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Prospective Associations between Screen-based Sedentary Behaviors and Cognitive Performance among Children aged 5-7 Years

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Abstract

Background: The 5- to 7-year shift is a critical period for cognitive development and is particularly sensitive to lifestyle factors such as sedentary behavior (SB). Screen-based activities can be classified into two types: mentally active SB requires higher cognitive engagement (e.g., computer use, electronic gaming), and mentally passive SB involves less cognitive engagement (e.g., TV-watching). Although there has been a growing interest in understanding the role of such forms of SB on cognitive development has emerged in recent years, our knowledge of its influence in early childhood is still relatively scant. Thus, this study aimed to advance our understanding of how screen-based SB influence cognitive development trajectories, considering the moderating role of the SB duration, SB type, and sex.

Methods: Data from 12,257 children (6178 Boys; 6079 Girls) in the UK Millennium Cohort Study (MCS), a longitudinal and nationally representative birth cohort study in the UK, were analyzed. The MCS includes children born between September 2000 and January 2002. For this study, we used data from wave 3 (at the age of 5 years) to assess the association between computer use/e-gaming and TV-watching time with cognitive performance assessed in wave 4 (at the age of 7 years). Cognitive performance was assessed using the British Ability Scales II (BAS II), including word reading and pattern construction tests, and an adapted National Foundation for Educational Research (NFER) Progress in Maths test. Statistical analyses were performed via a Generalized Linear Model (GLM) adjusted for confounders and stratified by sex.

Results: For boys, computer use/e-gaming at the age of 5 years was associated with better word reading performance at the age of 7 years for those who engaged in it for less than 1 hour ($\beta = 0.148$, 95% CI: 0.081 to 0.215, $p < 0.001$) and 1 to 3 hours ($\beta = 0.209$, 95% CI: 0.128 to 0.290, $p < 0.001$) per day. Regarding math performance, computer use/e-gaming for less than 1 hour ($\beta = 0.179$, 95% CI: 0.120 to 0.237, $p < 0.001$) and 1 to 3 hours ($\beta = 0.181$, 95% CI: 0.101 to 0.261, $p < 0.001$) per day at the age of 5 years were associated with better math performance at the age of 7 years, whereas 7 hours or more per day were negatively associated with math performance when considering the same observation period ($\beta = -0.356$, 95% CI: -0.698 to -0.134, $p < 0.001$). For girls, TV-watching of 1 to 3 hours ($\beta = -0.224$, 95% CI: -0.383 to -0.065, $p = 0.006$), 3 to 5 hours ($\beta = -0.211$, 95% CI: -0.385 to -0.038, $p = 0.017$), and 7 hours or more ($\beta = -0.257$, 95% CI: -0.461 to -0.053, $p = 0.014$) per day at the age of 5 years were associated with worse math performance at the age of 7 years. No statistically significant prospective associations were found between daily time spent on screen-based SB and spatial construction performance.

Conclusions: Our study adds to the literature in demonstrating that the prospective associations of screen-based SB and cognitive performance are moderated by SB type, daily exposure duration, and biological sex. The observation that in boys spending an age-appropriate amount of time in early stages of childhood (i.e., at 5 years) on mentally active SB positively predict aspects of cognitive development assessed in a later stage (i.e., at 7 years), while in girls in the same period a detrimental association was observed for mentally passive SB, imply that interventions and policies aiming to promote children's optimal cognitive development should (i) consider sex differences and (ii) focus on limiting the time spent on mentally passive SB.

Keywords: sedentary behavior, cognitive development, mathematics ability, screen time, child development, cognitive performance

Journal Pre-proof

1 Introduction

2 In human ontogenesis, the early years of life are critical for physical and cognitive
3 development (Irwin et al., 2007; Alex et al., 2024). In particular, the “5-to-7-year shift”, a
4 transitional period in which rapid development of the human brain (Gilmore et al., 2018) and
5 cognitive abilities occur (Del Giudice et al., 2009) can be considered a critical window within
6 individual maturation. During this transitional phase, children typically show significant
7 progress in the development of math, reading, and spatial reasoning skills - core components
8 essential for later academic success (Chou et al., 2022; Malone et al., 2022; Allee et al.,
9 2024). Given that well-developed cognitive abilities are crucial for mastering almost every
10 aspect of daily life (e.g., academic and job achievement), it is critical to gain a better
11 understanding of the factors that are detrimental or beneficial to cognitive development.
12 Evidence generated by such studies can meaningfully guide policymakers and educators in
13 implementing effective early intervention programs that promote children’s optimal cognitive
14 development and academic success (Tucker-Drob et al., 2013).

15 Although the genetic influence on cognitive development has been extensively investigated
16 (Tucker-Drob et al., 2013), lifestyle factors-such as sedentary behavior (SB) have recently
17 received increasing attention (Mallawaarachchi et al., 2024). SB is defined as any waking
18 activity characterized by relatively low energy expenditure (≤ 1.5 METs) while in a sitting,
19 reclining, or lying position (Tremblay et al., 2017; Pinto et al., 2023) has emerged as a key
20 lifestyle factor influencing cognition in childhood although the complex relationships with
21 cognition (e.g., the role of moderators) are not fully understood (Mallawaarachchi et al., 2024;
22 Zou et al., 2024). In particular, SB (e.g., , screen-based activities such as sitting in front of a
23 computer or television screen) can occupy more than 60% of a child's waking hours (Amaral
24 de Andrade Leão et al., 2025). In addition, a recent systematic review with meta-analysis
25 indicated that globally 44% of children aged between 2 to 5 years typically spend more than
26 2 hours per day in screen-based SB (McArthur et al., 2022).

27 Given the high prevalence of screen-based SB, its associations with cognitive measures has
28 been extensively investigated (Lubans et al., 2008; Tremblay et al., 2011; LeBlanc et al.,
29 2012; Carson et al., 2015, 2016; Chaput et al., 2017; Wiley et al., 2021). However, Zou et
30 al.'s (2024) review on the influence of screen-based SB on cognition yielded mixed results
31 for vulnerable populations such as children. For example, some cross-sectional and
32 longitudinal studies reported a negative association between the duration or frequency of TV
33 watching with attention and learning abilities in children (Johnson et al., 2007; Landhuis et
34 al., 2007), whereas such negative associations were not observed in other studies (Munasib
35 & Bhattacharya, 2010; Ruiz et al., 2010). Furthermore, a longitudinal study observed that
36 more time spent on screen-based SB (i.e., video game playing) was associated with more
37 pronounced attention problems in children (Swing et al., 2010), whereas non-significant
38 associations were observed for other cognitive measures (e.g., verbal, numeric, and
39 reasoning abilities) (Ruiz et al., 2010). Such mixed findings preclude firm conclusions
40 concerning screen-based SB's influence on children's cognition. Thus, further research is
41 necessary to provide more conclusive evidence to inform relevant stakeholders (e.g.,
42 policymakers, and teachers).

