Title

The Impact of Environmental Pollution on Cognitive Development and Learning in Children and Adults

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The Impact of Environmental Pollution on Cognitive Development and Learning in Children and Adults

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ABSTRACT

Communities located near industrial sites and highways have increased exposure to air pollutants like PM2.5 and NO2, which have been linked to cognitive and respiratory impairments. Prior research shows that prenatal and early childhood exposure to these pollutants correlates with lower cognitive performance and reduced working memory growth. This literature review synthesizes existing research studies such as the BREATHE project to examine how pollution exposure impacts neurological and cognitive health.

Keywords: air pollution, cognition, respiratory health, neurological health

The Impact of Environmental Pollution on Cognitive Development and Learning in Children and Adults

INTRODUCTION

Communities residing near industrial sites and major highways face heightened exposure to environmental pollutants, which pose significant public health risks. Research has consistently linked air pollution, particularly particulate matter and nitrogen dioxide, to negative health outcomes, ranging from respiratory problems to impaired cognitive development in children. For instance, studies have demonstrated that prenatal exposure to air pollution, including PM10 and PM2.5, is associated with lower cognitive and motor scores in young children, with exposure during critical periods of pregnancy resulting in the most detrimental effects (Morgan et al., 2023).

Children attending schools near high-traffic areas are especially vulnerable to pollution's harmful effects. An assessment of PM10 exposure at schools near a major highway interchange revealed pollutant levels approaching concentrations known to cause negative respiratory health impacts (Korenstein & Piazza, 2002). These findings highlight the disproportionate burden of pollution on marginalized communities, where proximity to pollution sources is often linked to limited access to healthcare and other resources.

This paper aims to synthesize existing research on the health impacts of environmental pollutants in populations living near pollution hotspots. By examining the intersection of exposure timing, pollutant type, and demographic factors, we seek to highlight the ways through which environmental inequities translate into long-term health disparities.

METHODOLOGY

While the search for how pollution impacts cognitive development is in a sense a very broad subject; we were able to find specific articles that provided evidence pointing to, not only cognitive effects, but respiratory effects due to the exposure of industrial sites and more. We used numerous resources trying to find the best articles that had any evidence that supported our question. The resources ranged from JSTOR, to the National Library of Medicine and even ScienceDirect. It definitely wasn't easy narrowing down our search to only being concerned about air pollution around industrial sites or major highways. However we made do by first searching through articles of air pollution and its negative effects and then from there filtering to the specific areas we were interested in. In an article titled "Early-Life Exposure to Air Pollution and Childhood Asthma Cumulative Incidence in the ECHO CREW Consortium", we see that they chose a very lengthy research method to track the effects of air pollution on children. Their study was specifically on 8 cohorts of children and they were studied since birth on not only cognitively but also on around what age any of them suddenly got asthma or any other respiratory disease. Not only that but they also collected estimates on PM2.5 and NO2 levels over the years. We thought this article was incredibly valuable to our research question due to the fact that it directly addresses our biggest concerns.

Due to our research question focusing on cognitive effect we realized fairly quickly that data centering around how well people did academically proved to be useful to us. In an article from 2019 titled, "Does Pollution Drive Achievement? The Effect of Traffic Pollution on Academic Performance". It was through this article that we obtained valuable information such as how wind is a huge factor in how the air pollution from major highways spreads. To add on to that they were really precise on what they categorized as major highways which proved to be helpful in looking for evidence that supported our question. To reiterate, we were able to find numerous sources supporting the question of air pollution and its negative effects but finding sources that supported our exact question were not easy and there is still much research to be done.

Literature Review

Neurological Impacts on Adults

Our study investigated the neurological effects of environmental pollutants on communities living near industrial sites, highways, and other high-emission areas. We analyzed cognitive performance metrics, neurodevelopmental assessments, and air quality data to assess the impact of prolonged pollutant exposure on brain health.

Data from the BREATHE project revealed a significant negative correlation between traffic-related air pollution and cognitive growth in primary school children and adolescents. Children and teenagers attending schools in high-pollution areas showed reduced improvements in working memory and attentiveness over a year compared to their peers in lower pollution zones. For instance, the growth in working memory was significantly smaller in students exposed to higher levels of elemental carbon and nitrogen dioxide both indoors and outdoors. Additionally, adolescents demonstrated increased susceptibility to attention deficits and slower cognitive processing in response to prolonged exposure to airborne pollutants.

