs? (yes or no)" while 18- and 24-month screen exposures were based on caregiver responses to the question "Over the past 30 days, on average, how many hours per day did your child watch TV and/or DVDs?"

Statistical Analysis

First, we calculated descriptive statistics for the study population using means and counts. To account for missing data, we performed multivariate imputation by chained equations using the MICE package, version 3.15.0(The R Project for Statistical Computing).[46] To study the association between screen exposure and sensory processing, we performed multinomial regression analyses with each of the 4 quadrant variables as outcomes and digital media exposure variable at 3 time points separately (thus 12 models), adjusting for prenatal and family context variables. The covariates adjusted for in the model were child age (in months), birth prematurity (less than 36 weeks' gestation vs 36 weeks' or more gestation), female or male, household income decile, caregiver education (some college or more vs high school or less), race and ethnicity (minority status vs nonminority status (ie, non-Hispanic White), and 2 measures of caregiver engagement with their child at 12 months of age: plays with toys with child (daily vs less than daily) and child takes walks with caregiver (2 or more days per week vs 1 day or less per week). The covariates were selected a priori based on past literature regarding factors associated with sensory and developmental outcomes and data availability.[20-24,47] We created 100 sets of imputed data, and the regression estimates were combined using Rubin's formula.[48] We presented the adjusted odds ratios (ORs) and 95% CIs and deemed the results to be statistically significant if the 95% CI does not include 1.00. While the study was preregistered, the following deviations were made from the preregistration data plan. Prenatal alcohol exposure was omitted as a covariable due to the low prevalence (only 5 caregivers endorsed both having at least a single occurrence of binge drinking in the first trimester and continuing to drink later in pregnancy. Due to small cell sizes of individual minority groups, race and ethnicity categories were re-coded to combine Hispanic; non-Hispanic Black and non-Hispanic other (American Indian and Alaska Native, Asian, Native Hawaiian and other Pacific Islanders, multiple races, and other race) as minority status, vs non-Hispanic White categorized as nonminority status. Rather than including all 3 digital media exposures (ie, 12-, 18-, and 24-month) in 1 regression analysis, separate regression analyses were conducted for each to better isolate the effects of exposure at each time period.

Results

A total of 1621 caregivers completed the ITSP; however, 150 completed the ITSP when their child was older than 36 months, which is the upper age limit with norms for the ITSP. Data from these 150 participants were omitted, resulting in a sample of 1471 children (50% male) (**Table 1**). Of 1471 children, the information on screen viewing was missing for 392 children at 12 months (26.6%), 213 at 18 months (14.5%), and 133 at 24 months (9.0%). A total of 910 children had screen viewing information from all 3 measurement periods. The number of children with nonmissing screen viewing information at 2 time points ranged from 971 (12 months and 18 months) to 1172 (18 months and 24 months). The variable with the most missingness was parent education, where only 1006 records were present. **Table 2** presents the distribution of the study sample across the 4 ITSP quadrants and their categories. For all 4 quadrants, most children were in the typical group. About one-fifth of children exhibited less frequent sensory sensitivity and

Table 1. Characteristics of the Study Sample (N = 1471)

Characteristics	No. (%)
Child age, mean (SD), mo	32.7 (1.94)
Sex	
Male	637 (43.3)
Female	633 (43.0)
Missing	201 (13.7)
Race and ethnicity	
Minority race and ethnicity	269 (18.3)
Non-Hispanic White	804 (54.7)
Missing	398 (27.1)
Parent education (n = 1006)	
High school or less	277 (18.8)
Some college or more	729 (49.6)
Missing	465 (31.6)
Children in first quartile of the income distribution of parents	160 (13.6)
Missing	296 (20.1)
Premature birth	
No	1185 (80.6)
Yes	69 (4.7)
Missing	217 (14.8)
Watches TV or DVDs at 12 mo	
No	389 (26.4)
Yes	690 (46.9)
Missing	392 (26.6)
Time watching TV or DVDs at 18 mo, h/d	
0	160 (10.9)
1	711 (48.3)
2	265 (18.0)
3	62 (4.2)
4	37 (2.5)
5	23 (1.6)
Missing	213 (14.5)
Time watching TV or DVDs at 24 mo, h/d	
0	2 (0.1)
1	326 (22.2)
2	691 (47.0)
3	116 (7.9)
4	146 (9.9)
5	57 (3.9)
Missing	133 (9.0)
Caregiver plays with toys with child at 12 mo	
Less than daily	81 (5.5)
Daily	998 (67.8)
Missing	392 (26.6)
Caregiver takes walks with child at 12 mo, d/wk (n = 1078)	
≤1	312 (21.2)
≥2	766 (52.1)
Missing	393 (26.7)

sensation avoiding. The distribution of quadrant scores by screen exposure status at age 12 months is provided in the **Figure**, which shows that median quadrant scores are smaller (indicating greater frequency of sensory-related behavior) for television or video watchers compared with nonwatchers across all quadrants.

