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Original Article

Screen exposure exacerbates ADHD symptoms indirectly through increased sleep disturbance

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A B S T R A C T

Objectives: The aim of this study was twofold. First, to confirm the deleterious aspect of evening screen exposure in school-aged children, in particular the effect of screens in the bedroom. Second, to explore the three-way association between degree of screen exposure, sleep disturbance, and ADHD symptoms. Solid evidence exists on the link between sleep disturbance and ADHD symptoms, and screen exposure and sleep disturbance. However, no studies have formally assessed the impact of screen exposure on ADHD symptoms in children, as a function of sleep disturbance.
Methods: Parents of 374 French children (201 girls, 173 boys, mean age of 10.8 ± 2.8 years old) completed the Sleep Disturbance Scale for Children (SDSC), the Attention-Deficit/Hyperactivity Disorder (ADHD) Rating Scale, and a questionnaire about their children's screen habits (total hours in the morning, afternoon, and evening per day). Correlational analyses between evening screen exposure, sleep quality and behavioral problems were conducted. Then, formal mediation analyses were run in order to quantify the relationship between variables.
Results: School-aged children with screens in their bedrooms demonstrated more sleep and behavioral problems. Evening TV exposure was associated with higher SDSC and ADHD scores. Furthermore, the Structural Equation Modelling approach confirmed that evening screen exposure is directly associated with more disrupted sleep, which in turn is directly associated with behavioral problems.
Conclusions: These findings encourage families to avoid putting screens in their children's bedrooms, and limit evening screen exposure. They furthermore demonstrate the importance of taking into account screen exposure time (morning, afternoon, evening) and location (bedroom or elsewhere) in future studies.

1. Introduction

Over the past 30 years, children are increasingly spending more and more time in front of digital screens (television, computer, and mobile devices) [1]. For example in France, on average there are 5.5 screens per household, with at least one television in 94% of households [2]. According to the World Health Organisation (WHO), nearly 70% of French teenagers watch television for more than two hours a day. Moreover, the increasing number of screens placed directly in children's bedrooms is impressive: between the ages of 6–8, 25% of children already have a screen in

Abbreviations: ADHD, Attention Deficit Hyperactivity Disorder; BMI-for-age, Body Mass Index for age (z-score); SDSC, Sleep Disturbance Scale for Children; SEM, Structural Equation Model; DST, Daily Screen Exposure Time (entire day); EST, Evening Screen Exposure Time.

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their bedroom and 41% between 13 and 14 years old. Average daily screen exposure has thus been formally characterized as excessive for all age groups [3–5], in fact most children far exceed [6,7] the American Academy of Pediatrics recommendations [8]. Unfortunately, strong empirical evidence has demonstrated that excessive screen exposure can disturb a child's development [9], well-being [10,11], weight balance (obesity) [12,13], and sleeping patterns [14–18].

A recent study showed that preschoolers exposed to more than one hour of screen time per day slept less and slept less well than their peers who watch less than one hour of screen per day [19]. Crucially, screen exposure leads to decreased sleep duration [15] and increased sleep disturbance [20]. For instance, Lan et al. [19] found, in a preschooler population, that each hour of screen time was associated with a 6–11 min decrease in daily sleep time, and moreover, that the use of electronic devices in the child's room was associated with an increase in the risk of social jet lag by a factor of 1.40.

A direct causal link has been established between screen exposure and sleep disturbance. Experimental studies measuring physiological and polysomnographic information in individuals have demonstrated that screen light significantly disrupted sleep continuity and architecture [21]. Specifically, it has been found that short wavelength light emitted from monitors stop or delay normal production of melatonin [22], exposure to light in the evening has a direct impact on the circadian cycle of melatonin [23], leading to circadian rhythm disorders and insomnia [24–26]; and this effect is most pronounced in adolescents and is less observable in adults [27]. In respect to preschool children, only exposure to screens at night seems to disturb sleep [28], especially if the screen is in the child's bedroom [28,29]. Indeed, in a sample of 100 children aged 1–6 years old (2.7 years on average), Brockmann et al. [28] showed that the presence of a screen in the preschooler's bedroom and evening exposure are associated with a reduction in sleep quality.

