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Effects of Prenatal Exposure to Ambient Air Pollution on the Development of Infants

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Abstract

The early exposures to environmental contaminants like ambient air pollution during the prenatal period may play a critical role in the development of a child. In the present study, infants of Kanpur city in India; one of the most polluted cities of the World, were studied for the developmental effects of air pollution. The city was divided into three areas; highly polluted (HPA), moderately polluted (MPA) and least polluted (LPA). The green area on the outskirts of the city was considered as the unexposed area (UA). Sample constituted of hundred healthy full term infants of lower middle income families; twenty five from each of the four areas; HPA, MPA, LPA and UA selected through purposive cum random sampling method. Mental and motor development of children was measured using the 'Developmental Assessment Scale for Indian Infants' (DASII) by Dr. Pramila Pathak. A significant difference was found between the mean scores of infants of exposed and control group in both the cases i.e., motor and mental development.

Keywords: Prenatal exposure, ambient air pollution, mental development, motor development, infants.

1. Introduction:

Ambient air pollution is an important problem affecting human health worldwide. Extensive literature reveals that air pollution is a multifaceted environmental toxicant that comprises a diverse mixture of particulate matters (PMs), including organic components and metals, and gases, such as nitrogen oxides, sulfur oxides, and ozone. The level of the major air pollutants is continuously on rise in various cities due to urbanization and industrialization. There is an enormous increase in emissions from industrial establishments, automobiles and non-point sources like open refuse burning, construction and demolition activities. Respiratory problems, watery eyes, dizziness and other physical health problems are the most apparent consequences of short term exposure to air pollution [12, 17, 24, 30]**.** However, the subtle impact of persistent long term exposure to ambient air pollution and bioaccumulation of certain air pollutants on the functioning of brain and central nervous system is an aspect which needs to be explored. Especially in India there is a dearth of studies on neurobehavioural toxic effects of ambient air pollutants.

Evidences prove that many of the air pollutants like particulate matter (PM) easily enter the brain directly through nasal olfactory mucosa due to its fine/ minute size [6, 19, 25, 16]**.** Oxidative stress and inflammation are the two major processes by which air pollutants like PM are believed to exert their toxicity on Central Nervous System [18, 41]**.** Reduced cognitive and psychomotor development are the major brain functions affected among children and adults due to increase in exposure to air pollutants like polycyclic aromatic hydrocarbons (PAH), nitrogen-di-oxide (NO_2), sulphur-di-oxide (SO_2) and particulate matter (PM) [23, 33, 2, 28]. Exposure to air toxins like lead, mercury and polychlorinated biphenyls (PCBs), have also been found to be associated with behaviours similar to those of developmental disorders like autism and attention deficit hyperactivity disorder (ADHD), functional abnormalities, poor school performance and learning disabilities in children [37, 32, 7]. Majority of these toxicology studies have featured the impact of individual air pollutants like PM, SO_2, NO_2 etc. on human beings or animals. There is a need for greater scientific understanding of the cumulative effect of all the air pollutants present in the environment on human behaviour. Young children being one of the highly susceptible

populations require greater attention from the researchers.

1.1. Exposure to Air Pollution during Prenatal Development and Its Effects on Infant Development:

Human life begins at conception. Prenatal development is said to be a period of rapid growth and changes. It is one of the most sensitive and critical stage of human life. Many environmental factors like mother's diet, health status, medication have been found to affect the development of a child in the mother's womb. Pollution in the air being inhaled by the mother could be one of them. Recent researches have examined associations between ambient air pollution and adverse pregnancy outcomes such as low birth weight [42, 40], preterm delivery [3, 20] intrauterine growth retardation [29, 1] and birth defects [1].

Mental and motor developments of a child rely heavily on the development of brain or nervous system of the child. The development of a child's brain starts three weeks after conception. Formation of about 100 billion neurons and the synapses; the tiny packets of chemical neurotransmitters between them during the prenatal stage are some of the major processes of brain development which have an impact on the mental processing of a person [5]. Thus, any kind of exposure to toxic chemicals could prove to be harmful for the development of child's brain and even fatal for the child.

Even after birth, the process of changes in neurons and synapses goes on. Mylenation of nerve cells is another factor which is said to control the neural processing and begins around birth. These early stages of development of brain and its functioning play an important role in shaping human behavior and development.

