SLEEPJ, 2021, 1–11

doi: 10.1093/sleep/zsaa158
Advance Access Publication Date: 24 August 2020
Original Article

Original Article

Sleep and screen exposure across the beginning of life: deciphering the links using big-data analytics

Michal Kahn[1,*], Natalie Barnett[2], Assaf Glazer[2] and Michael Gradisar[1]

[1]College of Education, Psychology and Social Work, Flinders University, Adelaide, Australia and [2]Research Department, Nanit, New York, NY

*Corresponding author. Michal Kahn, College of Education, Psychology and Social Work, Flinders University, Sturt Road, Bedford Park, 5042 SA, Australia. Email: michalkahn10@gmail.com.

Abstract

Study Objectives: Evidence for the association between screen time and insufficient sleep is bourgeoning, and recent findings suggest that these associations may be more pronounced in younger compared to older children, and for portable compared to non-portable devices. However, these effects have yet to be investigated within the beginning of life. Importantly, there are no data for the relationship between screen exposure and objectively measured infant sleep. This study examined the moderating role of age for both touchscreens' and television's relationship with sleep, using auto-videosomnography within a big-data sample of infants.

Methods: The sleep of 1074 infants (46% girls) aged 0–18 months was objectively assessed using computer-vision technology in this cross-sectional study. Sleep was additionally reported by parents in an online survey, as was infant exposure to screens.

Results: Age significantly moderated the relationship between daytime touchscreen exposure and sleep with a distinct pattern for younger infants, in which screen exposure was associated with decreased daytime sleep, but with a proposed compensatory increase in nighttime sleep consolidation. Compared to touchscreens, television exposure was less likely to be associated with sleep metrics, and age moderated this relationship only for daytime and 24-hour sleep duration.

Conclusions: In young infants, a daytime-nighttime sleep "trade-off" emerged, suggesting that the displacement of daytime sleep by screens may lead to greater accumulation of sleep homeostatic pressure, which in turn facilitates more consolidated nighttime sleep.

Statement of Significance

The screen-sleep link constitutes a major health care concern, but little is known about its presentation in infancy. This study assessed this link by employing the largest reported sample yet that has utilized objective measures of infant sleep. Age was found to moderate the screen-sleep relationship, with more pronounced effects for touchscreen compared to television exposure. Whereas the expected negative associations emerged for older infants, screens displaced daytime sleep for younger infants but were linked with more consolidated nighttime sleep, likely due to increased nightly sleep homeostatic pressure. Future research should examine these pathways using longitudinal and experimental designs, and assess the role of sleep homeostatic pressure as an underlying mechanism.

Key words: infant sleep; media screen exposure; touchscreens; auto-videosomnography; big-data

Submitted: 30 January, 2020; **Revised:** 28 July, 2020

Introduction

"Screens" were introduced into the family home with the domestic television (TV) around the 1950s [1]. For the second half of the 20th century, concerns were raised about the mesmerizing and negative effects of TVs on children [2, 3], and indeed, the emerging evidence [4] and legal acts [5] during this time led the American Academy of Pediatrics (AAP) to recommend TV viewing be discouraged for children under 2 years of age [6]. Yet, there were four more technological inventions that occurred in relatively quick succession over two decades that, again, changed the family environment, if not the world. From the late 1970s, personal computers (PCs) were made available to consumers, and from 1995 PCs were hardwired to the world wide web [7]. Then, from 1999 to 2007, both Wi-Fi and "gorilla glass,"[1] respectively, were invented for home use [8, 9], allowing for the portability of miniaturized PCs (e.g. phones, tablets) as well as touchscreens, that allowed even the smallest of humans to use screens with the touch, swipe or pinch of their fingertips.

From 2010 to 2015, numerous systematic reviews and meta-analyses were demonstrating a link between the use of media devices and sleep in school-aged children and adolescents [10–13]. The main conclusions from these studies were: (1) using technology was associated with later bedtimes, (2) and decreased sleep duration. The proposed mechanisms for the detrimental and alerting effects of technology use on children's sleep include the displacement of time being spent on sleep with time-consuming technology [14], the stimulating nature of screens [15–17], and the light emitted from them, that may affect circadian timing via melatonin suppression [18, 19].

Whilst many researchers and clinicians believe "we" have found the truth about the links between sleep and screens, there remain areas that are unexplored. The focus of this field has been on young people (13–30 years) who have an affinity for technological devices [10–13]. Despite Steve Jobs inventing touchscreen devices that "an illiterate 6-year-old can use without instruction" [9], very little is known about the effect of screen use on young children's sleep, and even more so on infants' sleep. The relatively few studies that have been conducted in this population have provided evidence for associations between longer exposure to screens and shorter, poorer infant sleep [20–22]. Exposure to screens has also been associated with adiposity, cognitive or motor development, and psychosocial health in young children [23]. Accordingly, as recent as 2019, both the AAP[2] and the World Health Organization have recommended that children under 2 years of age not be exposed to screens [24, 25].

These recommendations are based on findings that very young children may be vulnerable to the effects of media screens. A 2019 study by Twenge and colleagues [22] showed that for the children and adolescents assessed (0–17 years), it was the youngest age group (0- to 1-year-old) who showed the largest effects between technology use and sleep, especially for portable devices such as computers, cell phones, and handheld videogames. Similarly, Przybylski [26] demonstrated the moderating role of age, by showing that every hour of screen exposure was associated with 8 fewer minutes of sleep in 6-month to 5-year-olds, compared to only three fewer minutes of sleep in 5- to 17-year-old children. These larger effects may be due to a greater sensitivity of younger children to screen light [22, 27]. They may also be due to younger children's lower experience with screens, and thus a lack of habituation (as observed in some adolescents) [28].

Although these two studies represent an important step towards deciphering the screen-sleep link in young children, they are limited in that (1) they included broad age categories, making it impossible to detect trends within infancy, which is a sensitive developmental period characterized by dramatic evolution in sleep–wake patterns [29, 30]; (2) both studies pooled both daytime (naps) and nighttime sleep into the same outcome, thus missing the opportunity to observe distinctive effects of technology use on naps and nighttime sleep [22, 26]; and (3) as all other studies evaluating sleep and screen exposure in children, they relied solely on parent-reported sleep. Measuring sleep subjectively may have significant limitations, as parents may not be aware of precise sleep durations, as well as certain sleep–wake related events that occur throughout the night (e.g. awakenings in which the child does not call for parental attention) [31, 32]. In line with these notions, in its most recent guidelines on sleep in young children, the World Health Organization defined the dearth of objective measurement as a research gap in this field [24].

With the introduction of computer-vision technologies, we can now investigate sleep–wake patterns of infants using validated objective measures in "big-data" samples [33]. In addition to producing objective outputs, camera-based devices incorporating computer-vision algorithms have the potential to yield nightly metrics throughout prolonged periods of time. Furthermore, as these devices are typically used by parents for tracking their infant's sleep in naturalistic settings, they provide real-world ecologically valid data, as opposed to data produced to conform with external requirements, such as participation in research [34].

Using this state-of-the-art auto-videosomnography technology, the present study aims to observe links between both touchscreen and TV exposure with both daytime and nighttime sleep, within the first 18 months of life. We do so by utilizing a real-world big-data sample of infants, assessed both objectively and using parent-reports. We anticipate that age will moderate the relationship between screen exposure and sleep, with greater effects in younger compared to older infants, and for touchscreen compared to TV exposure.