43 The mixed observations outlined above are likely to be driven by the influence of moderators
44 such as SB dosage (e.g., frequency and duration of SB), SB type (mentally passive SB such
45 as TV watching versus mentally active SB such as video game playing), or sex (boys versus
46 girls) (Hallgren et al., 2020; Mallawaarachchi et al., 2024; Zou et al., 2024). For example,
47 recent findings suggest that engaging in less than 2 hours of daily screen-based SB is
48 associated with additional health and developmental benefits (e.g., improved academic
49 achievement) (Allee et al., 2024; Saunders et al., 2014). In line with the displacement
50 hypothesis (Hofferth, 2010; Kostyrka-Allchorne et al., 2017), prolonged exposure to SB is
51 likely to reduce the time spent on activities that benefit cognitive development such as
52 physical activity or sleep (Erickson et al., 2019; Mason et al., 2021). Thus, the literature
53 supports the view that the duration of SB should be considered as an important moderator.
54 Further, there is growing evidence that SB typology (i.e., mentally active vs. mentally passive)

55 differentially influences cognition. Mentally active SB requires higher cognitive engagement
56 (e.g., computer use, electronic gaming), while mentally passive SB involves less cognitive
57 engagement (e.g., TV-watching) (Hallgren et al., 2020; Mallawaarachchi et al., 2024; Zou
58 et al., 2024). However, large-scale investigations considering such moderators in addition to
59 the role of sex when investigating the relationship between SB and cognitive development
60 are absent from the literature, particularly during the critical 5–7-year developmental period
61 (Zimmerman & Christakis, 2005; Allee et al., 2024; Mallawaarachchi et al., 2024; Zou et al.,
62 2024). Despite its importance, this transitional developmental stage has received
63 comparatively little attention in contemporary research practice compared to preschool or
64 later childhood. Thus, the 5-7 developmental period should be focused on in future research
65 (Carson et al., 2015, 2016; Zhu et al., 2024)

66 To address these gaps, this study investigated the prospective associations between screen-
67 based SB at the age of 5 years and cognitive performance at the age of 7 years and
68 focused on three key domains: math, reading, and spatial reasoning. By utilizing longitudinal
69 data from the UK Millennium Cohort Study (MCS), we examined how SB type (active vs.
70 passive), SB duration (1–7 hours/day), and sex differences interact to influence cognitive
71 outcomes. These findings aim to provide actionable evidence for public health strategies and
72 educational interventions targeting cognitive development during this pivotal developmental
73 period.

74 **2. Methods**

75 *2.1 Cohort design and sample*

76 Data were drawn from the longitudinal MCS. The MCS is a nationally representative,
77 multidisciplinary, observational cohort study established to follow the lives of children born
78 around the turn of the 21st century. The study recruited 18,552 families (18,818 children) in
79 the first wave and included seven waves of data collection at ages 9 months, 3, 5, 7, 11, 14,
80 and 17 years (Ian Plewis et al., 2007), with data collection for the 23-year-old cohort currently
81 underway. The MCS entails a wide range of health-related data, as well as measures of child

82 development, cognitive abilities, and educational attainment (Connelly & Platt, 2014).
83 Additionally, the MCS includes rich social, economic, and demographic information about the
84 cohort members and their families and links these data to administrative resources, such as
85 health records. The MCS serves as a unique and valuable resource for analyzing health
86 outcomes and inequalities, offering significant insights into the early determinants of later life
87 outcomes. In the present study, relevant data collected at age 5 (Wave 3) and age 7 (Wave
88 4) were used to examine the relationships between screen-based SB at age 5 and cognitive
89 measures at age 7. The dataset is freely accessible to researchers through the UK Data
90 Service <http://ukdataservice.ac.uk>, with detailed information about the study available on the
91 MCS website <http://www.cls.ioe.ac.uk/mcs>.

92
93 [Insert Figure 1]

94 *2.2 Screen-based SB at age 5 (Independent variables)*

95 SB at age 5 was assessed using data from the parents' interviews conducted at wave 3.
96 Specifically, parents rated the amount of time their children spent on SB types, including TV
97 watching and computer use/playing electronic games (hereafter referred to as computer
98 use/e-gaming). For example, in terms of TV watching, parents were asked: "On a normal
99 weekday during term time, how many hours does your child spend watching television, videos,
100 or DVDs? Please remember to include time before school as well as time after school."
101 Additionally, in terms of computer use/e-game playing, parents were asked "On a normal
102 weekday during term time, how many hours does your child spend using a computer or
103 playing electronic games outside of school lessons? Please remember to include time before
104 and after school". In this study, responses of the above-presented questions were rated on a
105 6-point scale, with being operationalized as follows: 1 = none, 2 = less than an hour, 3 = 1
106 hour to less than 3 hours, 4 = 3 hours to less than 5 hours, 5 = 5 hours to less than 7 hours,
107 and 6 = 7 hours or more (NatGen, 2006).

108 *2.3 Cognitive performance assessment at age 7 (dependent variables)*

109 Cognitive performance was assessed via word reading, pattern construction, and
110 mathematical tests. Specifically, word reading and pattern construction were measured via
111 the age-appropriate version of the British Ability Scales II (BAS-II) (Hill, 2005), whereas
112 mathematical skills and knowledge were evaluated using the modified version of the Progress
113 in Maths test (PiM) (NatCen, 2006). The above-presented cognitive tasks are widely used in
114 educational psychology research, and the procedures and scoring for each task are detailed
115 in Supplementary File 2.

116 *2.4 Covariates*

117 Previous studies indicated cognitive development correlated with age (Luo et al., 2023),
118 ethnicity (Zhang et al., 2017), the number of siblings (Symeonides et al., 2021; Neufeld et al.,
119 2024), body mass index (BMI, kg/m²) of participant (Veldwijk et al., 2011; Hansen et al., 2022)
120 and biological mother (West et al., 2023), maternal mental health (Aranbarri et al., 2023;
121 Kwon et al., 2023), maternal educational level (Tamayo Martinez et al., 2022; Xu et al., 2023;
122 Liu et al., 2024), regular bedtime (Kelly et al., 2013), poverty level (Aranbarri et al., 2023),
123 general health of participant (Sui et al., 2021) and biological mother (Pugh et al., 2015),
124 cognitive assessments (raw scores) at 5 years (Zhou & Tolmie, 2024), the number of days
125 spent on in PA engagement per week (Chacón-Cuberos et al., 2020; Brazendale et al., 2021;
126 Latino & Tafuri, 2024), the frequency of engaging in PA along with parent(s) (Rhodes et al.,
127 2020; Latino & Tafuri, 2024), and emotional and behavioral problems of participants (Bowe
128 et al., 2021; Tsomokos & Flouri, 2024). To this end, these above-mentioned variables are
129 considered as covariates in the present study. Given that screen-based SB usually changes
130 over time, such behavior (i.e., time spent on TV watching and computer use/e-game playing)
131 at 7 years old was retrieved and considered as covariates to maximize internal validity.
132 Information for these variables is detailed in Supplementary File 2.

