Profile of cognitive deficits among children residing in areas with high ambient air pollution in Odisha

Kulumina Dash,
Pratap Kumar Jena,
Jigyansa Ipsita Pattnaik[1],
Sayali Mishra[1],
Jayaprakash Russell Ravan[1]

Department of Public Health, KIIT Deemed to be University, Bhubaneswar, Odisha, [1]Department of Psychiatry, Kalinga Institute of Medical Sciences, KIIT Deemed to be University, Bhubaneswar, Odisha, India

Address for correspondence:
Dr. Jigyansa Ipsita Pattnaik, Department of Psychiatry, Kalinga Institute of Medical Sciences, KIIT Deemed to be University, Bhubaneswar, Odisha, India.
E-mail: Drjigyansaipsita@gmail.com

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ABSTRACT

Background: The detrimental effects of air pollution on human health, particularly among vulnerable populations such as children, have raised concerns globally. While prior research has explored the association between air pollution and cognitive impairments, it is poorly studied in the Indian population. **Aim:** This study aims to specifically profile the cognitive deficits experienced by children residing in areas with high ambient particulate matter air pollution (PM_{10} and $PM_{2.5}$) in Odisha. **Material and Methods:** A total of 30 children aged 6–8 years from Kalinga Nagar, Odisha were sampled, and their cognitive functions covering domains such as memory, attention, IQ, executive function, verbal skills, vocabulary, visuospatial ability, and processing speed and accuracy were assessed using the Malin's Intelligence Scale for Indian Children (MISIC). **Results:** The mean full-scale IQ of the children was 84 as per MISIC, indicating that on average, the children's IQ falls below the normal range. Specifically, the children showed lower performance in tests assessing attention, working memory, general knowledge acquisition, mathematical skills, vocabulary, and spatial reasoning. **Conclusion:** Six- to eight-year-old children residing in areas with high ambient particulate pollution exhibited lower cognitive abilities, including deficits in attention, working memory, mathematical skills, vocabulary, and visual-spatial processing.

Keywords: Air pollution, children, cognitive functions, cognitive deficits, MISIC

Air pollution, a global environmental risk factor, accounts for seven million premature deaths annually, predominantly in low- and middle-income countries.[1,2] Of the air pollutants, particulate matter is a serious threat to human health worldwide. Approximately 98% of children under the age of 5 years are exposed to $PM_{2.5}$ levels above World Health Organization (WHO) air quality standards in low- and middle-income countries worldwide.[3] In contrast, 52% of children under 5 years in high-income nations are exposed to levels above WHO air quality limits.[3] In India, half the population resides in areas exceeding $PM_{2.5}$ levels of 40 $\mu g/m^3$.[4] Exposure to $PM_{2.5}$ and PM_{10} is linked to a deleterious impact on children's neurodevelopment.[5] Lower IQ and neurological effects

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have been linked to increased exposure to $PM_{2.5}$ and other air pollutants.[6,7] Deficits in IQ, memory, attention, language skills, and academic performance are among the detrimental effects of air pollution on cognitive functions.[8,9] Epidemiological evidence shows that exposure to increased $PM_{2.5}$ and PM_{10} levels is associated with decreased IQ.[10] Long-term exposures (the 1-year average concentrations) to $PM_{2.5}$, PM_{10}, SO_2, and ozone are associated with poorer performance in working memory, inhibitory control, behavioral regulation, and metacognition in children.[11] Direct childhood exposure to air pollution ($PM_{2.5}$) is associated with a reduction in cognitive abilities[11,12] and psychomotor development.[13] Moreover, exposure to $PM_{2.5}$ has been linked to poorer performance in cognitive tests in children related to working memory,[13] attention,[14] selective attention, sustained attention, and visual information processing speed.[15] Long-term exposure to air pollution impairs verbal and math exam performance.[16]