Methods

Participants

Parents of 1074 infants (46% girls) aged 2 weeks to 18 months (M = 8.6 months, SD = 4.8) participated in this study. Demographic and sleep characteristics are presented in Table 1 for the entire sample, as well as for infants with daytime and evening–nighttime screen exposure durations above and below the mean (M = 22.4 minutes, SD = 30.1 for daytime touchscreen and TV exposure; M = 4.7 minutes, SD = 6.6 for evening–nighttime touchscreen and TV exposure).

Procedures

Users of Nanit baby monitors, which automatically generate sleep metrics using computer-vision technology, were

[1] "Gorilla glass" refers to chemically strengthened damage-resistant glass, used primarily as cover glass for portable electronic devices.

[2] The American Academy of Pediatrics recommends avoiding screen media use other than video chatting for children under 18 months.

Table 1. Demographic and sleep characteristics of infants and parents presented for the entire sample, and separately for infants with high and low daytime and evening–nighttime screen exposure

	Entire sample (*N* = 1074)	High daytime screen exposure (*N* = 357)	Low daytime screen exposure (*N* = 717)	High evening–nighttime screen exposure (*N* = 206)	Low evening–nighttime screen exposure (*N* = 868)
Infants					
Age (months)	8.6 (4.8)	10.6 (4.8)	7.8 (4.6)	10.4 (5.1)	8.3 (4.7)
Gender (% girls)	499 (46.5%)	170 (47.6%)	329 (45.9%)	100 (48.5%)	399 (46.0%)
Room sharing	127 (12.1%)	30 (8.6%)	97 (13.8%)	20 (10.0%)	107 (12.6%)
Breastfeeding	504 (50.9%)	121 (37.1%)	383 (57.6%)	58 (33.5%)	446 (54.5%)
Parents					
Age (years)					
21–24	11 (1.1%)	6 (1.7%)	5 (0.7%)	4 (2.0%)	7 (0.8%)
25–29	176 (17.4%)	68 (19.5%)	108 (16.3%)	41 (20.6%)	135 (16.7%)
30–34	483 (47.9%)	163 (46.8%)	320 (48.4%)	86 (43.2%)	397 (49.0%)
35–39	271 (26.9%)	87 (25.0%)	184 (27.8%)	52 (26.1 %)	219 (27.0%)
40–44	56 (5.6%)	19 (5.5%)	37 (5.6%)	12 (6.0%)	44 (5.4%)
45–49	10 (1.0%)	5 (1.4%)	5 (0.8%)	2 (1.0%)	8 (1.0%)
50 or older	2 (0.2%)	0 (0.0%)	2 (0.3%)	2 (1.0%)	0 (0.0%)
Gender (% mothers)	655 (60.9%)	196 (54.9%)	459 (64.0%)	121 (58.7%)	534 (61.5%)
Marital status					
Domestic partnership or married	1016 (96.6%)	333 (93.8%)	683 (98.0%)	191 (93.2%)	825 (97.4%)
Never married	22 (2.1%)	16 (4.5%)	6 (0.9%)	10 (4.9%)	12 (1.4%)
Separated, divorced or widowed	14 (1.3%)	6 (1.7%)	8 (1.1%)	4 (2.0%)	10 (1.2%)
Region					
North America	951 (94.8%)	337 (96.0%)	614 (94.2%)	196 (96.1%)	755 (94.5%)
Europe	17 (1.7%)	3 (0.8%)	14 (2.1%)	4 (2.0%)	13 (1.6%)
South America	12 (1.2%)	5 (1.4%)	7 (1.1%)	3 (1.5%)	9 (1.1%)
Middle East	8 (0.8%)	2 (0.6%)	6 (0.9%)	0 (0.0%)	8 (1.0%)
Asia	6 (0.6%)	1 (0.3%)	5 (0.8%)	1 (0.5%)	5 (0.6%)
Oceania	7 (0.7%)	3 (0.8%)	4 (0.6%)	0 (0.0%)	7 (0.9%)
South Africa	2 (0.2%)	0 (0.0%)	2 (0.3%)	0 (0.0%)	2 (0.3%)
Ethnicity					
White/Caucasian	796 (78.0%)	273 (78.4%)	523 (77.7%)	155 (75.6%)	641 (78.6%)
Asian	83 (8.1%)	23 (6.6%)	60 (8.9%)	19 (9.3%)	64 (7.8%)
Hispanic	71 (7.0%)	29 (8.3%)	42 (6.2%)	18 (8.8%)	53 (6.5%)
African American	18 (1.8%)	9 (2.6%)	9 (1.3%)	8 (3.9%)	10 (1.2%)
Other	53 (5.2%)	14 (4.0%)	39 (5.7%)	5 (2.4%)	48 (5.9%)
Education					
Highschool degree or less	25 (2.5%)	17 (4.8%)	8 (1.2%)	9 (5.2%)	16 (1.9%)
Some college	110 (10.9%)	50 (14.0%)	60 (9.2%)	31 (18.0%)	79 (9.4%)
College degree	487 (48.2%)	185 (51.9%)	302 (46.2%)	89 (51.7%)	398 (47.5%)
Postgraduate degree	388 (38.4%)	104 (29.1%)	284 (43.4%)	43 (25.0%)	345 (41.2%)
Household income					
<$50 000	42 (4.2%)	17 (4.9%)	25 (3.8%)	15 (7.8%)	27 (3.4%)
$50 000–$100 000	197 (19.8%)	82 (24.0%)	115 (17.6%)	55 (28.5%)	142 (17.7%)
$100 000–$150 000	237 (23.9%)	96 (28.1%)	141 (21.6%)	51 (26.4%)	186 (23.2%)
$150 000–$200 000	205 (20.6%)	67 (19.6%)	138 (21.1%)	29 (15.0%)	176 (21.9%)
>$200 000	314 (31.6%)	80 (23.4%)	234 (35.8%)	43 (22.3%)	271 (33.8%)
Objective infant sleep					
Nighttime sleep duration	9.45 (1.38)	9.61 (1.36)	9.38 (1.38)	9.53 (1.51)	9.43 (1.34)
Nighttime sleep efficiency	0.86 (0.08)	0.87 (0.08)	0.85 (0.08)	0.85 (0.10)	0.86 (0.07)
Number of nighttime awakenings	3.75 (2.22)	3.21 (2.05)	4.01 (2.25)	3.28 (2.12)	3.86 (2.23)
Parent-reported infant sleep					
Daytime sleep duration	2.90 (1.41)	2.46 (1.04)	3.12 (1.52)	2.79 (1.44)	2.93 (1.41)
Nighttime sleep duration	9.95 (1.37)	9.94 (1.43)	9.96 (1.34)	9.85 (1.48)	9.98 (1.34)
24-hour sleep duration	12.86 (1.74)	12.41 (1.57)	13.09 (1.78)	12.64 (1.61)	12.91 (1.76)
Nighttime sleep quality	5.20 (0.91)	5.21 (0.91)	5.19 (0.92)	5.21 (0.91)	5.19 (0.91)
Number of nighttime awakenings	1.31 (1.18)	1.19 (1.19)	1.37 (1.17)	1.28 (1.24)	1.32 (1.17)

Data are given as mean (*SD*) for continuous variables, and *n* (valid%) for categorical variables. Sleep durations are presented in hours.

