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COVID-19 and Neurodevelopmental Delays in Early Childhood: A Longitudinal Analysis of Developmental Outcomes in Korean Children

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ABSTRACT

This study employed a longitudinal analysis to evaluate the association between the coronavirus disease 2019 pandemic and neurodevelopment by analyzing over 1.8 million children from the Korean Developmental Screening Test for Infants and Children included in South Korea's National Health Screening Program. We compared the developmental outcomes in five age groups—9–17 months, 18–29 months, 30–41 months, 42–53 months, and 54–65 months—between the pre-pandemic (2018–2019) and pandemic (2020–2021) periods. Significant increases in potential developmental delays were observed during the pandemic in communication, cognitive, social interaction, self-care, and fine motor skills across most age groups. All five age groups experienced notable disruptions in communication and fine motor skills. Children from socioeconomically disadvantaged backgrounds faced higher risks across all domains. These findings highlight the need for targeted interventions and continuous monitoring to support the developmental needs of children affected by pandemic-related disruptions.

Keywords: COVID-19; Pandemics; Child Development; K-DST

The coronavirus disease 2019 (COVID-19) pandemic has raised significant concerns regarding its potential impact on child development.[1-3] Emerging research suggests that the pandemic has impeded the developmental trajectories of infants and young children.[4-8] Most studies, however, have focused on school-aged children and often come from smaller-scale or narrowly focused research. This underscores the urgent need for comprehensive and longitudinal studies to fully understand the pandemic's impact. Furthermore, early childhood is considered a critical and sensitive period for development, especially for language,[9-12] yet data on these age groups are particularly scarce. Therefore, this study aimed

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Author Contributions
Conceptualization: Lee KS, Choi YY, Kim YS, Kim MH. Data curation: Lee KS, Lee J. Formal analysis: Lee KS, Choi YY. Investigation: Lee KS, Choi YY. Methodology: Kim MH, Lee KS, Lee J. Software: Lee KS, Choi YY. Validation: Lee KS, Choi YY, Park SG, Sung HK, Kim MH. Writing - original draft: Lee KS, Choi YY. Writing - review & editing: Kim MH, Sung HK, Park SG, Lee JH, Kim YS.

to determine whether infants and young children of preschool age who experienced the pandemic are more likely to exhibit developmental delays compared to a reference group of their peers who did not experience the pandemic.

The National Health Insurance and Medical Aid program in South Korea (hereafter, Korea), a universal health security system, covers over 99% of the population.[13] In 2007, it launched the National Health Screening Program for Infants and Children (NHSPIC), which has been available to all children. This program has achieved an average screening rate of 75% from 2018 onward (**Supplementary Fig. 1**). The program serves as an exemplary data source for our study due to its wide coverage and robust population surveillance capabilities. The NHSPIC evaluates development at six time points using the Korean Developmental Screening Test for Infants and Children (K-DST). Although each screening is recommended at the ages of 9–12, 18–24, 30–36, 42–48, 54–60, and 66–71 months, delayed screenings are allowed. This assessment covers six fundamental domains: gross motor, fine motor, cognition, communication, social interaction, and self-care. Outcomes in each domain are classified into three categories based on the K-DST scores: "good," "requires follow-up examination," or "requires detailed assessment." The latter two categories indicate potential neurodevelopmental delays.[14]

In this study, we specifically focused on children who were 65 months old or younger at the time of their baseline screening. Each child included in this study underwent two consecutive screenings over two years: April 2018 to December 2019 for the pre-pandemic cohort and January 2020 to December 2021 for the pandemic cohort. The first year (2018 or 2020) served as the baseline, while the second year (2019 or 2021) was used for follow-up assessments. April 2018 was chosen because it marked the implementation of the revised K-DST.