133 *2.5 Statistical analyses*

134 We conducted analyses using a total of 12,257 (Boys = 6178, Girls = 6079) valid samples,
135 longitudinally tracking the same participants from ages 5 to 7 years. Rigorous assessments

136 and handling of missing data were conducted (García-Laencina et al., 2010; Jadhav et al.,
137 2019; Ren et al., 2023; Quesada & Orozco-Beltran, 2025), including multiple imputations
138 utilizing Predictive Mean Matching (PMM) with 55 imputations, ensuring robust and reliable
139 imputation outcomes (See details in Supplementary File 7). Survey weights were applied to
140 account for our clustered sampling design, enhancing the representativeness of our results.

141 To examine whether associations between SBs and cognitive outcomes differed by sex, we
142 first conducted interaction analyses. Given the significant interaction effects observed, we
143 proceeded with sex-stratified analyses to provide more detailed insights. Descriptive statistics
144 characterizing the sample are presented in Table 1, and all statistical analyses were stratified
145 by sex. Our analytical approach underwent comprehensive sensitivity tests confirming the
146 stability and robustness of key findings across multiple model specifications and thereby
147 supported the scientific rigor and statistical reliability of our results. All analyses were
148 conducted using Stata 18.0 (StataCorp, 2023), with statistical significance defined as $p <$
149 0.05. (See details in supplementary Files 3-22).

150 [Insert Figure 2]

151 **3. Results**

152 **3.1 Participant Characteristics**

153 At age 5, significant sex differences were observed in BMI of cohort member (CM) ($p = 0.032$),
154 SDQ (Total score) ($p < 0.001$), Naming Vocabulary Raw Score ($p < 0.05$), Pattern
155 Construction Raw Score ($p < 0.001$), Picture Similarities Raw Score ($p < 0.001$), General
156 Health of CM (i.e., Fair, $p = 0.001$; Good, $p = 0.001$), Maternal General Health (i.e., Fair, $p =$
157 0.012), PA Days (i.e., One day a week, $p = 0.04$; Two days a week, $p < 0.001$; Three days a
158 week, $p < 0.001$; Four days a week, $p < 0.001$), PA Frequency (i.e., At least once a month, p
159 = 0.004; Every day or almost every day, $p = 0.011$). Non-significant findings for other
160 participant characteristics are presented in Table 1.

161 At age 5, significant sex differences were observed concerning the daily time spent on
162 computer use/e-game playing (i.e., None, $p < 0.001$; 1 hour to less than 3 hours, $p < 0.001$; 3
163 hours to less than 5 hours, $p < 0.001$; 5 hours to less than 7 hours, $p = 0.002$; 7 hours or more,
164 $p = 0.014$), and TV-watching (i.e., None, $p = 0.048$; Less than an hour, $p < 0.001$). At age 7,
165 significant sex differences were observed concerning the daily time spent on computer use/e-
166 game playing (i.e., 1 hour to less than 3 hours, $p < 0.001$; 3 hours to less than 5 hours, $p <$
167 0.001 ; 5 hours to less than 7 hours, $p = 0.013$; 7 hours or more, $p < 0.001$), and TV-watching
168 (i.e., Less than an hour, $p = 0.045$, 3 hours to less than 5 hours, $p = 0.007$; 7 hours or more,
169 $p = 0.003$), respectively. Significant sex differences on two cognitive measures were also
170 observed and included pattern construction ($p = 0.027$), and word reading performance ($p <$
171 0.001).

172 [Insert Table 1]

173 **3.2 Prospective associations between screen-based SB and word reading**

174 Table 2 provides an overview of the associations between screen-based SB types at the age
175 of 5 years and word reading at the age of 7 years. As compared to children who did not
176 engage in screen-based SB, computer use/e-game playing for less than 1 hour ($\beta = 0.148$,
177 95% CI: 0.081 to 0.215, $p < 0.001$), and 1 hour to less than 3 hours ($\beta = 0.209$, 95% CI: 0.128
178 to 0.290, $p < 0.001$) per day were significantly associated with better performance on word
179 reading among boys. In contrast, there were no significant associations observed among girls.

180 [Insert Table 2]

181 **3.3 Prospective associations between screen-based SB and pattern construction**

182 Table 3 provides an overview of the associations between screen-based SB types at the age
183 of 5 years and pattern construction at the age of 7 years. No significant associations were
184 observed for both girls and boys.

185 [Insert Table 3]

186 **3.4 Prospective associations between screen-based SB and math**

187 Table 4 shows the associations between screen-based SB types at the age of 5 years and
188 mathematical performance at the age of 7 years. For boys, computer use/e-game playing for
189 less than 1 hour ($\beta = 0.179$, 95% CI:0.120 to 0.237, $p < 0.001$), and 1 hour to less than 3
190 hours ($\beta = 0.181$, 95% CI:0.101 to 0.261, $p < 0.001$) per day were associated with better
191 mathematical skills and knowledge. Conversely, computer use/e-game playing 7 hours or
192 more per day ($\beta = -0.356$, 95% CI:-0.698 to -0.134, $p = 0.041$) was associated with worse
193 mathematical skills and knowledge. For girls, TV-watching for 1 hour to less than 3 hours (β
194 = -0.224, 95% CI:-0.383 to -0.065, $p = 0.006$), 3 hours to less than 5 hours ($\beta = -0.211$, 95%
195 CI:-0.385 to -0.038, $p = 0.017$), and 7 hours or more ($\beta = -0.257$, 95% CI:-0.461 to -0.053, p
196 = 0.014) per day were associated with worse mathematical skills and knowledge. All reported
197 associations are in comparison to children who did not engage in any screen-based SB
198 (reference group).

199 [Insert Table 4]

200 **4. Discussion**

201 We examined the prospective associations of type and duration of screen-based SB at the
202 age of 5 years and cognitive performance at the age of 7 years, followed by a sex-stratified
203 analysis. Duration of the time spent on mentally active SB (i.e., computer use/e-game playing)
204 was associated with better performance on word reading and math among boys. For girls,
205 the duration of the time spent on mentally passive SB (i.e., TV watching) was associated with
206 worse performance in math. Such findings are consistent with evidence that mentally active
207 SB can benefit cognition, whereas mentally passive SB does not confer a similar benefit
208 (Hallgren et al., 2020; Mallawaarachchi et al., 2024; Zou et al., 2024).