Table 2. Infant age-by-daytime touchscreen and television exposure as determinants of objective and parent-reported sleep (N = 1074)*,†

		Age			Daytime touchscreen exposure		
		b	*SE*	*F* (*p*)	*b*	*SE*	*F* (*p*)
Objective	Nighttime sleep duration	6.37	0.57	126.98 (<0.001)	−0. 10	0.36	0.08 (0.78)
	Nighttime sleep efficiency	0.007	0.001	175.70 (<0.001)	0.00	0.00	0.02 (0.88)
	Number of nighttime awakenings	−0.28	0.02	367.69 (<0.001)	−0.01	0.009	1.72 (0.19)
Parent-report	Daytime sleep duration	−6.19	0.64	92.34 (<0.001)	−1.56	0.40	14.81 (<0.001)
	Nighttime sleep duration	6.29	0.62	101.59 (<0.001)	−1.04	0.40	6.66 (0.01)
	24-hour sleep duration	−0.81	0.81	0.99 (0.32)	−2.51	0.56	20.27 (<0.001)
	Nighttime sleep quality	0.04	0.008	30.03 (<0.001)	−0.005	0.005	1.01 (0.32)
	Number of nighttime awakenings	−0.08	0.009	66.63 (<0.001)	−0.002	0.006	0.11 (0.74)

*Models adjusted for infant sex, breastfeeding, room-sharing, daytime sleep duration (for nighttime sleep outcomes), nighttime sleep duration (for daytime sleep outcomes), parent age, education, ethnicity, and family income.
†Sleep and screen exposure durations were entered in minutes. Age was entered in months.

invited via email to participate in an online survey. Parents who had electronically consented to provide their infants' sleep data for research purposes were invited, and informed consent was obtained electronically prior to the collection of parent-reported data. Participants who completed the survey were offered a respondent reward (raffle prize for a $500 gift card). Data were collected anonymously, using participant ID codes. All procedures were approved by IntegReview institutional review board (Protocol identifier: Nanit 2017-01; integreview.com).

Initially, 1775 survey entries were documented. Responses were excluded if the responder did not identify as the infant's parent, or in cases for which infant age was >18 months. For the remaining 1543 participants, objective infant sleep data were collected using the Nanit algorithm from the consecutive 14-day period prior to survey completion (i.e. online survey completion was timed as the day after the 14th night of objective sleep data collection), all dated between mid-November and mid-December 2019. To be included, a minimum of three codable nights were required, in which infants slept in their cot or crib, and activated their monitor. In total, objective sleep data were obtained for 1074 infants who comprised the final sample, with 13 786 assessed nights (mean number of nights per participant = 12.8). For analysis purposes, average sleep metrics were computed across the assessment period for each infant.

Measures

Objective sleep data.
Objective sleep data were collected using Nanit camera monitors in the infant's naturalistic setting. These small monitor devices are mounted above the infant's crib, continuously recording motion at a pre-defined nighttime period, allowing assessment of nighttime—but not daytime—sleep. As real-world consumers of these devices were recruited, no additional instructions were given to participating parents. A computer-vision algorithm was employed to automatically analyze sleep–wake patterns, based on videosomnography methodology. Similar to actigraphy, the algorithmic approach detects motion and stillness patterns over a specific epoch into metrics of wakefulness and sleep (Supplementary Figure S1). Whereas actigraphy records the movement of the ankle or wrist, auto-videosomnography system records movement of the entire body. This system allows for collecting "big"-real-world data in a noninvasive way, without the extensive costs of manual coding. Derived metrics have been previously validated against polysomnography as well as actigraphy, in seven healthy infants aged 0–24 months whose sleep was evaluated overnight in an accredited pediatric sleep laboratory. Auto-videosomnography showed adequate sensitivity (75.2% for PSG and 73.3% for actigraphy) and excellent specificity (89.1% for PSG and 87.9% for actigraphy) in appraising infant sleep [35]. The following sleep metrics were used for the purpose of the present study: (1) "Nighttime sleep duration," indicated by the total minutes scored as sleep during the sleep period; (2) "Nighttime sleep efficiency," scored as the percentage of the sleep period spent asleep (i.e. minutes scored as sleep divided by the nocturnal sleep period in minutes, from bedtime to the time the infant was taken out of the cot * 100); and (3) "Number of nighttime awakenings," characterized as awakenings lasting a minimum of 3 minutes within the nocturnal sleep period.

Brief Infant Sleep Questionnaire (BISQ).
The BISQ is a well-validated sleep questionnaire aimed at assessing parent-reported infant sleep patterns [36]. Parents completed this questionnaire as part of the online survey. The derived measures used in this study were: (1) "Daytime sleep duration" (i.e. naps; in hours and minutes); (2) "Nighttime sleep duration" (in hours and minutes); (3) "24-hour sleep duration" (in hours and minutes); (4) "Sleep quality," as indicated by an item asking parents to rate how well their child usually sleeps at night, scored on a 6-point Likert-scale from 1 (*very poorly*) to 6 (*very well*); and (5) "Number of nighttime awakenings."

Touchscreen and television exposure.
Questions regarding screen exposure were based on previous investigations of screen media use in young children [37, 38]. As part of the online survey, parents reported average exposure durations for both touchscreen devices (smartphones, tablets, laptops, and handheld game players) and TV. Minutes of exposure were reported for each of the following four times of the day: (1) morning (*from the time the child awakens until lunch time*); (2) afternoon (*between lunch and an hour before bed*); (3) during the hour

Daytime TV exposure			Age × daytime touchscreen exposure			Age × daytime TV exposure		
b	*SE*	*F* (*p*)	*b*	*SE*	*F* (*p*)	*b*	*SE*	*F* (*p*)
−0.18	0.08	4.92 (0.03)	−0.18	0.06	7.55 (0.006)	0.00	0.00	0.32 (0.57)
0.00	0.00	1.62 (0.20)	0.00	0.00	5.95 (0.01)	0.00	0.00	0.07 (0.79)
−0.001	0.002	0.09 (0.76)	0.004	0.002	6.21 (0.01)	0.00	0.00	0.36 (0.55)
−0.27	0.09	9.02 (0.003)	0.21	0.07	8.35 (0.004)	0.06	0.02	11.60 (0.001)
−0.10	0.09	1.41 (0.24)	−0.09	0.07	1.61 (0.21)	−0.002	0.02	0.02 (0.90)
−0.35	0.12	8.02 (0.005)	0.14	0.10	2.16 (0.14)	0.06	0.03	5.43 (0.02)
−0.001	0.001	0.54 (0.46)	−0.002	0.001	4.01 (0.04)	0.00	0.00	2.30 (0.13)
0.00	0.001	0.001 (0.98)	0.003	0.001	9.87 (0.002)	0.00	0.00	0.21 (0.65)

before bed; and (4) during the night. Parents selected the average durations from 15-minute response categories for morning and afternoon time periods (e.g. 0, 1–15 minutes). For the hour before bed and during the night, parents selected average durations from 10-minute response categories (e.g. 0, 1–10, 11–20, up to 51–60 minutes). Numeric values were assigned to categories (e.g. 0, 5.5, 15.5, up to 55.5) to construct an approximately continuous measure of screen exposure for each time of day [37], both for TV and touchscreen minutes of exposure (for descriptive statistics of screen exposure by time of day, see Supplementary Table S1). Morning and afternoon exposure times were summed to form combined daytime screen durations, and evening and nighttime exposure times were summed to form evening–nighttime exposure durations.

