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Intelligence-Dependent Differential Effects of Media Exposure on Executive Function Changes in Children: A Population-Based Cohort Study With a Longitudinal Design

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ABSTRACT

Background: Excessive media use is known to be associated with executive dysfunction in children, but it's unclear whether this exposure can lead to long-term changes of executive function. This study aimed to investigate the association between media exposure and longitudinal changes in executive function within a population-based study, while considering the potential influence of intelligence.
Methods: This study used data from 1,209 participants in the Panel Korea Study for Children. The children's media exposure was measured at ages 7 and 8, and executive function was evaluated annually from ages 7 to 10 using the Executive Function Difficulty Screening Questionnaire. Participants were grouped by media exposure level (low, medium, or high), and longitudinal changes in executive function were analyzed using linear mixed effects models. Subgroup analysis was conducted to investigate how executive function changes varied based on intelligence within each media exposure group.
Results: Children with high media exposure (n = 97) had severer executive function difficulties than those with low (n = 141) or medium (n = 971) exposure in all waves. The high exposure group demonstrated persistent higher executive function difficulties up to age 10 after controlling for child gender, intelligence, parental education level and maternal depression. Children with intelligence quotient (IQ) ≤ 100 in the medium to high media exposure group had significantly more severe executive function difficulties than those with IQ > 100.
Conclusion: This study provided evidence of a longitudinal negative association between media exposure and executive function. The findings suggest that excessive media exposure may lead to long-term changes in executive function in children and highlight the importance of implementing targeted interventions and educational strategies to mitigate the potential negative effects of excessive media use, particularly for children with lower cognitive abilities.

Keywords: Media Exposure; Executive Function; Longitudinal Study; Screen Time; Cognitive Development

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those of the authors. They do not necessarily represent views of the funding agency.

Disclosure

The authors have no potential conflicts of interest to disclose.

Author Contributions

Conceptualization: Oh Y, Joung YS. Data curation: Oh Y. Formal analysis: Oh Y. Investigation: Oh Y. Resources: Oh Y. Supervision: Oh Y, Baek JH, Joung YS. Validation: Baek JH. Visualization: Oh Y, Baek JH. Writing - original draft: Oh Y, Baek JH, Joung YS. Writing - review & editing: Oh Y, Baek JH, Joung YS.

INTRODUCTION

The rapid development and universalization of digital devices have extensively changed children's everyday routine.[1] While educational media programs for children have some positive effects on learning, negative effects of media exposure on physical, mental, and cognitive outcomes have also been demonstrated.[2-4] In particular, significantly increased media exposure during the coronavirus disease 2019 (COVID-19) pandemic had been reported to be associated with poor child mental health.[5,6] Thus, excessive media exposure in children has been identified as a notable problem.[7]

Despite increasing clinical concerns about excessive media use, there are very few studies on the causal relationship between media exposure and long-term executive function changes. Most studies reporting executive function impairment in excessive media are cross-sectional.[8-11] Only one study with a prospective and longitudinal design on the causal relationship between long-term media exposure and executive function has been reported,[12] showing somewhat contradictory results with existing cross-sectional studies. Also, there is no previous study that adjusted intelligence, which is closely related to executive function and plays a protective role in negative mental health outcomes.[13-17] Therefore, additional prospective studies are needed to clarify this discrepancy.

Strong evidence supports that early childhood media exposure is associated with executive dysfunction. Executive functions develop from early infancy to early adulthood. They play a key role in children's cognition, behavior, and emotional control.[18-21] According to a review paper on the neurodevelopmental trajectory of executive function, age of 7–9 is a critical period when growth spurts of cognitive flexibility, goal setting, and information processing appear. Executive function is relatively matured by the age of 12.[22] During this period, chronically high levels of media exposure may impede the development of executive functions as they deprive them of sufficient opportunities to train executive functions. Several previous studies have demonstrated that those with internet gaming disorder showed a decrease in frontal function, an increase in impulsivity, and changes in the dopamine reward circuit.[23-25] In this context, our hypothesis was that children with high media exposure at age of 7–8 years might have a severe executive function difficulty at 7, 8, 9, and 10 years than those with a low media exposure.

To clarify the association between media exposure and executive function in children, a population-based sample of children aged 7 years from the Panel Study on Korean Children (PSKC) was used. In this regard, this study was conducted to compare executive functions according to media exposure with a longitudinal study design. Whether changes of executive function difficulties over time would differ according to media exposure level was also investigated.