Research from the NIH study demonstrated the adverse effects of prenatal pollutant exposure on early childhood development. Higher exposure to particulate matter (PM10 and PM2.5) and NO2 during mid to late pregnancy was associated with lower cognitive, motor, and language scores at two years of age. These findings emphasize the vulnerability of the developing brain to ambient pollution during critical growth periods. Furthermore, early-life exposure has been linked to ongoing cognitive challenges in adolescence, including difficulties in executive functioning and academic performance.

Our findings across childhood and adolescence highlight the persistent threat posed by air pollution to neurological health. The results underscore the urgent need for targeted public health interventions and policy reforms to reduce pollution exposure, particularly in vulnerable communities near pollution hotspots.

Through our observations throughout the numerous articles that we analyzed we were able to see that the exposure to air pollution negatively affected not only verbal but math test performances as well. Specifically in the case of the verbal tests there was a significantly negative association with air pollution and with older people. These findings were found in data collected from a study done in China on the effects of air pollution on several different age groups. To continue the results of both exams concluded that there was indeed a large decline with age.

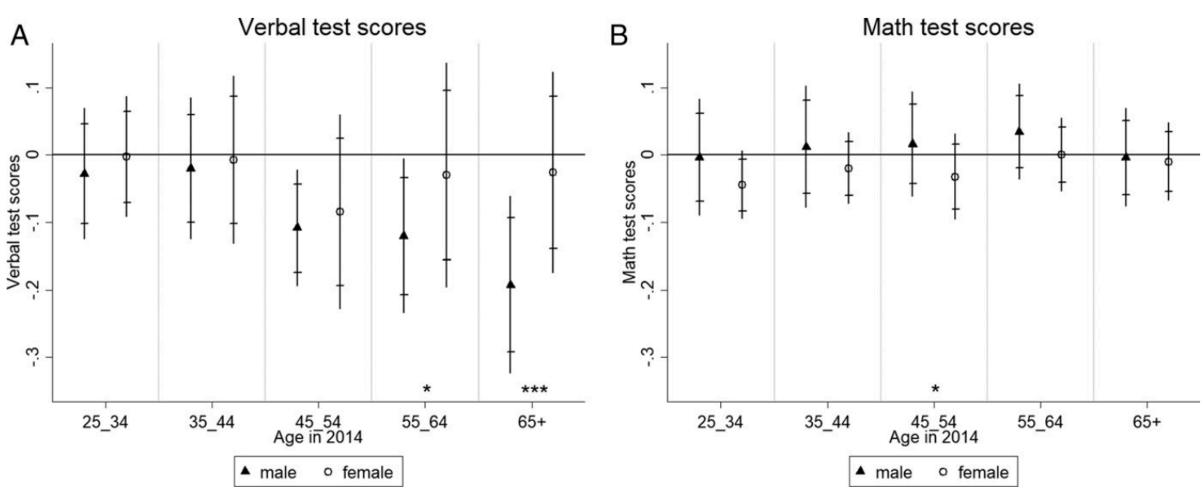

Figure 1: *Age cohort effects of air pollution on cognitive test scores ages 25-65+* (Zhang et al., 2018)

While the data in terms of math scores seems to level off stay around the same range there is still a subtle decline. Meanwhile in verbal tests scores there is definitely a more noticeable decrease with age. To add on, the asterisks were added to signify the significance levels between males and females the more asterisks added the less of an impact. For example a singular asterisk signified 10% significance level and three asterisks signifying 1% significance levels. These results highlight the noteworthy effects of air pollution.

Neurological Impacts on Children

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Data from the BREATHE project revealed a significant negative correlation between traffic-related air pollution and cognitive growth in primary school children and adolescents (Sunyer et al, 2015, Table 1). Children and teenagers attending schools in high-pollution areas showed reduced improvements in working memory and attentiveness over a year compared to their peers in lower pollution zones. For instance, the growth in working memory was significantly smaller in students exposed to higher levels of elemental carbon and nitrogen dioxide both indoors and outdoors. Additionally, adolescents demonstrated increased susceptibility to attention deficits and slower cognitive processing in response to prolonged exposure to airborne pollutants.