Analysis plan

Data analyses were performed using SPSS version 25.0 (IBM Corporation, United States). Outliers were identified using the interquartile range rule [39], and winsorized by replacing the outlying score with the closest value not identified as an outlier [40]. For objective sleep efficiency and nighttime awakenings, 10 (0.9%) and 3 (0.3%) outliers (respectively) were identified and winsorized. For parent-reported daytime, nighttime and 24-hour sleep duration and nighttime awakenings, 22 (1.4%), 8 (0.5%), 11 (0.7%), and 3 (0.2%) outliers (respectively) were identified and winsorized.

Within the final sample, data were missing for several parent-report items (0%–8% for demographic variables, 7.3% for parent-reported sleep variables, and 23.4% for screen exposure variables). Using the MCAR test, it was confirmed that data were missing completely at random (χ^2 (32) = 29.28, n.s.). Thus, missing data were replaced using the expectation-maximization method, allowing for data analysis of the entire sample [41]. As a sensitivity analysis, analyses were repeated with only participants who had complete data available.

Demographic characteristics were compared between infants with screen exposure durations above and below the mean using t-tests and Chi-square testing. To examine the moderating role of age on the relationship between screen exposure and sleep, univariate general linear models were employed. For each sleep metric, a separate model was built, including main effects of age, touchscreen exposure, TV exposure interaction terms

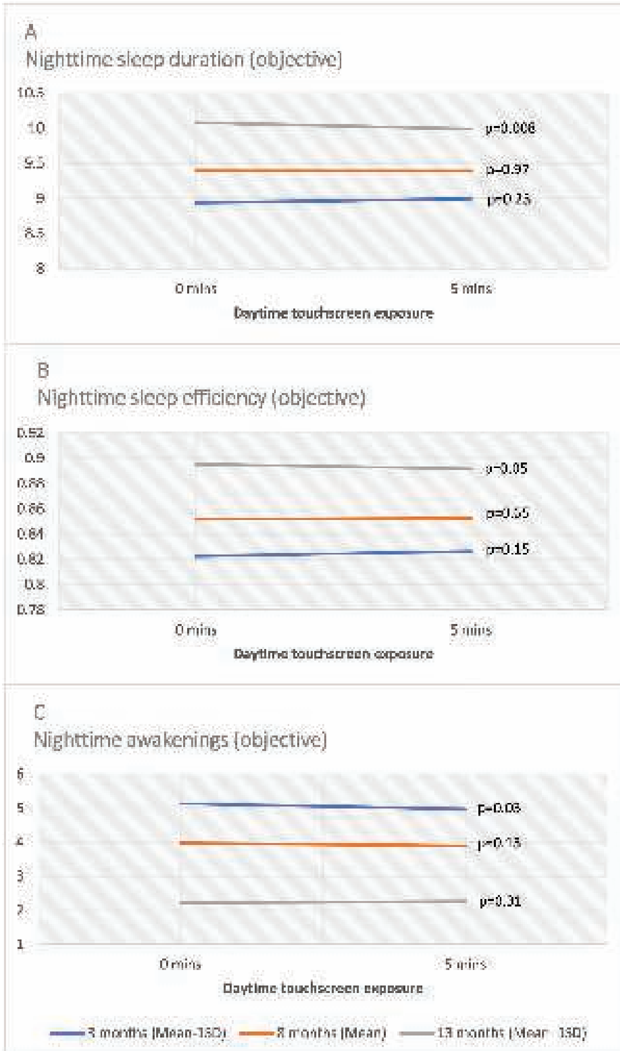

Figure 1. Objective nighttime sleep duration (A), efficiency (B), and awakenings (C) as a function of daytime touchscreen exposure by infant age.

between age and exposure to each screen type. Predictor variables were centered at the mean to facilitate the interpretation of model coefficients. Based on previous research [20, 22, 26],

Table 3. Infant age by evening–nighttime touchscreen and television exposure as determinants of objective and parent-reported sleep (N=1074)*,†

		Age			Evening–nighttime touchscreen exposure		
		b	*SE*	*F* (*p*)	*b*	*SE*	*F* (*p*)
Objective	Nighttime sleep duration	6.04	0.56	116.57 (<0.001)	2.09	1.51	1.91 (0.17)
	Nighttime sleep efficiency	0.007	0.001	169.92 (<0.001)	0.003	0.001	5.46 (0.02)
	Number of nighttime awakenings	−0.28	0.02	370.07 (<0.001)	−0.05	0.04	1.29 (0.26)
Parent-report	Daytime sleep duration	−6.47	0.64	103.45 (<0.001)	5.04	1.70	8.76 (0.003)
	Nighttime sleep duration	5.98	0.62	93.92 (<0.001)	−4.28	1.66	6.58 (0.01)
	24-hour sleep duration	−1.49	0.81	3.40 (0.07)	0.40	2.35	0.03 (0.87)
	Nighttime sleep quality	0.04	0.007	24.69 (<0.001)	−0.01	0.02	0.36 (0.55)
	Number of nighttime awakenings	−0.07	0.009	63.37 (<0.001)	0.04	0.03	2.26 (0.13)

*Models adjusted for infant sex, breastfeeding, room-sharing, daytime sleep duration (for nighttime sleep outcomes), nighttime sleep duration (for daytime sleep outcomes), parent age, education, ethnicity, and family income.
†Sleep and screen exposure durations were entered in minutes. Age was entered in months.

we controlled for potential covariates by adjusting each model for infant sex, breastfeeding (yes/no), room-sharing (yes/no), parent age, education, ethnicity, and family income. We additionally adjusted for daytime sleep duration in models predicting nighttime sleep, and for nighttime sleep duration for models predicting daytime sleep. To address multicollinearity, we calculated the variance inflation factor (VIF) for each predictor variable. VIF values were all found below the conservative 2.5 threshold (range: 1.02–1.75), indicating lack of substantive multicollinearity [42]. Significant interaction terms were probed and plotted using simple slope analyses at 1 *SD* below and above the mean, utilizing Hayes' PROCESS modeling [43].

Results

Comparisons between infants with high and low screen exposure duration revealed that infants with low daytime screen exposure were more likely to be younger ($t(1072) = 8.87$, $p < 0.001$), share a room with their parents ($\chi^2 = 6.10$, $p = 0.01$), be breastfed ($\chi^2 = 37.07$, $p < 0.001$) and have parents with higher education levels ($\chi^2 = 32.60$, $p = 0.002$). Similarly, infants with low evening–nighttime screen exposure were more likely to be younger ($t(1072) = 5.68$, $p < 0.001$), breastfed ($\chi^2 = 24.77$, $p < 0.001$) and have more educated parents ($\chi^2 = 40.45$, $p < 0.001$) compared to infants with high evening–nighttime screen exposure durations. Evening–nighttime screen exposure was additionally associated with ethnicity ($\chi^2 = 15.14$, $p = 0.004$). Post hoc residual analysis [44] showed that African American infants were more likely to be exposed to screens for longer evening–nighttime durations ($\chi^2 = 7.36$, $p = 0.007$), whereas infants whose ethnicity was defined as "other" were more likely to have shorter evening–nighttime screen exposure ($\chi^2 = 4.34$, $p = 0.04$).