Age categorization was systematically arranged according to specific intervals designated for each scheduled assessment: Age Group 1 (9–17 months at baseline, 18–29 months at follow-up), Age Group 2 (18–29 months at baseline, 30–41 months at follow-up), Age Group 3 (30–41 months at baseline, 42–53 months at follow-up), Age Group 4 (42–53 months at baseline, 54–65 months at follow-up), and Age Group 5 (54–65 months at baseline, 66–71 months at follow-up). Children with pre-existing disabilities listed on the Korea National Disability Registration System were excluded.[15] We classified children with K-DST results of "requires follow-up examination" or "requires detailed assessment" in any domain as potential neurodevelopmental delays in that specific domain.

Because this longitudinal study repeatedly observed the developmental screening results of each child, the statistical analyses accounted for potential correlation in the data. A generalized linear model with the generalized estimating equation method was employed to fit models, focusing on the association of the pandemic with neurodevelopmental screening results indicating potential delays in the follow-up screening (**Supplementary Data 1**).[16] We added an interaction term between indicator variables for the screening point (baseline or follow-up) and the COVID-19 pandemic period. We also considered potential confounders: the children's age in months, gender, months between screenings, Medical Aid beneficiary status, residence urbanity, pediatrician-to-child ratios in the residential area (as a measure of healthcare accessibility), maternal age, and maternal nationality.

Data were obtained from 803,756 children during the pre-pandemic period and 1,046,787 children during the pandemic period (**Fig. 1**). **Table 1** shows the sociodemographic characteristics of the study population at baseline. **Fig. 2** and **Supplementary Table 1** show

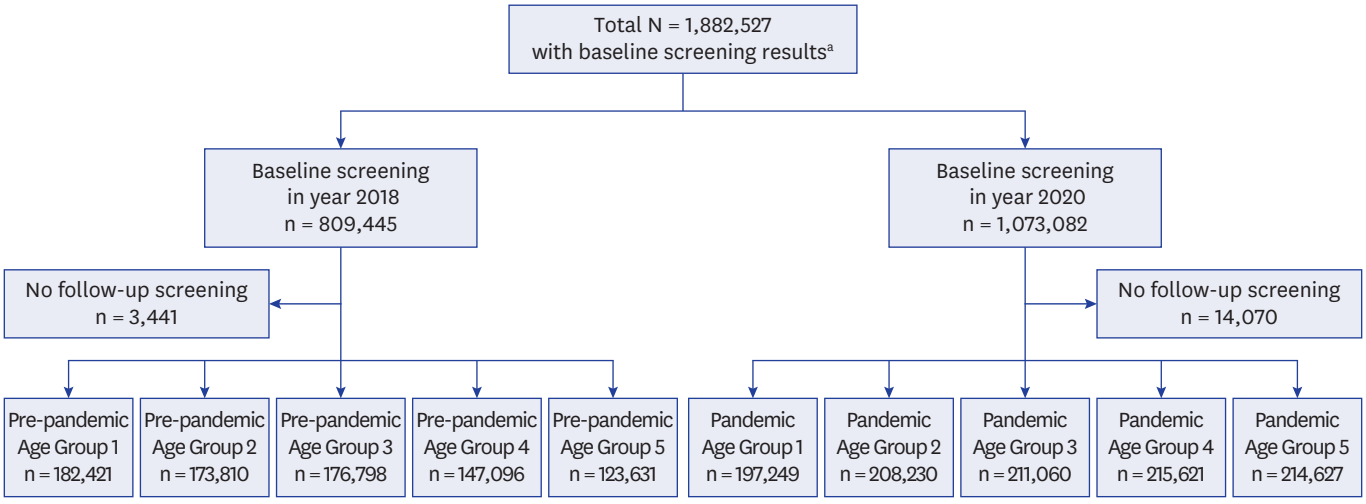

Fig. 1. Data diagram for the study. Age Group 1 (9–17 months at baseline, 18–29 months at follow-up); Age Group 2 (18–29 months at baseline, 30–41 months at follow-up); Age Group 3 (30–41 months at baseline, 42–53 months at follow-up); Age Group 4 (42–53 months at baseline, 54–65 months at follow-up); Age Group 5 (54–65 months at baseline, 66–71 months at follow-up).
[a]Children with pre-existing disabilities listed on the Korea National Disability Registration System were pre-excluded.