Moreover, sleep disturbance has been found to be associated with behavioral disorders [30,31], attentional disorders, irritability, emotional lability, and a low tolerance for frustration [32], hence leading to an increased risk of ADHD [33]. Children with ADHD are more likely to have current and lifetime sleep disorders [34]. However, the impact of screen exposure on Attention-Deficit/Hyperactivity Disorder (ADHD), and intermediary symptoms thereof, is still debated [35–38]. Formal longitudinal studies have shown that early screen exposure is associated with a later onset of ADHD symptoms [35,37] but cross-sectional survey studies, using structural modelling, have failed to find such associations [36,38,39]. Moreover, a review in 2019 on children and adolescent populations concluded that the association between screen time and behavioral problems, anxiety, hyperactivity and attention was weak [11]. However, to our knowledge such previous studies did not take into account two crucial factors in this problematic: sleep disturbance (eg, duration, insomnias, parasomnia) and its link according to *when* screen exposure occurs (eg, morning vs. evening). Furthermore, it is worth assessing the interplay of how the presence of a screen in the child's bedroom may be associated with greater evening screen exposure.

The aim of the present study was (a) to confirm the harmfulness of evening screen exposure and bedroom screen presence on sleep in older children than Brockmann et al.'s sample [28] and with this confirmation (b), test our hypothesis that there is a significant association between sleep disturbance, evening screen exposure, and ADHD symptoms. Specifically, that evening screen exposure impacts daytime hyperactivity/attention deficits in children, and that this impact is significantly mediated by sleep disruption.

2. Methods

2.1. Study design and population

The research approach involved a large cross-sectional survey with statistical analyses and modeling. The study was approved by the presiding research ethics board, namely the Léon Bérard Committee for the Protection of People.

The survey was comprised of three major components: (*i*) the French version of the Sleep Disorder Scale for Children (SDSC) [40], (*ii*) the French version of the ADHD Rating Scale IV [41], and (*iii*) a questionnaire on television and video game exposure habits.

The data were collected in 2012–2014, the survey, which included the validated French version of the SDSC, was sent to 540 parents whose children were 6–16 years old and were attending partner schools of the study. Questionnaires were accompanied with an explanatory cover letter and a parental consent form. When returned, the questionnaires were checked to ensure that they were fully completed. Participants with one or more unanswered questions were excluded from the study.

2.2. Assessment of television and video game exposure

Parents provided information on their child's daily average exposure to television and video games for each part of the day (ie, morning, afternoon, and evening; being after 4pm), in respect to school days, as well as days off (Wednesday, Saturday, and Sunday in France). Parents also indicated whether a screen is present in the child's room. To obtain a measure of total Daily Screen Time (DST) for statistical testing, a composite daily average exposure was calculated per child by the following calculation. First, television and video game full day durations were combined, then across days, were averaged in which school days were weighted by 4/7 and rest days weighted by 3/7 (given 7 days in a week). The measure for Evening Screen Time (EST) was calculated in the same way, including only screen exposure time after 4pm.

2.3. Assessment of ADHD symptoms

The French version [41] of the ADHD Rating Scale IV [42] was filled out by the parents of each child. Specifically, parents provided information on the frequency of 18 criteria in the Diagnostic and Statistical Manual of Mental Disorders IV-TR (DSM IV-TR) [43] for ADHD. The reliability of the ADHD Rating Scale IV has been found to be very good (Cronbach's α of 0.94) [44]. The ADHD Rating Scale IV results in a total score, which is a composite of the individual scores for the severity of inattention and hyperactivity/impulsivity symptoms. The cut-off for an ADHD diagnosis is a total score of at least 22 (or 24, depending on age). This testing instrument hence allows children to be screened for ADHD, as well as the incidence of intermediary symptoms.

2.4. Assessment of sleep

The level of sleep disturbance (or absence thereof) was measured for each child with the French version [40] of the Sleep Disorder Scale for Children (SDSC) [45]. The SDSC scale is one of the pediatric sleep scales currently known to have the best psychometric properties (as per a Cronbach's α of 0.85) [46]. Parents were asked to rate for their child (ie, using a 5-point scale) the frequency of 25 items, each item corresponding to a sleep symptom. The SDSC scale assesses the general quality of sleep via the composite of five subscores, namely: insomnia, breathing difficulties, drowsiness, parasomnia, and non-restorative sleep. According to the SDSC, the cut-off for being diagnosed with sleep disorder is a total score of 45

[40]. This instrument hence allows children to be screened for their level of sleep disturbance, up to a full sleep disorder.

2.5. Covariates

In addition to the other measures collected, chronological age and gender information was collected for every child. We also controlled for Body Mass Index (BMI)-for-age (in z-scores) [47] since overweightness/obesity has been found to be linked with sleep quality [48] and screen exposure [49] levels.

