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Cross-sectional and prospective associations between screen time and childhood neurodevelopment in two Brazilian cohorts born 11 years apart

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Abstract

Background: The aim of this study was to investigate the associations between screen time from ages 2 to 4 years and child neurodevelopment at age 4.

Methods: The participants were from the 2004 ($N = 3787$) and 2015 ($N = 3604$) Pelotas (Brazil) birth cohort studies. Childhood neurodevelopment was assessed at age 4 using the Battelle Development Inventory. The time children spent on screen devices was reported by their guardians at ages 2 and 4 years. Linear regression models were used to investigate the association of: (i) time spent on television at ages 2 and 4 years; (ii) time spent on other screens at age 4; and (iii) total screen time at age 4 (television + other screens) with childhood neurodevelopment at age 4.

Results: Average daily screen time among children born in 2004 and those born in 2005 aged 4 years were 3.4 (SD: 2.4) and 4.4 h (SD: 2.9), respectively. Overall, few associations of very small magnitude between screen time and child neurodevelopment were observed. Television time at 2 years of age was statistically associated with lower neurodevelopment at 4 years of age in the 2015 cohort ($\beta = -0.30$, 95% CI $= -0.55$; -0.05). Conversely, television time ($\beta = 0.17$, 95%CI $= 0.07, 0.26$) and total screen time ($\beta = 0.22$, 95%CI $= 0.13, 0.31$) at age 4 were associated with higher neurodevelopment at age 4 in the 2004 cohort.

Conclusions: The findings of this study suggest that the amount of time spent on screen devices might not be associated with neurodevelopment of children under 5 years of age. The small magnitude and inconsistencies in the direction of associations did not find evidence to support the current guidelines for screen time at this age. Therefore, more studies, especially those with longitudinal data, are important to comprehend the true effect of screen time on neurodevelopment and other health outcomes.

KEYWORDS
child behaviour, child development, cohort studies, screen time

1 | BACKGROUND

Early childhood neurodevelopment is critical to health and social outcomes across the lifespan (Nelson, 2000). Early experiences with caregivers, interactions with siblings and engaging in new activities have an impact on growth, health and the development of specific traits of neurodevelopment, such as cognitive, motor and language skills. These early influences have long-term implications for education, employment, health and other outcomes that span the course of an individual's life (Sameroff, 2009).

Screen use has become a major part of young children's lives in the modern world. Data from population-based studies indicate that children are engaging in high levels of screen time. Recent studies have shown that access to technologies such as smartphones and tablets is nearly universal in middle and high-income countries (Ashton & Beattie, 2019; Kabali et al., 2015; Rideout, 2017; Stiglic & Viner, 2019). Data from Thailand have shown that two-year olds spent a median of 5 h per day on screen media devices (Supanitayanon et al., 2020). In Australia, in 2015, four-year old children spent approximately 2 h per day on electronic media use, including activities such as program viewing on devices like TV/DVD, using applications/electronic games on portable handheld devices (e.g. tablets and smartphones) or playing non-active console games like Playstation or Xbox (McNeill et al., 2020). Furthermore, a study conducted in 2018–2019 that measured time on smartphones and tablets showed that children aged 3 to 5 years spent around 2 h per day on various devices (Radesky et al., 2020). However, despite the empirical knowledge suggesting that there has been a substantial increase in screen time among children over the past few decades, there is little evidence on time trends in children under five, especially in low and middle income countries (Rideout, 2017).

The current public health recommendation from the World Health Organization (WHO) suggests that children under 5 years should be limited to 1 h of screen time per day (World Health Organization, 2019). This recommendation is supported by existing evidence, which indicates that screen time can have negative effects on child health outcomes, including adiposity, depressive symptoms and motor and cognitive skills development (Madigan et al., 2019; Stiglic & Viner, 2019). However, the systematic review of reviews on the effects of screen time on children's health that provides the evidence-based for the WHO guidelines suggests that there is weak evidence linking total time spent on screen, particularly television viewing, to cognitive development and educational attainments (Stiglic & Viner, 2019). Furthermore, the majority of the original studies included in these systematic reviews were cross-sectional and conducted in high-income countries. As a result, both the Canadian Paediatric Society (Canadian Paediatric Society, 2017) and the recent WHO recommendations for children under 5 years of age (World Health Organization, 2019), emphasise that the evidence on the impact of screen time on neurodevelopment remains limited and based on studies of very low quality.

Repeated population-based studies, such as the Pelotas (Brazil) birth cohorts (Hallal et al., 2018; Santos et al., 2011) offer valuable opportunities to investigate temporal trends in screen time and explore the intricate relationships between screen time, child neurodevelopment and contextual factors such as societal norms and economic development. One cohort was born in Brazil in 2004, a period with limited technological development and children were exposed to a limited range of screen time options. Meanwhile, the other cohort was born in 2015, a time when there was widespread exposure to various forms of media. By investigating and comparing the associations between screen time and neurodevelopment in early childhood among these cohorts, it is possible to gain valuable insights into how different confounding structures based on population characteristics may influence this association, ultimately advancing our understanding of the impact of screen time on neurodevelopment.