Table 1. Summary of population characteristics at baseline

Variables	Age Group 1[a]		Age Group 2[a]		Age Group 3[a]		Age Group 4[a]		Age Group 5[a]	
	Pre-pandemic	Pandemic	Pre-pandemic	Pandemic	Pre-pandemic	Pandemic	Pre-pandemic	Pandemic	Pre-pandemic	Pandemic
Number	182,421	197,249	173,810	208,230	176,798	211,060	147,096	215,621	123,631	214,627
Age in months	12 (11–13)	12 (11–13)	23 (21–24)	24 (22–25)	35 (33–36)	36 (34–37)	47 (44–48)	48 (46–49)	59 (56–60)	60 (58–61)
Sex										
Boys	94,003 (51.5)	101,742 (51.6)	89,008 (51.2)	106,653 (51.2)	90,343 (51.1)	108,305 (51.3)	75,247 (51.2)	109,957 (51.0)	62,983 (50.9)	109,162 (51.0)
Girls	88,418 (48.5)	95,507 (48.4)	84,802 (48.8)	101,577 (48.8)	86,455 (48.9)	102,755 (48.7)	71,849 (48.8)	105,664 (49.0)	60,648 (49.1)	105,465 (49.1)
Medical security										
Medical Aid	1,146 (0.6)	1,137 (0.6)	1,614 (0.9)	1,622 (0.8)	2,000 (1.1)	1,824 (0.9)	1,954 (1.3)	2,170 (1.0)	2,046 (1.7)	2,416 (1.1)
National Health Insurance	181,275 (99.4)	196,112 (99.4)	172,196 (99.1)	206,608 (99.2)	174,798 (98.9)	209,236 (99.1)	145,142 (98.7)	213,451 (99.0)	121,585 (98.4)	212,211 (98.9)
Interval between screenings, mon	11 (9–12)	11 (10–12)	12 (11–13)	12 (11–13)	12 (11–13)	12 (11–13)	12 (11–13)	12 (11–13)	12 (11–12)	12 (10–13)
Maternal age, yr										
20–29	58,860 (32.3)	67,398 (34.2)	47,682 (27.4)	61,013 (29.3)	41,470 (23.5)	53,265 (25.2)	30,987 (21.1)	46,910 (21.8)	24,025 (19.4)	41,583 (19.4)
30–39	114,255 (62.6)	115,779 (58.7)	113,423 (65.3)	126,707 (60.9)	117,202 (66.3)	128,747 (61.0)	95,481 (64.9)	129,392 (60.0)	76,462 (61.9)	122,693 (57.2)
40 and over	9,306 (5.1)	14,072 (7.1)	12,705 (7.3)	20,510 (9.9)	18,126 (10.3)	29,048 (13.8)	20,628 (14.0)	39,319 (18.2)	23,144 (18.7)	50,351 (23.5)
Maternal nationality										
Korea	144,387 (79.2)	146,003 (74.0)	139,361 (80.2)	159,305 (76.5)	144,093 (81.5)	165,806 (78.6)	120,400 (81.9)	173,621 (80.5)	101,746 (82.3)	176,024 (82.0)
Foreign	4,249 (2.3)	6,009 (3.1)	5,008 (2.9)	6,475 (3.1)	4,443 (2.5)	6,413 (3.0)	4,468 (3.0)	6,380 (3.0)	3,777 (3.1)	5,570 (2.6)
Unknown	33,785 (18.5)	45,237 (22.9)	29,441 (16.9)	42,450 (20.4)	28,262 (16.0)	38,841 (18.4)	22,228 (15.1)	35,620 (16.5)	18,108 (14.7)	33,033 (15.4)
Region										
Non-urban	102,506 (56.2)	112,156 (56.9)	97,715 (56.2)	119,704 (57.5)	99,776 (56.4)	122,369 (58.0)	83,828 (57.0)	126,943 (58.9)	70,856 (57.3)	126,523 (59.0)
Urban	79,915 (43.8)	85,093 (43.1)	76,095 (43.8)	88,526 (42.5)	77,022 (43.6)	88,691 (42.0)	63,268 (43.0)	88,678 (41.1)	52,775 (42.7)	88,104 (41.1)
Pediatrician-to-child ratios										
None	3,750 (2.1)	4,322 (2.2)	3,580 (2.1)	4,387 (2.1)	3,577 (2.0)	4,486 (2.1)	3,184 (2.2)	4,428 (2.1)	2,773 (2.2)	4,446 (2.1)
Below the average	89,273 (48.9)	90,711 (46.3)	84,637 (48.7)	95,862 (46.4)	85,435 (48.3)	96,909 (46.3)	70,981 (48.3)	99,128 (46.3)	59,475 (48.1)	98,452 (46.2)
Average or above	89,382 (49.0)	100,752 (51.5)	85,587 (49.2)	106,334 (51.5)	87,784 (49.7)	108,012 (51.6)	72,931 (49.6)	110,522 (51.6)	61,383 (49.7)	110,139 (51.7)