Table 2. Distribution of Quadrant Scores and Their Categories at 33 Months[a]

Sensory categories	Mean (SD) score	No. (%) High	No. (%) Typical	No. (%) Low
Low registration (n = 1270)	49.9 (4.75)	183 (14.4)	895 (70.5)	192 (15.1)
Sensation seeking (n = 1021)	37.9 (8.80)	120 (11.8)	790 (77.4)	111 (10.9)
Sensory sensitivity (n = 1213)	48.1 (5.44)	105 (8.7)	842 (69.4)	266 (21.9)
Sensation avoiding (n = 1241)	51.8 (5.90)	136 (11.0)	814 (65.6)	291 (23.4)

[a] The number for each sensory characteristic indicates nonmissing observations for that characteristic.

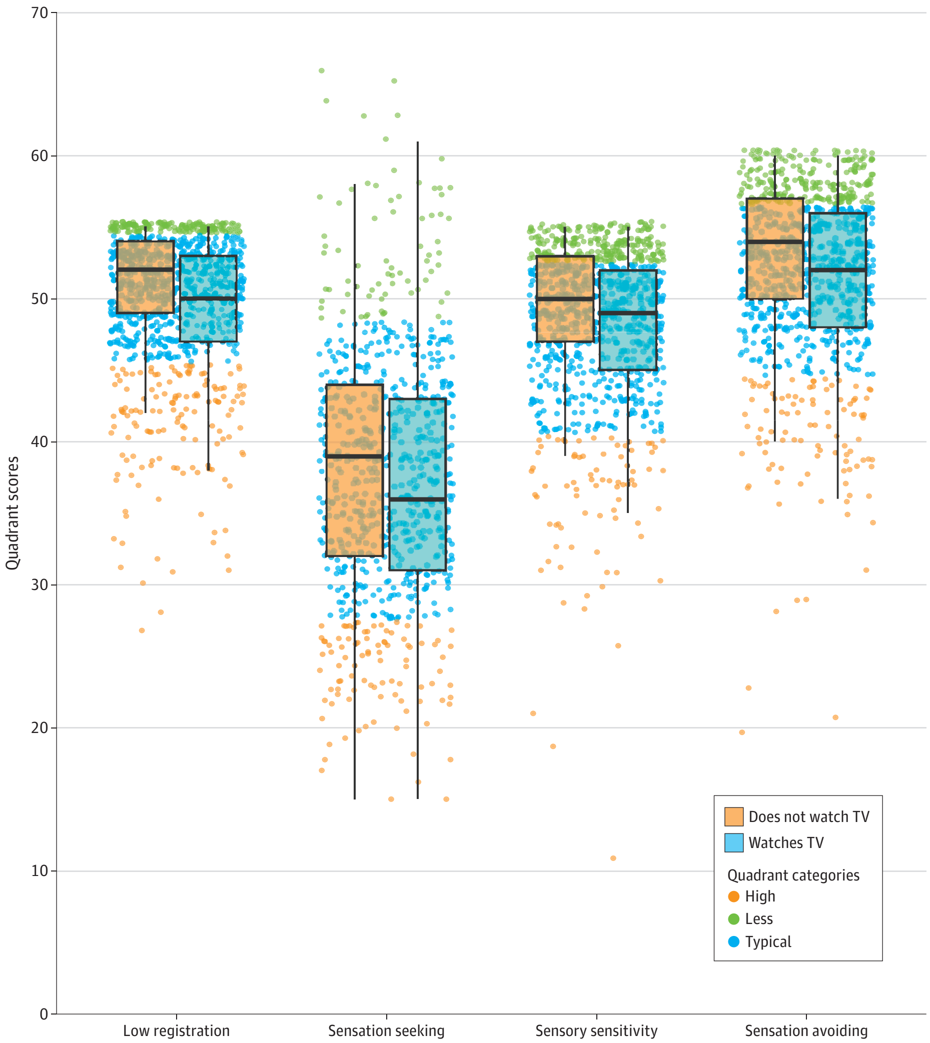
Table 3 presents the ORs associated with screen viewing based on multinomial regression analyses using multiply-imputed dataset run separately for each of the 3 screen exposure variables and 4 quadrant categories. The full regression results, including the estimated ORs associated with covariates, are shown in Supplement 1 (eTables 2 through 4 and eResults in Supplement 1). The 12-month screen exposure was significantly associated with sensory processing outcomes in low registration, sensation seeking, and sensation avoiding. Children who watched television or videos at 12 months compared with children who did not had a 2-fold increased risk of being in the high category of low registration (OR, 2.05; 95% CI, 1.31-3.20). Additionally, at 12 months of age, the odds of being in the low category instead of the typical category of low registration, sensation seeking, and sensation avoiding decreased, with OR of 0.64 (95% CI, 0.44-0.92), 0.55 (95% CI, 0.35-0.87), and 0.69 (95% CI, 0.50-0.94), respectively, (Table 3) for children who watched television or videos compared with children who did not.

