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## Screen exposure exacerbates ADHD symptoms indirectly through increased sleep disturbance

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### ► To cite this version:

Eddy Cavalli, Royce Anders, Louise Chaussoy, Vania Herbillon, Patricia Franco, et al.. Screen exposure exacerbates ADHD symptoms indirectly through increased sleep disturbance. *Sleep Medicine*, 2021, 83, pp.241-247. 10.1016/j.sleep.2021.03.010 . hal-04128164

**HAL Id: hal-04128164**

**<https://hal.science/hal-04128164v1>**

Submitted on 22 Jul 2024

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1 **Screen exposure exacerbates ADHD symptoms indirectly through increased**  
2 **sleep disturbance**

3  
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29

30 **Abbreviations:**

31 ADHD: Attention Deficit Hyperactivity Disorder

32 BMI-for-age: Body Mass Index for age (z-score)

33 SDSC: Sleep Disturbance Scale for Children

34 SEM: Structural Equation Model

35 DST: Daily Screen Exposure Time (entire day)

36 EST: Evening Screen Exposure Time

37 **ABSTRACT**

38 *Objectives:* The aim of this study was twofold. First, to confirm the deleterious aspect of  
39 evening screen exposure in school-aged children, in particular the effect of screens in the  
40 bedroom. Second, to explore the three-way association between degree of screen exposure,  
41 sleep disturbance, and ADHD symptoms. Solid evidence exists on the link between sleep  
42 disturbance and ADHD symptoms, and screen exposure and sleep disturbance. However, no  
43 studies have formally assessed the impact of screen exposure on ADHD symptoms in  
44 children, as a function of sleep disturbance.

45 *Methods:* Parents of 374 French children (201 girls, 173 boys, mean age of 10.8 +/- 2.8 years  
46 old) completed the Sleep Disturbance Scale for Children (SDSC), the Attention-  
47 Deficit/Hyperactivity Disorder (ADHD) Rating Scale, and a questionnaire about their  
48 children's screen habits (total hours in the morning, afternoon, and evening per day).  
49 Correlational analyses between evening screen exposure, sleep quality and behavioral  
50 problems were conducted. Then, formal mediation analyses were run in order to quantify the  
51 relationship between variables.

52 *Results:* School-aged children with screens in their bedrooms demonstrated more sleep and  
53 behavioral problems. Evening TV exposure was associated with higher SDSC and ADHD  
54 scores. Furthermore, the Structural Equation Modelling approach confirmed that evening  
55 screen exposure is directly associated with more disrupted sleep, which in turn is directly  
56 associated with behavioral problems.

57 *Conclusions:* These findings encourage families to avoid putting screens in their children's  
58 bedrooms, and limit evening screen exposure. They furthermore demonstrate the importance  
59 of taking into account screen exposure time (morning, afternoon, evening) and location  
60 (bedroom or elsewhere) in future studies.

61

62 *Keywords:* screen time, sleep disorders, children, Attention-Deficit/Hyperactivity Disorder  
63 (ADHD)

## 64 **1. Introduction**

65 Over the past 30 years, children are increasingly spending more and more time in front of  
66 digital screens (television, computer, and mobile devices) (1). For example in France, on  
67 average there are 5.5 screens per household, with at least one television in 94% of households  
68 (2). According to the World Health Organisation (WHO), nearly 70% of French teenagers  
69 watch television for more than two hours a day. Moreover, the increasing number of screens  
70 placed directly in children's bedrooms is impressive: between the ages of 6-8, 25% of children  
71 already have a screen in their bedroom and 41% between 13-14 years old. Average daily  
72 screen exposure has thus been formally characterized as excessive for all age groups (3–5), in  
73 fact most children far exceed (6,7) the American Academy of Pediatrics recommendations  
74 (8). Unfortunately, strong empirical evidence has demonstrated that excessive screen  
75 exposure can disturb a child's development (9), well-being (10,11), weight balance (obesity)  
76 (12,13), and sleeping patterns (14–18).

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

84 A direct causal link has been established between screen exposure and sleep disturbance.  
85 Experimental studies measuring physiological and polysomnographic information in  
86 individuals have demonstrated that screen light significantly disrupted sleep continuity and  
87 architecture (21). Specifically, it has been found that short wavelength light emitted from  
88 monitors stop or delay normal production of melatonin (22), exposure to light in the evening  
89 has a direct impact on the circadian cycle of melatonin (23), leading to circadian rhythm

90 disorders and insomnia (24–26); and this effect is most pronounced in adolescents and is less  
91 observable in adults (27). In respect to preschool children, only exposure to screens at night  
92 seems to disturb sleep (28), especially if the screen is in the child’s bedroom (28,29). Indeed,  
93 in a sample of 100 children aged 1 to 6 years old (2.7 years on average), Brockmann et al.  
94 (28) showed that the presence of a screen in the preschooler’s bedroom and evening exposure  
95 are associated with a reduction in sleep quality.