2.6. Statistical analysis

Descriptive variables and statistical tests (2-tailed paired, or group mean comparison *t* tests, as appropriate, and χ^2 tests) were used to assess the effect of having a screen in a children's bedroom on the level of ADHD symptoms, SDSC scores, total daily screen time (DST) and evening screen time (EST).

Based on our hypotheses developed in the Introduction, formal mediation analyses were then used to assess the relationships between Screen Time (EST, DST), sleep disturbance (SDSC), and ADHD symptoms (ADHD). These analyses were implemented via a canonical linear Gaussian network, known as a Structural Equation Model (SEM [50–55], which involves a system of regression models. To prepare the data for this modeling (appropriately satisfy regression conditions: eg, normality of errors, homoscedasticity), we applied a Box–Cox transformation to the scores that will be predicted within the SEM (ADHD and SDSC, see Fig. 1). A $\lambda = 0.34$ was found to maximize the log-likelihood of a normal distribution for the ADHD scores, and $\lambda = -1.03$ for the SDSC scores. Furthermore, we *z*-scored (scaled) all continuous variables.

3. Results

3.1. Descriptive statistics

Out of the 474 parents that participated in the study, 374 completely filled all three parts of the questionnaire; leading to a sufficient response rate (87% respondents, 69% included). The population sample consisted of 201 females (54%) and 173 males (46%). The mean age was 10.8 (2.8) and the mean BMI was 16.4 (3.1). Only a few children viewed screens exclusively in the morning (N = 2), or afternoon (N = 6); this variable was therefore not included in the analyses.

Overall, 36% of the children had a screen in their room. In respect to age of first exposure to screens, the mean was 4.4 years (2.5). The average DST was 1.56 h (1.22) and average EST was 1.30 h (1.04). The mean ADHD score was 12.17 (9.19), with 11.2% of the children scoring above the pathological threshold. The average SDSC score was 38.61 (8.88) with 21.1% of the children scoring above the pathological threshold.

3.2. The effect of having a screen in the child's bedroom

As per the results presented in Table 1, children with an in-room digital screen exhibited longer screen time per day than their counterparts (2.5 h versus 1.69, $p < 0.001$). Moreover, they also presented significantly more disturbed sleep symptoms ($p < 0.001$)