Therefore, the overall aim of this study was to investigate the associations between time spent on different types of screen devices at ages 2 and 4 years and child neurodevelopment at age 4 in two large birth cohorts from Brazil recruited 11 years apart. The specific aims were to: (1) describe time spent on screen devices in 2 and 4 year-old children born in 2004 and 2015 and (2) compare the associations of screen time with child neurodevelopment between the two cohorts from the same city.

Key Messages

- Findings from two well-established large birth cohorts born 11 years apart show inconsistent longitudinal associations between total screen time and neurodevelopment scores of children.
- Overall, associations between screen time and childhood neurodevelopment were small in magnitude, suggesting that the amount of screen-time might not influence neurodevelopment at the age 4 years.
- Daily total screen-time at age 4 was 3.4 h in children born in 2004 and 4.4 h among those who were born in 2015.
- Future studies should shift their focus beyond solely considering the duration of screen use and focus on the content and context of screen exposure as well.

2 | METHODS

2.1 | Study population

This study used the data from the 2004 and 2015 Pelotas (Brazil) birth cohort studies. These cohorts recruited all hospital-delivered newborns between 1 January and 31 December of 2004 ($N = 4231$) and 2015 ($N = 4275$) in Pelotas, Brazil. Similar protocols for recruitment and measurement of participants were used in both cohorts (Bertoldi et al., 2019). Pelotas is a medium-sized city located in the extreme southern Brazil and has experienced significant transformations in the social, economic and health characteristics of its population over the past decades (Bertoldi et al., 2019).

The data were collected from children and their guardians who provided information during the perinatal period, as well as at 2- and 4-year follow-ups. For the 2004 cohort, the follow-up rates for the 2- and 4-year assessment were 94% and 92%, respectively, and data collection was conducted at the participant's home (Santos et al., 2011; Santos et al., 2014). In the 2015 cohort, the children were evaluated at a research clinic for both the 2- and 4-year follow-ups, with a similar follow-up rate of 95% at both ages. Written informed consent was obtained from all participants during the interviews. All study protocols were approved by the Research Ethics Committees of the Federal University of Pelotas (CAAE registration number: 26746414.5.0000.5313 and 4.06.01.116) Detailed methodological information about each cohort has been published elsewhere (Hallal et al., 2018; Santos et al., 2011; Santos et al., 2014).

For this study, only children with available neurodevelopment data at age 4 were included in the analytical sample ($N = 3787$ for the 2004 cohort; $N = 3604$ for the 2015 cohort) (Figure 1). Overall, there were no differences in sociodemographic and health characteristics between the analytical sample and the original sample recruited for each cohort. (Table 1 and Supplementary Table S1).

2.2 | Child neurodevelopment

Neurodevelopment of children at age 4 was measured using the screening version of the Battelle Development Inventory (BDI). This screening tool included direct observation of children while they engaged in various activities and the collection of information from caregivers regarding their children's behaviour. The original version of this standardized tool includes 96 items and has been widely used to assess neurodevelopment across different domains (personal-social, adaptive, fine and gross motor, communication and cognitive domains) in children under 8 years of age (Newborg et al., 1988). Previous studies have shown that BDI has good validity in predicting later neurodevelopment scores, especially in children aged 3 years or older (Behl & Akers, 1996). In the 4-year follow-up of both cohorts, an adapted version of the original scale, comprising 66 items for children aged 0 to 5 years, was used to assess child neurodevelopment. The scores obtained for each domain were combined to generate a total neurodevelopment score, ranging from 0 to 132, with higher scores indicating better neurodevelopmental outcomes. Twelve children (nine from the 2004 and three from the 2015 cohort) with scores lower than 50 were excluded from the analyses because of the presence of severe cognitive impairment or invalid data. All assessments were conducted by research assistants who received training and supervision from psychologists specialized in child development (Barros et al., 2010; Hallal et al., 2018).

2.3 | Screen time

At ages 2 and 4 years, the mother or caregiver reported the amount of time their child spent watching TV during the morning, afternoon and evenings on a regular day. At age 4, similar questions regarding other screens (computer and videogame) were applied for the 2015 cohort. For the 2004 cohort, average time spent by the child using videogames and computers during the past 6 months were collected. To encompass the relevant technologies at the time of the 4 year-follow-up, the questionnaire used in the 2015 cohort also included items on the amount of time spent on tablets/iPad and smartphones on a regular day. All the questionnaires are available online (www.epidemio-ufpel.org.br) or can be requested from the corresponding author. Because of a programming error in the questionnaire during the 2-year follow-up in the 2015 cohort, TV time was not collected among children who were born between January and June. Consequently, the analytical sample for the analyses involving TV time at 2 years in the 2015 cohort included 1262 children. Sensitivity analyses were