Does age moderate the relationship between objective sleep and screen exposure?

As expected, significant age-by-daytime touchscreen exposure interaction effects were found across all objective sleep measures (Table 2). Simple slopes analyses revealed an interesting pattern of results. For objective nighttime sleep duration, increased daytime touchscreen exposure was significantly associated with sleep duration for older ($b = -0.02$, $SE = 0.006$, $p = 0.008$; see Figure 1A), but not younger infants. On average, for every 1 min of daytime touchscreen time gained, 1 min of nighttime sleep was lost for 13-month old infants. Similarly, daytime touchscreen exposure was associated with decreased sleep efficiency in older, but not younger, infants ($b = -0.0007$, $SE = 0.0004$, $p = 0.05$).

For objectively measured nighttime awakenings, post hoc analyses yielded significant effects for younger, but not older infants. Specifically, more daytime touchscreen exposure was associated with fewer awakenings ($b = -0.03$, $SE = 0.01$, $p = 0.03$; see Figure 1C) in children aged 3 months (~1 *SD* below the mean).

In contrast to daytime touchscreen exposure, interactions between daytime TV exposure and age were nonsignificant for all objective sleep metrics (Table 2). Furthermore, as seen in Table 3, evening–nighttime touchscreen and television screen exposure did not significantly interact with age to predict objectively measured sleep.

Does age moderate the relationship between parent-reported sleep and screen exposure?

Significant interaction effects were found between daytime touchscreen exposure and age for parent-reported daytime sleep duration, and nighttime sleep quality and awakenings (Table 2). Simple slopes analyses showed that daytime sleep duration was negatively associated with daytime touchscreen exposure for younger ($b = -2.62$, $SE = 0.62$, $p < 0.001$; see Figure 2A), but not older infants. For 3-month-old infants, 5 minutes of daytime touchscreen exposure was associated with an average decrease of 13 minutes in daytime sleep.

Post hoc testing yielded a negative association between daytime touchscreen exposure and sleep quality for older ($b = -0.01$, $SE = 0.005$, $p = 0.004$), but not younger infants (Figure 2B). Daytime touchscreen exposure was also associated with more nighttime awakenings for older infants ($b = 0.02$, $SE = 0.006$, $p = 0.01$), whereas for younger infants it was associated with fewer nighttime awakenings ($b = -0.02$, $SE = 0.009$, $p = 0.05$; Figure 2C).

Of all sleep measures, daytime exposure to TV interacted with age to predict parent-reported daytime and 24-hour sleep

Evening–nighttime TV exposure			Age × evening–nighttime touchscreen exposure			Age × evening–nighttime TV exposure		
b	*SE*	*F* (*p*)	*b*	*SE*	*F* (*p*)	*b*	*SE*	*F* (*p*)
−0.90	0.38	5.43 (0.02)	−0.3	0.24	1.19 (0.28)	0.06	0.06	0.82 (0.37)
−0.001	0.00	14.42 (<0.001)	0.00	0.00	3.24 (0.07)	0.00	0.00	0.33 (0.57)
0.007	0.01	0.56 (0.46)	0.01	0.007	2.05 (0.15)	0.001	0.002	0.19 (0.67)
0.15	0.44	0.12 (0. 73)	−0.72	0.30	5.85 (0.02)	−0.08	0.08	1.12 (0.29)
−0.59	0.42	1.96 (0.16)	0.43	0.29	2.18 (0.14)	0.07	0.07	0.95 (0.33)
−0.32	0.60	0.29 (0.57)	−0.24	0.41	0.33 (0.57)	−0.01	0.10	0.01 (0.91)
−0.006	0.005	1.38 (0.24)	−0.003	0.004	0.72 (0.40)	0.001	0.001	0.84 (0.36)
0.004	0.006	0.48 (0.49)	0.002	0.004	0.26 (0.61)	−0.001	0.001	0.47 (0.49)

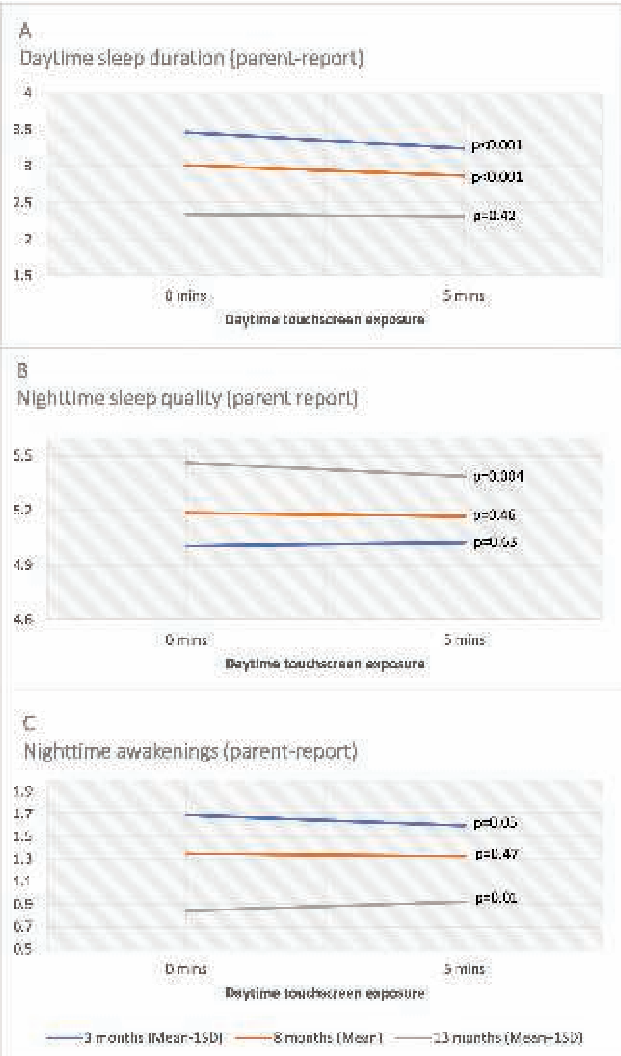

Figure 2. Parent-reported sleep duration (A), quality (B), and awakenings (C) as a function of daytime touchscreen exposure by infant age.