Children are particularly vulnerable to the detrimental effects of air pollution due to the increased permeability of the blood-brain barrier during their developmental stages.[17] The interference of air pollution with neural processes, such as neuronal growth and synaptic functioning, can have lasting impacts on brain development, which is most active during infancy and childhood.[18] Airborne PM can enter the brain via either the olfactory route, which involves the olfactory system, or the trigeminal nerve, after entering the circulation, inducing neurotoxic effects in the brain.[19] The small particles enter the bloodstream and raise systemic inflammation, cross the blood-brain barrier, and injure the central nervous system.[15] Then, the deposited PM can induce neurotoxicity, oxidative stress, neuroinflammation, and blood-brain barrier and neurovascular unit damage. These adverse effects on the brain may result in neurodegenerative pathology and cognitive impairment.[19] However, data from developing countries like India, where air pollution levels are often higher, are limited. Consequently, the study aims to specifically profile the cognitive functions of 6–8-year-old children residing in areas with high ambient (particulate) air pollutants in Odisha.

MATERIAL AND METHODS

Study design

A cross-sectional design was followed for collecting primary data from the sampled respondents during the month of July 2022.

Study Setting

A community-based sampling in Kalinga Nagar, Jaipur district, Odisha. Kalinga Nagar was selected for its susceptibility to particulate matter pollution, with high PM_{10} and $PM_{2.5}$ levels exceeding the WHO and India's National Ambient Air Quality guidelines. Data regarding the line list of 6–8-year-old children were obtained after enumeration around a 1.5-km radius from air quality monitoring stations.

Participants

A sample of 30 children was obtained for data collection after screening through inclusion and exclusion criteria. Eligible children 6–8 years old were recruited after verifying their date of birth and address and obtaining consent from the parents. The screening of samples was done using the screening tool prepared by the researcher. Inclusion criteria: children residing for 6 years or more in the areas earmarked were selected for the study. Children who had not lived outside their normal place of residence for a total of 12 months and whose age corresponded with the duration of their stay at the current residence were selected for the study. Children diagnosed with mental retardation, developmental disability (including cerebral palsy, hearing impaired, visual impaired, and seizures (clinical diagnosis as per the ICD 10/11)), genetic disorders such as Down's syndrome, and born out of consanguineous marriage were excluded from the studies.

Procedure

The details of the households in the area within a 1.5-km distance from the ambient air quality Monitoring Stations of Odisha State Pollution Control Board were collected, and the parents of children were contacted at their respective houses. A door-to-door household visit was conducted to identify the sample universe. Once the sample universe was identified using a door-to-door survey, 30 children were selected from the site by using a simple random sampling technique. Informed consent from the parents and verbal assent from the children were obtained. Considering the difficulty in assessing the cognitive functions in community settings owing to the child's age and environment, the help of community leaders, Accredited Social Health Activists, and Auxiliary Nursing Midwifery were taken. Those children studying in the selected areas were approached for testing at their respective schools.

We approached the selected children in the designated areas and conducted cognitive function tests at their respective schools. Permission was obtained from the school authorities, written informed consent of parents was obtained, and verbal assent of children was obtained before conducting the cognitive tests. The MISIC scale was administered and scored by a trained individual certified by a qualified psychologist. The study commenced after obtaining ethical clearance from the institutional ethics committee. Ethical approval was obtained from the institutional ethics committee (Ref No. 921/2022).

Tools of data collection

To ascertain the cognitive function status, all the sampled children were tested for cognitive functions such as attention, executive function, IQ, memory, verbal skills/vocabulary, visual-spatial ability, and perceptual speed and accuracy by using Malin's Intelligence Scale for Indian Children (MISIC). MISIC is the Indian Adaptation of the Western Intelligence Scale for Children adapted to suit Indian culture.[20] The scale consists of two major components: the verbal score and the performance score. The mean intelligence quotient (IQ) was calculated by averaging the subscale scores.

Variables

The variables of interest in our study were cognitive function status, basic sociodemographics, socioeconomics, and other covariates associated with indoor air pollution. The data were collected using Epi collect v software. Under sociodemographics, we took age, gender, birth history, monthly income of the family, education of parents, occupation of parents, type of family, and socioeconomic status (SES) (Kuppuswamy scale). Other factors included smoking inside the house, cooking fuel used, and ventilation of the house.