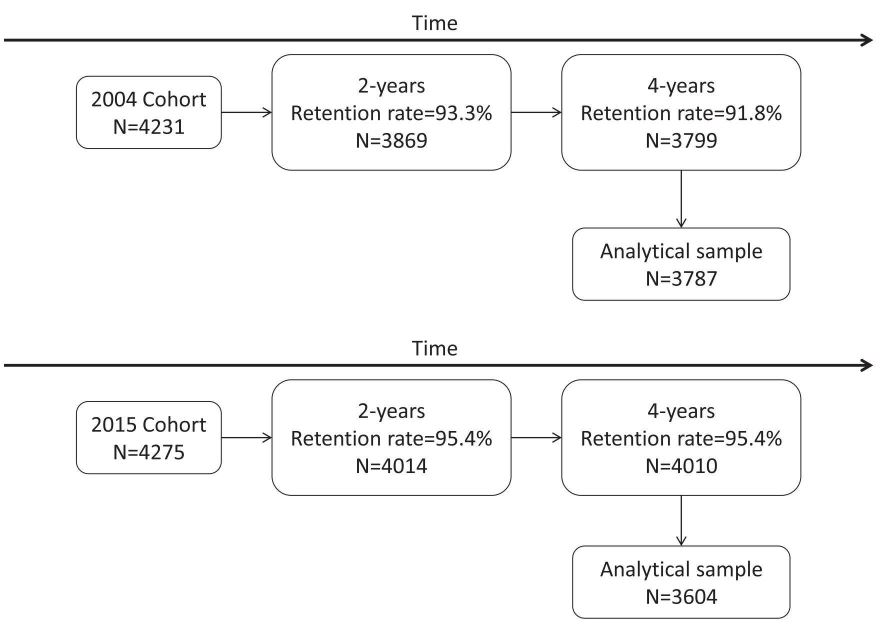

FIGURE 1 Flowchart of participants at birth, 2 and 4 years of the 2004 and 2015 Pelotas cohorts.

TABLE 1 Description of analytical sample from the 2004 ($N = 3867$) and 2015 ($N = 3604$) Pelotas, Brazil, birth cohort studies.

	2004 cohort N (%)	2015 cohort N (%)
Sex		
Female	1825 (48.2)	1787 (49.6)
Male	1962 (51.8)	1817 (50.4)
Family income (quintiles)[a]		
1 (low)	759 (20.1)	710 (19.7)
2	759 (20.1)	743 (20.6)
3	748 (19.7)	726 (20.2)
4	789 (20.8)	729 (20.2)
5 (high)	732 (19.3)	694 (19.3)
Maternal education (years)		
0–4	568 (15.1)	326 (9.0)
5–8	1558 (41.6)	928 (25.8)
9–11	1251 (33.4)	1255 (34.8)
12+	373 (9.9)	1094 (30.4)
Maternal age (years)		
<20	707 (18.8)	522 (14.5)
20–34	2559 (67.6)	2558 (71.0)
≥35	519 (13.7)	524 (14.5)
Maternal depression		
No	3074 (84.0)	2795 (84.0)
Yes	585 (16.0)	531 (16.0)
Stimulation score		
≤1	388 (10.3)	509 (14.4)
2	873 (23.0)	889 (25.2)
3	1378 (36.4)	1197 (34.0)
4	1148 (30.3)	929 (26.4)
Centre-based childcare		
No	3193 (86.2)	2310 (66.9)
Yes	511 (13.8)	1144 (33.1)

[a]Monthly minimum wage in Brazil was approximately US$ 89.00 in 2004 and US$ 237.00 in 2015.

conducted and showed that participants with missing information on TV time at age 2 did not differ from the original cohort in terms of sociodemographic and outcome variables (data not shown).

For the present study, five screen time variables were created: (a) total TV time at 2 years of age; (b) total TV time at 4 years of age; (c) changes in total TV time from ages 2 to 4 years; (d) use of other screens at 4 years of age and (e) total screen time at 4 years of age (including both TV time and other screens).

2.4 | Covariates

The following covariates were measured in the perinatal study: sex (female or male), maternal age (≤20, 21–34 and ≥35), family income at birth (quintiles), maternal education (0–4, 5–8, 9–11 and 12+ years of schooling). Maternal depression was assessed using the Edinburgh Postnatal Depression Scale (EPDS) (Cox et al., 1987) at 2 years. A cut-off point of ≥13 points was used to indicate presence of at least moderate depression (Santos et al., 2007). Stimulation and centre-based childcare attendance were evaluated at age 2 in both cohorts. Centre-based childcare was coded as positive if the child attended childcare at some point prior to the 2-year follow-up. A stimulation score, ranging from 0 to 4 points, was generated based on the sum of four activities: (a) whether anyone read or told stories to their child (yes, no); (b) whether the child visited the house of other people in the past week (yes, no); (c) whether the child went to a park in the last week (yes, no) and (d) whether the child had story books at home (yes, no) (Barros et al., 2010).