METHODS

Participants

This study used PSKC cohort data established from 2008 by the Korea Institute of Child Care and Education, a national policy research agency. Stratified multi-stage sampling based on resident registration population data in 2008 was used to select the representative population of newborns born in 2008. Detailed methodologies on the PSKC study have been described elsewhere.[26]

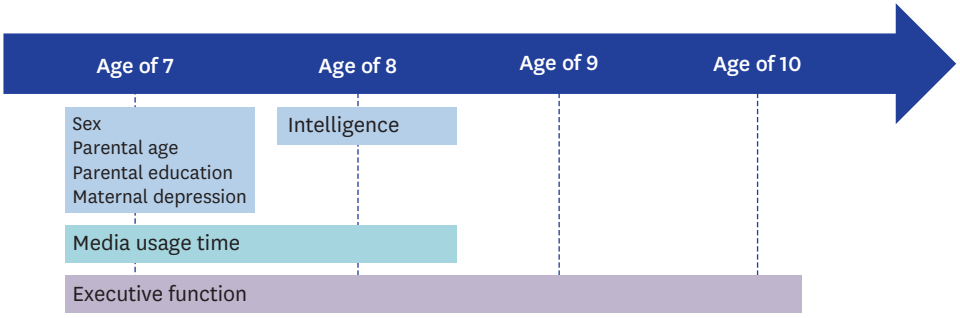

Fig. 1. Study design. Demographic information and maternal depression were assessed at the age of 7. Media usage time was investigated at ages 7 and 8. Intelligence was evaluated at the age of 8. Executive function was assessed four times annually from ages 7 to 10.

Executive function was evaluated every year from age 7 to 10 using Executive Function Difficulty Screening Questionnaire (EFDSC). A total of 1,209 subjects were included in this study after excluding those who did not complete the evaluation of executive function at ages 7, 9, and 10 (**Fig. 1**).

Measures

Media exposure

Average time of watching TV during the week and on the weekend were investigated at age 7 and 8. Through this, the average TV viewing time per day was calculated. In addition, to investigate media usage other than TV, average weekday and weekend hours of internet, game console, mobile phone, and tablet PC were investigated at age 7. Average weekday and weekend hours of smartphone and PC use were investigated at age 8. Daily average usage time was then calculated. Media exposure was calculated by adding the average daily TV viewing time and media usage other than TV in each wave.

Several previous studies have reported that the prevalence of high-risk media addiction among children ranges from 8–12% of the total population.[27,28] Therefore, for this study, the high-risk threshold was defined as 3.5 hours, representing the top 10% of total media usage. Additionally, taking into consideration the World Health Organization's recommendation of 2 hours of maximum screen time and the high exposure group of this study constitutes 10% of the total samples, the cutoff for the low exposure group was set at 1 hour.[29] The group with an average media exposure of less than 1 hour per day was defined as the low exposure group. The group with media exposure greater than 1 hour and less than 3.5 hours per day was defined as the medium exposure group. The group with more than 3.5 hours per day was defined as the high exposure group.

Maternal depression

Maternal depressive symptoms were evaluated at age 7 using Kessler's six-question short-form scale self-reported questionnaire (K6).[30] The K6 is a validated tool to screen for depressive mood in epidemiological studies, with a high internal consistency (Cronbach's alpha: 0.889).[31] Each item was rated on a 5-point Likert scale from 1 ("none of the time") to 5 ("all of the time"), with higher scores indicating more severe depressive symptoms. A previous study has reported that maternal depression trajectory during the first 3 years of life can affect the executive function of school-age children.[32] Therefore, in this study, maternal depression was included as an important covariate. According to the score obtained through the maternal depression measure evaluated at age 7, maternal depression severity was divided

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into a no depression group (13 points or less), a mild depression group (14 points or more and 18 points or less), and a moderate depression group (19 points or more).

EFDSC

EFDSC was developed and validated in Korea as a self-reporting questionnaire for assessing children's executive functioning.[33] The EFDSC consists of a total of 40 items. Its total score is 120 using a 3-point Likert scale, with higher scores indicating greater executive function difficulty. The EFDSC consists of four parts: planning-organizing difficulties, behavior control difficulties, emotional control difficulties, and attention-concentration difficulties. In this study, children's original version of the scale was used to develop a questionnaire that was reviewed by the original authors and modified to the adult version. Mothers were asked to respond the EFDSC based on their children's behavior over the past six months.

Multifactorial intelligence test (M-FIT)

The intelligence of children was measured using the M-FIT at the age of eight.[34] The M-FIT consists of six factors: vocabulary, language inference, schematization, calculation, spatial perception, and reasoning. Each factor consists of 20 items and is configured to answer as much as possible within the time limit. The reliability of the items on this scale was 0.82 for vocabulary, 0.76 for language inference, 0.76 for schematization, 0.84 for calculation, 0.76 for spatial perception, and 0.81 for reasoning. In this study, subjects were classified into two groups: the intelligence quotient (IQ) ≤ 100 group and the IQ > 100 group, based on the average IQ of 100 calculated using M-FIT.