96 Moreover, sleep disturbance has been found to be associated with behavioral disorders  
97 (30,31), attentional disorders, irritability, emotional lability, and a low tolerance for  
98 frustration (32), hence leading to an increased risk of ADHD (33). Children with ADHD are  
99 more likely to have current and lifetime sleep disorders (34). However, the impact of screen  
100 exposure on Attention-Deficit/Hyperactivity Disorder (ADHD), and intermediary symptoms  
101 thereof, is still debated (35–38). Formal longitudinal studies have shown that early screen  
102 exposure is associated with a later onset of ADHD symptoms (35,37) but cross-sectional  
103 survey studies, using structural modelling, have failed to find such associations (36,38,39).

104 Moreover, a review in 2019 on children and adolescent populations concluded that the  
105 association between screen time and behavioral problems, anxiety, hyperactivity and attention  
106 was weak (11). However, to our knowledge such previous studies did not take into account  
107 two crucial factors in this problematic: sleep disturbance (e.g., duration, insomnias,  
108 parasomnia) and its link according to *when* screen exposure occurs (e.g., morning vs.  
109 evening). Furthermore, it is worth assessing the interplay of how the presence of a screen in  
110 the child’s bedroom may be associated with greater evening screen exposure.

111 The aim of the present study was (1) to confirm the harmfulness of evening screen exposure  
112 and bedroom screen presence on sleep in older children than Brockmann et al.’s sample (28)  
113 and with this confirmation, (2) test our hypothesis that there is a significant association  
114 between sleep disturbance, evening screen exposure, and ADHD symptoms. Specifically, that

115 evening screen exposure impacts daytime hyperactivity/attention deficits in children, and that  
116 this impact is significantly mediated by sleep disruption.

## 117 **2. Methods**

### 118 **2.1. Study Design and Population**

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

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

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

### 131 **2.2. Assessment of Television and Video Game Exposure**

132 Parents provided information on their child's daily average exposure to television and video  
133 games for each part of the day (i.e., morning, afternoon, and evening; being after 4pm), in  
134 respect to school days, as well as days off (Wednesday, Saturday, and Sunday in France).

135 Parents also indicated whether a screen is present in the child's room. To obtain a measure of  
136 total Daily Screen Time (DST) for statistical testing, a composite daily average exposure was  
137 calculated per child by the following calculation. First, television and video game full day  
138 durations were combined, then across days, were averaged in which school days were  
139 weighted by 4/7 and rest days weighted by 3/7 (given 7 days in a week). The measure for

140 Evening Screen Time (EST) was calculated in the same way, including only screen exposure  
141 time after 4pm.

142

### 143 **2.3. Assessment of ADHD Symptoms**

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

153

### 154 **2.4. Assessment of Sleep**

155 The level of sleep disturbance (or absence thereof) was measured for each child with the  
156 French version (40) of the Sleep Disorder Scale for Children (SDSC) (45). The SDSC scale is  
157 one of the pediatric sleep scales currently known to have the best psychometric properties (as  
158 per a Cronbach's  $\alpha$  of 0.85) (46). Parents were asked to rate for their child (i.e., using a 5-  
159 point scale) the frequency of 25 items, each item corresponding to a sleep symptom. The  
160 SDSC scale assesses the general quality of sleep via the composite of five subscores, namely:  
161 insomnia, breathing difficulties, drowsiness, parasomnia, and non-restorative sleep.  
162 According to the SDSC, the cut-off for being diagnosed with sleep disorder is a total score of  
163 45 (40). This instrument hence allows children to be screened for their level of sleep  
164 disturbance, up to a full sleep disorder.

165        **2.5.    Covariates**

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

170        **2.6.    Statistical Analysis**

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

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

185

186        **3. Results**

187        **3.1.    Descriptive Statistics**

188    Out of the 474 parents that participated in the study, 374 completely filled all three parts of  
189    the questionnaire; leading to a sufficient response rate (87% respondents, 69% included). The



190 population sample consisted of 201 females (54%) and 173 males (46%). The mean age was  
191 10.8 (2.8) and the mean BMI was 16.4 (3.1). Only a few children viewed screens exclusively  
192 in the morning (N = 2), or afternoon (N = 6); this variable was therefore not included in the  
193 analyses.

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

199

### 200 **3.2. The Effect of Having a Screen in the Child's Bedroom**

201

202 As per the results presented in Table 1, children with an in-room digital screen exhibited  
203 longer screen time per day than their counterparts (2.5 hours versus 1.69,  $p < .001$ ).  
204 Moreover, they also presented significantly more disturbed sleep symptoms ( $p < .001$ ) as per  
205 all the SDSC sub-scores, except for the breathing difficulty score. Particularly, they  
206 demonstrated higher scores (i.e. greater symptoms) on items related to sleep duration  
207 (1.9 versus 1.4,  $p < .001$ ), difficulty in falling asleep (2.3 versus 2.0  $p < .05$ ), night  
208 awakenings (1.7 versus 1.4,  $p < .01$ ), sleep attacks (1.1 versus 1.0,  $p < .01$ ), hypnagogic  
209 hallucinations (2.0 versus 1.7  $p < .05$ ), nocturnal hyperkinesia (2.2 versus 1.9,  $p < .05$ ),  
210 feeling tired with non-restorative sleep (2.6 versus 2.1,  $p < .001$ ) and sleep paralysis (1.5  
211 versus 1.3,  $p < .05$ ). With regard to ADHD symptoms, they had higher scores for inattention  
212 ( $p < .01$ ) and hyperactivity-impulsivity ( $p < .05$ ). Note that the list of sleep symptoms,  
213 according screen presence in the child's room, are provided in the Supplementary Table 1.  
214 Finally, children having an in-room digital screen were on average 1.4 years older ( $p < .001$ )  
215 and had a lower BMI-for-age z-score ( $p < .001$ ).