Values are presented as number (%) or median (interquartile range).
[a]Age Group 1 (9–17 months at baseline, 18–29 months at follow-up); Age Group 2 (18–29 months at baseline, 30–41 months at follow-up); Age Group 3 (30–41 months at baseline, 42–53 months at follow-up); Age Group 4 (42–53 months at baseline, 54–65 months at follow-up); Age Group 5 (54–65 months at baseline, 66–71 months at follow-up).

the adjusted odds ratio (aOR) of the potential neurodevelopmental delay for each domain in each age group associated with the COVID-19 pandemic.

Exposure to the COVID-19 pandemic affected different developmental domains and age groups to varying extents (**Fig. 2** and **Supplementary Fig. 2**). All five age groups experienced

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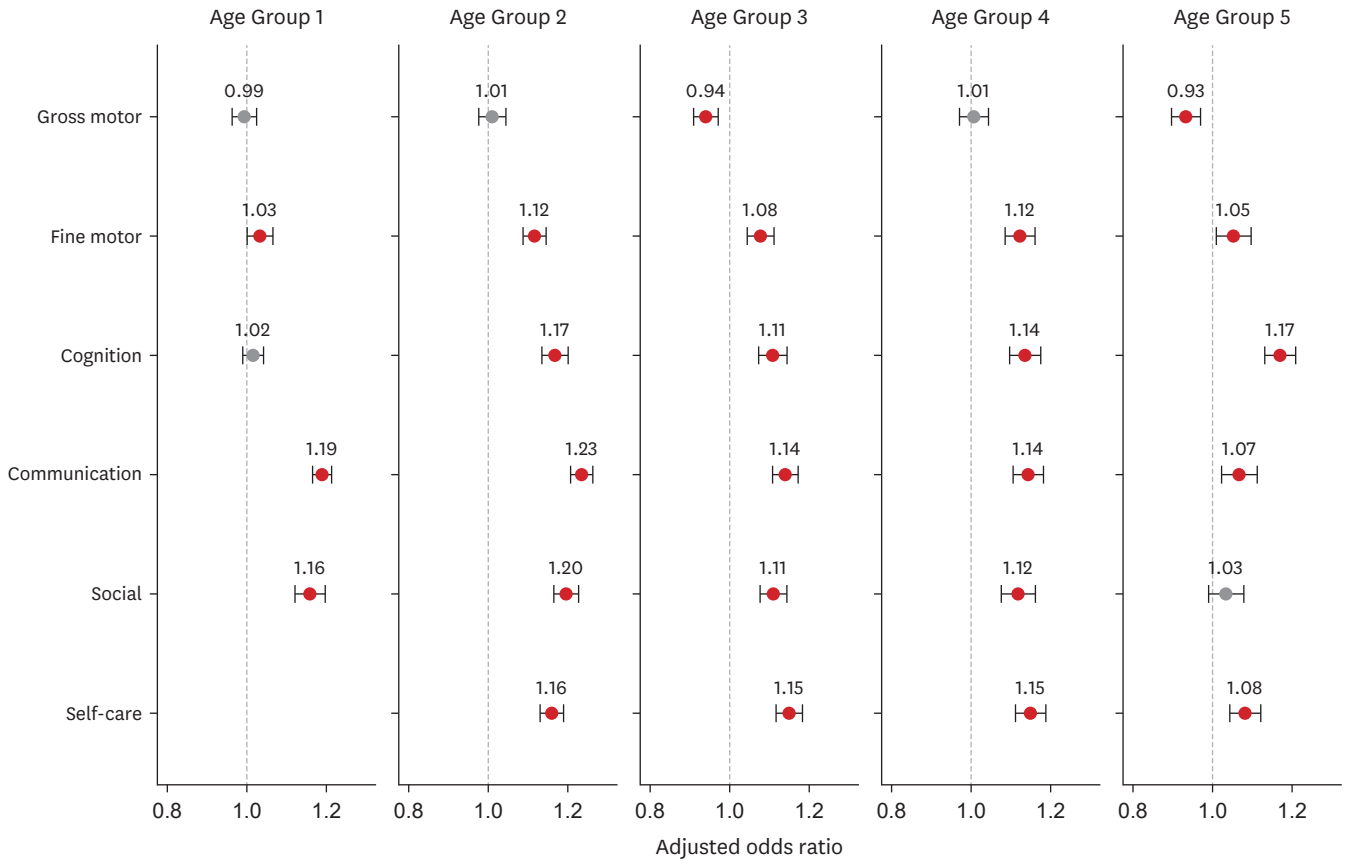