Statistical analysis

Demographic characteristics of children according to media exposure were compared with χ^2 test for categorical variables. Linear-by-linear association (LLA) test was used for parental education and maternal depression to examine the trend across media exposure groups. Continuous variables such as parental age were compared between groups using analysis of variance (ANOVA).

To compare executive functions between media exposure groups, ANOVA was performed. A generalized linear mixed-effect model was used to test the primary hypothesis, with media exposure group as a fixed effect and subject as a random effect. A group × time interaction effect estimated whether the change in child executive function significantly differed over time. The dependent variable was executive function. Children's gender, intelligence, parental education, and maternal depression were included as covariates. To investigate the longitudinal executive function change between intelligence groups according to media exposure level, subgroup analysis was performed for each exposure group. In the high exposure group, a generalized linear mixed-effect model with executive function as the dependent variable, the IQ group (IQ ≤ 100, IQ > 100) as a fixed effect, and the subject as a random effect, and adjusting gender, parental education, and maternal depression was used. The same analysis was performed in the medium exposure group and the low exposure group. All analyses were executed using SPSS version 22.0 (SPSS Inc., Chicago, IL, USA). Statistical significance was defined at P value < 0.05.

Ethics statement

The study protocol was approved by the Institutional Review Board (IRB) of the National Center for Mental Health (IRB approval number 116271-2021-11). Informed consent was submitted by parents of the enrolled children.

Table 1. Child and parental characteristics by media exposure group (N = 1,209)

Characteristics	Low exposure (n = 141)	Medium exposure (n = 971)	High exposure (n = 97)	*P* or *P* for trend value
Child characteristics				
Sex				0.010
Male	62	477	60	
Female	79	494	37	
IQ at 8 yr	113.12 ± 12.64	107.79 ± 13.02	100.55 ± 12.83	< 0.001
IQ ≤ 100	21	288	49	< 0.001
IQ > 100	120	683	48	
Maternal characteristics at 7 yr				
Age, yr	37.53 ± 3.08	37.90 ± 3.70	37.87 ± 4.19	0.524
Depression				< 0.001
No symptom	117	759	58	
Mild depression	17	163	28	
Moderate depression	7	49	11	
Education				< 0.001
High school graduate or below	20	265	54	
University graduate	106	653	43	
Postgraduate	15	52	0	
Paternal characteristics at 7 yr				
Age, yr	39.87 ± 3.32	40.23 ± 3.92	40.56 ± 4.19	0.381
Education				< 0.001
High school graduate or below	26	249	49	
University graduate	89	612	43	
Postgraduate	26	95	2	

Values are presented as number or mean ± standard deviation.
IQ = intelligence quotient.

RESULTS

Children and parental characteristics by media exposure

Table 1 shows children and parental characteristics classified according to media exposure. The media exposure group was divided into three groups: a low exposure group (mean media use < 1 hour), a medium exposure group (1 hour ≤ mean media use < 3.5 hour), and a high exposure group (mean media use ≥ 3.5 hour). There was a significant difference in the gender of the children between groups. In the low exposure group, there were 62 boys and 79 girls, whereas in the high exposure group, there were 60 boys and 37 girls. There was also a significant difference in intelligence between the three groups. The average intelligence of the low exposure group was the highest with 113.12 (standard deviation [SD] = 12.64), followed by the medium exposure group with 107.79 (SD = 13.02), and the high exposure group with the lowest intelligence with 100.55 (SD = 12.83). LLA test for trend results demonstrated significant association between intelligence (IQ ≤ 100, IQ > 100) and media exposure. There were significant linear associations between parental education and media exposure (*P* for trend < 0.001). In addition, there is a significant linear association between maternal depression and media exposure, which shows that the higher the media exposure the higher the maternal depression (*P* for trend < 0.001). However, demographic characteristics such as parental age did not show significant differences among the three groups.

Executive function of children according to media exposure

Table 2 shows executive functions of children according to media exposure (**Fig. 2**). At the age of seven, there were differences in significant executive function among the three groups ($P < 0.05$ for all). Post hoc test results for all subscales except for inattention revealed that the high exposure group showed significantly higher scores of executive function difficulties than the low exposure and medium exposure groups did. At 8, 9, and 10 years of age, there were

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Table 2. Child executive function difficulties according to exposure of media use (N = 1,209)