In addition to this, the intake of toxic air pollutants is found to be more in case of children as compared to the adults. In a recent study it has been proved that children two years of age and under have ten times the risk of adults from exposure to toxins because infants take 45 breaths to 10 adult breaths [27]**.** Per pound of body weight, infants and children drink more fluids and eat more food than adults. Their lungs, airways and immune systems are weaker. Their skin is thinner and more permeable, and they have a larger surface area for absorption relative to weight [37]. Henceforth, children could be more susceptible to the exposure to hazardous air pollutants as compared to the adults. By assessing the infant's mental and motor development, the effects of prenatal exposure to air pollution could be studied.

1.2. Assessment of Development of Infants as Affected by the Air Pollution:

The studies on the impact of hazardous air pollutants on human beings are basically of two types; one studying the biological changes in the structure of brain and the other focusing on the functional changes of the nervous system. However, the studies on the functioning of brain are found to be more reliable sources of information about consequences of significant brain changes as compared to the studies on biological changes in the human brain [10].

Assessment of brain function in infants involves studying the cognitive and psychomotor abilities of the child. The development of motor and mental abilities and skills in a child is sequential in progress as studied by many psychologists like Arnold Gessell and Jean Piaget. There are many developmental checklists available which can be used and ticked on asking the mothers. But, they are heavily biased and lack direct observation of the child. Thus, Psychological Tests could prove to be a better option for child study. Another important aspect in studying young children is consideration of cultural or regional variations. Developmental Assessment Scale for Indian Infants (DASII) the Indian Adaptation of Bayley's Scale of Infant Development (BSID), developed by Dr. Pramila Pathak is a test very popular in assessing the development of infants in Indian culture. Henceforth, DASII has been used in the following study for assessment of infant development. Further, BSID has been used extensively in assessment of the effects of pollutants like lead [31, 34], polychlorinated biphenyls (PCB) [38]**,** methylmercury [11] and dichloro diphenyl dichloroethylne [35] on children in other studies.

2. Materials and Methods:

The present study was conducted with an objective to study the association between development (mental and motor) of infants and ambient air pollution.

2.1. Locale of the study:

Kanpur, one of the most polluted cities of the world, was selected for the study. The Air Quality Index of various areas of Kanpur city was found to range from 150 to 350, which is considered to be unhealthy for sensitive people, children and adults. The level of major pollutants like Particulate Matter (PM_{10}) was found to be more than three times the standard level of 60µgm/ m^3 [36]. According to WHO, Kanpur is the ninth most polluted city in the world [14]. The major sources of pollution in the city are overwhelming increase in number of vehicles, industrial establishments, domestic fuel and area sources like hotels etc. Moreover, non-paved roads, mixed traffic pattern, road encroachments and meter gauge railway tracks traversing the city length aggravate the problem.

2.2. Sample and Sampling Method:

On the basis of last five year Ambient Air Quality data collected by the State Pollution Control Board, the city was divided into three areas; highly polluted area (HPA), moderately polluted area (MPA) and least polluted area (LPA) **(Table no.1)**.

Table No. 1. Description of Sampling Areas

Sampling Area	Description of the Area	Sources of air pollution based on land use
Unexposed Area (UA)	Area having minimum or least pollution	Domestic cooking, light vehicles
Low Polluted Area (LPA)	Residential Area	Domestic cooking, generator sets, vehicles, road dust, garbage burning,
Moderately Polluted Area (MPA)	Commercial/ Traffic Area	Domestic cooking, generator sets, vehicles, road dust, garbage burning, restaurants, overcrowding
Highly Polluted Area (HPA)	Industrial Area	Industries, domestic cooking, generator sets, vehicles, road dust, garbage burning,

The green area on the outskirts of the city having no industries and few vehicles was considered as the unexposed area (UA). Parents of infants (0-2years) from different households residing within one kilometer areal distance from environmental monitoring stations of the State Pollution Control Board were approached. Written consent was obtained from the parents of the infants for collection of personal information about their children and testing the children using the DASII. A total of number of hundred healthy full term infants; twenty five from each of the four areas; highly polluted (HPA), moderately polluted (MPA), least polluted (LPA) and background areas/ unexposed area (UA) were selected using purposive cum random sampling method. The children belonging to lower middle income families were selected to match them on diet and parent's education. Children of the mothers residing since a minimum of five years in the study areas were only selected for the sample. Other major exclusion criteria were children having any postpartum history or complications, infants born to mothers consuming alcoholic beverages, unusual amounts of meat, fish, chicken or chalk/ mud during pregnancy, born premature or children not vaccinated or infants from families having any history of mental illness or diseases.