209 *4.1 Linking Screen-based SB to Word Reading*

210 Word reading is recognized as one of the most important predictors of academic success,
211 social communication, and well-being in early childhood and has been extensively
212 investigated in recent years (Lee, 2011; Ramsook et al., 2020). Such research has a key
213 concern with elucidating the role of modifiable (risk and protective) factors influencing word

214 reading performance to identify promising intervention approaches to foster the development
215 of this cognitive ability early in life (Perdue et al., 2022). In line with several recent reviews
216 (Takahashi et al., 2023; Mallawaarachchi et al., 2024; Zou et al., 2024), the main findings
217 from the present study indicated: (1) positive associations between mentally active SB with
218 performance on word reading among boys only, with no significant associations observed for
219 girls, and (2) a negative association between mentally passive SB and (what cognitive
220 domain). The positive association between mentally active SB and word reading performance
221 is perhaps related to the fact that reading activities/instructions embedded within computer
222 use/e-gaming supports supplementary alphabetic, and/or reading fluency skills (Arndt, 2016;
223 Verhoeven et al., 2022). In contrast, prolonged TV watching (i.e., passive SB) is associated
224 with adverse attentional control and may negatively influence the ability to concentrate on
225 reading (e.g., word reading accuracy and fluency) (Furenes et al., 2021). These findings are
226 in line with the Cognitive Engagement Theory stating that cognitively stimulating activities
227 (e.g., computer use and e-game playing) promote learning (Ke et al., 2016). In contrast, the
228 negative association observed for TV-watching may reflect the displacement of cognitively
229 enriching experiences, as proposed by the Displacement Hypothesis (Hofferth, 2010), that is,
230 prolonged engagement in passive screen time limits opportunities for interactive and
231 developmentally beneficial activities (e.g., reading or social interaction).

232 Sex-stratified analyses indicated that daily computer use/e-game playing for less than 1 hour,
233 and 1 hour to less than 3 hours per day were beneficially associated with word reading among
234 boys. Such findings support the notion that there is a “sweet spot” (i.e., specific dosage) to
235 achieve a balanced daily time-use behavior wherein the time spent for one behavior (i.e.,
236 mentally active SB) does not lead to a displacement of time that can be spent on other
237 behaviors (i.e., physical activity, and sleep) – a balance that may potentially benefit cognitive
238 development. From a public health perspective, these findings may inform more tailored
239 strategies to optimize children’s screen use patterns. The findings from this study suggest
240 potential guidelines for screen time that may vary by screen type and child sex. For boys, the
241 data indicate that limiting recreational computer/e-game play to less than 3 hours per day

242 may support cognitive development, whereas for girls, who demonstrated greater sensitivity
243 to TV exposure in the analyses, reducing television viewing to under 1 hour on a typical
244 weekday appears potentially beneficial. Moreover, such recommendations should be
245 considered within the broader context of movement behavior balance including sufficient
246 physical activity, adequate sleep, and reduced sedentary time (Tremblay et al., 2016)
247 Additionally, intermittent and purposeful use of computer/e-game play that integrates
248 educational content may be beneficial and is therefore encouraged (Reynaldo et al., 2021).

249 *4.2 Linking Screen-based SB to Pattern Construction*

250 In contrast to word reading, no statistically significant associations were found between
251 screen-based SB and spatial abilities (as measured by the Pattern Construction test). For
252 boys, no significant associations were observed between computer use/e-game playing and
253 spatial abilities. For girls, although spending 3-5 hours on computer/e-game playing showed
254 a trend for a positive association with better spatial abilities ($\beta = 0.214$, 95% CI: -0.001 to
255 0.428, $p = 0.051$), this result did not attain a conventional level of statistical significance.
256 These finding suggests that spatial abilities are less sensitive to the influence of SB, and adds
257 to the finding that in preschoolers non-screen-based active SB is associated with higher
258 visual-spatial performance in girls (D. Li et al., 2024). However, given that the current
259 evidence on the effects of specific lifestyle behaviors (e.g., SB or PA) on spatial abilities is less
260 developed than other cognitive abilities (e.g., executive functions), future research in this
261 direction is required before more robust conclusions can be drawn.

262 *4.3 Linking Screen-based SB to Math*

263 Mathematical knowledge and reasoning have been widely recognized to play a critical role in
264 academic performance and future career success (Cahoon et al., 2021; Davis-Kean et al.,
265 2022). The main findings of this study suggest that computer use/electronic game play and
266 TV watching are positively and negatively associated with math performance, respectively.
267 Our findings are partially consistent with findings of a systematic review with meta-analysis
268 indicating that mentally active SB is associated with better cognition, whereas mentally

269 passive SB does not confer similar benefits (Mallawaarachchi et al., 2024). It is possible that
270 that distinct neural activation patterns between mentally passive and mentally active SB may
271 explain our behavioural observations. In particular, the positive association between mentally
272 active SB and cognitive performance may be explained by evidence suggesting that video
273 game play engages higher cognitive resources (e.g., increased activity within prefrontal
274 cortical networks supporting executive function) than that associated with TV watching
275 (Choi et al., 2020; Jordan & Dhamala, 2022). Neuroimaging studies have shown that playing
276 electronic games activates several key brain regions including the prefrontal cortex
277 (associated with executive function and attention control), parietal cortex (linked to spatial
278 attention and visuomotor coordination), cingulate cortex (involved in conflict monitoring and
279 cognitive control), hippocampus (supporting spatial memory and navigation), and occipital
280 cortex (responsible for visual processing) (Choi et al., 2020). In contrast, TV watching
281 typically elicits less activation in these regions, particularly in prefrontal areas responsible for
282 executive functions. Thus, mentally active SB may stimulate adaptive brain processes
283 benefiting the development of strategic thinking, spatial awareness, and multitasking abilities-
284 skills closely related to mathematical knowledge and reasoning (Choi et al., 2020; Jordan &
285 Dhamala, 2022).