Child outcomes	Low exposure	Medium exposure	High exposure	F	*P* value	Post hoc level[a]
At 7 yr						
Plan-organization difficulty	16.70	17.03	19.15	11.90	< 0.001	1, 2 < 3
Behavior control difficulties	13.76	14.02	15.93	14.83	< 0.001	1, 2 < 3
Emotional control difficulties	11.00	11.18	12.64	9.50	< 0.001	1, 2 < 3
Inattention	14.65	14.78	15.93	3.66	0.026	2 < 3
Total	56.11	57.01	63.65	14.15	< 0.001	1, 2 < 3
At 8 yr						
Plan-organization difficulty (n = 1,185)	17.49	17.90	19.78	8.23	< 0.001	1, 2 < 3
Behavior control difficulties (n = 1,185)	13.54	13.91	15.59	12.77	< 0.001	1, 2 < 3
Emotional control difficulties (n = 1,184)	11.41	11.45	12.28	2.49	0.083	
Inattention (n = 1,185)	15.33	14.99	16.06	3.00	0.050	
Total (n = 1,182)	57.71	58.23	63.70	8.91	< 0.001	1, 2 < 3
At 9 yr						
Plan-organization difficulty	17.65	18.00	19.71	6.45	0.002	1, 2 < 3
Behavior control difficulties	13.52	13.85	15.18	8.42	< 0.001	1, 2 < 3
Emotional control difficulties	11.60	11.51	12.41	2.80	0.061	
Inattention	15.63	15.39	16.18	1.40	0.247	
Total	58.40	58.74	63.47	6.07	0.002	1, 2 < 3
At 10 yr						
Plan-organization difficulty	16.92	17.28	19.00	6.61	0.001	1, 2 < 3
Behavior control difficulties	13.31	13.36	14.58	7.10	0.001	1, 2 < 3
Emotional control difficulties	11.40	11.20	12.07	3.01	0.049	
Inattention	15.06	15.05	15.49	0.43	0.651	
Total	56.69	56.89	61.14	5.12	0.006	1, 2 < 3

[a]Low exposure = 1, medium exposure = 2, high exposure = 3.

significant differences in plan-organization difficulties subscale, behavior control difficulty subscale, and total score between groups. In the post hoc test, the high exposure group showed significantly higher executive function difficulty scores than the low and medium exposure groups, indicating that they had severer executive difficulties.

Association between media addiction severity and executive function

Results of the mixed-effect model of child executive function are described in **Table 3**. The overall group effect was significant except in case of plan-organization difficulty and inattention, confirming a significant executive function difference according to the media exposure group. The time effect was insignificant, indicating that executive function subscales did not significantly change over time. Executive function exhibited a non-significant group × time interaction, indicating that changes of executive function subscales over time did not differ between groups. Behavior control difficulty, emotional control difficulty, and total executive function difficulty showed a slight, but not statistically significant decrease over time in the high exposure group compared to the low exposure group.

Association between intelligence and executive function according to media exposure

Table 4 shows the results of the mixed effect model of child executive function according to each media exposure group. In the high exposure group, there was a significant IQ group effect in plan-organization difficulty, behavioral control difficulty, and total score, indicating that the IQ ≤ 100 group had significantly severer executive function difficulty than the IQ > 100 group. Also, there were no significant time effect and the group × time interaction.

A similar trend was also observed in the medium exposure group. In the plan-organization difficulty, behavioral control difficulty, and total score, the IQ ≤ 100 group showed severer

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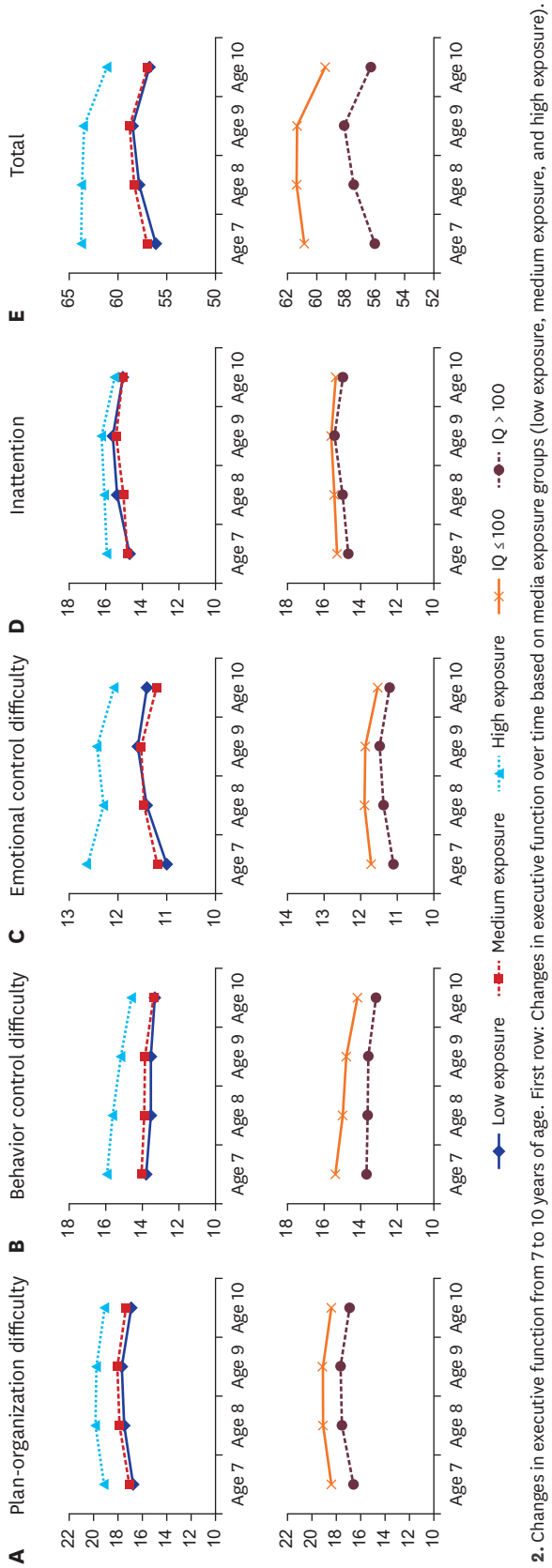