216 **Table 1.** Differences in screen exposure, ADHD scores, sleep disturbance, and BMI based on  
 217 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	
<b>Screen Time per week (hours) – Total</b>	<b>17.5 ± 9.7</b>	<b>11.8 ± 7.3</b>	<b>6.40***</b>
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***
<b>ADHD – Total</b>	<b>13.9 ± 10.6</b>	<b>11.2 ± 8.2</b>	<b>2.83**</b>
Inattention	7.3 ± 6.1	5.7 ± 4.7	2.77**
Hyperactivity-Impulsivity	6.6 ± 5.4	5.4 ± 4.4	2.26*
<b>SDSC – Total</b>	<b>41.2 ± 9.7</b>	<b>37.1 ± 8.0</b>	<b>4.12***</b>
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***
<b>Age</b>	<b>11.7 ± 2.7</b>	<b>10.3 ± 2.7</b>	<b>4.8***</b>

218 \* p < .05 ; \*\* p < .01 ; \*\*\* p < .001

219 **3.3. Correlations Between Model Variables**

220 Pearson correlation coefficients were calculated (with a *p*-value FDR-correction) between the  
 221 sleep, ADHD, and daily screen time variables for SEM analysis. Sleep disturbance (SDSC)  
 222 was significantly correlated with ADHD ( $r = 0.37, p < .001$ ) and EST was significantly  
 223 correlated with SDSC ( $r = 0.11, p = .04$ ), but DST was not ( $r = 0.08, p = .18$ ). Similarly, EST  
 224 was significantly correlated with ADHD ( $r = -0.11, p = .04$ ), but not DST ( $r = -0.09, p = .09$ ).  
 225 Additional analyses found all SDSC subscores to be positively correlated significantly with  
 226 ADHD ( $r$  values between .15 to .27,  $p < .003$ ), and EST to be notably correlated with  
 227 Insomnia ( $r = 0.20, p < .001$ ) and not correlated with Somnolence, Sleep Breathing Disorders,  
 228 Parasomnia, Nonrestorative Sleep ( $r = .04, -.02, .00, \text{ and } .06$  respectively).

229 **3.4. The Relationship of Screen Time and Sleep Disturbance with ADHD Symptoms**