Statistical analysis

The collected data were analyzed using SPSS software. Descriptive and analytical statistics were used to present/infer the results. Descriptive statistics were presented using means, standard deviations, frequencies, and percentages.

RESULTS

A total of 30 children participated in the study, including 17 boys and 13 girls. The majority of the children were 7 years old, and there were more girls than boys in this age group. More than two-thirds of the households had poor ventilation in their houses and burnt mosquito repellent coils. The majority of families had a monthly family income of INR 6175–18,496. The socioeconomic status distribution revealed a considerable percentage of children falling into the "upper lower" categories. Most of the families were using both LPG and biomass (mixed fuel) for cooking [Table 1].

The full-scale IQ is an overall measure of intellectual functioning, combining both verbal and performance scores. The mean full-scale IQ of the children was 84.5 as per MISIC, indicating that on average, the children's IQ falls below the normal range, with eight participants having IQs between 70 and 79 (borderline intelligence), 14 participants between 80 and 89 (dull average), and eight between 90 and 109 (average). The mean verbal IQ was 84.65 (±6.72),

Table 1: Basic sociodemographic characteristics of study participants (*n*=30)

Variables	Characteristics	Frequency *n* (%)
Age	6 years	6 (20)
	7 years	16 (53.33)
	8 years	8 (26.67)
Sex	Male	17 (56.67)
	Female	13 (43.33)
Birth Order	1	9 (30)
	2	11 (36.67)
	3 & Above	10 (33.33)
Caste	ST	10 (33.33)
	SC	5 (16.67)
	OBC	10 (33.33)
	General	5 (16.67)
Father Education	Illiterate	5 (16.67)
	Primary	7 (23.33)
	Upper Primary	11 (36.67)
	High School	3 (10)
	Intermediate/Under Graduate	3 (10)
	Graduate	1 (3.33)
Mother Education	Primary	12 (40)
	Upper Primary	10 (33.33)
	High School	6 (20)
	Intermediate/Under Graduate	2 (6.67)
Father Occupation	Laborer	16 (53.33)
	Business	5 (16.67)
	Private Service	8 (26.67)
	Other	1 (3.33)
Mother Occupation	Housewife	27 (90)
	Laborer	1 (3.33)
	Private Service	1 (3.33)
	Other	1 (3.33)
Monthly Family Income in Rupees	<=6174	4 (13.33)
	6175–18,496	26 (86.67)
Socioeconomic Status (SES) (Kuppuswamy Scale)	Lower	3 (10)
	Upper Lower	24 (80)
	Lower Middle	3 (10)
Type of Family	Nuclear	14 (46.67)
	Joint	16 (53.33)
Type of House	Pucca	8 (26.67)
	Kutcha	15 (50)
	Semi-pucca	7 (23.33)
Type of Cooking Fuel	Unimproved Fuel	5 (16.67)
	Improved Fuel	2 (6.67)
	Mixed Fuel	23 (76.67)
Ventilation of House	Moderate	9 (30)
	Poor	21 (70)
Smoking Inside the House	Yes	4 (13.33)
	No	26 (86.67)
Use of Mosquito Coils	Yes	22 (73.33)
	No	8 (26.67)
Place of Delivery	Home	5 (16.67)
	Institution	25 (85.33)
Type of Birth	Normal Vaginal	29 (96.66)
	Cesarean	1 (3.33)

suggesting that on average, the children's verbal abilities are slightly below the expected norm. The mean performance IQ was 84.36 (±11.07), which showed children's lower performance on non-verbal tasks, such as visual-motor skills, spatial reasoning, and problem-solving. Specifically, the children showed lower performance in tests assessing attention, working memory, mathematical skills, vocabulary, and spatial reasoning. However, their performance was good in tests measuring general comprehension, spatial navigation, and visual-motor coordination. The cognitive profile of the participants as a whole is graphically represented in Figure 1, where indices and subtests are considered separately.