Fig. 2. Changes in executive function from 7 to 10 years of age. First row: Changes in executive function over time based on media exposure groups (low exposure, medium exposure, and high exposure). Second row: Changes in executive function over time based on intelligence groups (IQ ≤ 100, IQ > 100).
IQ = intelligence quotient.

executive function difficulty than the IQ > 100 group. There was a non-significant group × time interaction except behavioral control difficulties. Behavioral control difficulties demonstrated a significant time effect (β = −0.15, P = 0.001), indicating behavioral control difficulties decreased over time. There was a significant group × time interaction (β = −0.19, P = 0.030), showing behavioral control difficulties greater decreases over time in the IQ ≤ 100 group than in the IQ > 100 group.

In the low exposure group, there were no significant executive function difficulties between the IQ groups, and the time effect was not significant (**Fig. 3**).

DISCUSSION

Consistent with previous cross-sectional studies, we found a prospective association between child media exposure and executive function. This association remained significant even after adjusting for gender, intelligence, parental education level, and, most importantly, maternal depression, which had been proven as a factor influencing executive function and media exposure in previous studies.[32,35] Also, we found that in the medium-to high media exposure group, the IQ ≤ 100 group had significantly severer executive function difficulty than the IQ > 100 group, and there was no difference in executive function between the IQ groups in the low exposure group.

In our study, the difference in executive function between the high exposure group and the low exposure group was significant from the baseline age of 7 years. It persisted until the age of 10 years. The difference in executive function between the media exposure groups at baseline was significant, consistent with previous cross-sectional studies.[11,23-25] One of the possible explanations was that children's predisposing executive dysfunctions might have influenced the determination of media exposure level. Alternatively, the influence of media exposure in the preschool period, which was not measured in this study, on executive function might have been reflected. In addition, the tendency of parents with executive function difficulty to give their children high media exposure might reflect a genetic influence of parents' cognitive characteristics as a parenting environment factor. This bidirectional influence between executive function and media exposure could create a reinforcing cycle, where difficulties in executive function lead to increased exposure to certain media content, and in turn, prolonged media exposure might further impact executive function development negatively.

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Table 3. Mixed effect models estimating the effect of media exposure on child executive function over time