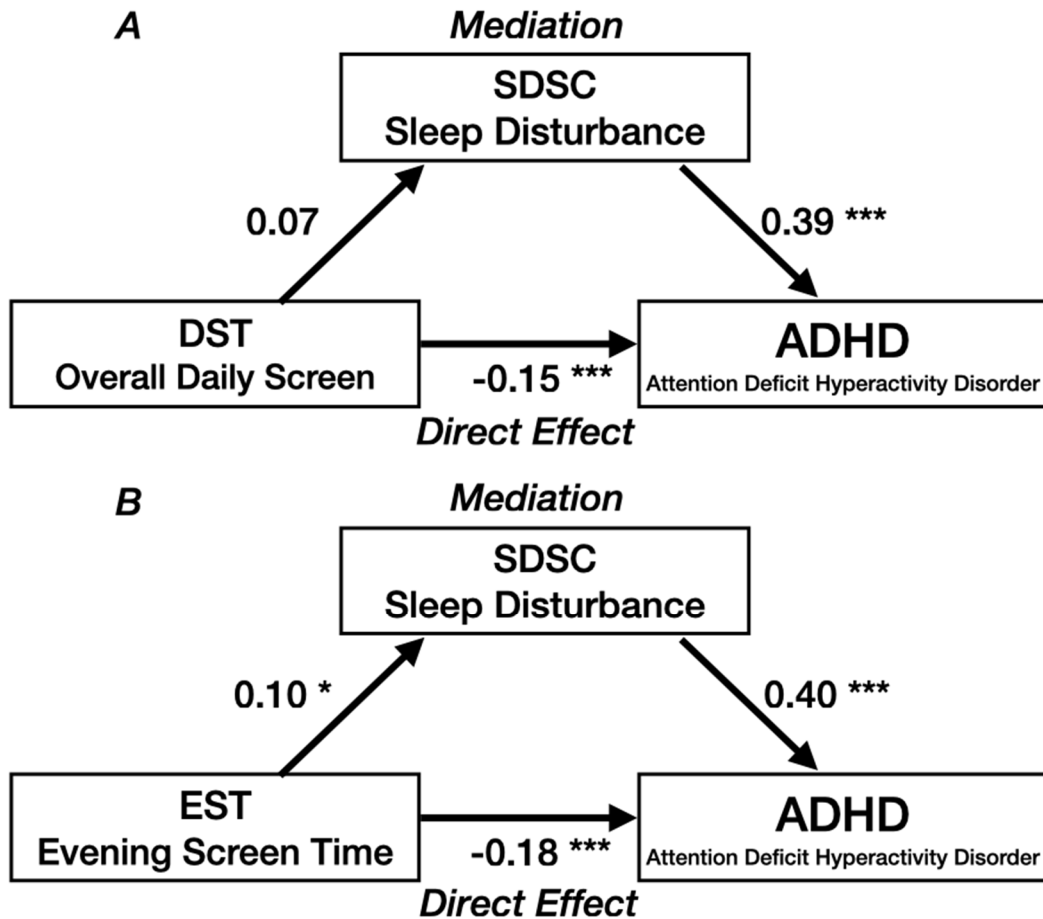
230

231 As a model check prior to implementing the SEM mediation analysis, the direct relationships  
232 of DST and EST on ADHD, as well as SDSC on ADHD, were tested in individual regression  
233 models. Longer DST predicted lower parent-child ratings of ADHD Scores, ( $\beta = -0.12$ , SE =  
234  $.051$ ,  $p = .017$ ) as did EST ( $\beta = -0.14$ , SE =  $.051$ ,  $p = .006$ ). Higher SDSC scores strongly  
235 predicted higher ADHD Scores ( $\beta = 0.38$ , SE =  $.048$ ,  $p < .001$ ).

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

239 Firstly, model checks were satisfactory: in both model A and model B, the direct effect  
240 components of DST ( $\beta = -0.15$ , SE =  $.05$ ,  $p < .001$ ), EST ( $\beta = -0.18$ , SE =  $.05$ ,  $p < .001$ ), and  
241 SDSC (model A:  $\beta = 0.39$ , SE =  $.05$ ,  $p < .001$ ; model B:  $\beta = 0.40$ , SE =  $.05$ ,  $p < .001$ )  
242 were replicated as in the individual regression models. Next with regard to testing the  
243 mediation: EST significantly modulated SDSC (model B:  $\beta = 0.10$ , SE =  $.05$ ,  $p = .048$ ), hence  
244 supporting a mediation effect, whereas DST did not ( $\beta = 0.07$ , SE =  $.05$ ,  $p = .172$ ).

245



246  
247

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

252 **4. Discussion**

253 **4.1. Key Results**

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

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

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

#### 269 **4.2. Interpretations**

270 Consistent with Brockmann et al. (28), our study with 374 school-age children also found  
271 evening screen exposure to be associated with greater sleep disturbance. In line with the  
272 results of Brockmann et al. (28), we find a significant effect of the presence of screens in  
273 children's bedrooms on some sleep symptoms. However, we observe slight differences  
274 between the two studies on the SDSC items affected by screen exposure. The pre-school study  
275 highlights *nightmares*, *night terrors*, *sleep talking* and *tired when waking up* as being affected  
276 by the presence of a screen in the bedroom. In the current study, these affected items are  
277 mainly related to difficulties in initiating and maintaining sleep (i.e. sleep duration, difficulty  
278 in falling asleep, night awakenings), parasomnia (i.e. hypnagogic hallucinations, nocturnal  
279 hyperkinesia) and excessive drowsiness and non-restorative sleep (sleep attacks, feeling tired  
280 with non-restorative sleep and sleep paralysis). Moreover, the length of time that children are  
281 exposed to screens during the day (DST) does not seem to be associated with sleep issues.  
282 Only evening screen exposure is significantly associated with the latter. It is therefore  
283 reasonable to conclude that only evening screen exposure negatively affects children's sleep.  
284 The counternatural effect of viewing bright light (short wavelengths) from screens (26) during  
285 the evening, independent of violent content or not (56), is well-founded by a number of  
286 physiological studies that screens (25) perturb melatonin secretion. By disrupting the

287 production of this important hormone, bright screens disturb sleep quality which in turn  
288 negatively affects the diurnal functioning of the individual.

289 It is important to note that similar to the other two correlational studies that did not find a link  
290 between daily screen exposure and ADHD (36,39), our correlation analyses found only  
291 marginal values ( $r=-.11$ ) with ADHD, and they were moreover negative. This suggests that  
292 parents may rate their children as more calm (lower ADHD scores) when they are frequently  
293 entranced in front of a screen. As a result, one may speculate that parents of children with  
294 ADHD may place a screen in the child's room to cope with their hyperactive-impulsive  
295 behavior. In fact a  $\chi^2$  proportion test applied to our data found significantly more ADHD-  
296 positive children with screens in their room than not ( $\chi^2 = 10.82, p = .001, 22\% \text{ vs. } 9\%$ ).

297 Hence this deceptive interplay provides a challenge, or confound, to assess how screen  
298 exposure may exacerbate ADHD symptoms (where correlation analyses alone, may not be  
299 sufficient to resolve this question); and may very well provide an explanation to the ongoing  
300 debate.

301 In this light, our study found evening screen exposure to be associated with greater sleep  
302 disturbance. Moreover, consistent with Paavonen et al. (33), sleep disturbance strongly  
303 predicted higher ADHD scores. Hence, the natural logic was to formally test the screen-sleep-  
304 ADHD mediation link with the standard framework, structural equation modeling (SEM).