Fig. 2. Association of coronavirus disease 2019 pandemic with neurodevelopmental screening result indicating potential delays, categorized by age groups and developmental domains. Age Group 1 (9–17 months at baseline, 18–29 months at follow-up); Age Group 2 (18–29 months at baseline, 30–41 months at follow-up); Age Group 3 (30–41 months at baseline, 42–53 months at follow-up); Age Group 4 (42–53 months at baseline, 54–65 months at follow-up); Age Group 5 (54–65 months at baseline, 66–71 months at follow-up). Red circles indicate statistically significant odds ratios ($P < 0.05$) while gray circles indicate non-significant odds ratios.

significant disruptions in communication development during the pandemic, with aORs ranging from 1.07 to 1.23. Cognitive development was also impacted, but the extent of the effect varied by age group. The youngest group (Age Group 1) showed no significant change (aOR, 1.02, $P = 0.241$), while older groups (Age Groups 2 to 5) experienced significant developmental changes (aORs ranging from 1.11 to 1.17, all $P < 0.001$). The development of social skills was significantly affected in Age Groups 1 to 4 (aORs ranging from 1.11 to 1.20, all $P < 0.001$), except for the oldest group (aOR, 1.03, $P = 0.132$). Self-care skills were evaluated in Age Groups 2 to 5, and all four age groups experienced significant disruptions (aORs ranging from 1.08 to 1.16, all $P < 0.001$). While potential delays in fine motor skills were increased across all age groups, delays in gross motor development did not increase and even decreased in Age Groups 3 and 5 (aOR, 0.94 and 0.93, respectively, $P < 0.001$ for both).

Aside from the pandemic, children from socioeconomically disadvantaged backgrounds—such as Medical Aid beneficiaries and those with mothers of foreign nationality—were more likely to be vulnerable. These children exhibited a significantly higher risk of neurodevelopmental delays across all six domains, with aORs ranging from 1.45 to 2.85, as detailed in **Supplementary Fig. 3**.

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This study evaluated the association between the COVID-19 pandemic and child development, utilizing extensive data from the NHSPIC in Korea. Significant associations were revealed between pandemic exposure and potential developmental delays. A previous cross-sectional study we conducted found elevated risks of neurodevelopmental delays in communication and social interaction among children aged 30–36 months.[17] The findings of the current study are even more alarming. The COVID-19 pandemic has burdened nearly all aspects and age ranges of early childhood development. This is particularly concerning given the critical importance of early childhood for language and social development.[18-21]

Educators and parents were concerned that non-pharmaceutical interventions, such as mask-wearing, social distancing, and daycare/kindergarten closures, might limit essential social interactions and sensory experiences, thereby threatening child development. Previous studies indicated pandemic-related delays in language, cognition, and social development.[4-6,22] Similarly, our study observed developmental delays in these areas. These findings underscore the critical nature of early childhood as a formative period for language acquisition, cognitive development, and social interaction.