Function difficulties	β	95% CI	*P* value
Plan-organization difficulties			
Intercept	20.58	19.20–21.96	< 0.001
Group, with low exposure group as the reference			
Medium exposure group	−0.13	−1.12–0.86	0.796
High exposure group	1.25	−0.22–2.72	0.097
Time, with age 7 as the reference	0.07	−0.22–0.37	0.616
Group by time interaction			
Medium exposure group × time	0.01	−0.30–0.33	0.932
High exposure group × time	−0.15	−0.61–0.31	0.527
Behavioral control difficulties			
Intercept	17.10	16.15–18.06	< 0.001
Group, with low exposure group as the reference			
Medium exposure group	0.04	−0.65–0.74	0.901
High exposure group	1.58	0.54–2.61	0.003
Time, with age 7 as the reference	−0.15	−0.36–0.06	0.165
Group by time interaction			
Medium exposure group × time	−0.06	−0.29–0.16	0.575
High exposure group × time	−0.33	−0.66–0.00	0.053
Emotional control difficulties			
Intercept	11.94	10.89–12.98	< 0.001
Group, with low exposure group as the reference			
Medium exposure group	0.12	−0.64–0.88	0.762
High exposure group	1.29	0.15–2.43	0.026
Time, with age 7 as the reference	0.13	−0.10–0.36	0.254
Group by time interaction			
Medium exposure group × time	−0.12	−0.37–0.13	0.341
High exposure group × time	−0.33	−0.70–0.03	0.075
Inattention			
Intercept	16.37	15.01–17.72	< 0.001
Group, with low exposure group as the reference			
Medium exposure group	−0.06	−1.00–0.87	0.893
High exposure group	0.91	−0.49–2.31	0.201
Time, with age 7 as the reference	0.14	−0.13–0.41	0.303
Group by time interaction			
Medium exposure group × time	−0.05	−0.33–0.24	0.742
High exposure group × time	−0.33	−0.75–0.09	0.126
Total			
Intercept	65.91	62.12–69.70	< 0.001
Group, with low exposure group as the reference			
Medium exposure group	−0.043	−2.65–2.57	0.974
High exposure group	5.07	1.16–8.98	0.011
Time, with age 7 as the reference	0.20	−0.54–0.94	0.601
Group by time interaction			
Medium exposure group × time	−0.22	−1.01–0.58	0.591
High exposure group × time	−1.14	−2.31–0.03	0.057

Adjusted by gender, intelligence, parental education level, and maternal depression.
CI = confidence interval.

We identified the differential impact of media exposure on executive function between intelligence groups. The IQ ≤ 100 group had severer executive function difficulties than the IQ > 100 group in medium to high media exposure group. This finding showed a dose-dependent relationship, with the IQ ≤ 100 group having the severest executive function difficulties in the high exposure group compared to the IQ > 100 group, followed by a small but significant difference in the medium exposure group than in the high exposure group. There was no difference between the IQ groups in the low exposure group. To the best of our knowledge, there are no previous studies examining changes in executive function considering intelligence in media exposure. In other previous studies, it has been reported on the protective role of

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Table 4. Mixed effect models estimating the effect of intelligence on child executive function over time according to the media exposure

Variables	High exposure			Medium exposure			Low exposure		
	β	95% CI	*P* value	β	95% CI	*P* value	β	95% CI	*P* value
Plan-organization difficulties									
Intercept	19.37	15.65–23.08	< 0.001	19.13	17.94–20.32	< 0.001	18.17	14.95–21.39	< 0.001
Group, with IQ > 100 as the reference									
IQ ≤ 100 group	2.96	0.69–5.23	0.011	1.58	0.81–2.36	< 0.001	0.99	−1.62–3.59	0.457
Time, with age 7 as the reference	−0.13	−0.65–0.38	0.609	0.13	0–0.26	0.062	0.10	−0.22–0.42	0.532
Group by time interaction									
IQ ≤ 100 group × time	0.12	−0.60–0.83	0.750	−0.13	−0.38–0.11	0.296	−0.17	−0.99–0.64	0.676
Behavioral control difficulties									
Intercept	14.66	11.43–17.89	< 0.001	16.13	15.34–16.91	< 0.001	15.11	13.02–17.20	< 0.001
Group, with IQ > 100 as the reference									
IQ ≤ 100 group	3.72	1.78–5.67	< 0.001	1.53	0.99–2.06	< 0.001	0.48	−1.24–2.20	0.581
Time, with age 7 as the reference	−0.20	−0.64–0.24	0.367	−0.15	−0.25–0.06	0.001	−0.14	−0.35–0.08	0.209
Group by time interaction									
IQ ≤ 100 group × time	−0.53	−1.13–0.08	0.087	−0.19	−0.36–0.02	0.030	−0.09	−0.63–0.46	0.754
Emotional control difficulties									
Intercept	11.13	8.33–13.94	< 0.001	11.93	11.06–12.81	< 0.001	10.13	7.59–12.68	< 0.001
Group, with IQ > 100 as the reference									
IQ ≤ 100 group	0.71	−1.14–2.56	0.450	0.44	−0.15–1.04	0.141	1.24	−0.85–3.33	0.246
Time, with age 7 as the reference	−0.26	−0.70–0.19	0.257	0.03	−0.07–0.14	0.534	0.18	−0.08–0.43	0.178
Group by time interaction									
IQ ≤ 100 group × time	0.12	−0.49–0.73	0.705	−0.06	−0.26–0.13	0.513	−0.28	−0.95–0.38	0.403
Inattention									
Intercept	18.72	14.86–22.57	< 0.001	15.75	14.57–16.93	< 0.001	14.92	11.57–18.28	< 0.001
Group, with IQ > 100 as the reference									
IQ ≤ 100 group	0.79	−1.47–3.04	0.494	0.50	−0.24–1.23	0.183	0.97	−1.55–3.49	0.451
Time, with age 7 as the reference	−0.32	−0.81–0.18	0.206	0.11	−0.01–0.24	0.064	0.19	−0.10–0.48	0.191
Group by time interaction									
IQ ≤ 100 group × time	0.25	−0.43–0.94	0.472	−0.08	−0.30–0.15	0.505	−0.36	−1.10–0.39	0.350
Total									
Intercept	63.73	53.39–74.07	< 0.001	62.85	59.55–66.15	< 0.001	58.30	48.98–67.62	< 0.001
Group, with IQ > 100 as the reference									
IQ ≤ 100 group	8.16	2.14–14.19	0.008	4.06	2.01–6.12	< 0.001	3.64	−3.39–10.67	0.310
Time, with age 7 as the reference	−0.92	−2.23–0.40	0.171	0.12	−0.22–0.46	0.497	0.33	−0.48–1.14	0.423
Group by time interaction									
IQ ≤ 100 group × time	−0.04	−1.86–1.78	0.964	−0.46	−1.08–0.16	0.147	−0.90	−2.99–1.20	0.402