2.3. Description of the Tool used:

As mentioned before, the development of these infants residing in varying pollution levels was assessed using the DASII by Dr. Pramila Pathak, the Indian Adaptation of BSID. The scale consists of 67 items for motor development and 163 items for mental development. The motor development items cover the child's development from supine to erect posture, basic locomotive skills like walking, climbing, jumping, skipping etc. The mental development items record the child's cognizance of objects in the surroundings, perceptual pursuit of moving objects, exploring them to meaningful manipulation, development of communication and language comprehension etc. The total 230 items simultaneously and independently evaluate the two basic aspects of development i.e., motor and mental performances. The reliability of test used is 0.88 for motor scale and 0.91 for mental scale [21]. The norms of the test have been developed using age placements at 50% pass level for various items. For assessment of a child's motor and mental development, initially the obtained raw scores of a child were converted into motor age and mental age as per the norms given in the test manual. The motor age and mental age were further used for calculating Motor and Mental Development Quotients (DMoQ & DMeQ) respectively by comparing them with child's chronological age and multiplying it by 100. The

performance of the child was assessed using the 'average performance' range of 90-110, less than 90 as 'lower performance' and more than 110 as 'higher performance'.

2.4. Method of Data Collection:

After the ethics committee approval and informed consent, the mothers and their children were contacted in their respective houses. An interview schedule prepared by the researcher was used for collection of personal information like education, occupation of parents and family income etc.. The mothers were also enquired about the details of delivery of the child and characteristics of the child at the time of birth. DASII was applied on children in presence of their mothers in a quiet room with least distractions. Each child's behaviour was observed very closely. His/ her interest in certain materials being used and the mood of the child were especially taken care of. Motor and mental development scale items were administered simultaneously to avoid repetition of certain items and to make the test less exhaustive for the child. On an average the time taken for testing a 12-15 months old child was one and a half to two hours. On completion of the test, a small toy was given to each child as a reward.

3. Results And Discussions:

3.1. Personal Characters of the Sample:

Personal, social and demographic characteristics of the subjects studied are shown in table no. 2. The mean age of infants was 12.7 months. The mean weight of infants was also found to be 7.8 Kg which was almost similar in all the pollution exposed and unexposed areas. As revealed in table no.2, overall in all the four areas, majority of the parents were educated till graduation, highschool or intermediate. A significantly greater percentage of mothers were found to be illiterate (16%) as compared to the fathers (3%). Mothers were mainly housewives (92%). The education level and the occupation of mothers and fathers were found to be similar in all the four areas.

Majority of the fathers (61%) in all the four areas were involved in some kind of service either private or government. Most of the families were earning monthly income within the range of Rupees 5000 to Rupees 15000. Houses mainly had two or three rooms with proper ventilation and all the basic amenities like T.V., refrigerator, and cooking gas.

In most (62%) of the households, the families were joint families having 5to 8 family members. Very few families had a member who was reported to be smoking inside/ outside the house in daily routine.