2.5 | Statistical analysis

Means, standard deviations and proportions were used to describe sociodemographic variables in both cohorts. The BDI score and average screen time were described according to sociodemographic variables in each cohort. Student's *t*-test and analysis of variance (ANOVA) were used to explore the associations of sociodemographic characteristics with the five screen time variables as well as child neurodevelopment within each cohort. The associations between screen time variables and child neurodevelopment were investigated using unadjusted and multivariable linear regression models. Two different models were used to explore the potential role of various confounders: Model 1 included child age, sex, family income, maternal age and education. Model 2 included all variables of Model 1 along with maternal depression, stimulation and childcare attendance. Model 2 was included to adjust for variables that are related to child stimulation and therefore provide further understanding of different confounding structures. Initially, fractional polynomial terms were tested in the regression models to account for the potential non-linearity of the association between screen time and child neurodevelopment. However, as there was no evidence of non-linear relationships, the final models did not incorporate fractional polynomial terms. Assumptions for regression analyses were verified by examining the normality of residuals and leverage versus-residual-squared plots. Unstandardized coefficients were presented. For instance, a coefficient of 1 in the linear regression indicates that, on average, the BDI score is 1 point higher for each hour of screen time. Predictive margins based on the linear regressions were used to describe the predicted scores of neurodevelopment for different levels of screen time. Analyses were stratified by cohort because of the presence of effect modification in the associations between screen time and neurodevelopment, as indicated by a significant *p*-value for the interaction test ($p < 0.001$). All statistical analyses were conducted using Stata 16.0. Statistical significance was set at 5%, and 95% confidence intervals are provided.

3 | RESULTS

Sociodemographic characteristics of children and mothers/caregivers in each cohort analytical sample are presented in Table 1. Both cohorts had a similar proportion of boys and girls. The mean age at the 4-year follow-up was 4.1 years (SD = 0.15) in the 2004 cohort and 3.8 years (SD = 0.21) in the 2015 cohort. Mean family income was 3.2 (SD = 4.4) minimum wages in the 2004 cohort and 3.9 (SD = 5.5) in the 2015 cohort. The proportion of women with 12+ years of education increased from 10% in 2004 to 30% in 2015. In both cohorts, women were mostly 20–34 years old, and 16% had depression symptoms. In the 2004 cohort, only 15% of children were enrolled in external childcare at age 2; this proportion doubled in the 2015 cohort. More than half of children in both cohorts had a stimulation score of 3 or higher.

Descriptions of the screen time variables for each cohort are presented in Figure 2. The 2015 cohort had higher mean values of screen time outcomes, except for TV at 4-years (Figure 2). The mean screen time in hours was as follows: TV at 2 years (2004 cohort: 1.8, SD: 1.7; 2015 cohort: 2.4, SD: 1.9), TV at age 4 (2004 cohort: 3.3, SD: 2.2; 2015 cohort: 2.8, SD: 2.1), other screens at age 4 (2004 cohort: 0.3, SD: 0.7; 2015 cohort: 2.1, SD: 1.9), total time at age 4 (2004 cohort: 3.4, SD: 2.4; 2015 cohort: 4.4, SD: 2.9).

Mean scores of child neurodevelopment and total screen time according to the sociodemographic characteristics in each cohort are presented in Table 2. Total screen time was highest in boys. Children from low-income families had the highest average total screen time in the 2015 cohort, whereas this was not observed in the 2004 cohort. High maternal education was associated with high total screen time in the 2004 cohort, but with low total screen time in the 2015 cohort. Young mothers had children with higher average screen time in both cohorts. Only in the 2015 cohort, mothers with depressive symptoms had children with higher screen time than mothers without depressive symptoms. Overall, less stimulated children and those who did not attend centre-based childcare had higher screen time than their counterparts. In general, the distribution pattern of other screen time variables, such as TV at 2 years, TV at 4 years and other screens at 4 years, according to child and maternal characteristics was similar to that observed for total screen time (Supplementary Table S2).

The children in the 2004 cohort had an average neurodevelopment score of 118.6 (SD = 7.2), whereas the mean score for the 2015 cohort was 113.4 (SD = 8.7). As indicated in Table 2, higher average neurodevelopment scores were observed among girls, children from higher-income families, those with more educated and older mothers, children of mothers without depression, those with higher stimulation scores and children in external childcare.

Associations between different types of screen time and child neurodevelopment scores are presented in Table 3. In the 2004 cohort, higher change in TV from ages 2 to 4, TV time at 4 years and total screen time at 4 years were associated with higher child neurodevelopment scores, even after adjustment for confounding factors (β = 0.22; 95%CI = 0.13, 0.31 for total screen time). Conversely, in the 2015 cohort, higher TV time at age 2 was the only screen time variable statistically associated with lower scores of neurodevelopment (β = −0.30; 95%CI = −0.55, −0.05). As observed in Figure 3, which is used to demonstrate the predictive scores of neurodevelopment for different levels of screen time, the associations between screen time and neurodevelopment were of small magnitude even among children with high levels of screen time.