286 Sex-stratified analyses indicated that: (1) computer use/e-game playing for less than 1 hour,
287 and 1 hour to less than 3 hours per day were associated with better mathematical
288 performance among boys; (2) daily computer use/e-game playing for 7 hours or more was
289 associated with lower mathematical performance among boys; (3) TV-watching for all
290 categories of duration was associated with lower mathematical performance among girls for
291 all but two categorical groups (i.e., less than 1 hour, 5 to less than 7 hours per day). In terms
292 of dose-response, as a recent guideline recommends less than 2 hours of daily screen time
293 to improve overall health (Tremblay et al., 2016), children in the present study who spent less
294 than 1 hour on mentally passive (SBs were marginally linked to worse mathematical
295 performance. Non-significant findings for another categorical group (i.e., 5 to less than 7
296 hours of SB per day) may be attributed to the relatively small sample size of 115 children

297 (Greenland et al., 2016). Taken together, the results of the current study suggest that the
298 duration of screen-based SB (i.e., computer use/e-game playing) should be limited to not
299 more than 3 hours on a typical day among boys and would be ideally interrupted with
300 sedentary breaks (i.e., brief bouts of physical activity that break up periods of prolonged sitting)
301 (Owen et al., 2020; Chueh et al., 2022; J. Li et al., 2022; Yu et al., 2025, 2022; Pinto et al.,
302 2023). Likewise, when children engage in screen-based SB (i.e., concerning educational
303 content), mentally active SB with a high task relevance (i.e., educational content) should be
304 encouraged because such content may benefit cognitive development.

305 **5. Study strengths and limitations**

306 A strength of the current study is the prospective analysis of the association between SB and
307 cognition in a nationally representative sample of children considering moderators such as
308 SB duration (i.e., refined into categorical dimensions of 1-7 hours), SB type, and sex, and a
309 broad set of important covariates. However, the following limitations should be considered
310 when interpreting the findings of the present study. First, in the relatively short follow-up
311 period of two years the negative effects of SB may not have been manifested in measurable
312 changes in cognition. Second, all assessments were self-reported by the children's caregiver
313 making them somewhat prone to a social desirability bias. Third, the separation of the
314 influence of internet use from that of video game playing was not possible because such
315 differentiation is absent from the original survey. Thus, we cannot rule out whether our
316 observations are driven by a single factor (e.g. either computer use or playing video games)
317 or the interaction of several factors. Fourth, although we adjusted for a range of covariates,
318 there remains the possibility that unmeasured confounders such as parental history of mental
319 disorders and multi-task-induced cognitive load may affect our observations (Zou et al., 2025).
320 Fifth, the baseline cognitive tests were not the same as the follow-up tests which could
321 contribute to residual confounding. Sixth, the exact content of media use was not assessed
322 in the original survey (i.e., relevance to the cognitive assessments), including the absence of
323 items querying for newer forms of screen exposure such as smartphones and iPads.

324 Therefore, it remains open whether the content of computer use, playing video games, and
325 TV watching may moderate or confound the observed associations with cognition.

326 **6. Conclusions**

327 Our study provides evidence that less than 3 hours per day of mentally active SB – computer
328 use or playing video games - is positively associated with mathematical and word reading
329 performance among boys, while TV watching for over 1 hour per day is associated with lower
330 mathematical performance among girls. Thus, our findings support the assumption that future
331 interventions and policies aiming to promote children’s cognitive development should
332 consider sex differences and focus on limiting the time spent on on mentally passive SB (e.g.,
333 TV watching) to achieve an age-appropriate balance between different movement behaviors.

334

335 **Declaration of generative AI and AI-assisted technologies in the writing process**

336 During the preparation of this work, the author(s) used ChatGPT (OpenAI) solely to assist in
337 improving the grammar, clarity, and overall readability of the manuscript. The tool was not
338 used to generate scientific content, conduct data analysis, or draw research conclusions. All
339 outputs from ChatGPT were carefully reviewed and edited under human oversight. The
340 author(s) take full responsibility for the content and integrity of the final published article.