Table no. 2. Personal Characteristics of the sample

Variable	UA	LPA	MPA	HPA	TOTAL
	N=25	N=25	N=25	N=25	N=100
Mean (SE)					
Age (months)	13.6 (1.24)	10 (0.9)	15.2 (1.6)	12 (1.04)	12.7
Weight (Kg)	8.8 (1.78)	7.2 (0.91)	8.0 (1.93)	7.2 (1.17)	7.8
Height (cm)	74.8 (8.92)	69.3 (3.62)	71.9 (8.45)	69.9 (4.06)	71.4
Frequency (Percentage)					
Gender					
Girls	17 (68)	9 (36)	10 (40)	15 (60)	51
Boys	8 (32)	16 (64)	15 (60)	10 (40)	49
Fathers Education					
Illiterate	0 (0)	0 (0)	2 (8)	1 (4)	3
Junior Secondary or less	4 (16)	6 (24)	4 (16)	3 (12)	17
High School	2 (8)	10 (40)	8 (32)	6 (24)	26
Intermediate	8 (32)	3 (12)	2 (8)	4 (16)	17
Graduation	7 (28)	6 (24)	5 (20)	5 (20)	23
Post Grduation	4 (16)	0 (0)	4 (16)	6 (24)	14
Mothers Education					
Illiterate	1 (4)	1 (4)	6 (24)	8 (32)	**16**
Junior Secondary or less	1 (4)	7 (28)	5 (20)	2 (8)	15
High School	7 (28)	3 (12)	2 (8)	4 (16)	16.0
Intermediate	9 (36)	7 (28)	7 (28)	2 (8)	25.0
Graduation	5 (20)	5 (20)	0(0)	6(24)	16.0
Post Grduation	2(8)	2(8)	5(20)	3(12)	12.0

Variable	UA	LPA	MPA	HPA	TOTAL
	N=25	N=25	N=25	N=25	N=100
Fathers Occupation					
Labourer	0(0)	1(4)	3(12)	3(12)	7.0
Buisness	5 (20)	9 (36)	9 (36)	7 (28)	30.0
Service	18(72)	15 (60)	13 (52)	15 (60)	61.0
Others	2 (8)	0 (0)	0 (0)	0 (0)	2.0
Mothers Occupation					
Housewife	22 (88)	25 (100)	23 (92)	22 (88)	92.0
Teacher	1 (4)	0 (0)	0 (0)	1 (4)	2
Business	1 (4)	0 (0)	0 (0)	1 (4)	2
Service	1 (4)	0 (0)	2 (8)	1 (4)	4
Period of Residence					
6-10 years	21 (84)	21 (84)	17 (68)	18 (72)	77
More than 10 years	4 (16)	4 (16)	8 (32)	7 (28)	23
Monthly Income of Family (Rs.)					
5000-15000	21 (84)	23 (92)	19 (76)	23 (92)	90
15001-25000	4 (16)	1 (4)	4 (16)	2 (8)	7
25001 - 35000	0 (0)	1 (4)	2 (8)	0 (0)	3
Type of Family					
Nuclear	10 (40)	6 (24)	11 (44)	11 (44)	38
Joint	15 (60)	19 (76)	14 (56)	14 (56)	62
Total no. of Family Members					
3 to 4	8 (32)	7 (28)	8 (32)	6 (24)	29
5to 8	15 (60)	15 (60)	11 (44)	15 (60)	56
9 to 12	2 (8)	3 (12)	6 (24)	4 16)	15

Mothers were also enquired about birth of the child, the details of their own feeding habits or any medication during pregnancy and the feeding habits of their child. In most of the cases it was a full term normal delivery under supervision of a registered medical practitioner in the hospital. No medication was done during pregnancy. None of the mothers reported to be consuming exceptional amount of fish or had any special craving habits like pica during pregnancy. All of them were engaged in four to five hours of household work daily during pregnancy. All infants were breastfed till one year of age and weaning was started at the age of six months on an average.

3.2. Motor Development of Infants and Ambient Air Pollution:

The motor development of a child which is a coordinated effort of muscles and nerves is controlled by the motor cortex in the frontal cortex of brain [22]**.** Motor development of a child follows a predictive pattern. As per the cephalocaudal law, after the birth of a child, the motor control initiates from control over neck and later to other body parts. The basic locomotion skills involving the gross motor coordination like sitting, standing and walking develop initially. The finer motor skills like holding a cup, scribbling with a pencil, jumping develop later on as per the 'general to specific' law of development. And lastly develops the manipulative skills like finer grasping of objects and walking on the board, stairs etc. The DASII used to assess the motor development of infants as affected by exposure to air pollution in the present study incorporates all these items.

The researchers have attempted to find the impact of exposure to air pollutants like particulate matter, SO_2, NO_2 on the motor development parameters on infants previously also [33, 39, 4, 13, 15]. On the basis of these researches, it was hypothesized that the motor development of infants would be associated with ambient air pollution of the city.