4 | DISCUSSION

The present study investigated the association between the time spent using different types of screen devices and child neurodevelopment in two large and comparable birth cohorts in Brazil, established

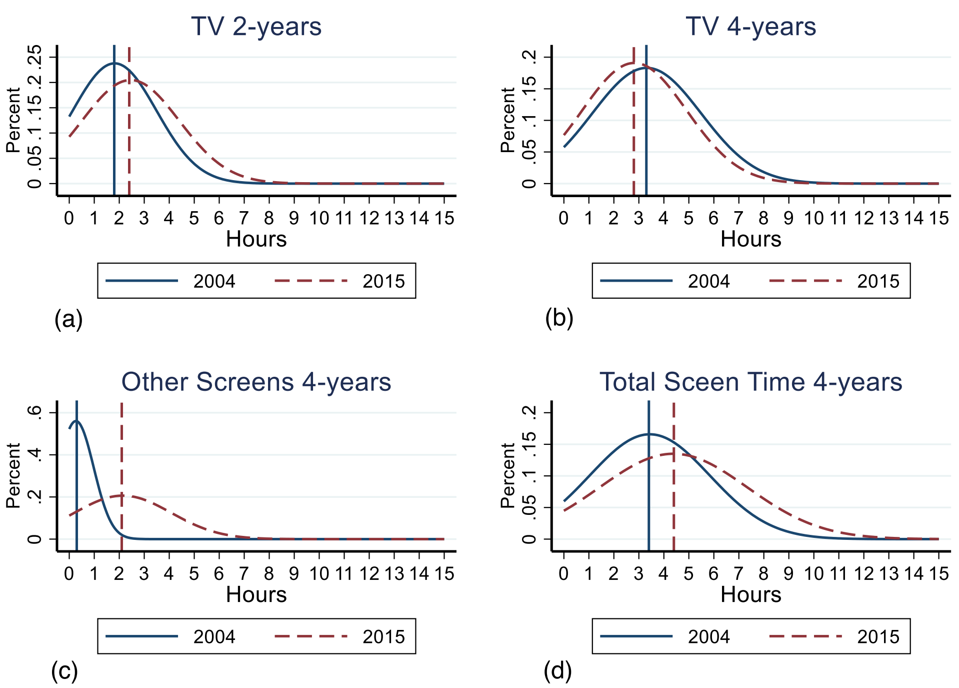

FIGURE 2 Distribution of screen time variables of children from the 2004 and 2015 Pelotas cohorts.

TABLE 2 Neurodevelopment and total screen time means at 4-years from the 2004 and 2015 Pelotas cohorts.

	Child neurodevelopment				Total screen time			
	2004 cohort		2015 cohort		2004 cohort		2015 cohort	
	Mean (SD)	*p*-value	Mean (SD)	*p*-value	Mean (SD)	*p*-value	Mean (SD)	*p*-value
Total	118.6 (7.2)	-	113.4 (8.7)	-	3.4 (2.4)	-	4.4 (2.9)	-
Sex	-	<0.001	-	<0.001	-	<0.001	-	0.03
Female	119.6 (6.6)	-	115.1 (7.5)	-	3.2 (2.2)	-	4.3 (2.9)	-
Male	117.5 (7.5)	-	111.8 (9.5)	-	3.6 (2.5)	-	4.5 (3.0)	-
Family income (quintiles)	-	<0.001	-	<0.001	-	0.36	-	<0.001
1 (low)	116.9 (7.1)	-	111.1 (9.0)	-	3.3 (2.4)	-	4.6 (3.1)	-
2	117.1 (7.6)	-	112.2 (8.7)	-	3.4 (2.4)	-	4.7 (3.0)	-
3	118.6 (6.9)	-	113.6 (8.6)	-	3.5 (2.4)	-	4.6 (3.1)	-
4	119.4 (6.8)	-	114.1 (8.5)	-	3.5 (2.5)	-	4.2 (2.7)	-
5 (high)	120.8 (6.8)	-	116.2 (8.2)	-	3.5 (2.3)	-	3.9 (2.6)	-
Maternal education (years)	-	<0.001	-	<0.001	-	<0.001	-	<0.001
0–4	116.2 (7.9)	-	110.0 (9.0)	-	3.1 (2.3)	-	4.7 (3.7)	-
5–8	117.4 (7.2)	-	111.8 (8.8)	-	3.6 (2.6)	-	4.7 (3.1)	-
9–11	120.1 (6.3)	-	113.6 (8.4)	-	3.4 (2.3)	-	4.6 (2.9)	-
12+	121.5 (6.0)	-	115.6 (8.4)	-	3.4 (2.1)	-	3.8 (2.5)	-
Maternal age (years)	-	0.002	-	0.001	-	<0.001	-	0.003
<20	117.7 (6.8)	-	112.1 (8.7)	-	3.7 (2.6)	-	4.7 (3.1)	-
20–34	118.7 (7.2)	-	113.7 (8.5)	-	3.4 (2.3)	-	4.4 (3.0)	-
≥35	119.0 (7.7)	-	113.5 (9.8)	-	3.1 (2.4)	-	4.1 (2.5)	-
Maternal depression	-	0.0003	-	0.02	-	0.34	-	0.007
No	118.7 (7.1)	-	113.6 (8.8)	-	3.5 (2.4)	-	4.3 (2.9)	-
Yes	117.6 (7.7)	-	112.6 (8.8)	-	3.3 (2.5)	-	4.7 (3.2)	-
Stimulation score	-	<0.001	-	<0.001	-	0.18	-	<0.001
≤1	114.5 (9.3)	-	111.0 (9.1)	-	3.4 (2.8)	-	4.8 (3.4)	-
2	117.5 (7.1)	-	111.8 (9.5)	-	3.4 (2.4)	-	4.7 (3.0)	-
3	118.8 (6.9)	-	114.0 (8.3)	-	3.5 (2.4)	-	4.4 (2.9)	-
4	120.5 (5.9)	-	115.4 (7.9)	-	3.3 (2.2)	-	3.9 (2.7)	-
Centre-based childcare	-	<0.001	-	<0.001	-	<0.001	-	<0.001
No	118.2 (7.3)	-	112.8 (8.8)	-	3.5 (2.4)	-	4.6 (3.0)	-
Yes	120.4 (6.1)	-	114.7 (8.4)	-	2.9 (2.0)	-	4.0 (2.8)	-