Journal Pre-proof

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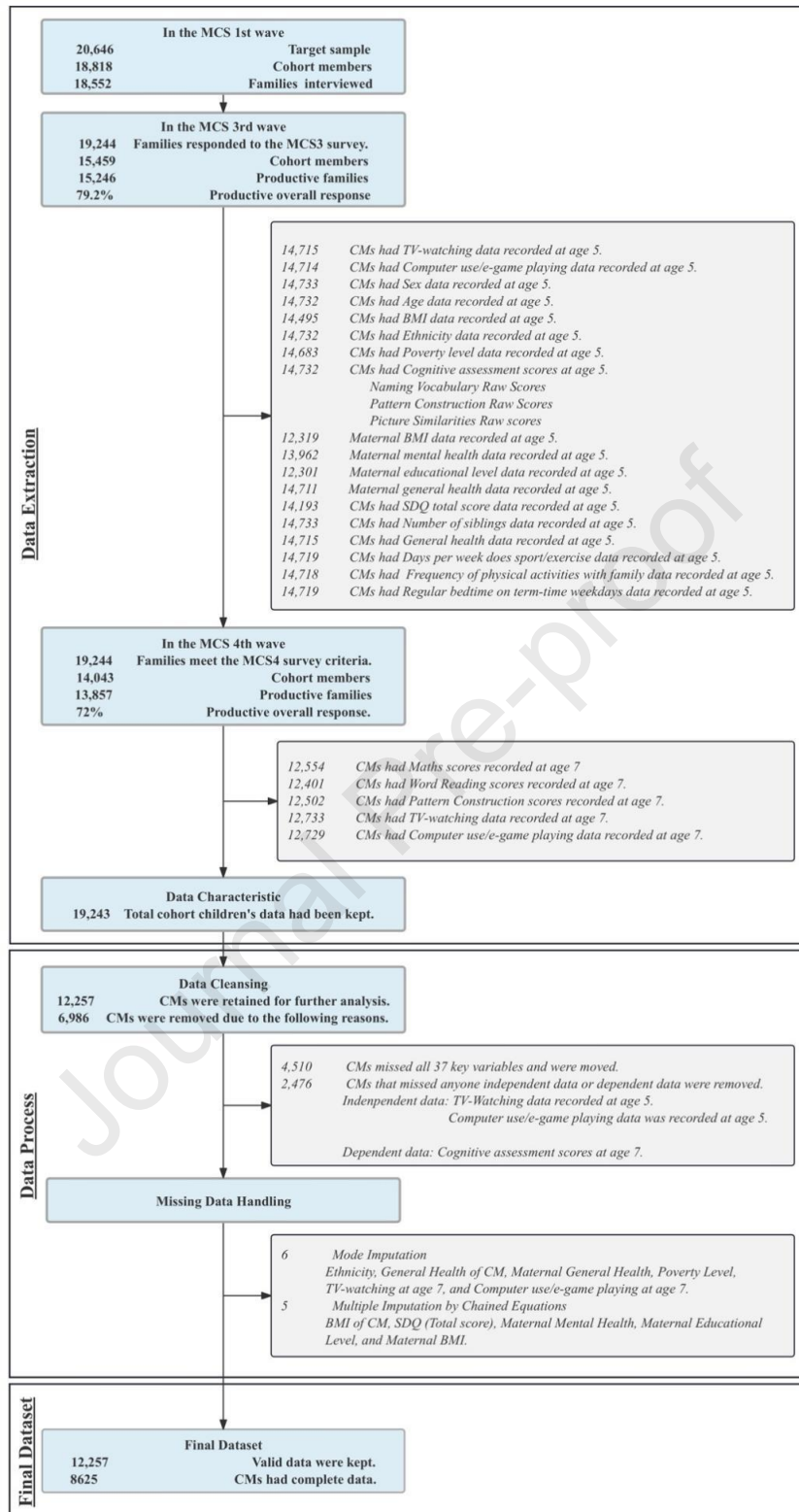
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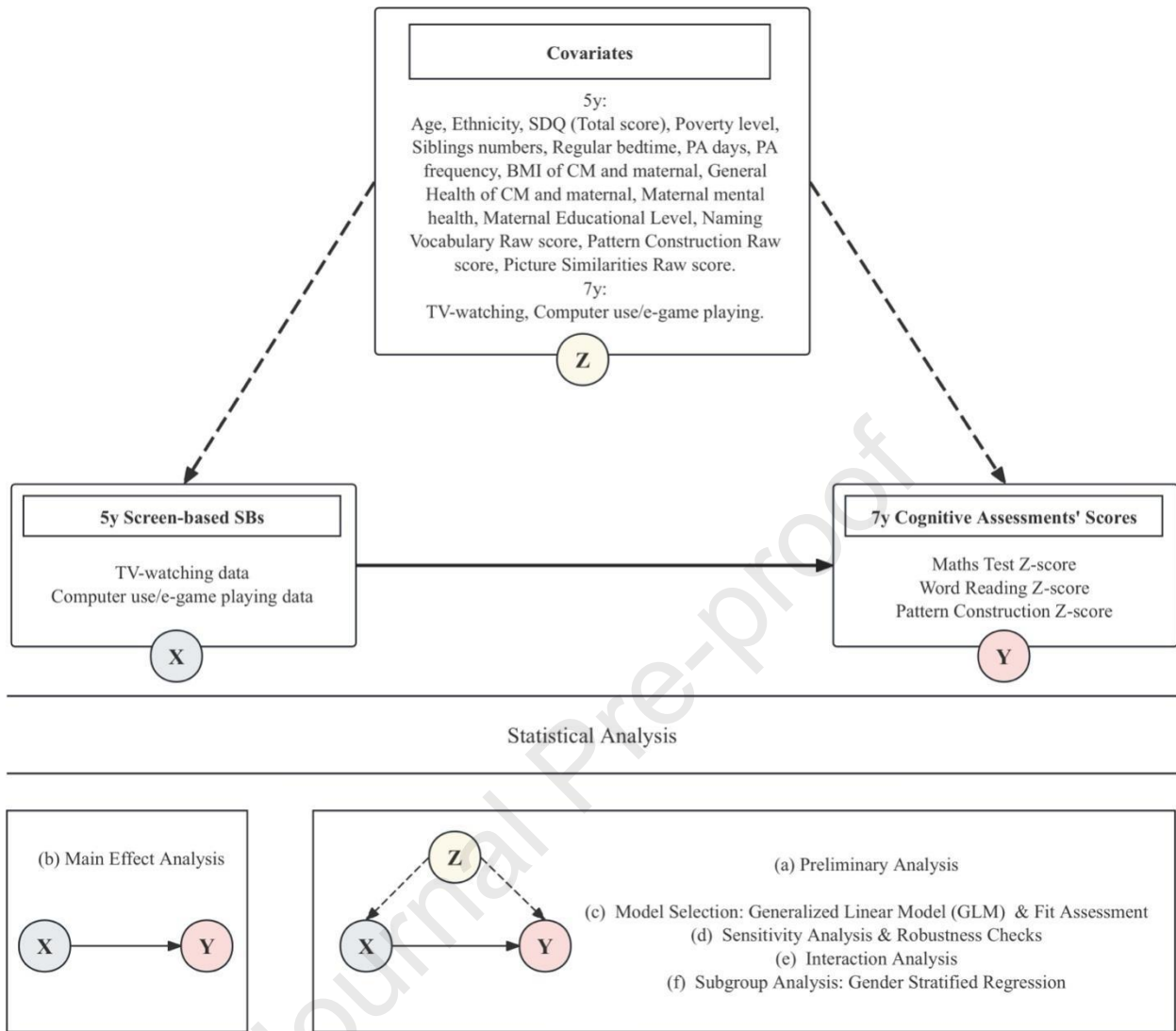


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667 Note: BMI = Body Mass Index, CM = Cohort Member, MCS = Millennium Cohort Study, SDQ = The Strengths and Difficulties
 668 Questionnaire.

669

Figure 1 Flowchart of Data Extraction



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671 Note: BMI = Body Mass Index, CM = Cohort Member, PA = Physical activity, SDQ = The Strengths and Difficulties
 672 Questionnaire, SB = Sedentary behavior, Z-score = Standard Score.

673

Figure. 2 Statistical analysis chart

Table 1. Weighted and imputed descriptive characteristics of the sample stratified by sex

Characteristics	Boys (n=6178)		Girls (n=6079)		<i>p</i>
	N (%)	Mean (Std. err.)	N (%)	Mean (Std.err.)	
5 y					
Age (days)		1,901.57 (1.83)		1,901.79 (1.72)	0.908
BMI of CM, kg/m ²		16.37 (0.03)		16.29 (0.03)	0.032*
Maternal BMI, kg/m ²		25.18 (0.08)		25.19 (0.09)	0.948
SDQ (Total score)		7.89 (0.08)		6.82 (0.10)	<0.001**
Maternal Mental Health		3.24 (0.06)		3.23 (0.07)	0.958
Naming Vocabulary Raw Score		14.32 (0.08)		14.58 (0.09)	0.001**
Pattern Construction Raw Score		17.93 (0.18)		19.36 (0.18)	<0.001**
Picture Similarities Raw Score		15.45 (0.09)		15.88 (0.08)	<0.001**
Poverty Level					
Above 60% median	4,307 (69.71)		4,154 (68.33)		(reference)
Below 60% median	1,871 (30.29)		1,925 (31.67)		0.161
Siblings (numbers)					
0	1,018 (16.47)		1,005 (16.53)		0.750
1	3,013 (48.76)		2,922 (48.07)		(reference)
2	1,402 (22.69)		1,481 (24.37)		0.073
3	525 (8.50)		472 (7.76)		0.330
4	141 (2.29)		125 (2.06)		0.538
5	57 (0.93)		50 (0.83)		0.653
6-12	22 (0.35)		24 (0.39)		0.707
Ethnicity					
White	5,371 (86.94)		5,272 (86.73)		(reference)
Black or Black British	193 (3.13)		171 (2.81)		0.474
Indian	126 (2.04)		107 (1.76)		0.346
Pakistani and Bangladeshi	240 (3.88)		256 (4.21)		0.333
Mixed	180 (2.91)		203 (3.34)		0.258
Other Ethnic group	68 (1.10)		70 (1.15)		0.823
Regular Bedtime					
Almost never	272 (4.40)		291 (4.79)		0.254
Sometimes	307 (4.97)		336 (5.53)		0.168
Usually	1,631 (26.40)		1,655 (27.23)		0.256
Always	3,968 (64.24)		3,797 (62.45)		(reference)
General Health of CM					
Poor	36 (0.58)		36 (0.59)		0.889
Fair	246 (3.99)		170 (2.80)		0.001**
Good	844 (13.66)		740 (12.18)		0.001**