The mean values of motor development quotients (DMoQ) of infants on DASII test in the four study areas are shown in the table no. 3.

Table no. 3. Motor development quotients (DMoQ) of the infants (0-2years) of different pollution exposed (LPA, MPA & HPA) and unexposed areas (UA).

Area	Mean	SE
UA (n=25)	107.1	2.5
LPA (n=25)	95.7	2.4
MPA (n=25)	93.7	2.9
HPA (n=25)	92.6	1.9
F-value (3,96)	7.423 (p=0.000)	

The statistical significance of mean values in the four groups was analysed using analysis of variance technique. Significantly decreasing trend of mean DMoQ score was observed with increasing pollution levels in the four areas as depicted in the table (F-ratio 7.42, $p < 0.0001$). Similar evidences of decreased motor development quotients due to increase in the air pollutant polycyclic aromatic hydrocarbons (PAH) was found in the study by [33].

As per the norms of the DASII scale, DMoQ value of less than the standard value of 100 was considered as lower motor performance. Prevalence of lower motor performance among infants in three different pollution exposed areas and unexposed areas are shown in table no. 4 and figure 1.

Table no. 4. Prevalence of Lower Motor Performance among infants of different pollution exposed (LPA, MPA & HPA) and unexposed areas (UA).

Area	N	Percent	O R (χ2)	LCL-UCL (95% C.I.)
UA n=25	6	24	1	0
LPA n=25	16	64	5.62(8.11**)	1.71-18.48
MPA n=25	14	56	4.03(5.33*)	1.23-13.15
HPA n=25	20	80	12.66(15.7**)	3.6-44.46

**: p< 0.05 & **: p< 0.01*

Prevalence of lower motor performance in subjects exposed to low pollution (LPA) (64%) was found to be higher in comparison to subjects in exposed to moderate pollution (MPA) (56%). However, the prevalence of lower motor performance in all the three pollution exposed areas i.e., in the subjects exposed to low (LPA), moderate (MPA) and high (HPA) pollution was significantly higher in comparison to subjects from unexposed area UA (24%) (UA vs LPA, OR=5.62, $p < 0.01$, UA vs MPA, OR=4.03, $p < 0.05$ and UA vs HPA, OR=12.66, $p < 0.01$). The risk of lower motor performance was found to be associated with higher pollution level as shown in the figure 1. Other studies involving children of the same age group also found reduced psychomotor development due to air pollutants like PAH and NO_2 [33, 9].

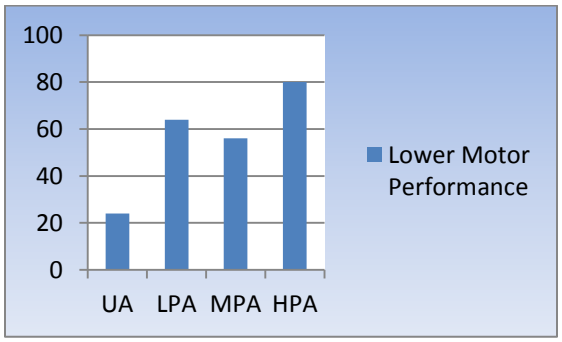

Figure.1. Prevalence (percent) of lower motor performance

3.3. Mental Development of Infants and Ambient Air Pollution:

Mental development is another aspect of child development which can be assessed as a part of neuro-toxicological effects of the air pollutants like particulate matter. The prefrontal, parietal and occipital cortexes in the brain control the mental processing processes of visual and auditory cognizance, memory and language acquisition [22]. The child basically is in the sensory-motor stage of cognitive development during the infancy stage (0-2 years) and follows a predictive pattern of development like motor development. The child's learning and attention processes are purely based on the sensory stimuli till 6 to 8 months. Gradually till the end of two years, the child develops the concept of object permanence and selective attention leading to perceptual products to store in memory [26]. The DASII scale being used in the study has 163 items to assess the mental development of 0-2 year children. All the items are arranged in a progressive series.

The mean values of mental development quotient (DMeQ) of infants are depicted in the table no.5.

The mean values of DMeQ of 0-2 year children of the four study areas were found to decrease with increasing pollution levels, except in case of MPA, the mean value of DMeQ (94.7) was slightly more than that in LPA (DMeQ=94.4) **(Table no.5)**. On statistical analysis using the analysis of variance, the difference between the DMeQ values of different exposed and unexposed areas was found to be significant (F-ratio: 9.024).