Note: Screen time means in hours. *t*-test and ANOVA.

11-years apart. Over the course of these two studies, there was a notable shift in the pattern of child screen time exposure among children born in 2004 to 2015. Overall, findings from our study did not suggest any consistent associations between screen time and child neurodevelopment in children. Interestingly, TV time at age 2 years of age was found to be statistically associated with lower child neurodevelopment scores at age 4 only in the 2015 cohort, whereas TV time as well as total screen time at age 4 were associated with higher scores of neurodevelopment among children who were born in 2004. However, it is important to note that despite these associations, the magnitude of association, as indicated by small beta coefficients, remains minimal, even at higher levels of screen time.

Similar to previous studies (Madigan et al., 2019; Rideout, 2017; Supanitayanon et al., 2020; Tandon et al., 2011; Wartella et al., 2013), the results from our study revealed high levels of screen time use among children at ages 2 and 4, with average screen time levels higher than what the current guidelines recommend (World Health Organization, 2019). Moreover, data from our study suggested that total screen time at age 4 was higher among those born in 2015 than those born in 2004. This difference may be attributed to the 2-h increase in the usage of non-TV screens, including video games, computers, tablets and smartphones. It is likely that the significant expansion in access to new technologies contributed to the increased time screen time among children born in 2015 (Ashton & Beattie, 2019;

TABLE 3 Association between early neurodevelopment and screen time on the 2004 and 2015 Pelotas cohorts.

	Child neurodevelopment					
	2004			2015		
	Crude β (95%CI)	Model I β (95%CI)	Model II β (95%CI)	Crude β (95%CI)	Model I β (95%CI)	Model II β (95%CI)
TV at 2-years (h)	−0.06 (−0.21, 0.08)	−0.05 (−0.18, 0.09)	−0.06 (−0.20, 0.07)	−0.26 (−0.52, 0.001)	−0.29 (−0.54, −0.04)	−0.30 (−0.55, −0.05)
TV at 4-years (h)	0.12 (0.02, 0.22)	0.13 (0.03, 0.23)	0.17 (0.07, 0.26)	−0.18 (−0.32, −0.04)	−0.08 (−0.21, 0.05)	−0.03 (−0.17, 0.10)
Change in TV (h)	0.10 (0.002, 0.20)	0.12 (0.03, 0.22)	0.16 (0.07, 0.26)	−0.16 (−0.36, 0.04)	−0.01 (−0.21, 0.18)	0.04 (−0.16, 0.24)
Other screens at 4-years (h)	0.42 (0.09, 0.74)	0.28 (−0.03, 0.59)	0.25 (−0.05, 0.56)	−0.28 (−0.45, −0.12)	−0.18 (−0.34, −0.03)	−0.16 (−0.32, 0.01)
Total screen at 4-years (h)	0.21 (0.11, 0.30)	0.19 (0.10, 0.28)	0.22 (0.13, 0.31)	−0.12 (−0.21, −0.02)	−0.05 (−0.14, 0.04)	−0.02 (−0.11, 0.08)

Note: Linear regression. Model 1: included age, sex, family income, maternal age and education; Model 2: included all variables of Model 1 plus maternal depression, stimulation and childcare attendance.