305 Indeed, evening screen exposure was found to be a significant exacerbator of ADHD  
306 symptoms through its negative influence on sleep quality (mediator). Sleep seems to play a  
307 determining role in the effect of screen exposure. This is why it is necessary to take it into  
308 account in studies on the impact of screens on daily life. For example, a recent study has just  
309 shown the mediating effect of sleep on the relation between screen exposure and depressive  
310 symptoms among teenagers (57).

311 **4.3. Limitations**

312 Firstly, the causal links between our three variables of interest should be taken with caution.

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

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

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

335 Fourth, we did not analyze for ADHD effects as a function of media content on the screens,  
336 for example if viewing violent content leads to a greater effect (56). We also did not take into

337 account the type of screen used. For example, recent studies have shown that non-portable  
338 electronic devices (TV, game consoles) have a lower effect than portable electronic devices  
339 on sleep duration (19,59,60); and thus that the type of technology can have a different  
340 influence on parasomnias (61). The same applies for the type of media used, with a greater  
341 effect of social media and use of internet, especially in teenagers (62).

#### 342 **4.4. Generalizability**

343 In previous studies, only the means of screen exposure by television (35,37) or by television  
344 and video games (36,38) were used, which guided the parameters of the current study. Given  
345 the rapid embrace of technological devices, it is now important to also include screen  
346 exposure durations with regard to telephones and tablet devices. Moreover, as it is well  
347 known that there is almost universally, an early adoption of mobile media devices in young  
348 children from urban, low-income, minority communities (63), it would be insightful to  
349 replicate the current study in taking into account the socioeconomic status of the children  
350 (64).

### 351 **5. Conclusions**

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

359 It furthermore demonstrates the importance of taking into account screen time and screen  
360 location in future studies. Further studies are required to confirm the sleep-screen-ADHD



361 association in preschool children and analyze more deeply the links with other covariables,  
362 such as obesity-sleep-screen.

## 363 **Funding**

364 This research did not receive any specific grant from funding agencies in the public,  
365 commercial, or not-for-profit sectors.

## 366 **References**

- 367 1. Chen W, Adler JL. Assessment of Screen Exposure in Young Children, 1997 to 2014.  
368 JAMA Pediatr. 2019;173(4):391-3. doi:10.1001/jamapediatrics.2018.5546
- 369 2. Observatoire de l'équipement audiovisuel des foyers [Internet]. Conseil Supérieur de  
370 l'Audiovisuel. 2017. Available on: [https://www.csa.fr/Informer/Toutes-les-](https://www.csa.fr/Informer/Toutes-les-actualites/Actualites/5-a-6-ecrans-par-foyer-pour-regarder-des-videos)  
371 [actualites/Actualites/5-a-6-ecrans-par-foyer-pour-regarder-des-videos](https://www.csa.fr/Informer/Toutes-les-actualites/Actualites/5-a-6-ecrans-par-foyer-pour-regarder-des-videos)
- 372 3. Vandewater EA, Rideout VJ, Wartella EA, Huang X, Lee JH, Shim M -s. Digital  
373 Childhood: Electronic Media and Technology Use Among Infants, Toddlers, and  
374 Preschoolers. PEDIATRICS. 2007;119(5):e1006-15. doi:10.1542/peds.2006-1804
- 375 4. Certain LK, Kahn RS. Prevalence, Correlates, and Trajectory of Television Viewing  
376 Among Infants and Toddlers. PEDIATRICS. 2002;109(4):634-42.  
377 doi:10.1542/peds.109.4.634
- 378 5. Lucena JMS de, Cheng LA, Cavalcante TLM, Silva VA da, Farias Júnior JC de.  
379 Prevalência de tempo excessivo de tela e fatores associados em adolescentes. Rev Paul  
380 Pediatr. 2015;33(4):407-14. doi:10.1016/j.rpped.2015.04.001
- 381 6. Trinh M-H, Sundaram R, Robinson SL, Lin T-C, Bell EM, Ghassabian A, et al.  
382 Association of Trajectory and Covariates of Children's Screen Media Time. JAMA  
383 Pediatr. 2020;174(1):71. doi:10.1001/jamapediatrics.2019.4488
- 384 7. Rubin R. Too Much Screen Time for Young Children, Experts Say. JAMA.  
385 2020;323(4):300. doi:10.1001/jama.2019.21854
- 386 8. COUNCIL ON COMMUNICATIONS AND MEDIA. Media and Young Minds.  
387 Pediatrics [Internet]. 2016;138(5). doi:10.1542/peds.2016-2591
- 388 9. Madigan S, Browne D, Racine N, Mori C, Tough S. Association Between Screen Time  
389 and Children's Performance on a Developmental Screening Test. JAMA Pediatr.  
390 2019;173(3):244. doi:10.1001/jamapediatrics.2018.5056
- 391 10. Hinkley T, Verbestel V, Ahrens W, Lissner L, Molnár D, Moreno LA, et al. Early  
392 Childhood Electronic Media Use as a Predictor of Poorer Well-being: A Prospective  
393 Cohort Study. JAMA Pediatr. 2014;168(5):485. doi:10.1001/jamapediatrics.2014.94