The pandemic's effects on fine motor skills and self-care highlight its broader impact across various developmental domains. These adverse effects are likely due to restricted explorative play and interaction with objects during peak pandemic times.[23] However, contrary to other studies,[6,22] no substantial impacts on gross motor development were found. This discrepancy suggests that certain developmental domains may be more resilient to pandemic disruptions or that compensatory factors, such as enhanced parental engagement, may vary depending on the child's environment and specific developmental domain.

Fortunately, the young brain's plasticity offers a robust potential for recovery.[24,25] Targeted interventions and support programs should be developed to address young children's specific needs during and after a pandemic crisis. Children from socioeconomically disadvantaged backgrounds should receive particular attention since they are vulnerable even without the pandemic,[26] and are likely to suffer more during such crises.[8,17,27] Studies encompassing a broader age range and longer durations are necessary to monitor post-pandemic developmental progress, determine potential resilience, and evaluate effective catch-up strategies. Comparative studies between children who catch up and those who continue to lag could also identify vital interventions and resilience factors.

The study's strengths include its large-scale, longitudinal design and the comprehensive screening data from the NHSPIC. However, the study has limitations. Although our longitudinal approach provides deeper insights into the pandemic's effects, long-term studies are necessary. Potential unmeasured confounders—such as the presence of siblings, attendance at daycare or kindergarten, secular trends, and selection bias arising from compliance with the NHSPIC—make it challenging to directly attribute developmental delays solely to the COVID-19 pandemic. Furthermore, because the K-DST may not capture the full spectrum of child development, a comprehensive neuropsychological evaluation could potentially offer a more thorough understanding than the K-DST alone.

In conclusion, the COVID-19 pandemic has undeniably posed challenges to child development, particularly for the youngest in our society. This study highlights the necessity for vigilant monitoring and proactive support for child development in the pandemic's aftermath, emphasizing the importance of early detection and intervention.

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Ethics statement

This study protocol was reviewed and approved by the Institutional Review Board of the National Medical Center (approval number: NMC-2023-01-001) and performed according to the tenets of the Declaration of Helsinki. The requirement for written informed consent was waived because of the retrospective nature of this study.

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SUPPLEMENTARY MATERIALS

Supplementary Data 1
Methods

Supplementary Table 1
Association of coronavirus disease 2019 pandemic with abnormal neurodevelopmental screening outcomes by age groups

Supplementary Fig. 1
Screening rates of the National Health Screening Program for Infants and Children during 2018–2021. Age Group 1 (9–17 months at year 1, 18–29 months at year 2); Age Group 2 (18–29 months at year 1, 30–41 months at year 2); Age Group 3 (30–41 months at year 1, 42–53 months at year 2); Age Group 4 (42–53 months at year 1, 54–65 months at year 2); Age Group 5 (54–65 months at year 1, 66–71 months at year 2). Only children who underwent two consecutive screenings over two years were included in the study.

Supplementary Fig. 2
Proportions of children with potential delays in neurodevelopment before and during the coronavirus disease 2019 pandemic, categorized by age groups and developmental domains.

Supplementary Fig. 3
Association of socioeconomic factors with neurodevelopmental risks. Age Group 1 (9–17 months at baseline, 18–29 months at follow-up); Age Group 2 (18–29 months at baseline, 30–41 months at follow-up); Age Group 3 (30–41 months at baseline, 42–53 months at follow-up); Age Group 4 (42–53 months at baseline, 54–65 months at follow-up); Age Group 5 (54–65 months at baseline, 66–71 months at follow-up). Adjusted for children's age, gender, screening point (baseline or follow-up), months between screenings, pandemic period, Medical Aid beneficiary status, residency urbanity, pediatrician-to-child ratios in the residential area, maternal age, and maternal nationality.

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