DISCUSSION

The present study aimed to assess the cognitive profile of 6–8-year-old children living in high ambient particulate areas in Odisha. The results obtained from the present study indicated that the children in the areas with high air pollution had cognitive deficits which are consistent with previous studies that have reported adverse effects of air pollution on cognitive development among children.[5,13,14] The current study, which identified challenges with spatial reasoning, visual processing, and visual-motor intelligence, supports previous findings of air pollution exposure leading to deficiencies in visual-spatial processing.[15] An earlier study had shown that long-term exposure to air pollution impairs verbal and mathematical performance.[16] which is similar to the findings of the present study. Children's academic performance may be impacted by reduced mathematical skills, digit span, and digit span backward. This kind of lower productivity can lead to a population that performs below expectations, which might negatively impact the productivity of the country as a whole.

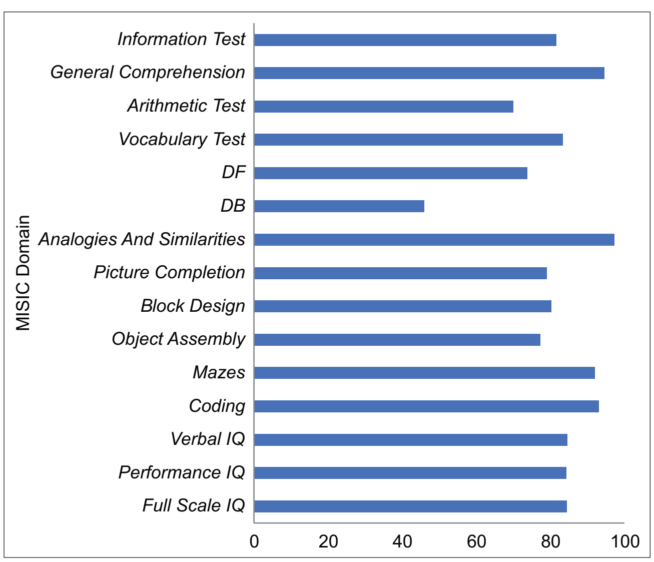

Figure 1: Depiction of domain-wise scores and full-scale scores on Malin's Intelligence Scale for Indian Children (MISIC) scale: IQ, Intelligence Quotient; DF, Digit Span Forward; DB, Digit Span Backward

Specifically, the children showed lower performance in attention and working memory in the present study, which is similar to the findings of a previous epidemiological study that documented the association between PM and NO_2 and deficits in attention[13] and working memory in children.[14] The results of the present study on lower performance on working memory are similar to the study that found that long-term exposure to pollutants such as particulate matter, NO_2, ozone, and SO_2 reduced memory in schoolchildren.[11] The decline in IQ and cognitive deficits of the study aligns with a comprehensive review of the impacts of outdoor air pollution on brain health and neurodevelopment.[18] The present study has shown the children's IQ falls below the normal range and is similar to the study that showed that exposure to increased PM_{10} and $PM_{2.5}$ is associated with decreased IQ in children.[10] An earlier study reported that people who were exposed to high levels of $PM_{2.5}$ had lower IQs.[21] For the children's cognitive development, policy initiatives should place a high priority on lowering air pollution, increasing awareness, and fostering healthier settings.

Limitations

The small sample size limits the generalizability of the findings. A similar study with a larger sample size will be helpful in better understanding the cognitive profile of the children. Despite these limitations, this is the first study of its kind to examine how children's cognitive abilities are affected by living in places where ambient PM_{10} and $PM_{2.5}$ levels are noticeably higher.

CONCLUSION

6–8-year-old children residing in areas with high ambient particulate pollution exhibited lower cognitive abilities, including deficits in attention, working memory, mathematical skills, vocabulary, and visual-spatial processing. This pressing public health issue has not received adequate attention, emphasizing the urgency of addressing air pollution's impact on children's cognitive development. Implementing targeted cognitive interventions, stricter environmental regulations, and increasing awareness among caregivers and policymakers are essential steps.

Data Availability Statement

Data will be shared on reasonable request.

Author's contribution

Conception, Design: KD, PKJ, JIP, JRR. Acquisition, Interpretation: KD, JIP,SM. Analysis: KD, JIP. Manuscript preparation and editing: all authors. Guarantor: JRR.

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Conflicts of interest

There are no conflicts of interest.

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