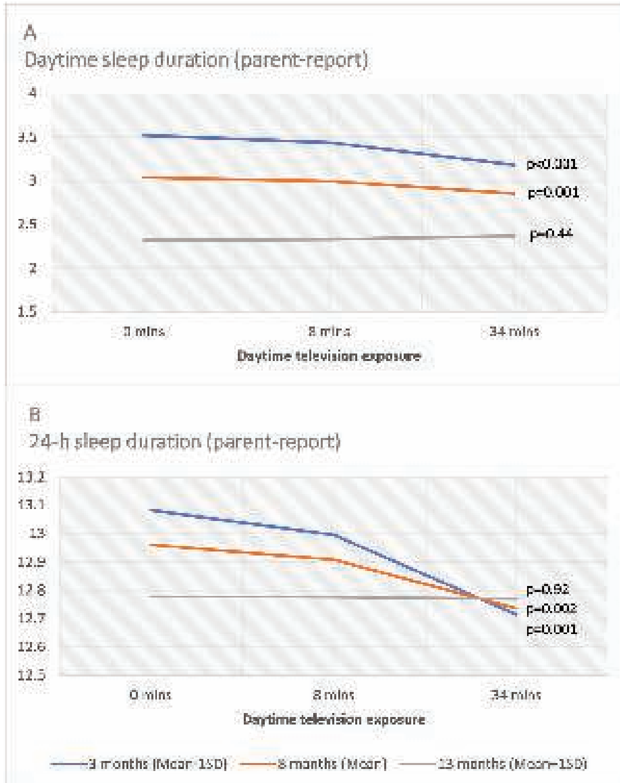

Figure 3. Parent-reported daytime sleep duration (A) and 24-hour sleep duration (B) as a function of daytime television exposure by infant age.

duration. Post-hoc testing revealed that daytime TV exposure was negatively linked to daytime sleep duration (b = −0.60, SE = 0.14, p < 0.001; see Figure 3A) and 24-hour sleep duration (b = −0.65, SE = 0.19, p = 0.001; see Figure 3B), for younger but not older infants. For 3-month-old infants, 34 minutes of exposure to TV during the daytime (~1 *SD* above the mean) were associated with a 20-minute decrease in daytime sleep duration, and a 22-minute decrease in 24-hour sleep duration.

As for evening–nighttime exposure to screens, a significant interaction effect with age was found for parent-reported daytime sleep (Table 3). Post hoc analysis showed that increased evening–nighttime touchscreen exposure was associated with increased daytime sleep duration in younger, but not older infants (b = 7.51, SE = 2.72, p = 0.03). Interaction terms between age and evening–nighttime exposure to touchscreens and television were nonsignificant for all other subjective sleep measures.

Sensitivity analyses revealed similar patterns of moderation effects when participants with any missing data were excluded (Supplementary Tables S2 and S3). As with the imputed sample, significant age-by-screen exposure interaction effects were found mostly for touchscreen and daytime screen exposure.

Correlations between sleep and screen exposure measures

Pearson correlations between sleep measures, and daytime and evening–nighttime touchscreen and TV exposure durations can be found in Supplementary Table S4. All objective sleep metrics were significantly associated with their corresponding parent-reported measures (e.g. for objective and parent-reported nighttime sleep duration $r = .55$, $p < 0.001$). Touchscreen and TV exposure durations were significantly correlated both in the daytime and evening–nighttime. Associations between touchscreen exposure and sleep were more common than associations between TV exposure and sleep. Additionally, sleep was more robustly associated with daytime, compared to evening–nighttime, screen exposure durations.

Discussion

The effects of screens on sleep have been a focus of public health concern for decades. Whilst the sleep-media link has been extensively investigated in young people [10, 11], this study is the first to assess it across the very beginning of life, examining the moderating role of infant age for both TV's and touchscreens' relationship with sleep. Furthermore, to the best of our knowledge, the present study is not only the first to assess these links using objective sleep measurement, it is also the largest reported sample to date that has utilized objective measures of infant sleep. Real-life data from 1074 infants were examined, with nearly 14 000 assessment nights. In comparison, the largest actigraphy studies thus far have reported sample sizes of 150–600 infants [45, 46], and the largest videosomnography studies have examined approximately 80 infants [47, 48].

As expected, age significantly moderated the relationship between touchscreen exposure and objectively measured nighttime sleep duration, efficiency, and awakenings, as well as parent-reported daytime sleep and nighttime sleep quality and awakenings. These moderation effects revealed distinct age-related pathways. Whereas for older infants, associations were in the expected directions (i.e. exposure to touchscreens was negatively associated with sleep duration and quality), the opposite directions were found for younger infants' nighttime sleep. Namely, increased screen exposure was linked with decreased objective and parent-reported nighttime awakenings. These surprising results may be understood in light of the significant decrease in daytime sleep with greater screen exposure in young infants. Specifically, 5 minutes of daytime touchscreen exposure was associated with a 13-minute decrease in daytime sleep duration in 3-month-old infants. Since sleep in the early months of life tends to be fragmented into multiple episodes that are distributed throughout the day and night, it is crucial to consider sleep–wake patterns of these infants in the context of 24-hour periods. This notion is further highlighted by the predominance of effects found for daytime rather than evening–nighttime screen exposure. The displacement of daytime sleep may lead to greater accumulation of sleep homeostatic pressure, which in turn facilitates longer, more consolidated nighttime sleep [29]. This daytime-nighttime sleep "trade-off" has been previously documented in young children [49], with demonstrated associations between longer naps and shorter nighttime sleep. Moreover, evidence-based interventions for sleep problems, such as bedtime fading [50, 51] and sleep restriction therapy [52], are based on the physiologic theory linking higher homeostatic "sleep pressure" with improved sleep quality.

A close examination of our results reveals some discrepancies between findings yielded from objective compared to subjective sleep measures. Whereas a significant age-by-touchscreen interaction effect was found when nighttime sleep duration was measured objectively, this was not the case for parent-reported nighttime sleep duration. For the latter outcome, increased touchscreen exposure was associated with shorter sleep duration, regardless of infant age. Negative associations between screen exposure and sleep duration were found for parent-reported daytime and 24-h sleep durations as well, replicating findings from previous investigations [10, 53]. This is to be expected since all previous studies on the relationship between screen and sleep durations in infants relied solely on parent-reports [54]. However, measuring sleep from the point-of-view of parents alone may have its limitations. Parents might not be aware of the precise duration of time spent asleep or of all nighttime awakenings [31, 32]. Parent-reports may thus reflect an overestimation of sleep duration and quality [55, 56]. On the other hand, parents are able to communicate information that is less likely to be detected by objective measurement of sleep, such as the extent to which infants are reliant on their parents to fall asleep [57]. For instance, when assessed subjectively, older infants' number of awakenings in this study increased with more screen exposure but remained stable when assessed objectively. This finding may imply that those older infants who are more exposed to screens are also more inclined to signal to their parents upon awakening, perhaps indicating a higher dependency on external stimulation and regulation. While the present study does not allow for confirmation of these postulations, it highlights the importance of assessing sleep both objectively and from the parents' point of view, in the effort to achieve a broad understanding of sleep–wake states and behaviors.

This study additionally found that compared to TV exposure, touchscreen exposure was more robustly associated with sleep, as indicated by the higher number of relationships between these measures. Moreover, whereas age moderated daytime touchscreen exposure's link with all but two sleep metrics, for TV exposure, age was only found to moderate the link with daytime and 24-hour sleep duration. This suggests that age plays a more substantial role when it comes to touchscreen compared to TV exposure. These findings are in line with previous studies demonstrating the greater impact of portable compared to non-portable devices on children's sleep, particularly for younger children [13, 20, 22]. Given their smaller size, touchscreen devices are usually positioned closer to the face compared to non-portable screens. Considering that the intensity of light emitted from the screen increases with physical proximity, and the decrease in sensitivity to light with age [27, 58, 59], it seems that young infants may be vulnerable to the effects of these devices on sleep–wake rhythms. Their high accessibility may make touchscreens even more likely to affect young infants' sleep, with increasing rates of parents making use of these devices for soothing and regulation purposes [60].