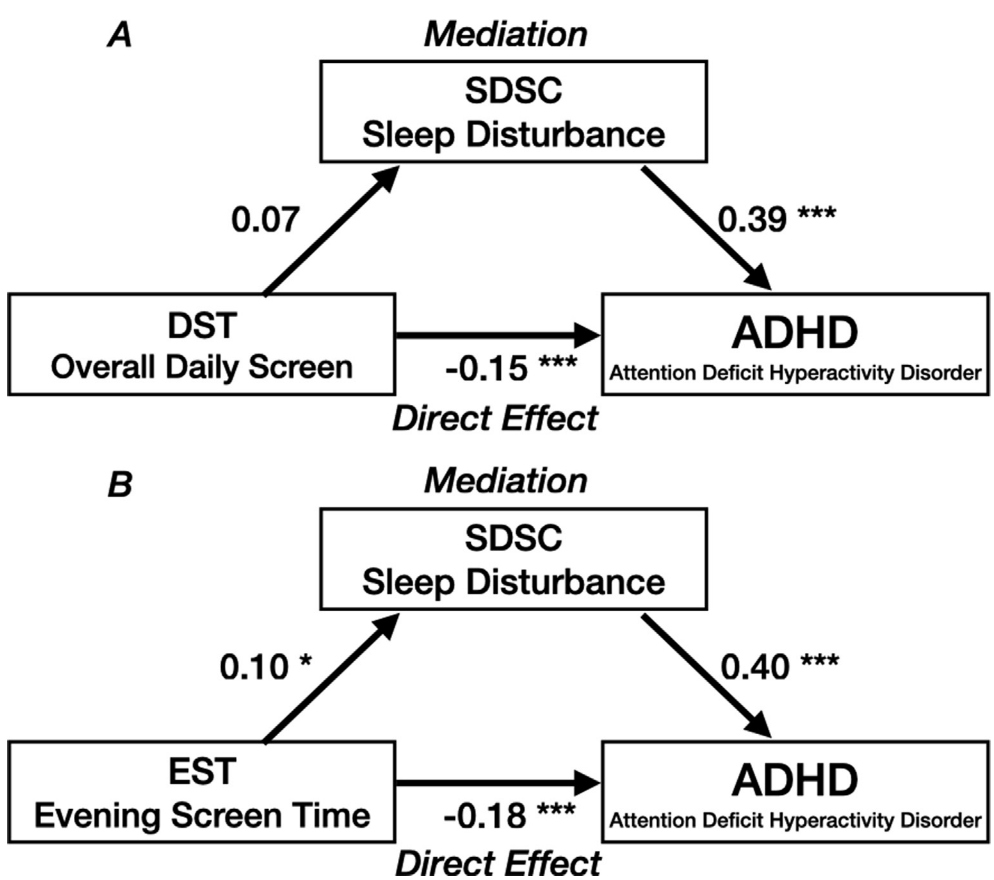

Fig. 1. The mediation models tested. In model Version A, Overall Daily Screen Time (DST) has a direct effect on ADHD Scores, but its effect may be further mediated by Sleep Disturbance (SDSC). In model Version B, Evening Screen Time (EST) is modeled rather than DST.

Table 1
Differences in screen exposure, ADHD scores, sleep disturbance, and BMI based on screen presence in child's bedroom.

	Screen in child's bedroom n = 136	No screen in child's bedroom n = 238	t-test
	Mean ± sd	Mean ± sd	
Screen Time per week (hours) – Total	**17.5 ± 9.7**	**11.8 ± 7.3**	**6.40*****
Hours of Evening Screen Time (EST)	1.8 ± 1.2	1.0 ± 0.8	6.80***
Hours of total Daily Screen Time (DST)	2.1 ± 1.4	1.3 ± 1.0	6.20***
ADHD – Total	**13.9 ± 10.6**	**11.2 ± 8.2**	**2.83****
Inattention	7.3 ± 6.1	5.7 ± 4.7	2.77**
Hyperactivity-Impulsivity	6.6 ± 5.4	5.4 ± 4.4	2.26*
SDSC – Total	**41.2 ± 9.7**	**37.1 ± 8.0**	**4.12*****
Insomnia, disorders of initiating and maintaining sleep	13.3 ± 4.8	11.6 ± 3.8	3.75***
Somnolence	3.5 ± 1.0	3.3 ± 0.6	2.32*
Sleep breathing disorders (SBD)	7.0 ± 2.5	6.6 ± 2.4	1.36
Parasomnia	11.2 ± 3.3	10.3 ± 2.8	2.76**
Nonrestorative sleep	6.3 ± 2.7	5.4 ± 2.4	3.44***
Body Mass Index-for-age (z-score)	0.82 ± 1.08	–0.5 ± 1.35	0.01***
Age	**11.7 ± 2.7**	**10.3 ± 2.7**	**4.8*****

*p < 0.05; **p < 0.01; ***p < 0.001.

as per all the SDSC sub-scores, except for the breathing difficulty score. Particularly, they demonstrated higher scores (ie, greater symptoms) on items related to sleep duration (1.9 versus 1.4, $p < 0.001$), difficulty in falling asleep (2.3 versus 2.0 $p < 0.05$), night awakenings (1.7 versus 1.4, $p < 0.01$), sleep attacks (1.1 versus 1.0, $p < 0.01$), hypnagogic hallucinations (2.0 versus 1.7 $p < 0.05$), nocturnal hyperkinesia (2.2 versus 1.9, $p < 0.05$), feeling tired with non-restorative sleep (2.6 versus 2.1, $p < 0.001$) and sleep paralysis (1.5 versus 1.3, $p < 0.05$). With regard to ADHD symptoms, they had higher scores for inattention ($p < 0.01$) and hyperactivity-impulsivity ($p < 0.05$). Note that the list of sleep symptoms, according screen presence in the child's room, are provided in the Supplementary Table 1. Finally, children having an in-room digital screen were on average 1.4 years older ($p < 0.001$) and had a lower BMI-for-age z-score ($p < 0.001$).

3.3. Correlations between model variables

Pearson correlation coefficients were calculated (with a p-value FDR-correction) between the sleep, ADHD, and daily screen time variables for SEM analysis. Sleep disturbance (SDSC) was significantly correlated with ADHD ($r = 0.37$, $p < 0.001$) and EST was significantly correlated with SDSC ($r = 0.11$, $p = 0.04$), but DST was not ($r = 0.08$, $p = 0.18$). Similarly, EST was significantly correlated with ADHD ($r = -0.11$, $p = 0.04$), but not DST ($r = -0.09$, $p = 0.09$). Additional analyses found all SDSC subscores to be positively correlated significantly with ADHD (r values between 0.15 and 0.27, $p < 0.003$), and EST to be notably correlated with Insomnia ($r = 0.20$, $p < 0.001$) and not correlated with Somnolence, Sleep Breathing Disorders, Parasomnia, Nonrestorative Sleep ($r = 0.04$, -0.02, 0.00, and 0.06 respectively).