Adjusted by gender, parental education level, and maternal depression.
CI = confidence interval, IQ = intelligence quotient.

intelligence for the delinquent behavior, which is consistent with the severe behavioral control difficulties of executive function in the IQ < 100 group in this study.[36,37]

In general, intelligence is known to be determined by several genetic and environmental factors, and adverse social and environmental factors such as maternal depression, maternal smoking, low house income, and low parental education also affect cognitive function.[32,38,39] Although gender, parental education level, and maternal depression were adjusted in this study, the impact of media exposure on executive function between intelligence group was still significant. We found that the IQ ≤ 100 group were more vulnerable to executive function difficulty than the IQ > 100 group in the medium to high media exposure group.

A recent two-year follow-up prospective study has reported differential effects of media contents on intelligence of children aged 9–10 years.[40] In particular, video gaming showed a positive correlation with intelligence after 2 years of follow-up, suggesting cognitive benefit of video gaming. Another prospective study reported that increased media use, including television, video games, and computers at 11-year-old showed significant associations with increased working

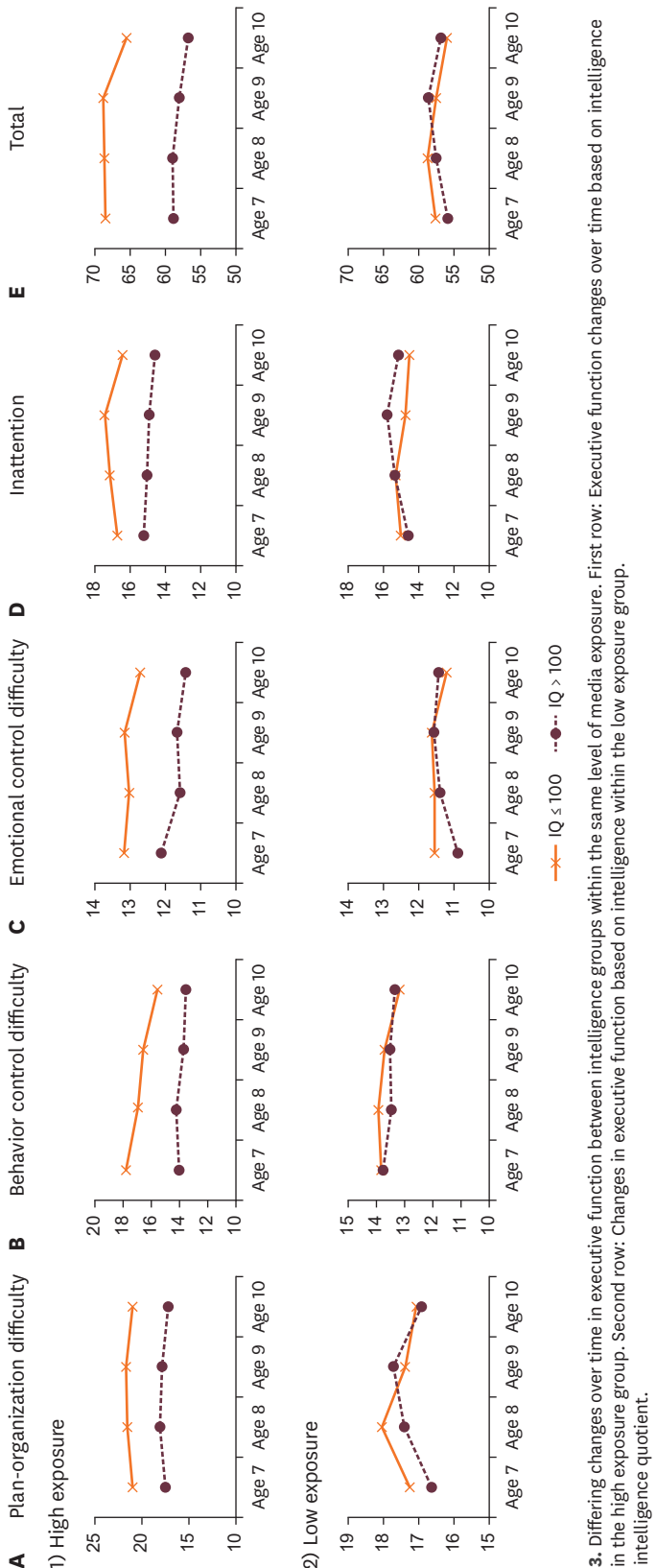

Fig. 3. Differing changes over time in executive function between intelligence groups within the same level of media exposure. First row: Executive function changes over time based on intelligence within the high exposure group. Second row: Changes in executive function based on intelligence within the low exposure group.
IQ = intelligence quotient.

memory at 22-year-old.[12] These findings about cognitive benefits of media exposure are consistent with results of our study.
In terms of behavior control difficulties, emotional control difficulties and total executive function difficulties, high media exposure group showed a slight, but not statistically significant decrease over time than low media exposure group. Also, in the subgroup analysis of the medium exposure group, behavioral control difficulties were found to decrease significantly over time, and the IQ < 100 group showed a significant decrease over time compared to the IQ > 100 group. Therefore, it is necessary to confirm the impact of media exposure on cognition through additional research that defines media contents and extends the follow-up period until adulthood.

In this study, we did not find any evidence that executive function worsened over time in the high media exposure group compared to the low media exposure group. Negative effects of media exposure on development have been well established in several prospective studies of preschool-age children.[41-43] A recent study has reported abnormalities in the integrity of the brain white matter tract related to language skills and executive function in children with high screen exposure.[41] One longitudinal design study has also reported that media exposure at 24 and 36 months was associated with poor outcomes in developmental delay screening test of children aged 36 and 60 months.[42] A recent meta-analysis has reported a relationship between greater quantity of screen use and lower language skills.[43] However, our findings mitigated concerns that long term high media exposure would exacerbate executive function difficulty.