- 394 11. Stiglic N, Viner RM. Effects of screentime on the health and well-being of children and  
395 adolescents: a systematic review of reviews. *BMJ Open*. 2019;9(1):e023191.  
396 doi:10.1136/bmjopen-2018-023191
- 397 12. Borghese MM, Tremblay MS, Katzmarzyk PT, Tudor-Locke C, Schuna JM, Leduc G, et  
398 al. Mediating role of television time, diet patterns, physical activity and sleep duration in  
399 the association between television in the bedroom and adiposity in 10 year-old children.  
400 *Int J Behav Nutr Phys Act*. 2015;12(1):60. doi:10.1186/s12966-015-0221-5
- 401 13. Dennison BA, Erb TA, Jenkins PL. Television Viewing and Television in Bedroom  
402 Associated With Overweight Risk Among Low-Income Preschool Children.  
403 *PEDIATRICS*. 2002;109(6):1028-35. doi:10.1542/peds.109.6.1028
- 404 14. Thompson DA. The Association Between Television Viewing and Irregular Sleep  
405 Schedules Among Children Less Than 3 Years of Age. *PEDIATRICS*.  
406 2005;116(4):851-6. doi:10.1542/peds.2004-2788
- 407 15. Marinelli M, Sunyer J, Alvarez-Pedrerol M, Iñiguez C, Torrent M, Vioque J, et al. Hours  
408 of Television Viewing and Sleep Duration in Children: A Multicenter Birth Cohort  
409 Study. *JAMA Pediatr*. 2014;168(5):458-64. doi:10.1001/jamapediatrics.2013.3861
- 410 16. Carter B, Rees P, Hale L, Bhattacharjee D, Paradkar MS. Association Between Portable  
411 Screen-Based Media Device Access or Use and Sleep Outcomes: A Systematic Review  
412 and Meta-analysis. *JAMA Pediatr*. 2016;170(12):1202-8.  
413 doi:10.1001/JAMAPEDIATRICS.2016.2341
- 414 17. Li S, Jin X, Wu S, Jiang F, Yan C, Shen X. The Impact of Media Use on Sleep Patterns  
415 and Sleep Disorders among School-Aged Children in China. *Sleep*. 2007;30(3):361-7.  
416 doi:10.1093/sleep/30.3.361
- 417 18. Van den Bulck J. Television Viewing, Computer Game Playing, and Internet Use and  
418 Self-Reported Time to Bed and Time out of Bed in Secondary-School Children. *Sleep*.  
419 2004;27(1):101-4. doi:10.1093/sleep/27.1.101
- 420 19. Lan Q-Y, Chan KC, Yu KN, Chan NY, Wing YK, Li AM, et al. Sleep duration in  
421 preschool children and impact of screen time. *Sleep Med*. 2020;76:48-54.  
422 doi:10.1016/j.sleep.2020.09.024
- 423 20. Hale L, Guan S. Screen time and sleep among school-aged children and adolescents: A  
424 systematic literature review. *Sleep Med Rev*. 2015;21:50-8.  
425 doi:10.1016/j.smr.2014.07.007
- 426 21. Wood B, Rea MS, Plitnick B, Figueiro MG. Light level and duration of exposure  
427 determine the impact of self-luminous tablets on melatonin suppression. *Appl Ergon*.  
428 2013;44(2):237-40. doi:10.1016/j.apergo.2012.07.008
- 429 22. Higuchi S, Motohashi Y, Liu Y, Ahara M, Kaneko Y. Effects of VDT tasks with a bright  
430 display at night on melatonin, core temperature, heart rate, and sleepiness. *J Appl*  
431 *Physiol*. 2003;94(5):1773-6. doi:10.1152/jappphysiol.00616.2002
- 432 23. Münch M, Kobjalka S, Steiner R, Oelhafen P, Wirz-Justice A, Cajochen C. Wavelength-  
433 dependent effects of evening light exposure on sleep architecture and sleep EEG power