3.4. The relationship of screen time and sleep disturbance with ADHD symptoms

As a model check prior to implementing the SEM mediation analysis, the direct relationships of DST and EST on ADHD, as well as SDSC on ADHD, were tested in individual regression models. Longer DST predicted lower parent-child ratings of ADHD Scores, ($\beta = -0.12$, SE = 0.051, $p = 0.017$) as did EST ($\beta = -0.14$, SE = 0.051, $p = 0.006$). Higher SDSC scores strongly predicted higher ADHD Scores ($\beta = 0.38$, SE = 0.048, $p < 0.001$).

Next, two mediation models were assessed: in model A, we tested if the effect of DST on ADHD is significantly mediated by SDSC; in model B, the SDSC mediation was tested in respect to EST rather than DST. These models and their results are outlined in Fig. 1.

Firstly, model checks were satisfactory: in both model A and model B, the direct effect components of DST ($\beta = -0.15$, SE = 0.05, $p < 0.001$), EST ($\beta = -0.18$, SE = 0.05, $p < 0.001$), and SDSC (model A: $\beta = 0.39$, SE = 0.05, $p = < 0.001$; model B: $\beta = 0.40$, SE = 0.05, $p = < 0.001$) were replicated as in the individual regression models. Next with regard to testing the mediation: EST significantly modulated SDSC (model B: $\beta = 0.10$, SE = 0.05, $p = 0.048$), hence supporting a mediation effect, whereas DST did not ($\beta = 0.07$, SE = 0.05, $p = 0.172$).

4. Discussion

4.1. Key results

This study replicated a principal result of Brockmann and colleagues [28], that was obtained from a larger population sample, and in older children: evening screen exposure, and especially the presence of a screen in children's bedroom, is associated with sleep disturbances. Children who watch television or play video games in their room are described by their parents as having more sleep disturbance [29], and as a new finding herein, are described by them as having more attentional deficits and hyperactivity-impulsivity symptoms.

Furthermore, evening screen exposure is associated with a disruption in daytime attention/behaviors in children aged 6 to 16 through its mediated effect on exacerbating sleep disturbance.

This mediated effect could explain the absence of correlation between screen exposure and ADHD symptoms observed in several other correlational studies [36–39], because they did not control sleep perturbation (SDSC scores), nor the time of day of screen exposure (morning, afternoon, evening). Only longitudinal studies were able to observe the deleterious effect of screen exposure on ADHD symptoms in children [35–37].

4.2. Interpretations

Consistent with Brockmann et al. [28], our study with 374 school-age children also found evening screen exposure to be associated with greater sleep disturbance. In line with the results of Brockmann et al. [28], we find a significant effect of the presence of screens in children's bedrooms on some sleep symptoms. However, we observe slight differences between the two studies on the SDSC items affected by screen exposure. The pre-school study highlights *nightmares*, *night terrors*, *sleep talking* and *tired when waking up* as being affected by the presence of a screen in the bedroom. In the current study, these affected items are mainly related to difficulties in initiating and maintaining sleep (ie, sleep duration, difficulty in falling asleep, night awakenings), parasomnia (ie, hypnagogic hallucinations, nocturnal hyperkinesia) and excessive drowsiness and non-restorative sleep (sleep attacks, feeling tired with non-restorative sleep and sleep paralysis). Moreover, the length of time that children are exposed to screens during the day (DST) does not seem to be associated with sleep issues. Only evening screen exposure is significantly associated with the latter. It is therefore reasonable to conclude that only evening screen exposure negatively affects children's sleep.

The counternatural effect of viewing bright light (short wavelengths) from screens [26] during the evening, independent of violent content or not [56], is well-founded by a number of physiological studies that screens [25] perturb melatonin secretion. By disrupting the production of this important hormone, bright screens disturb sleep quality which in turn negatively affects the diurnal functioning of the individual.