Very good	1,947 (31.51)	1,908 (31.39)	0.242
Excellent	3,105 (50.26)	3,225 (53.05)	(reference)
Maternal General Health			
Poor	177 (2.86)	166 (2.73)	0.784
Fair	633 (1.03)	728 (11.98)	0.012*
Good	1,834 (29.68)	1,719 (28.27)	0.462
Very good	2,305 (37.31)	2,241 (36.86)	(reference)
Excellent	1,229 (19.89)	1,225 (20.15)	0.627
Maternal Educational Level			
NVQ level 1	708 (11.46)	653 (10.75)	0.230
NVQ level 2	2,222 (37.41)	2,274 (37.41)	Base
NVQ level 3	1,072 (17.35)	1,014 (16.68)	0.245
NVQ level 4	1,941 (31.41)	1,907 (31.37)	0.466
NVQ level 5	235 (3.81)	231 (3.79)	0.696
PA Days			
Less often or not at all	3,063 (49.56)	2,619 (43.07)	(reference)
One day a week	1,786 (28.91)	1,680 (27.63)	0.040*
Two days a week	874 (14.15)	1,077 (17.72)	<0.001**
Three days a week	309 (5.00)	518 (8.52)	<0.001**
Four days a week	89 (1.45)	143 (2.36)	<0.001**
Five or more days a week	57 (0.93)	42 (0.07)	0.484
PA Frequency			
Less often or never	683 (1.11)	708 (1.17)	0.402
At least once a year	79 (1.27)	92 (1.51)	0.339
Every few months	295 (4.78)	325 (5.34)	0.233
At least once a month	830 (13.44)	977 (16.06)	0.004*
Once or twice a week	2,411 (39.03)	2,364 (38.89)	(reference)
Several times a week	1,107 (17.91)	978 (16.09)	0.111
Every day or almost every day	773 (12.51)	635 (10.45)	0.011*
Computer use/e-game playing Time at age 5			
None	1,750 (28.33)	2,212 (36.38)	<0.001**
Less than an hour	2,687 (43.49)	2,794 (45.96)	(reference)
1 hour to less than 3 hours	1,509 (24.42)	956 (15.72)	<0.001**
3 hours to less than 5 hours	134 (2.17)	72 (1.18)	<0.001**
5 hours to less than 7 hours	45 (0.73)	18 (0.30)	0.002*
7 hours or more	53 (0.86)	27 (0.45)	0.014*
TV-watching Time at age 5			
None	94 (1.53)	122 (2.01)	0.048*
Less than an hour	1,059 (17.15)	1,258 (20.70)	<0.001**

1 hour to less than 3 hours	4,054 (65.62)	3,851 (63.34)	(reference)
3 hours to less than 5 hours	624 (10.10)	564 (9.28)	0.533
5 hours to less than 7 hours	140 (2.26)	115 (1.90)	0.257
7 hours or more	207 (3.34)	169 (2.77)	0.228
7 y			
Maths Z-score		0.03 (0.03)	0.01 (0.02) 0.299
Pattern Construction Z-Score		-0.01 (0.02)	0.03 (0.02) 0.027*
Word Reading Z-Score		-0.04 (0.02)	0.13 (0.02) <0.001**
Computer use/e-game playing Time at age 7			
None	593 (9.56)	832 (13.69)	0.082
Less than an hour	2,906 (47.02)	3,613 (59.42)	(reference)
1 hour to less than 3 hours	2,330 (37.72)	1,496 (24.61)	<0.001**
3 hours to less than 5 hours	259 (4.20)	95 (1.56)	<0.001**
5 hours to less than 7 hours	44 (0.72)	29 (0.47)	0.013*
7 hours or more	46 (0.75)	14 (0.24)	<0.001**
TV-watching Time at age 7			
None	112 (1.81)	109 (1.78)	0.839
Less than an hour	1,029 (16.67)	1,144 (18.82)	0.045*
1 hour to less than 3 hours	3,990 (64.59)	3,983 (65.51)	(reference)
3 hours to less than 5 hours	726 (11.76)	607 (9.99)	0.007*
5 hours to less than 7 hours	141 (2.28)	114 (1.88)	0.118
7 hours or more	180 (2.91)	122 (2.01)	0.003*

Note: BMI = Body Mass Index, CM = Cohort Member, NVQ = National Vocational Qualifications, PA Days = Number of Days the Participant Engages in Physical Activities, PA Frequency = Frequency of Physical Activities Jointly Engaged by the Participant and One Parent, SDQ = Strengths and Difficulties Questionnaire, Std. err. = Standard Error.

The reported p value is for sex differences. ① p values for continuous variables (i.e., Age, BMI of CM, Maternal BMI, SDQ (Total score), Maternal Mental Health, Naming Vocabulary Raw Score, Pattern Construction Raw Score, Picture Similarities Raw Score, Maths Z-score, Pattern Construction Z-score, Word Reading Z-score) were obtained from survey-adjusted linear regression models (mi estimate: svy: regress), which accounted for multiple imputations and complex survey design. ② p values for categorical variables (i.e., Poverty Level, Siblings, Ethnicity, Regular Bedtime, General Health of CM, Maternal General Health, Maternal Educational Level, PA Days, PA Frequency, Computer use/e-game playing Time, TV-watching Time) were derived from survey-adjusted multinomial logistic regression (mi estimate: svy: mlogit) or logistic regression (mi estimate: svy: logistic), depending on the number of outcome categories. ③ “(reference)” indicates the reference group against which other categories are compared. Reference categories are selected to facilitate interpretation of statistical comparisons and to avoid multicollinearity in regression analyses.