As one of the possible explanations for this discrepancy, since children before the age of 7 are more vulnerable to the environment such as media exposure than school-age children, the effect of media exposure appears much more prominently than school-age children. The effect might not be clearly expressed in school-aged children. In school-aged children, cognitive development has already been achieved to some extent, enabling language comprehension, reading, writing, and simple arithmetic.[44] In addition, since children are exposed to a common environment of learning in a standardized and structured situation at school, environmental factors (education, nutrition, social interaction) of children are not absolutely determined by the caretaker.[45]

We defined the high exposure group as 3.5 hours or more of average daily media exposure measured at 7 and 8 years, which greatly exceeded the American Psychological Association recommendation for screen time of 2 hours a day for children

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5 years and older.[46] However, according to a recent report, the average screen time of children aged 7 to 9 years per day has increased sharply to 5 hours and 36 minutes after the COVID-19 pandemic.[47] Therefore, preschool children who have experienced the COVID-19 pandemic are likely to have a much severer level of executive function difficulty than confirmed in this study. Further research is needed to confirm this in the future.

This longitudinal study revealed an association between executive function and media exposure in middle childhood. The current study had an advantage of applying a longitudinal design assessing a total of four times during the period of childhood. This is the first study to adjust IQ, which is closely related to executive function, and to examine the effects of different media exposure according to IQ groups. It also had an advantage of being a longitudinal study using population-based data.

This study has several limitations. First, the qualitative aspect of media exposure was not investigated. Some studies have suggested that educational programs can improve children's language skills and cognitive development.[43] Further research is needed to define media contents used by children and methods of using media (e.g., one-sided watching, bidirectional interactive participation, and auxiliary teaching materials for classes). Second, the amount of media exposure and executive function were evaluated based on the caretaker's report which might have been influenced by respondents' subjective impressions. An important limitation was the lack of significant effect observed in media exposure over time, possibly attributed to the insufficient observation period and other unaccounted factors. Future research should consider conducting extended longitudinal studies and exploring additional variables to gain a comprehensive understanding of media exposure's evolving impact on diverse outcomes.

In conclusion, we found that executive function difficulty was the significantly higher in the high media exposure group at baseline and severer in children with low intelligence. This trend persisted into middle childhood. Importantly, the results emphasize the need to consider the potential impact of intelligence when examining the association between media exposure and executive function.

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