Kabali et al., 2015; Rideout, 2017; Stiglic & Viner, 2019). For example, screen-based devices such as computer and videogames accounted for approximately 10% of the total time spent on screens at age 4 among children of the 2004 cohort. In contrast, this proportion was nearly 50% for the 2015 cohort (also taking into account tablets/iPads and smartphones, which at this age were only available for children in the last cohort). Similar patterns were observed in the United States, were mobile devices represented only 4% of screen time in 2011 but increased to 35% in 2017 (Rideout, 2017). Furthermore, data from nationwide surveys of children and adolescents conducted in Brazil in 2009, 2012, 2015 and 2019 showed that, despite the proportion of participants who reported two or more hours per day of TV time decreased from 64% in 2009 to 40% in 2019 (Instituto Brasileiro de Geografia e Estatística, 2022), there was an increase in access to other screens, such as smartphones and tablets between 2015 (when they were first assessed) and 2019 (Instituto Brasileiro de Geografia e Estatística, 2022).

In line with previous research (Atkin et al., 2014; Tandon et al., 2011; Trinh et al., 2020), in both cohorts, screen time was highest among males, children from younger mothers and those who did not attend centre-based childcare. However, only among the cohort born in 2015, children who were less stimulated, from families with low income, had mothers with lower formal education, and experienced post-natal depression had higher screen time than their counterparts. For instance, the associations between sociodemographic variables and screen time observed only among those born in 2015 may be attributed to the inclusion of other screens in the assessment for 2015 cohort, and also may indicate that high screen time levels are associated with an environment characterised by limited care and stimulation (Law et al., 2023).

Findings from the present study should be interpreted beyond the *p*-value and statistical significance of associations. We observed few associations of very small magnitude between screen time and child neurodevelopment. Specifically, we found television time at 2 years was statistically associated with lower neurodevelopment at age 4 in the 2015 cohort, whereas television time and total screen time at age 4 were statistically associated with higher neurodevelopment at age 4 in the 2004 cohort. However, it is important to note that despite these statistically significant associations, the magnitude of those associations, as demonstrated by the coefficient betas of the regressions, were marginal and are unlikely to be clinically meaningful. For example, based on the predictive models used in our study, children exposed to screen based devices for 10 h a day would be expected to have a neurodevelopmental score that was, on average, 3 points lower than those who reported less than 1 h per day of screen time. This difference of 3 points equates to approximately one-third of the standard deviation of the BDI score observed in this sample. Considering the mean screen time observed in 2015 cohort was 4.4 h, it would be expected that any changes in mean neurodevelopment scores due to screen time exposure would be very small. Overall, previous studies that have sought to investigate the potential impacts of total screen time on neurodevelopmental outcomes in children (Kerai et al., 2022; Madigan et al., 2019; Madigan et al., 2020;

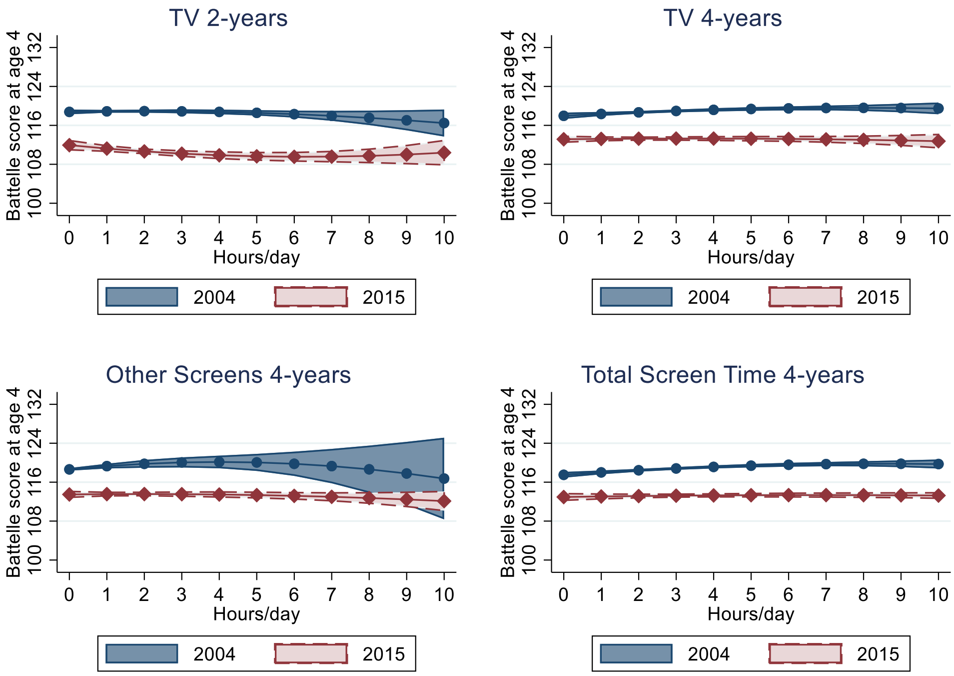

FIGURE 3 Predictive margins of screen time and neurodevelopment association from the 2004 and 2015 Pelotas cohorts.