All analyses were conducted using multiple imputation by chained equations (MICE) with 55 imputations, using predictive mean matching (PMM) as the imputation model, and survey weighting to account for the complex sample design.

* $p < 0.05$; ** $p < 0.001$ indicate statistical significance

Table 2. Associations between different types of screen-based sedentary behavior at the age of 5 years and word reading score at the age of 7 years

Word Reading Z-Score at 7 years	Boys		Girls	
	P	β (95% CI)	P	β (95% CI)
Computer use/e-game playing Time at age 5				
None	(reference)	(reference)	(reference)	(reference)
Less than an hour	<0.001**	0.148 (0.081 to 0.215)	0.612	0.012 (-0.034 to 0.058)
1 hour to less than 3 hours	<0.001**	0.209 (0.128 to 0.290)	0.909	-0.004 (-0.081 to 0.072)
3 hours to less than 5 hours	0.067	0.155 (-0.011 to 0.322)	0.164	0.187 (-0.077 to 0.451)
5 hours to less than 7 hours	0.142	0.243 (-0.082 to 0.568)	0.868	-0.037 (-0.472 to 0.398)
7 hours or more	0.071	0.417 (-0.035 to 0.870)	0.594	-0.072 (-0.338 to 0.193)
TV-watching Time at age 5				
None	(reference)	(reference)	(reference)	(reference)
Less than an hour	0.540	0.058 (-0.127 to 0.243)	0.703	0.035 (-0.145 to 0.215)
1 hour to less than 3 hours	0.988	0.001 (-0.177 to 0.180)	0.715	-0.032 (-0.204 to 0.140)
3 hours to less than 5 hours	0.890	-0.014 (-0.209 to 0.181)	0.402	-0.082 (-0.273 to 0.110)
5 hours to less than 7 hours	0.932	0.009 (-0.209 to 0.228)	0.650	0.064 (-0.212 to 0.340)
7 hours or more	0.172	-0.165 (-0.403 to 0.072)	0.104	-0.177 (-0.391 to -0.036)

Note: *Significance at the .05 level; **Significance at the .01 level. Z-Score = Standard Score.

Table 3. Associations between different types of screen-based sedentary behavior at the age of 5 years and Pattern Construction performance at the age of 7 years

Pattern Construction Z-Score at 7 years	Boys		Girls	
	P	β (95% CI)	P	β (95% CI)
Computer use/e-game playing Time at age 5				
None	(reference)	(reference)	(reference)	(reference)
Less than an hour	0.096	0.047 (-0.008 to 0.102)	0.877	-0.004 (-0.053 to 0.045)
1 hour to less than 3 hours	0.274	-0.036 (-0.099 to 0.028)	0.127	-0.057 (-0.131 to 0.016)
3 hours to less than 5 hours	0.230	0.110 (-0.070 to 0.291)	0.051	0.214 (-0.001 to 0.428)
5 hours to less than 7 hours	0.912	0.017 (-0.285 to 0.319)	0.148	-0.266 (-0.627 to 0.095)
7 hours or more	0.1134	-0.237 (-0.548 to 0.073)	0.598	-0.089 (-0.421 to 0.243)
TV-watching Time at age 5				
None	(reference)	(reference)	(reference)	(reference)
Less than an hour	0.264	-0.124 (-0.341 to 0.094)	0.146	-0.132 (-0.310 to 0.046)
1 hour to less than 3 hours	0.577	-0.062 (-0.280 to 0.156)	0.394	-0.075 (-0.249 to 0.098)
3 hours to less than 5 hours	0.554	-0.069 (-0.296 to 0.159)	0.566	-0.055 (-0.241 to 0.132)
5 hours to less than 7 hours	0.869	-0.022 (-0.282 to 0.238)	0.651	-0.050 (-0.266 to 0.166)
7 hours or more	0.517	-0.078 (-0.316 to 0.159)	0.217	-0.146 (-0.377 to 0.086)

Note: *Significance at the .05 level; **Significance at the .01 level. Z-Score = Standard Score.

Table 4. Associations between screen-based sedentary behavior at the age of 5 years and mathematical performance at the age of 7 years

Math Z-Score at 7 years	Boys		Girls	
	P	β (95% CI)	P	β (95% CI)
Computer use/e-game playing Time at age 5				
None	(reference)	(reference)	(reference)	(reference)
Less than an hour	< 0.001**	0.179 (0.120 to 0.237)	0.167	0.034 (-0.014 to 0.083)
1 hour to less than 3 hours	< 0.001**	0.181 (0.101 to 0.261)	0.338	-0.034 (-0.104 to 0.036)
3 hours to less than 5 hours	0.059	0.169 (-0.007 to 0.345)	0.639	0.052 (-0.167 to 0.271)
5 hours to less than 7 hours	0.337	0.159 (-0.166 to 0.484)	0.869	-0.044 (-0.568 to 0.480)
7 hours or more	0.041*	-0.356 (-0.698 to -0.134)	0.356	-0.138 (-0.430 to 0.155)
TV-watching Time at age 5				
None	(reference)	(reference)	(reference)	(reference)
Less than an hour	0.404	0.078 (-0.106 to 0.263)	0.054	-0.162 (-0.337 to 0.003)
1 hour to less than 3 hours	0.191	0.121 (-0.060 to 0.301)	0.006*	-0.224 (-0.383 to -0.065)
3 hours to less than 5 hours	0.262	-0.114 (-0.085 to 0.313)	0.017*	-0.211 (-0.385 to -0.038)
5 hours to less than 7 hours	0.566	0.065 (-0.158 to 0.288)	0.131	-0.190 (-0.437 to 0.057)
7 hours or more	0.107	0.202 (-0.044 to 0.448)	0.014*	-0.257 (-0.461 to -0.053)

Note: *Significance at the .05 level; **Significance at the .01 level. Z-Score = Standard Score.

Highlights

- **Effects of Active Screen Time (Computer use/e-games):** For boys, using a computer use/electronic gaming (-e-game) for less than 3 hours daily at age 5 was associated with better word reading and math performance at age 7. However, usage of 7 hours or more was significantly linked to lower math performance.
- **Impact of Passive Screen Time (TV watching):** In contrast, TV-watching had negative effects, especially for girls. Watching TV for 1 hour to less than 3 hours per day was linked to lower mathematical performance.
- **No Significant Impact on Pattern Construction:** No significant associations were found between screen-based sedentary behaviors (SB) and pattern construction skills for either boys or girls.
- **Gender-Specific Effects:** The cognitive effects of screen-based sedentary behaviors vary significantly based on biological sex. Active SB (e.g., computer use) tended to enhance cognitive functions in boys, while passive SB (e.g., TV-viewing) appeared to have more negative cognitive impacts on girls.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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