Research from the NIH study demonstrated the adverse effects of prenatal pollutant exposure on early childhood development. Higher exposure to particulate matter (PM10 and PM2.5) and NO2 during mid to late pregnancy was associated with lower cognitive, motor, and language scores at two years of age (Morgan et al., 2023, Table 2). These findings emphasize the vulnerability of the developing brain to ambient pollution during critical growth periods. Not only that but they also bring to light the need for targeted public health especially in marginalized communities located near pollution hotspots. Furthermore, early-life exposure has been linked to ongoing cognitive challenges in adolescence, including difficulties in executive functioning and academic performance.

Our findings across childhood and adolescence highlight the persistent threat posed by air pollution to neurological health. The results underscore the urgent need for targeted public health interventions and policy reforms to reduce pollution exposure, particularly in vulnerable communities near pollution hotspots.

Cognitive Outcome	**High/Low Traffic**	**Outdoor (Courtyard)**			**Indoor (Classroom)**		
		EC	**NO_2**	**UFP**	**EC**	**NO_2**	**UFP**
Units per interquartile range	—	0.7 μ g/m^3	23.3 μg/m^3	6,110 counts	0.92 μg/m^3	18.1 μg/m^3	8,872 counts
Working memory (two-back numbers, *d′*)							
Baseline	−5.3 (−16, 5.1)	−5.8 (−12, 0.56)	−7.5 (−16, 0.99)	−6.4 (−14, 1.5)	−3.0 (−11, 4.8)	−6.1 (−14, 1.9)	−1.3 (−13, 9.9)
12-mo change	−9.9 (−16, −3.5)*	−4.1 (−8.0, −0.2)*	−6.6 (−12, −1.2)*	−4.9 (−10, 0.22)	−6.2 (−11, −2.0)*	−5.6 (−11, −0.44)*	−7.9 (−15, −1.3)*
Superior working memory (three-back numbers, *d′*)							
Baseline	−1.4 (−10, 7.1)	0.25 (−5.2, 5.7)	1.5 (−5.8, 8.8)	−0.95 (−7.4, 5.6)	1.4 (−5.0, 7.9)	1.3 (−5.4, 8.0)	−0.078 (−9.1, 8.9)
12-mo change	−5.8 (−11, −0.74)*	−4.4 (−7.6, −1.3)*	−6.7 (−11, −2.3)*	−5 (−9.1, −0.96)*	−5.8 (−9.2, −2.4)*	−5.1 (−9.2, −0.91)*	−6.0 (−11, −0.75)*
Inattentiveness (HRT-SE, milliseconds)							
Baseline	5.2 (−6.2, 17)	1 (−6.3, 8.4)	4.8 (−5.0, 14)	4.5 (−4.0, 13)	6.8 (−1.7, 15)	7.0 (−1.8, 16)	6.2 (−5.8, 18)
12-mo change	5.2 (0.68, 9.7)*	3.8 (1.0, 6.6)*	3.8 (−0.10, 7.6)	3.9 (0.31, 7.6)*	3.8 (0.79, 6.8)*	2.6 (−1.0, 6.3)	4.6 (−0.13, 9.2)

Difference (95% CI) in the 12-mo change adjusted for age, sex, maternal education, residential neighborhood socioeconomic status, and air pollution exposure at home; school and individual as nested random effects.

*$p < 0.05$.

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Sunyer et. al, 2015, Table 1

Associations Between Average Prenatal Exposure to Ambient Air Pollutants and Neurodevelopmental Outcomes at 2 Years