Despite the strengths of this study, including the large sample size and objective real-world measurement of infant sleep, several limitations should be borne in mind. First, the cross-sectional nature of the study limits conclusions regarding cause-effect relationships. Although research has mostly focused on the possible effects of screen exposure on sleep, the alternative directionality should be considered as well. Parents may employ screens to cope with sleep-related problems, and it may also be that infants with shorter sleep durations (whether due to their natural sleep need, or due to sleep problems) simply have more time available in wakefulness, during which they consume screen media [53]. The relation between sleep and screen exposure may also be moderated by additional factors, including parent-infant bedtime interactions and routines, socio-economic, and cultural factors. Future investigations may wish to examine the role of these potential moderators, and apply longitudinal designs (to test temporal relationships) or experimental designs (to test for acute sensitivity effects from daytime technology use on naps) to evaluate the causal pathways between screen exposure and sleep across the beginning of life.

Second, the relatively homogeneous sample, representative mostly of middle-upper socio-economic status in North America, limits the generalizability of our findings. In addition, several differences in demographic characteristics were apparent between infants with high and low screen exposure durations. Lower screen exposure was associated with younger age, breastfeeding, room-sharing, higher parental education, and ethnicity characterized as "other," whereas African American ethnicity was associated with higher screen exposure. These findings are in line with previous investigations demonstrating links between media use and socio-cultural factors in children [61]. While these demographic variables were controlled for in analyses, statistical control may not fully un-confound their effects on infant sleep [62].

Furthermore, although nighttime sleep was assessed both objectively and using parent-reports, daytime sleep and screen exposure durations were exclusively reported by parents (as auto-videosomnography was pre-defined by users to record solely nighttime sleep), and are thus subjected to social desirability bias and imprecision. Parents may be inclined to under-report screen exposure durations, given their familiarity with health recommendations discouraging exposure to media screens in the first 2 years of life [24]. Finally, data were not collected regarding the content of media consumed. Previous studies suggest that exposure to age-inappropriate content may be particularly detrimental for child sleep [63]. Future investigations should thus attempt to evaluate the links between sleep and the specific media content to which infants are exposed.

Notwithstanding these limitations, the present study provides evidence for the association between screen exposure and sleep, particularly for touchscreen devices and for younger infants. It additionally reveals a daytime-nighttime sleep "trade-off" for young infants, in which touchscreen exposure is associated with decreased daytime sleep duration, but also with more consolidated nighttime sleep. Although most of the research in this field, and consequent healthcare recommendations, have focused on technology's associations with sleep duration, the quality and consolidation of sleep may be equally essential for infant development and wellbeing [64–66]. Thus, while the ever-rising ubiquity of electronic devices in young children's lives requires caution and in some cases intervention, it is also important to consider the possible benefits of these devices, in order to profoundly understand the intricate relationship between screen exposure and sleep.

Supplementary material

Supplementary material is available at *SLEEP* online.

Acknowledgments

The authors wish to thank the participating families for their contribution to the study.

Funding

This study was supported by Nanit.

Conflict of interest statement. M.K. and N.B. have served as consultants for Nanit. A.G. was an employee of Nanit at the time of study implementation. M.G. has served a Pro-Bono consultant for Nanit.

References

1. Luke C. *Constructing the Child Viewer: A History of the American Discourse on Television and Children, 1950–1980*. New York, NY: Greenwood Publishing Group; 1990.
2. Endsley RC, *et al*. Children's reactions to TV violence: a review of research. *Young Child*. 1970;**26**(1):4–11.
3. Owens J, *et al*. Television-viewing habits and sleep disturbance in school children. *Pediatrics*. 1999;**104**(3):e27. doi:10.1542/peds.104.3.e27.
4. Heald GR. Television viewing guides and parental recommendations. *JQ*. 1980;**57**(1):141–144.
5. Kunkel D. Crafting media policy: the genesis and implications of the Children's Television Act of 1990. *Am Behav Sci*. 1991;**35**(2):181–202. doi:10.1177/0002764291035002008.
6. American Academy of Pediatrics. Children, adolescents, and television. *Pediatrics*. 2001;**107**(2):423. doi:10.1542/peds.107.2.423.
7. Bickerstaff S. Shackles on the giant: how the federal government created microsoft, personal computers, and the internet. *Tex Law Rev*. 1999;**78**:1.
8. Jordan R, *et al*. Wireless communications and networking: an overview. *IEEE Antennas Propag Mag*. 2002;**44**(1):185–193.
9. Isaacson W. *Steve Jobs: The Exclusive Biography*. London, UK: Little Brown Book Group; 2011.
10. Cain N, *et al*. Electronic media use and sleep in school-aged children and adolescents: a review. *Sleep Med*. 2010;**11**(8):735–742.
11. Hale L, *et al*. Screen time and sleep among school-aged children and adolescents: a systematic literature review. *Sleep Med Rev*. 2015;**21**:50–58.