Radesky & Christakis, 2016; Ribner et al., 2020; Sanders et al., 2019; Stiglic & Viner, 2019; Supanitayanon et al., 2020; Zimmerman & Christakis, 2005) also showed weak evidence that the total amount of screen time negatively impacts cognitive development or is associated with poorer educational attainment (Stiglic & Viner, 2019).

One important factor that may moderate the associations between screen time and child neurodevelopment is the content (Madigan et al., 2019; Madigan et al., 2020; Ribner et al., 2020; Sanders et al., 2019). This has been demonstrated in previous studies, which found that passive screen time was associated with worse psychological, health and educational outcomes, whereas educational and interactive screen time were associated with higher education-related outcomes (Sanders et al., 2019). For instance, in the language domain, background television was found to be negatively associated with language skills, whereas educational programs were positively associated with language skills (Madigan et al., 2020). Such moderation effects based on the type of screen use may have influenced the different patterns of associations observed in the two cohorts of the present study. However, because of a lack of data on type or content of screen use, such possibilities cannot be tested.

Strengths of this study include the comparison between two well-matched birth cohorts in a middle-income country. This unique approach adds robustness to the findings as it enabled the analysis of the associations between screen time variables and neurodevelopment in children from the same base population but exposed to different sociodemographic scenarios. The use of data collected at ages 2 and 4 years allowed for the investigation of longitudinal associations, which contributes to a better understanding of the temporal relationships between screen time and neurodevelopment. The measurement of different types of screen time provided an opportunity to improve understanding of how different screens may impact child neurodevelopment. The adjusted models included in the analyses took into account the important correlations of screen time and child neurodevelopment such as maternal stimulation, which were often overlooked in previous studies (Kerai et al., 2022; Zhao et al., 2022).

The study has limitations that should be acknowledged. There were slight differences in the total screen time variables used at age 4 years between the cohorts. Because of the technological advancements that occurred during the data collection period, for the 2004 cohort, 'other screens' only considered computers and videogames, while for the 2015 cohort, smartphones and tablets were included. Considering that the first iPhone was launched in the United States in 2007, we expect that children from the 2004 cohort did not have access to mobile devices at the 4 year-measurement follow-up. For TV viewing at the age of 2 years, about 50% of the data were missing in the 2015 cohort, which may affect the present findings. Measures of the content to what children were exposed on screens or co-viewing characteristics were not available, which may be important modifiers of this association (Tooth et al., 2021). Although the instruments used to assess neurodevelopment were identical in both cohorts, at the 4-year follow-up, the children from the 2004 cohort were evaluated at home, whereas the children from the 2015 cohort were assessed at the university research clinic. It is plausible that the unfamiliar and potentially uncomfortable environment of the research clinic may have influenced the children's test results, particularly those related to cognitive performance (Fernald et al., 2009), resulting in slight lower neurodevelopment scores among children of 2015 cohort than those in the 2004 cohort. Also, the slight difference in the mean age of children assessed at the 4-year follow-up between the cohorts (with 2015 children being younger than 2004) may also explain the lower BDI scores in 2015. Sensitivity analysis showed that when individuals from the 2015 cohort who are younger than 4-years were excluded from the analyses, the mean neurodevelopment scores were similar between the cohorts. Importantly, the results of the associations between screen time variables and neurodevelopment scores remained unchanged. Residual confounding due to parenting behaviours, primary caregiver and frequency of stimulation cannot be ruled out. Unfortunately we were not able to assess simultaneous screen use, which may have led to an overestimation of screen time in our sample. Finally, it is important to point out that the most complete screen time variable was collected at 4 year olds, turning the cross-sectional analysis the majority of the paper. However, the longitudinal analysis based on TV time improves the results, which also shows inconsistent associations of small magnitude.

5 | CONCLUSION

Our findings from the two well-established large birth cohorts could be used to enhance the quality of the current evidence-based guidelines to inform parents and caregivers about the potential effects of total screen time on child neurodevelopment. Despite public health recommendations suggesting that children under five should have limited screen use, the small magnitude and inconsistencies in the direction of associations observed in this study did not support the current guidelines when only considering neurodevelopment as outcome. More longitudinal studies are necessary to truly understand the influence of amount of time on screens, alongside content and context of screen exposure, on neurodevelopment and health outcomes at this age.

AUTHOR CONTRIBUTIONS

Otávio Amaral de Andrade Leãoa, Gregore Iven Mielke and Andréa Dâmaso Bertoldi coordinated and supervised the data collection, analyzed and interpreted the data, drafted the initial manuscript and reviewed and revised the manuscript. Marlos Rodrigues Domingues, Joseph Murray, Iná Silva Santos, Aluisio J D Barros and Alicia Matijasevich conceptualized and designed the study and critically reviewed and revised the manuscript for important intellectual content. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no competing interests.

DATA AVAILABILITY STATEMENT

The data used for this study are available from the corresponding author upon reasonable request.

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