		NO_2			PM_{10}			$PM_{2.5}$		
		β	**95% CI**	**p**	**β**	**95% CI**	**p**	**β**	**95% CI**	**p**
Motor Scores	Fine Motor Score	0.05	-0.26, 0.37	0.74	-0.40	-0.71, -0.09	**0.01**	-0.27	-0.58, 0.04	0.09
	Gross Motor Score	0.09	-0.25, 0.43	0.59	-0.37	-0.70, -0.04	**0.03**	-0.13	-0.46, 0.20	0.44
	Motor Scaled Score	0.19	-0.36, 0.73	0.51	-0.77	-1.30, -0.24	**0.005***	-0.41	-0.94, 0.13	0.14
	Composite Motor Score	0.55	-1.11, 2.22	0.51	-2.35	-3.95, -0.74	**0.004***	-1.22	-2.84, 0.40	0.14
Cognitive	Cognitive Scaled Score	-0.06	-0.42, 0.30	0.75	-0.34	-0.70, 0.01	0.06	-0.28	-0.64, 0.07	0.12
	Composite Cognitive Score	-0.70	-2.62, 1.22	0.47	-2.01	-3.89, -0.13	**0.04**	-1.97	-3.83, -0.10	**0.04**
Language Scores	Receptive Communication Score	-0.03	-0.37, 0.31	0.87	-0.25	-0.59, 0.08	0.13	-0.18	-0.52, 0.15	0.28
	Expressive Communication Score	-0.07	-0.38, 0.24	0.65	-0.36	-0.66, -0.05	**0.02**	-0.15	-0.46, 0.16	0.34
	Language Scaled Score	-0.10	-0.68, 0.48	0.74	-0.61	-1.18, -0.05	**0.03**	-0.33	-0.90, 0.24	0.25
	Composite Language Score	-0.33	-2.02, 1.36	0.70	-1.87	-3.52 -0.22	**0.03**	-1.01	-2.67, 0.65	0.23

Morgan et. al, 2023, Table 2

DISCUSSION

Our findings reinforce the evidence that prolonged exposure to environmental pollutants has detrimental effects on neurological health across different life stages. The observed inverse relationship between air pollution and cognitive function aligns with previous research, underscoring the urgent need for public health interventions in at-risk communities. However, some discrepancies remain in the literature regarding the specific pollutants most responsible for cognitive impairments, suggesting a need for more targeted investigations into exposure thresholds and effects.

The broader implications of these findings are substantial. From a public health perspective, they underscore the urgent need for stricter air quality regulations, particularly in urban areas where pollution exposure is highest. In a clinical context, recognizing pollution as a modifiable risk factor for cognitive decline could help inform early intervention strategies aimed at preserving cognitive health, particularly in aging populations.

However, our study has limitations. The reliance on existing datasets introduces potential inconsistencies in exposure measurement methodologies, which may affect comparability across studies. Additionally, the presence of confounding factors such as socioeconomic status, and genetic predispositions to cognitive decline could impact our results.

Future studies should explore potential mitigation strategies and expand the study to various geographic locations with differing pollution levels to determine if there are any populations that are more resilient or vulnerable to air pollution exposure.

Discussion of Cognitive Effects on Adults:

Our findings indicate that there was indeed a relationship between air pollution and negative cognitive effects on adults over 25 years old. A key observation was made when we not only saw declines in both verbal test scores but math ones as well. Although scores in math stayed relatively stable across various ages, there was a slight decline, displaying the idea that prolonged exposure to air pollution contributes to decreased cognitive performance.
However, the piece of evidence that really stood out was the extreme decline in verbal test scores, especially the fact that they got lower with age. This pattern indicates that there appears to be a more profound impact of air pollution on language related cognitive functions.

Discussion of Cognitive Effects on Children:

Our findings indicate that exposure to ultrafine particles in childhood leads to lower improvement in cognitive development. Compared to children that attended low-air-polluted schools, children from high-air-polluted schools had a lower improvement in working memory. Furthermore, high exposure to ultrafine particles also led to increased inattentiveness. Regarding fine particles, a higher average PM2.5 during pregnancy was associated with slightly lower IQ in late childhood. The reductions were specifically observed in Working Memory IQ and Processing Speed IQ.

CONCLUSION

In conclusion, our research displays the significant impact of air pollution on cognitive development in communities near industrial sites and major highways. From reviewing sources such as JSTOR, the National Library of Medicine, and ScienceDirect, we discovered evidence linking exposure to pollutants like PM2.5 and NO2 to both cognitive and respiratory health issues. Moreover, studies tracking children's development from birth, as well as research on academic performance in relation to traffic pollution, provided valuable understanding into how environmental factors shape cognitive outcomes. As a result, our findings reinforce the need for future investigation into the long-term effects of air pollution on cognitive function. Future studies might include researching additional variables such as socioeconomic factors and mitigation strategies to better understand and address the issue.

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