- 434 density in men. *Am J Physiol - Regul Integr Comp Physiol.* mai 2006;290(5).  
435 doi:10.1152/ajpregu.00478.2005
- 436 24. Green A, Cohen-Zion M, Haim A, Dagan Y. Evening light exposure to computer screens  
437 disrupts human sleep, biological rhythms, and attention abilities. *Chronobiol Int.*  
438 2017;34(7):855-65. doi:10.1080/07420528.2017.1324878
- 439 25. Cajochen C, Frey S, Anders D, Späti J, Bues M, Pross A, et al. Evening exposure to a  
440 light-emitting diodes (LED)-backlit computer screen affects circadian physiology and  
441 cognitive performance. *J Appl Physiol.* 2011;110(5):1432-8.  
442 doi:10.1152/jappphysiol.00165.2011
- 443 26. Figueiro MG, Rea MS. The Effects of Red and Blue Lights on Circadian Variations in  
444 Cortisol, Alpha Amylase, and Melatonin. *Int J Endocrinol.* 2010;2010:1-9.  
445 doi:10.1155/2010/829351
- 446 27. Nagare R, Plitnick B, Figueiro M. Effect of exposure duration and light spectra on  
447 nighttime melatonin suppression in adolescents and adults. *Light Res Technol.*  
448 2019;51(4):530-43. doi: 10.1177/1477153518763003
- 449 28. Brockmann PE, Diaz B, Damiani F, Villarroel L, Núñez F, Bruni O. Impact of television  
450 on the quality of sleep in preschool children. *Sleep Med.* 2016;20:140-4.  
451 doi:10.1016/j.sleep.2015.06.005
- 452 29. Owens J, Maxim R, McGuinn M, Nobile C, Msall M, Alario A. Television-viewing  
453 Habits and Sleep Disturbance in School Children. *Pediatrics.* 1999;104(3):e27-e27.  
454 doi:10.1542/peds.104.3.e27.
- 455 30. Smedje H, Broman J-E, Hetta J. Associations between disturbed sleep and behavioural  
456 difficulties in 635 children aged six to eight years: a study based on parents' perceptions.  
457 *Eur Child Adolesc Psychiatry.* 2001;10(1):1-9. doi:10.1007/s007870170041
- 458 31. Bayes DM, Bullock B. Sleep Problems in School Aged Children: A Common Process  
459 across Internalising and Externalising Behaviours? *Clocks Sleep.* 2019;2(1):7-18.  
460 doi:10.3390/clockssleep2010002
- 461 32. Dahl RE. The impact of inadequate sleep on children's daytime cognitive function.  
462 *Semin Pediatr Neurol.* 1996;3(1):44-50. doi:10.1016/S1071-9091(96)80028-3
- 463 33. Paavonen EJ, Raikkonen K, Lahti J, Komsu N, Heinonen K, Pesonen A-K, et al. Short  
464 Sleep Duration and Behavioral Symptoms of Attention-Deficit/Hyperactivity Disorder in  
465 Healthy 7- to 8-Year-Old Children. *PEDIATRICS.* 2009;123(5):e857-64.  
466 doi:10.1542/peds.2008-2164
- 467 34. Gau SS-F, Chiang H-L. Sleep Problems and Disorders among Adolescents with  
468 Persistent and Subthreshold Attention-deficit/Hyperactivity Disorders. *Sleep.*  
469 2009;32(5):671-9. doi:10.1093/sleep/32.5.671
- 470 35. Landhuis CE, Poulton R, Welch D, Hancox RJ. Does Childhood Television Viewing  
471 Lead to Attention Problems in Adolescence? Results From a Prospective Longitudinal  
472 Study. *PEDIATRICS.* 2007;120(3):532-7. doi:10.1542/peds.2007-0978

- 473 36. Stevens T. There Is No Meaningful Relationship Between Television Exposure and  
474 Symptoms of Attention-Deficit/Hyperactivity Disorder. *PEDIATRICS*.  
475 2006;117(3):665-72. doi:10.1542/peds.2005-0863
- 476 37. Christakis DA, Zimmerman FJ, DiGiuseppe DL, McCarty CA. Early Television  
477 Exposure and Subsequent Attentional Problems in Children. *Pediatrics*.  
478 2004;113(4):708-13. doi:10.1542/peds.113.4.708
- 479 38. Christakis DA, Zimmerman FJ. Viewing Television Before Age 3 Is Not the Same as  
480 Viewing Television at Age 5. *PEDIATRICS*. 2006;118(1):435-435.  
481 doi:10.1542/peds.2006-0981
- 482 39. Ferguson CJ. The influence of television and video game use on attention and school  
483 problems: A multivariate analysis with other risk factors controlled. *J Psychiatr Res*.  
484 2011;45(6):808-13. doi:10.1016/j.jpsychires.2010.11.010
- 485 40. Putois B, Leslie W, Gustin MP, Challamel M-J, Raoux A, Guignard-Perret A, et al. The  
486 French Sleep Disturbance Scale for Children. *Sleep Med*. 2017;32:56-65.  
487 doi:10.1016/j.sleep.2016.12.008
- 488 41. Mercier C, Roche S, Gaillard S, Kassai B, Arzimanoglou A, Herbillon V, et al. Partial  
489 validation of a French version of the ADHD-rating scale IV on a French population of  
490 children with ADHD and epilepsy. Factorial structure, reliability, and responsiveness.  
491 *Epilepsy Behav*. 2016;58:1-6. doi:10.1016/j.yebeh.2016.02.016
- 492 42. DuPauI GJ, Anastopoulos AD, Power TJ, Reid R, Ikeda MJ, McGoey KE. Parent  
493 Ratings of Attention-Deficit/Hyperactivity Disorder Symptoms: Factor Structure and  
494 Normative Data. *J Psychopathol Behav Assess*. 1996;20(1):83-102.  
495 doi:10.1023/A:1023087410712
- 496 43. American Psychiatric Association, éditeur. *Diagnostic and statistical manual of mental  
497 disorders: DSM-IV ; includes ICD-9-CM codes effective 1. Oct. 96. 4. ed., 7. print.*  
498 Washington, DC; 1998. 886 p.
- 499 44. Cronbach LJ. Coefficient alpha and the internal structure of tests. *Psychometrika*.  
500 1951;16(3):297-334. doi:10.1007/BF02310555
- 501 45. Bruni O, Ottaviano S, Guidetti V, Romoli M, Innocenzi M, Cortesi F, et al. The Sleep  
502 Disturbance Scale for Children (SDSC) Construct ion and validation of an instrument to  
503 evaluate sleep disturbances in childhood and adolescence. *J Sleep Res*.  
504 1996;5(4):251-61. doi:10.1111/j.1365-2869.1996.00251.x
- 505 46. Spruyt K, Gozal D. Pediatric sleep questionnaires as diagnostic or epidemiological tools:  
506 A review of currently available instruments. *Sleep Med Rev*. 2011;15(1):19-32.  
507 doi:10.1016/j.smr.2010.07.005
- 508 47. Butte NF, Garza C, de Onis M. Evaluation of the Feasibility of International Growth  
509 Standards for School-Aged Children and Adolescents. *J Nutr*. 2007;137(1):153-7.  
510 doi:10.1093/jn/137.1.153
- 511 48. Chaput J-P, Brunet M, Tremblay A. Relationship between short sleeping hours and  
512 childhood overweight/obesity: results from the 'Québec en Forme' Project. *Int J Obes*.  
513 2006;30(7):1080-5. doi:10.1038/sj.ijo.0803291