Table no. 5. Mental development quotients (DMeQ) of the infants (0-2years) of different pollution exposed (LPA, MPA & HPA) and unexposed areas (UA).

Area	Mean	SE
UA (n=25)	110.01	3.1
LPA (n=25)	94.4	2.3
MPA (n=25)	94.7	2.0
HPA (n=25)	93.8	2.9
F-value (3,96)	9.024 (p=0.000)	

Thus, the mental development of the infants was found to be adversely affected by the air pollution in the city. The results were in consistence with the findings of earlier researches [23, 8, 13].

Further, DMeQ value of less than the standard value of 100 was considered as lower mental performance. Prevalence of lower mental performance among infants in three different pollution exposed areas and unexposed areas are shown in table no. 6 and figure 2. Prevalence of lower mental performance in subjects exposed to low, moderate and high pollution (56%, 60% and 72% respectively) was found to be higher in comparison to subjects in unexposed area (16%). The difference was found to be statistically significant also as shown in the table no.6 (UA vs LPA, OR=6.68, $p < 0.01$, UA vs MPA, OR=7.87, $p < 0.01$ and UA vs HPA, OR=13.5, $p < 0.01$). The risk of lower mental performance was thus found to be associated with higher pollution level as also studied by Perera etal [23].

Table no. 6. Prevalence of Lower Mental Performance among infants of different pollution exposed (LPA, MPA & HPA) and unexposed areas (UA)

Area	N	Percent	O R (χ2)	LCL-UCL (95% C.I.)
UA n=25	4	16	1	0
LPA n=25	14	56	6.68(8.68**)	1.88-23.64
MPA n=25	15	60	7.87(10.27**)	2.22-27.82
HPA n=25	18	72	13.5(15.9**)	3.75-48.5

***: p< 0.01*

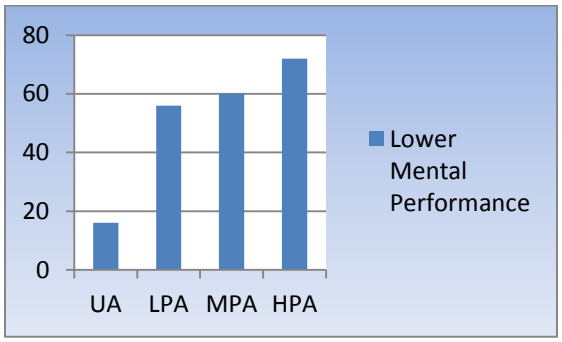

Figure.2. Prevalence (percent) of lower mental performance

4. Conclusion:

The study is a unique ex-post facto field study which throws light on one of the important impact of already occurred ambient air pollution on neuropsychological development of infants. Especially in a country like India where mental health and performance is a nascent field, the results of the study will be of great implications for both Child Psychologists and Environmentalists. In the present study, the motor and mental performance of infants was found to be adversely affected by ambient air pollution. The delayed or lower motor and mental performance of a child may further affect his/ her performance in curricular and co-curricular activities in later life.

The results of the present study lay a strong base for future research in the study of neurobehaviour functioning of humans as affected by the ambient air pollution. Future researches could also involve neuroscience approach of studying the brain structure and physiology being affected by air pollution along with the cognitive or neuropsychological approach.

An important limitation of the study was that the personal monitoring of the air pollutants inhaled by the mothers and infants during and after pregnancy could not be done as it requires highly technical instruments and medical supervision. However, the air pollution data monitored by the State Pollution Monitoring Stations using 24 hour method (4-hourly sampling for gaseous pollutants and 8-hourly sampling for particulate matter) twice a week has been considered which is an important measurement used by the government to check air pollution.

Although the study was conducted on a small sample, the tool used for the study (DASII) was

very exhaustive and covered each and every detail of mental and motor development of infants starting from neck control to language development. The results of the study will be of utmost importance for child health workers, town planners and policy makers. It will be of great assistance in planning the city and taking stringent measures to curb air pollution. An important suggestion of the study is that the residential areas should be planned away from industries and congested commercial areas to ensure protection of children's health and development**.**

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