At 18 months of age, greater screen exposure was associated with a more frequent exhibition of low registration (OR, 1.23; 95% CI, 1.04-1.44) and sensation avoiding (OR, 1.23; 95% CI, 1.03-1.46) (Table 3). Similarly, greater screen exposure at 24 months of age was associated with more frequent exhibition of sensation seeking (OR 1.20; 95% CI, 1.02-1.42), sensory sensitivity (OR, 1.25; 95% CI, 1.05-1.49), and sensation avoiding (OR, 1.21; 95% CI, 1.03-1.42). (Table 3).

Discussion

Early-life screen time was associated with atypically high frequency of low registration (associated with greater screen time at 12 and 18 months), sensation avoiding (associated with greater screen time at 18 and 24 months), sensation seeking, and sensory sensitivity (each associated with greater screen time at 24 months of age). At 12 months of age, screen viewing was also associated with reduced likelihood of low sensation seeking, sensation avoiding, and low registration, suggesting the same direction of association between screen time and increased quadrant-related sensory behaviors as seen with older exposure, just at the low end of the frequency scale, possibly reflecting differences due to the earlier time of exposure or to the yes/no format at this earlier age (vs hours per day

Figure. Distribution of Quadrant Scores by Television or Video Viewing Status at Age 12 Months



The horizontal bar inside the box represents median. The lower and upper hinges correspond to the first and third quartiles. The upper whisker extends from the hinge to the largest value no further than 1.5 IQR from the hinge (where IQR is the IQR range or distance between the first and third quartiles). The lower whisker extends from the hinge to the smallest value at most 1.5 IQR of the hinge.

Table 3. Adjusted Odds Ratio (OR) Associated With Screen Exposure From Separate Multinomial Logistic Regression Models of Quadrant Categories With Typical Sensory Processing as Baseline[a]

	Adjusted OR (95% CI)							
	Low registration		Sensation seeking		Sensory sensitivity		Sensation avoiding	
Variables	High	Low	High	Low	High	Low	High	Low
TV or video at 12 mo (yes vs no)	2.05 (1.31-3.20)	0.64 (0.44-0.92)	1.34 (0.85-2.11)	0.55 (0.35-0.87)	1.52 (0.88-2.63)	0.78 (0.57-1.07)	1.57 (0.94-2.63)	0.69 (0.50-0.94)
TV or video at 18 mo (hrs/d)	1.23 (1.04-1.44)	1.03 (0.86-1.23)	1.02 (0.84-1.23)	0.93 (0.74-1.16)	1.13 (0.93-1.38)	0.95 (0.81-1.10)	1.23 (1.03-1.46)	0.95 (0.82-1.11)
TV or video at 24 mo (hrs/d)	1.17 (1.00-1.35)	0.98 (0.84-1.14)	1.20 (1.02-1.42)	1.09 (0.90-1.31)	1.25 (1.05-1.49)	0.93 (0.80-1.07)	1.21 (1.03-1.42)	0.93 (0.81-1.06)

[a] The models were adjusted for child age, sex, race and ethnicity, parent education, income (decile), prematurity of birth (yes or no), child playing with toys at 12 months (daily vs less than daily), and caregiver taking a walk with the child at 12 months (2 or more days per week vs less).

at older ages). While atypically high sensory-related behavior in each of the quadrants is associated with adverse developmental and behavioral outcomes,[6,12,18,19] the clinical relevance of low frequency sensory-related behavior is less clear. The current findings add atypical sensory processing to the list of suboptimal developmental outcomes, including language delay, lower cognitive development, ADHD, ASD, behavioral problems, emotional dysregulation, and sleep problems, associated with early screen exposure.[24,25,30-33,49,50]

While atypical sensory processing can occur among typically developing children, it is particularly prevalent among children with ADHD (approximately 60%) and ASD (70% to