- 514 49. Robinson TN, Banda JA, Hale L, Lu AS, Fleming-Milici F, Calvert SL, et al. Screen  
515 Media Exposure and Obesity in Children and Adolescents. *Pediatrics*.  
516 2017;140(Supplement 2):S97-101. doi:10.1542/peds.2016-1758K
- 517 50. Iacobucci D. Introduction to Mediation. In: *Mediation Analysis* [Internet]. 2011.  
518 doi:10.4135/9781412984966.n1
- 519 51. Lee H, Herbert RD, McAuley JH. Mediation Analysis. *JAMA Guide Stat Methods*.  
520 2019;321(7):697-8. doi:10.1001/jama.2018.21973
- 521 52. Imai K, Keele L, Yamamoto T. Identification, Inference and Sensitivity Analysis for  
522 Causal Mediation Effects. *Stat Sci*. 2010;25(1):51-71. doi:10.1214/10-STS321
- 523 53. MacKinnon DP. *Introduction to statistical mediation analysis*. New York: Lawrence  
524 Erlbaum Associates; 2008. 477 p. (Multivariate applications).  
525 doi:10.4324/9780203809556
- 526 54. Iacobucci D. *Mediation Analysis*. (Sage University Papers Series on Quantitative  
527 Applications in the Social Sciences, No. 07-156). Thousand Oaks, CA: SAGE  
528 Publications; 2008.
- 529 55. Sakia RM. The Box-Cox Transformation Technique: A Review. *The Statistician*.  
530 1992;41(2):169-78. doi:10.2307/2348250
- 531 56. Council on Communications and Media. Media Violence. *PEDIATRICS*.  
532 2009;124(5):1495-503. doi:10.1542/peds.2009-2146
- 533 57. Li X, Buxton OM, Lee S, Chang A-M, Berger LM, Hale L. Sleep mediates the  
534 association between adolescent screen time and depressive symptoms. *Sleep Med*.  
535 2019;57:51-60. doi:10.1016/j.sleep.2019.01.029
- 536 58. Klakk H, Wester CT, Olesen LG, Rasmussen MG, Kristensen PL, Pedersen J, et al. The  
537 development of a questionnaire to assess leisure time screen-based media use and its  
538 proximal correlates in children (SCREENS-Q). *BMC Public Health*. 2020;20(1):664.  
539 doi:10.1186/s12889-020-08810-6
- 540 59. Twenge JM, Hisler GC, Krizan Z. Associations between screen time and sleep duration  
541 are primarily driven by portable electronic devices: evidence from a population-based  
542 study of U.S. children ages 0–17. *Sleep Med*. 2019;56:211-8.  
543 doi:10.1016/j.sleep.2018.11.009
- 544 60. Falbe J, Davison KK, Franckle RL, Ganter C, Gortmaker SL, Smith L, et al. Sleep  
545 Duration, Restfulness, and Screens in the Sleep Environment. *PEDIATRICS*.  
546 2015;135(2):e367-75. doi:10.1542/peds.2014-2306
- 547 61. Arora T, Broglia E, Thomas GN, Taheri S. Associations between specific technologies  
548 and adolescent sleep quantity, sleep quality, and parasomnias. *Sleep Med*. févr  
549 2014;15(2):240-7. doi:10.1016/j.sleep.2013.08.799
- 550 62. Hisler G, Twenge JM, Krizan Z. Associations between screen time and short sleep  
551 duration among adolescents varies by media type: evidence from a cohort study. *Sleep*  
552 *Med*. 2020;66:92-102. doi:10.1016/j.sleep.2019.08.007

- 553 63. Kabali HK, Irigoyen MM, Nunez-Davis R, Budacki JG, Mohanty SH, Leister KP, et al.  
554 Exposure and Use of Mobile Media Devices by Young Children. PEDIATRICS.  
555 2015;136(6):1044-50. doi:10.1542/peds.2015-2151
- 556 64. Cartanyà-Hueso À, Lidón-Moyano C, Martín-Sánchez JC, González-Marrón A, Matilla-  
557 Santander N, Miró Q, et al. Association of screen time and sleep duration among  
558 Spanish 1-14 years old children. Paediatr Perinat Epidemiol. 2021;35(1):120-9.  
559 doi:10.1111/ppe.12695

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