12. Van den Bulck J. The effects of media on sleep. *Adolesc Med State Art Rev.* 2010;**21**(3):418–429, vii.
13. Bartel KA, *et al*. Protective and risk factors for adolescent sleep: a meta-analytic review. *Sleep Med Rev.* 2015;**21**:72–85.
14. Bartel K, *et al*. New directions in the link between technology use and sleep in young people. In: *Sleep Disorders in Children*. Springer; 2017:69–80. doi:10.1007/978-3-319-28640-2_4.
15. King DL, *et al*. The impact of prolonged violent video-gaming on adolescent sleep: an experimental study. *J Sleep Res.* 2013;**22**(2):137–143.
16. Higuchi S, *et al*. Effects of playing a computer game using a bright display on presleep physiological variables, sleep latency, slow wave sleep and REM sleep. *J Sleep Res.* 2005;**14**(3):267–273.
17. Weaver E, *et al*. The effect of presleep video-game playing on adolescent sleep. *J Clin Sleep Med*. 2010;**6**(2):184–189.
18. van der Lely S, *et al*. Blue blocker glasses as a countermeasure for alerting effects of evening light-emitting diode screen exposure in male teenagers. *J Adolesc Health.* 2015;**56**(1):113–119.
19. Heath M, *et al*. Does one hour of bright or short-wavelength filtered tablet screenlight have a meaningful effect on adolescents' pre-bedtime alertness, sleep, and daytime functioning? *Chronobiol Int*. 2014;**31**(4):496–505.
20. Cheung CH, *et al*. Daily touchscreen use in infants and toddlers is associated with reduced sleep and delayed sleep onset. *Sci Rep*. 2017;**7**:46104. doi:10.1038/srep46104.
21. Chindamo S, *et al*. Sleep and new media usage in toddlers. *Eur J Pediatr.* 2019;**178**(4):483–490.
22. Twenge JM, *et al*. Associations between screen time and sleep duration are primarily driven by portable electronic devices: evidence from a population-based study of U.S. children ages 0-17. *Sleep Med*. 2019;**56**: 211–218.
23. Poitras VJ, *et al*. Systematic review of the relationships between sedentary behaviour and health indicators in the early years (0-4 years). *BMC Public Health.* 2017;**17**(suppl 5):868.
24. World Health Organization. *Guidelines on Physical Activity, Sedentary Behaviour and Sleep for Children Under 5 Years of Age*. Geneva, Switzerland: World Health Organization; 2019.
25. American Academy of Pediatrics. Media and young minds. *Pediatrics*. 2016;**138**(5):e20162591. doi:10.1542/peds.2016-2591.
26. Przybylski AK. Digital screen time and pediatric sleep: evidence from a preregistered cohort study. *J Pediatr.* 2019;**205**:218–223.e1.
27. Higuchi S, *et al*. Influence of light at night on melatonin suppression in children. *J Clin Endocrinol Metab.* 2014;**99**(9):3298–3303.
28. Ivarsson M, *et al*. The effect of violent and nonviolent video games on heart rate variability, sleep, and emotions in adolescents with different violent gaming habits. *Psychosom Med*. 2013;**75**(4):390–396.
29. Jenni OG, *et al*. Understanding sleep-wake behavior and sleep disorders in children: the value of a model. *Curr Opin Psychiatry.* 2006;**19**(3):282–287.
30. Henderson JM, *et al*. The consolidation of infants' nocturnal sleep across the first year of life. *Sleep Med Rev.* 2011;**15**(4):211–220.
31. Sadeh A. The role and validity of actigraphy in sleep medicine: an update. *Sleep Med Rev*. 2011;**15**(4):259–267. doi:10.1016/j.smrv.2010.10.001.
32. Meltzer LJ, *et al*. Use of actigraphy for assessment in pediatric sleep research. *Sleep Med Rev.* 2012;**16**(5):463–475.
33. Schwichtenberg AJ, *et al*. Pediatric videosomnography: can signal/video processing distinguish sleep and wake states? *Front Pediatr.* 2018;**6**:158.
34. Kuula L, *et al*. Using big data to explore worldwide trends in objective sleep in the transition to adulthood. *Sleep Med.* 2019;**62**:69–76.
35. Barnett N, *et al*. Computer vision algorithms outperform actigraphy (Conference abstract). *ERJ Open Research*. 2019;**5**:134. doi:10.1183/23120541.sleepandbreathing-2019.P134.
36. Sadeh A. A brief screening questionnaire for infant sleep problems: validation and findings for an Internet sample. *Pediatrics*. 2004;**113**(6):1795-1795. doi:10.1542/peds.113.6.e570.
37. Cespedes EM, *et al*. Television viewing, bedroom television, and sleep duration from infancy to mid-childhood. *Pediatrics*. 2014;**133**(5):e1163–e1171.
38. Nathanson AI, *et al*. The relation between use of mobile electronic devices and bedtime resistance, sleep duration, and daytime sleepiness among Preschoolers. *Behav Sleep Med*. 2018;**16**(2):202–219.
39. Hoaglin DC, *et al*. Fine-tuning some resistant rules for outlier labeling. *J Am Stat Assoc*. 1987;**82**(400):1147–1149. doi:10.1080/01621459.1987.10478551.
40. Rivest L-P. Statistical properties of Winsorized means for skewed distributions. *Biometrika*. 1994;**81**(2):373–383. doi:10.1093/biomet/81.2.373.
41. Pigott TD. A review of methods for missing data. *Educ Res Eval*. 2001;**7**(4):353–383. doi:10.1076/edre.7.4.353.8937.
42. Keith TZ. *Multiple Regression and Beyond: An Introduction to Multiple Regression and Structural Equation Modeling*. New York, NY: Routledge; 2014.
43. Hayes AF. *Introduction to Mediation, Moderation, and Conditional Process Analysis: A Regression-Based Approach*. New York, NY: Guilford Publications; 2017.
44. Beasley TM, *et al*. Multiple regression approach to analyzing contingency tables: post hoc and planned comparison procedures. *J Exp Educ*. 1995;**64**(1):79–93. doi:10.1080/00220973.1995.9943797.
45. Teti DM, *et al*. Sleep arrangements, parent-infant sleep during the first year, and family functioning. *Dev Psychol.* 2016;**52**(8):1169–1181.
46. Del-Ponte B, *et al*. Validity of the Brief Infant Sleep Questionnaire (BISQ) in Brazilian children. *Sleep Med.* 2020;**69**:65–70.
47. Goodlin-Jones BL, *et al*. Night waking, sleep-wake organization, and self-soothing in the first year of life. *J Dev Behav Pediatr.* 2001;**22**(4):226–233.
48. Henderson JM, *et al*. Sleeping through the night: the consolidation of self-regulated sleep across the first year of life. *Pediatrics*. 2010;**126**(5):e1081–e1087.
49. Nakagawa M, *et al*. Daytime nap controls toddlers' nighttime sleep. *Sci Rep*. 2016;**6**:27246.
50. Gradisar M, *et al*. Behavioral interventions for infant sleep problems: a randomized controlled trial. *Pediatrics*. 2016;**137**(6):e20151486. doi:10.1542/peds.2015-1486.

51. Mindell JA, *et al*. Behavioral treatment of bedtime problems and night wakings in infants and young children. *Sleep*. 2006;**29**(10):1263–1276.
52. Spielman AJ, *et al*. Treatment of chronic insomnia by restriction of time in bed. *Sleep*. 1987;**10**(1):45–56.
53. LeBourgeois MK, *et al*. Digital media and sleep in childhood and adolescence. *Pediatrics*. 2017;**140**(suppl 2):S92–S96.
54. Moorman JD, *et al*. The implications of screen media use for the sleep behavior of children ages 0–5: a systematic review of the literature. *Curr Sleep Med Rep*. 2019;**5**(3):164–172. doi:10.1007/s4067.
55. Iwasaki M, *et al*. Utility of subjective sleep assessment tools for healthy preschool children: a comparative study between sleep logs, questionnaires, and actigraphy. *J Epidemiol*. 2010;**20**(2):1002030129-1002030129. doi:10.2188/jea.JE20090054.
56. Dayyat EA, *et al*. Sleep estimates in children: parental versus actigraphic assessments. *Nat Sci Sleep*. 2011;**3**:115–123.
57. Sadeh A. Commentary: comparing actigraphy and parental report as measures of children's sleep. *J Pediatr Psychol*. 2008;**33**(4):406–407.
58. Higuchi S, *et al*. Effects of VDT tasks with a bright display at night on melatonin, core temperature, heart rate, and sleepiness. *J Appl Physiol (1985)*. 2003;**94**(5):1773–1776.
59. Akacem LD, *et al*. Sensitivity of the circadian system to evening bright light in preschool-age children. *Physiol Rep*. 2018;**6**(5):e13617. doi:10.14814/phy2.13617.
60. Levine LE, *et al*. Mobile media use by infants and toddlers. *Comput Human Behav*. 2019;**94**:92–99. doi:10.1016/j.chb.2018.12.045.
61. Duch H, *et al*. Screen time use in children under 3 years old: a systematic review of correlates. *Int J Behav Nutr Phys Act*. 2013;**10**:102.
62. Tu YK, *et al*. Simpson's paradox, lord's paradox, and suppression effects are the same phenomenon–the reversal paradox. *Emerg Themes Epidemiol*. 2008;**5**:2.
63. Garrison MM, *et al*. Media use and child sleep: the impact of content, timing, and environment. *Pediatrics*. 2011;**128**(1):29–35.
64. Dewald JF, *et al*. The influence of sleep quality, sleep duration and sleepiness on school performance in children and adolescents: a meta-analytic review. *Sleep Med Rev*. 2010;**14**(3):179–189.
65. Scher A. Infant sleep at 10 months of age as a window to cognitive development. *Early Hum Dev*. 2005;**81**(3):289–292.
66. Lemola S, *et al*. Sleep quantity, quality and optimism in children. *J Sleep Res*. 2011;**20**(1 Pt 1):12–20.