95%).[6-8,51,52] The current study does not establish a causal relationship between screen exposure and sensory processing. However, it does raise the question of whether early-life high screen time could potentiate the sensory brain hyperconnectivity seen in ASD, such as overgrowth of sensory-processing cortical surface areas at 6 to 12 months, heightened brain responses to sensory stimuli, and sensory driven neuroconnectivity impairing higher-level cortical processing.[53-56] Furthermore, could early-life screen time contribute to sensory-related outcomes, including behavior, function, and quality of life, as well as parental stress?[11-19] In children with ADHD, atypical sensory processing is associated with more severe attention problems and worse quality of life.[6,16] In children with ASD, atypical sensory processing is associated with socialization and communication deficits and restricted or repetitive behavior, core symptoms of ASD included in the diagnostic criteria.[8,14,15,17,56,57]

In young children with ASD, atypical sensory processing predicts later social impairment, and this relationship is mediated by children's poor social attending.[58] For example, children who are wholly absorbed in sensation seeking, such as spinning or twirling of objects, may be more difficult to engage in social interaction. Those with sensory sensitivity and sensation avoidance may be so overwhelmed by the environment that they have greater difficulty learning from the people around them.[56] The sensory mediated lack of social engagement may further diminish future social opportunities from which to develop social cognition.[4,56,58] Sensory avoiding, associated with screen time at 18 and 24 months of age, is associated with caregiver stress or strain, even above that explained by maladaptive behaviors of children with ASD.[18,19]

To the extent that high screen time may increase risk for ASD symptoms,[24,25] the current findings raise the possibility that screen time may do so by impacting sensory development. On a positive note, improvements in ASD symptoms and reduction in parental stress have been reported when high screen time is replaced with socially oriented activities.[59-62] Furthermore, children who initially exhibited developmental improvements following screen reduction were found to subsequently exhibit increased ASD symptoms, including restricted/repetitive behavior that is associated with atypical sensory processing,[14,17] on the return of high levels of screen time.[63]

As high screen time in the first few years of life is associated with multiple developmental and behavioral problems, it may be reasonable to consider a trial of screen reduction, in addition to usual sensory processing interventions provided by occupational therapists,[64,65] in young children with high screen use and sensory dysfunction. Since screen time is a modifiable exposure, further study regarding the potential benefits of limiting screen time on sensory processing outcomes is indicated.

Strengths and Limitations

To our knowledge, this is the first prospective study to examine the association between screen exposure and sensory processing among children. The current study's strengths include its use of a relatively large dataset to examine digital media exposure as a prospective risk factor for atypical sensory processing. Nonetheless, several limitations deserve mention. The association found between early-life digital media exposure and subsequent atypical sensory processing does not establish causality, as parents may be more likely to allow higher levels of screen time for children with challenging sensory behaviors. While child characteristics may contribute to increased screen time, studies suggest that parents' attitudes regarding screen time for children, the parents' own screen time, and parenting style have the most significant impact on young children's viewing habits.[66,67] While the ITSP is a validated caregiver questionnaire, a more objective measure of sensory processing would be important to include in future research. In addition, only children whose parents completed the ITSP were included, adding a potential selection bias to the sample. Furthermore, the assessments of screen exposure were from single-item caregiver reports that do not fully capture the quantity, type, and quality of screen exposure or the possible buffering impact of parent coviewing. Also, our analyses do not account for other developmental delays that may impact sensory processing. Lastly, we also note that this observational study did not correct for multiple comparisons.

Conclusions

This study is unique in prospectively finding early-life digital media exposure to be associated with later atypical sensory processing across multiple sensory domains. These findings are particularly important, as behavioral and developmental problems which can be challenging for young children and their families are significantly associated with children's sensory profiles.[6-19,51,52] While the present study associates early-life digital media experiences with later atypical sensory processing involving all 4 quadrants, it will be important to understand if these findings also relate directly to altered sensory neuroconnectivity and behavior in children at risk of developing ADHD, ASD, or other neurodevelopmental disorders. Since screen time is potentially modifiable through parent training and education, we advocate for greater adherence to the American Academy of Pediatrics recommendations to avoid screen viewing in children younger than 18 to 24 months,[68] and for greater public awareness of the research involving the association between early-life digital media exposure and developmental outcomes.

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Concept and design: Heffler, Subedi, Bennett.
Acquisition, analysis, or interpretation of data: All authors.
Drafting of the manuscript: Heffler, Acharya, Subedi.

Critical review of the manuscript for important intellectual content: Heffler, Subedi, Bennett.
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