It is important to note that similar to the other two correlational studies that did not find a link between daily screen exposure and ADHD [36,39], our correlation analyses found only marginal values ($r = -0.11$) with ADHD, and they were moreover negative. This suggests that parents may rate their children as more calm (lower ADHD scores) when they are frequently entranced in front of a screen. As a result, one may speculate that parents of children with ADHD may place a screen in the child's room to cope with their hyperactive-impulsive behavior. In fact a χ^2 proportion test applied to our data found significantly more ADHD-positive children with screens in their room than not ($\chi^2 = 10.82$, $p = 0.001$, 22% vs. 9%). Hence this deceptive interplay provides a challenge, or confound, to assess how screen exposure may exacerbate ADHD symptoms (where correlation analyses alone, may not be sufficient to resolve this question); and may very well provide an explanation to the ongoing debate.

In this light, our study found evening screen exposure to be associated with greater sleep disturbance. Moreover, consistent with Paavonen et al. [33], sleep disturbance strongly predicted higher ADHD scores. Hence, the natural logic was to formally test the screen-sleep-ADHD mediation link with the standard framework, structural equation modeling (SEM). Indeed, evening screen exposure was found to be a significant exacerbator of ADHD symptoms through its negative influence on sleep quality (mediator). Sleep seems to play a determining role in the effect of screen exposure. This is why it is necessary to take it into account in studies on the impact of screens on daily life. For example, a recent study has just shown the mediating effect of sleep on the relation between screen exposure and depressive symptoms among teenagers [57].

4.3. Limitations

Firstly, the causal links between our three variables of interest should be taken with caution. While our interpretations are consistent with prior literature (see Introduction) that found a causal link between screen light and sleep disturbances, it is likely that the links highlighted in this study are bidirectional. For example, as previously discussed, it is possible that parents whose children have insomnia, phase delays, or ADHD may be more likely to allow their children to use displays at night in bed. Thus, therefore in turn, there may be a vicious cycle between screen, behavior and sleep that could worsen the intensity of the disorders.

Secondly, the present data set did not allow us to define several cohorts of children based on age groups and which times of day they exclusively viewed screens (eg, too few morning cases). In future research, the findings of the current study can be improved upon in several ways. One can consider a study that controls for two child groups: one that is authorized to view screens only the evening, and the other only the morning. For said study, it would be advantageous to collect data during periods of school vacations in order to give equal chance of morning/afternoon screen exposure.

Thirdly, while the DSM-IV TR ADHD rating scale demonstrates strong reliability, the fact that it was filled by the parents can introduce a bias. For example, the more a child is occupied by a screen in his/her room, the more he/she may be described as calm and undisturbed by their parents. One solution may be to replicate the current study, where in addition to the parents filling out the ADHD rating scale, the teachers who observe the child's behavior outside of screen viewing times fill out the Conners questionnaire. Finally, in terms of improved psychometrics, a standardized questionnaire on screen viewing and time of day would be a welcome development. To our knowledge there is only one questionnaire of this type, and it has only recently been published [58].

Fourth, we did not analyze for ADHD effects as a function of media content on the screens, for example if viewing violent content leads to a greater effect [56]. We also did not take into account the type of screen used. For example, recent studies have shown that non-portable electronic devices (TV, game consoles) have a lower effect than portable electronic devices on sleep duration [19,59,60]; and thus that the type of technology can have a different influence on parasomnias [61]. The same applies for the type of media used, with a greater effect of social media and use of internet, especially in teenagers [62].

4.4. Generalizability

In previous studies, only the means of screen exposure by television [35,37] or by television and video games [36,38] were used, which guided the parameters of the current study. Given the rapid embrace of technological devices, it is now important to also include screen exposure durations with regard to telephones and tablet devices. Moreover, as it is well known that there is almost universally, an early adoption of mobile media devices in young children from urban, low-income, minority communities [63], it would be insightful to replicate the current study in taking into account the socioeconomic status of the children [64].

5. Conclusions

This cross-sectional study confirmed that evening screen exposure directly disturbs sleep, and indirectly disturbs daytime attention/behaviors in school-aged children. This finding encourages families to avoid putting screens in their children's bedrooms, and limit evening screen exposure. It is important to note that the American Academy of Pediatrics (2016) indeed recommends that children should not sleep with devices in their bedrooms, including TVs, computers, and smartphones, and avoid exposure to devices or screens for 1 h before bedtime [8].

It furthermore demonstrates the importance of taking into account screen time and screen location in future studies. Further studies are required to confirm the sleep-screen-ADHD association in preschool children and analyze more deeply the links with other covariables, such as obesity-sleep-screen.

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Conflict of interest

None declared.

The ICMJE Uniform Disclosure Form for Potential Conflicts of Interest associated with this article can be viewed by clicking on the following link: https://doi.org/10.1016/j.sleep.2021.03.010.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.sleep.2021.03.010.

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